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Rethinking Public Transit Networks Using Climate Change Mitigation and Social Justice Lenses: Great Victoria Area Case Study

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Abstract: Public transit has a relatively low GHG-to-passenger ratio and offers affordable options for local travel compared with personal vehicle travel. Investments in an effective public transit network are therefore critical for progress toward climate change mitigation and social justice. Using the Greater Victoria Area (GVA) in British Columbia, Canada, as a case study, this research identified, mapped, and examined three new regional transit network scenarios, which, respectively, align with the objectives in the planning and policy areas of (1) climate change mitigation, (2) social justice, and (3) climate justice. The methods involved a literature review to develop an analytical framework for mapping and examining new transit networks using the climate change mitigation, social justice, and climate justice lenses. The framework was revised through a research practitioner workshop, and it was then applied using network analysis techniques to (re)map the GVA's transit networks under the three scenarios. The key outcomes of the project included an analytical framework and a process for analyzing and remapping transit networks in ways that align with climate and social justice objectives. The findings indicated the need to add some bus routes and stops, especially in the northern part of the GVA, and two new fast transit networks according to the justice lenses.

Keywords: transportation; climate change; urban planning; climate justice; transit equity; network analysis; scenario planning

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1. Introduction

Transportation is a critical policy area for climate change mitigation strategies. In the context of Canada (where the case study for this research is located), the transportation sector is the second largest (next to the oil and gas sector) producer of greenhouse gas (GHG) emissions [1]. Transportation is also a critical social justice and equity issue, as it is the among largest expenses for Canadian households [2], and, typically, those in lower income brackets are impacted more acutely by transportation expenses [3]. Accordingly, transportation should be considered a critical policy area for 'climate justice', a concept that frames the impacts of and solutions to climate change using a social justice lens [4].

Public transit is a mode of transport that offers a low GHG-to-passenger ratio compared with personal vehicle transportation; thus, it is frequently identified as a solution for climate change mitigation [5–7]. Public transit can also offer affordable options for commuting to work and travelling to recreation and shopping; thus, it can be used to support the development of equitable transportation systems [8]. Accordingly, transit networks are a key target area for climate justice work, as they can be developed as a strategy for reducing GHG emissions while also benefiting vulnerable groups that require transportation support (e.g., low-income populations and people living with disabilities). However, climate mitigation and social justice outcomes are not guaranteed by simply implementing a transit system, as ridership levels and transportation access for equity-seeking groups are dependent on many factors such as physical proximity to residential and job locations [9], how pleasant and safe the transit stops are [10], options for multi-modal transit that involve transit stops near walkways [11], and other factors. In the context of climate change mitigation and climate justice, it is important to ask: (1) does the transit system encourage and maximize ridership (i.e., mitigation), and (2) does the transit system effectively provide transportation options to those who would benefit most from having access to it (i.e., justice)?

This research explored how public transit networks can be redesigned using climate change mitigation and social justice lenses. It relates to what is referred to as the public transit network design problem (PTNDP), which involves optimizing public transportation systems by considering factors such as bus capacity, desired ridership levels, bus trip frequency, placement of bus stops, and roundtrip time [12–14]. The research focused on climate change mitigation and social justice issues within the transit network's design, thus examining PTNDP through these lenses. To elaborate, climate change mitigation in public transportation involves reducing vehicular GHG emissions by increasing demand and reliance on public transit [15], which cannot be achieved without addressing the considerations of the PTNDP, such as improving and increasing ridership. With respect to social justice, addressing the PTNDP requires considerations around sufficient and equitable access and the availability of public transportation options, particularly for marginalized groups [16].

Using the Greater Victoria Area (GVA) in British Columbia, Canada, as a case study, this research developed a framework for redesigning public transit networks to better align with the objectives of climate change mitigation and social justice. The research developed three scenarios for redeveloping the GVA, with each, respectively, aligning with one of the following planning and policy areas: (1) climate change mitigation, (2) social justice, and (3) climate justice. The following article presents the methods and outcomes of this research. The research project was conducted through a collaboration between the Community Social Planning Council of Greater Victoria and Royal Roads University, and more information on the work can be found on the project's website [17].

2. Literature Review

2.1. Social Justice, Climate Mitigation, and Climate Justice Lenses in Public Transit

Social justice planning includes both the equitable distribution of benefits and trade-offs (i.e., distributive justice) and processes for improving inclusion and equitable participation in planning (i.e., procedural justice) [18]. Both the distributive and procedural dimensions of social justice are pertinent to transit planning, with the former being particularly relevant to the design and structure of transit networks. Indicators for assessing whether public transit has effectively included distributive justice centre on the availability and accessibility of transit services to vulnerable populations, such as residents at lower socioeconomic levels and older demographics [16]. Other indicators related to transit and distributive justice include considerations around which neighbourhoods benefit from reduced congestion and which populations are well serviced by high-frequency and pleasant, multi-modal (e.g., a combination of walking and transit) transportation opportunities [19].

Along with social justice, transit planning is highly relevant to climate action, particularly the mitigation aspect of climate action. Climate change mitigation strategies aim to reduce GHG emissions through such strategies as sustainable energy technologies, enhancing energy efficiencies, and influencing and guiding human behaviours toward sustainable outcomes. The latter is an area often explored in transportation planning, with cities developing effective public transit networks, cycling routes, and footpaths to encourage people to take fewer trips via personal vehicles and thus reducing transportation-related GHG emissions [20]. Accordingly, the main indicator for assessing whether transportation initiatives have successfully contributed to climate change mitigation outcomes is the degree of GHG emission reductions achieved while people continue to meet their transportation needs [21]. In transportation planning research, such an indicator can be calculated and presented as the potential annual GHG reductions under different ridership scenarios [22,23]. Additionally, researchers have found that a number of factors can influence transit ridership levels (and thus transportation-related GHGs), such as opportunities for multi-modal transportation [24], residential and business densities around bus routes [25], and route trip frequency [9]. As these factors lead to increased ridership and, consequently, the climate change mitigation objectives of transit networks, they can serve as the basis of an indicator framework that can be applied to assess a transit network's effectiveness as a climate action strategy.

Climate justice is another planning and policy area that is highly relevant to transit planning. The concept is often used to describe inequities around climate vulnerabilities and climate change adaptation strategies, with scholars arguing that those who are least responsible for producing GHG emissions are those who are most impacted by the effects of climate change and have the lowest capacity to adapt to a changing climate [26,27]. Climate justice considerations also relate to climate change mitigation strategies, as certain solutions for reducing GHG emissions benefit some groups more than others [28]. As identified by Moran in the context of the CleanBC climate change mitigation strategy for the province of British Columbia, Canada, such inequities can be found in the transportation sector, with wealthier groups benefiting more from strategies for transitioning to green transportation options [29]. Transportation thus presents a critical area for designing and implementing plans and policies related to the complex concept of climate justice (i.e., not just climate change mitigation and/or social justice).

2.2. Network Analysis and Public Transit Design

This research explored new options and configurations for a public transit network in ways that contribute to the required climate mitigation and justice objectives, and it relied on the use of network analysis techniques performed by geographic information system (GIS) software (Arc GIS pro 3.1.2). Network analysis can be used to better understand and improve ridership levels, as well as to explore new ways of increasing access to transit for certain groups and communities. For instance, Tomej and Liberd illustrated how network analysis can be used to improve transit accessibility in their study based in Hungary [30]. In two Australian examples, Scheurer and Woodcock presented an application of network analysis that identified ways for improving coverage and access in the public transportation system of Melbourne, and Yigitcanlar et al. discussed the use of network analysis for developing a land-use and public transit accessibility plan on the Gold Coast [31,32]. As a final example, Sarker et al. used network analysis to evaluate walking access to public transit stations in Munich, Germany, with their analysis using both geographic and perception-based factors [33].

Network analysis can also be used to examine current transit systems with respect to strengths, issues, and gaps in order to reveal ways of improving these systems. Haznagy et al. used network analysis in urban areas in Hungary to identify the most usable and accessible stations, which produced insights into how to improve the public transit system [34]. Reyna et al.'s study on the ridership effects of Mexico City's closure of metro stations during the COVID-19 pandemic revealed ways of improving the connectivity and efficiency of the city-wide transit system after the lifting of the COVID-19 public health measures [35]. Wang et al. developed a method that combined geospatial and complex network analyses for examining the roles urban nodes currently play and potentially could play in transportation systems to identify new optimal configurations for transit networks [36]. Similar to the studies described above, this research aimed to contribute to local and regional public transit planning, specifically with respect to the objectives of climate change mitigation and social justice.

