تقييم الإستدامة لوسائل النقل الحضرية الحديثة ودورها في الحد من انبعاث غازات الإحتباس الحراري: دراسة حالة للمترو باص في لاهور

¹سيد عمران حسين شاه، ²راب نواز، ³سجاد أحمد، ⁴محمد أرشد، ⁵رابية ناصر، ⁵محمد ياسين،
²صبيحة جافيد، ²محمد عاطف إرشاد

¹قسم الإدارة البيئية، الكلية الوطنية لإدارة الأعمال والاقتصاد، لاهور، باكستان

²قسم العلوم البيئية، جامعة لاهور، لاهور، باكستان

³قسم العلوم البيئية، معهد كومسات لتكنولوجيا المعلومات، حرم فيهاري، باكستان

⁴قسم الزراعة وتكنولوجيا الأغذية، كلية العلوم الحياتية، جامعة كاراكورام الدولية، جيلجيت، باكستان

⁵مركز البحوث في حفظ الجبال، جامعة البنجاب، لاهور، باكستان

الملخص

تغير المناخ يؤدي إلى ارتفاع تدريجي في درجة حرارة كوكبنا. وتُعتبر غازات الإحتباس الحراري السبب وراء هذه الظاهرة. يحدد الجزء الأول من هذه الدراسة مقدار انخفاض غازات الإحتباس الحراري المنبعثة وذلك بواسطة تحويل نظام النقل في لاهور من الشاحنات، الحافلات، السيارات ذات الثلاث عجلات والدراجات النارية وأنواع المركبات الآلية الأخرى إلى المتروباص. علاوة على ذلك، تُقَيَّم الدراسة استدامة المترو باص في لاهور من خلال مجموعة من المؤشرات المحددة. تم إجراء مسح لتصنيف المسافرين وفقاً لأنماط سفرهم ومسافة السفر قبل استخدام المترو باص. تم جمع المعلومات بما في ذلك نوع الوقود وعدد الأميال المقطوعة ومتوسط سعة المركبات للركاب لتقدير حجم غازات الإحتباس الحراري المنبعثة. وكانت الكميات الصافية من ثاني أكسيد الكربون وغاز الميثان وأكسيد النيتروز التي تم تجنبها هي 14242.66 و 159.68 و 632.03 طن على التوالي. وكان إجمالي مقدار غازات الإحتباس الحراري السنوية التي تم تجنبها بعد استعمال المترو باص هي 15034.38 طن (أي بنسبة 59.25%). وجدنا أن الإنبعاثات السنوية من غازات الإحتباس الحراري لكل مسافر / الكيلومتر هي 1.06 كجم بواسطة المترو باص. بينما كان مقدار الإنبعاث هو 4.41 كجم بواسطة المركبات الخرى قبل استخدام المترو باص. وانخفض إجمالي الوقود المستهلك سنوياً بمقدار 6574.52 كيلو لتر. ويشير ذلك إلى توفر استدامة كبيرة مرتبطة بشكل عام مع مترو باص لاهور من النواحي الاجتماعية والاقتصادية والثقافية والبيئية. ومع ذلك، هناك حاجة إلى تحويل مصدر الطاقة لحافلة المترو من الوقود الأحفوري إلى الطاقة المتجددة للتخفيف من العوامل التي تؤدي إلى تغير المناخ وللحفاظ على التنمية المستدامة. علاوة على ذلك، تمت مصادفة بعض المشاكل التي تتعلق بإدارة الكوارث بسبب عدم وجود خطة/ مخرج للطوارئ ولعدم توفر معدات لمكافحة الحرائق على الوجه الأمثل. من شأن الإدارة الفعالة لحركة المرور ومواقف السيارات إلى جانب التخطيط المناسب لتعزيز وسائل نقل بديلة للسيارات الخاصة أن تضمن مستويات كافية من السلامة على الطرق والتنقل المستدام داخل المنطقة الحضرية.

Sustainability assessment of modern urban transport and its role in the reduction of greenhouse gas emissions: A case study of Metro Bus System (MBS), Lahore

Syed Imran Hussain Shah[1], Rab Nawaz[2,*], Sajjad Ahmad[3], Muhammad Arshad[4], Rabiya Nasir[2],
Muhammad Yaseen[5], Sabiha-Javied[2], Muhammad Atif Irshad[2]

[1]*Dept. of Environmental Management, National College of Business Administration and Economics (NCBA&E), Lahore, Pakistan*

[2]*Dept. of Environmental Sciences, The University of Lahore, Lahore, Pakistan*

[3]*Dept. of Environmental Sciences, COMSATS Institute of Information Technology, Vehari Campus, Pakistan*

[4]*Dept. of Agriculture and Food Technology, Faculty of Life Sciences, Karakoram International University (KIU), Gilgit, Pakistan*

[5]*Centre for Research in Mountain Conservation, University of the Punjab, Lahore, Pakistan*

*Corresponding author: rnuaf@yahoo.com

Abstract

Increasing atmospheric greenhouse gasses (GHGs) is a major cause of rising global temperatures. The first part of this study quantifies emission reduction of greenhouse gases by shifting the mode of transport from vehicles including vans, buses, 3-wheelers and motorcycles to Metro Bus System (MBS), Lahore.. Secondly, the study assesses the sustainability of MBS through a set of specific indicators. A survey was conducted to categorize the passengers according to their modes of transportation and travel distance before the metro bus. Fuel type, mileage and average passenger capacity of vehicles information was collected in order to estimate the levels of GHG emissions. The net reduction of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) was 14242.66, 159.68 and 632.03 tonnes CO_2-e, respectively. The total annual reduction of GHGs was 15034.38 metric tons CO_2-e (59.25%) by MBS project. The annual emissions of GHGs per passenger kilometer were 1.06 kg CO_2-e by MBS. Before the MBS, this value was 4.41 kg CO_2-e for different vehicles. The total annual fuel reduction was 6574.52 kL (kiloliters). Significant social, economic, cultural, and environmental sustainability can generally be associated with the implementation of MBS, Lahore. However, MBS should transition to renewable fuel for climate change mitigation and sustainable development. In addition, disaster management problems exist due to a lack of emergency plans/routes and the poor condition of firefighting equipment. Officials must improve traffic flow and parking while promoting alternatives to personal vehicle use. In so doing, sustainability will increase safety and livability in the urban environment.

Keyword: Climate change mitigation ; GHGs reduction; sustainable development; sustainable mobility.

1. Introduction

The transport sector is the fastest growing energy-dependent sector that contributes to increased greenhouse gas (GHG) emissions. Around 15% of the total global emissions of GHGs and 23% of total CO_2 emissions are emitted by the transport sector (WRI, 2017). Combustion of fossil fuels accounts for 30% of CO_2 emissions. Passenger cars use the most energy in the transport sector, 80% (Sims *et. al.* 2014; OECD 2010; Ribeiro *et. al.* 2007). Public transport has become the backbone of mobility in urban areas, making it a worldwide focus of policymakers in major metropolises. Some cities such as Hamburg and Oslo have recently announced their plans to become (partly) private car free. This will reduce emissions of GHG, air pollution and noise pollution (Nieuwenhuijsen & Khreis).

