Electric Trolleybus System Proposed for Downtown St. John's for Private Vehicles Control and Climate Change Mitigation

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Abstract

Transportation is the second largest fuel consumer after industry and is blamed for causing air pollution, global warming, and traffic congestion and accidents. Vehicle prevalence could lead to oil depletion and result in rising oil prices. To reduce the negative effects of on-road vehicles, this paper is proposing that the City of St. John's adopt a more environmentally friendly public transit system for its downtown area, specifically an electric trolleybus system for controlling both on-road vehicle volumes and emissions. Supplementary strategies to promote public transit over private vehicles are also proposed.

Keywords: fossil fuel, air pollution, climate change, global warming, external costs, vehicle population, electric vehicles(EVs), trolleybus, downtown St. John's.

Résumé

Le secteur des transports, deuxième plus gros consommateur de combustible après l'industrie, est considéré comme responsable de la pollution de l'air, du réchauffement du globe ainsi que de la congestion de la circulation et des accidents. La prédominance des véhicules pourrait mener à l'épuisement des ressources en pétrole et entraîne une augmentation du prix du carburant. Dans le but de réduire les effets négatifs des véhicules sur route, le présent article propose que la ville de St. John's se dote, dans son centre-ville, d'un réseau de transport en commun, à savoir un système de trolleybus électriques. Présentant moins de danger pour l'environnement,celui-ci permettrait de diminuer le nombre de véhicules sur la route et, par conséquent, les émissions polluantes. On suggère aussi des stratégies supplémentaires visant à privilégier le transport en commun par rapport aux véhicules privés.

Mots-clés: combustible fossile, pollution de l'air, changement climatique, réchauffement du globe, coûts externes, parc de véhicules, véhicules électriques (VE), trolleybus, centre-ville de St. John's.

1. Introduction

For over 150 years fossil fuels have been inexpensive, easily extracted, abundant in supply, topping eighty million barrels of crude oil per day, and have been the primary energy source for automobiles [1]. In the mid 1800's attempts were made to couple the internal combustion engine (ICE) with electric power [2] and to propel automobiles with steam engines but high costs and risk of boiler explosion discouraged these efforts[1].

Gasoline and particularly diesel used in heavy duty buses and construction equipment produce carbon dioxide (CO_2). About 99% of the carbon in diesel is emitted as CO_2 significantly elevating atmospheric levels [3]. Particulate matter, volatile organic compounds, carbon monoxide, and nitrogen oxides are also emitted and are air pollutants and human health hazards. Initially fossil fuel-powered vehicles entered the market on a small scale as luxury vehicles and they had negligible environmental and human health impacts, but with increasing automobile affordability and popularity and urban sprawl, the impacts became important and global warming, climate change, and ocean acidification become serious problems.

One objective of this paper is to summarize the advantages of electric public transit, specifically electric trolleybuses, with regards to limiting vehicle emissions and slowing the depletion of fossil fuels. A second objective is to identify the potential of an electric trolleybus system as the primary transit for the downtown core of St. John's with the expected consequences of reduced congestion on the main streets, more space being available for business and environmental purposes, improved working and living conditions, and expansion of the tourist industry.

1.1 Global Warming

In 2009 the atmospheric CO_2 reached about 387 ppm or 37 ppm above the estimated safe limit of 350 ppm [1,4] and so far increasing temperatures have contributed towards an estimated two trillion tones of melted sea ice having entered the oceans [1]. Increasing ocean levels threaten to shrink coastal areas and swallow small island nations and increasing temperatures will force oceans to release trapped CO_2 back into atmosphere further elevating temperatures, disrupting ecosystems and affecting the food supply in the crop sensitive tropics and sub-tropics.

1.2 The effect of climate change on ecosystems

Climate change has contributed to an alarming rate of species extinctions. Ecosystems are robust, resilient and adaptable in the face of change through diversity of species. A consequence of the now dangerous rate of biodiversity loss is that ecosystems are vulnerable to catastrophic system changes [4]. For example, warmer weather invited in pests that damaged a large area of alpine forest in Western Canada and continuous high temperatures induced a twelve-year drying season in one region of Australia, leading to ferocious bushfires, while another region experienced the worst flooding on record [1]. Now 52% of cycads, 30% of amphibians, 23% of mammals, and 12% of bird species are on the verge of extinction [1,4].