3. Case Study

The Greater Victoria Area (GVA) is located in the southwestern region of the Canadian province of British Columbia, which encompasses 13 municipalities (Figure 1) and has nearly 400,000 residents [37]. Due to significant shifts and changes in the population's distribution, with many moving to suburban and rural neighbourhoods rather than the urban core, the GVA is experiencing increasingly severe challenges related to traffic congestion. Langford, a municipality in these suburban areas, was identified as the third fastest-growing city in Canada in the most recent census [38].

The GVA's population is estimated to exceed 450,000, with 1.7 million daily trips in 2038 [39]. This estimated growth may result in an increase in transportation-related GHG emissions through higher traffic congestion. In addition, as many of the areas that are growing rapidly are those with previously low populations (i.e., suburban and rural areas), these areas historically have low levels of public transit service. Without updating the transit network, this can lead to social justice issues. There is a need to redesign the current transit system in the GVA to adapt to the significant shifts in the regional demographics and distribution; thus, the GVA made for a useful case study for this research.

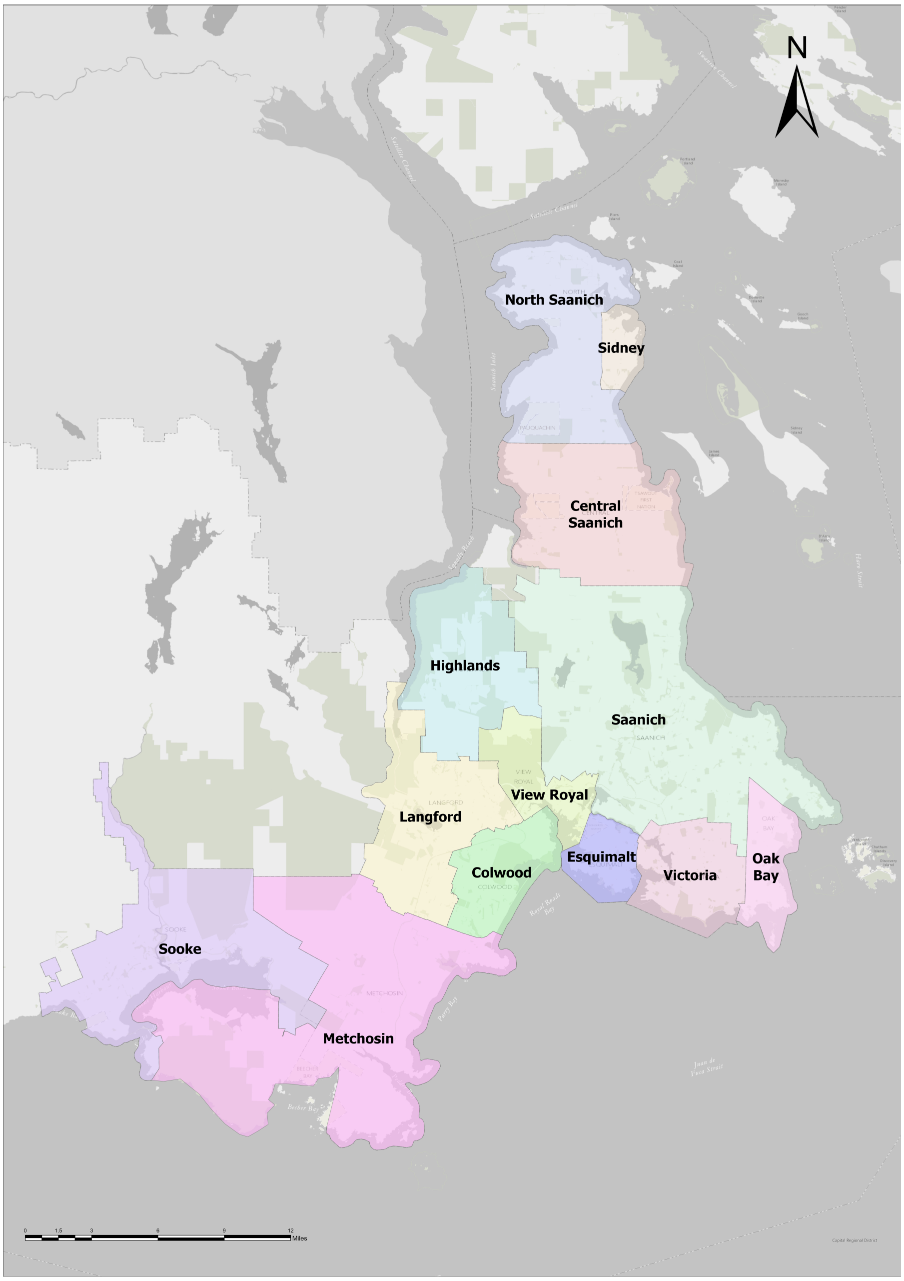


Figure 1. The Great Victoria Area. Source: [40].

4. Methods

The study was based on the multi-criteria decision-making theory [41] and began with the development of an indicator framework for analysing and mapping new transit networks using the social justice, climate mitigation, and climate justice lenses. This work involved a literature review to develop an initial framework. This framework was then revised through workshop that included members of the collaborating organizations (i.e., Royal Roads University and the Community Social Planning Council of Greater Victoria). The workshop also involved the attribution of weights to the indicators that characterized their relative importance with respect to meeting the objectives of climate change mitigation, social justice, or climate justice.

The research then involved a scenario mapping exercise. This work began by collecting the spatial data (from public data sources) for the indicators included in the framework. The exercise then used network analysis and weighting techniques to analyse the GVA's current public transit network in ways that revealed new potential routes for covering currently inaccessible areas.

4.1. Indicator Framework Development

A comprehensive literature review method [42] was used to develop the indicator framework and explore what indicators are important for examining how the design of a public transit contributes to (or conflicts with) the objectives of climate change mitigation and social justice. Google Scholar was used for the review, and the search was guided by the keywords: 'public transportation', 'public transit', 'TOD', 'sustainable transit planning', 'social justice', 'climate mitigation', and 'climate justice'. The inclusion criteria included that sources were written in English and available electronically. The review prioritized research on Canadian case studies, and all articles selected for this work were published within the last two decades In total, 30 sources were found and used to create the indicator framework, and the indicators were organized into nine emergent themes (Table 1).

Table 1. The study's indicators.

Outcomes	Indicators	CM	SJ	CJ	Sources
1. Transit network and diversity in modes	1-1 Average trip distance		✔	✔	[43–45]
	1-2 Bus lanes numbers	✔	✔	✔	[43,46–53]
	1-3 Car parking facilities	✔	✔	✔	[43,47,50,51,54–56]
	1-4 Average number of daily trips	✔		✔	[36,45,57,58]
	1-5 The integration of pedestrian ways and bike lanes with public transit	✔	✔	✔	[43,46–48,52,53,56,57,59–62]
	1-6 Transit mode diversity		✔	✔	[45,46,48,57,59,63]
2. Accessibility	2-1 Accessible for all people		✔	✔	[36,43,46–49,51,54–56,58–60,63–67]
	2-2 Accessibility to bus stops/metro stations	✔	✔	✔	[36,46–52,54–56,58–60,63–66,68–70]
3. Reduced emissions	3-1 Carbon emissions by public transportation	✔		✔	[43,45–49,55,58–60,63,65,69]
	3-2 Fuel consumption rate	✔		✔	[43,45–49,55,58–60,63,65,69]
	3-3 Provision of green infrastructure and closeness to green areas	✔		✔	[47,61,66]
	3-4 Vehicle age distribution	✔			[45]
4. Biodiversity conservation	4-1 Habitat fragmentation	✔			[43,46–48,69]
5- Populations	5-1 Employment density		✔	✔	[44,50–52,54–56,66]
	5-2 Population density		✔	✔	[44–46,51,52,54,55,58,61,66,71]

