Transition to Compressed Natural Gas Rickshaws for Urban Mobility: a Case of Dar es Salaam City

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Abstract

In Dar-es-Salaam, Tanzania, rickshaws are chiefly employed as taxis in short distant trips. However, due to increased demand and urban traffic congestion, rickshaws have become a major source of pollution in the city. Despite the abundance of natural gas in Dar-es-Salaam, there are no commercially successful compressed natural gas (CNG) rickshaws available to reduce tailpipe emissions. This study evaluates the feasibility of transition to CNG rickshaws by estimating the fuel and environmental savings. The results reveal that by shifting from petrol to CNG, it is possible to save 54.38 Tshs/km, 6,965 Tshs/day and 2,507,410 Tshs per year, with a payback distance of 17,849.2km. The estimated annual savings, CNG requirement, and $PM_{2.5}$ emissions are 125.37 billion Tshs, 100 million tonne, and 102 tonne, respectively. The study suggests that CNG 4-stroke rickshaws be prioritized due to their superior attributes such as lower fuel consumption, lower fuel costs, and environmental friendliness.

Keywords: Three-wheeler Motorcycle, Compressed Natural Gas, Fuel-saving, Environmental Saving.

Introduction

In most urban areas, air quality and energy are the twin serious concerns that have been reported around the world (Sreejith & Rajagopal, 2016). The two issues are primarily attributed to rising urbanization and living standards, which in turn raises the demand for motorization (Greyson *et al.,* 2021a). In 2019, the transport sector consumed more than 40% of the global oil demand (Bloomberg, 2020). The main adverse pollutant, known as $PM_{2.5}$ is reported to cause premature death and adverse effects on the cardiovascular system (EPA, 2019). An airborne collection of vehicle-pollutant particles caused the deaths of tens of thousands of people in New York City in 1966 (Cohen, 2017), and London in 1952 (Klein, 2012). Rickshaws are responsible for 10 percent of India's road pollution and nine out of the top ten most polluted cities worldwide (Singh & Jena, 2018). As a result of acute health and environmental concerns, innovative technologies began to gain traction in the automotive industry a few years ago, with the goal of improving drive train conversion efficiency while reducing dependency on fossil fuels.

Compressed Natural Gas (CNG) is one of the alternative fuels being used to address the growing need for urban motorization while reducing the negative consequences of fossil fuel (Greyson *et al.,* 2021b). As of today, in many cities around the world, CNG-powered rickshaws are becoming more popular for short-distance travel. CNG rickshaws were used in Dhaka to reduce road pollution and to replace imported liquid fuel (Asian Development Bank, 2011). In Cardiff, London, CNG rickshaws were used due to their low fuel cost (Sonwalkar, 2018). Karhad, (2018) reported that CNG rickshaws are cheaper, customized, and more flexible than taxis and city buses. According to a study conducted by Iqbal *et al.* (2013) in Sylhet City in Bangladesh, CNG drivers earn nearly twice as much as electric drivers. Similarly, BUSTLINGPUNE.COM, (2017) claimed that rickshaw drivers can earn a decent daily income of an average of 3 euro per day after deducting all expenses and vehicle maintenance. Aside from the socioeconomic benefits, CNG rickshaws are used as an anti-air pollution measure. In India, for example, CNG rickshaws have been mandated (Harding *et al.,* 2016) to supplement Delhi's noxious air and toxic particulates. Reynolds *et al.* (2011) reported that a 2-stroke rickshaw has higher CO emissions than 4-stroke engines. In Dar es Salam, Tanzania, the transportation sector contributed 57 percent of the total CO_2 budget in 2014 due to fuel combustion (Shrestha, 2019). Despite the fact that CNG is abundant in Tanzania and that CNG rickshaws have the potential to reduce road emissions and improve socio economic development, particularly in Dar es Salaam, their use is very low. It is estimated that up to 2020, about 450 natural gas vehicles have been converted (Kamala, 2020). A large portion of daily in-city motorization is still provided by petrol-powered rickshaws, whose fuel is expensive and emits harmful pollutants. Furthermore, there is little understanding of the benefits of switching from conventional to CNG-powered rickshaws.

The goal of this study is to determine the feasibility of transitioning to CNG rickshaws by evaluating fuel and environmental savings based on urban driving in Dar es Salaam. Finally, the payback distance is calculated to determine the driving distance required to recover the initial investment for converting the rickshaw to use CNG through fuel cost savings.