1.3 The changing ocean properties

The drop in the pH of oceans from a pre-industrial level of 8.2 to 8.1 can damage marine habitats [1,4]. Coral reefs, despite occupying < 1% of the ocean floor, support 25% of the ocean's organisms [5,6,1]. Ocean acidification has negatively changed the fundamental reef process of calcification [8] since at close to pH 8.1 corals lose their ability to create reefs [1]. The sea surface temperature (SST) also strongly controls coral reef distribution and health [6] and a higher SST can cause coral bleaching and disease outbreaks and threaten reef dependent organisms. Coral reefs are losing their resilience and becoming seriously damaged because now they are also under attack from ocean pollution, increased sedimentation, over-fishing, and other destructive fishing practices [6].

1.4 The depletion of traditional energy sources

Fossil fuel powered vehicles are depleting a non-renewable energy source that took millions of years to form. The decline in oil reserves may mean that, excluding new discoveries, existing oil supplies may be insufficient to meet demand by 2020 [1]. Approaching oil shortages could increase crude processing costs to deeply exploit existing sources, or find new ones [7]. World oil prices rose from $62/barrel in 2009 to $ 79/barrel in 2010, and are expected to reach $125/barrel in 2035 [8]. In 2008, transportation accounted for 54% of energy consumption, and in 2035 it could reach 60% and account for 82% of the total increase in world fuel consumption. Since many may be willing to pay higher prices governments will need to step in to promote new clean energy technologies. The greatest energy demand growth will be from the technologically developing countries [8].

1.5 Other indirect effects of widespread vehicle use

In areas of high annual precipitation, the runoff from paved roads constructed using hazardous materials is an indirect source of vehicle pollution. During dry, windy conditions and heavy traffic, unpaved gravel roads are a major non-point source of particulate loading to the atmosphere, harming the health of nearby residents and stunting the growth of downwind vegetation by shading plants and clogging their pores [9]. Fine dusts increase freshwater turbidity and affect aquatic habitats and dust suppressants derived from non-environmentally friendly materials also trigger problems [9]. Additionally, paved areas absorb more heat, remain warmer overnight, reduce the summer contrast between land and sea temperatures, and produce weak night-time winds that are unable to disperse smog and air pollutants produced by day time activities [10,11].

2. The external costs of vehicle use

The environmental and social costs of traditional on-road vehicles are associated with carbon removal from the atmosphere, global temperature reduction, management of air pollution related diseases, emissions reduction, provision of parking and road facilities, and traffic accidents and congestion [11]. These costs are not borne solely by vehicle owners but by the whole society, and though difficult to monetize some solutions still exist.

2.1 Global warming cost

CO_2 emissions from fossil fuel combustion increase the global warming costs connected with atmospheric removal of CO_2, and marginal climate change damages such as agricultural failure, habitat collapse, and health impacts can also be assigned a monetary metric. Marginal damage costs may be reliable references for global warming costs, though values of $10 to $300 per ton of CO_2 have been proposed, depending on the assumed discount rates and the way data is collected [11]. Assigning a cost per ton of CO_2 emitted and knowing the CO_2 potential of every gallon of fuel, each vehicle’s global warming cost can be determined.

2.2 Health damage cost

Vehicle-related health costs are from air pollution and traffic accidents. To quantify the health costs of chemical emissions, wind speed distributions and wind direction frequencies are combined with source emission rates to obtain incremental ground-level concentrations that are related to the increased incidence of health damage [12]. Health damage costs include the costs of air pollution related illness, wage and productivity losses, and the level of health insurance an individual buys [12]. Traffic accident costs include those due to bodily injury, vehicle damage and vehicle insurance, though some outside factors should not be ignored. For instance smoking can inflate the cost of bronchitis attributed to a vehicle impact, and result in an overestimate of the vehicle related illness damage cost [13].