Table 1. *Cont.*

Outcomes	Indicators	CM	SJ	CJ	Sources
6. Satisfaction with services	6-1 Affordability of public transit		✔		[43,46,48,49,54,55,58,60,69]
	6-2 Wait time		✔		[36,43,49–51,58,68,70]
	6-3- Passenger-kilometers (by mode, purpose)		✔		[44,46,50,58]
	6-4 Reliability of the schedule		✔		[43,47,49,55,58,60,64]
7. Integrated land use and transportation planning	7-1 Integration of land use and transportation planning	✔	✔	✔	[43,45–49,55,58–60,63,65,69]
	7-2 Land use diversity	✔	✔	✔	[43,46–48,54,55,57–61,63–65,69,70]
8. Economic efficiency	8-1 Damage reduction and safety		✔		[43,46–48,54,55,57–61,63–65,69,70]
9. Transit trade-offs	9-1 Air pollution exposure		✔		[46–49,60,69,70]
	9-2 Noise levels, costs		✔		[43,46–49,55,59,60,65,70]

Following the literature review and development of the indicator framework, the framework was reviewed in a workshop that gathered researchers and practitioners from the collaborating organizations, that is, Royal Roads University and the Community Social Planning Council of Greater Victoria [72]. The workshop had two objectives: (1) examining the variable list to determine what is relevant to redesigning the GVA's public transit network in terms of the climate change mitigation, social justice, and climate justice scenarios, and (2) adding weights to the indicators that represent their importance with respect to redesigning/remapping the transit network.

The workshop ran for 2 h and was conducted at the Community Social Planning Council of Greater Victoria's office in August 2023. The workshop included seven participants. Two of the participants were from academia, with research and teaching expertise (respectively) in local climate action planning and social justice. Five participants were practitioners from the non-governmental organization sector, with expertise on community-level social issues and equity considerations. The participants were contacted and invited to the workshop via email.

The workshop began with a presentation on the study, and this was followed by a discussion about how public transit relates to the objectives of climate change mitigation and social justice. The attendees were then organized into two groups, and each group was given a sheet of paper and coloured sticky notes. The groups were asked to write ideas on what indicators should be considered to design public transit networks based on the objectives of climate change mitigation (blue sticky notes), social justice (yellow sticky notes), and climate justice (green sticky notes) (see Figure 2). Following this exercise, each group was given the opportunity to review and comment on the other group's work.

The final activity of the workshop involved the attendees reviewing and revising the indicator framework developed from the literature review. This activity involved identifying to which of the three scenarios the indicators were most relevant, as well as commenting on the clarity of the indicators and whether any other indicators were missing. The group also provided ratings of how important/significant the indicators were to each of the three scenarios; these ratings ranged from 1 (very low) to 5 (very high), and they were used to create indicator weights for the redesigning/remapping transit network exercise. The result of this work was a revised indicator framework, complete with indicator weights.

Following the workshop, the indicator ratings were recorded in a Microsoft Excel spreadsheet, and the averages were calculated. The averages were standardized on a scale of 0–1, and the resulting values were used as the indicator weights. The indicator list was then organized into two categories to identify the indicators that were in the scope of the research and those that were out of scope (due to lack of data availability or clarity with respect to metrics that should be used). The in-scope indicators were further organized into two sub-categories: those that should be included in the analysis of the GVA in terms of public transit access needs (analysis indicators), and those that provide considerations for redeveloping the public transit system (development indicators).

Figure 2. Academic and practitioner workshop indicator brainstorming activity.

4.2. Scenario Mapping

Spatial data related to the indicators were collected from three sources: CRD Geospatial Data [40], BC Transit Open Data [73], and Statistics Canada [2]. Land use and road data were sourced from the CRD database. The BC Transit database was used for data on the GVA's current bus stops and bus routes. Population data were sourced from Statistics Canada's 2021 census, and spatial data collected were at the resolution of the census tract. All spatial data were in shapefile format to be imported to and analysed in Arc GIS.

Scenario mapping was carried out using Arc GIS Pro 3.1.2, and it was performed in three steps: (1) developing the GVA's zoning maps that captured the importance of different areas in terms of access to public transit; (2) examining the current public transit network with respect to low or no access to public transportation; and (3) remapping the transit networks by identifying bus routes and stops that improve accessibility to transit. The indicator framework was used to identify what makes for 'good' or 'improved' access, as per the climate change mitigation, social justice, and climate justice scenarios.

4.2.1. The GVA's Zoning Maps

The GVA's 'zoning maps' were developed by identifying walking service areas around areas where bus stops are or should be located, using the 400 m walking distance defined through BC Transit's standards [74]. Network analysis was used to identify the distances between features of interest (such as destinations and amenities) and bus stops' locations (potential and current), both measured along the street network. The case of provincial parks was an exception to this analytical approach, as a buffering method (instead of network analysis) was used to identify accessibility to park access points. The buffering approach was used for provincial parks because these features encompass large areas. Walking service areas for neighbourhoods were also handled differently, as they were not created using network analysis or buffers due to how these areas were already prepared as polygon (i.e., not point) data.

The indicator weights were used to determine the importance of a particular service area with respect to the different scenarios. A weighting technique was used (Equation (1)), which involved a model where the dependent variable was the scenario-related importance (i.e., weighting with respect to the scenario), the coefficients were the indicator weights, and the independent variables were the indicator data. In cases where the indicator referred to a particular land use, a location was attributed a value of 1 when the type of land use was present and 0 when absent. When the indicators involved demographic and census data, the data were converted into a scale of the highest (G1), medium (G2), and lowest (G3) values based on tertile divisions.

$$Y = \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6 + \ldots BnXn \quad (1)$$

The outputs of the weighting calculations provided data on how important a location was for transit services and accessibility as per a given scenario's objectives. These outputs were grouped into three main categories of low, medium, and high importance, using the natural breaks classification method. The results of this work were the zoning maps, which were used to examine and remap/redesign the GVA's public transit network.

4.2.2. Analysis of the GVA's Public Transit Network

The existing public transit network was evaluated in terms of its coverage and accessibility, and this was achieved by creating 400 m service areas around existing bus stops using network analysis. These service areas were then compared with the zoning maps to identify where gaps existed with respect to important areas for providing transit accessibility. Providing services to every developed area in the GVA is inefficient; thus, the gaps analysis targeted the medium- and high-importance areas in terms of accessibility to public transit stops in the zoning map. Specifically, areas that were located in these medium- and high-importance zones but did not currently have 400 m walking distance access to bus stops were identified.

4.2.3. Identifying New Public Transit Routes and Stops

Proposed public transit routes and stops were added to the different scenario maps in accordance with their zoning maps. These routes and stops provided new services to medium- and high-importance areas that currently have low or no access to transit. This exercise in remapping the transit network resulted in relatively modest changes, as an aim of this work was to utilize as much of the existing infrastructure as possible to reduce the necessity of extensive new construction. Additionally, the remapping exercise took into account BC Transit's rules and standards, such as the fact that bus routes require roads that are at least 3.3 m in width [75].

5. Results

5.1. The Indicators

Table 2 presents the list of indicators identified for the redesign of the GVA's public transit network, as per the climate change mitigation, social justice, and climate justice scenarios. The indicators are organized into five themes: transit network diversity, accessibility improvement, reduced emissions and habitat connectivity, population density considerations, satisfaction with services, and integrated land use and transportation planning. The indicators are shown in three phases: indicators that are used in the process of developing zoning maps (development indicators), indicators used in the redesigning stage (design indicators), and the other important indicators which should be considered but were not within the scope of this study (out-of-scope indicators).

Table 2. Indicators for designing public transit network using climate change mitigation, social justice, and climate justice lenses.

