OCAD University in collaboration with
Canadian Urban Transit Research & Innovation Consortium (CUTRIC)

Sustainable Development and Electrification of Transit

Knowledge Synthesis Report
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Table of Contents

1. Executive Summary

1.1 Background

The adoption of Zero-Emissions Bus (ZEB) buses fits squarely within a sustainable transit electrification strategy (STES). A sustainable transportation system is one that is safe, affordable, accessible, efficient and resilient, and that contributes minimal emissions of carbon and other pollutants. ZEB transit is recognized by all levels of government in Canada as a critical step in meeting clean growth goals and zero-emissions targets. ZEB includes Battery Electric Buses (BEB) and Hydrogen Fuel Cell Electric Buses (FCEB) as well as hybrid diesel and battery buses. Many Canadian transit authorities are planning ZEB adoption, with significant trials completed or underway and a generous funding infusion from Infrastructure Canada, the Canada Infrastructure Bank, some provinces and municipalities on the table. Sustainability initiatives have become increasingly more prominent in transit related discussions and the United Nations (UN) has identified sustainability goals intended to address the climate crisis. If achieved, ZEB impacts are far-reaching: reduction of emissions and particulates, improved quality of urban life through less pollution and noise, improved health of residents, more equitable and affordable reach and choice of transit, industry growth, and green job creation. Secondary benefits include densification and cost reduction of pollution-induced disease for the healthcare system.

1.2 Objectives

Sustainable Development Electrification of Transit analyzes Canadian and international literature, governmental, academic and industry data sources, and tools to undertake analysis and implementation of ZEB; linking with sustainable development goals to enable both expert and non-expert decision-makers to deliver on clean growth goals, with positive economic impacts, social and health benefits. Our intention is to contribute to national capacity for investment, implementation, and assessment of ZEB. This research was undertaken in collaboration with the Canadian Urban Transit Research & Innovation Consortium (CUTRIC).

1.3 Results

There are 175 ZEBs deployed across Canada.[1] BEBs do not have the range of diesel buses, hence transit agencies may face buying more buses to sustain their current levels of service. New infrastructures are complex, implementation demands process and management changes that necessitates careful planning. Electrification represents the disruption of the whole transportation system, including retraining administrators, managers, drivers, and mechanics. It is difficult for agencies to decide which technology to choose and there is a lack of standardization of equipment. Yet ZEB adoption, whether battery electric buses or hydrogen fuel cell electric buses is transformative and could result in long-term cost savings, fare reductions and improved transit services and healthier communities. It is a core pillar in Canada's overall transition away from fossil fuel dependencies. Winnipeg provides a valuable case study on transitioning its transit fleet to zero-emission, as it began with an early trial, learned lessons, and gathered data, then incorporated ZEB into a comprehensive transit strategy, with strong academic collaboration, and has garnered significant support from the provincial government.

Despite gaps Canada has significant research capacity, data sources, and access to tools to support implementation. In addition to excellent federal ministries and Statistics Canada Data sets ZEB adoption would be served by more open-source transit data, the collection of localized greenhouse gas (GHG) emissions, airborne particulates, and noise pollution data; provincial and territorial energy consumption and costs and health data relevant to pollutants; and data relevant to ZEB trials and adoption, including battery lifecycles. Addressing some of these needs, CUTRIC's ACES (Autonomous, Connected, Electric & Shared) Big Data Trust provides anonymized and aggregated data for its members, from multiple municipal sources that streams into one legally, and cyber-secured, repository to enable and promote sharing between data owners to support comparative analysis and learning.[2]

Supplements to existing ZEB implementation and transit system monitoring tools should include tools to simulate e and analyze the impact of transit design and electrification at a city and neighbourhood level, undertake financial costing of ZEB, provide wells to wheels environmental impacts, support change management implementation, and evaluate and respond to current and future passenger experiences and needs. Researchers can develop a sustainable transit index and expand tools such as Life Cycle Assessment (LCA) to correlate ZEB infrastructure impacts on Canada's economy, environment, health, and social well-being. Future research includes assessments of neighbourhood and traveller type requirements in relation to transit access and equity; longitudinal health research to monitor impacts of emission reduction in relation to heart, lung diseases, and cancers and the correlated reduction of health care costs. Research with Indigenous communities should develop electrification strategies that coincide with infrastructure investment and Indigenous ownership of resources and research.

[1] Figures were provided by the CUTRIC Canadian ZEB Database™
[2] See https://cutric-crituc.org/project/aces-big-data-trust/

- Approach the electrification of transit within a systems analysis of transit needs and transformation. Treat transit as a public good and a pillar of democracy with economic benefits to society. Use this approach in assessing life cycle costs and ROI of electrification, with a longer cycle of investment than the election cycle. Expand economic cost benefit analysis to include indirect savings from cleaner air and fewer emissions and social benefits of expanding ridership. This is an opportunity to improve service as well as achieving positive environmental, equity and health impacts. Hence, stabilize public transit while it recovers during and after COVID-19 and support efforts to rebuild ridership.
- Operational costs savings result from ZEB adoption; the capital expenditure is the barrier. Create long-term stable funding with collaboration between all three levels of government that support ZEB adoption and minimize the risk to transit agencies. The $2.75 billion Zero-Emission Transit Fund is a significant investment in infrastructure and future investment is necessary to sustain this transition. A mix of funding tools should include direct subsidy as well as loans.
- Incorporate health improvement goals, including particulate reduction and noise reduction measurements, correlated with disease reduction goals and outcomes, and include cost-benefit analysis to public health in future policy initiatives.
- Align grid upgrades and clean electricity with ZEB adoption and support clean hydrogen investment. Establish national codes and standards for hydrogen vehicles. Expert integration guidelines are also necessary.
- Set clear federal and provincial GHG reduction policies with dates and targets. Develop a mature system of carbon pricing, with consistent methods of understanding the true impacts of ZEB implementation using consistent formulae.
- Invest in Indigenous communities' transit infrastructure with electrification as an integrated component.
- Position Canada as an innovation, industry and circular economy leader in ZEB development, working with Indigenous, industry and community stakeholders, from the mining of rare minerals, to manufacturing, components capacity, IT tools to implementation services.
- Develop a Sustainable Transit Planning Index that can monitor Environmental, Economic and Social (Equity and Health) metrics.

1.4 Key messages

ZEB adoption is most successful when fully integrated into a holistic planning process that modernizes transit systems, includes rail, last-mile services and active transit, and ensures equal and preferably better access for both intense users of transit and those excluded from effective transit. Expanded transit use remains an overarching goal as it takes more personal vehicles off the road, reduces congestion, has a positive impact on GHG emissions, and finances transit. Personal electrical vehicle expansion is less effective in addressing GHG emissions as vehicles, batteries, and materials produce both GHG emissions and pollutants throughout the life cycle of the product from production to waste/recycling and many individuals cannot afford an EV even with subsidy and lack capacity for onsite charging. A clean transit system supports population growth and densification along urban corridors through better, cleaner services. A strong focus of planning and implementation is the reduction of emissions in the vicinity of transit corridors, where there are large concentrations of residents. This means a better quality of life for city residents, and the reduction of cancer, lung, and cardiovascular illnesses. Effective planning can pair active transportation with ZEB routes, as it is easier to encourage people to ride their bicycles or walk along an emission - free routes, with less particulates. Communities are more receptive to expanding transit services in their residential neighborhoods as ZEB buses are quiet and without fumes. While the GHG reduction benefits of public transportation electrification is less than commercial fleets it is important that public transit play a leadership role.

Canada enjoys substantive opportunities to become a key player in the ZEB supply chain, as a vehicle and components manufacturer, mining minerals necessary for battery production, supplying green or blue hydrogen and IT technology and services. Trials, pilots, and well-planned staging continue to play an important role in effective implementation. CUTRIC has played a valuable role in organizing these efforts across Canada, providing planning tools and creating a data trust. The most significant barrier to ZEB adoption is the cost of implementation of ZEB purchases, related infrastructure costs, and energy sources. Consistent long-term funding and clear communications from all three levels of government is essential to successful ZEB adoption.

1.5 Methodology (search methods, selection criteria, data collection and analysis)

We began the research by undertaking a systematic literature review that identified key words extracted from this field of study and practice. We added themes and additional literature review materials through suggestions from expert interview subjects. Data sources were extracted from literature and through subject matter data searches. Tools searches encompassed those discussed in academic literature as well as commercially available and open-source technology. We selected literature, data, and tools which bore a relationship to the electrification of transit and related topics that impact a sustainable transit approach, such as transit system design, or equity informed approaches to data collection. Sources were stored in searchable databases and analyzed according to sub-themes relevant to Transportation Systems, Environmental, Economic, Social (including Equity and Health), ZEB and Analytic Technology categories. Data collection methods and types as well as equity considerations (GBA+) were considered for all sources, anticipating future analysis and knowledge mobilization. Stakeholder interviews and a workshop supplemented the literature review, data analysis, and tool analysis. We undertook thirty-four interviews, thirty-three by video conferencing and one by email. Interview subjects included representatives from transit authorities, municipalities, provincial and federal officials, politicians, technology providers, urban, transit and equity advocacy groups and associations, infrastructure, energy and electricity providers, funders/investors, boards of trade, consultants, academics, and CUTRIC staff.

The literature review and interviews were analyzed thematically using NVivo and relevant ideas and sub-themes extracted and reflected throughout the report. Analytics Tools were the largest theme that emerged from NVivo treatment of the Literature Review and Economic Impacts emerged as dominant in the interview analysis. After these differences there was convergence in concerns. Health research and action on social and equity concerns are less represented in literature but loom large in policy concerns and gap identification in interviews, which should help to guide future research.

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2. Background

2.1 Research Question

We ask, “What are best practices, lessons learned, and indicators of success, as well as critical gaps in research, data, tools, and policy needed to effect environmental, economic, social equity, and health drivers to support the implementation of ZEB transit infrastructure?” This report analyzes existing literature, governmental, academic and industry data sources, and tools to undertake analysis and implementation; linking with sustainable development goals to enable both experts and non-expert decision-makers to deliver on clean growth goals, with positive economic impacts, and social and health benefits. We do this by mapping current research and non-academic (grey) literature themes from Canadian and international sources, identifying available data and gaps in research and data, and connecting these findings with sustainable development goals to better enable knowledge and data sharing. When appropriate to the analysis we differentiate Canadian and international sources to better identify knowledge that we can gain from other contexts or gaps. Further, we recognize that planning and implementation tools are called for to support ZEB adoption, hence we identify existing tools and connect these to research themes and data sources. Our goal is to build a national argument for investment, implementation, and assessment of ZEB.

2.2 Sustainable Transit Development Goals

A sustainable transportation system is one that is safe, affordable, accessible, efficient and resilient, and that contributes minimal emissions of carbon and other pollutants. This sustainable system demands creative thinking about a future framework that is within the realm of possibility, is desirable to its users, and addresses the important role of transportation in a sustainable city (Zito & Salvo, 2011). Sustainable transit draws from the concept of a sustainable development system provided by Brundtland (1987): “Sustainable development fulfils the needs of the present without compromising the ability of future generations to meet their own needs” (11). This implies that a sustainable transportation system must consider the possible impacts of transportation on environmental considerations, economic growth and employment, and societal dimensions such as affordable access (Bowes et al., 2021; Tanguay et al., 2010; Litman, 2008). According to the definition provided to the Centre for Sustainable Transportation by Gilbert et al. (2003), a sustainable transportation system is one that:

1. “Allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations.
2. Is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy.
3. Limits emissions and waste within the planet’s ability to absorb them, minimizes consumption of non-renewable resources, reuses and recycles its components, and minimizes the use of land and the production of noise.” Gilbert et al., 2003, 4.

Further, the impacts of transport on climate are reiterated in the Paris Agreement, since almost 25 percent of energy related to global GHG emissions are emitted by transport systems (Bowes, et al., 2021). In response to these data world leaders agreed to deploy greener technology such as electric vehicles for transport (High-level Advisory Group on Sustainable Transport, 2016).

However, realizing a sustainable transit system is a challenge. City and regional planners have struggled to find balance between providing convenient, frequent mobility for residents and the obligation to address the economic, social, and environmental implications of transportation systems. Electrification of transit fits squarely within a sustainable transit electrification strategy (STES). If achieved its impacts are far-reaching: reduction of emissions and particulates, improved quality of urban life through less pollution and noise, improved health of residents, more equitable and affordable reach and choice of transit, industry growth, and green job creation. Secondary benefits include densification and cost reduction of pollution induced disease.

As was clear in the grey literature citations, ZEB transit is identified by all levels of government in Canada and transit authorities as a critical step in meeting clean growth goals and Zero-emissions targets. The Government of Canada announced that it would invest $2.5 billion over five years through the Zero Emission Transit Fund (2021). Infrastructure Canada set the goal of 5,000 transit and school buses to be on the roads over five years, "to accelerate the adoption of zero emission buses and charging infrastructure so Canadians can have cleaner commutes" (Jarratt, 2020). The realization of this target necessitates effective partnerships across all levels of government and industry.

2.3 CUTRIC's Role in the Canadian Ecosystem

CUTRIC is a collaborator on this research grant. CUTRIC is a socially responsible non-profit organization that spearheads, designs, and launches technology and commercialization projects that advance next-generation zero-carbon mobility and transportation solutions across Canada. Its vision is to make Canada a global leader in low-carbon smart mobility technologies across heavy-duty and light-duty platforms, including advanced transit, transportation, and integrated mobility applications. It supports the commercialization of technologies through industry-led collaborative research, development, demonstration, and integration (RDD&I) projects that bring innovative design to Canada's low-carbon smart mobility eco-system. CUTRIC has played a vital role in identifying the opportunities and best practices of electrification (Petrunic, Abotalebi, & Raj, 2020).

CUTRIC develops low-cost simulation tools that help transit agencies across Canada and the United States predict how their battery electric buses (BEBs), Hydrogen Fuel Cell Electric Buses (FCEBs) and autonomous smart vehicles (for first kilometre/last kilometre solutions) will operate in real-time on roads and in service. These advancements seek to grow the low-carbon and smart technology eco-system across Canada and North America, leading to job growth and economic development over the long-term. CUTRIC's work further seeks to decrease fuel consumption, reduce emissions, reduce congestion, and improve the quality of life for mobility customers and transit riders. When appropriate CUTRIC's role within ZEB planning, implementation and technology support are cited in this report.

2.4 Defining ZEB

Our definition of ZEB includes battery BEB and FCEB buses. BEB adoption currently dominates the Canadian funding and planning context. However, municipalities have also adopted hybrid diesel-electric buses as a transitional technology that has longer range than BEBs and provides heating in the winter. Some municipalities are choosing FCEBs for their range and electricity use efficiency. Others include renewable natural gas produced from landfill or biowaste as a viable option.

3. Methods

We provide strengths, gaps, and recommendations for the Canadian context. We reviewed and analyzed literature, data, and tools according to the categories of ZEB adoption, environment, economy, social (including equity), and health. We sought to draw out appropriate intersections between these categories and found correlations between factors, for example, tertiary benefits of electrification of transit are reduced healthcare costs because of the drop in airborne particle pollutants.

3.1 Quantitative Analysis and Thematic Coding

NVivo, (a qualitative data analysis (QDA) software) was deployed to complement researchers' empirical content analysis for the literature review as well as the interview and workshop transcripts as it provides the mechanisms for a recounting of the phenomenon of interest using both inductive and deductive analytic processes (Elo & Kyngäs, 2008). The primary value was to both identify themes that dominated literature across this area of investigation and the concerns of interview respondents.

3.2 Secondary Sources – Print, Data and Tool Resources

We began the research by undertaking a systematic literature review that identified key words extracted from this wide field of study and practice. Academic and grey literature was aggregated from sources in an ongoing manner: bibliographies of key researchers in the field of transit electrification, previous projects from our research lab on which this report builds, scans of central databases, recommendations from partners, sector leaders and interview respondents, and ongoing research.[3] Sources were analyzed in a central database where key information was extracted and displayed in a comparative format to enhance ease of analysis. The literature database of over 500 entries functioned as a dynamic, centralized information hub throughout the study.

The literature was analyzed according to Transportation Systems, Environmental, Economic, Social, Equity, Health, ZEB, and Analytic Technologies which correspond to the sections of this report. We used this framework to undertake interviews and the workshop. The team disaggregated key themes through the inclusion of inductively generated sub-domains to gain a more robust understanding of the thematic weighting and nuanced categorical relationships of the literature sources. We summarized literature, indicated its relevance to electrification, including annotation of methodologies employed in the research, considered whether specific tools were used in a study, asked how the data was sourced, generated, or used in a report, and how it was expressed and shown. In instances where data was used directly to generate insights or conclusions in a report, we recorded variables and their descriptors to discern standard inputs being recorded and deployed within our research area to support the development of our interactive tool.

We extracted an understanding of data types essential for a full environmental, economic, social, equity and health impact analysis of electrification from the literature review and identified where Canadian sources of such data exist and where there are gaps. We also undertook online searches for available Canadian and international data using the same categories and compiled a separate database. By mapping available data, gaps, and connecting these data with sustainable development goals, our research suggests avenues to enable data sharing, investment in data collection, implementation, and assessment.

Tools analysis expanded prior research that identified stakeholders' requirements for data analysis and visualization tools in the larger context of municipal transit and transportation planning (Bowes, 2021 ; Gordon, 2018) While analyzing the literature we identified key aspects specific to transit planning, electrification, associated social, equity and health concerns that required support tools, and this information was compiled in a master database of source information, tool type and application, highlighting the associated data needs and provisions. We further searched for commercial and open-source tools. Our goal was to identify applied best practices of tools, gaps either in tools or in interoperability of tools, and guidelines for adoption in the context of sustainable development.

3.3 Primary Sources – Interview and Workshop

Stakeholder interviews supplemented the literature review, data analysis and tool analysis. We undertook thirty-four semi-structured one-on-one virtual interviews, thirty-three by video conferencing and one by email. Interview subjects included representatives from transit authorities, municipalities, provincial and federal officials, politicians, technology providers, urban, transit and equity advocacy groups and associations, infrastructure, energy and electricity providers, funders/investors, boards of trade, consultants, academics, and CUTRIC staff. As with the literature data and tool review, we explored environmental, economic, social, equity, and health benefits and best practices, challenges, data used and gaps, tools used and gaps, and recommendations for future research and policy. We undertook an intersectional analysis, inquiring about the value or challenges of bringing these factors together. Interviews were confidential and data anonymized. The role type of the respondents is provided in Appendix 8.1, and each is identified by a number in the text (e.g., #1) to preserve their anonymity. We presented our research to date and questions and received responses from participants in a workshop.

3.4 Thematic Coding Analysis

The NVivo literature review search indicated that themes Analytic Technology and Social (which included Health and Equity) appeared most frequently in abstracts and articles. The footnote provides details of themes and

[3] Grey literature includes municipal, provincial, and federal policy papers regarding transit and transportation policy, climate, environmental policy, power generation, and ZEB policy. There are press releases regarding ZEB adoption which provide a sense of timeliness of this issue and resulting news reports and editorials. Industry technology descriptions from several sectors, ZEB bus and battery providers, charging systems, hydro and other electrical companies, and tool companies and consulting firms are included as these provide a key source of information. As part of the literature review, we identified case studies which included best practices tools and data sources. This information was tabulated in a separate database of key Canadian and case international studies.

subthemes.[4] The tree map (Figure 1) indicates the weighting of these topics with a graph view of topics shown in Figure 2.