2.3 Noise cost

Sleep disturbance, cardiovascular effects, and hearing impairment are the main human health impacts from vehicle noise [14] and property market values can be adversely affected for areas exposed to continuous vehicle noise [15]. Quiet residential areas are the most preferred although being located near a shopping mall, business center, or school, can mitigate the effects of vehicular noise. Ecological integrity and biodiversity is also threatened by unnatural vehicular noise which can reduce the ability of a species to perceive the sounds made by their kind, prey, or predators and negatively impact reproductive success, group cohesion, and locating prey. However, stressors such as chemical pollution and habitat fragmentation need to be isolated when testing for transportation noise effects [16].

2.4 Parking space cost

A typical parking space is 2.4-3.0 m wide by 5.5 – 6.0 m long or 13-19 m^2 and off-street parking lots may occupy greater space in order to provide access and landscaping [17]. An individual or government office parking space is based mainly on the land cost and that can range from thousands to millions of dollars per hectare [11]. The external cost of a general parking lot depends on what was sacrificed to devote the land to parking spaces [17], such as a business building, a “green” park area, and additional sidewalks or bike lanes.

2.5 Traffic congestion cost

Congestion costs due to non-free flowing traffic are due to poor fuel economy, overuse of road space, time delays, and heat energy loss from more accelerator and brake use [18] and the vehicle owner must pay for fuel wastage, engine wear and time lost. To monetize congestion costs, the price of eliminating congestion is estimated [19]. When the roadway volume to capacity ratio, V/C is > 1.00, all road users must pay to control the traffic volume. Another approach is to estimate the delay added by each vehicle entering the road, with long SUVs, vans, and pickup trucks producing longer travel delays than cars [11]. During heavily congested stop and go traffic when engines are left running, nitrogen oxides and carbon monoxide emissions increase, [20,21] and the resulting air pollution can be measured to attribute costs.

3. The status of current transportation systems

The transportation sector generates the highest external costs and is the main contributor to urban air pollution. Despite newer vehicles having advanced fuel saving ICE technology [22], air quality in urban areas such as Novi Sad, Paris, and Lyon, still greatly exceeds acceptable levels [23,22]. Congestion pricing and vehicle and fuel taxes can help manage adverse impacts [24] and Beijing and Shanghai have a forced limit on the number of private on-road vehicles allowed per day, but their air still remains extremely unhealthy. If vehicle pricing included the product values and social costs incurred by society, private vehicles would be less affordable [7]. Compared to private vehicles, public transit consumes less fuel per passenger kilometer, is more energy efficient and contributes to lower external costs [7] as buses may seat 20 to 50 persons or more if standing passengers are permitted.

4. Methodologies for improving the transportation system

4.1 Energy alternative – bio-fuels

The global vehicle population has multiplied ten times since 1950 [25] and continues to increase in technologically developing countries [24,22]. To reduce external costs in the transportation sector, clean alternative energy sources are needed. Bio-fuels may have a small future application [26] but if used extensively crops could become diverted into energy since only some parts of non-edible plants are usable in biofuels. This would increase food costs and pollution from field tillage [27] and biofuels still need further development.

4.2 Electric vehicle popularity

Electric vehicles (EVs) can be a low carbon solution for reducing the stress on fossil fuels if renewable energy sources are used to generate the electricity.

4.2.1 Battery-powered electric vehicles

Battery-powered electric vehicles (BPEVs) were widely produced in America, Britain, and France during the last decade of the 19th century [29] but by the 1930s had vanished from the market due to high capital cost, short driving distance, long battery charging time and mass production of improved ICEs [29,28]. The 1970's energy crises refocused attention on EVs [28,30] though present BPEVs are still not efficient for large transport vehicles, long travel distances, or frequent stopping [28,30]. To overcome the short battery life and reduce the time for charging batteries, London has midway service stations to provide other fully charged EVs [28]. However, the costs of constructing optimally located midway service stations could make BPEVs lose their overall competitiveness. The lithium-ion batteries in use now have little self-discharge, are easy to maintain, and have a high energy density and efficiency [31]. However, energy use and emissions in processing battery components and managing old batteries need careful consideration for BPEVs to maintain an advantage over ICEs [31].