Themes	Indicators	Description	Data Usage	Indicators Considered	Weight		
					Climate Mitigation	Social Justice	Climate Justice
1. Transit network and diversity in modes	1-1 Average trip distance	–	Outside scope	Out-of-scope indicators	0.68	0.70	0.68
	1-2 Number of bus stations and lanes for the provision of accessibility		Network redesign	Design indicators	-	0.60	0.60

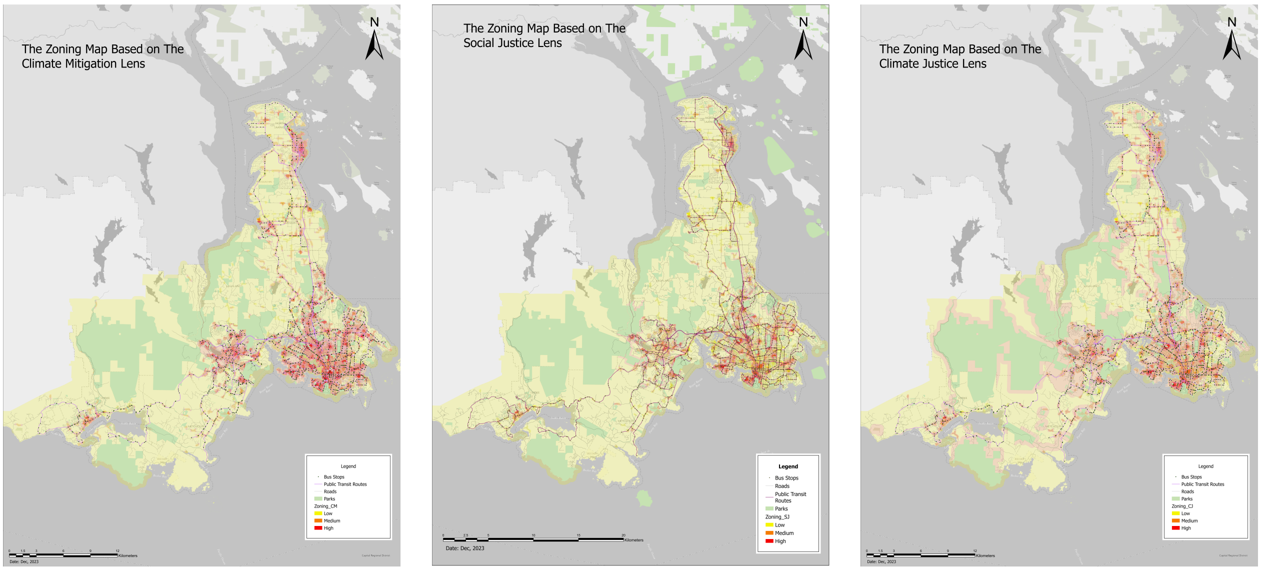
Table 2. *Cont.*

Themes	Indicators	Description	Weight				
			Data Usage	**Indicators Considered**	**Climate Mitigation**	**Social Justice**	**Climate Justice**
1. Transit network and diversity in modes	1-3 Accessibility to car parking facilities	–		Design indicators	0.43	0.48	0.50
	1-4 The integration of pedestrian ways and bike lanes with public transit		Outside scope	Out-of-scope indicators	0.69	0.70	0.68
	1-5 Diversity of transit modes		Network redesign	Design indicators	0.77	0.77	0.77
2. Accessibility improvements	2-1 Accessibility for elderly groups	The percentage of elderly people in the census tracts	Zoning maps	Development indicators	-	0.60	0.70
	2-2 Accessibility for lower-income people	The percentage of people with an annual income lower than CAD 39,999 in the census tracts	Zoning maps	Development indicators	-	0.70	-
3. Reduced emissions and habitat connectivity	3-1 Carbon emissions by public transportation		Outside scope	Out-of-scope indicators	0.71	0.70	0.63
	3-2 Proximity of public transit to green spaces	Priority of designing transit routes near green spaces	Network redesign	Design indicators	0.50	0.40	0.80
	3-3 Reduction of barrier effects	30 km/h speed limit for routes near habitats	Network redesign	Design indicators	0.47	0.40	0.40
4. Population density considerations	4-1 Employment density	The percentage of employed people in the census tracts	Zoning maps	Development indicators	0.80	0.80	0.90
	4-2 Population density	The percentage of the population in each census tracts	Zoning maps	Development indicators	0.70	0.60	0.70
5. Satisfaction with services	5-1 Public transit's affordability		Network redesign	Design indicators	0.80	0.90	0.93
	5-2 Wait times		Network redesign	Design indicators	0.20	0.50	0.53
6. Integrated land use and transportation planning	6-1 Provision of accessibility to regional entertainment places	Recreational land-uses (regional scale)	Zoning maps	Development indicators	0.70	0.60	0.67
	6-2 Provision pf accessibility to diverse types of land use, especially those for day-to-day life	CM: Institutional, commercial, recreational (urban scale), mixed land uses SJ: All land uses considered for the CM lens plus food banks and shelters CJ: All land-uses considered for CM and SJ		Development indicators	0.70	0.70	0.80

Sources: [43–45].

5.2. The Zoning Maps

Figure 3 illustrates the zoning maps showing the final the accessibility-related importance of each location in the GVA as per the three scenarios. Spots are categorized into three distinct levels of importance: low, medium, and high. As can be seen in the maps, the accessible areas required on the basis of the climate justice lens is broader than that for the two other lenses. All zoning maps indicate the necessity of a good level of accessibility in the downtown areas of Victoria, Saanich, and Langford, and some coastal areas of Sydney.



(**a**) (**b**) (**c**)

Figure 3. The GVA's zoning maps based on the (**a**) climate change mitigation, (**b**) social justice, and (**c**) climate justice lenses.

5.3. Current Accessibility in the Transit Network

Figure 4 shows the 400 m service areas around the existing bus stops in the GVA. The current transit network provides good accessibility for users in areas that have had a long history of a high population and development density. Such areas include downtown Victoria (with Victoria being the core city in the GVA) and Saanich (a city that is adjacent to Victoria).

Figure 5 illustrates the transit-inaccessible areas of the GVA as per the different scenarios' objectives. Improvements in public transit routes and stops are required to provide the accessibility needed. These represent gaps in the current transit network. The gaps inform us where new routes and stops need to be added to improve the transit network in ways that align with the objectives of climate change mitigation and social justice.