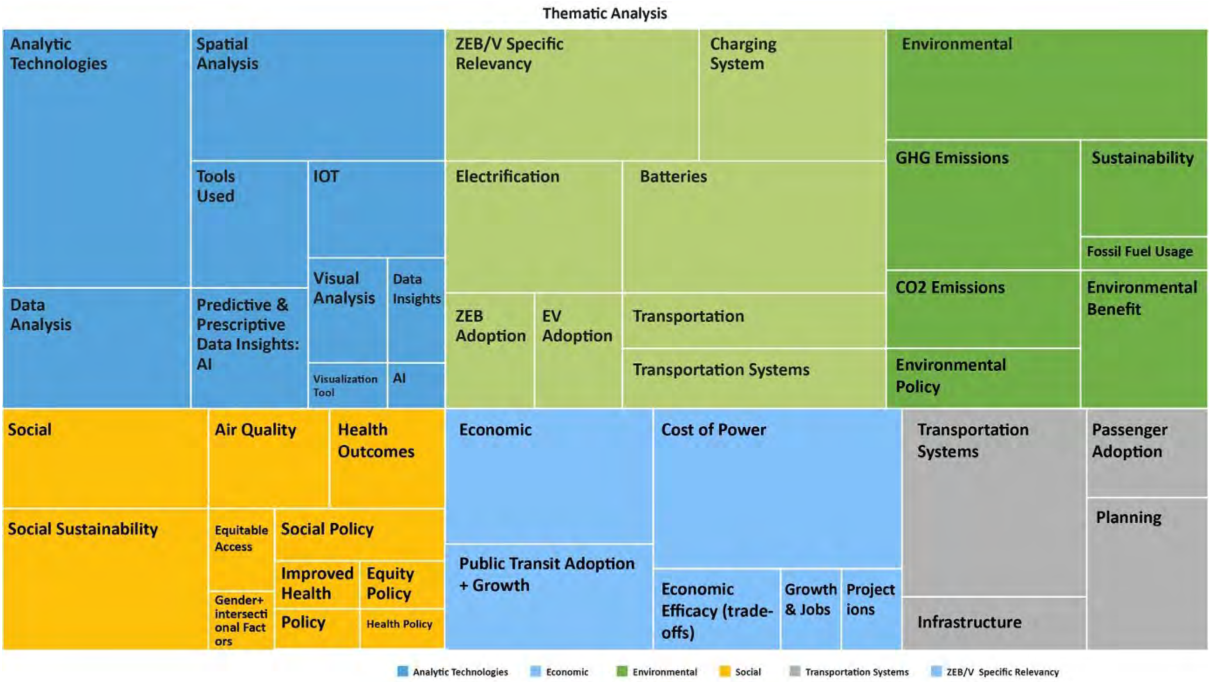

Figure 1. Tree map of Literature themes and relative weighting of topics.

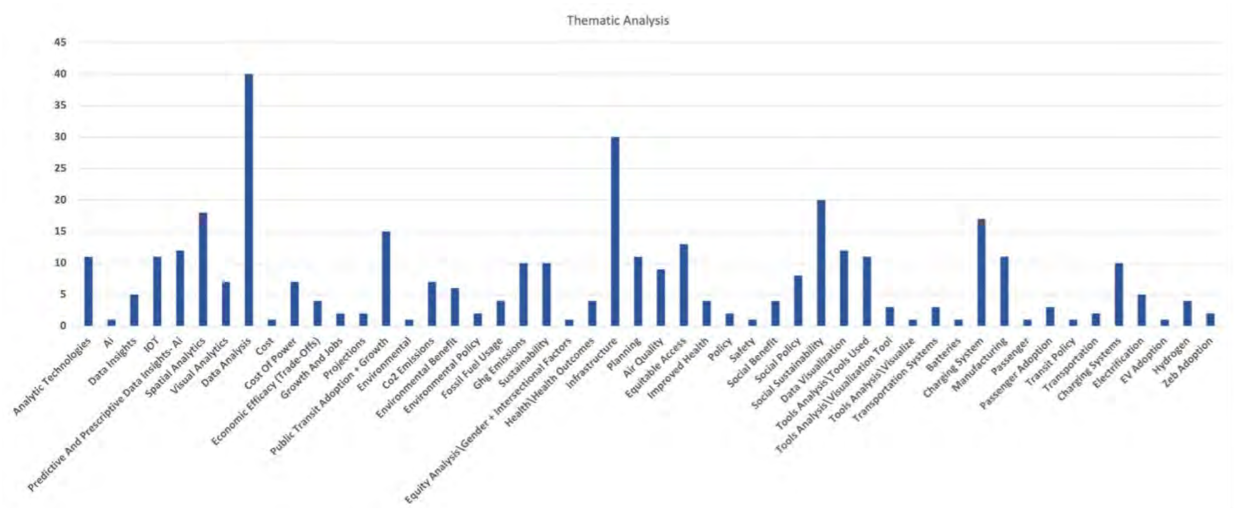

Figure 2. Graph of Literature review themes and relative weighting of topics.

Interview transcripts were subject to a content analysis in a two-part process which examined ZEB adoption, environmental, economic, social, health, and equity-based themes. We manually excerpted highlights of

[4] Significant themes in Analytics Technology literature were Predictive and Prescriptive Data Insights- AI, Spatial Analytics Visual Analytics and design, Data Visualization, Tools Used, IOT Sensors Analytics. Significant social themes were Equity Policy, Gender + Intersectional Factors, Equitable Access, Social Benefit, Social Policy, Social Sustainability, Transit Policy. If disaggregated Health received less attention, with concerns including Improved Health, Policy, Safety, Health Outcomes, Health Policy, Air Quality. Major themes in Transportation Systems were Infrastructure, Planning, Transportation, Technologies, Passenger Adoption, Manufacturing. Articles that bore ZEB/EV Relevancy focused on Batteries, Charging System, ZEB Adoption, EV Adoption, Electrification, Hydrogen. Dominant themes in Environmental were CO2 Emissions, Fossil Fuel Usage, GHG Emissions, Environmental Sustainability The significant codes in Economic were Cost of Power, Economic Efficacy (trade-offs), Growth and Jobs, Projections, Public Transit, Adoption and Growth.

interviews analyzed these for thematic content. We then set a wide net of descriptors (see Appendix 8.1) and used NVivo to capture themes. Economic impacts, Transportation Systems and Environmental factors received most comments from interview subjects. Figure 3 provides a tree map of themes and weighting. The footnote provides details of sub-themes.[5]

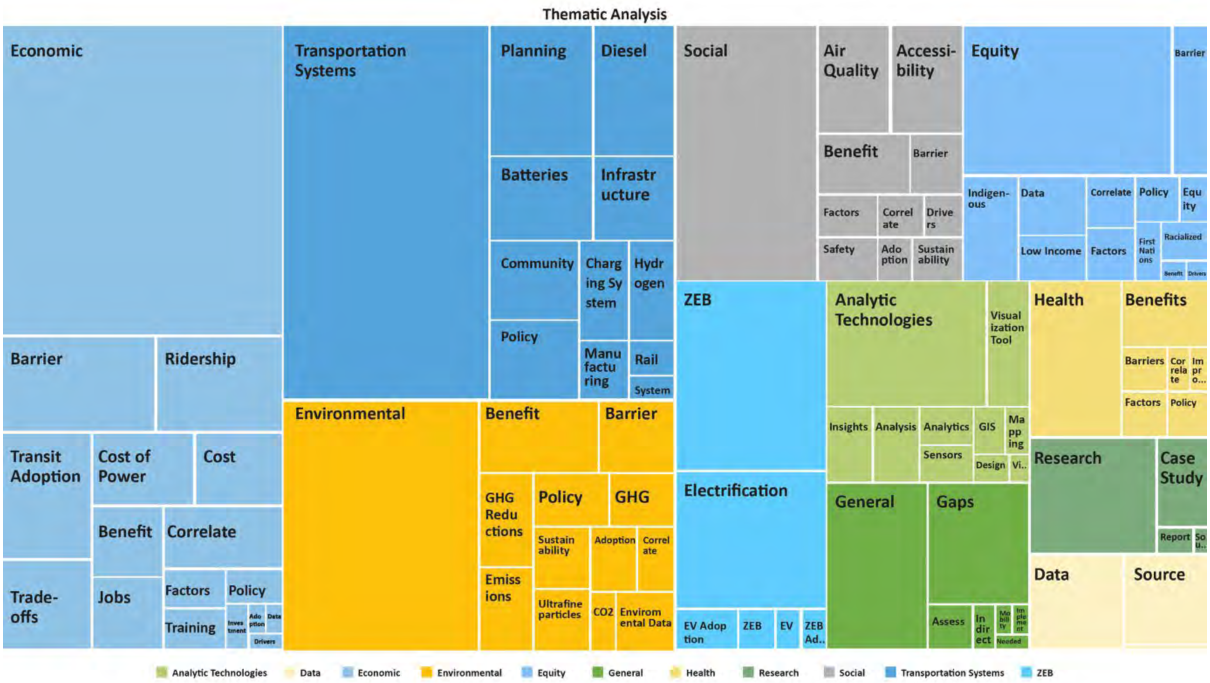

Figure 3. Tree map of interview themes and relative weighting of topics.

As noted, Analytics Tools was the dominant theme that emerged from NVivo treatment of the Literature Review and Economic Impacts was the dominant theme in the interview analysis. Health research and action on social and equity concerns are less represented in literature, but loom large in policy concerns, which should help to guide future research. After these differences there was more convergence in topical interest.

3.5 GBA+ Framework

Nearly a decade ago, in May 2013, the federal government instituted an expanded gender-based analysis (GBA) framework called "GBA+". GBA+ stands for gender-based analysis plus intersectionality. Status of Women Canada explained that "the 'plus' in the name highlights that gender-based analysis goes beyond gender and includes the examination of a range of other intersecting identity factors (such as age, education, language, geography, culture, and income)" (Government of Canada, 2013, p. 1).

GBA+ allows researchers and policymakers to investigate the "simultaneous interactions between different aspects of social identity" (Hankivsky & Cormier, 2009, p. 3), power structures, and health outcomes. Thus, factors such as gender and cultural patterns are examined within a holistic framework that also considers an individual's or collectivity's race/ethnicity, Indigeneity, immigration/refugee patterns, class, sexuality, and religion. It is important to note that these intersectional or identity factors are mutually constituted, and additionally, socially constructed, elastic and in constant production within a specific time and place (Butler & Weed, 2011). One's intersectional or identity factors, such as gender or class, do not necessarily dominate as an influencer and predictor of health outcomes – all the factors will intertwine to influence health and wellbeing. As a result, intersectionality should not be an "additive approach" (Hankivsky, 2012, p. 1713), whereby identity

[5] Economic concerns were Benefits and Costs, Trade-offs, Ridership, transit adoption and the cost of power. Transportation Systems interests included Transit Planning, Infrastructure, Transit Policy, Community, Diesel, Transit Policy, Hydrogen and Batteries. Dominant concerns of Environmental Impacts were Environmental benefits and barriers, GHG reduction, Emissions, Ultra Low-Sulfur Diesel Fuel, Sustainability. ZEB key themes were Electrification, Charging Systems, and EV's. Social Concerns included Accessibility, Air Quality, and Social Impacts. Equity focuses highlighted Equity Barriers, Low-Income and Indigenous needs; Health themes were Benefits. Concerns that dominated Analytic Technologies were Visualization and Data Insights.

factors are collected to assess their effect on health outcomes. Instead, the enmeshment of multiple identity factors within power structures and hierarchies are analyzed within their specific temporal context.

3.6 Visual Analytics Approach for Interaction Design

Our research includes the development of an online interactive guide that provides a "mind map" that indicates themes and the connections between themes derived from analysis of the literature review, data, and tools databases. This online interactive guide will support professional and research audiences who could find our research of value. It will be available at the completion of the research grant. We build on previous approaches, specifically Compara (Gordon et al., 2018) which was a multisectoral theme and visualization map regarding design tools. Nodes are used to show hierarchical connections and cross-connections and their weightings. Users will be able to filter and reorganize information. The interactive guide will be user facing while our extensive databases will provide details of sources, descriptions and themes.

Figure 4. Excerpt from Compara (2018**)**

4. Results, Best Practices, Gaps and Recommendations

4.1 Transit Systems

4.1.1Transit Systems Strengths and Research

ZEB planning and delivery occurs within the context of broader transit systems. Research considered the context of transportation systems and the principle of transit-oriented development (Dittmar & Ohland, 2004) which argues that planning at all levels, from neighbourhood, to region, to province, must take transportation, and within this transit, into account. Goals are mixed land use, mixed income and demographic integration, accessible transit, walkability, efficient transportation connectivity to resources outside of a community, and healthy communities with a range of transit options. Both COVID-19 and the affordability crisis for housing have led to the acknowledgement of the connection between affordable housing and transit access, looking more at transit-oriented development (Schwartz, 2020).

We reviewed and summarized research on transit systems in the following transportation categories; Road and Rail Transportation Systems; Energy Efficiency and Optimization; Design; Predictive and Prescriptive Data Insights; Spatial Analytics, GIS, and Cartography; IOT sensors; and Data Analysis and Visual Analytics. This work was instrumental in providing us with a foundation of material that identified key aspects of transit systems, from which we could extract research themes, best practices, available data, and gaps in requisite data. The literature review identified tools that would benefit future decision making, system and equipment planning, and investment.

We consistently read of and heard about the importance of integrating electrification of buses, whether BEB, hybrid diesel-BEB or FCEB into a holistic planning process that modernized transit systems, included rail and last-mile services, and ensured equal and preferably better access for both intense users of transit and those excluded from effective transit (Welch, 2017). A further goal is attracting users back who have abandoned public transit during the COVID-19 pandemic. COVID-19 demonstrated that transit cannot only provide access to a downtown core but must respond to heaviest demand, for example the Shepherd and Finch buses which moved service and manufacturing workers throughout Toronto. (#3, #19)[6]. An additional advantage of ZEBs is mobility; they can easily be managed in tunnels, or beneath buildings because the ventilation issues are minimal and allow more flexible route planning (#4). Bus rapid transit (BRT) can provide dedicated lanes for energy efficient buses that are flexible, less expensive over the life cycle and which can be redirected to serve population change, building support for buses as a mode of transit. (#19)

[6] Numbers in parentheses refer to interview respondents. See Appendix 8.1 for details of roles.

Canadian
Electrification of transit calls for an analysis of existing transit systems down to the individual route, and projection of future demand and service strategies at the systems level. Hence, ZEB acts as catalyst for a larger system redesign, and to understand all operations from a customer-centric perspective. (#21). The holistic planning of the system will allow the integration of different vehicle types to suit differing contexts. Canadian municipalities large and small, West to East and North to South, have tabled transit plans that include electrification. These are often coupled with municipal and provincial climate change mitigation and environmental strategies. Examples include the Halifax Rapid Transit Strategy (2020) and the Winnipeg Transit Master Plan (WTMP) (2021) which sets a 25-year vision for transit service and infrastructure in the city,

> The WTMP includes transit service classification, service guidelines, infrastructure guidelines, Winnipeg Transit Plus recommendations, and a fare strategy…resulting in a simpler, more efficient, more effective, and more accessible transit system - one that is better positioned to become people's first choice for travelling around Winnipeg. WTMP, 2021, 11 [7]

In Winnipeg, ZEB will be prioritized on the rapid transit network, which is the backbone of a skeletal accessible network with FCEB buses. 60 percent of people live within walking distance of the of the grid itself. As one planner expressed it, a long electric bus is a cheaper train. "People want comfort, no acceleration and deceleration extremes; electric buses do not start and stop abruptly." (#14). Small zero-emissions vehicles will come to local streets, while standard high frequency routes will be last to receive ZEB. (#14) The new technology available with ZEBs allows the expansion of bus service with lighter, quieter vehicles into communities that would not typically want a heavy-duty diesel bus operating in their neighborhood, including on-request services. A network realignment will have a larger impact in the citywide GHG environmental impacts, so service improvements and new services will have a stronger benefit overall, but ZEBs are a key strategic component (#6).

The Toronto Regional Board of Trade's discussion paper *Towards a Greater Golden Horseshoe Transportation Plan*. (2021) reflects approaches of many regions in Canada. It describes transportation as a complex system of provincial, municipal, and private sector infrastructure, services, and programs. The goal is to set a long-term vision for regional mobility from 2021 to 2051 and set a path to achieve shared goals for the transportation system. This report addresses public transit and includes commercial transportation requirements and the transition to personal electric vehicles. *NEXT STOP Building Universal Transit Access* (Toronto Regional Board of Trade, 2021) proposes four pillars for an effective system that attracts users and is sustainable: accessibility, that is service every 10 minutes; seamless integration of regions; improved infrastructure and improved innovation and multimodality, including on demand and last mile services, all deploying green solutions services.

Public transport awareness: Traveller behaviour & satisfaction
A funder (#3) perceived, "transportation as the mobility of people in a region - a mosaic of roads, bikes, mobility of all types, and a business, that has a high cost to operate and therefore has to have a high value in terms of its usage in the community." An NGO representative (#8) believed that rather than a cost, transit investment and supporting policy should be seen as an asset to the community. Tools to assist and evaluate passenger experience are essential feedback to making decisions around route management, frequency, safety, comfort, and convenience and attract passengers. (#31) Dublin developed a *Real Time Public Transport Awareness System* (Bouillet, 2015) that ingests, analyzes, and visualizes high volumes of passenger data coming from a variety of sources to ensure efficient operation and meet passenger demand.

4.1.2 Transit Systems Data
According to Ma and Chen (2019), "Massive data are generated during the public transportation operation process. These data are highly continuous, have wide coverage, contain comprehensive information, and update dynamically and quickly (for example real time data); thus, they have high application value to public transportation operation and planning" (176) Data is required to undertake effective planning and analysis of transportation systems. Examples of these data include annual transit ridership, passenger-kilometer (by mode, purpose), total kilometer driven, transport intensity (passenger or tom-kilometer/GDP), length of railways and main roads (km), average traffic speeds, average congestion delay, and public transport performance.

Transport Canada is the federal institution that is responsible for transportation policies and programs. (https://tc.canada.ca/en) and provides a wide range of transportation system data. Canadian Urban Transit Association (CUTA) holds transit history data gathered from more than 100 transit systems across Canada. The

[7] WTMP is cited as a case study that sets the framework for addressing ZEB adoption as well as rethinking transit access and efficiency, provides environmental benefits and challenges, includes electrifications and the limits of current technologies, and brings potential positive impacts on equity.

data is only available to members. (https://cutaactu.ca/news-resources/statistics/) An example of municipal data is the Montréal origin-destination (OD) survey by the Autorité régionale de transport métropolitain (ARTM which documents traveler mobility in the Greater Montréal area. It provides insights on how to improve planning for public transit, road systems, and urban development (https://www.artm.quebec/origin-destination-survey/). BIXI Montréal is a non-profit organization created by the city of Montréal that manages its bike-sharing system. It holds open data for trip history and purchases by members and occasional users, and real-time station status. (https://bixi.com/en/open-data), of value in correlating e-bus implementation and active transit. The Transportation Tomorrow Survey (TTS) is a travel survey conducted about urban travel in southern Ontario area every five years (http://www.transportationtomorrow.on.ca/. There are valuable open data repositories. Toronto Transit Commission (TTC) Operating Statistics (https://www.ttc.ca/transparency-and-accountability/Operating-Statistics) provides key facts and statistics about the transit system's annual performance in overall service. Winnipeg Transit's Open data web service offers an API for retrieving live information about Winnipeg Transit's services, including routes, stops, streets, trips, live status, schedule, locations, destinations, etc. (https://data.winnipeg.ca/). The City of St. Albert's Open Data Portal provides open data of the public transportation, including traffic count, transit routes, stops, streets, pathway and sidewalks, and transit fleet inventory etc. (https://data.stalbert.ca/)

There are transportation data sources in other countries that suggest appropriate data types that Canada could collect to provide opportunities for comparison and analysis. Sources include the International Road Federation (IRF) Statistics – Official Site of the International Road Federation (www.irf.global) IRF presents links to international frequently requested road mobility and infrastructure statistics. Membership based Millennium Cities collects information about public transport and urban mobility through gathering and exchanging knowledge with their extensive network of urban mobility stakeholders and offers the Mobility In Cities Database (https://www.uitp.org/data/) and the (www.uitp.org/knowledge/Statistics.cfm). International Transport Forum (www.internationaltransportforum.org) is a thinktank for policy makers and a repository. A transportation focused repository is Global Transport Intelligence Initiative (www.slocat.net). The Organisation for Economic Co-operation and Development (OECD) data base includes demographic data and transport statistics (www.oecd.org) as does the Statistics European Commission (europa.eu) and Eurostat (the statistical office of the European Union) https://ec.europa.eu/eurostat). Australian data can be found at the Australian Transportation Data Action Network (www.nss.gov.au/transportmetadata). Overall American data which includes transit and transportation are the U.S. Highway Statistics Annual Report (www.fhwa.dot.gov/policyinformation/statistics.cfm) and the American Statistical Association (http://amstat.org). The Global EV Outlook 2021 – Analysis – IEA (https://www.iea.org/reports/global-ev-outlook-2021) considers EV adoption.