Growing cities in Asia have been experiencing urbanization and rapid economic development since the latter half of the 20th century. Urban growth coupled with a rising middle class has increased personal vehicle ownership. As a result, more individuals are driving into the city. This development has caused a number of issues. First is the increased use of fossil fuels and increased emissions (Nawazish *et. al., 2017*). Second, roadways have

not been expanded in relation to the increase in number of cars, resulting in more traffic jams and congestion. In addition, traffic accidents have increased. All of these contribute to a decline in urban livability (Milam, et al. 2017). Increased fossil fuel consumption relates to positive economic growth. However, the higher usage of coal, gas, and oil (by power plants, factories, homes, and vehicles (has resulted in more CO_2 emissions, the most prominent GHG. It is now largely accepted as fact that economic development, urbanization and population growth are the major driving forces behind increased energy demand (World Energy Council, 2016).

Increased GHGs are severely affecting Earth's environment. Pakistan is a very small contributor to the greenhouse effect and is ranked 135 among the countries of the world on the basis of per capita GHG emissions (GOP 2010). Lahore is one of metropolitan cities of Pakistan that is experiencing rapid urbanization with a population growth rate of 2% per annum (WPR, 2017). The current climate change scenario is a major obstruction to its future development. Proactive steps are needed to mitigate the local effects posed by climate change. Cities are responsible for 70% of the global GHG emissions from burning fossil fuels. There is need of new scientific and technological research, and adaptation of existing knowledge and technologies to specific local and regional contexts for sustainable development goals (UN, 2019).

Currently, it is not possible to establish perfect sustainable transport system with zero emissions and impacts (Sweeting & Winfield, 2012). However, it has been agreed that the international community must make efforts to reduce GHG emissions. Following this agreement, many countries have established goals for emission reduction. The present study was conducted to assess the role of Metro Bus Lahore on climate change mitigation and in achieving sustainable transport.

2. Methodology

2.1 Description of study area

Being among the world's fastest growing cities and ranked as the 34th most populated city, Lahore is home to around 10 million residents. It is the capital of Punjab province. Many historians are of the view that Lahore was built by Hindu Rajas in the earlier second century and is one of the ancient cities in the sub-continent. It is considered a major historic and cultural center of the Punjab region.

The metropolitan city lies between 31.5546° N, 74.3572° E, and is elevated 217m above sea level. Like most other cities in Pakistan, Lahore has a semi-arid climate. Maximum rainfall is recorded during the monsoon months from July through August (Qamar *et. al.*, 2009).

2.2 Metro Bus System (MBS), Lahore

The MBS is a modern transport system in Lahore, Pakistan. It comprises a 27-km long course with 29 transport stations between Gajumata and Shahdara. The route system covers numerous private and business neighborhoods near the city's fundamental routes, i.e., Ferozepur Street, connecting Lytton Street, Jain Mandir, MAO College, Lower Mall, Civil Secretariat, District Courts, the Shrine of Hazrat Data Ganj Bakhsh, Ravi Road, and Shahdra Town. About 8 kilometers of the network is raised. The system utilizes e-ticketing and Intelligent Transportation System (Sheikh, 2014).

2.3 Data collection

2.3.1 Primary data

A questionnaire was given to passengers of MBS. Sample size for the social survey was calculated using the formula from Yamane (1967):

$$n = \frac{N}{1+N(e)^2}, \qquad (1)$$

where, *n* is sample size, *N* is finite population size, and *e* is precision (i.e. 5%). Using a population size of 180,000, a sample size of 399 was calculated. The objective was to categorize passengers into different groups on the basis of their traveling mode prior to the implementation of MBS (Table 1).

Table 1. Mode of transportation before Metro Bus

Sr. No.	Mode of Transport	Passenger	
		Number	%
1	Motorcycle	76	19.048
2	Auto	52	13.033
3	Rickshaw(3-wheeler)	95	23.810
4	Van	103	25.815
5	Bus	73	18.296
	Total	399	100.000

Data were collected from passengers traveling by metro bus. The survey asked passengers how they traveled before the bus system started.

2.3.2 Secondary Data

Secondary data were collected from the Punjab Metro Bus Authority, Lahore. The data included the number of operational buses, number of trips per bus per year, fuel consumption per trip, and the total number of passengers per year.

An interview of drivers was also conducted in order to get information regarding fuel type, mileage and number of passengers in different vehicles (motorcycles, autos, rickshaws, vans, and bus). The information was used to estimate the GHG emissions from different vehicles.

2.4 Estimation of GHG emissions from fuel combustion

The following formula was used to estimate GHG emissions from the combustion of each type of fuel used for transport energy purposes (DEE, 2014):

$$E_{ij} = \frac{Q_i \times EC_i \times EF_{ijoxec}}{1000}. \qquad (2)$$

For this equation, E_{ij} is the emission of gas type (j), CO_2, CH_4 or N_2O, from fuel type (i) (CO_2-e metric tons). Q_i is the quantity of fuel type (i) (kiloliters, kL) combusted for transport energy purposes. EC_i is the energy content factor of fuel type (i) (gigajoules per kiloliter, (GJ/kL)) used for transport energy purposes. EF_{ijoxec} is the emission factor for each gas type (j) (and which includes the effect of the anoxidation factor) for the fuel type (i) (kilograms CO_2-e per GJ) used for transport energy purposes.

2.4.1 Quantity of fuel

The quantity of fuel for metro bus and different vehicles was calculated using the following equations:

Fuel quantity used by different vehicles:

$$Quantity\ of\ Fuel\ (kL) =$$

$$\frac{Route\ Distance\ (km) \times No.of\ Vehicles}{Mileage\ (km/L) \times 1000} \qquad (3)$$

Fuel quantity used by Metro Bus:

Fuel quantity by metro bus was calculated using number of buses, their trips and fuel consumption per trip.

The required number of vehicles was calculated as

$$No.of\ Vehicles = \frac{Total\ No.of\ Passengers}{Average\ Capacity\ per\ Vehicle} \qquad (4)$$

The total number of passengers for different vehicle types was calculated using the percent data for different vehicles from the questionnaire.

2.5 Energy content and emissions factor

Energy content and emissions factors for diesel and gasoline are given in Table 2.

Table 2. Energy contents and emission factors for diesel fuel and gasoline

Fuel Type	Energy Content Factor, EC (GJ/kL)	Emissions Factor, EF (kg CO₂-e/GJ)		
		CO_2	CH_4	N_2O
Gasoline	34.2	66.7	0.6	2.3
Diesel	38.6	69.2	0.2	0.5

Source: Modified from DEE (2014)

2.6 Sustainability assessment of transport

There are different indicators of sustainability. These indicators can be applied to the evaluation of the sustainability of transport (UN, 2019). Indicators are given for:

- Environmental sustainability
- Social sustainability
- Economic sustainability
- Cultural sustainability
- Governance and planning
- Public health and safety

Using these indicators, data were collected through the survey and observations. The survey method used was self-administered and closed ended. The formula (Eq. 1) was used to calculate the sample size. Passengers were grouped by their mode of transportation in the absence of metro bus service. The results of the survey were applied to all the passengers travelling in Metro Bus.