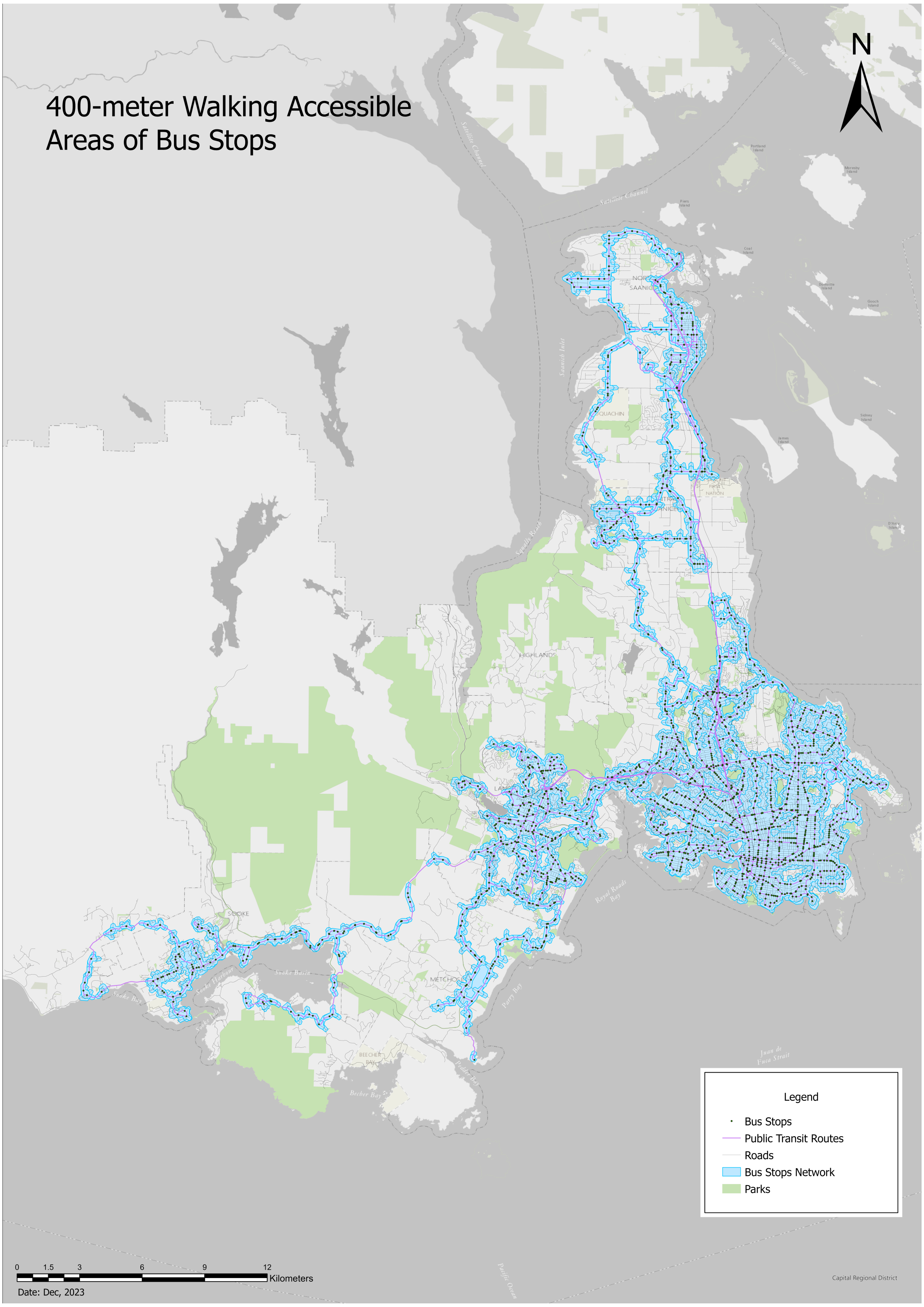
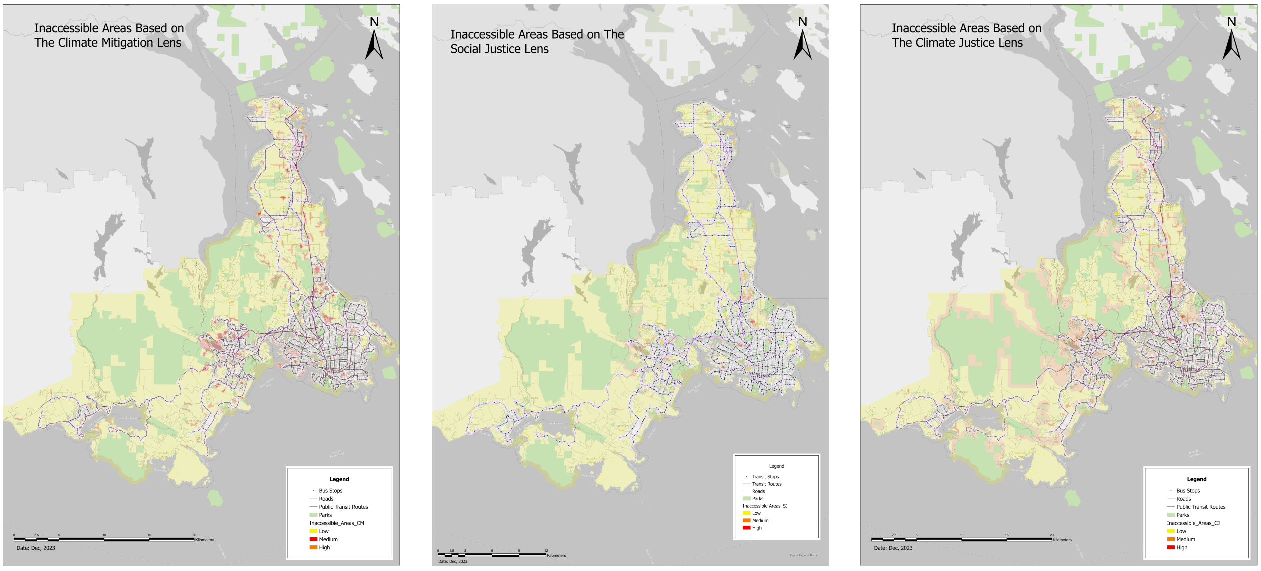


Figure 4. The GVA bus stops' 400 m service areas.



(**a**) (**b**) (**c**)

Figure 5. The GVA's inaccessible areas for public transit based on the (**a**) climate change mitigation, (**b**) social justice, and (**c**) climate justice scenarios.

The research resulted in a remapping of the public transit system based on the objectives of the climate change mitigation, social justice, and climate justice scenarios. In the climate change mitigation scenario (Figure 6), two bus routes were added, a new bus stop was added, a route was lengthened, and two other routes were altered. In the social justice scenario (Figure 7), four routes were altered, and two bus rapid transit routes were added that each run from the rapidly growing suburban areas (i.e., the Westshore and the Saanich Peninsula) to downtown Victoria. To increase the usage of these bus rapid transit lines, the stops were allocated near parking lots so users have the option of using public transit as a part of their trip. The climate justice scenario (Figure 8) combined features of both the climate change mitigation and social justice scenarios.