4.1.3 Transit Systems Tools

Technological innovations adopted by transit authorities can improve cities' sustainability through the effective use of information and communication technologies that enable appropriate route planning, reducing traffic congestion, traffic collisions, and travel distance and time as outlined by López et al. (2018) and Venne (2019). In the larger context of municipal transit and transportation, we found that some tools address systems planning, and others focus on the integration and analysis of ZEB infrastructure and implementation. These are found in the ZEB adoption section. Overall transit systems planning tools are described below:

- Fleet specific data viz tools – total vehicle inventory, characteristics, bus life, purchase cost, and loan costs.
- Annual operations data tools - driver, fuel, and station costs.
- Maintenance tools - average maintenance costs, frequency, fuel, and station maintenance, including overhaul and retrofitting costs.
- Operational technology support tools for bus route visualization - to monitor, track and visualize daily operations of scheduling, vehicle routing travel times - frequencies, and routes' cycle times, GPS vehicle tracking of data such as speed, latitude, longitude, and timestamp, GIRO (https://www.giro.ca/en-ca/), (Sanchez-Hidalgo & Maria-DoloresCano, 2018). This approach is underscored in Maji's conceptual model for a Smart Bus System (Maji, 2017).
- Route characteristics and topography analysis, weather, and road conditions - (Barkah & Robert, 2018)
- Passenger capacity data tools - travel times, train load information, boarding and alighting passenger counts, bus frequencies, and routes' cycle times, to identify both direct and indirect impacts of traffic patterns (Shalaby et al., 2018, Bouillet et al., 2015).
- Closely related are information tools divided in Sobral et al.'s (2019) discussion of Intelligent Transport Systems (ITS) into three subgroups: activity-based, device-based, and location-based. These collect and represent data with different attribute types, with the goal of improving passenger experience.

Faulin et al. (2019) propose a broad, systemic range of considerations that should be optimized when planning ZEB or other electric mobility integration into a transit system from a sustainable transit perspective. These are: infrastructure development; centralized and decentralized energy sources; charging/refueling options; communication technologies; network design; intermodal compatibility (e.g., places for bicycles on buses); last mile connectivity; EV technology; autonomous vehicles; operations; and vehicle routing.

4.1.4 Transit Systems Challenges and Gaps The complexity of transit planning demands a holistic systemic planning and organizational approach to understand all the various stakeholders needs, and this challenge can only be met through the integration of cumulative initiatives and actions at all levels of the transit system. Analysis and tools provide support for fleet procurement and management, operations and maintenance. However, there are perceived weaknesses in passenger experience design and means to integrate and evaluate social, environmental, and equitable goals in planning. (#34) Ollier (2018) argues that to succeed, public transit planning must integrate environmental and social objectives, "In order to be environmentally performant, transportation planning requires social coherence and inclusivity" (2). Her Montreal study demonstrates that such analysis on the part of transit authorities is not always present, although agencies engaged in this study were eager to address these issues.

The development of transit must be passenger responsive, to create successful transit experiences and driven by the wishes of stakeholders who utilize the system, and tools to evaluate that experience that provide real time data should be integrated into new systems. Kwon et al. (2020) consider eight attributes that impact riders: safety, ride comfort, environmental friendliness, exterior design, cleanliness, crowding, seat comfort, and convenience getting on/off. They surveyed riders using the best-worst scaling method. Similar attributes were identified by Munim & Noor (2020) in their survey of young e-bus riders in cold climates that focused on customer satisfaction. They urged improvements in punctuality of scheduling, availability of bus routes, provision of compensation in cases of loss, and paying attention when boarding on and off passengers. Cao et al. (2015) evaluated the BRT system in Ghuangzhou, China as it was electrified. They used a three-factor analysis: basic factors, performance factors, and excitement factors. Passengers' priorities were safety while riding the service, safety while at a station/stop, and comfort while waiting at a station/stop.

4.1.5 Transit Systems Research Required

A funding agency representative (#3) reinforced the value of research to support transit-oriented communities planning that clusters dense housing around transit stations with the goals of better quality of life, less commuting, and healthier outcomes. Research would evaluate means for ZEB integration to address transit corridor placement, localized pollution, and socio-demographic/economic neighbourhoods. (#13) Feasibility studies for technological transition and transit master planning were recommended. (#1). Research by regional authorities to understand their ridership was a consistent suggestion. (#5, #7, #20, #31) Several respondents noted that it was important to understand people's enjoyment for their daily commute, as a transition or buffer from work and home rather than as deficit time pointing to a potential reframing of transit amenities to enhance ridership. Transit planning research could better understand population change and needs by addressing migration and immigration patterns. (#13)

4.1.6 Transit Systems Data Required

Researchers involved in master planning have occasion for power supply, availability, cost, and consumption data and open-source and centralized GTFS route data. Researchers and policy makers felt that data collection from transit cards like Presto was essential to understand behaviour and supplement surveys. (#25)

4.1.7 Transit Systems Tools Challenges, Gaps and Requirements

A respondent identified the need for tools that could demonstrate the impacts on commuter traffic of a transition from personal vehicle usage to mass transit to commuters and politicians, showing the reduction in commute times and emissions (#7). Other tool essentials are analytics to indicate frequency of service per passenger and the underlying demographic data in areas, levels of service and utilization in particular locations, and combine this data to show patterns in the city. (#18) Respondents noted that Toronto is a leader in transportation surveys (The Transportation Tomorrow Survey (TTS)) but would benefit from a nuanced real-time map and digital twin that shows gradations of the quality of services, indicates where people are traveling point to point, and enables simulation modelling. Tools to assist and evaluate passenger experience are essential to guide route management, frequency, safety, comfort, and convenience.

4.1.8 Transit Systems Policy Requirements

Respondents advised that electrification of transit be placed within a systems analysis of transit needs and transformation.

4.2 ZEB Adoption

4.2.1. ZEB Adoption Strengths and Research

The transition to ZEB has been identified as a driver for cities, prompting transit planning, environmental improvements and accelerating green electricity planning, creating ZEB supply chain investment for industry, and establishing environmental credentials through ZEB deployment for cities (Pejcic et al., 2021). In their Canadian study Mohamed et al. (2017) cited the need for technological standardization, elimination of the limitations of range/charge-time and operational flexibility, the need for federal support, the creation of monetary incentives, and the implementation of demonstration projects, as pivotal points to facilitate implementation. There is positive momentum on many of these requirements as well as remaining challenges.

Most Canadian public transportation systems rely on buses that run on fossil fuels. There are currently 175 in service ZEB in Canada, with 55 in Alberta, 4 in British Columbia, 76 in Ontario and 40 in Quebec. In 2020 there were 4324 diesel and 550 hybrid buses. Figures were provided by the CUTRIC Canadian ZEB Database™.

In 2017 Infrastructure Canada through its Public Transit Infrastructure Fund Program began to recognize and invest in the opportunity that ZEBs offer.[8] CUTRIC (2019) provided municipalities with a holistic overview of ZEB adoption process. The report supports transit fleets and municipal, provincial, and federal planners by providing informed policy-making and suggestions to shape electric bus programming regarding both capital and operational investments in the near- to mid-term futures. The report summarized results from an extensive literature review of different transit electrification deployments and experiences, including service provider insights, charging standards overviews, and electric bus deployment data from Canadian agencies as well as globally. It also provided an overview of project goals emanating from implemented or planned transit electrification projects in Canada and the U.S., as well as an evaluation of data collected from widespread document reviews and interviews.

Over the past three years there were announcements of ZEB planning or purchases in cities across Canada, following some earlier trials. These investments were primarily leveraged through municipalities' direction of existing revenues from the gas tax and provincial transit investments towards ZEB adoption and some federal dollars. One of the most significant was La Société de transport de Montréal (STM), an agency that used ZEB to rethink a critical corridor and to introduce twenty articulated ZEB buses beginning in 2022, to provide service 24 hours a day on Boulevard Pie-IX using a dedicated middle portion of the boulevard.[9] In Toronto Mayor John Tory underscored that an initial $140-million bus purchase, which was jointly funded by the city and federal government, would help Toronto reach its target of cutting its greenhouse gas emissions by 80 percent from 1990 levels by 2050, "with the goal of converting the entire TTC fleet to zero emissions vehicles by 2040 " (Spurr, 2019, p. 1).

Smaller cities such as London, Ontario also announced ZEB planning and acquisition (Litman, 2021; Lebel, 2020). London Transit Commission approved a $83K feasibility study into electrifying its bus fleet, with all three levels of government assisting. British Columbia's TransLink announced its ZEB adoption with the purchase of its first battery electric bus (Chan, 2019) accompanied by an updated strategy (TransLink, 2020). BC Transit announced that it was switching its entire fleet to electric buses. The Region of Waterloo (2020) proposed an all-electric fleet of buses. CBC News (2019) reported that Halifax Transit and Nova Scotia Power were teaming up on an electric bus study, a collaboration that follows best practices in transit electrification. The City of Brampton (2019) announced that it had secured $11.15 million investment for a milestone electric bus pilot project. Provinces such as Manitoba announced strategies, theirs bore the telling title, *Manitoba's Electric Vehicle Road Map: Driving toward Fossil Fuel Freedom* (2019).

Despite these initial efforts Parsons (2019) expressed concerns that despite the global take up of transit electrification and Canada's position as a leading technology manufacturer of ZEB there has "been no groundswell of adoption of new electric technologies by Canadian transit authorities" (ii). The most consistent challenge was a lack of, "suitable ongoing, consistent, and accessible funding to support advanced low-emission bus technologies

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[8] For example, the federal government, British Columbia and the City of Vancouver all made the Drive to Zero Pledge this spring, an initiative of US-based Calstart, facilitated by Clean Energy Canada. This pledge committed its signatories to actively accelerating the adoption of zero-emission commercial vehicles, with the goal of these vehicles dominating the market by 2040.

[9] According to the STM, the level of service projected on the future SRB Pie-IX, which will be as frequent as the metro, will require the use of about fifty buses, "to ensure a 100% electric service offer" on this infrastructure, which could carry from its opening up to 70,000 passengers per day. The SRB Pie-IX will not be a bus line like the others. The infrastructure will occupy the middle portion of the boulevard and the buses will run on lanes strictly reserved for public transport" (Bisson, 2019, p. 1)

within Canada. Major projects involving BEB and FCEB technologies for a long time have all tended to involve one-off funding arrangements and combinations of funds, nothing ongoing or consistent. (ii)" The cost challenges were exacerbated by weakness of the Canadian dollar in a context where ZEB components are made in the United States, a lack of expediency in fund disbursement, misaligned incentives among implementation stakeholders, and a lack of recognition of meaningful contextual differences affecting the cost of power and a frequent failure to fund essential charging infrastructure in addition to ZEB acquisition itself.

This context shifted significantly with the announcement of substantial investment by the Government of Canada in ZEB through the $2.75 billion (Zero Emissions Fund, 2021). It offers support to public transit and school bus operators across Canada who are electrifying their fleets. The Zero Emission Fund (2021) supports the federal government's commitment to help purchase 5,000 zero-emission buses over the next five years. This investment includes the Canada Infrastructure Bank's commitment to invest $1.5 billion in zero-emission buses as part of its three-year Growth Plan. The combination of direct investment and loans is propelling another level of planning and activity on the part of municipalities. CUTRIC has been an effective lobbying voice in underscoring the importance of zero-emission and electric technologies to decrease the amount of local pollution and greenhouse gas emissions from the transportation sector and this is reflected in current Canadian federal government policy.

CUTRIC's ZEB Committee is a national forum where members share up-to-date information and data related to ZEB procurements, deployments, predictive and empirical data and funding and financing options. It ensures that Canadian transit agencies have access to the highest-quality transit-led ZEB data and ZEB procurement and deployment knowledge across Canada and the United States. Some highlights of best practice for ZEB integration include the following: Cities scale up through pilots, trials and integration that test bus types for their specific conditions, beginning with 2–3 % of fleet, to 30% of fleet, then full fleetwide deployment (Bowes, et al., 2021; Parsons, 2019). Ideally, ZEBs should be provided with reserved corridors for performance, their own signals and should not be blocked by left turning vehicles and should be able to go around parked vehicles (Mercado et al., 2012) (#20, #24) Electrification creates opportunities to meet appropriate transit requisites, whether 60-foot Hydrogen fuel cell articulated buses or small-scale hydrogen vehicles that can go door to door, expand access and income for transit including just in time services. (#22). ZEB introduction can address congestion by allowing tunnels under cities which are not viable with diesel, allowing efficiency and increasing innovation potential within the field of transit planning (#4).

International

The literature review provided a series of comprehensive studies regarding ZEB adoption, some across jurisdictions and other focused on specific regions or municipalities. Like Canada, there are many announcements of conversion to ZEB fleets, with an air of competition in the European context. In the pre-Brexit era, London, UK (London to have Europe's largest double-decker electric bus fleet, 2019) announced that it would have the largest double-decker bus fleet in Europe and by 2019 had achieved the largest ZEB fleet in Europe (O'Connor, 2019).

Hanlin et al.(et al. (2019) provide an overview of the Transit Cooperative Research Program which studies transit system ZEB adoption and documents current practices of transit systems in the planning, procurement, infrastructure installation, operation, and maintenance of battery BEBs. Certain American studies (Raimondi, 2021; Horrox & Casale, 2019; Kaplan et al., 2014) underscore that advances in electric bus technology and a rapid decline in battery costs over recent years have made ZEBs an increasingly viable option for many transit agencies and school districts. They studied six years of early adoption of ZEB. Challenges noted are that electric buses are still an emerging technology. They recommend that to speed up the rollout of ZEBs and ensure that cities see the benefits of these vehicles, state and city officials should commit to a transition to ZEBs on a specific timeline and create favorable utility rate structures for transit agencies that include reduced off peak energy rates and limited demand charges.

As in Canada, studies highlight the value of pilots. For example, in Eindhoven's pilot of 43 VDL BEBs every bus traveled up to 350 kilometres a day, with all 43 buses together traveling nearly 4 million kilometres. The experiment proved the operational advantages of battery technology in combination with fast charging solutions. Aldama (2019) details the role of Chinese state driven centralized planning in the efficient Chinese rollout and transition to at least 421,000 ZEB. Keegan (2018) note the positive environmental and noise reduction impacts of electrification on Shenzhen, with its completion of 100 percent electrification in 2018.

Aggregated Canadian and International research indicates that zero-emission buses have several advantages and disadvantages compared to other kind of buses in terms of costs, feasibility, performance, and environment as reported in (World Bank, 2019) Table 1 offers the key advantages and disadvantages of main bus technologies:

Technology	Advantages	Disadvantages
Diesel	• Familiar technology • Lower purchase price • No new infrastructure needed	• High GHG emissions • Particulate emissions • Noise pollution • Groundwater pollution • Subject to availability of ultra-low sulfur diesel • Price fluctuations of diesel
Hybrid Diesel Electric (HBD)	• 20 – 30% GHG reduction • Relatively mature technology • Lower maintenance costs • Provides heating in winter • No new infrastructure needed	• Emission benefits depend strongly on duty cycle and driver efficiency • Higher acquisition costs than diesel
Battery Electric Bus (BEB)	• Zero tailpipe emissions • 50-100% GHG savings (depends on electricity source) • Lower maintenance and operations costs • Starting to become commercially available • Canadian manufacturers • Battery costs declining • BEBs expected to have same upfront costs as diesel by 2030	• Exceedingly high bus purchase price • Secondary market value uncertain • Evolving technology • Electricity infrastructure upgrades needed for rapid charging • Range limitations for some BEB • Unknown cost of battery replacement • Potential of battery pollution as no circular economy for batteries • Heating challenges in winter, need to add diesel heaters • Sources of rare metals bring supply chain and ethical challenges
Hydrogen Fuel Cell Electric Bus (FCEB)	• Zero tailpipe emissions (clean water) • 100% green electricity possible • Not dependent on rare earth • Capable of long range • No heating challenges in winter	• Lack of hydrogen sources or requirement to create hydrogen production infrastructure • Hydrogen very costly in Canada • Higher acquisition costs than diesel • Safety concerns as with other combustibles

Table 1. Advantages and disadvantages of different bus technologies (Factors build on Table 1.1. of World Bank, 2019)

4.2.2 ZEB Adoption Data

Those implementing ZEB desire access to data that begins with a baseline of diesel performance and allows for comparative study. Examples of required data includes kilometers, total cost of ownership, product availability (overnight-charging battery BEBs, on-route opportunity charging, and FCEB), average energy consumed per day (kWh), energy cost (SEK/km), and total input/output energy (kWh).

The Canadian Centre for Data Development and Economic Research (CDER) provides data of ZEBs available by manufacturer (Table 6.10 & Table 6.11). (https://tedb.ornl.gov/data/) Statistics Canada has limited data on the proportion of zero emission vehicles (ZER) registrations. (https://www150.statcan.gc.ca/n1/pub/11-627-m/11-627-m2021033-eng.htm) Geotab (Fleet Tracking and Management|Geotab) is fleet management software that aggregates fleet data. CUTRIC has established the Autonomous, Connected, Electric & Shared (ACES) Big Data Trust for a data-driven mobility innovation. https://cutric-crituc.org/project/aces-big-data-trust/ ACES is a unique innovation in which anonymized and aggregated data from multiple municipal sources streams into one legally, and cyber-secured, repository to enable and promote sharing between data owners such as transit agencies, cities and utilities, data enhancers such as provide sector companies and data consumer businesses needing data (other transit agencies, utilities, mobility service providers). ACES will support the transition to zero emission mobility platforms, provide smaller transit agencies with needed resources and support the development of data-driven software solutions. CUTRIC has developed CloudTransit™ for cloud-based data storage and analysis of real-time data from ACES systems to enable city-to-city data sharing. Real time data from CUTRIC's Pan-Canadian Battery Electric Bus Demonstration and Integration Trial is currently being collected from the trial's assets in Brampton, Vancouver and York Region to allow for analysis and cross comparison between cities. The EPA (2020), Green Community Checklist, U.S. Environmental Protection Agency (https://www.epa.gov/dera) provides data and action lists to address diesel pollutants.

4.2.3 ZEB Adoption Tools

Fundamental to ZEB adoption are tools that look at the energy profile for the fleet conversion, then consider the fleet emissions profile, applying Life Cycle Analysis. If conversion entails moving from 10 to 15 buses to cover routes, then it is the new total that must be analyzed. (#27) Analysis must be coupled with an economic assessment of Return on Investment over the duration of the infrastructure. (#27) There are many innovative companies providing supportive visualization and analytics tools for day-to-day operations, for instance Giro's Hastus system of applications which are a series of eBus on-demand transport software solutions for the diverse operations. Siemen's depot management software (https://new.siemens.com/global/en/products/energy/medium-voltage/solutions/emobility/ebus-depot/evdepot-digital.html), or Chargepoint's Electric performance data dashboard tool (https://www.chargepoint.com/en-ca/), and Vericiti (https://viriciti.com/) are others. Many of these tools operate within the context of a separate data analysis system, and while some share common metrics, they are not integrated into a wider environmental impacts analysis, or a sustainable development context, a challenge that identifies value of common indices of comparison to validate strategies for more resilient change. Other energy efficiency and consumption tools to measure battery performance are provided by researchers such as Vepsalainen et al. 2018, Chaoui, et al. 2018, Mahmoud et al. 2016, Tzeng et al. 2005.

CUTRIC has created tools for ZEB planning. RoutΣ.i™ 2.0. CUTRIC developed RoutΣ.i™ 2.0 (with a 3.0 version release in early 2022) an electric bus and transit simulation tool that allows transit agencies to accurately predict the performance of battery electric buses (BEBs) with various charging strategies (in-depot, on route, and combined solutions), as well as hydrogen fuel cell electric buses (FCEB) with H2 fuelling time and delivery strategies. It supports zero emissions bus or transit lifecycle assessments; Feasibility and cost analysis; Comprehensive transit or public fleet schedule analysis; Greenhouse gas emissions reduction analysis; zero emission transit roll out strategy and planning; Predictive performance modelling and analysis.

The accompanying tool for Battery Electric Buses (BEBs), RoutΣ.i™ 2.0 predicts vehicle and fleet range, charging needs, total energy and power needs, total energy costs, CO_2e reductions, and scheduling challenges/optimization to support effective BEB charging requirements. For Hydrogen Fuel Cell Electric Buses (FCEBs), RoutΣ.i™ 2.0 predicts vehicle and fleet range based on hydrogen fuel parameters, fuelling time needs, total energy needs, total energy costs, CO_2e reductions based on the source of H2, and scheduling challenges/optimization to support effective FCEB fuelling requirements. CUTRIC's RoutΣ.i™ 2.0 research team completes feasibility assessments on a block-based or route-based format. For full fleet analysis, CUTRIC always recommends block-based analysis inclusive of pull in, pull out, and deadheading requirements to generate a full picture of the energy consumption and charging requirements of your transit system. CUTRIC assists organizations in accessing government funding and ensures that they have accurate data before moving to procurement and deployment.

Sebastiani et al. (2016) have developed a simulation tool that evaluates bus energy consumption using a mathematical model that considers different load and friction forces using an optimization strategy that utilizes a bi-objective genetic algorithm to minimize both the number of charging stations and the average extra time stopped in the station to recharge. Information, including passenger demand, bus speed, distances, and route elevation profiles are data used in the simulation. Maji's (2017) "Proposed Smart Bus System in a Smart city" describes a system of smart stops, smart buses, and other smart city services as an integrated cloud sensor system.