Materials and Methods

Study area and CNG consumption

Figure 1 depicts the routes evaluated in the study region within Dar es Salaam city. In this work, specifications of petrol-powered rickshaws in Dar es Salaam that have the potential to be converted to CNG are utilized.

This study's fuel consumption was estimated by comparing it to that of similar current rickshaws in other countries (see Table 1). Thus, data from 4-stroke SI CNG-powered rickshaws from different countries are compared before deciding on the consumption. The consumption of 28.5 km/kg from Delhi is equivalent to the consumption of a similar CNG rickshaw in Dar-es-Salaam for the cities stated in Table 1.

Later, as illustrated in Figure 2, the amount of CNG is computed for specified routes in the city. The primary assumption is that there are sufficient CNG filling stations and that all

Figure 1: Route considered in the study area

rickshaws are located in the City Center. Table 2 provides a summary of the study routes.

Table 1: Rickshaws' consumption from other cities

City	CNG cons. (km/kg)	Ref
Pune (India)	20-25	Dastane. (2012)
Delhi (India)	28.50	Reynolds *et al.* (2011)
Cardiff (UK)	27.80	Flynn. (2006).

distance per day is taken as the longest distance in the study route, about 155.4 km, which refers to case 1 + case 5. The fuel prices, running cost and savings are computed in Tanzanian shillings (Tsh) as per 7th September 2020. For converting the petrol fueled rickshaw to CNG fueled one, the conversion cost covers the prices for the conversion kit, wages and other supporting materials. After switching from petrol to CNG, the savings are calculated as a difference in the running costs of petrol and a CNG rickshaw. The payback distance defines the distance in kilometer that the rickshaw owner can recover the cost of conversion from petrol to CNG by saving fuel cost. On the other side, the annual saving is computed without covering other charges required by the local by-laws which demand fees for parking and road license, assuming that the costs are the same for both petrol and CNG

Table 2: Study routes for calculation the volume of CNG in rickshaw

Case #	Route	Distance (km)
1	City Center to Point 1 back to City Center	76
2	City Center to Point 2 back to City Center	6
3	City Center to Point 3 back to City Center	25
4	City Center to Point 4 back to City Center	49
5	City Center to Point 5 back to City Center	79
6	City Center to Point 6 back to City Center	21
7	case 1 + case 2	136
8	case 1 + case 3	101
9	case 1 + case 4	126
10	case 1 + case 5	155
11	case 1 + case 6	97
12	case 2 + case 3	85
13	case 2 + case 4	109
14	case 2 + case 5	139
15	case 2 + case 6	139
16	case 3 + case 4	74
17	case 3 + case 5	104
18	case 3 + case 6	46
19	case 4 + case 5	128
20	case 4 + case 6	70
21	case 5 + case 6	100

Fuel and Environmental Saving

Fuel-saving

The fuel demand comprises the CNG rickshaw consumption. The fuel-saving of a CNG 4-stroke rickshaw is compared with that of the petrol-powered rickshaw. The running rickshaw. Finally, the expected annual revenue obtained for refueling all rickshaws in Dar-es-Salaam is estimated.

Environmental saving

The environmental savings are calculated by comparing the emissions from CNG-powered rickshaws to those from gasoline-powered rickshaws. Because of the strong correlation between $PM_{2.5}$ emissions and adverse health effects, an emphasis is placed on reducing $PM_{2.5}$ emissions on an annual basis. Because of the lack of test equipment, this work adopts the results of Reynolds *et al.* (2011). The obtained $PM_{2.5}$ values from CNG and petrol rickshaws were used in their tests to calculate the annual reduction of $PM_{2.5}$ after switching from petrol to CNG.

Results and Discussion

Fuel saving

The amount of energy required for rickshaw city driving is shown in Figure 2. The vertical axis of Figure 2 depicts two cases; case 1-from city center to any point and back to the city center while case 2-city center → any point →back to city center → another point → city center. Furthermore, the horizontal axis displays the results of energy demand (blue bar). According to Figure 2 (case 1), a round trip from the city center to any point and back does not exceed 100 km. So, 4 kg of CNG is sufficient for one round trip in the city or 8 kg for two round trips of approximately 160 km. The number on top of the bar shows route distance. City routes with dashed purple box (on y-axis) are one round trip routes whereas those in dashed red box are two round trip routes.