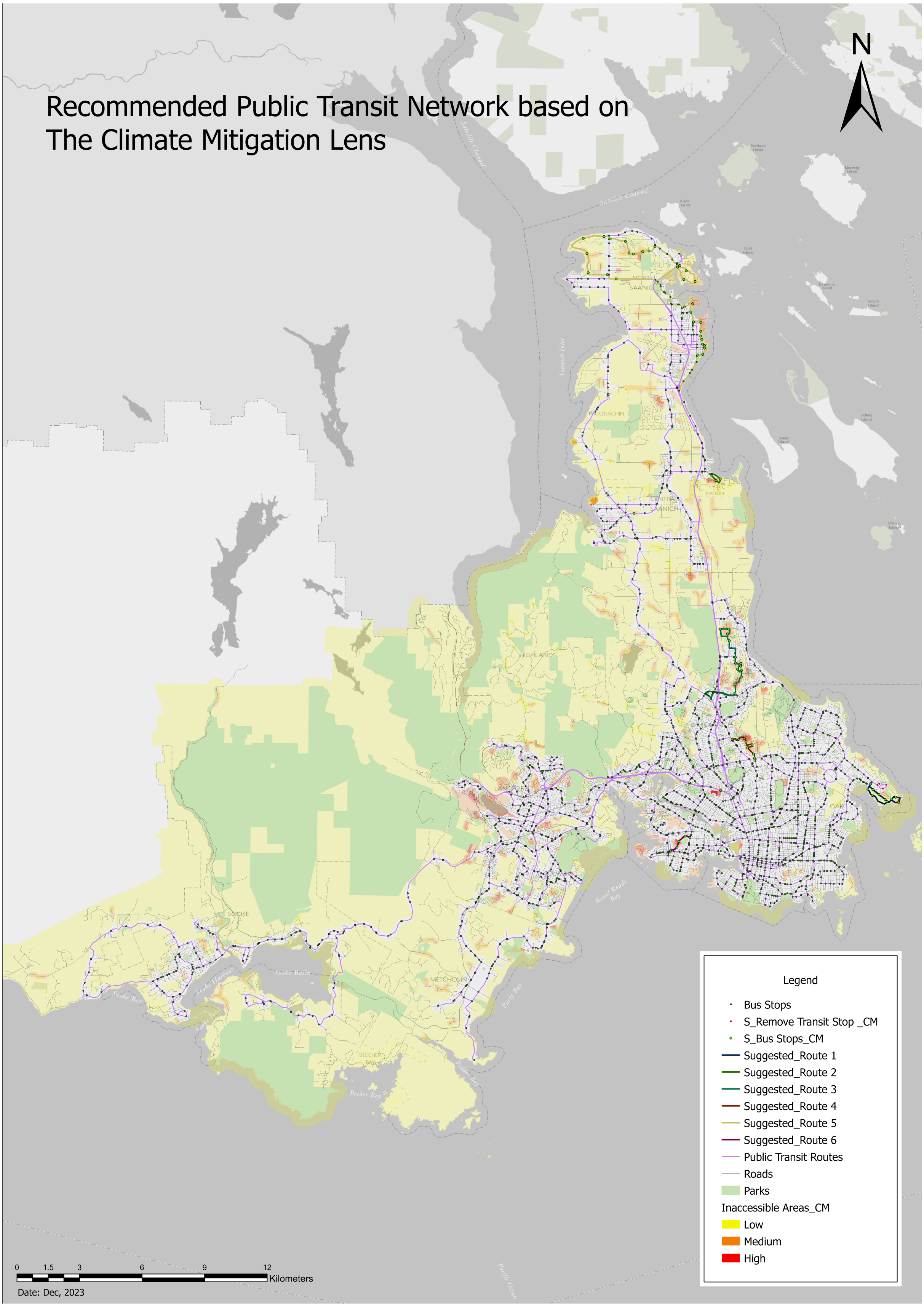


Figure 6. *Cont.*

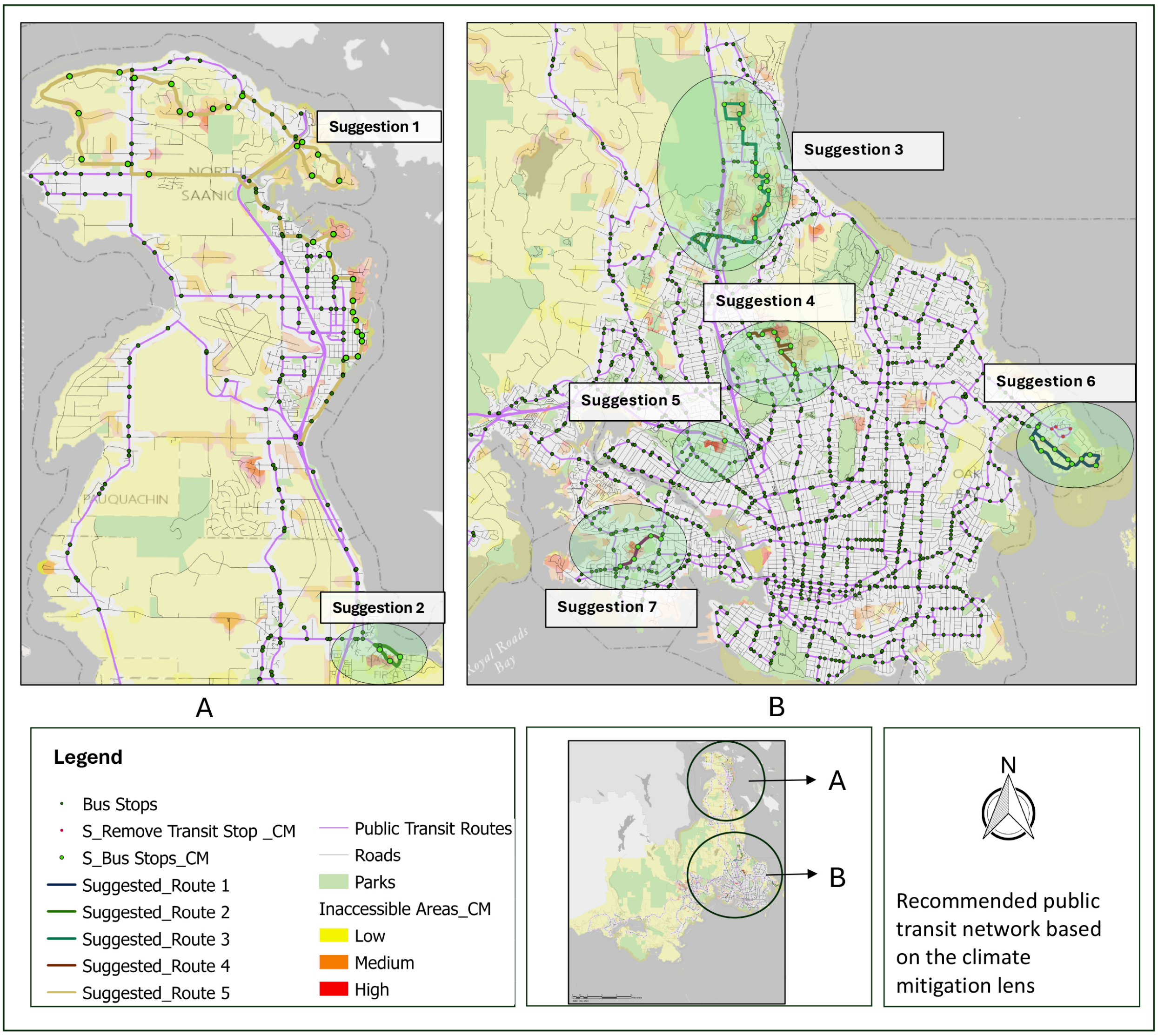


Figure 6. Suggestions for redesigning the GVA's public transit network based on the climate mitigation lens.