Data from the sustainability questionnaire was analyzed by t-test and one-way ANOVA using the Statistical Package for Social Science (SPSS).

3. Results and discussion

3.1 Emissions of greenhouse gases by different vehicles

The figures were based not only on the type of vehicle but also on the fuel type and number of passenger. Other factors, like vehicle condition and maintenance, were considered by average mileage of the vehicles.

3.1.1 Carbon dioxide (CO_2): Figure 1 shows the annual emissions of CO_2 from motorcycles, autos, rickshaws, vans and buses. The highest amount of CO_2 was emitted by motorcycles (8326.16 metric tons/year) followed by buses (5067.50 metric tons/year). High emissions from motorcycles may be due to the large number of them in the city and they have two-stroke engines. High emissions by buses might be due to congested and mixed roads and slow driving speed in urban areas (Baidya & Borken-Kleefeld, 2009). The amount of CO_2 emitted by rickshaws is 2792.63 metric tons/year, while the total amount of CO_2 emitted by vans is 3996.39 metric tons/year. The total amount of CO_2 emitted by autos is 4297.05 metric tons/year. Although all modes of transportation in Lahore are major sources of carbon emissions, motorcycles seemed to be the biggest hazard for both human health and the environment. Another cause of higher levels of emissions from all transport types may relate to little control of vehicle emissions and a lack of effective inspection and maintenance systems (Hayashi *et. al.*, 2004).

3.1.2 Methane (CH_4): Figure 1 shows the annual emissions of CH_4 from motorcycles, autos, rickshaws, vans and buses. The highest amount of CH_4 is emitted by motorcycles (74.90 metric tons/year) followed by autos (38.65 metric tons/year). The amount of CH_4 emitted by rickshaws is 25.12 metric tons/year. The total amount of

CH_4 emitted by vans is 35.95 metric tons/year. The total amount of CH_4 emitted by buses is 14.65 metric tons/year. Higher emission levels for some modes of transport may result from poor vehicle emissions control and/or a lack of effective inspection and maintenance systems (Hayashi *et. al.*, 2004). Comparatively, buses show the lowest CH_4 emission levels in Lahore.

3.1.3 Nitrous oxide (N_2O): Figure 1 shows the annual emissions of N_2O from motorcycles, autos, rickshaws, vans and buses. The highest amount of N_2O is emitted by motorcycles with a maximum of 287.11 metric tons/year. Automobiles followed with 148.17 metric tons/year. The total amount of N_2O emitted by vans is 137.81 metric tons/year. The amount of N_2O emitted by rickshaw is 96.3 metric tons/year. The total amount of N_2O emitted by buses is 36.61 metric tons/year.

3.1.4 Greenhouse gases: Figure 1 compares the annual emissions of greenhouse gases to the different modes of transport in Lahore. The highest amount of GHGs was emitted by motorcycles (8688.17 metric tons/year) followed by buses (5118.76 metric tons/year). The high emissions recorded by motorcycles is due to their large number in the city (Hassani & Hosseini, 2016). The relatively high emissions by buses can be attributed to low mileage and congestion on the roads (Milam, et al. 2017). The amount of GHGs emitted by rickshaws was 2914.04 metric tons/year.

This research was based on an estimation of GHG emissions from different vehicles used by passengers traveling in metro bus (180,000). This study does not represent 100% of total emissions before the MBS. After launching the metro bus, the number of vehicles decreased as more individuals began to ride the public transportation system. The metro bus did not completely replace any other transport system. Table 1 shows the survey results from passengers travelling by bus.
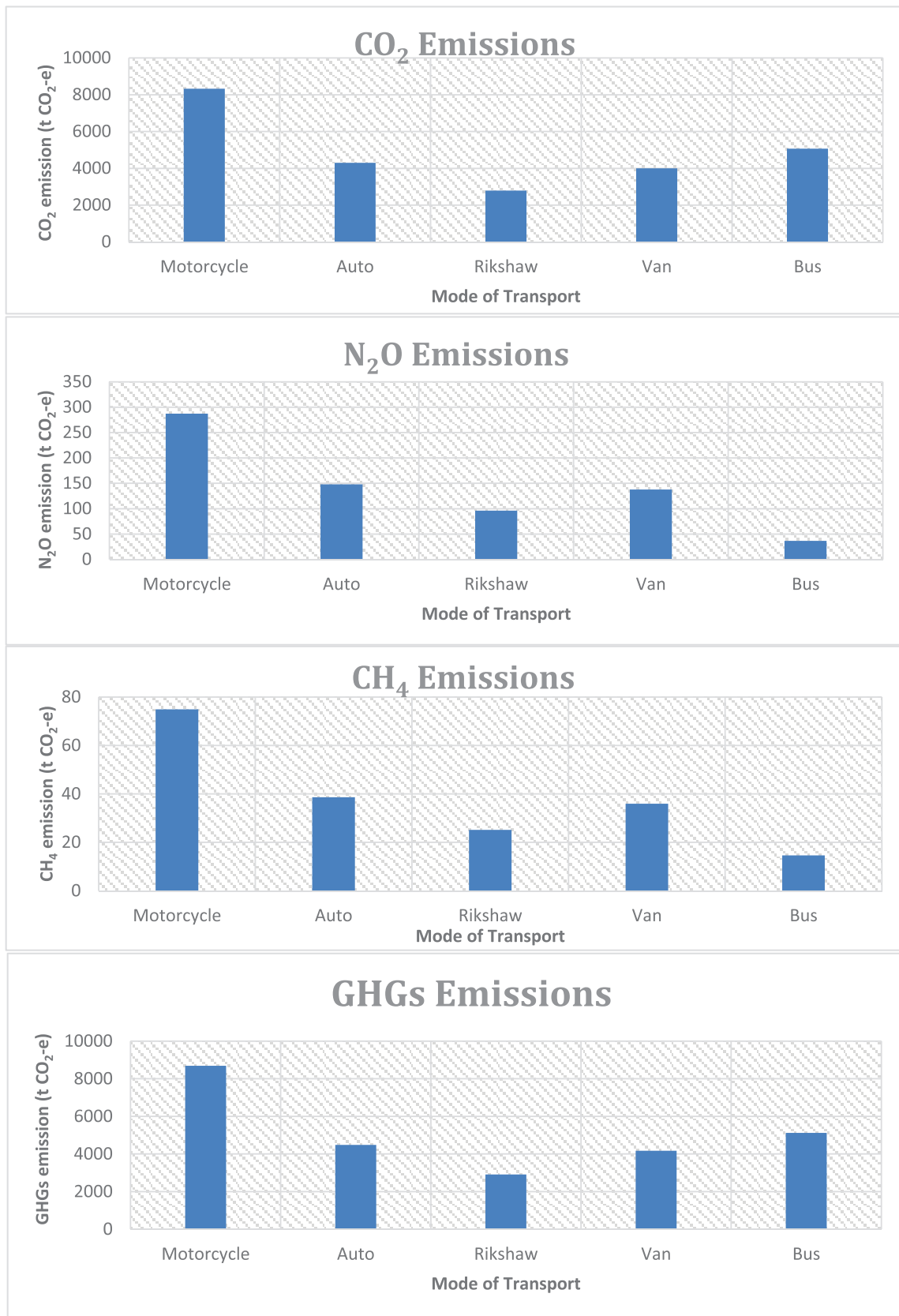
Fig. 1. Annual emission of greenhouse gases by different types of vehicles.