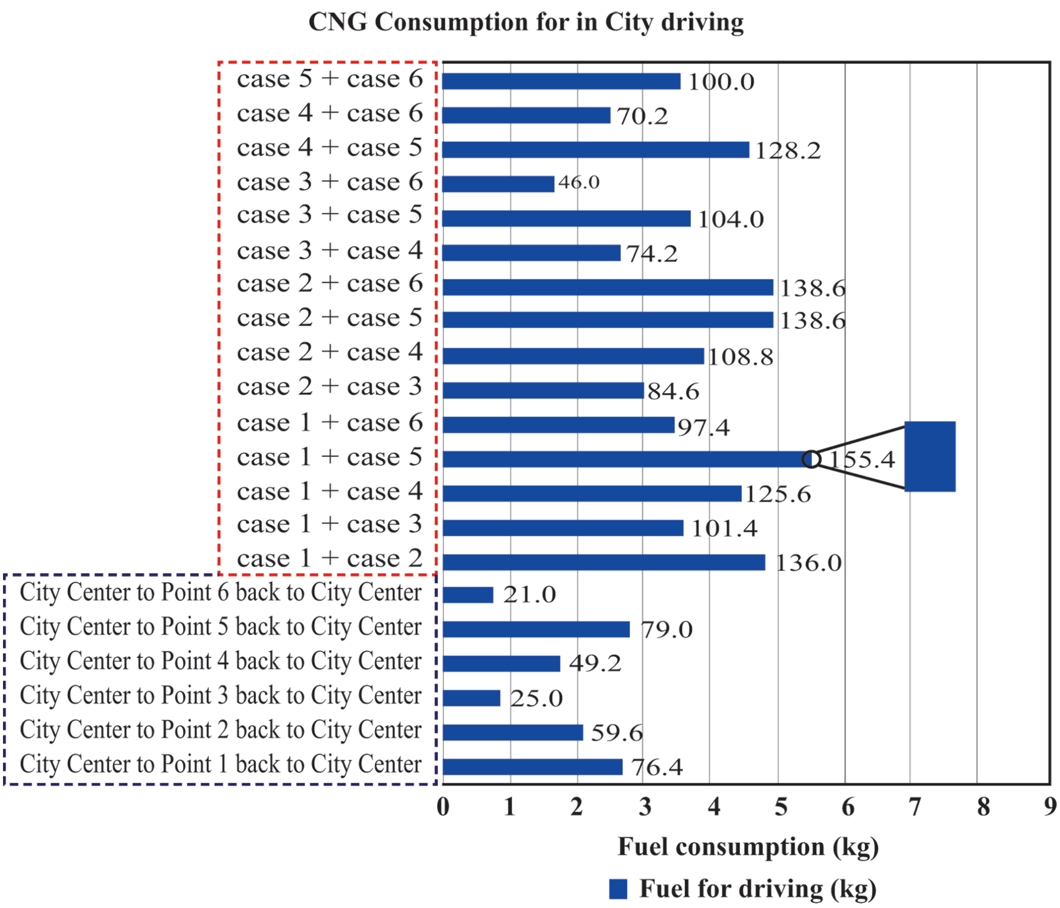

Figure 2: CNG consumption for in-city driving

The next step is to determine the size of the cylinder that will hold the CNG for driving. This work estimates that the driving distance equals to two round trips, resulting in a demand of approximately 8 kg of CNG. According to Misra Auto Gas, (2017), a standard cylinder weighing 9 kg of CNG with a standardized working pressure of approximately 200 bar appears to be adequate for these requirements.

Table 3 shows the calculation of rickshaw fuel savings after switching from petrol to CNG. It can be seen that the energy content of CNG is