4.2.2 Hybrid electric vehicles

Hybrid electric vehicles (HEVs) with ICEs and electric motors have been available since the early 1900's [28]. They include HEVs that use ICEs to supplement energy and plug-in HEVs (PHEVs) with larger batteries which are recharged by the ICE or by an electrical grid [28,29]. HEVs surpass BPEVs in their longer driving range, smaller batteries, and lower operating emissions. HEVs usually switch to oil for highway speeds and for climbing steep hills [30] but use the battery at slower city speeds, however, their higher purchase price may prevent their being widely used [29,28]. If manufacturers do not focus on safety, users of HEVs could be harmed by high voltages produced by the electric generators inside the cars [29]. Since HEVs produce emissions if the ICE mode is switched on, they will not be optimal for controlling air pollution in the long term or for relieving the energy burden on fossil fuels.

4.2.3 Fuel cell electric vehicles

Chemical energy from reacting hydrogen (H_2) and oxygen (O_2) is used to generate electricity for fuel cell electric vehicles (FCVs) [27]. Though FCVs have zero emissions, high efficiency, and quiet operation, the fuel and cells are costly, improved on-board H_2 storage is needed, H_2 refuelling stations need to be built [28,29] and FCVs might only be economically competitive after 10 or 20 years [27]. The method for feeding H_2 to the fuel cells, automatic control systems, and other operating features are still at the developmental stage [29,27,32].

4.2.4 Solar powered electric vehicles

EVs powered by solar energy are more promising for reducing fossil fuel use than HEVs [28, 29]. However, where average annual solar insulation is inadequate, solar-powered EVs carrying outside PV modules that transfer solar energy into electricity for driving, will also have to be equipped with larger and heavier battery systems [33], adding to battery issues.

4.2.5 Other types of electric vehicles

Online electric vehicles (OLEVs) powered through non-contact electromagnetic induction draw energy from a power line below the ground with a high efficiency on-board power pick-up device [34]. The battery capacity is small and only for emergency purposes, thus minimizing battery-related problems [34]. This wireless charging technology is under development and the electromagnetic radiation may pose a health risk.

EVs can also receive energy directly through grid-connected overhead wires or an underneath third rail. Trolleybuses, electric trains, and trams are generally equipped on top with two poles that link to power lines with sliding and swivelling connectors, or underneath with metal contact blocks. Compared to ICEs, electric motors with connected overhead wires are superior at climbing steep gradients [35]. These EVs can improve air quality, reduce emissions, [34] and are least dependent on energy storage but a series of batteries or ICEs with supplementary fuel are needed for passing around obstacles or going off-wire for maintenance [36].

5. Downtown St. John’s and the proposed public transit changes

5.1 Background information for downtown St. John’s

St. John's, Newfoundland the “City of Legends” is the oldest and easternmost port city of North America with unique architectural, historical, and natural attractions [37]. The downtown and harbour area has been a socio-cultural center since the 1800’s. Government House and commercial entities developed here (Duckworth, Holloway, and Water streets and Queen’s and Military roads) and in 1900 were serviced by an electric streetcar (Fig. 1a) [38] powered by a hydro power plant at the nearby Petty Harbour pond [39,40]. However, streetcars getting stuck on mud-covered tracks, citizens having to push cars back on the tracks, expansion of city boundaries and growing automobile use, brought the streetcar system to an end in 1948 [40].

Many attractive, historical buildings and former homes along Water and Duckworth Streets now house offices, shops and restaurants though their external historic features have been retained [41] (Fig 2a). In contrast, George Street has no historic attraction but is famous for its night clubs and taverns that play blues, rock, contemporary and traditional local music and in summer attracts thousands to open air concerts and social events.