The total amount of GHGs emitted by vans was 4170.15 metric tons/year. In addition, the total amount of GHGs emitted by autos is 4483.88 metric tons/year. The figures show that all modes of transportation in the Lahore metropolitan area emit high levels of harmful GHG, but motorcycles are the biggest hazard for environmental and public health.

Figure 2 depicts the total annual emissions of GHGs in percent from different vehicles on the Lahore bus system. CO_2 (96%) was the most prevalent of all the GHGs.
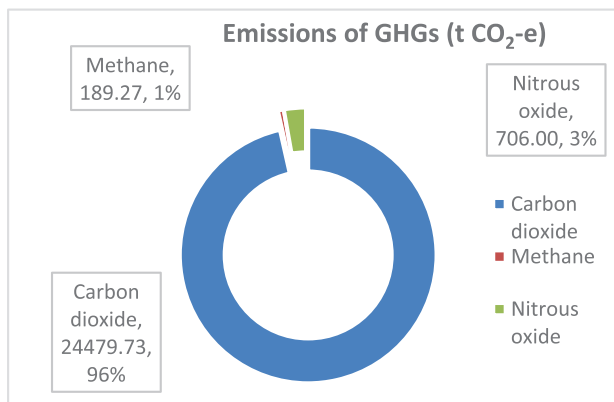

Fig. 2. Annual emissions of greenhouse gases from different vehicles.

The total annual emissions of CO_2 from different vehicles were 2470.73 metric tons/year. On the other hand, the annual emissions of N_2O and CH_4 are 706 metric tons/year (3%) and 189.27 metric tons/year (1%), respectively.

3.2 Comparison of GHGs emissions from MBS and other vehicles

Figure 3 compares the annual emissions of all GHGs (CO_2, CH_4 and N_2O) from different vehicles to the emissions of GHGs by the MBS. The annual emissions of CO_2 by MBS was estimated at 10237.07 metric tons/years. Figure 3 clearly demonstrates that the annual emissions of CO_2 would have been around 24,479.73 metric tons/year (twofold higher) had there been no MBS servicing the Lahore area. It is clear that transportation by MBS has significantly lowered CO_2 emissions than all other modes of transport. The results show a reduction in the annual emissions of CO_2 by 58.18 % (14,242.66 metric tons/year) with the introduction of MBS. The CO_2 reduction is a result of less cars, vans, rickshaws and motorcycles on the roads. Reducing CO_2 emissions helps mitigate climate change.

Figure 3 also shows the annual emissions of CH_4 gas by metro bus. It was estimated at 29.59 metric tons/year. The annual CH_4 emissions would have been around 189.27 metric tons/year in the absence of MBS. It is clear that metro bus services have significantly lowered CH_4 emissions more than all other modes of transportation. There was an 84.37% reduction (159.68 metric tons/year) in the annual emissions of CH_4 through the launch of the metro bus system service in Lahore. Bus service reduces CH4 gas emissions to a reasonable level, which can improve air quality in the city and lessen climate change impacts.

Figure 3 also compares the annual emissions for N_2O from different vehicles to the emissions from MBS. The annual N_2O emissions from MBS were estimated as 73.97 metric tons. The annual emissions of N_2O would have been around 706 metric tons/year in the absence of MBS. Metro bus service has significantly lowered N_2O emissions more than all other modes of transportation. There is a reduction in the annual emissions of N_2O by around 632.03 metric tons/year (89.52%) with the launching of the metro bus system service in Lahore. As more passengers use the buses, N_2O emissions are significantly reduced.

The annual emissions of GHGs by metro bus were calculated as 10340.62 metric tons. The annual emissions of CO_2 would have been around 25,375 metric tons without bus service. Transportation by metro bus has significantly lowered CO_2 emissions more than all other modes of transport. There was a reduction in the annual emissions of CO_2 by 59.25% (15034.38 metric tons) with the introduction of Metro Bus Lahore. Such public transport reduces the use of individual transportation. Shapiro *et. al.* (2002) conducted a comparative study and found that public transport produces 45% less CO_2, 48% less NO_2 and 95% less CO as compared to private vehicles.
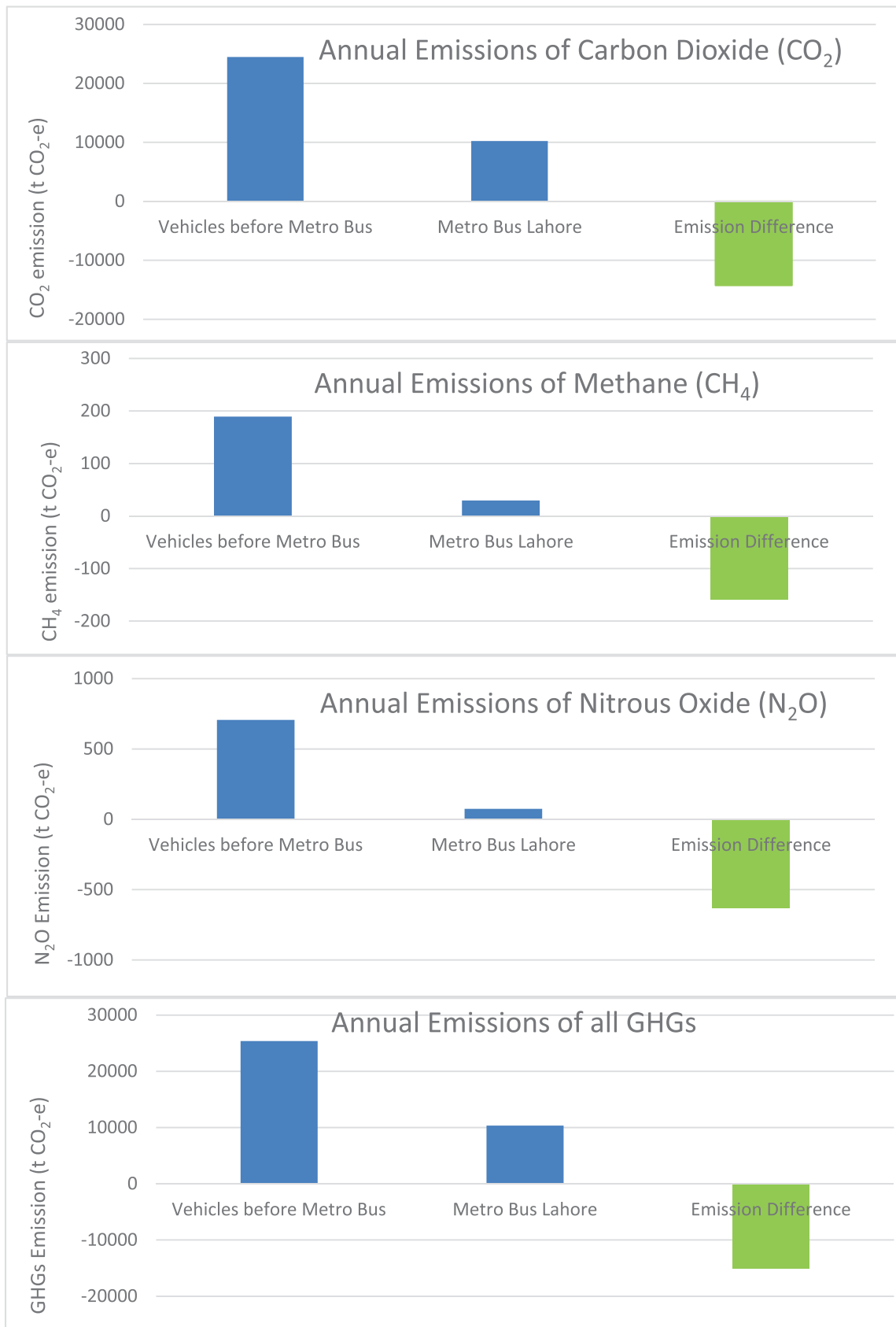
Fig. 3. Comparison of GHG emissions between metro bus and different vehicles.

