Comparative analysis of public transport modes available in Karachi, Pakistan

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Abstract

This study presents a comparative analysis of selected parameters of existing formal and informal Public Transport (PT) modes being operated on three different types of fuels. The performance of PT modes is analysed on fuel consumption, capacity, transportation cost, and emissions resulting from these modes. The required data were collected using route-check survey method and conducting a questionnaire-based survey from drivers and operators of these modes. Furthermore, the performance of proposed buses for an under-construction BRT corridor is also evaluated and compared with the existing PT modes. The comparative analysis of the existing PT modes in Karachi shows that CNG operated PT modes are economically more efficient, which caused the conversion of diesel engines of buses and minibuses to CNG fuelled-engines. The study, for the first time, evaluates and compares the performance of informal PT mode (chingchi) with other modes of PT. Results show that the PT modes with less capacity, such as chingchi, should be discouraged due to their comparatively lower performance on the selected parameters. This study can be used by the authorities to analyze the performance of existing modes and prioritize the PT modes for future planning.

Keywords Modes of public transport · Energy efficiency · Fuel consumption · Emissions · Public transport mode capacity

1 Introduction

Megacities all over the world are experiencing rapid growth of motorized transportation [1, 2]. Karachi is one of the megacities that face severe transportation problems [3, 4]. The situation is deteriorating day-by-day due to a lack of appropriate transport policies and decision making. The lack of a properly regulated and monitored public transport system results in a gap which is filled by the non-professional private sector. The informal private sector works on the principle of profit maximization, which results in a poor level of service for commuters. In this situation, commuters experience problems in comfort, availability, accessibility, and safety which trigger commuters to

switch to either private vehicles or paratransit/e-hiring services. The lack of a proper public transport system resulted in increased dependency on motorbikes and cars [5, 6] which contributes to more traffic congestion [7, 8]. The number of motorbikes registered in Karachi has increased by 50% during a period of four years from 2013 to 2017, whereas the number of cars has increased by 38% during the same period [9]. Public transit routes are decreasing continuously, which dropped to 90 routes in 2017 in comparison with 149 routes in 2012 [10].

The informal public transport system in Karachi comprises of various modes, which includes minibus, bus, and chingchi as shown in Fig. 1. The routes for buses and minibuses are approved by the Regional Transport Authority

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Fig. 1 Public Transport Modes in Karachi: Bus (left top), Minibus (right top), Chingchi Bike (left bottom) and Chingchi Rickshaw (right bottom)

Table 1 Type of public transport modes available and their fuel type

Public transport modes	
Type	Fuel
Bus	CNG
Minibus	CNG
Minibus	Diesel
Chingchi bike	Petrol
Chingchi Rickshaw	CNG

(RTA), whereas chingchi, which carries a significant number of public transport commuters, operates without approved service routes. These modes have distinct characteristics related to capacity, fare, operational cost, and type of fuel used by the vehicle. At present, three different fuels are used by public transport, which includes petrol, diesel and Compressed Natural Gas (CNG). Different types of fuels used by public modes of transportation are given in Table 1. Almost all the buses and minibuses were diesel operated until 2005 [11]. The significant difference between fuel cost on CNG and diesel encouraged the operators of buses and minibuses to transform the engines of buses to CNG engines, which resulted in minibuses operating on two different fuels (diesel or CNG) and all the buses converted to CNG-based engines.

Chingchi, a low-capacity three-wheeler public transport service, has now become an integral component of the

public transport network in Karachi. Two different types of chingchis are operated, which include CNG rickshaw converted chingchi and petrol operated motorbike converted chingchi. Currently, chingchi operates on shorter routes comprising of collectors and minor arterials. The operation of chingchi on most of the major arterials is prohibited by the authorities.

In developing countries, most of the energy demand is derived from petroleum and fossil fuel-based products [12] for decades [13]. The transportation sector of Pakistan is the major consumer of fossil fuel. In Pakistan, almost 56% of petroleum products were used in the transportation sector during 2016–2017. The consumption of petroleum products in transportation is increasing at a rate of 9.8% per year [14], which also affects the growth of associated sectors of the economy [15]. The increase in petroleum consumption leads to the expenditure of more foreign exchange in the import of petroleum products, which negatively impacts the already struggling economy. On the contrary, developed country such as the USA spends 29% of its total energy in the transportation sector, whereas 55% of total energy demand is derived from petroleum-based products in the US [16]. The transportation sector of the European Union (EU) countries consumes 42% of total energy in which the share of renewable energy was 17% in 2016 [17, 18]. The energy consumption in the transport sector leads to greenhouse gas emissions.