4.2.4 ZEB Adoption Policy

Interview subjects lauded federal and where available, provincial capital costing programs that facilitate transit purchase by agencies (#4) and the government commitment to accelerate ZEB adoption. (#6) Flexible provincial and federal capital costing funding programs and supportive policy would smooth out transitions to innovative technologies and provide initiatives to encourage municipalities and authorities to procure ZEB solutions. (#4, #18). These should be available for peri-urban regions, and to service indigenous communities as well. (#5)

4.2.5 ZEB Adoption Challenges and Gaps

Without question, in the literature review, workshop and interviews, cost emerges as the primary, ongoing challenge, one that varies according to province and municipality, as transit funding demands collaboration across all three levels of government. While many municipalities announced feasibility planning or their first acquisition of ZEB buses or pilot fleets, others acknowledged that the financial challenges of ZEB buses made adoption impossible (CBC News, 2020). Costs are discussed in detail in the Economic Impacts section of this report. Over and above the barrier of increased BEB and infrastructure costs, key barriers are the performance of fleet vehicles in cold weather, unclear end-of-life options for batteries, the complexity of charging infrastructures, and the location and supply of utility support. (Bloomberg, 2018, 48). It is important to establish best practices for battery life maximization and analyze costs. (#31, #32)

Culture of adoption, Bus stigma

Several respondents (#5, #10, #15, #17, #20) remarked that in their planning efforts they found that Canadians see buses as a second-class transportation mode compared with rail solutions, which is a marked cultural difference with Europeans. ZEB buses could provoke a change in attitude as they are quiet, comfortable and the ride is smooth. Observing EV uptake as a precedent in cultural adoption of electric vehicles could prove valuable in facilitating this mindset shift.

Integration

Parsons (2019) identified integration as a critical issue facing transit operations as they implement BEB, stating, “Transit involves complex networks incorporating many buses, with the nature the systems, importantly, having built-up over time primarily around the characteristics of diesel buses” (2019, 7). Transit planners underscored that the complexity of infrastructure and transition to BEBs calls for changes in their organizations, new modes of planning. (#1), new scheduling processes, major retraining programs and a new value chain. (#7, #10) One challenge that faces planners is whether to deploy buses on the lines where with the most densely populated neighborhoods, or on the lines that would achieve the biggest greenhouse gas reductions. (#17) One aspect of this process of implementation that begs for further attention is supply chain management, to ensure sustainable practices of local sources for equipment, infrastructure etc. are utilized wherever possible.

Battery Electric Buses and Range

Range is one of the primary challenges in ZEB adoption resulting in transit companies buying more BEBs to cover existing services. (#34) ZEB buses are not capable of the same range as a diesel bus without recharging, creating “range anxiety” for adopters (Franke, T. et al. 2012) Range compounds with other challenges such as inclement weather, and performance on hills (Levy, 2019). Lithium-nickel-manganese-cobalt (NMC) and lithium-iron phosphate (LFP) batteries dominate the market. These batteries take 4–6 hours to charge. Transit authorities note that it is too difficult to manage fleets with buses that have different battery sizes, capacities, ranges for routes, charging times and hence different parking needs. (#3) Batteries that provide a longer range are heavier, thus road maintenance costs may be impacted. On route charging extends range but is not viable for some cities.[10] On route charging sites interrupt street aesthetics and transmission lines for electricity, which would to be added, are controversial from an environmental and urban public realm perspectives. Buses are often supplemented by diesel heaters for winters, reducing their environmental benefit as electric heat proves too large a drain on battery life (Levy, 2019).

Choice of technologies

Another significant challenge is the decision about which technology to adopt (Ballard, 2019) There are competing bus companies and charging stations. There are four major ZEB brands operating in North America. For example, BYD has been the world’s largest electric vehicle manufacturer for the past three years running, in both consumer and commercial/industrial electric vehicles.[11] New Flyer is a Canadian bus manufacturer based in Winnipeg. There is a lack of uniform charging standards although the UITP 2019 ASSURED project is bringing standardisation one step closer. CUTRIC (2019) has played a role in assessing different standards and arguing for the adoption of uniform standards, providing a report pertaining to conductive charging of light-medium and heavy-duty electric vehicles.

[10] Winnipeg tried anon route charging strategy in their trial but there were too many operational challenges including winter conditions.

[11] A respondent proposed that RFPs require that buses be sourced from democracies. (#32)

FCEB vs BEB

FCEB offer longer range capacity and GHG reductions. Some agencies are adopting FCEBs and BEBs. BEB buses are not able to reach outlying communities hence planners also look to FCEB to fill that capacity. Winnipeg is considering 60' articulated FCEBs with one planner stating, "Really the only truly zero-emissions bus option is a hydrogen fuel cell". One possibility is to purchase an electrolyzer which will produce green hydrogen because water and electricity are the only inputs.[12] An alternative is blue waste hydrogen that agencies can buy (#2). Parsons (2019) argues that transit agencies consider FCEB vs BEB depending on the state of their grid. "Variations of grid mix across Canada suggest differential selection could be prudent. BEB are most usefully applied where the grid is cleanest, obviously Quebec, Manitoba, British Columbia, and Newfoundland and Labrador. On the other hand, where the grid still has higher emissions, such as Alberta, Saskatchewan or Nova Scotia, HEB [FCEB] could represent a better interim solution (Parsons, 2019, p.11)." [13]

The supply chain for hydrogen remains an issue. Agencies must either produce their own hydrogen or work with local suppliers. There are initiatives in capacity building for hydrogen resources in Canada, as well as trials and integrated planning. In 2020, The University of British Columbia Clean Energy Research Center (CERC) undertook a study to consider the integration of hydrogen into the transportation sector, arguing that there must be a balance of vehicle growth and supply chain. They state, "Considering the significant capital investment which will be followed by a long period of underutilization, the new supply chain will face a long period of negative cash flow".[14] Progress necessitates national codes and standards for hydrogen vehicles as well as expert integration guidelines. A respondent emphasized renewable natural gas as an alternative as it is produced from landfill or biowaste, uses existing infrastructure and contributes to the circular economy. (#32)

Grid Capability

The adoption of ZEBs calls for significant grid capacity and increased efficiency in the production of electricity. Mohamed et al. (2016) modelled the implementation of battery operations to quantify the energy demands, design the infrastructure of the charging station, test the transit operation feasibility, and generate the charging load profile. They used the generated charging load profile for each BEB operation to study the impact on the utilization and lifetime of the transformers, and the operation of the local distribution grid. Findings from this study highlight that the selection of BEBs in a full network transit operation hinge on achieving feasible operations while managing impacts on the utility grid. For example, in the Winnipeg context they will need new transmission lines if they exceed 100 buses. These would necessitate A Class redevelopment permits and federal review. (#6, #22) Grid requirements are further discussion in the Environmental chapter of this report.

4.2.6 ZEB Adoption Research Requirements

Continued value was placed on operational planning research to understand how to build schedules and deploy services to manage battery consumption, minimize all instances of acceleration and deceleration of buses to prolong the life of the charge of the battery charge, and reduce environmental impacts. (#1) Further research around emerging technologies and the life cycle assessment of implementing ZEB, focusing on comparative battery and hydrogen technologies is called for. Implementation research could develop effective systems to manage scheduling, charging constraints, and schedules for charging that are in line with the bus schedules and with the drivers' schedules, manage battery consumption, and route planning support. (#1) CUTRIC plays a role is supporting both these requirements. While pilots to test out equipment and systems can provide valuable information, integrating the bus into the daily fleet systems to understand how to adapt operations to meet the new technology, rather than a pilot, provides a more extensive bus driver training program around service and maintenance so the bus performance, and equipment such as on-route charging can be tested. (#6)

4.2.7 ZEB Adoption Data Gaps, Challenges and Requirements

Agencies and funders must access data to undertake cost benefit analysis, life cycle analysis and track implementation in the real world. (#26) Since ZEB technologies are recent technologies, there is a lack of longitudinal data for some indicators. While near term data is valuable, long-term and continuous operational data collection and analysis are more useful for sustainability development assessments. Another challenge is that data is often proprietary, making it difficult to acquire or share, or it is unavailable to public use. Without access to comparative data from pilots and trials, transit agencies are in a zero-sum game where each initiative must start

[12] An electrolyzer is a system that uses electricity to break water into hydrogen and oxygen in a process called electrolysis. Through electrolysis, the electrolyzer system creates hydrogen gas.

[13] A conventional transit bus is around 60 liters of diesel per 100 km in Canada. An electric bus is 160-kilowatt hour per 100 km. Parsons argues that if an agency makes hydrogen electrolytically, it takes 50 to 55 kilowatt hours of electricity to make a kilo hydrogen.

[14] The research develops a formula to support the sustainable rollout of hydrogen and influence rollout policies and incentive plans and update the optimization based on different motivators and constraints.

from scratch. Both literature and respondents noted that real world data must be analyzed to understand and aid decision making on how differing systems; BEB versus FCEB depot charging, and opportunity charging, or a combination, perform versus vendor claims. (#1) For smaller agencies it is a challenge to own the tools to collect and analyze data. (#15) CUTRIC's ACES initiative seeks to address this challenge.

4.2.8 ZEB Adoption Tools Challenges, Gaps and Requirements

There is a need for an energy consumption tool, that highlights a list of key performance indicators (KPI's), in relation to bus performance data, battery life cycle assessments including cost, length of operation, recycle-ability, and disposal efficiency of chargers and the associated utility costs, and monitor the cost of hydrogen dispensed. (#6, #34)

Tools to provide information around passenger satisfaction and travel experience will be of importance as ZEB rolls out. Researchers would value data from Presto cards which would contain actual trip patterns with more accurate origin destination information.

4.3 Environmental Impacts

4.3.1 Environmental Impacts Strengths & Research

> Regardless of the archetype, all cities mentioned environmental credentials
> as one of the major reasons for considering electric buses.
> Bloomberg, 2018, 48

Transport is the fastest growing source of greenhouse gas emissions worldwide. In Canada it responsible for 23% of total CO_2 emissions from fuel combustion, and emissions from the transportation sector are the second largest source of emissions after the oil and gas sector. Replacing the diesel bus with an electric bus is perceived to have a significant impact on climate mitigation. For decades, air pollution has been recognized as having a substantial impact on human health as well as the environment (Environment Canada, 2007), so a reduction of emissions from fuel combustion could reduce ill health impacts. The transportation industry consumes the second-highest amount of energy and transportation GHG emissions have increased 27 percent from 2000 to 2018 in Canada (Natural Resources Canada, 2021). Mohamed et al. (2017) focus on the Canadian context, highlighting that due to the substantial hydropower and nuclear generation methods electric bus reductions in GHG are very competitive with other forms of zero-emission buses such as CNG and FCEB (Mohamed et al., 2017).

The environmental benefits of ZEBs are primarily a reduction of greenhouse gases at the tailpipe, and with those reduced carbon emissions, less pollution, noise reduction, and progress towards climate change targets. (#6,#7, #18, #25) In a case study in Bengaluru, India comparing BYD ZEBs to diesel, researchers determined that the amount of CO_2 emissions generated by diesel versus the CO_2 emission generated to charge ZEB was 25 times more. (Adheesh et al., 2016) Removing TTC diesel emissions will decrease air pollution generated by transit vehicles by 250,000 tons per year. (#9) Benefits are a reduction of emissions in the vicinity of transit corridors, where there tend to be large concentrations of residents, heralding a better quality of life for city residents. (#2)

Intensification increased ridership and multimodal transit

The investment in public transit provides a sustainable alternative to driving and reduces private vehicles on the streets and highways and supports population growth and intensification through better service for existing populations as well as serving new growth. (#9, #15) Transit planners and analysts feel that the high visibility of ZEB coupled with more frequent service are means to attract people away from their cars. (#6, #14) Planners will pair active transportation with ZEB routes to encourage people to ride bicycles along emission-free routes. (#20)

Transitional Role of the Electricity / Grid

Utility leaders and transit planners perceive an optimal scenario where electric grids transition to green energy as electrification of transit occurs. (#15, #12, #34) Grid decarbonization must occur to provide additional emission reductions. New Brunswick, Nova Scotia, and Ontario have dropped overall emissions through decarbonization. (#22) Grid modernization includes the move to smart grids which is also a considerable investment. Sebastiani et al. (2016) define a smart grid as a system in which technologies, tools and techniques allow the management of electricity through computational means, including data analytics, AI, and the visualization of the system. Smart grids are more efficient and allow social and resource challenges such as the equitable distribution of electricity and security to be better addressed and monitored (Sanchez-Hidalgo et al., 2018). Clairand's (2019) review of types of electric vehicles, and smart charging techniques include the Vehicle-to-Grid (V2G) concept, where the EV not only charges from the grid, but it supplies energy when necessary, becoming a generation/storage device.

Respondents noted that electricity costs are not yet aligned with electric mobility, hence utilities will benefit by reassessing their rate structure and through planning with municipalities and transit agencies. (#22, #34)

CUTRIC's Power Providers Working Group for Transit Electrification (2021) is soon to be a formal Power Providers and Utilities (PPU) Electrification Committee in January 2022 and works with its national transit agencies and utilities to establish a systematic national dialogue. They review and assess the opportunities, challenges and solutions associated with the growing role for utilities across Canada with regards to electrification of transportation, including electric vehicle supply equipment for both high-powered and low-powered electric transit systems, as well as hydrogen fuel cell electric transit systems. The working group learns about the latest technology innovations related to electric bus and fuel cell electric bus technologies, including integrated energy storage systems, while exploring utility business models that may work within certain jurisdictions or under specific conditions to enable utility business development in this space. The working group discusses related technologies, such as High-powered and low-powered charging systems; Energy storage integration at the site of transit stations and garages in support of charging systems; Communications standardization between e-buses, e-chargers and grid operators; Cybersecurity standardization across e-buses, e-chargers and grid operators; and Hydrogen on-site generating systems; smart electrolysis system that generates hydrogen using electricity.

4.3.2 Environmental Gaps and Challenges

Sources of Electricity

This system-wide transformation calls for IT, infrastructure and systems modifications that must link together, such as integrating more distributed energy resources and having on site solar and storage. (#25) The generation of greenhouse gases is moving "from the road to the power station" (#21) hence life cycle consideration of batteries, materials, and garage construction should be considered. The sources of electricity for ZEB determine the ability to achieve GHG reductions. (Petrunic et al, 2020) have noted that companies providing electrical power have varied degrees of commitment, levels of preparedness, and ability to transition to green sources. Hence, CUTRIC's Power Providers Working Group for Power Electrification offers collegial knowledge sharing.

Unclear Knowledge Performance Indicators (KPI's) with government process & policy gaps

There is a lack consistency in how environmental benefits are calculated, and some analysts see the need for a mature system of carbon pricing, with consistent methods of understanding the true impacts of ZEB implementation. (#27) Analysts seek a more transparent political support process for implementation and decision-making, with improved communication between various levels of government. (#5, #8)

4.3.3 Environmental Research Requirements

Researchers should undertake life cycle assessment of battery development and recycling to understand and create a circular economy. (#2, #31, #32). Wells to Wheels assessments are needed to measure impacts. (#34) Research is needed to establish contingency plans for power outages. (#1)

4.3.4 Environmental Data Gaps, Challenges and Requirements

Respondents stated that it is challenging to obtain current environmental energy and emissions data for transit vehicle usage. Some of this data is available only through proprietary manufacturing pilots. As more transit and transportation infrastructure is implemented, more operational data should be available. Data would allow researchers to track the rate of adoption of ZEBs, and the resulting impacts on the shift in GHG and air pollution particles. (#3, #4, #25) There is value in comparative data on the true costs of electrification in America, Europe, Australia, and other jurisdictions. (#5)

4.3.5 Environmental Tools Challenges, Gaps and Requirements

Tools are needed to evaluate progress and impact of ZEB implementation and infrastructure deployment, from a national to a municipal level. Informational tools that allow comparative analysis of the number of ZEB's deployed in major centres across Canada, along with the overall benefit of this, through the quantification of GHG emission reductions and air quality will demonstrate the benefits of investment to the broad community, and especially riders. (#7, #13). It is important to localized air pollution along routes to understand the effectiveness of reduction measures in real-world circumstances. (#2, #25)

4.3.6 Environmental Policy Requirements

Literature and respondents suggested that policy initiatives should address environmental benefits and barriers around several thematic areas: funding, GHG reduction and energy policies, transit planning policy and public awareness campaigns to explain and support for ZEB implementation. There was general agreement amongst those interviewed, that federal and provincial environmental policies with significant "teeth" are needed that translate down to the municipal level and include funds for transit. (#7, #9). Funding or regulatory support tools that incorporate on-site storage, solar, or distributed energy resources would help to offset the carbon footprint and manage costs for the agencies. (#25) The federal and provincial mandate of GHG reduction policies needs to include dates and targets to be effective. (#7, 15).

Policy coherence is helpful. Winnipeg is governed by one policy, Winnipeg's Climate action plan, which mandates a zero-emission fleet by 2040, creating a consistent approach to transit planning. (#2) Another example is Nova Scotia's, Environmental Goals Act, which has targets for 53% reduction of GHG emissions below 2005 by 2030. Net 0 by 2050. (#15) Respondents encouraged governments to be discerning about investments, consider technology lifecycles and include a framework for end-of-life scenarios. (#18)

4.4 Economic Impacts

4.4.1. Economic Strengths and Research

Academic literature and interview subjects underscored that electrification of transit must be integrated not only into transit system redesign, as discussed earlier, but overall economic planning. Access to transit in most instances drives land value. (#20) Transit oriented design should be a strategy as mass transit enables densification at the nodes and along the corridors. Electrification is best seen within both economic and transit renewal. As one interview subject noted, these are "Macroeconomic issues around the speed at which you're able to create more mobility in the region which has a domino effect to our economy. Can the operator be more efficient? But can our economy be more efficient and more productive because of electric? It's not just steel and wheels! It is country building, it's city building." (#16) The integration of desirable, quiet, and attractive electric public transit will be particularly important in the post-COVID era as the urban economy continues to transition. (#19) It is not yet known whether transit ridership will return in the same numbers as before COVID-19 as work patterns are still emerging. A perceived asset of buses is that they are above ground with the potential of stimulating local economies as riders can see businesses. (#19)

Dollars to address ridership

The focus on transit investment should be on ridership, with ZEB adoption as an integrated component. Policies and initiatives must support a holistic view of transit to provide health benefits, environmental benefits, social benefits, and the development of communities. (#8, #19, #33) Some respondents named this, "a triple bottom line approach", that would factor improved air quality and noise reduction, which would in turn attract ridership through both improved quality and accessibility of services and would in turn subsidize public transit. (#11) This means prioritizing getting ZEBs to people who are actual transit users. (#25) Fare reductions are a possibility once operational savings are realized through ZEB further stimulating ridership. (#27) Interview subjects argued that municipalities and provinces must be careful of policy that favours individual EV adoption over public transit options.

Economic Benefits of Noise Reduction

The quietness of ZEBs is primarily associated with increased wellness, however researchers argue that it also carries economic benefit by reducing the "cost of noise" on people and businesses. (#22) Sweden has emphasized the beneficial reduction of noise pollution for cafes businesses neighbourhoods. (#29)

Lifecycle Analysis of ZEB, Efficiencies and Transit Budgets

There is an estimated substantive operational savings for ZEB as the cost of electricity is significantly lower than the cost of diesel and ZEB buses are expected to last for 20 years with little maintenance (#6) One of the challenges of transit funding in North America is that there are funds available from federal, provincial, and state governments for capital purchase but little for operations, where passengers keenly feel the lack of quality service. The plan of agencies is to migrate funds from capital to operating costs. (#4) The integration of electric vehicles into overall transit planning and the complexity of infrastructure, electricity provision, route management, and training are also an argument for rethinking the efficiency of transit agencies, to ensure that they operate in faster, coherent, and transparent ways. (#8) Effective collaboration with electricity providers is of critical importance to ensure the effective use of funds. (#9)

Price stability

A positive quality of ZEBs is price stability, or the reduction of fuel price volatility, because utility rates tend to increase at a more consistent rate than diesel fuel prices, which fluctuate. (#6, #13) This volatility is likely to accelerate, according to one respondent, as by 2030 diesel will be the dominant fuel as the backbone of just in time business operations. For example, the TTC currently uses about 100,000,000 liters of diesel fuel per year. They estimate $60m in annual savings. (#9). For these reasons there is less concern with the waning of gas tax which currently funds transit agencies.