3.3 Reduction of GHGs emissions by Metro Bus

Table 3 compares the annual per passenger emissions of greenhouse gases by different vehicles to emissions by MBS. The annual emissions of greenhouse gases from MBS were estimated as 57.45 kg CO_2-e. The annual per passenger emissions of greenhouse gases would have been around 151.54 kg CO_2-e in the absence of metro bus Lahore. Clearly, metro bus use by citizens significantly lowered the emissions of greenhouse gases per capita than all other modes of transportation. There is a reduction in the annual per capita emissions of greenhouse gases by 94.1 kg CO_2-e (62.09%) with the inception of the metro bus system in Lahore. In addition, 75.94% of the annual GHG emissions per passenger

kilometer has been reduced by the Lahore metro bus project from 4.41 to 1.06 kg CO_2-e. The reduction in per passenger kilometer emissions of GHGs might be helpful in mitigating the impacts of climate change. This significant reduction in per passenger emissions of GHGs is due to lower fuel consumption. MBS consumed 63.17% less fossil fuel (3832.5 kL) as compared to other vehicles (10407.02 kL).

Although the MBS has significantly reduced GHG emissions, the use of fossil fuels makes the program less sustainable. Therefore, there is a need to transition the urban transport system to a sustainable one by using renewable energy (DECC, 2014; EC, 2011).

Table 3. Comparison of the annual per person GHG emissions and fuel consumption by metro bus and different vehicles

	Annual GHG Emissions (t CO_2-e)		Annual GHG Emissions Reduction	
	Different Vehicles	Metro Bus Lahore	t CO_2-e	%
Carbon dioxide	24479.73	10237.07	14242.66	58.18
Methane	189.27	29.59	159.68	84.37
Nitrous oxide	706.00	73.97	632.03	89.52
Total GHGs	25375.00	10340.62	15034.38	59.25
	Annual GHG Emissions (kg CO_2-e)		**Annual GHG Emissions Reduction**	
	Different Vehicles	Metro Bus Lahore	kg CO_2-e	%
Per passenger	151.54	57.45	94.10	62.09
Per passenger kilometer	4.41	1.06	3.35	75.94
	Annual Fuel Consumption		**Annual Fuel Reduction**	
	Different Vehicles	Metro Bus Lahore	Fuel	%
Total Fuel (kL)	10407.02	3832.50	6574.52	63.17
Per passenger Fuel (L)	57.82	21.29	36.53	63.17
Per passenger Km Fuel (L)	1.68	0.39	1.29	76.63

Table 4. Emission reductions by passenger transports

Transport Project	Emission Reductions (t CO_2)	Reference
RENFE-Spain	2,460,488/year	RENFE, 2008
Lisbon Metro-Portugal	130,275/year	Lisbon Metro, 2010
Porto Metro-Portugal	46,996/year	Porto Metro, 2013
Lahore Metro Bus	15,034/year	Present Study

3.4 Sustainability assessment

As mentioned, the sustainability assessment was carried out through a survey of passengers riding the Lahore Metro Bus. Some indicators were evaluated through site visits and personal observations.

3.4.1 Environmental sustainability

According to the data in Figure 4, a large number of people were satisfied with the positive impact of MBS on the environment. The majority of them agreed with the prospect of less air, water and noise pollution. They were in agreement with increased habitat protection, noise pollution reduction, lowering solid waste generation, lowering land use and reducing fossil fuel consumption. Air and noise pollution should be minimized to achieve environmental sustainability (Bahadure & Kotharkar, 2015). However, a small number of people still think that MBS is not an environmentally friendly service in Lahore. In addition, less than half of the respondents had a neutral opinion on the environmental sustainability of the metro bus, while the number of people who strongly disagree was significantly smaller and negligible.

3.4.2 Social sustainability

Figure 5 shows the results from the social sustainability questionnaire. The findings clearly demonstrate the huge *positive* impact on the general public. Most people are of the view that the use of metro bus is extraordinarily beneficial when it comes to community livability, satisfaction and comfort, reliability, traffic crime rates, traffic casualties, and health and fitness. However, despite an overwhelming response from the general population, a negligible number of respondents still disagree that the metro bus will improve social sustainability. A small number of people had a neutral opinion on the matter.

3.4.3 Economic sustainability

Figure 6 illustrates the economic sustainability of metro bus. The majority of survey respondents strongly agreed that the system offers low-cost travel and a reduced commute time. It also lowers congestion delays and manages mobility. Many respondents strongly agreed with land use planning, transport diversity at stations, educational institutional accessibility, and employment accessibility. However, more than 150 people strongly disagreed with electronic communication. This indicates the poor Internet (3G & 4G) and cellular services at Metro Bus stations. Meanwhile, most of them had a neutral opinion on transport diversity, electronic communication at stations, employment accessibility and land use planning. In general, this results imply that the majority of people travelling by MBS are satisfied in terms of economic sustainability.

The economic growth of developing cities depends on road-based transport. Buses are often the only means to access public services, education and employment. As the majority of people have limited access to automobiles in developing cities, these destinations are beyond feasible cycling or walking distances. Bus services in developing cities are often uncomfortable, unreliable, inconvenient, or even dangerous (Pojani & Stead, 2015). Economic indicators recommended by Zheng *et al.* (2011) include affordability, mobility, finance, equity and resilience to economic fluctuations.