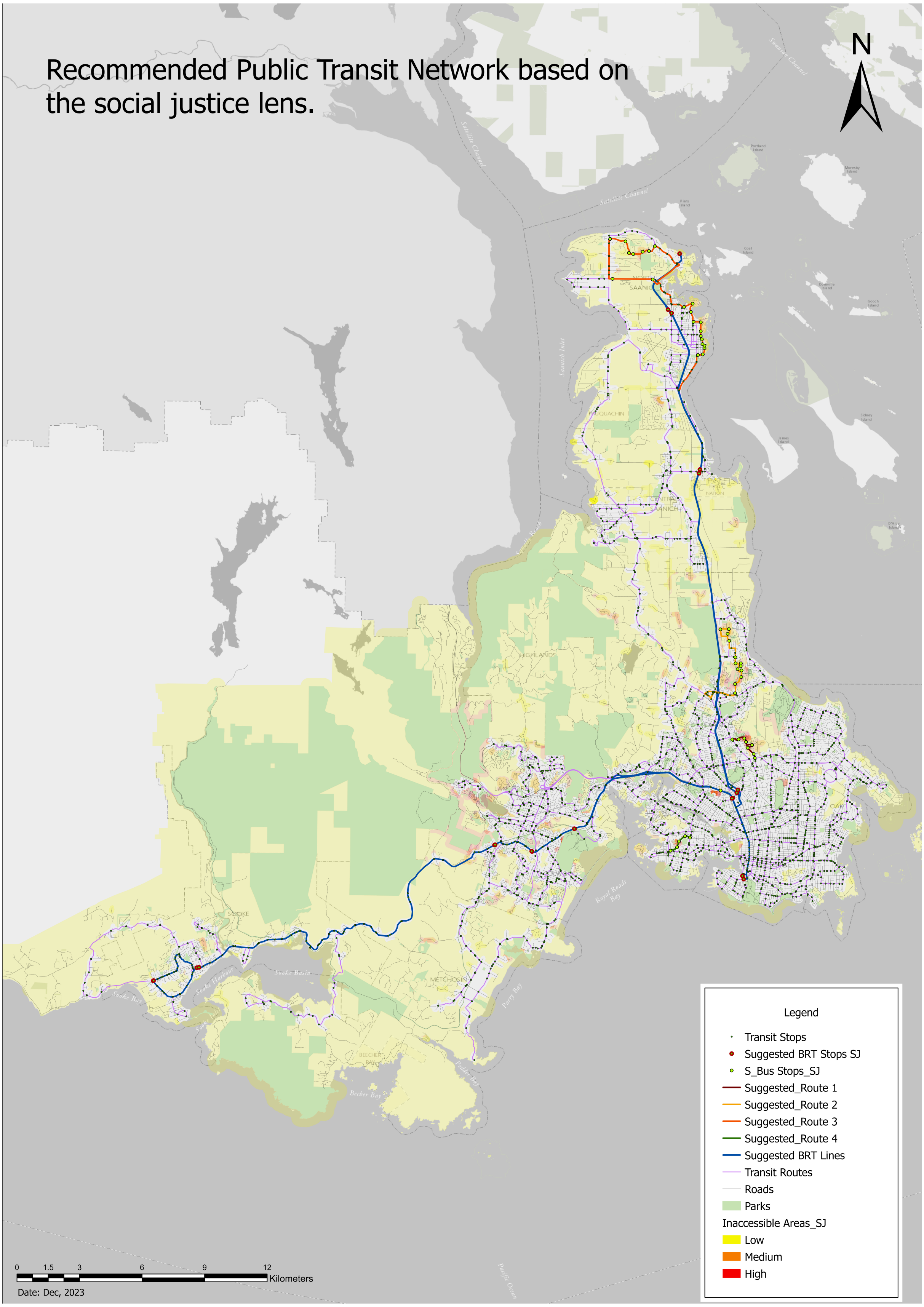


Figure 7. *Cont.*

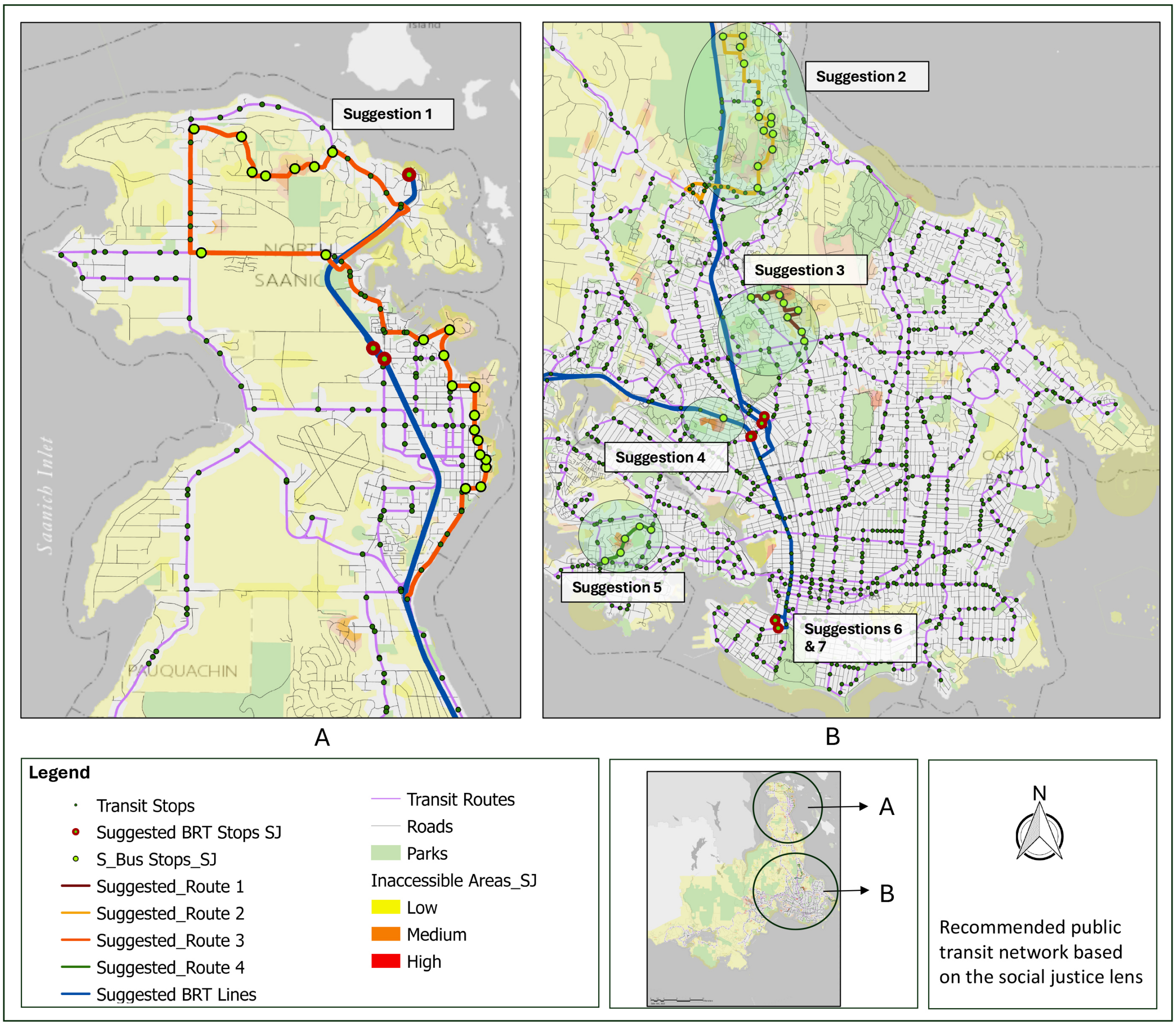


Figure 7. Suggestions for redesigning the GVA's public transit network based on the social justice lens.

As described above, the network was strategically designed to provide accessibility to areas deemed to have high and medium importance in the zoning maps. However, in general, the scenarios represented modest changes to the current public transit system. This is, in part, because they involve leveraging the existing infrastructure without a need for extensive new construction. For example, potential new routes are targeted for roads that are 3.3. m in width to avoid the need for widening the roads, and the bus rapid transit lines use the current bus stops where available and applicable. The remapping work also focused on altering and changing the current bus routes rather than adding completely new routes to build on the previously established network and system. Finally, the remapping exercise involved improving opportunities for multi-modal transportation by co-locating parking facilities, bus stops, and transit hubs.

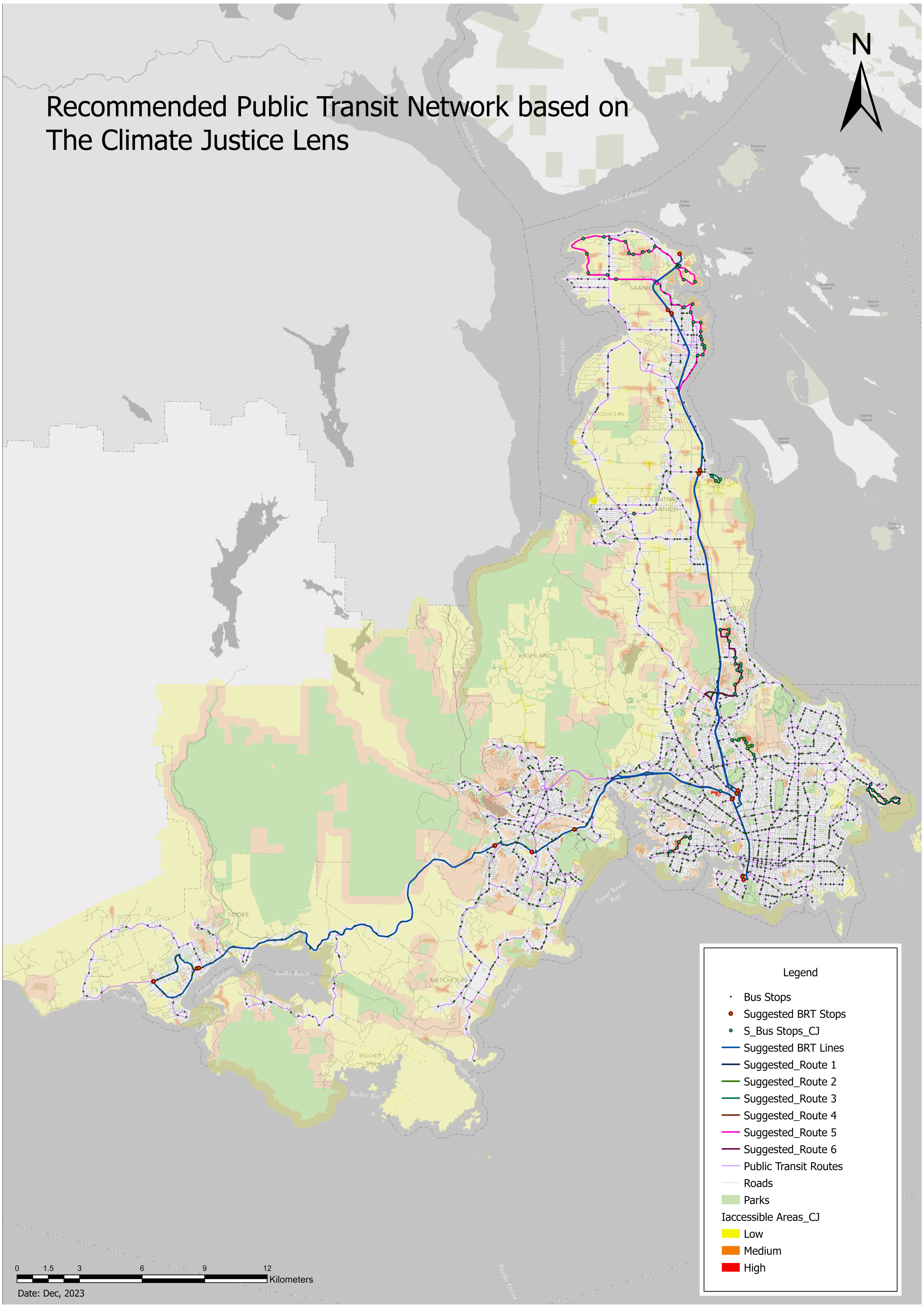


Figure 8. Suggestions for redesigning the GVA's public transit network based on the climate justice lens.