Table 3: Comparison of fuel saving between CNG 4-stroke and petrol rickshaws

Type of vehicle	**3-wheelers (rickshaws)**	
Fuel	**CNG**	**Petrol**
Measuring unit	**kg**	**L**
Unit equivalence	Energy content: 13.3 kWh/kg ~ 1.5 L of petrol per 1 kg CNG	Energy content: 8.6 kWh/L 1L
Fuel cost (Tsh per unit)	1,550a	1852b
Mileage (km/unit of fuel)	28.50	(28 km/1.5 L) = 18.67
Operating cost per km (Tsh/km)	54.38	99.20
Average vehicle running (km/day)	155.4c	155.4c
Annual vehicle running [DA] (km/year)	155.4 km/day × 30 days/mon× 12mon/year = 55,944 km/year	55,944 km/year
Operating cost/day (Tsh/day)	8,450	15,415
Saving cost of fuel per km [S] (Tsh/km)	99.20 - 54.38 = 44.82	
Saving cost of fuel per day (Tsh/day)	15,415 - 8,450 = 6,965	
Saving cost of fuel per month [SCF](Tsh/month)	44.82 × 30 days/mon × 155.4 km/day = 208,950.84	
Saving cost of fuel per year (Tsh/year)	208,950.84 Tsh/mon × 12mon/year = 2,507,410	
Saving cost of all rickshaws per year (Tsh/year)	2,507,410 Tsh/year/rickshaw × 50,000d rickshaws = 125.370504 bil.	
Approximate conversion cost [CV] (Tsh)	800,000	
Payback distance [PD] (km)	CV / S= 800,000 Tsh / 44.82 km/year = 17,849.2 km	
Payback period [PB] (months)	CV / SCF = 800,000 Tsh / 208,950.84 Tsh/mon = 3.8 ≈ 4 months[e]	
Fuel consumed per rickshaw per day (kg/day)	155.4 km/day × 28.5 km/kg = 5.45 kg/day	
Fuel consumed per rickshaw per year (ton/year)	5.45 kg/day × 366 days/year ≈ 2 tonnes	
Fuel consumed for all rickshaws per year (ton/year)	2 tonnes/rickshaw/year × 50,000 rickshaws ≈ 100 million tonnes/year	
CNG revenue for all rickshaws per year (Tsh/year)	100 million tonnes/year × 1,550 Tsh = 155 bil[f]	

[a] The CNG price per kilogram in Dar-es-Salaam as on 7 September 2020.

[b] The petrol price per litre in Dar-es-Salaam as on 7 September 2020 (EWURA, 2020).

[c] The average running per day is the longest distance in the current study plan (case 1 + case 5).

[d] The number of registered rickshaws resulted into direct jobs (Shrestha, 2019).

[e] A simple payback is considered.

[f] An expected fuel revenue after conversion to CNG.

higher than that of petrol, which allows CNG to have better energy use. Another important factor in explaining energy consumption is fuel price. It can be stated that the high price of petrol and the low mileage of the petrol-powered rickshaw, as a result of the low energy content, results in a higher operating cost per kilometer per day.

This analysis shows that for any route, the operating cost per km for CNG (54.38 Tsh/km) is lower than for petrol (99.20 Tsh/km). As a result, the operating cost per day for petrol is nearly doubles that of CNG and provides a savings of 6,965 Tsh/day when driving on CNG. In other words, 45.18% of the fuel cost of petrol can be saved when complemented by CNG fuel. CNG rickshaw can save 2,507,410 Tshs per year based on this calculation. CNG rickshaw starts to pay off after 17,849.2 km when used daily. This fuel economics were intended to make better economic sense to the rickshaw owners. An increase in the number of CNG rickshaws can result in higher earnings to the government and society as a whole. For example, 50,000 CNG rickshaws in Dar es Salaam are estimated to save 125.37 billion Tshs per year. Finally, the CNG demand for 50,000 rickshaws comes to 100 million tonnes per year.

Environmental saving

Reynolds *et al.* (2011) discovered that CNG and petrol 4-stroke engines emit approximately 12 mg/km and 48 mg/km of $PM_{2.5}$, respectively. Thus, converting all 50,000 rickshaws in Dar-es-Salaam to CNG would result in an annual reduction of $PM_{2.5}$ emissions of about (50,000 rickshaws x 56,876 km x (48 mg/km - 12 mg/km)) 102 tonnes. This estimate may be slightly exaggerated because all rickshaws were assumed to travel the same annual distance.

Conclusion

This study examines the feasibility of switching to CNG rickshaws by calculating fuel and environmental savings based on Dar es Salaam city driving.The findings show that the operating cost per km for CNG (54.38 Tsh/km) is lower than for petrol (99.20 Tsh/km). As a result, the operating cost per day for petrol is nearly double that of CNG and provides a savings of 6,965 Tsh/day when driving on CNG. According to the findings, 45.18% of the fuel cost of petrol can be saved when supplemented by CNG fuel, which is equivalent to 6,956 Tshs/day or 2,507,410 Tshs/year. When used daily, a CNG rickshaw begins to pay off after 17,849.2 kilometers. For environmental saving, the complete shift from petrol to CNG may annually reduce $PM_{2.5}$ emissions to about 102 tonne.