3.4.4 Cultural sustainability

Figure 7 shows the results of the cultural sustainability portion of the survey conducted on the metro bus. Results show that riders believe that the metro bus has a positive impact on tourism, as it improves access to historical sites, and community livability. Public opinion is that modern

urban transport enhances visits to touristic and historical sites, such as the Badshahi Mosque, Lahore Fort, Lahore Museum, Minar-e-Pakistan, and Data Darbar. The high scores of "strongly agree" for positive impacts on tourism, access to historical sites, and community livability indicate that residents are satisfied.

3.4.5 Governance and planning

Figure 8 shows the survey results regarding governance and planning. The majority of the respondents strongly agree that the metro bus has efficient pricing. Many respondents had neutral opinions about public engagement in planning decisions and the availability of information and documents of the project to the public.

Important public transport attributes include service reliability and frequency. Fare promotions and habit-

interrupting measures can be useful in changing travel behavior and attracting car users (Redman *et al.*, 2013). Sustainability can be achieved by encouraging public transport. The transport system of Singapore is a good reference for other countries of the world (Haque, 2013).

3.4.6 Public health and safety

Table 5 shows the level of different practices for public health, safety and environment at the project site. These results are based on site visits and personal observations. There was excellent management of solid waste. Sanitation services and training of employees were also ranked as "good". However, satisfactory and poor scores were given to fire extinguisher availability and an emergency exit plan, respectively. These results could cause problems in cases of disaster management.
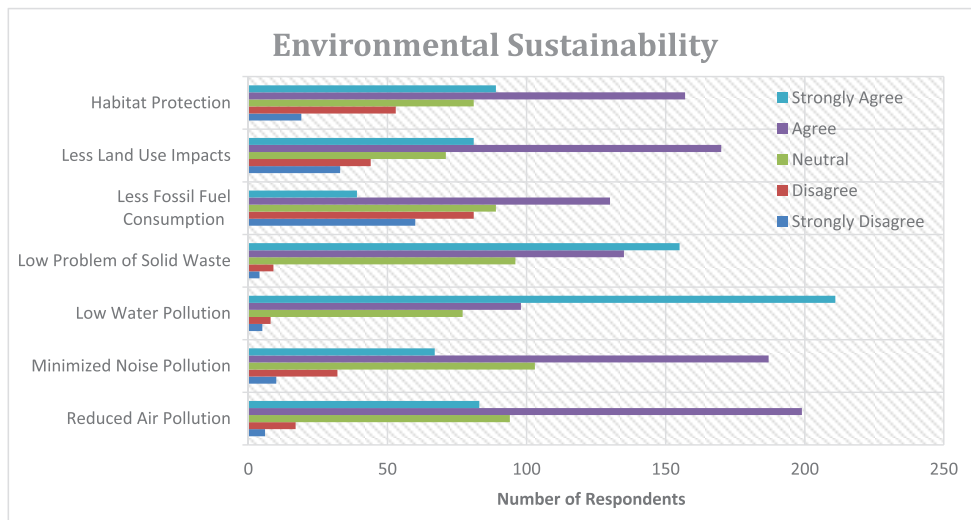

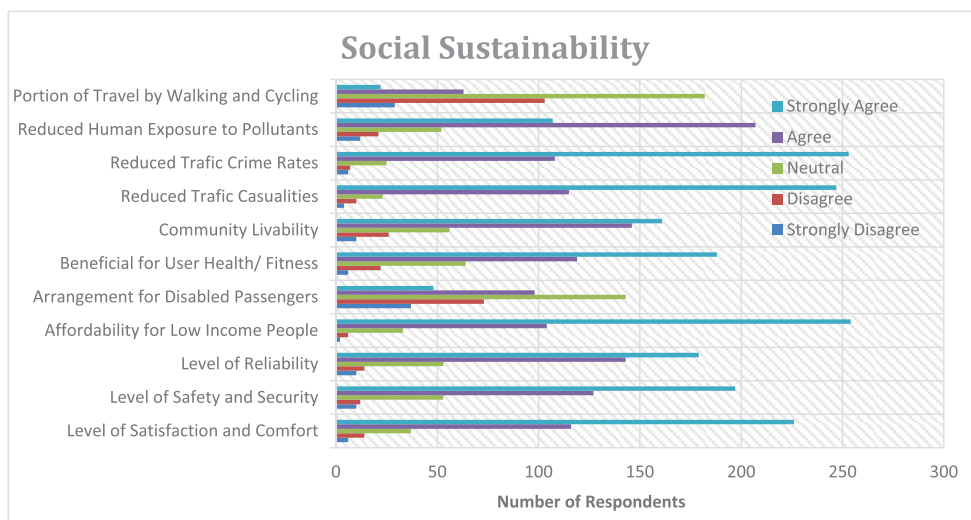**Fig. 4.** Response of passengers to different parameters of environmental sustainability.

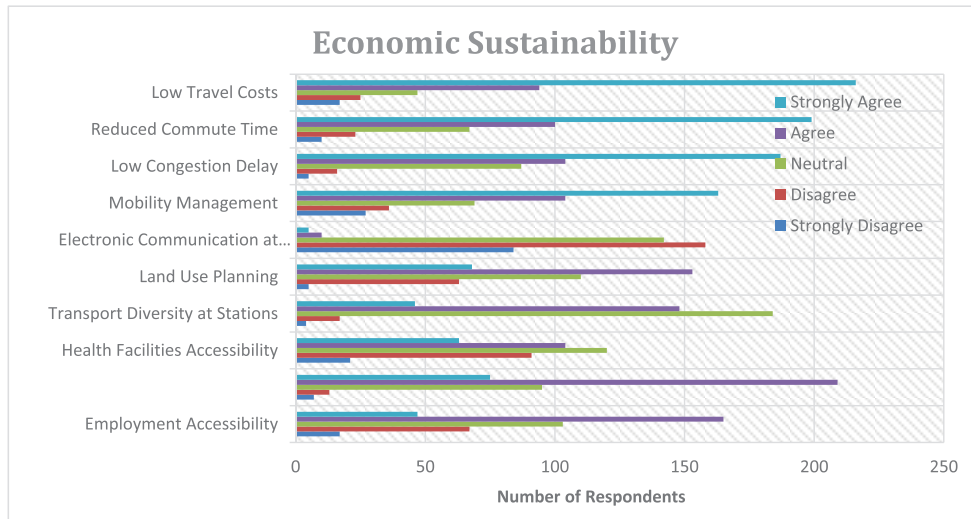**Fig. 5.** Response of passengers to different parameters of social sustainability.