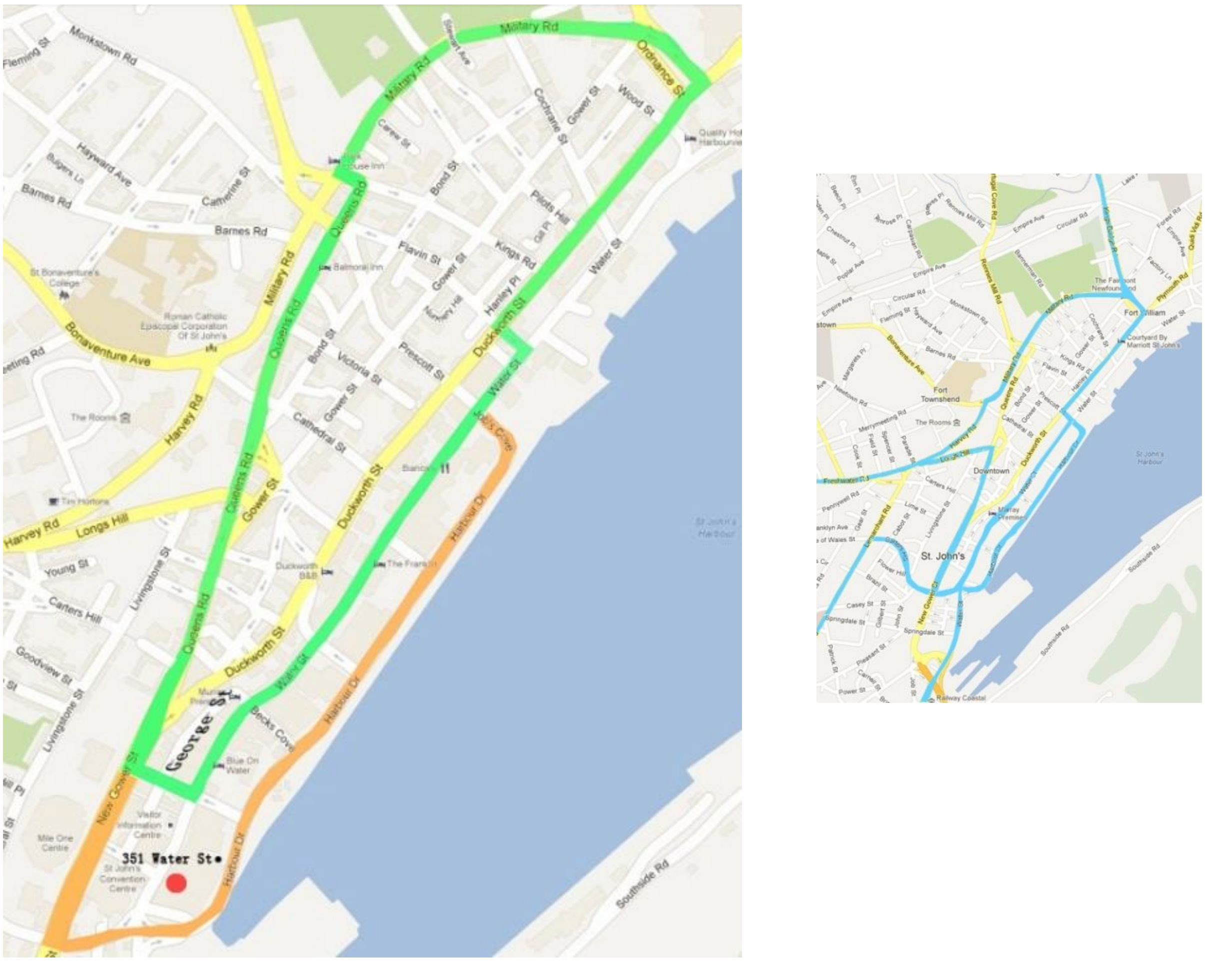

Figure 1. Downtown St. John's with a) the original streetcar route (green) and the proposed trolleybus route (orange) and b) the Metrobus routes now (blue) (drawn from Google maps).

5.2 Downtown St. John's development and challenge

Most buildings in the downtown Heritage area are restricted to 15 m in height but there has been pressure to expand this height limit because shortages of office space and hotels are being experienced. Further stresses are due to the increasing vehicle population and congestion along Water and Duckworth Streets during peak hours with cars parked at the sides of streets (Fig 2b). More people are working, living and visiting in the area but the Heritage regulations also limit parking and do not accommodate growth within the city's downtown area.