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Reference

Asian Development Bank. (2011). Bangladesh: Dhaka Clean Fuel Project. Project No: BAN 35466. https://www.adb.org/sites/default/files/project-document/61557/35466-01-ban-pcr.pdf (accessed 12 September 2020)

Bloomberg NEF. (2020). Oil Demand From Road Transport: Covid-19 and Beyond. https://about.bnef.com/blog/oil-demand-from-road-transport-covid-19-and-beyond/ (accessed 12 September 2020)

BUSTLINGPUNE.COM (2017). The macroeconomics of the Indian auto rickshaw; income of 250 rupees a day. https://bustlingpune.com/2017/02/28/the-macro-economics-of-the-indian-auto-rickshaw-income-of-250-rupees-a-day/ (accessed 12 September 2020)

Cohen, M. (2017). Remembering New York City's days of deadly smog. https://www.6sqft.Com/remembering-new-york-citys-days-of-deadly-smog/ (accessed 12 September 2020)

Dastane, S. (2012). Autos give 20-25 km mileage per litre/kg. https://timesofindia.india times.com/city/pune/Autos-give-20-25-km-mileage-per-litre/kg/articleshow/1387815.cms (accessed 12 September 2020)

EPA. (2019). Air Pollution: Current and Future Challenges. https://www.epa.gov/clean-air-act-overview/air-pollution-current-and-future-challenges (accessed 12 September 2020)

EWURA (2020). Cap prices for petroleum

products effective Wednesday, 2nd September 2020. https://www.ewura.go.tz/wp-content/uploads/2020/09/Cap-Prices-for-Petroleum-Products-wef-02-September-2020-English-.pdf (accessed 12 September 2020)

Flynn, N. (2006). CNG-Powered Rickshaws Come to the UK. https://www.greencarcongress.com/2006/07/cngpowered_rick.html (accessed 12 September 2020)

Greyson, K.A., Gerutu, G.B., Mohamed, C.H., & Chombo, P.V. (2021a). Exploring the adoption of e-bicycle for student mobility in rural and urban areas of Tanzania. *Sustainable Energy Technologies and Assessments,* 45, 101206.

Greyson, K.A., Gerutu, G.B., Bobi, S., & Chombo, P.V. (2021b). Exploring the potential of compressed natural gas as a sustainable fuel for rickshaw: A case study of Dar es Salaam. *Journal of Natural Gas Science and Engineering,* 96, 104273.

Harding, S.E., Badami, M.G., Reynolds, C.C.O., & Kandlikar, M. (2016). Auto-rickshaws in Indian cities: Public perceptions and operational realities. Transport Policy, 52: 143–152. doi:10.1016/j.tranpol.2016.07.013

Iqbal, M., Akhter, S., & Ahmad, S. (2013). Study on merits and demerits of two transport systems: Battery operated easy bike with CNG operated auto rickshaw at Sylhet city in Bangladesh. *IOSR Journal of Mechanical and Civil Engineering,* 5(5): 25-32

Karhad, B.D. (2018). Auto-rickshaw drivers in Jalgaon city: problems and measures. *International Research Journal of Commerce Arts and Science,* 9(3): 231-238.

Kamala, J. (2020). DIT to train locals as CNG demend climbs. Daily News. https://dailynews.co.tz/news/2020-04-075e8c8fabc8878.aspx (accessed 18 October 2020)

Klein. C. (2012). The Great Smog of 1952. https://www.history.com/news/the-killer-fog-that-blanketed-london-60-years-ago (accessed 12 September 2020)

Misra Auto Gas. (2017). Top CNG Kit Fitment Center. http://misraautogas.in/wp/cng-questions-answers/ (accessed 12 September 2020)

Reynolds, C.C.O., Kandlikar, M., & Badami, M.G. (2011). Determinants of PM and GHG emissions from natural gas-fueled autorickshaws in Delhi. *Transport and Environment* Part D, 16: 160-165.

Reynolds, C.C.O., Grieshop, A.P., & Kandlikar, M. (2011). Climate and Health Relevant Emissions from in-Use Indian Three-Wheelers Fueled by Natural Gas and Gasoline. *Environmental Science and Technology,* 45: 2406–2412: dx.doi.org/10.1021/es102430p

Shrestha, S. (2019). Tanzania pilot project concept: E-mobility for last-mile connectivity in Dar es Salaam. Urban Pathways, Berlin

Singh, V.P. & Jena, L.P. (2018). Financing for Low-Carbon Auto Rickshaws. https://www.climatepolicyinitiative.org/publication/financing-for-low-carbon-auto-ricksha ws/ (accessed 12 September 2020).

Sonwalkar, P. (2018). More towns in UK taking to auto-rickshaws. https://www.hindustantimes.com/world-news/more-uk-towns-taking-to-auto-rickshaws/story-eWVKRq5BvuEkJclUM281rO.html (accessed 12 September 2020)

Sreejith, R. & Rajagopal, K.R. (2016). An insight into motor and battery selections for three-wheeler electric vehicle. *IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems.*