Globally almost one-quarter of the total greenhouse gas emissions are contributed by the transport sector [19]. In the US, transport sector generates about 29% of the total CO₂ emissions. The transport sector in Ontario, Canada accounts for 20% of the overall CO₂ emissions, whereas 27% of total CO₂ emission in the EU is generated from the transport sector [20–22].

Increasing environmental concern contributes to making the transportation system more fuel-efficient. Vehicular emissions are one of the major negative traits of the transportation process [23]. Continuous efforts have been made to reduce vehicular emissions by improving vehicular technologies, such as replacement of fossil fuel-powered based bus fleet with the electric buses [24]. Various models have been proposed to optimize the demand for fuel in the transportation sector by encouraging public transport and using energy-efficient buses. Yasmeen et al. highlighted the need for upgrading the existing energy consumption structure in Pakistan to a more sustainable structure to reduce CO₂ emissions [25]. A fuel consumption model was developed to reduce the emissions for bus operation while public transport serving on main routes of the network [26]. Similarly, several analytical and linear models have been proposed to estimate the fuel consumption and efficiency of different operations in the vehicle, such as acceleration, cruising at a constant speed and Advance Driving Assistance System (ADAS) in different modes of transport [27, 28].

Increased efficiency in fuel consumption and a more environment-friendly transport sector can be achieved by using alternative fuel and electric-powered vehicles which are less harmful to the environment [24]. Extensive efforts have been made in analysing the use of different fuel on the bases of various parameters, such as lifecycle cost, operation cost, and maintenance cost of different engine types [29]. Comprehensive cost–benefit analysis of public transport buses was performed to analyze the advantages and disadvantages of different fuels in buses [30–32]. Exhaustive multi-criteria analysis on advance fuel options, such as electricity, methanol, and hydrogen fuel cell in hybrid electric buses was performed which shows that electricity is the best alternative for the buses in the study area with less emission in comparison with other fuel options [33]. Vehicular emissions and energy consumption are driving factors in transforming the existing transport system to the sustainable transport system, which is being achieved in developed countries by converting the existing fleet into electric vehicles and by changing fuels to CNG or Bio-Fuel in developing countries.

In addition to energy and emissions, the capacity of the public transport mode is also important in the selection of a public transport mode for a city. Different modes of public transport have different capacities and Passenger-Car

Equivalent (PCE) factors. The value of PCE is an indicator of road capacity utilization for the given mode. Preference should be given to the mode of transport with the highest value of passenger carrying capacity per Passenger-Car Unit (PCU). A study in Dhaka, Bangladesh concluded that commuters prefer the mode of public transport with a higher capacity [34]. Another study performed in Dublin, Ireland compared the stress among commuters of two different tram routes with different capacities and passenger load. The research concluded that the stress level is affected by the passenger load to the capacity ratio of the tram route [35]. The transit capacity of a route is also an important factor to make the public transport successful, as highlighted in the study of Santiago bus-based transit system [36]. Furthermore, the higher capacity mass transit system is highly feasible to the cities having high-density population [37, 38].

The existing literature on public transport provides the comparison of PT and car users [39], analysis on BRTS (Bus rapid transit system) and MRTS (Mass rapid transit system) [40], and also the comparison of advance mobility services like PRT (Personal rapid transit), e-bikes (electric bicycles) with BRT and LRT (Light rail transit) [41]. However, the existing literature lacks in detailed performance evaluation of chingchi as a mode of public transport. Therefore, the contributions of the present study are listed below:

- This study performs a detailed evaluation of chingchi as a mode of public transport and compares its performance with other modes:
- This study evaluates the major performance indicators such as energy consumption, emissions, and capacity of public transport of a megacity in a developing country.

The results of this study are useful in the evaluation of public transport modes, which should be given due consideration in the planning and operations of the transport system of a city.

2 Methodology and data collection

Karachi is the economic hub and most populous city of Pakistan with an area of 3,780 km² [42]. According to the census conducted in the year 2017, the population of Karachi city was 16.62 million [43]. According to the Regional Transport Authority, Sindh, the existing public transport network of Karachi consists of 12 routes of buses and 59 routes of minibuses [44]. The data on existing routes of chingchi is not available, as chingchi operates without officially approved routes.