Canadian Innovation and job creation

The expansion of ZEBs in an opportunity to support Canadian industrial innovation and production whether it is New Flyer in Winnipeg or BYD's 45,000 square foot assembly plant in Newmarket, Ontario. The TTC purchased ten BYDs and St. Albert has purchased seven. There are opportunities to grow the supply chain of components for ZEBs and play a leadership role as a Northern country with ideal weather conditions for test-driving. (Petrunic et al., 2020; #25) CUTRIC has taken the initiative of analyzing skills demanded by the growing ZEB industry and for adoption by agencies and is working with community colleges and universities to provide training and research programs to ensure that Canada can fill labour force demands. Other jurisdictions quantify the ways in which the transformation to a clean energy economy can stimulate the demand for job growth and serve as an economic opportunity catalyst for underserved communities by provided skills training to fill skills gaps (Chandler et al., 2016). Transit investment benefits the economy as transit agencies buy in bulk with planned acquisitions over many years. (#27)

Parsons (2017) and several interviewees noted that Canada has an opportunity to develop mineral mining of lithium and other materials essential for batteries in northern Manitoba and Ontario's Ring of Fire, ideally in collaboration with Indigenous communities. Natural Resource Canada verifies that, "Canada has some of the largest known reserves and resources (measured and indicated) of rare earths in the world, estimated at over 15 million tonnes of rare earth oxides" (1) This opportunity would shift reliance away from China, the world's largest producer of rare metals (NRCAN, 2018) and from African nations (Ispionline, 2021).[15]

Funding models (investment, ridership, efficiencies of etransit)
Cost is the major barrier to ZEB adoption as ZEB are 30 to 50 percent more expensive than diesel vehicles (Aber, 2016). It is important that stable forms of funding exist for ZEB adoption. Infrastructure Canada has provided direct investment which most municipalities opt for as the larger portion of their funding as public transit is seldom profitable. The Canada Infrastructure Bank (CIB) is another important investor, supporting a segment of capital costs. CIB invests in infrastructure projects that have an underlying ability to generate revenue and then use the revenue to pay back investment. They bring private capital into projects where revenue can eventually repay their investment. CIB lends to municipalities at lower rates than those provided by pension funds or banks, bringing down the cost of capital. CIB creates metrics that its investors must meet. CIB has two criteria for success – increased ridership and GHG reduction.[16] (#3)

4.4.2 Economic Data

Economic productivity refers to progress toward economic growth such as economic efficiency, increased income, response to population density, employment, and inclusion of diverse demographics in the economy. ZEB implementation could be measured in relation to these factors. Examples of relevant data for economic impact analysis include the Residential and Civil Construction Alliance of Ontario (RCCAO) which researches and reports on the economic impact of transit and transportation in Ontario. (https://rccao.com/research/transit-transportation.php). CUTA data includes economic factors. International data relevant for economic impact analysis include the Millennium Development Goals Indicators (http://mdgs.un.org/unsd/mdg/Default.aspx); the World Bank – World Development Indicators (WDI) Online Database (https://data.worldbank.org/); the International Energy Agency (IEA; www.iea.org/statistics) data on costs of energy and the World Resources Institute (WRI) Climate Analysis Indicators Tool (http://cait.wri.org/). Also informative is the U.S. Net Petroleum Imports by Country (https://www.programmableweb.com/category/all/apis)

4.4.3 Economic Challenges and Gaps

Costs
The most significant challenge in ZEB adoption is cost. ZEB remain an emerging technology and priced as such, costing 30 – 50 per cent above a diesel bus. (#7, #10, #15, #22) Other expenses are charging and maintenance infrastructure, and retraining of mechanic and drivers. (#6, #7, #24). Agencies must provide redundancy to cover the possible inability of BEB to fully meet schedules or routes. Other cost elements of concern are the need to replace battery packs as buses last for 18 years and batteries for 12 and battery disposal costs. (#3) The additional weight of ZEB buses may increase the wear and tear on streets by three years. (#6, #22). Cost benefit analysis balance the costs of fuel versus the cost of BEBs and infrastructure and agencies assume that once the infrastructure is in place buses will be less expensive, (#18) but the realities are unknown, and savings depend on the cost of electricity (Freedman, 2014)

ZEB acquisition brings space implications and costs as garages must be updated and expanded or new infrastructure built. (#6) This takes long-term planning. For example, Winnipeg projects a twenty-year path to

[15] Nambia, Malawi, Angola, Tanzania, Uganda, Madagascar, Mozambique, and South Africa all have rare metals.
[16] For example, the CDPQ, the Quebec pension fund is an investor in the Réseau express métropolitain (REM) project in Montreal. They are going to be paid back based on how many people ride the system and how far those people ride the system.

electrify their current fleet of 640 buses considering infrastructure upgrades and maximizing the benefit from their current fleet which have an 18-year lifecycle. (#3) Effective planning demands collaboration with utilities to partner on infrastructure development and explore whether there are other users that can benefit from infrastructure if they build it. For these reasons, it takes time to transition from diesel to electric. (#34)

Cost consciousness from some provinces, ratepayers, and customers means that agencies and electricity providers feel that despite seeing the possibility of significant redesign they must only modestly improve systems. (#12) While transit planners are optimistic about savings in operating costs, the tradition segregation of budgets between capital and operations means that they don't accrue lifecycle benefits, although they anticipate savings in fuel, savings in maintenance, or jobs efficiencies. (#15)

Electricity, including green electricity is expensive. Power regulation is a provincial matter. The structure of electricity providers varies from province to province as does who they answer to.[17] Deregulated utilities can invest in infrastructure, while regulated utilities may face restrictions, hence the burden is on the municipality to fund electricity. (#6) There are challenges from both ends as electricity providers try to expand and enable transit electrification while keeping costs in check. There is also concern about embracing technologies that could become "stranded assets", or obsolete technology. Providers want to better understand the life cycle of batteries before fully investing. (#18).

Supply chain issues
Many of the respondents spoke of the importance of a stable supply chain for batteries and their source materials. Many electronic components are produced in the USA hence are impacted by currency fluctuations. (#20) Demand for rare metals will become exponential with private EV adoption. (#23) In Parsons et al.'s (2019) overview of adoption challenges they note that attention should be paid to growing concerns regarding rare battery mineral extraction from countries with human rights abuses. Shaharudin et al. (2018) survey current and emerging issues in supply chain management of mineral, materials and electronic parts, identifying risk in the just-in-time qualities of these sources.

Jobs impacts
There is resistance on the part of some drivers and unions, based on fear of job loss. (#6) This occurs at a time when recruiting drivers across all industries is difficult. Agencies have prioritized retraining through their own centres or in partnership with Canadian colleges, who are also training new drivers. (#2, #15)

Limited funding sources
One consultant noted that funding sources are a perpetual challenge for public transit. Dedicated funding sources such as a gas taxes, sales tax, land transfer tax, or development charges all fail in recession as ridership falls, and hence are an insufficient source. If there are cuts, and additions in wait time users will be further alienated. (#4) This is challenging in the COVID era with changes in work patterns and a shift to private vehicles. (Schwartz, 2020) Some employers are encouraging their employees to use their own cars or on demand services as a safety measure. (22)

4.4.4 Economic Research Requirements
ZEB business model research remains a necessity. Other suggestions align with previous sections in the report: evaluation methods to establish and measure economic, environmental, and social benefits and ongoing data collection and research to document those benefits to encourage investment. Impact studies are needed on the road system impacts and comparative maintenance costs regarding implementation of ZEB with heavier weight profiles.

4.4.5 Economic Data Challenges, Gaps and Requirements
Several respondents believe that there are significant gaps in data. While provinces collect some data on electrification planning, they rely on data from the EU where ZEBs are long implemented. (#16)

4.4.6 Economic Tools Challenges, Gaps and Requirements
Workshop participants and interview subjects again noted the need to monitor and quantify ridership, undertake consistent surveys, and intervene to build back public use of transit.

[17] Policies differ between jurisdictions, for example, in California the utility is a leader at the state level through state funded programs contrasted with Ontario where the federal government is pushing a climate change agenda.

Several interview subjects highlighted the value of tools that provide "true operating costs" with respect to long term lifecycle factors, including the sources of power generation, difficult to measure social factors with economic implications. (#18) and tools that provide accurate predictions of potential savings. (#3)

An interview subject underscored the benefits of creating a measurement system or tool that looked at Equity, Environmental and Indigenous impacts as part of economic impacts. They noted that there is no "balance sheet system" that allows this and suggested looking at the banks who have moved towards ESG's as a standard for way to measure community benefit and environmental benefit. (#16)

4.4.7 Economic Policy Requirements

Support public transit and minimize agency risk

There was consensus that governments must subsidize public transit while it gets back on its feet after COVID to sustain the efficiency of transit or further risk losing riders. (#18) The Canadian Urban Transit Association is launching a keep transit running campaign.

Transit funding models were seen as requiring flexibility, to enable increased funding at times when revenues are dropping because of a recession and the uncertainty of COVID (#5). Respondents valued financial programs that minimize the risk to transit agencies. (#3) The example of Manitoba was held up where the province is investing $500 million in transit infrastructure with $280 million to ZEB, with the first $105 million dedicated to the Winnipeg fleet. (#2)

Mix of financing tools

Participants argued for a mix of funding tools that included direct subsidy as well as loans. For example, Infrastructure Canada funding is supporting 70 percent of Winnipeg bus acquisition which would be impossible without funding. Other programs (Canada Infrastructure Bank) bring financing rather than funding. Some municipal transit planners describe these programs as a second resort as they felt that the financial burden remains with municipalities. (#6) Canada Infrastructure Bank has calculated significant savings from the purchase of ZEB bus versus a diesel bus once the purchase cost of the bus is amortized up front and the bus operated for 10 to 15 years. A $500,000,000 diesel and a $1 million ZEB bus results in $600,000 of savings. Unknown costs such as the possibility of battery replacement remain a risk. (#3) Another option (Melo et al., 2019) is the creation of a $250,000 direct rebate for each ZEB sold to a transit agency. This would eliminate a complex application process and get more ZEB buses on the road, especially for smaller municipalities.

Carbon Pricing

Interview subjects held contrasting views on the value of a carbon tax, or the substance of what that tax should be. There was concern that costs of diesel are passed back to consumers who do not react to price volatility. Instead funding from diesel use should be passed back to the trucking industry to support electrification and transit agencies should be exempt from a diesel tax if they are undertaking a modal shift. (#22) Others felt that carbon pricing should be used to support up-front capital costs which are high for cutting-edge technologies. (#18)

Regulatory change

Provincial rates for electricity costs were seen as inhibiting smaller municipalities and a respondent noted it is timely to review rates to ensure that smaller municipalities could adopt ZEBs. (#28)

Include social, equity, environmental and health benefits in KPIs

Interview subjects argued that governments must think of transit as a public good with respect to life cycle costs, with a longer cycle of investment than the election cycle. (#11) This proposes an accompanied shift in focus from the economic cost benefit analysis, to include indirect savings that a government might be able to achieve with cleaner air and fewer emissions; demonstration of all potential societal benefits, including health related ones, in conjunction with the electrification of transit fleets. (#29)

4.5 Social and Equity Impacts

This section of the report considers overall social impacts and attitudes towards the electrification of transit and ZEB adoption and equity imperatives and impacts as a sub-section of an overall social framework.

4.5.1. Social Attitudes Strengths and Research

Interviews revealed there are currently social barriers to ZEB uptake, including generalized public attitudes towards public transit. For example, interviewees pointed to "car culture" (#29) and the challenge that many commuters, "don't like to take a bus" because these are identified with poverty or an uncomfortable ride. (#20) A researcher agreed that transit decisions, for those who have access to a car, are often based on, "emotional not logical behaviour" (#13). However, "younger generations of millennials will demand better transit" (#7) and that, "depending upon the design of the vehicles, if they're quiet and beautiful looking and they have Wi-Fi, then the public perceptions of buses might improve" (#20). Transit agencies see electrification as a broader signal to the public that they are modernizing their systems to better serve them. Customer satisfaction surveys that transit agencies conduct routinely show that the quality of service is important – it's on time performance, the convenience of the service, the right quality, the cleanliness. (#1) If transit is framed as an "investment in environmentally friendly trains or buses," it can, "overcome Nimbyism (not in my backyard) around transit development and infrastructure." (#8)

As reiterated earlier in this report, both the literature review (Schwarz, 2020) and respondents underscored that above all, efficiency of service must be maintained or improved in the transition to electrification or transit will lose ridership.[18] "Quality of service benefits" represent service improvements that improve access, reduce travel time, and improve the traveller's experience.

Urban design innovation
BEBs allow innovation for urban design. Boarding and deboarding passengers during charging is a challenge and an opportunity. In Sweden, ZEB buses swing into a comfortable service-rich lounge area where riders wait while bus is charged. (#29) Public art can draw users to public transit. It can further strengthen traveler's waiting experience, be a component of ZEB rider experience and grace stations.

4.5. 2 Equity Strengths and Research
Argument for transit
Equity begins with an understanding the accessible, high quality, efficient public transit is essential in creating an equitable society. Hertzel et al (2016) describe transit as a "lifeline". There are two related issues. Low income, IBPOC (Indigenous, Black, People of Colour) communities are frequent users of public transit when it is available. Low income, IBPOC individuals also live in communities that are the least accessible by public transit, where commute times to work, healthcare and other needed resources are the longest. Kaplan et al. (2014) use connectivity to measure equity in transit provision and find that marginalized communities often have the least connectivity to downtown cores and must transfer the most. A consultant interviewed indicated more racialized individuals live within the peripheral areas of the city compared to the core and experience fewer bus routes and more delays than the downtown, creating more automobile or ride sharing dependencies and inhibiting mobility. (5). Keil et al. (2021) underscore that transit access limitations have expanded with the GTA's expansion. They note that groups' vulnerabilities are, "linked to systemic patterns of disconnectedness in this situation" (Keil et al., 2021, 1). They find that patterns are caused by long-term biases in transportation and infrastructure investments that have led to "transit deserts" that tend to be concentrated in "in-between cities" or "third cities", those that are not just neglected by mobility infrastructures but are generally socially and economically disadvantaged through lacking employment opportunities, substandard housing, underfunded educational institutions, limited food retail and nutrition choices, and overall disinvestment" Mercado et al. (2012) also identified gaps in quality transportation access for low-income workers in Ontario and Quebec.

Fare and service integration are crucial to connecting equity seeking groups to opportunities across some of these borders with or without electrification. (Hertzel et al., 2016; #25) The literature review and our interviews reinforced the critical role that buses play in creating an equitable and universal transit system as these are the dominant mode used by marginalized and IBPOC communities (Toronto Regional Board of Trade, 2021). In cities with subways or other rapid rail transit the neighbourhoods immediately around these services are expensive. Buses provide access to these backbone or trunk services yet have often been deprived of investment.

Establish equity lens as methodology
In "Evaluating Transportation Equity" (2021) Litman argues for both horizontal equity in overall design and vertical equity to address existing inequalities,

> Horizontal equity requires that people with comparable needs and abilities be treated equally, for example, receiving similar benefits and bearing similar costs. It implies that people should "get what they pay for and pay for what they get," unless a subsidy is specifically justified. It can also justify compensation for external costs. Vertical equity requires that the allocation of benefits and costs favors disadvantaged people. This tends to justify universal design that accommodates people with diverse needs and abilities, multimodal planning that provides transportation options for nondrivers, planning

[18] In systems where there is a "pass-by," that is not enough buses to serve existing demand, additional service needs to be added to attract ridership.

> for affordability, special discounts and exemptions for lower-income travellers, and special protections or benefits for vulnerable or disadvantaged groups. A useful way to incorporate equity into planning is to define various equity goals. Litman, 2021, 56

The TTC used a vertical equity strategy in its rollout of electrification priorities, focusing on high use neighbourhoods with lower incomes and more extreme levels of pollution. It also undertook consultation with key stakeholders in communities prioritized for ZEB rollout. (#9) Winnipeg considered overall transit design to increase universal access and quality, using a grid pattern, and then applied a vertical equity strategy to consider issues like gender differentiated travel use. Women more often change vehicles during trips than men as women more often want to go destinations that are not downtown. The new travel plan emphasized connectivity and amenities. (#14) Respondents agreed that it was important to both improve ride comfort, reduce pollution, and improve frequency of service. (#4, #29)

Strategies

Several strategies are discussed in the previous section of this report. Other considerations include the development of electric micro services (#19, #23); provision of ZEB or hydrogen cell electric vans or small buses to underserved areas to increase connectivity and the addition of on-demand services where ridership is slim (W#18); the integration of specialized and non-specialized services into small vehicles in the fleet, expanding access for people with disabilities to core or backbone transit lines while increasing efficiency; the inclusion of wheelchair, stroller and bicycle access on buses, to accommodate those with disabilities and families, and encourage multimodal transit; and the use of electric micro transit as a social inclusion tool. E bikes and cargo bikes, EV fleets or EV vans, electric shuttles could form an electrified micro mobility fleet across Toronto as part of public transit. Cargo bike hubs could be provided through partnerships with apartment buildings. (#23) Equally important is co-design of solutions with marginalized communities. One consultant works in close collaboration with Indigenous communities to develop transportation strategy, with over four years of on the ground planning and trust building. First Nations individuals lead the discussion in community. (#5)

Indigenous ZEB

Several respondents and reports considered the needs of Indigenous communities and users. A consultant working closely with Indigenous communities, notes that leaders and community members are aware of emerging technologies but have no access to dollars or infrastructure, hence it is not simply introducing new bus routes or electrifying routes, many reserves do not have buses. There are no service stations, grocery stores, and often there are dirt roads for 30 minutes that are unsafe to drive on. In some instances, community members must walk to town or drive 1 to 2 hours or walk that long to get groceries. This situation forces individuals and families off reserve into the city. As well, most reserves lack access to active transportation, bike lanes and sidewalks. The recommendation is to fill the transportation infrastructure gap and electrify at the same time. (#5) The Canada Infrastructure Bank is committed to reconciliation and helping develop Indigenous infrastructure. Rather than substituting ZEB buses for diesel, they work to indigenous communities as investors in projects, encourage the transition from diesel, create clean water, and nurture partnerships with Indigenous communities for development projects. (#3)

Addressing Pollution

Side by side with access and service quality improvement is the importance of improving air and noise quality for heavy use communities and for the underserved as transit rolls out to them. (#4) Interview subjects argued that transit strategy should prioritize areas that have suffered from highest pollution counts. (#29)

International

Social Attitudes and Impact

Welch (2017) compares the impacts of electrifying transit and school buses in American low-income areas with diesel and evaluates the benefits of reduced pollutants on air quality and greenhouse gases for low-income and marginalized populations. He develops a cost comparison to highlight this. Teunissen et al. (2015) outlines the importance of social inclusion in transportation approaches in Bogota. This analysis is relevant to planning ZEB rural services, on demand services, and electric microservices.

4.5.3 Social and Equity Data

Trip patterns of people living in various parts of the city through Toronto’s Transportation Tomorrow Survey, (TTS) http://www.transportationtomorrow.on.ca/ shed light on the distances that people travel, and the transportation means that they use. These data can be correlated with income and other factors. This data also allows an analysis of the suitability of traveling by active transportation or by E bike based on the current travel patterns for work and non-work trips (Farber). Canada provides comprehensive demographic data such as family, education, and social support in its General Social Survey (GSS) (https://www150.statcan.gc.ca/n1/en/catalogue/89F0115X). Geography census data includes information on population, age, sex, families, households, marital status, income, diversity, housing, education, and labour etc. (https://www150.statcan.gc.ca/n1/en/catalogue/98-404-X). Comparative data from international sources include the Mercer Quality of Living Survey (www.mercer.com), The United Nation Development Programme's Human Development Index (http://hdr.undp.org/en), Economist's Quality-of-Life Index (www.economist.com/media/pdf/QUALITY_OF_LIFE.pdf) and The Legatum Institute's Prosperity Index (www.prosperity.org/ranking.aspx). The Canadian and international sources suggest factors that can be measured when seeking to improve quality of life through ZEB adoption.

4.5.4 Social and Equity Tools

Foth et al. (2013) emphasize the importance of transit equity and use a social indicator based on census tract level socio-economic characteristics to measure the relationship between social disadvantage and accessibility to jobs and transit travel time in the Toronto region over time. They consider spatial relationships, time to travel, and job types. Farber and Fu (2017) have developed a new data object called the public transit travel time cube which contains the shortest path transit travel time between sets of origins and destinations in the city, at all times of day. This approach can be applied to underserved areas of the city or areas with high densities of transit users who are financially challenged. Considering different times of day can help to account for gender variations in transit usage.

Community mapping is a tool in which Indigenous participants, planners and consultants create drawings supported by artists that provide visual guides to transit solutions. These are accessible maps that individuals in community who were not working on city building projects could contribute to and understand. (#5) Interview subjects discussed two uses of visualizations and explanatory videos in the context of social and equity drivers, firstly to present data and information in the consulting process and secondly to convince individuals to support ZEB adoption.