5.3 Current solutions to solve the downtown office shortage and parking problems

The City recently excluded 351 Water Street from the Heritage sites to allow a 12 storey office building with indoor parking to increase business space but providing parking for patrons only. To improve general outside parking and help drivers better manage their time, a driver pays a parking fee before leaving his car, and if he overstays he pays a ticket much higher than the parking fee. However, during peak hours this still doesn't sufficiently alleviate parking problems.

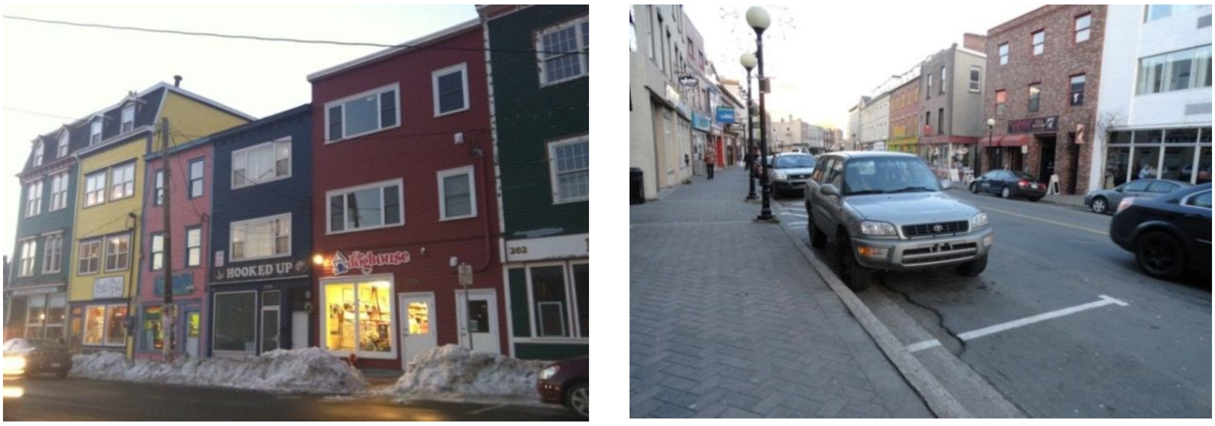

Figure 2. Duckworth Street, a) Historical houses converted into contemporary uses, and b) with cars parked on the side (Photos by Mengyang Zhang, Nov. 23, 2012 and Jan. 8, 2013).

6. The proposed solution on the way

It is proposed to 1) promote public transit with reasonable routes and increased conveniences and 2) encourage clean, renewable energy use to reduce the private vehicles in downtown St. John's and free up some land currently used for parking spaces available for other purposes to improve liveability for residents, employees and tourists. Grid connected EVs or trolleybuses, with electricity generated from hydro or wind power is recommended. Although photovoltaic solar powered EVs are also popular, St. John's has only 1,497 hours of annual sunshine, which could lower the efficiency of solar modules and require large scale energy storage [42].

The St. John's public bus system, Metrobus, services the downtown area (Fig 1b, blue) with routes close to the old streetcar lines (Fig 1a, green), which indicates that the most frequented parts of St. John's are still near the harbour and should be the centre of a new system. The precise area for the electric trolleybus system is shown by the orange and green loops in Fig 1a.

Metrobus busses run on diesel and release noticeably black smoke when then start moving. Also a complaint of the system is that if one misses a bus one could wait 30 minutes or more for the next bus and this can discourage transit users. The government could take measures to encourage public transit use and the following possible improvements are recommended.