Two types of surveys were performed in this research to collect the data required to compare the selected parameters of available modes of public transport in Karachi.

2.1 Questionnaire-based survey

The data about the average fuel consumption, route lengths, frequencies, passenger capacity, and operation cost were collected by conducting surveys from drivers and operators of buses and chingchi. The number of samples for each mode of public transport is shown in Table 2. In total, the opinion of 102 experienced drivers was collected through the questionnaire. The questionnaire survey included the question on the following parameters:

- Length of route
- Type of fuel
- Fuel capacity
- Number of completed trips per day
- Frequency during peak-hour and off peak-hour
- The average number of passengers served per trip
- Fuel consumption per trip

The data acquired from the questionnaire survey was used to analyse the trend of route length for different modes of public transport. The average fuel consumption per kilometre and average fuel consumption per passenger-km are based on the data acquired from the survey. The average fuel consumption data forms the basis of estimating average fuel cost and emissions for different public transport modes.

2.2 Route survey

Route survey was performed on the selected routes of public transport to estimate the number of passengers boarding and alighting at different bus-stops, and travel time of the selected mode. Three observations were made on each of the surveyed routes of a specific mode of public transport. The data was collected in peak hours of working days to capture the average trend of commuting. This data

was needed to estimate average passenger load, as the analysis is performed per passenger units.

The surveys were performed in December 2018. The fuel prices used in the analysis for comparison were also based on the fuel prices at the time of the survey, although there has been a fluctuation in prices since then.

3 Data analysis and results

3.1 Comparison of capacity and trip length

In public transport, the mode capacity and route/trip length are the most important parameters to make it valuable for the planners and commuters. The frequency of buses is increased during peak-hour and buses with higher capacity such as articulated or bi-articulated buses are operated during peak hours. Similarly, during off-peak hours buses with low capacities are operated at a lower frequency to meet the demand to ensure optimal operation of the public transport system. However, in Karachi, the public transport modes (bus/chingchi) with fixed capacity are operated. The operators of public transport routes adjust the frequency of the bus/chingchi to meet the fluctuating demand. It is also observed that the operators purposely keep the frequency lower than the demand to ensure maximum profit, as there is no framework in place to ensure a certain level-of-service. Another important parameter associated with the mode of public transport is its PCE, especially when it operates in mixed traffic. Table 3 shows the capacities and PCE factors of the available modes of public transport in Karachi.

Table 3 shows that the capacity of bus service is highest among the existing modes of public transport, which is relatively higher as compared to other public transport, which are 75 persons per bus. Whereas, the capacity of a minibus is 40 persons and petrol operated bike-chingchi has the sitting capacity of 8 persons per vehicle.

The mode of public transport with the highest value of passengers per PCU should be preferred, as it is an

Table 2 Sample size for data collection

Type of public transport	Fuel	Number of routes	Surveyed routes	Observations for route survey	Sample for questionnaire-based survey
Bus	CNG	12	5	15	15
Minibus	CNG	59	10	30	40
Minibus	Diesel		3	9	11
Chingchi-bike	Petrol	Unknown	3	9	12
Chingchi-Rickshaw	CNG	Unknown	5	15	24
Total			28	78	102

Table 3 Capacities and PCE factors of public transport modes

Type	Capacity (sitting + standing)	PCE factor [54]
Bus	60	2.5
Minibus	40	2
Chingchi bike	8	0.5
Chingchi rickshaw	8	0.5

Fig. 2 Passenger capacity per PCU for different modes of public transport **Fig. 3** Average trip lengths of public transport modes

indicator of optimal road space utilization. Figure 2 compares the values of passengers per PCU for different modes of public transport and it indicates that the bus has the highest number of passengers per PCU with 28 passengers per PCU. Chingchi has the least values of passengers per PCU, which is 16 passengers/PCU. The higher value of passenger per PCU also highlights the significance of having a proper public transport system, where more persons can be accommodated in less space in comparison with private modes of transport. Furthermore, this analysis also suggests that bus or any other mode with higher capacity should be used in urban public transport.

The data of route lengths for the selected routes were collected and the average route length is shown in Fig. 3. Chingchi is operated without approved routes and its

Fig. 4 Relationship between passenger per trip and trip length **Fig. 5** Kilometre per litre and Passenger kilometre per litre or kg

operation on some major arterials is prohibited. Therefore, it operates mainly on collector roads with shorter routes. Thus, chingchi has the least observed route length with 12.87 km, whereas minibuses have the longest routes with around 49 km route length. Figure 4 shows the number of passengers served during a trip by different public transport modes. It indicates that, as expected, the number of passengers increases with the increase in trip length. Therefore, longer public transport routes are better for the transport system.