4.5.5 Social and Equity Challenges and Gaps

Scaling back service to support electrification

Academic literature and respondents emphasized the importance of maintaining service levels at current base lines as electrification is implemented despite the higher costs to electrify, including the purchase of additional buses. As one transit planner stated,

> "The one thing that's most important to anybody who depends on transit, especially people who live in poverty and don't have any other options, is you need frequent service. If we scale back service, you don't care about what the propulsion system is. All you know is that you have more trouble getting to your job or going shopping. If you want to drive density of use, its frequency that matters." (#3)

Policy Focus on EVs

Some respondents described a policy focus that subsidizes personal EVs as a deterrent to investment in an electrified public transit system. EVs are more accessible to people in a higher income bracket. (#5) Studies have shown that subsidy is going to the top 10 percent of Canadian households and that the wealthy are more able to handle fuel price shock and will choose electric alternatives. (#23) There are concerns that EV investment will see infrastructure and support flow into more affluent neighbourhoods where there are a threshold of adopters and that people who face more barriers and disadvantaged people will be left behind.[19] (#12) The same funds could be used to enable transit electrification. (#23)

Electrified micro transit is seen by several interview subjects as a full or partial alternative that supports equity and environmental objectives. However, cultural perceptions of bicycles may be a barrier to adoption as well as. gender barriers further nuanced by culture, and age. [20] (#23)

[19] Some agencies such as TO Hydro are working with Canadian Mortgage and Housing and Toronto Public Housing to provide infrastructure. This is not a focus of this report, but the concern does impact electrification of public transit.
[20] Studies in which families are given mobility tools to trial and receive adequate training would lead to understandings of benefits, and whether and how they take the information and make a sustainable decision going forward. Understanding how they share the experience and information with their social network would be of benefit. (#23)

4.5.6 Social and Equity Research Requirements

The literature review indicates insightful work, for example, by Ollier (2018), Farber (2017), Keil et al. (2021) and Litman (2021) regarding transit equity but little research brings ZEB into the picture despite initiatives by transit agencies. (#9, #14). Respondents proposed research to analyzes the demographics and needs of riders in a region and measure whether electrification betters their conditions. (#7) Qualitative research is capable, through storytelling to impact hearts as well as minds. (#13) Measurement is currently seen as focused on cost and environmental factors, not a triple bottom line approach. (#3) Research that builds on previous studies (Spinney et. Al., 2009) of the transportation requisites of seniors would be valuable as the aging populations is growing in many communities in Canada. Respondents felt that research could addresses strategies to provide clean transportation to rural communities. (#15)

4.5.7 Social and Equity Data Challenges, Gaps and Requirements

Case study data is of significant value if it is shared. Data that indicate change over time regarding income, jobs, transport use type, travel time, connectivity, and other access factors in neighbourhoods of cities and outlying municipalities is deemed essential. A lack of social impact and equity measurement is a general gap prohibiting an assessment of true costs and benefits.

Indigenous Protocols

Ownership, control, access, and possession (OCAP) principles are recommended for research with Indigenous communities. With these principles Indigenous organizations own their data collectively. https://www.afn.ca/uploads/files/nihbforum/info_and_privacy_doc-ocap.pdf. (#5)

4.5.8 Social and Equity Tools Challenges, Gaps and Requirements

Respondents pointed to the importance of integrating demographic data and impact analysis into tools or indices used to plan and monitor ZEB adoption and to add equity metrics within simulations, Cost Benefit Analysis tools and lifecycle evaluation. A respondent emphasized the importance of visualization and graphs in government reporting to ensure that vulnerable groups could understand the implications of policies. (5)

4.5.9 Social and Equity Policy Requirements

Access

Both literature and respondents argued that it is essential that marginalized communities, who rely on transit gain improved access and quality of service. Interview subjects expressed the importance of transit authorities understanding their ridership, for example the person "who works three jobs". Transit planners could devise policies that integrate the life experiences of IBPOC and lower income individuals, especially those who are not present in the system. Given gender and other demographic imbalances in the transit industry labour force it is important to create consulting tables that support conversations with IBPOC groups, represent gender diversity and deploy direct community engagement methods. (#5, #7)

Some respondents argued that transit should be a public good or public service, hence it should be run by the government because transit "binds a nation together". It should be free, or price regulated to the point where the cost of the competition would be managed. (#11) A respondent suggested that the electrification of transit should be seen as a community asset for a complete community, integrated into Complete Community policies and a distributed energy system. (#18)

Service Delivery

There were innovative solutions to providing equitable access and electrification with an emphasis on connectivity. Winnipeg Transit developed the concept of transit junctions. There are now hundreds of these throughout the City of Winnipeg with accessible infrastructure and passenger amenities. These connect passengers through connectivity at every node. (#14)

The concept of horizontal equity would ensure that the same level of transport service is being provided to all communities – especially where it is needed to access workplaces, jobs etc. Agencies were encouraged to set goals for the frequency of service per passenger, or the equivalent to ensure equitable services in all neighbourhoods – understanding key layers of demographic data and locations. (#7, #18) Transit agencies can provide directed services through demand type services with smaller electric vehicles for specific routes and groups. (#19)

Transit Affordability as lever

Fare reduction, for at least segments of the population should be a goal of electrification as operational savings re realized over time. (#7, #27) Others suggest variable pricing, for example seniors could travel for free or a lower rate. (#8)

Lack of basic infrastructure in Indigenous communities

There is a lack of infrastructure in Indigenous communities which impacts the quality of daily life. (#5) Respondents working with Indigenous communities recommended funding for bus routes and electric infrastructure on reserves, supported through Indigenous ownership principles (#3, #5).

4.6 Health Impacts

4.6.1. Health Strengths and Research

The adoption of ZEBs is identified in Canada and elsewhere with a reduction in GHGs, airborne particulates, diesel fumes, and toxic vehicle droppings, as well as noise pollution, with the expectation of measurable improvements in health and qualitative improvements in neighbourhoods and quality of life. (#6, #7, #19) A further topic of relevance to health and safety of ZEBs relative to diesel buses, includes the smoothness of rides and driver behaviour patterns that could influence safety. Inclusive design should include the needs of disabled riders to ensure that charging stations do not impede wheelchair mobility and that the blind can navigate e-bus layouts and receive audio cues to assist with navigation and safety. (#22, #31)

Diesel engines are one of the most significant contributors to environmental pollution caused by exhaust emissions and are a source of various health issues (Resitoglu et al., 2014). The key exhaust pollutants from diesel engines CO, NOx, HC, PM, and sulphur dioxide (SO_2). The World Health Organization (WHO) (2018) estimated that air pollution caused 4.2 million premature deaths in 2016 due to exposure to small particulate matter with a diameter of 2.5 microns ($PM_{2.5}$) or less, through cardiovascular stroke, and respiratory disease, and asthma. In recognition of this, the WHO has recently introduced a new air quality guideline, tightening them significantly (WHO, 2021). [21]Even at the lowest of levels of airborne particles characterized by Canadian cities, epidemiological evidence continues to find associations between exposure to air pollutants and increased risk of cardiovascular and respiratory disease and several types of cancers. (#17)

Health impacts align with income disparity as particulate and other emissions disproportionately impact people who live on main streets that have a lot of bus services. These individuals tend to be lower income or disadvantaged in other ways. (#25) There is another level of inequity whereby those people who choose to live close to bus corridors because they ride the bus contribute through fares to a more sustainable transportation systems, but they are exposed to higher levels of air pollution as there are higher levels of diesel exhaust related pollutants like black carbon and nitrogen oxides around bus corridors. (#17) According to Grollman (2014) health vulnerability intensifies for those who have double disadvantages, including race and gender. Big diesel buses are prone to self-infiltration which means that the exhaust of the bus makes it way inside the cabin amplifying street and neighbourhood exposures, creating an accumulation effect. Transit workers on diesel buses are exposed to poor air quality. (#4) Drivers and their unions in some jurisdictions have made air quality a health and safety issue and while concerned about job loss drivers are positive about a safer, quieter job with BEB and FCEBs. (#6)

These concerns are backed up by earlier Canadian studies regarding health risks and particulates. Crouse et al. (2010) found an association between exposure to outdoor concentrations of NOx and the incidence of postmenopausal breast cancer in Montreal, Canada. Although impact varied using estimates of exposure from different periods, they concluded that there was an increased risk of approximately 25 percent for every increase of 5 ppb (parts per billion) in exposure. Similar results were reported by Bonner et al. (2005) and Nie et al. (2007).

Weichenthal et al. (2019) evaluated the relation between ultrafine particles (UFPs, <0.1 μm) in a first epidemiologic study of incident brain tumors. They followed cohort members for malignant brain tumors (ICD-10 codes C71.0–C71.9) between 2001 and 2016 using Cox proportional hazards models (stratified by age, sex, immigration status, and census cycle) to estimate hazard ratios (HRs) adjusting for fine particle mass concentrations ($PM_{2.5}$), nitrogen dioxide (NO_2), and various sociodemographic factors. They identified 1,400 incident brain tumors during the follow-up period.[22]. Lavigne et al. (2020) studied ambient ultrafine particle concentrations and the incidence of childhood cancers. They identified 1,066 childhood cancers and found that first trimester exposure to UFPs (HR per 10,000/cm^3 increase = 1.13, 95% CI: 1.03–1.22) was associated with overall cancer incidence diagnosed before 6 years of age after adjusting for $PM_{2.5}$, NO_2, and for personal and neighborhood-level covariates. They concluded that UFPs may represent a previously unrecognized risk factor in the aetiology of cancers in children.

[21] These studies related GHG levels and human health (Crouse et al., 2010; Hung et al., 2011; Perera 2017; Varga et al., 2020).
[22] Each 10,000/cm3 increase in UFPs was positively associated with brain tumor incidence (HR = 1.112, 95% CI = 1.042, 1.188) after adjusting for PM2.5, NO2, and sociodemographic factors. UFP exposures were assigned to residential locations (i.e., six-digit postal codes, about the size of city block face or large apartment complex) using land-use regression models for Montreal (2011–2012) and Toronto (2010–2011). These models were developed using mobile monitoring data collected during the summer and winter months.

The WHO estimates that more than 40 percent of the burden of environmentally associated disease falls on the young, demonstrating their unique vulnerability. In their study, Perera (2017) explained that children have higher exposure to air pollution because they inhale more air per kilogram of body weight than adults and should consume three to four times the amount of food on a body-weight basis than adults (WHO, 2006). Particulate matter exposure has a negative impact on children's lung functions, resulting in lower peak expiratory flow and forced expiratory volume, especially in children with asthma, leading to an increase in emergency room visits, hospital admissions, and deaths. (Hellden et al., 2021). Seniors are also vulnerable. Underwood (2017) reported that exposure to $PM_{2.5}$ is implicated in increased risk of dementia and Alzheimer's disease because of progressive grey matter atrophy. Xie and Xu (2017) found that PM forms deposits on the lungs, respiratory bronchioles, and alveoli, resulting in respiratory and lung illnesses. In the United Kingdom PM in air pollution was responsible for 30,000 deaths and NO_2 for 10,000 annually (Le Page, 2016). The health impacts of PMs are described below:

Emission Type	Description	Health Impacts
Carbon monoxide (CO)	CO is a colorless, odorless gas that can be harmful when inhaled in large amounts.	• Reduces the amount of oxygen to the heart accompanied by chest pain (also known as angina) • Dizziness • Confusion • Unconsciousness • Death
Nitrogen oxides (NOX)	NOX is referred as nitrogen oxide (NO) and nitrogen dioxide (NO2).	• Damage lung tissue • Lowering the body's resistance to respiratory infection • Worsens chronic lung diseases, such as asthma • More effects on children and the elderly
Particulate Matter (PM)	PM stands for particulate matter (also called particle pollution): the term for a mixture of solid particles and liquid droplets found in the air.	• PM<10 micrometers in diameter can get deep into lungs or bloodstream. • PM<2.5 pose the greatest risk to health like cardiovascular, stroke, and respiratory disease, including asthma as well as cancers.
Hydrocarbons (HC)	HC is produces as the consequence of incomplete combustion of the hydrocarbon fuel (Mostly exhaust gases of gasoline fueled)	• Potential to respiratory tract irritation • Cancer
Sulfur Dioxide (SO2)	Sulfur dioxide (SO2), a colorless, bad-smelling, toxic gas, is part of a larger group of chemicals referred to as sulfur oxides (SOX).	• Harm the human respiratory system • Difficulty breathing. • Contribute to respiratory illness especially for people with asthma, children, and the elderly. • Aggravate existing heart and lung conditions • Eye irritation

Table 2. Health impacts of diesel exhaust emissions

Noise Pollution
Noise Pollution is also a factor that Canadian transit authorities and researchers have identified as bearing negative health impacts. Transit researchers identified patterns of noise complaint data with both diesel buses and subways. (#20) Biel et al. (2020) studied acute cardiovascular health effects in a panel study of personal exposure to traffic-related air pollutants and noise in Toronto, Canada. They discovered adverse changes in subclinical cardiovascular outcomes in response to both air pollution and noise, including changes in endothelial function and heart rate variability (HRV). Their findings showed that personal noise exposures can confound associations for air pollutants, particularly with HRV and had a measurable impact on heart health. At the same time, transit authorities express public safety concerns that mobility impaired or other pedestrians may not hear buses, therefore transit agencies may need to add noise producing devices to buses. (#6) According to the study by WHO (2011) road traffic noise increases the risk of heart disease and high blood pressure, cognitive impairment in schoolchildren, and annoyance and sleep disturbance are discovered as side effects of noise pollution (Wang and Moriarty, 2018).

Individual wellbeing, mental health and quality of life
One interview subject underscored that better mobility results in 3rd generation outcomes, that is better health. (#16) Another respondent noted that high quality, quiet and efficient public transit could decrease stress, due to many of the factors of vehicle ownership and commuting. (#11) Efficient, clean transit provides better access to healthcare for those reliant on transit. Ravensbergen (2020) writing about Canada's aging population emphasizes the relationship between mobility and healthy aging, associated with independence, health, and well-being. Older adults should remain mobile to meet their daily necessities and participate in social life.

Economic benefits of ZEB Health impacts
Minet, et al. (2021) created a baseline for illness and death caused by airborne particulates in the Greater Toronto and Hamilton Area, estimating, the burden of each vehicle fleet on population health in the units of years of life lost and premature deaths. They then quantify the expected reduction from electrifying private vehicles, transit buses, and replacing the oldest commercial vehicles with newer trucks and the associated drop in years of lives lost and deaths. These impacts could be correlated with costs to the healthcare system and the valuation of productivity loss or gain due to illness and death.

Parsons et al. (2020) undertook a preliminary Cost Benefit Analysis (CBA) of zero emission transit bus technologies, compared to base-case implementation of 16 conventional, 40-foot diesel buses. Three major bus options were considered, BEB, FCEB, and sufficient 100% renewable diesel. The study suggests that CBA from particulate reduction may be less important in the past because used lubrication oil disposal and acid precipitation emissions have now been "largely addressed, through stewardship programs and ultra-low sulphur diesel (ULSD) fuel respectively." However, other health researchers and engineers suggest that particulates remain an issue. (#17)

In his *Electric Bus Study for New York City Transit*, Judah Aber (2016) estimated the health cost savings from electrification combining fuel costs, the costs of bus purchases and maintenance and the costs associated with treating airborne diseases. He estimated,

> Typically, electric buses cost about $300k more than diesel buses, and annual savings are estimated at $39k per year over the 12-year lifetime of the bus, excluding health care cost benefits. Switching to electric buses eliminates the air pollution caused by diesel bus fuel combustion. The resulting health benefit to the populous of the city from the reduction of respiratory and other diseases is estimated at $150k per bus based on EPA data. Aber, 2016, 17.

The C40 cities have joined together to measure the impacts of electrification on health and resulting benefits including the reduction of healthcare costs. Ecuador has adopted electrification to address pollution with its impacts on respiratory and heart health, and studies of Quito measure change over time (C40 Cities, 2019). The estimate is a savings of $4,484m/year in savings for respiratory costs and $1,612m for cardiovascular disease.

4.6.2 Health Data
While the analysis in this report has focused on respiratory, heart health, and pollution exposure other considerations are crash injuries, passenger's satisfaction with safety levels, driver's level of capability, and vehicle and road condition. Data sources (quantitative data), and survey analysis (qualitative data) can be used to evaluate community perceptions and attitudes towards any changes. The Canadian Health Association for Sustainability & Equity (CHASE) gathers resources regarding the impact of public transit and ZEB on public health and social equity in Canada (https://chasecanada.org/transportation-health-and-climate/). The Canadian

Public Health Association (CPHA) holds resources about climate change, public transit, zero emission vehicles, and health. (https://www.cpha.ca/resources?topic=170) Air Quality Benefits Assessment Tool (AQBAT) of Health Canada AQBAT quantifies for $PM_{2.5}$ the chronic exposure mortality; the results are therefore of similar order of magnitude. Relevant international data includes the Mercer Quality of Living Survey (www.mercer.com); United States Department of Transportation (USDOT) Transportation and Heath Indicators (www.transportation.gov/transportation-health-tool/indicators and Data (Cancer rates, lung and heart disease) from Amsterdam and Denmark and San Francisco with higher ZEB integration rates.

4.6.3 Health Tools

Minet et al.'s (2021) collaborative efforts have resulted in a dashboard and index that can measure the impacts of diesel vs. electrified platforms on illness and morbidity. Alsina-Pages et al. (2016) designed an acoustic low-cost sensor network installed on public buses to measure the traffic noise in the city in real time. Noise maps are typically calculated by computing the average noise for one year and are updated every five years. The implementation of dynamic noise mapping systems could lead to short-term plan actions, besides helping to better understand the evolution of noise levels over time.

4.6.4 Health Challenges and Gaps

Financial impacts on health

With some exceptions there have been few studies that quantify the benefits of transit electrification to health and even fewer that estimate the reduction in healthcare costs due to electrification. (#1) As one researcher interviewed stated, "that's a big dollar sign that we're missing there" (#17). Correlating health data available through provincial government databases has also proven difficult or impossible for some interview participants.

4.6.5 Health Research Requirements

Measure impacts and change over time

While there are excellent longitudinal studies that demonstrate the impacts of particulates and noise there is a lack of day-to-day monitoring and analysis of health impacts and improvements beginning with baseline data from diesel deployment. Canada and the USA could conduct specific health and electrification correlation studies. Childhood cancer findings reinforce the importance of conducting further research on the effects of UFPs given the high level of exposure in urban areas. Research and planning can also be beneficial in the short term through collaborations with transit authorities to model routes, to prioritize which routes to electrify first, to reduce emissions and cut back on the pollution in higher risk areas (#7). Big population studies over many years are valuable. Research is warranted regarding whether there are carcinogenic impacts from batteries, as well as developing safe disposal. (#24) Data and studies that indicate the relationships between disabilities and pollution, and its reduction and health would be of value. (#7) Further studies on noise reduction and benefits and comparison to the diesel baseline would also be of value. (#20) Moreover, research regarding the relative safety of ZEBs and diesel buses including driving patterns and vehicle stability would be of value.

Correlations between investment, quality of life, and health outcomes would assist in encouraging investments by entities like the Canadian Infrastructure Bank, pension funds and impact investors.

4.6.6 Health Data Challenges, Gaps and Requirements

Access to data

Several interview subjects reinforced the need for evidence-based data and metrics on the environmental and pollutant impacts and performance reductions of diesel vs. CNG vs. FCEBs vs. BEB to lay the groundwork for policy changes based on health impacts. (#3, #9, #17) There is no consistent particulate data collection in Canada, rather currently pollution data is collected through "campaigns". Data are required for bus types trialed or acquired by transit agencies, how are these are driven, and how these are deployed over time to compare with diesel buses in relation to pollutants. Data are collected by different researchers for different purposes (for example, travel survey data, air quality data and related traffic data, and public health data) with different research questions requiring difficult data fusion.(#17) There is a need for partnerships between researchers and health authorities to enable access to provincial databases. (#7) Data access is compounded by individuals' hesitancy in self-reporting. (#7)

4.6.7 Health Tools Challenges, Gaps and Requirements

Respondents agreed on the need for improved tools to demonstrate the benefits of air quality impacts on human health, modeling the movement of the vehicles, their emissions dispersion through the atmosphere, and the location of people who are breathing the emissions, whether roadside and in backyards. (#20) This could be a map of the city with real-time or frequent measurement of localized air and noise pollution which could monitor change over time. (#4, #25)

4.6.8 Health Policy Requirements

Correlations and connections between polluting buses and emitting buses and impacts on health would presumably lay the groundwork for a policy framework mandating the transition to ZEB to mitigate those causes. (#25)

4.7 Intersectional Analysis

Respondents saw value in creating an intersectional analysis that built on efforts such as the International Institute for Sustainable Development's three pillars for sustainable development, and the UN climate and health outcomes as a guideline. These consider environmental, social, and economic costs and benefits and related indicators. (#11, #33) A sustainability framework could be used to assess trade-offs in a multi-criteria exercise to establish end goals. (#18) An urban planner noted that in transit planning studies they look at the environmental, economic, and social impacts at the front end of a transportation design project, leading to a cost benefit analysis. They then compare and rank design alternatives. In an intersectional analysis they would hit each point, "you can't have strong environmental and neglect social". (#25) A transit planner noted that health improvements could lead to higher employment rates, better integration into the economy, and a healthier community. They argued that politicians needed to understand the breadth of potential benefits to convince them to accept a "billion-dollar price tag". (#6).