Fig. 6. Response of passengers to different parameters of economic sustainability.
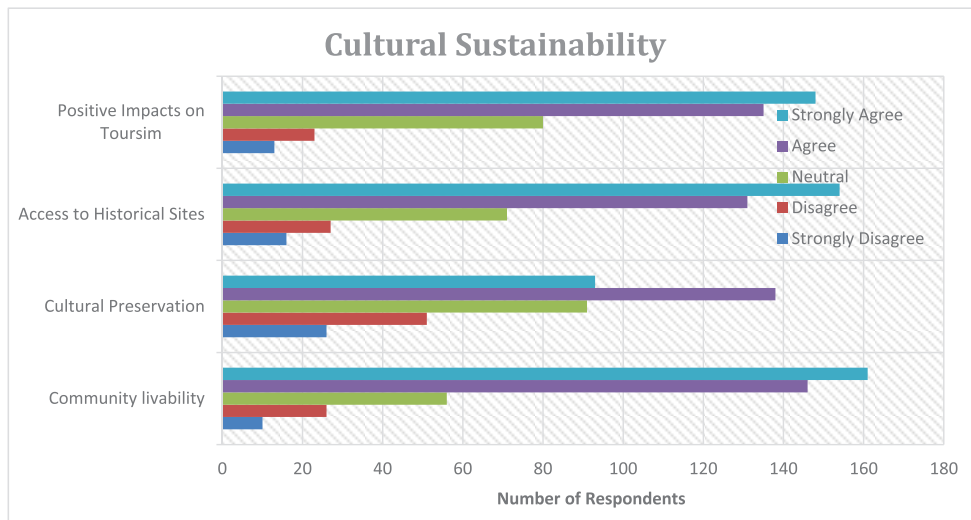

Fig. 7. Response of passengers to different parameters of cultural sustainability.
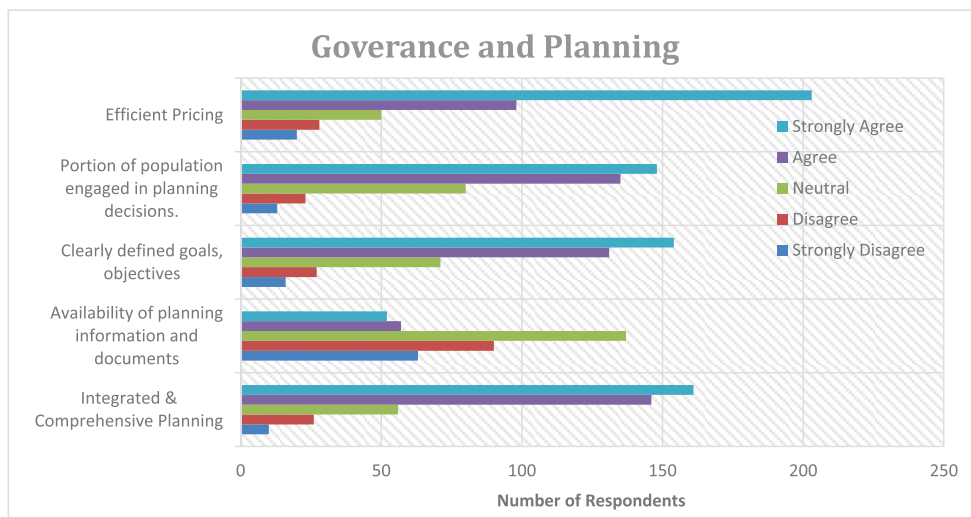

Fig. 8. Response of passengers to different parameters of governance and planning.

Table 5. Observations based upon results of public health and safety

	V Poor	Poor	Satisfactory	Good	Excellent
Solid Waste Management					●
Sanitation Services				●	
Fire Extinguisher			●		
Emergency Exit Plan/ Route		●			
Training to Employees				●	

Table 6. Factors associated with different elements of sustainability

Variables	Frequency (%)	Environmental Sustainability Mean (S.D)	Social Sustainability Mean (S.D)	Economical Sustainability Mean (S.D)	Cultural Sustainability Mean (S.D)	Governance & Planning Mean (S.D)
Gender						
Male	60.40	16.50 (5.73)	22.00 (7.61)	24.86 (7.92)	8.72 (3.55)	11.42 (4.48)
Female	39.60	15.30 (8.32)	21.05 (12.04)	22.70 (11.48)	8.11 (5.05)	10.60 (6.42)
		$t = 1.702$ ns (p = 0.089)	$t = 0.969$ ns (p = 0.333)	$t = 2.223$ ns (p = 0.027)	$t = 1.401$ ns (p = 0.162)	$t = 1.501$ ns (p = 0.134)
Age						
< 20	13.78	15.44 (8.54)	22.02 (12.45)	23.31 (11.82)	8.51 (5.40)	11.07 (6.83)
21-30	42.61	16.86 (6.09)	22.28 (7.89)	25.39 (8.31)	8.95 (3.72)	11.76 (4.78)
31-40	28.57	16.59 (7.34)	22.29 (10.68)	24.47 (10.16)	8.67 (4.34)	11.28 (5.48)
> 40	15.04	13.13 (5.74)	18.17 (8.34)	19.85 (8.16)	6.75 (3.71)	8.85 (4.54)
		$F = 4.888$** (p = 0.002)	$F = 3.113$ ns (p = 0.026)	$F = 5.344$*** (p = 0.001)	$F = 4.257$** (p = 0.006)	$F = 4.570$** (p = 0.004)
Education						
Illiterate	10.02	9.45 (2.14)	13.40 (1.65)	15.00 (2.38)	4.52 (0.78)	6.15 (1.12)
Primary/ Middle	6.77	12.67 (2.97)	17.00 (3.92)	19.89 (5.36)	6.67 (1.96)	8.85 (2.68)
Matric	33.33	17.52 (6.06)	23.22 (8.56)	25.84 (8.49)	9.20 (3.92)	12.07 (5.03)
Intermediate	19.80	23.40 (6.44)	31.97 (10.77)	34.70 (8.22)	13.04 (4.11)	16.68 (5.19)
Graduate/ above	30.08	12.47 (4.34)	16.83 (4.73)	18.87 (5.89)	6.41 (2.38)	8.48 (3.12)
		$F = 74.674$*** (p = 0.000)	$F = 66.743$*** (p = 0.000)	$F = 81.029$*** (p = 0.000)	$F = 69.975$*** (p = 0.000)	$F = 65.305$*** (p = 0.000)
Occupation						
Student	9.27	16.65 (8.33)	22.05 (10.25)	24.59 (10.72)	8.51 (4.87)	11.57 (6.59)
Govt. Job	10.28	13.51 (5.06)	18.37 (5.80)	20.76 (7.36)	7.10 (2.76)	9.27 (3.77)
Private Job	25.56	22.70 (6.85)	31.15 (11.22)	33.47 (9.28)	12.66 (4.50)	16.18 (5.72)

Business person	24.56	11.18 (2.90)	15.38 (3.12)	17.28 (4.38)	5.82 (1.83)	7.76 (2.31)
Unemployed	30.33	14.99 (4.65)	19.63 (5.75)	22.40 (6.47)	7.53 (2.76)	9.98 (3.40)
		F = 61.109*** (p = 0.000)	F = 60.608*** (p = 0.000)	F = 64.496*** (p = 0.000)	F = 58.495*** (p = 0.000)	F = 53.990*** (p = 0.000)

t = Independent sample t-test (used for comparison of two means)
F= one-way ANOVA (used for comparison of more than two means)
*Significant at p<0.05
**Strongly Significant at p<0.01
***Highly significant at p<0.001

Table 6 shows the statistical analysis of the questionnaire for sustainability assessment of Lahore Metro Bus. Significant results have been found for factors relating to age, education and occupation with sustainability scores. High scores were found for qualified respondents for all elements of sustainability. Students and private job holders also showed very high scores for all components of sustainability.