3.2 Comparison of fuel consumption and cost

The categories of PT modes for fuel analysis are more than the categories of PT modes used in previous sections, as minibuses and chingchi are operated on two different fuels. Bus and chingchi rickshaw only use CNG as fuel, chingchi bike uses petrol, and minibuses are operated on both CNG and Diesel. Fuel consumption for different modes on different fuel types is based on the survey data collected from drivers and operators of these modes. Estimated mileages in kilometre per unit of fuel are compared in Fig. 5 along with passenger kilometre per unit of fuel. Fuel consumption for petrol and diesel is measured in

litters and CNG is measured in kilograms. Figure 6 compares the cost per unit distance and cost per passenger kilometre for available modes of PT in Karachi.

The comparison shown in Fig. 5 reveals that CNG buses consume the highest amount of fuel to travel a unit distance in comparison with other modes. The most fuel-efficient mode of PT is chingchi rickshaw which gives highest km per kg of CNG i.e. 18 km per kg. In terms of fuel efficiency measured in passenger-km per unit fuel, the most efficient PT mode is CNG minibus, whereas the least fuel-efficient mode is petrol chingchi bike.

Figure 6 shows that per kilometre cost of travel is highest for CNG bus and lowest for CNG chingchi rickshaw. However, travel cost per passenger kilometre is lowest for CNG minibus with PKR 0.56 Rs/passenger-km, and highest cost is estimated for a diesel-fuelled minibus with 0.81 Rs/passenger/km. This shows that for similar types of minibuses, the change of engine from diesel to CNG reduces the fuel cost for transportation by 30%. The cost for all other modes exists within this range.

Statistical analyses of the collected data were performed to determine if there is a significant relationship between fuel consumption and the type of PT mode. The outcome of one-way ANOVA analysis is shown in Table 4. The null hypothesis assumed that there is no association between fuel consumption/cost and the mode of PT. The results show that p value for one-way ANOVA between mode of transport and cost of fuel per km and cost of fuel per passenger kilometre is less than 0.001, which means that null hypothesis is rejected and alternate hypothesis is accepted. Thus, it can be concluded that there is a significant association between different modes of public transport and their cost of travel.

3.3 Comparison of energy consumption

The comparison for fuel consumed by different modes of PT is discussed in the previous section. Fuel consumption

Table 4 Statistical analysis of cost parameter with available PT modes

	Degree of freedom	F value	P value
Cost of fuel per km	4	334.902	0.000
Cost of fuel per passenger per km	4	28.163	0.000

and energy consumption may be different, as the amount of energy produced by the combustion of the unit amount of different fuels may be different. Furthermore, the fuels in existing modes of PT are measured in different units, whereas the unit of energy consumption for all the fuels will be the same. The energy consumed in transporting a unit distance per person is estimated by multiplying the amount of fuel consumed per km per person with the energy produced by combustion of that fuel type. The data of the amount of fuel consumed per km per person was acquired in the survey from transport operators, which is presented in Fig. 5. The amount of energy produced by unit fuel combustion is taken from the available literature [45].

The comparison of energy consumption shows that the PT modes using high octane fuel are utilizing higher energy. Fuel types like diesel and petrol have higher energy contents in comparison with CNG measured in British Thermal Unit (BTU) [46]. Figure 7 compares the energy computation for different modes of PT. It shows that the diesel-driven bus consumes the highest amount of energy per passenger-km. There is a significant difference in the amount of energy consumed by CNG-powered engines and petrol/diesel driven engines. CNG minibus has the least value of energy consumption, which is 8.9 BTU per passenger kilometre in comparison with 275.9 BTU per passenger kilometre for diesel minibus.

Statistical analysis of energy consumption per kilometre and per passenger kilometre, represented in BTU, shows

Fig. 6 Cost per km and Cost per passenger-km

Fig. 7 Energy consumption per km and per passenger-km in BTU

that there is a significant association between modes of PT and energy consumption. The results of the one-way ANOVA are shown in Table 5. The P value for BTU per kilometre and BTU per passenger-km is less than 0.001, which shows that the alternate hypothesis may be accepted, indicating that there is an association between energy consumption and mode of PT.