4.7.1 Intersectional Analysis Research Requirements

An intersectional analysis is predicated on interdisciplinary research. For example, San Francisco has a group of medical researchers who work with transportation analysts, researchers, and economists, and they are developing a multi-factor analysis informed by longitudinal studies. (#17)

4.7.2 Intersectional Policy Requirements

One respondent discussed a three-pillar strategy that underscored correlations between social and economic status and environmental quality, describing this as environmental justice. Electrification of transit should provide more effective and more frequent service to communities with higher needs associated with a new business model given the relatively low maintenance costs of ZEB. They further linked this to building a new industry with new expertise, jobs, and training that corresponds to the multibillion transit program underway in Canada. They argued that Canada should be investing in "our own". (#16)

4.7.3 Intersectional Tools Requirements

Interview subjects identified the value of creating indices or measurement systems to evaluate intersectional impacts of transit electrification. One concept was a Sustainability Assessment Tool that could allow multicriteria evaluation type of exercise to understand critical trade-offs. (#18) Another measurement idea was a productivity index, that considers the cost of time saved when not commuting in private vehicles but on public transit (#11) An alternative evaluation matrix could assess social, environmental, and cost impacts because for transit agencies the cost benefit should be significant. (#24, #28) A participant urged the integration of Environmental, Social, & Governance (ESG) criteria into International Organization for Standardization (ISO) standards and global indicators for cities and transit.

There are several methods that can be integrated to develop a framework for sustainable electric transit analysis as suggested above, that include environmental, social (equity), and economic considerations. Some methods like CBA are for the purpose of economic benefit. CBA assesses actions in terms of their negative (costs) and positive outcomes (benefits) (Baum, 2012; Prokofieva et al., 2011). A common approach is life-cycle sustainability assessment (LCSA; Klopffer, 2008; Jeon, 2010; Finkbeiner et al. 2010) which considers sustainability performance in terms of social (equity), economic, and environmental factors and analysis. This method considers the equal weighting (importance) of a group of indicators. Multi-criteria analysis (MCA) is suitable for stakeholders with different preferences (weighting) to prioritize the importance of a group of indicators (Karvonen et al., 2017). Lopez et al. (2018) explores how technological innovations adopted by urban bus companies can improve cities' sustainability. A combined Importance Performance Analysis (IPA)–Analytic Hierarchy Process (AHP) method was applied. In this way, environmental and social sustainability effects were separately represented through hierarchical structures. This research focuses on EU case studies of evaluating sustainable transit through CBA and Life Cycle Costing (LCC) methodologies, using a combined Importance Performance Analysis (IPA)–Analytic Hierarchy Process (AHP) method was applied.

There have been several older but still relevant studies and analysis tools that have presented approaches for assessing intersectoral impacts of ZEB but would need to be updated considering climate change urgency,

COVID-19, and emerging technologies.[23] Karol and Brunner (2009) investigated the assessment tools toward sustainable environments at local scale from Australia, Great Britain, and the United State of America. In this paper, the themes are organized into four categories including environmental care, natural resources depletion, societal well-being, and economic well-being.
Minet et al. (2021) provide a specific set of sustainable and transport performance indicators to evaluate effects of policy measures, comparing different European cities in terms of development, sustainability, and infrastructures, by using transport performance indicators. A Normalized Transport Sustainability index measures and compares policies in different urban areas and allows fine-tuning of policies. Das, N.T. et al. (2016) measure economic growth in relation to a composite index of environmental damage. They conclude that economic growth alone is not enough to improve environmental quality. Therefore, creating a consistent, coherent, and effective environmental policy framework is essential to improve environmental quality that supports wellbeing and enables long-term economic development.

Some studies such as (Zito & Salvo, 2011) and Mameli and Marletto (2009) consider social, environment, and economic aspects to assess the sustainable development of transportation systems and integrate transit travelers' opinions to assess the effectiveness of policies for public transport mobility. These approaches can be integrated to create a Sustainable Transit Planning Index which could be a useful outcome from this phase of research.

5**. GBA+ Analysis**

A GBA+ analysis framework (as outlined in section 3.3.2 above) was integrated throughout the research and analysis process – from the inception of the project to the crafting of policy recommendations. As such, GBA+ considerations are evident in the schemata used to review and analyze existing literature and to particularly identify GBA+ gaps in current literature. Additionally, the workshop and interviews were designed to directly identify and address GBA+ factors in a holistic manner through the integration of economic, health, social, environmental influences on the wide-scale adoption of ZEB planning and infrastructure establishment. Other than studies that were focused on equity, access or of health IBPOC neighbourhoods and needs, or Indigenous communities we found little attention in data collection, survey respondent design, or research focus to GBA+ concerns. Respondents did identify the need to address equity issues. Our approach makes a break from existing research which primarily focuses upon environmental and economic benefits of ZEB adoption.

As a result, we recommend ZEB adoption be fully integrated into an inclusive planning process that updates transit systems, including rail and last-mile services, and places an emphasis on equal and improved access for both intense users of transit and those excluded from effective transit. Access should be defined in relation to equity by analyzing the demographics and needs of riders in specific regions from the perspectives of the riders themselves. These regional and participatory approaches unearth the complexities of mobility as they come to bear upon structural vulnerability, including intersectional factors such as age, class, gender, race, ability, family formation, etc. Both quantitative and qualitative data assist in highlighting these complexities, but it is particularly important to devise policies that integrate the lived experiences of IBPOC and lower income individuals, especially those who are not regularly present during public consultation. Moreover, government and other stakeholders should support outreach and conversations with these grouping over la longue duree to adjust policies in the future when access needs shift or change. There is also a specific need to address Indigenous transit access using Indigenous data protocols, including but not limited to ownership, control, access and possession (OCAP) principles through which Indigenous organizations own their data collectively.

The concept of equitable access must also include the premise that a clean transit system supports population growth and densification along urban corridors, thereby decreasing emissions for large concentrations of residents. This translates into better quality of life for city residents, including the reduction of cancer, lung, and cardiovascular illnesses. Thus, health improvement goals, including particulate reduction and noise reduction measurements, correlated with disease reduction goals and outcomes, and the resulting cost-benefit analysis should be factored into public health goals and objectives in future policy initiatives._Therefore, transit equity must extend to include heathier environments for structurally vulnerable communities in policy conversations and considerations. Post-COVID recovery provides the policy-oriented "window of opportunity" to do so as public transit stakeholders stabilize policies and systems in efforts to rebuild ridership as the Pandemic shifts to an endemic context.

[23] Tools included the Cascadia Scorecard, the Leadership in Energy and Environmental Design (LEED) for Neighbourhood Development Rating System, One Planet Living (OPL), the South-East England Development Agency (SEEDA) Checklist, Sustainable Project Appraisal Routine (SPeAR®), and VicUrban Master Planned Community Assessment Tool.

6. Summary Implications and Conclusions

6.1 Strengths and Research

ZEB adoption is most successful when fully integrated into a holistic planning process that modernizes transit systems, includes rail and last-mile services, and ensures equal and preferably better access for both intense users of transit and those excluded from effective transit. Expanded transit use remains an overarching goal as it takes more personal vehicles off the road, reduces congestion, has a positive impact on GHG, and finances transit. Personal electrical vehicle expansion is less effective in addressing GHG emissions as vehicles, batteries and materials produce both GHGs and pollutants. A clean transit system supports population growth and densification along urban corridors through better, cleaner services. A strong focus of planning and implementation is the reduction of emissions in the vicinity of transit corridors, where there are large concentrations of residents. This means a better quality of life for city residents, and the reduction of cancer, lung, and cardiovascular illnesses. Effective planning can pair active transportation with ZEB routes, as it is easier to encourage people to ride their bicycles along emission-free routes, with less particulates. Communities are more receptive to expanding transit services in their residential neighborhoods as ZEB buses are quiet and without fumes. While the GHG reduction benefits of public transportation electrification is less than commercial fleets it is important that public transit play a leadership role. Trials, pilots and well-planned staging continue to play an important role in effective implementation. CUTRIC has played a valuable role in organizing these efforts across Canada.

The adoption of ZEB is driven by the desire to reduce GHG and carbon emissions to meet climate change targets, and to lessen particulate air pollution and noise pollution. Planners see the need to synchronize ZEB adoption as part of the complete life cycle of energy generation, working with energy providers to plan and implement a transition of the grid to green technologies and to produce green hydrogen. At the same time, consideration of battery source materials and the development of recycling and reuse remain as considerations that must be addressed.

There are several equity issues. Communities that depend on bus service tend to also face economic and racial marginalization yet as users of public transit subsidize the services through their fares. Other communities, such as Indigenous communities, suffer from the lack of connected services, or in the worst case, have no service at all. ZEB allows cleaner, safer service for intensive users. Smaller ZEB transit vehicles can supply efficient, including just in time services, to underserved neighbourhoods.

There is a strong case that airborne particulates and noise result in cancer in adults and children, lung disease and heart disease. ZEB adoption will improve health. In doing so it will have an indirect economic benefit, reducing demands on healthcare services.

ZEB offers significant possibilities for Canada to develop economic and innovation strength as well as job growth along the entire supply chain, from needed rare metals, to parts and vehicle manufacturing, to green and blue hydrogen production, to renewable natural gas, to implementation planning and services.

6.2 Barriers

The most significant barrier to ZEB adoption is the cost of implementation of ZEB purchases, infrastructure costs, and energy sources. BEBs do not have the range of diesel buses, hence transit agencies may need to buy more buses to sustain their current levels of service. New infrastructures are complex, implementation demands process and management changes that necessitates careful planning. Electrification represents the disruption of a whole transportation system; including retraining staff, drivers, mechanics. It is difficult for agencies to decide which technology to choose and there is a lack of standardization of equipment. Technologies are not mature, hence there are concerns about investing in buses, batteries or charging stations that may upgrade and stabilize in the relatively near future hand in hand with price reduction. Implementation entails collaboration between all three levels of government.

Technical challenges include the unknown performance of fleet vehicles in cold weather, the unclear end-of-life options for batteries, the limitations of range/charge-time and operational flexibility and the location and supply of utility support, and the difficulty of adding on-route charging in some municipalities. There is a need for contingency plans if there is a power outage. Building hydrogen infrastructure and capabilities, BEB production and mining in Canada is imperative or Canada will be challenged by global supply chain and dollar volatility.

6.3 Data Requirements

Agencies and funders depend on data to undertake cost benefit analysis, life cycle analysis, and track implementation in the real-world implementation. Researchers seek data to analyze baseline contexts and evaluate impacts of ZEB.

Data requirements include:

- Open-source provincial data (vehicles, transit data, health impacts)
- Consistent data collection of localized GHG emissions, GHG average levels, other air pollutants, noise pollution, and landscape degradation.
- Provincial and territorial energy profiles, hydro energy production costs
- Lifecycle environmental footprints of buses and batteries. Zero-emission bus data for electric and fuel cell buses (FCEB) would support comparison. [24]
- To supplement available GTFS transit data is required to establish a baseline of diesel performance as a comparator to new technologies being considered.
- Data from pilot and implementation trials in real world conditions would balance vendor performance specifications.
- Socio-economic and demographic data to allow equity analysis and population projections.

6.4 Tools Requirements

Tool development should include:

- A life cycle approach, that involves both LCA and a FCSD for ZEB impact planning and assessment, including metrics on environmental, economic, social, equity, and health impacts. Integration of demographic data to equitable approaches to distributing ZEB resources to transit users and marginalized communities.
- Simulation models, including digital twins to understand the impact of design on the entire behavior of the city as well as neighbourhoods, test transportation solutions and pilot the ways that transit services align with urban form and differing density areas, route design, and the location of optimal charging infrastructure.
- Evaluation of passenger experience and engage users regarding route management, frequency, safety, comfort, and convenience.
- Supply chain management to ensure sustainable practices, local sources for equipment, and infrastructure.
- Financial modelling tools for ZEB implementation.
- Overall Transit systems planning for fleet and route management. CUTRIC has bridged this gap with the most effective tools available for ZEB planning; their RoutΣ.i™ – an electric bus and transit simulation tool which does provide a prediction of performance of differing ZEB bus types, along with the ability to provide feasibility studies of life cycle assessment. This tool also begins to satisfy the need for a life cycle approach, that involves both LCA and a FCSD.

6.5 Research Requirements

Research needs include:

- Understanding transit users and potential transit users to capture their travel requirements, attitudes to bus travel and include them into co-design approaches of ZEB integration into neighbourhoods.
- Longitudinal research studies that establish linkages between emission concentrations of local air pollutants to population exposure, physical health effects, mortality risks, and monetary damages, and the social and health costs of carbon emissions and measure change over time.
- Impact research studies to analyze whether ZEBs increase accessibility and the quality of services for neighbourhoods seeking improved service and whether and how underserved neighbourhoods are supported. Research can measure and demonstrate the impacts on accessibility and health outcomes of neighbourhoods and specific demographics (children, seniors, women).
- Research with Indigenous communities to develop electrification strategies that coincide with infrastructure investment and Indigenous ownership of resources.
- Research and related sustainability frameworks that develop metrics to correlate relationships between infrastructure and the broader environment, infrastructure impacts on the economy, environment, and social well-being in the Canadian context.
- Further research regarding emerging technologies and the life cycle assessment of implementing ZEB, focusing on comparative battery and hydrogen technologies.
- Wells to wheels analysis including mineral sourcing and circular economy environmental analysis.

[24] For example, ZEB performance, correlated with route configurations, topography and seasonal weather extremes, and their effect on battery performance and longevity; miles, total cost of ownership, product availability (overnight-charging battery BEBs, on-route opportunity charging, and FCEB), average energy consumed per day (kWh), energy cost (SEK/km), and total input/output energy (kWh).

- Research into distributed energy systems and the overall impacts of electrification of both transit and EVs on the grid.
- Operational planning research to understand how to build schedules and deploy services to manage battery consumption and charging constraint in line with the bus schedules and drivers' schedules, provide route planning, and minimize all instances of acceleration and deceleration of buses to prolong the life of the charge of the battery charge and reduce environmental impacts.
- Economic research into business models for ZEB.
- Road system impacts and comparative maintenance costs regarding implementation of ZEB with heavier weight profiles.
- Research regarding the relative safety of ZEBs and diesel buses including driving patterns and vehicle stability.
- Ensure strong research collaboration and translation between academic research and industry. CUTRIC can continue to play a role in this context.

6.6 Policy Requirements

These are policy recommendations:

- Approach the electrification of transit within a systems analysis of transit needs and transformation. Treat transit as a public good and a pillar of democracy with economic benefits to society. Use this approach in assessing life cycle costs and ROI of electrification, with a longer cycle of investment than the election cycle. Expand economic cost benefit analysis to include indirect savings from cleaner air and fewer emissions and social benefits of expanding ridership. This is an opportunity to improve service as well as achieving positive environmental, equity and health impacts. Hence, stabilize public transit while it recovers during and after COVID-19 and support efforts to rebuild ridership.
- Operational costs savings result from ZEB adoption; the capital expenditure is the barrier. Create long-term stable funding with collaboration between all three levels of government that support ZEB adoption and minimize the risk to transit agencies and provide accurate predictions of the potential savings. The $2.75 billion Zero-Emission Transit Fund is a significant investment in infrastructure and future investment is critical to sustaining this transition. A mix of funding tools should include direct subsidy as well as loans.
- Incorporate health improvement goals, including particulate reduction and noise reduction measurements, correlated with disease reduction goals and outcomes, and include cost-benefit analysis to public health in future policy initiatives.
- Align grid upgrades and clean electricity with ZEB adoption and support clean hydrogen investment.
- Set clear federal and provincial GHG reduction policies with dates and targets. Develop a mature system of carbon pricing, with consistent methods of understanding the true impacts of ZEB implementation using consistent formulae.
- Establish national codes and standards for hydrogen vehicles. Expert integration guidelines are also a necessity.
- Invest in transit infrastructure with electrification as an integrated component with Indigenous communities.
- Enact strategies to position Canada as an innovation and industry leader in ZEB development. Stimulate the circular economy capacities of a ZEB industry, working with Indigenous, industry and community stakeholders, from the mining of minerals, to manufacturing, components capacity, IT services and tools, to implementation services.

6.7 Developing a Sustainable Transit Planning Index

A Sustainable Transit Planning Index responds to the requirement identified through this research project for an intersectional means to plan and measure ZEB planning and implementation. The tool would provide a balance between environmental, economic dimensions, and social including equity and health dimensions. To enable implementation of these goals relevant indicators would be selected and defined that measure progress towards a sustainable transportation system. These indicators may reflect new technologies adopted by transit systems (such as zero emissions buses) and their effect on environmental quality, economic consideration, social and health goals. On this basis, a multi criteria decision making approach can be an appropriate methodology to plan and evaluate sustainable transit development, to provide insights and meaningful information for decision makers and transit agencies. The selection of indicators depends on the availability of data, the policy of transit agencies, and public priorities. Therefore, it is essential to develop a system to assess the sustainability of transportation systems, in part through aggregating specific discrete indices. The result with be a sustainable transit planning index (STPI) which considers multiple environmental, economic, and social factors in supporting ZEB implementation.

Figure 5 provides a holistic overview of the ways that environmental, economic, social, equity and health issue are mutually dependent. Successful ZEB implementation calls for a broad coalition of researchers, levels of government, policy leaders and NGOs.