6. Discussion

This research on enhancing public transit networks in the GVA provides a case study for redesigning public transit networks in ways that align with the objectives of climate change mitigation and social justice. The study identified that improvements in these areas could be made through modest changes to the transit system; however, such changes require considerations related to governance and planning processes. Developing the public transit system in the GVA would require BC Transit and Victoria Regional Transit Commission to engage and collaborate with the 13 municipalities in the region, with such collaboration involving discussions on bus stops' locations and enhancements of the infrastructure. These discussions may involve challenges related to road width and the infrastructure needed, which is why the remapping method developed in this study targeted appropriately wide routes and the use of the existing infrastructure. Identifying new routes in this manner can reveal options for improving public transit's benefits while recognizing budgetary constraints, as transit authorities and communities discuss and explore new options for improving local and regional transportation systems.

In addition to collaboration with local governments, transportation planning and development also require public and stakeholder engagement before implementing significant changes to transit routes and infrastructure, involving ongoing consultations involving school districts, health authorities, and the broader public. In some cases, transit authorities assemble stakeholder and expert committees to advise them on how to improve public transportation systems. In the case of the GVA, the Accessible Transit Advisory Committee is a key group that provides advice on accessibility issues. As the analysis and remapping work in this work centred heavily on the accessibility of transit, the committee could benefit from the analytical techniques and maps produced through this work, using these tools to inform the advice they provide to BC Transit. Documenting and reporting on the stakeholder engagement that followed this work is beyond the scope of this article; however, future research could centre on the use of these remapping techniques in planning and decision-making processes.

A major challenge in this type of transit mapping and redesign work is determining what constitutes 'accessible'. BC Transit uses a standard of a 400 m walking distance for over 85% of residents as their measure of accessibility [74]. Similarly, the definition of accessible areas to bus stops is defined in the literature as a 400 m walking distance around bus stops [76–79]. However, other research has used different thresholds for the accessibility of transit such as an 800 m walking distance [80], and some research has used time as an accessibility metric, such as the '15 min city' [81]. Therefore, although the 400 m standard is used frequently, there is no single universally accepted definition of accessibility, and those engaged in public transit network remapping and redesign exercises should recognize the variations and nuances among definitions of accessibility.

A major challenge when adding new routes to public transit networks involves navigating the balance between attracting new ridership and optimizing routes for existing commuters. Such a challenge relates to the 'chicken and egg' metaphor, as it raises questions about whether routes should be strategically designed to draw in new riders or enhance existing routes in efforts to cater to the needs of regular daily commuters. As discussed in this research, these questions are further complicated by a need for efficiency, that is, exploring ways of improving transit systems while also recognizing budgetary constraints (i.e., leveraging the current infrastructure).

The study conducted here focused on a spatial analysis; however, some public transportation changes that contribute to sustainability-related objectives are aspatial in nature. With respect to the climate change mitigation scenario, a number of spatial considerations are involved in the redevelopment of the transit system, such as a transit network design that targets high-density areas and offers convenient multi-modal transportation options (e.g., transit hubs next to parking lots). However, aspatial considerations also exist, such as transitioning the bus fleet to electric vehicles and encouraging the purchase of personal electric vehicles by the public.

Developing indicators and remapping the public transit network to align with social justice objectives involved a focus on demographic data and considerations. As with the objectives of climate change mitigation, some of these considerations are aspatial in nature and were not captured in the mapping exercise, such as programs aimed at reducing transit costs for specific groups, such as low-income individuals, seniors, and people with disabilities; and e-bike purchasing incentives for low-income households. Other considerations are highly spatial, such as ensuring that low-income populations have adequate walking access to bus stops.

While much overlap exists between the climate change mitigation and social justice scenarios with respect to the design of the public transit networks, there are cases where these scenarios and areas of objectives are not entirely aligned. Some transit routes may not yield significant climate change mitigation benefits, but nonetheless play an important role in promoting social justice by providing essential transportation services to specific communities. In the case of the GVA, this involves routes that serve First Nations communities with relatively low populations. Although these routes may not substantially contribute to climate action due to serving a lower population base, they are critical for making progress toward social justice and transportation equity. Such an example highlights the challenges and complexities that surround climate justice as a planning and policy area, as strategies toward achieving the best outcomes of climate change mitigation and social justice are not always aligned.

7. Conclusions

This research provides practical insights into the challenges and considerations for the successful implementation of an improved public transit system aligned with the objectives of climate mitigation and social justice. Policymakers should focus not only on technical aspects but also on fostering partnerships, securing financial support, and ensuring the equitable distribution of benefits. This research sets the stage for a more sustainable and socially-just urban transportation system, and it provides an analytical approach for producing information that can inform us on how to redesign a transit system in ways that contribute to environmental and social goals.

This study acknowledges several limitations that are worthwhile to mention and could be improved upon in future research. One such limitation relates to the case study approach used in this study. Previous transit network research has also used case study approaches, focusing on cities such as Melbourne [31] and Mexico City [35]; however, it is worth acknowledging that such approaches raise questions about the applicability of the research methods and findings to other cities and regions. In this case, the framework developed for the study and the findings are primarily applicable to the Greater Victoria Area, and the framework and methodological approach should be adapted when applied to other regions with different geographic, socioeconomic, and infrastructural contexts. Additionally, the analysis relied on available public data, which may have limitations in terms of their granularity and how current they are. Such limitations can affect the preciseness and timely relevance of the analysis, thereby impacting recommendations on where to locate new transit infrastructure and routes in efforts to improve the outcomes of climate change mitigation and social justice. Furthermore, the methodological approach primarily focused on a stop-based perspective, which may not adequately address the overlap in the service areas of nearby stops or efficiently group stops into routes for optimal service provision. While attempts were made to mitigate these shortcomings, further refinement is necessary to enhance the overall effectiveness of the proposed redesign.

Another limitation involves the fact that the study primarily offers theoretical redesigns without conducting a detailed assessment of the practical challenges related to developing transit networks, such as those related to the development of infrastructure, financial costs, and stakeholder buy-in. This being said, it is worth noting that the study, to some degree, engages with such considerations by redesigning the transit network with budgetary constraints and the need for efficiency in mind (e.g., by leveraging the current transit infrastructure and routes in the scenarios). In addition, although they were beyond the scope of this article, stakeholder interviews were conducted following the transit network redesign exercise, which revealed some of these practical considerations (see [70]).

As a final limitation, the article primarily focused on a method for guiding the redesign of transit networks, and estimating the potential outcomes of different transit network designs was beyond the scope of this work. Accordingly, this study could be followed by another analysis that examines the potential impacts of the proposed transit network changes by quantitatively estimating factors such as transit usage, emissions reduction, and equitable access to reliable transit services. This limitation, along with the others mentioned above, underscores the need for further research to build upon this work and expand its value.

Building on the work in this study, future research could refine and improve the framework and methods developed here for guiding a public transit network redesign exercise. Such potential research would include applying the framework to diverse geographic and urban contexts to validate its broader applicability. Additionally, incorporating knowledge and perspectives from a wider range of stakeholders, including transit users, local communities, and policymakers, could enhance the practical relevance of the framework developed in this study, as well as increase the feasibility of the proposed redesigns. Such broader inclusion would be valuable for addressing community-specific and place-based needs for local public transit systems, as well as for improving inclusivity in transportation planning processes.

Other potential future research includes conducting a cost–benefit analysis of the proposed scenarios. Such a study would provide valuable insights into the economic viability and potential return on investment of different transit network configurations, which, in turn, would aid decision-makers in allocating resources effectively. In addition, a long-term study that assesses the impact of the implemented changes on transit usage, social equity, and environmental outcomes would offer valuable insights into ways of refining the proposed framework and informing future policy interventions. By embracing a holistic approach to sustainable urban transit planning, future studies can contribute to creating more just and climate-friendly public transit networks.

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