4. Conclusions

This study investigated GHG emissions for the city of Lahore. A comparative analysis is given to show the impact of the Metro Bus System, Lahore and its effects on GHG levels. The total annual reduction of GHGs was 15034.38 metric tons CO_2-e (59.25%) with the launch of the Metro Bus Project. The annual emissions of GHGs per passenger kilometer were reduced to 1.06 kg CO_2-e by metro bus compared to 4.41 kg CO_2-e from all other vehicles. The survey suggests that the Metro Bus Lahore has average sustainability in terms of social, economic and environmental sustainability. Therefore, the metro bus system should transition from fossil fuels to renewable energy to mitigate climate changes and ensure further sustainable development. Furthermore, some problems were encountered regarding disaster management, such as a lack of emergency exit routes and the poor firefighting equipment. Recent investigations reveal that effective traffic and parking management coupled with appropriate planning by relevant authorities for the promotion of alternative to private car means would ensure adequate levels of road safety and sustainable mobility within the urban area (Perra *et. al.*, 2017).

References

Bahadure, S. & Kotharkar, R. (2015). Assessing sustainability of mixed-use neighbourhoods through residents' travel behaviour and perception: The case of Nagpur, India. Sustainability, **7**(9): 12164-12189.

Baidya, S., & Borken-Kleefeld, J. (2009). Atmospheric emissions from road transportation in India. Energy Policy, **37**(10): 3812-3822.

Department of Energy and Climate Change. (DECC). (2014). A review of data and methods to calculate greenhouse gas emissions from alternative fuel. Transport Final Report. DECC, London, UK, Pp. 42.

Department of the Environment and Energy. (DEE). (2014). National Greenhouse Accounts Factors. Australian Government, Canberra, Australia (Pp.16-17).

European Commission. (EC). (2011). Roadmap to a single European transport area, No. COM 144 Final. European Commission, Brussels, Pp. 1-31.

Hassani A., & Hosseini, V. (2016). An assessment of gasoline motorcycle emissions performance and understanding their contribution to Tehran air pollution. Transportation Research Part D: Transport and Environment, 47: 1-12.Haque, M. M., Chin, H. C., & Debnath, A.K. (2013). Sustainable, safe, smart—Three key elements of Singapore's evolving transport policies. Transport Policy, **27:** 20–31.

Hayashi, Y., Doi K., Yagishita, M. & Kuwata, M. (2004). Urban transport sustainability: Asian trends, problems and policy practices. Proceedings of the International Conference on Environmentally Sustainable Transport in the Asian Region. Nagoya, Japan.

Lisbon Metro. (2010). Relatório de Sustentabilidade, 2010. Metropolitano de Lisboa. Available online: http://www.metrolisboa.pt/wp-content/uploads/Relat%C3%B3rio-de-sustentabilidade2010.pdf.

Milam, R.T., Birnbaum, M., Ganson, C., Handy, S., & Walters, J. (2017). Closing the induced vehicle travel

gap between research and practice. Transportation Research Record, 2653(1): 10–16. Available online at https://doi.org/10.3141/2653-02

Nawazish, S., Bukhari, S.M., Muhammad, A., Khan, I.U., Alhassan, A.J., Hussain, M. & Azidi, A. (2017). Correlation analysis of toxic metals on motorway and national highway. Kuwait Journal of Science, **44**(2): 121–128.

Nieuwenhuijsen, M.J., & Khreis, H. (2016). Car free cities: Pathway to healthy urban living. Environment International, **94**: 251-262.

Organisation for Economic Co-operation and Development (OECD). (2010). Reducing transport greenhouse gas emissions, trends & data 2010. www.internationaltransportforum.org/Pub/pdf/10GHGTrends.pdf.

Perra, V-M., Sdoukopoulos, A. & Pitsiava-Latinopoulou, M. (2017) Evaluation of sustainable urban mobility in the city of Thessaloniki. Transportation Research Procedia, **24**: 329-336.

Pojani, D., & Stead, D. (2015). Sustainable urban transport in the developing world: Beyond megacities. Sustainability, **7**(6): 7784-7805.

Porto Metro (2013). Relatório de Sustentabilidade, 2013. Metro do Porto. Available onlineat http:// www.metrodoporto.pt.

Qamar, Z., Arif, M., Rasool, G. & Afzaal, M. (2009). Technical Report No. PMD-22/2009. Pakistan Meteorological Department.

Redman, L., Friman M, Gärling T. & Hartig, T. (2013). Quality attributes of public transport that attract car users: A research review. Transport Policy, **25**: 119–127.

Red Nacional de los Ferrocarriles Españoles (Renfe) (2008). Environmental Report. Available online at http://www.renfe.com/EN/docs/2008_Enviromental_Report.pdf

Ribeiro, K., Kobayashi, S., Beuthe, M., Gasca, J., Greene, D., Lee, D. S., & Kingdom, U. (2007). Transport and its infrastructure. In Metz, B., Davidson, O.R., Bosch, P.R., Dave, R. & Meyer, L.A. (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. United Kingdom and New York, NY, USA: Cambridge University Press (Pp. 48-52).

Shapiro, R.J., Hassett, K.A., & Arnold, F.S. (2002). Conserving energy and preserving the environment: The role of public transportation. Available online: http://sonecon.com/docs/studies/enenv_0702.pdf.

Sheikh, M. (2014). Metrobus: Mobility and sensibility. Dawn News, Lahore. Available online at https://www.dawn.com/news/1082358

Sims R., Schaeffer, R., Creutzig, F., Cruz-Núñez, X., D'Agosto, M., Dimitriu, D. et al. (2014). Transport. In Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., J. Minx, C. (Eds.), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Pp. 1–44.

Sweeting, W.J. & Winfield, P.H. (2012). Future transportation: Lifetime considerations and framework for sustainability assessment. Energy Policy, **51**: 927–938.

United Nations. (UN). (2019). The Fututre is Now. Global Sustainable Development Report 2019. Available online at https://sustainabledevelopment.un.org/content/documents/24797GSDR_report_2019.pdf

World Energy Council. (2016). World Energy Resources 2016. Available online: https://www.worldenergy.org/assets/images/imported/2016/10/World-Energy-Resources-Full-report-2016.10.03.pdf

World Population Review. (WPR). (2017). Available online at http:// worldpopulationreview.com/world-cities /lahore-population/.

World Resource Institute. (WRI). (2017). Climate Analysis Indicators Tool. Available online at http://cait.wri.org/historicalYamane, T. (1967). Statistics: An introductory analysis, 2nd Edition, New York: Harper and Row (Pp. 579).Zheng, J., Atkinson-Palombo, C., McCahill, C., O'Hara, R. & Garrick, N. (2011). Quantifying the economic domain of transportation sustainability. Transportation Research Record 2242, Pp. 19-28. Available online at http://amonline.trb.org/12koec/12koec/1.