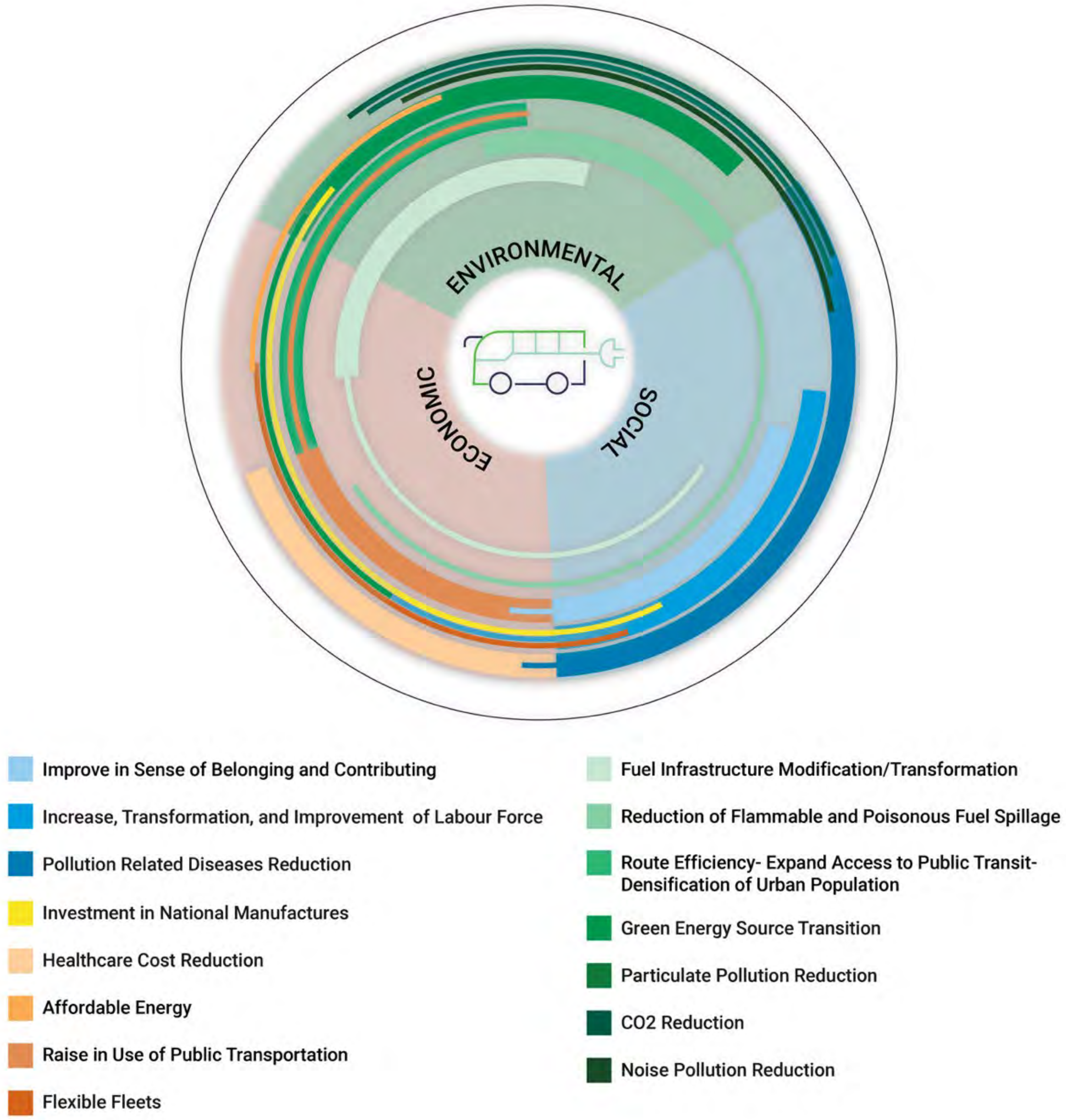

Figure 5. Visualizing Environmental, Economic and Social (Equity and Health) Impacts, Credit Sara Mozafari-Lorestani, OCAD University

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8.Appendices

8.1 Knowledge Mobilization Activities

Sustainable Development and Electrification of Transit will benefit a range of audiences in and adjacent to the transportation sector including:

- **Municipal transit authorities** who seek to align stakeholders, including future transit riders, as we emerge out of COVID-19, to support ZEB investment. Municipal transit agencies will lobby for provincial and federal dollars and invest their own resource and fares, in partnership with utility providers, ZEB companies and investors. The arguments for a sustainable development strategy are far-reaching, impacting the environment, improved quality of life in cities through the reduction of pollution and noise, the health of residents, more equitable and affordable reach and choice of transit, and job creation. Secondary benefits include densification and cost reduction of pollution induced disease. Research will support both experts and non-expert decision-makers.
- **Companies directly engaged in ZEB implementation** (bus manufacturers for example), or sectors impacted by requirements of implementation (utilities) gain from a multi-factor analysis and access to comprehensive data. Companies that manage and visualize data will benefit from understanding and accessing aggregated data sources and the opportunity to plan interoperability for more effective analytics and reporting and working to address gaps.
- **Researchers who are engaged in sustainable development research** regarding transit or addressing specific scientific challenges will benefit from access to a holistic approach and a well-structured and integrated literature and data resource.
- **Student researchers** who will participate in the research project will develop and apply knowledge and skills in environmental and transportation studies, design for health, inclusive policy, and visual analytics.
- **Advocates for a sustainable development approach to transit planning**, including NGOS will find a synthesis of resources, approaches, data sources and data visualization and simulation tools to add this important and transformative initiative.
- **Potential transit users and taxpayers** who are not informed about the potential, cost and benefits of ZEB infrastructure will have access to knowledge through media outreach.

For our research to be actionable for these stakeholders in the sustainable transportation ecosystem, we will be undertaking a series of activities related to discovery and dissemination. These activities build on process integrated engagements comprised of interviews and the workshop The integration of experts in our process increases the awareness of and investment in the process, increasing the likelihood of dissemination in conjunction with the following activities:

- This knowledge synthesis report, targeted at industry and government actors will be presented at the ZEB implementation members' meeting which includes a wide range of stakeholder. An accessible version of the report will be disseminated with the support of CUTRIC to its members and network, and by OCAD U to a broader network of stakeholders and associations, government officials at all levels and industry leaders. The report will be available through the OCAD U web site. We will disseminate it through international and Canadian academic, government and industry networks such as the Transportation Research Network.
- The report will be supported by an interactive online appendix that connects themes in literature and interviews, data sources and tools in March 2022.
- National Academic Advisory Committee: We will present our research in March of 2022 at an open virtual forum of CUTRIC's NAAC with outreach to a broader group of academic researchers and students.
- Industry and Peer-Reviewed Conferences & Journals: We will submit papers with industry stakeholders to present at conferences across our disciplinary fields (Feb. – March).
- We will submit an article to the Canadian Journal of Transportation or Public Transit, or Public Transport, the Journal by March 31.
- Media: We will undertake a media outreach campaign to mass and specialized media such as Electric Autonomy aligned with the release of our report and webinars which will reach a broader audience of stakeholders. Op-eds, commentary pieces and podcasts will reach a larger audience.

8.2 Interviews and Workshops

Before selecting interview candidates, we created a list of key stakeholders to guide our selection process and included municipal politicians, transit authorities, municipal policy makers, NGO representatives of advocacy groups and associations, private sector ZEB or technology companies, energy providers, federal and provincial policy leaders, academic researchers. We reached out to 150 potential interview subjects and interviewed 19% of these, that is 30 key stakeholders in the transit electrification and adjacent sectors with a focus on Ontario, The Prairies, British Columbia, Nova Scotia, and Quebec.

Table 3 indicates the role types and assigns a number to the interview subjects/respondents.

Role Type	Respondent number
Transportation Researcher	1
Municipal Transit planner	2
Funding Agency	3
Regional Association	4
Urban Planner	5
Municipal Transit Planner	6
Health Researcher	7
Urban Policy Expert	8
Politician, Transit Leader	9
Federal Government Transportation Strategist	10
Provincial Government Transportation Strategist	11
Utility Leader	12
Sustainability Researcher	13
Municipal Transit Planner	14
Provincial Government Transportation Strategist	15
Association Leader, NGO	16
Environmental Scientist	17
Climate Change Advisor	18
Urban Advocacy Leader, NGO	19
Transit Engineering Researcher	20
Infrastructure Technology Leader	21
Business and Economic Researcher	22
Sociology Researcher	23
Urban Planner	24
Energy Policy Consultant	25
Technology and ZEB Analyst	26
Industry Association Representative	27
Transportation Planner	28
Tourism and Transit Researcher	29
ZEB Technology Provider	30
Transportation Provider	31
Energy/Fuel Industry Leader	32
Provincial Government Transportation Strategist	33
Charging Technology Provider	34

Table 3. Interview Subjects/Respondents and Role

Interview Questions
The following questions guided the semi-structured interview:

Environmental Drivers to Implement Zero-Emissions Bus (ZEB) Transit Infrastructure

- What are the environmental benefits of ZEB? What research, data, policy initiatives and tools are needed to assess and address these benefits?
- What are the environmental barriers to achieving environmental benefits?
- What research is needed to address environmental benefits and barriers?
- What policy initiatives are needed to assess and address environmental benefits and barriers?
- What technical tools such are needed to assess and address benefits and barriers?

Economic Drivers to Implement Zero-Emissions Bus (ZEB) Transit Infrastructure

- What are the economic benefits of ZEB? What research, data, policy initiatives and tools are needed to assess and address these benefits?
- What are the economic barriers to implementation?
- What is the balance between short-term and long-term benefits?

Health Drivers to Implement Zero-Emissions Bus (ZEB) Transit Infrastructure

- What are the direct and indirect health benefits of ZEB implementation?
- What are the health barriers to implementation?
- What research, data, policy tools are needed to assess and address these benefits and barriers?

Social Drivers to Implement Zero-Emissions Bus (ZEB) Transit Infrastructure

- What are the social factors that encourage or discourage ZEB adoption?
- What research, data, policy initiatives and tools are needed to assess and address these benefits or barriers?

Equity Best Practices Development in the Introduction and Continued Use of Zero-Emissions Bus (ZEB) Transit Infrastructure

- How would you define equity in the context of ZEB planning, adoption and impact measurement?
- In your view what has gone well from an equity perspective? What are the barriers?
- How effectiveness are equity-oriented approaches best measured? What research, data, policy initiatives, programs and tools are needed to assess these benefits or barriers?

Relating Environmental, Economic, Social and Health Impacts

- Is it valuable to correlate impacts? Why or why not?
- What studies would support these correlations?
- What research, data, policy or tools support analyzing and evaluating these impacts?

To conduct the content analysis all interview and workshop transcripts were searched in NVivo . Table 4 provides a detailed list of the key word themes that were searched using NVivo technology.

Transportation Systems	Analytic Technologies/Tools	Environmental
• Hydrogen • Transportation • Transit System • Transit • Adoption • Passenger • Infrastructure • Transportation • Transit Planning • Manufacturing • Supplier • Charging system • Batteries • Transit policy • Diesel • Rail • Community	• IOT • Sensors • Analytics • Data Analysis • Visual Analytics • Design • Spatial Analytics • GIS • Predictive • Prescriptive • Data Insights • AI • Automation • Mapping • Visualization Tool • Data Visualization Tool • Visualize • RouteE.i-2.0	• CO2 • GHG • GHG Reductions • Emissions • Nitrogen oxides (NOx) • Benzene • Ultrafine particles UFPs • Fossil Fuel • Sustainability • Environmental Benefit
Economic	**Social**	**Equity**
• Trade-offs (Trade offs) • Cost • Cost of power • Projections • Economic Benefit • Growth • Jobs • Training • Transit Adoption • Ridership • Investment	• Social Benefit • Safety • Air Quality • Access • Accessibility • Social Sustainability	• Equity • Indigenous • First Nations • Racialized • Marginalized • BIPOC • Vulnerable • Low Income • Privilege
Health	**ZEB**	**Data**
• Health Benefit • Improved Health • Better Health • Health Outcomes	• ZEB • Electrification • ZEB adoption • EV adoption • EV	• Data Sources • Database • Information • Numbers • Figures
Research		
• Report • Case Study • Example • Source • Article		

Table 4. Themes used for NVivo analysis

8.3 Database Configurations

The following figures provide an overview of the structure of databases and the opportunity for queries within topics. Each database included a summary, relationship to ZEB adoption, analysis of how research was conducted, data acquisition processes, and GBA+ analysis was considered.

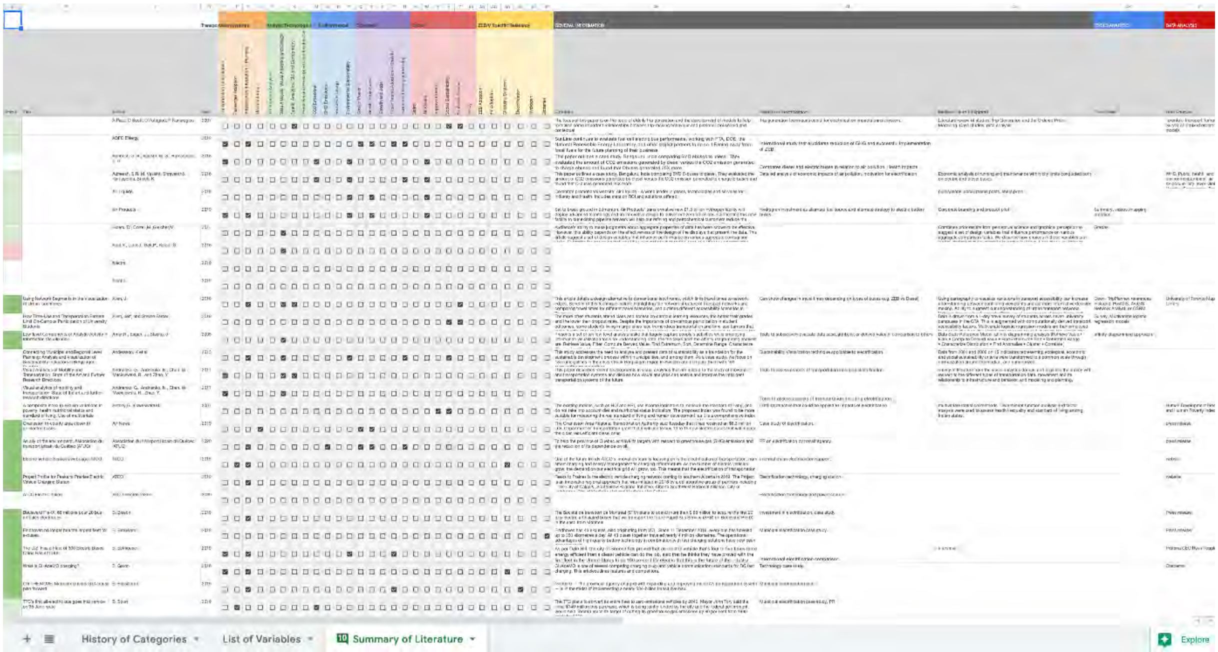

Figure 5. Literature review database extraction example

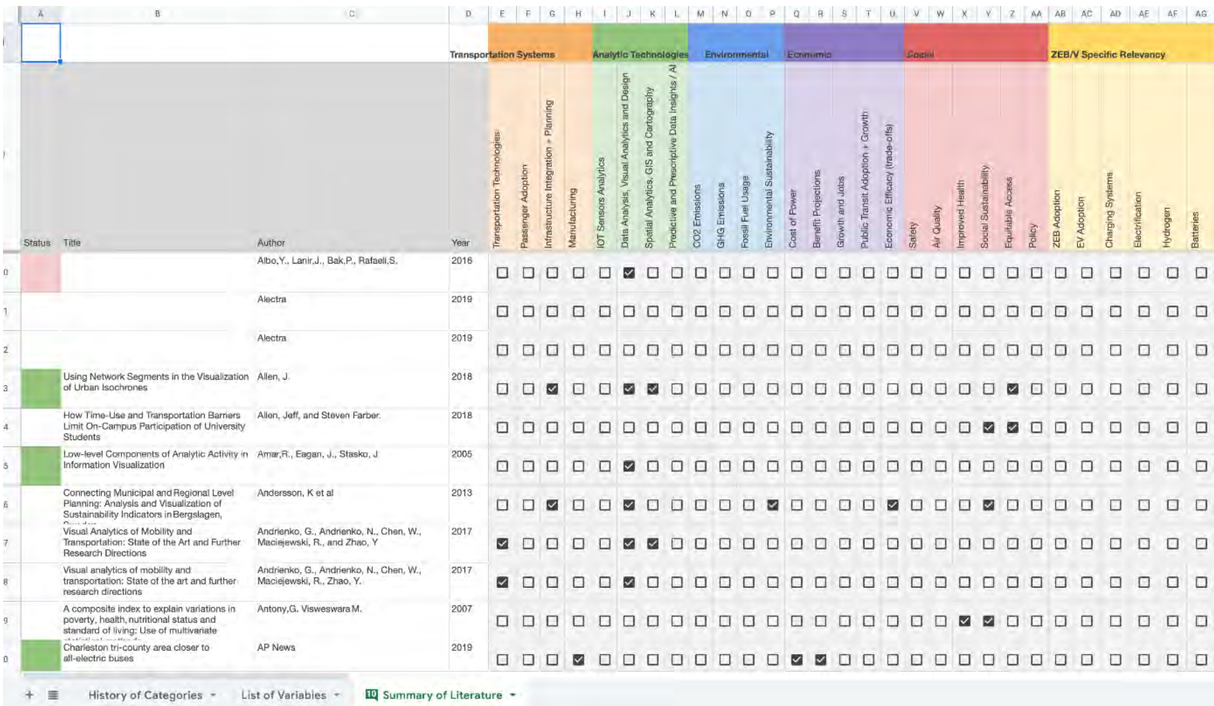

Figure 6. Literature review extraction example

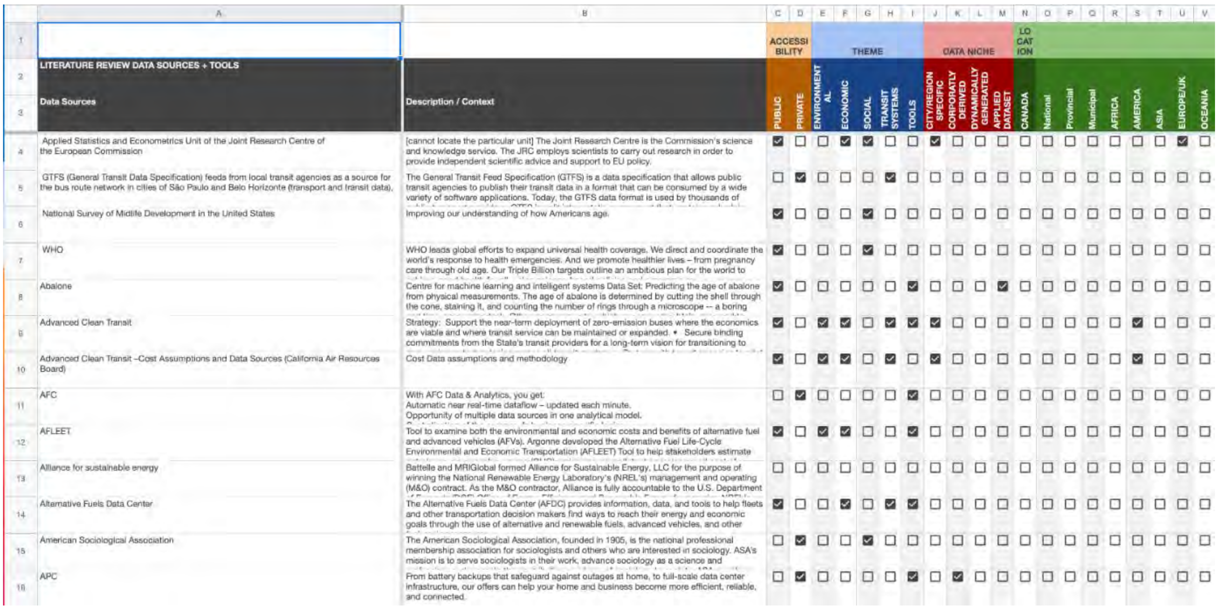

Figure 7. Data Database example extraction

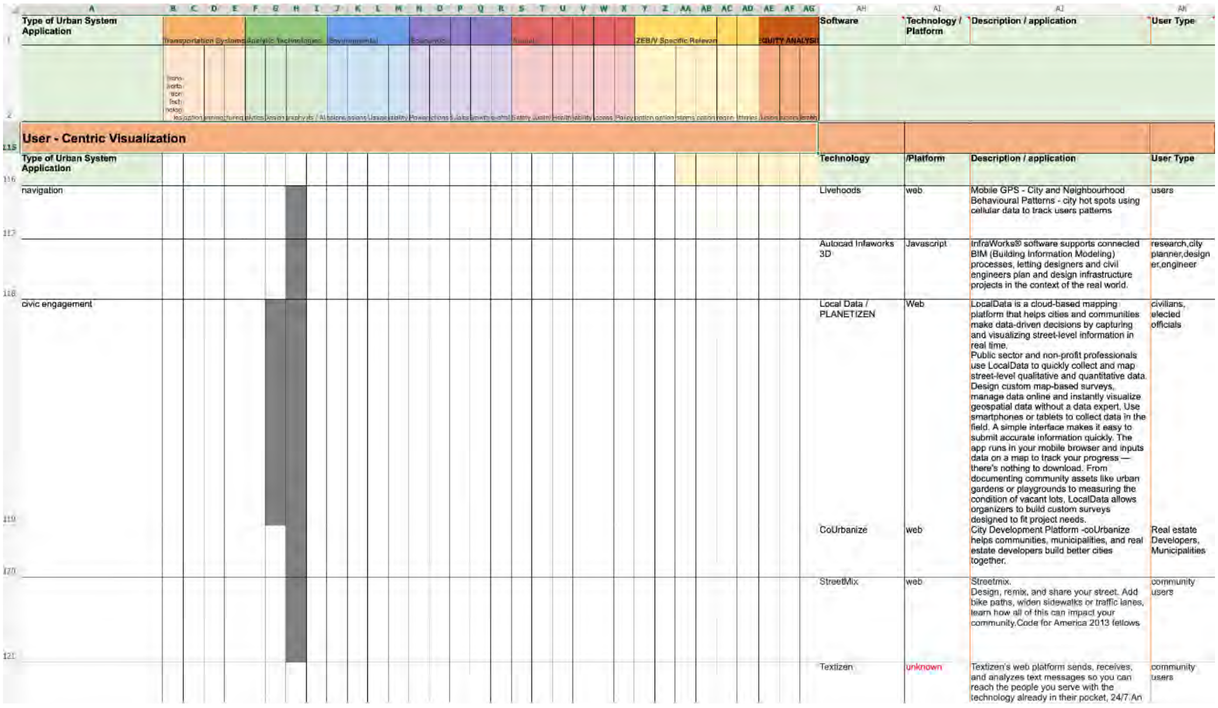

Figure 8. Tools database extraction example