3.4 Comparison of emission

The emissions from the transport sector are a major contributor to overall carbon-footprint. The emissions resulting from transport of persons can be reduced by increasing the share of public transport and reducing the dependency on private vehicles. Within various modes of public transport, the emissions are dependent on capacity and engine type of mode. This research also compares the emissions by different modes of PT in Karachi.

Actual emissions from a specific model can be accurately estimated using tailpipe emission analysis. Calibrated models exist for tailpipe emissions for different types of vehicles. However, there is no such data for the local modes of transport used in Karachi, as the emissions are affected by the type, age, maintenance and various operational parameters [47]. Due to lack of existing emission factors for local transport modes, this study estimates the emissions based on the fuel/energy consumption data collected from the survey along with standard values of emissions per unit consumption of energy [48].

The comparison of emissions for different modes of transport measured in the equivalent of CO₂ is shown in Fig. 8. Figure 8 shows a trend similar to the trend observed in Fig. 7. The emissions are directly dependant on the amount of energy produced during the combustion process. Results show that the highest emissions per passenger kilometre for travelling a unit distance are highest for the diesel-powered minibus. Similarly, CNG minibus emits the least CO₂ during transport of passengers.

The amount of emissions per passenger per km is higher in diesel and petrol-driven PT modes as compared to CNG-driven PT modes. Results show that two types of minibuses with the same transportation capacity but different fuels (diesel and CNG) have significantly different emissions. Figure 8 shows that diesel minibus emits

Fig. 8 Emission per km and per passenger-km

1.557 lb of CO₂ per km, whereas CNG minibus emits 0.0364 lb of CO₂ per km, which is around 42 times. Statistical analysis of emission per kilometre and emission per passenger-km shows a significant association between PT modes and emissions from various available modes, as indicated by results of one-way ANOVA shown in Table 6.

3.5 Introduction and comparison of BRT system

The existing public transport system in Karachi is dominated by poorly operated and informal modes. The public transport operates without enforcement of any level of service criteria (time headways, punctuality, and seat/space availability) by the authorities. No bus schedules exist for any mode and route of public transport in Karachi and the entire public transport is operated on the principle of profit maximization by their operators. This results in continuously decreasing dependency on PT and more reliance on private vehicles, which leads to unsustainable transport system [9].

Finally, authorities have realized the significance of having a proper mass transit system and five Bus Rapid Transit (BRT) routes, as suggested by JICA Japan International Cooperation Agency, are being introduced in Karachi. The routes have been named as Green Line, Orange Line, Red Line, Blue Line, and Aqua Line. The infrastructure for Green Line and Orange Line BRT routes is under construction, while the other three BRT lines are in the planning phase. Green Line has a 25 km long dedicated bus-corridor with right of way category A. This section compares the BRT

Table 5 Statistical analysis of energy consumption by different modes of PT

	Degree of freedom	F value	P value
BTU per km	4	863.598	0.000
BTU per passenger per km	4	1115.861	0.000

Table 6 Statistical analysis of energy consumption per Km with available PT modes

	Degree of freedom	F value	P value
Emission per km	4	880.12	0.000
Emission per passenger per km	4	1126.82	0.000

buses with the existing modes of PT to highlight the significance of the proposed mass transit system.

According to the official document, the fleet of buses for Green Line BRT will comprise of diesel-powered articulated buses with seating plus the standing capacity of 150 persons/bus [49, 50]. This research compares the attributes of the proposed diesel-powered bus with the existing modes of public transport. A CNG-powered articulated bus with similar capacity is also included in the analysis to compare the improvement in various operational parameters if a CNG operated bus would have been used instead of a diesel-driven bus.

The comparison of existing modes of PT with BRT is compared in Fig. 9. It shows that the BRT has a capacity of carrying 50 passengers per PCU, which is approximately twice the capacity of a bus. Thus, more passengers can be transported in comparatively lesser space with the introduction of BRT.

The data about the fuel consumption of the existing modes of PT was collected using the field survey. The fuel consumption of the proposed diesel bus is based on the data available from the official report [49, 50]. For comparative analysis, a CNG bus with similar capacity is selected. Figure 10 shows that passenger-km per litre of

fuel is comparatively higher for diesel articulated bus than the CNG articulated bus. The passenger-km per litre for diesel articulated bus is 320, whereas for diesel minibus 133 passengers are transported per litre of diesel. Similarly, passenger-km per litre for CNG articulated bus is significantly higher than CNG minibus. This shows that a significant amount of fuel can be saved by the introduction of BRT and replacing the existing PT routes with articulated buses.