- ***Exclusive bus lanes*** to promote bus use and reduce travel times for bus passengers
- ***Signal priority system*** that allows a bus to send a signal when approaching an intersection so it can receive a green light and not be required to wait for a light change
- ***Low–floor public transit*** makes the bus floor the same level as the bus stop to save boarding time, improve access and reduce slipping or falling, especially in winter
- ***Improved roadside station facilities*** including electronic notice boards showing bus arrival times and weather forecasts, sheltered areas, and at major stations temperature control
- ***Government intervention*** to limit private vehicle access to areas serviced by the proposed trolleybus system, to increase ridership and improve efficiency
- ***Proposed route sites in downtown St. John's*** are shown on Fig. 2 (green and orange) and located in the central business and tourist attractions area
- ***Parking buildings*** constructed at the entry of the trolleybus lines for passengers who also commute by car, to provide high density parking capacity and maximize land use

Figure 3. Downtown St. John's showing a) a steep incline off Duckworth Street and b) traffic congestion on Water Street (Photos by Mengyang Zhang, Nov. 23, 2012 and Feb. 2, 2013).

7. Expected consequences of the proposed solution

- Less vehicle volume on the main downtown streets, even during peak hours
- Road side parking space converted to expand the street area, build new office buildings, or to develop green spaces (for planting trees and flowers).
- Less noise from transportation as a result of fewer vehicles and the benefit of EVs
- Less air pollution and improved working and living conditions
- Restoration of natural beauty and an attraction for tourists

8. Potential of the new solution

Electricity rates in St. John's are relatively stable as greater than 80% of the island's electricity is generated with hydro power, and wind farms are slowly replacing fossil fuel power plants [43]. Electricity from renewable energy makes widespread grid-connected public transit in St. John's highly feasible and an electric trolleybus can carry eight times as many passengers as private vehicles using the equivalent energy [44]. The construction of a trolleybus system as proposed would absolutely result in huge initial capital costs compared to continuing with only the current Metrobus system, however, in the long term and with public cooperation benefits could be seen to far surpass private vehicles use. Additionally, costs of pollution and health and environmental impacts, would be decreased by relatively no emissions or noise. Finally, the trolleybus's ability to climb steep inclines is superior to that of regular ICE buses [37] which make it particularly attractive for hilly downtown St. John's streets (Fig 3a) and it could play an important role in controlling on-road private vehicles and congestion (Fig 3b).

Canada has already experienced success with this type of system in Vancouver, British Columbia, where an electric trolleybus system, supplied with power from hydroelectricity, has been in operation since 1948. A majority of the routes provide service to the downtown area and the trolleybus power consumption only reaches 2.7 kWh per km and is lower than the widely accepted value of 3.0 kWh per km in North America [45]. This is attributed to a Westinghouse Chopper Control System and the technique of braking energy transfer that is used [45]. The trolleybus also consumes less than half of the energy requirement of diesel buses for the same traveling distance. Avoiding non-renewable energy use in operation and in power generation (hydropower), the Vancouver trolleybus system has been deemed to produce zero emissions and provide comfortable living and working conditions for residents and visitors. Passenger use would normally increase by 10% to 15% when trolleybuses replace diesel buses [45,46].

9. Conclusions

Not only can electric public transit make a great contribution to the improvement of air quality but it can also play an important role in limiting the on-road vehicle population, fundamentally reducing time delays and traffic accidents. Even though HEVs have become popular recently, they are most suitable for small or private vehicles and have been rarely integrated into public transit. Other EVs, such as FCVs and OLEVs are still only at the developmental stage. By contrast, grid connected electric vehicles could be more suitable to the development of public transit, especially in St. John's where greater than 80% of electricity is now generated from hydropower. The design of downtown St. John's could make a trolleybus system more promising compared with light rail electric vehicles. With government support, appropriate routes, and improved roadside station facilities, more potential passengers could be encouraged to use a trolleybus system instead of private vehicles, thus effectively reducing the on-road vehicle volume.

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12. Biography

Mengyang Zhang was born in Chengde, Hebei, China. She holds a B.Eng. degree in Environmental Engineering from North University of China and is now pursuing an M.Env.Sci. degree from Memorial University of Newfoundland. She worked for one year in the Provincial government in China and last summer completed a work term with the Environmental Assessment group at Nalcor Energy on the Lower Churchill Hydro Project. She has published one journal paper on sewage treatment.