The fuel cost per km of travel and fuel cost per passenger kilometre is compared in Fig. 11. It shows that the fuel cost per passenger-km is lowest for diesel articulated bus, which is PKR 0.346 PKR per passenger-km, whereas the fuel cost for CNG articulated bus is 0.39 PKR per passenger-km. This could be the main reason behind the selection of diesel buses for Green Line BRT route. Furthermore, the supply of CNG is not consistent, as it suffers from a shortage of supply and closure on certain weekdays to manage the demand. However, using CNG is significantly environmental friendly. Figure 12 compares the energy consumed per passenger-km of BRT with the existing PT modes. The amount of energy consumed by diesel articulated bus is around seven times higher than the CNG articulated bus. The energy consumed per passenger-km for diesel articulated bus is significantly lower than current PT modes on diesel and petrol. Similarly, the CO₂ emission per passenger-km is significantly lower for CNG articulated bus in comparison with diesel articulated bus.

The comparison of CO₂ emissions from existing public transport modes and the proposed articulated buses for Green Line BRT is shown in Fig. 13. All the CNG fuelled modes have significantly lower emissions in comparison with petrol and diesel-fuelled modes. Furthermore, the diesel-fuelled articulated bus has less than half CO₂ emissions per passenger-km in comparison with the diesel operated minibus. The comparison of the proposed diesel-fuelled articulated bus with the assumes CNG articulated bus shows that the emissions from CNG

Fig. 9 Comparison of BRT passenger carrying capacity with existing PT modes

Fig. 10 Comparison of fuel consumption of BRT with existing modes of PT

Fig. 11 Comparison of fuel cost of BRT with existing modes of PT **Fig. 12** Comparison of energy consumption of BRT with existing modes of PT **Fig. 13** Comparison of CO₂ emissions of BRT with existing modes of PT

articulated bus are approximately ten times less than the diesel-fuelled articulated bus. This shows that emissions from CNG fuelled articulated buses are significantly

lower and the environmental impact of Green Line BRT can be reduced by considering CNG fuelled buses.

4 Discussion

The various attributes of public transport modes available in Karachi are compared in the previous section. All the existing public transport in Karachi is operated by the private operators without any subsidies and intervention by the transport authorities. This results in a suboptimal transport system which causes more fuel consumption and emissions.

The existing literature in the evaluation of public transport modes lacks in the comparative analysis of informal modes such as minibuses and chingchi. Furthermore, the studies on CNG operated public transport modes also lack in the existing literature. This study for the first time evaluates the performance of informal modes. The summary of all the estimated parameters for available public transport modes in Karachi is shown in Table 7.

Public transport substantially reduces emission and energy consumption in comparison with private transportation. A study in the US concluded that a passenger car with one person may yield 10.62 passenger-km per lit, whereas public transport can produce 69.3 passenger-km [51]. Another comparative study in the US compared the energy and emissions efficiency of various private and public modes of transport, which

shows that in the US, the efficiency of transit buses is measured at 15 passenger-km per liter [52]. Whereas, the estimated passenger-km per unit of fuel (kg of CNG) is 168, which is more than ten times the reported value from the US. For minibus, 133 passenger-km per litre of diesel is estimated, which is around nine times higher than the reported value of the US. This significantly higher number shows that public transport buses are operated at capacity or overloaded, as the operators of these modes want to maximize their profit. The public transport operators adjust the departure frequency of buses so that the profit of buses is maximized at the cost of reliability of public transport.

The comparison of CO₂ emissions from public transport modes of Karachi is compared with reported values of emissions from other cities including Pune (India), Mexico City (Mexico), and Shanghai (China) in Table 8 [53]. Among the above-mentioned cities, three-wheeler public transport is only found in Pune, India, which is mostly operated on Liquid Petroleum Gas (LPG). Furthermore, the values for CNG operated public transport modes for these cities are also non-existent. The comparison of Karachi and Pune shows that LPG operated three-wheeler in Pune produces less CO₂ per km than petrol operated chingchi in Karachi. Whereas, the CNG operated chingchi in Karachi is more environmental friendly

Table 7 Comparison of available public transport modes in Karachi

Modes	Karachi, Pakistan (This study)			
	Pass-km/L	BTU/pass-km	CO ₂ (lb)/pass-km	Pass/PCU
Bus (CNG)	168.185	9.768	0.001143	20
Minibus (diesel)	133.276	275.9	0.44	28
Minibus (CNG)	184.58	8.9	0.00104	28
BRT/articulated bus (diesel)	320	114.91	0.0185	50
BRT/articulated bus (CNG)	266.67	16	0.00192	50
Chingchi (petrol)	127	258.18	0.041	16
Chingchi (CNGI)	144	11.40	0.00134	16

Table 8 Comparison of emission results of this study with other cities

Type of vehicle	CO ₂ pound per vehicle-kilometre				
		Karachi (This study)	Pune India [53]	Mexico [53]	Shanghai [53]
Two wheeler	Petrol	–	0.097	0.1478	0.156
Three wheeler	Petrol	0.3648	0.1565	–	–
	CNG	0.106	–	–	–
Bus	CNG	0.063	–	–	–
	Diesel	–	2.839	1.763	2.234
Minibus	CNG	0.036	–	–	–
	Diesel	1.56	–	–	–
Articulated/BRT bus	CNG	0.307	–	–	–
	Diesel	2.965	–	–	–
Car	Petrol	–	0.77	0.832	0.91

in comparison with LPG operated three-wheeler in Pune. It is also evident from Table 8 that CNG operated buses in Pakistan produce 45 times lesser CO₂ in comparison with diesel operated buses in Pune.

5 Conclusions and recommendations

This study provides a detailed comparative analysis of existing modes of public transport in Karachi. The existing public transport system of Karachi is poorly regulated and operated by the private sector without any subsidies and checks on service parameters. The poor service of public transport results in commuters shifting to private transport modes, resulting in less demand for public transport. This decrease in demand causes further depreciation in the service of public transport and this vicious goes on. A recent shift in policy to introduce a proper mass transit system in the form of BRT is expected to improve the existing situation of transport networks in one of the most populous cities of the world.

A comparative analysis of selected parameters of existing public transport modes in Karachi is presented in this study. The data about operation parameters such as route lengths, average fuel consumption, and operating frequency was collected from the operators of public transport using questionnaire-based survey technique. The data about the average number of passengers for different modes were collected using the route-check method.

The analysis of data shows that buses have the highest number of passengers per PCU among the existing modes of public transport in Karachi. This shows that more persons can be transported in less space with public transport modes of higher capacity. Results show that chingchi has the highest mileage in kilometre per unit fuel among all the existing modes, whereas CNG operated minibus leads in passenger-km per unit fuel. Similarly, the fuel cost per passenger per km is lowest for CNG operated minibus among the existing modes; whereas diesel operated minibus has the highest cost per passenger per km. The comparison of energy consumption and emissions for the existing modes of public transport shows CNG fuelled public transport consumes less energy and is more environmental friendly in comparison with petrol and diesel operated modes.

This research also evaluates the performance of proposed buses for a 25-km BRT route under construction in Karachi. The diesel-fuelled articulated buses approved by the relevant authorities are compared with the existing modes of public transport in Karachi. A hypothetical scenario is created which assumes CNG buses instead of diesel buses for Green Line BRT. The comparison shows

that CNG articulated bus consumes less energy and is significantly less polluting in comparison with diesel-fuelled articulated buses. However, the fuel cost of CNG articulated bus is slightly higher than the diesel-fuelled bus. Based on this comparative analysis, it is recommended that CNG buses should be considered for Green Line BRT project in place of the proposed diesel-fuelled articulated buses. The authorities may ensure the continuous supply of the CNG for the BRT buses to make CNG a feasible fuel for the proposed BRT, which is significantly less polluting than the diesel buses.

This study can be used by the authorities to analyse the performance of existing modes and prioritize the PT modes for future planning. The estimation of emissions in this study is based on the fuel consumption data acquired from the operators of various existing modes. However, the actual emissions may vary depending on the type, life, maintenance and driving behaviour of drivers. The estimates of the emissions in this study can be further improved by measuring tail-pipe emissions from various existing public transport modes, which could be an interesting extension of this work.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval Authors confirm that this research survey complies with the ethical standards and it was approved by NED University Ethical Review Committee (ERC). The ERC policy document is available at the following link: <https://www.neduet.edu.pk/policies/EthicalPolicy.pdf>. The standards of NED University ERC are in alignment with national and international guidelines. The data has been recorded and analysed anonymously.

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