https://dx.doi.org/10.1016/j.jclepro.2020.119961

Accepted by *Journal of Cleaner Production* (2020)

Sustainability assessment of an urban rail system – the case of Hong Kong

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Abstract

Urban rail system is a critical component of a smart and sustainable city. Yet, there is scant literature to collect, analyze, and report the operational data of an urban rail system and to assess its sustainability performance over time. This paper addresses such an important research gap by applying the triple bottom line framework to one of the most heavily utilized rail systems in the world – the urban rail system of Hong Kong's MTR Corporation Limited. We collected data from MTR's annual reports and sustainability reports during the period of 2008-2017. The collected data showed that MTR urban rail system consumed 1,573 GWh in 2017, increasing steadily from 1,290 GWh in 2008. In terms of service capacity, MTR urban rail system handles 1.767 billion passenger-trips in 2017, increasing from 1.309 billon passenger-trips in 2008. As the average passenger-km travelled ranged from 10.4 to 11 km for city lines and from 28.4 to 29.5 km for airport express, the total passenger-km travelled was 19.38 billion in 2017, increasing from 13.82 billion in 2008. Sustainability analysis showed that MTR urban rail system had an efficiency of 0.076-0.093 kWh per passenger-km, implying a greenhouse gas emission of 0.055-0.071 kg CO_2-eq per passenger-km. Tobin's q value ranged from 1.00 to 1.41, suggesting that the capital

market has overvalued MTR to certain extent in the past decade. In terms of social performance, MTR rail operations had over 15 thousand employees in 2017 i.e. about 0.4 percent of Hong Kong's labor force, increasing from 11 thousand employees in 2008 i.e. about 0.3 percent of Hong Kong's labor force. MTR handled 38.2 percent of public transport in 2017, increasing steadily from 31.5 percent of public transport in 2008.

Keywords: urban rail, triple bottom line, greenhouse gases emissions, Hong Kong.

1. Introduction

Rail systems re-emerge as one of the most important infrastructures in the world (Huang et al., 2018; To, 2015; Wang et al., 2016). According to the World Factbook (US CIA, 2018), the total route length of rail systems is over 1.3 million km in which the United States has the largest rail system, followed by China. To meet the ever-growing needs of accessibility and efficiency, China spent RMB 4.7 trillion on rail projects between 2013 and 2018 (Luo, 2018). By the end of 2018, China's rail system had a total length of 131,000 km, up from 103,144 km in 2013. Although most of the rail length has increased due to the completion of high-speed rail links in China, it is the country's urban rails that carry the majority of people to and from their urban destinations throughout the year (TD, 2017; To, 2015; Wang et al., 2018). In fact, underground and elevated urban rail networks have been built and expanded continually to ease traffic congestion because the roads of Chinese cities are no longer adequate to serve the increasing number of vehicles (To, 2015). Besides, people can estimate rail travel time quite accurately and they can travel by rail under adverse weather conditions.

China's urban rail systems have a relative short history. At the turn of millennium, there were four mainland cities, namely Beijing, Tianjin, Shanghai, and Guangzhou with urban rail networks (Xue et al., 2002). The number of urban rail lines was 6 in total and the total rail length was merely 119.5 km. The number of China's urban rail lines increased rapidly to over 150 in 33 cities, with a total length of 4,500 km and carrying 18.5 billion passenger-trips in 2017 (Xinhua News, 2018). China's urban rail systems were further expanded to 185 urban lines with a total length of 5,761 km in 35 cities in 2018 (Xinhua News, 2019). Shanghai's urban rail system served 3.71 billion passenger-trips while Beijing's urban rail system served 3.12 billion passenger-trips in 2018. Additionally, Hong Kong, one of the major and most populous cities of China, has its own rail system, namely, MTR, which operates 10 city lines and an airport express with a total number of 93 stations, excluding its light rail system. The total route length of MTR urban rail system is 187.4 km and that of MTR light rail system is 36.2 km (MTR, 2019a). MTR urban rail system served 1.767 billion passenger-trips in 2017. Most of the notions relating to the continual development of China's including Hong Kong's urban rail systems are to cope with the growing population and transport demands, and to integrate land use and transport planning in order to deliver effective and efficient accessibility that promotes environmental sustainability, social well-being, and enhances job opportunities (Mulley et al., 2017; Stopher and Stanley, 2014). Although, there is a general consensus that urban rail is more environmentally friendly than private cars and taxis. It is not entirely clear whether urban rail is greener than other public transports such as public buses (Mulley et al., 2017). In order to shed light on answering this important research question, the objectives of the study are (i) to review the environmental impact of rail systems based on a review of the extant literature on urban rail systems, and (ii) to perform a sustainability assessment of an urban rail system – using Hong Kong's MTR rail system as an example.

1.1.Environmental impact of an urban rail – a brief review

The energy consumption and environmental impact of an urban rail depends significantly on how many passengers an urban rail would carry, how far passengers travel by rail, the energy mix for electricity production, and the energy consumed by the works and activities that support the operation of an urban rail. When it comes to the energy consumed by different modes of transport, Davis (1997) studied transportation energy use in the U.S. and suggested that energy intensity would be 3.05 MJ per passenger-km by transit bus with a load factor of 8.6 persons per bus and 2.50 MJ per passenger-km by transit rail with a load factor of 20 persons per train-car in 1995. The US transport-related energy intensity was reduced to 2.69 MJ per passenger-km by transit bus with a load-factor of 9.1 persons per bus and 0.50 MJ per passenger-km by transit rail with a load factor of 25.8 persons per train-car in 2016 (Davis and Boundy, 2018). Energy intensity was about 1.93 MJ per passenger-km by private car with a load factor of 1.5 persons per car (Davis and Boundy, 2018). On the other hand, Kenworthy (2008) reviewed energy use in the public transport systems of 84 international cities and reported that urban rails consumed in average 0.46 MJ per passenger-km while buses consumed in average 1.05 MJ per passenger-km. Kenworthy (2008) noted that urban rail systems in China's cities consumed only 0.05 MJ per passenger-km which was about 10 times more efficient than the survey's average, probably due to some high loading levels on China's urban rail systems.

Urban passenger transport has continuously been researched in the past decade. Mulley et al. (2017) explored greenhouse gas (GHG) emissions associated with urban rail and bus in Australia. Based on the full fuel cycle transport energy emission approach, Mulley et al. (2017) reported that urban bus emitted about 120-130 g CO_2-e per passenger-km while urban rail emitted about 115-140 g CO_2-e per passenger-km during the period of 1990-2014. In energy-term, it was estimated that Australian urban rail consumed about 0.46-0.56 MJ per passenger-km. Saxe et al. (2017) studied GHG emissions of the Sheppard Subway Line in Toronto, Canada. They reported that GHG emissions of the Sheppard Subway Line decreased from 114 g CO_2-e per passenger-km in 2003 to 34 g CO_2-e per passenger-km in 2012 due to the elimination of coal-based electricity generation in Canada. As the emission factor was 308 g CO_2-e per kWh in 2003 and 102.3 g CO_2-e per kWh in 2012 (City of Toronto, 2017), it was estimated that this urban rail in Toronto consumed 1.19 MJ per passenger-km in 2012, decreasing from 1.33 MJ per passenger-km in 2003. In China, Li et al. (2018) calculated GHG emissions of Shanghai's urban rail system using a life-cycle approach. Li et al. (2018) reported that the operation of Shanghai's urban rail system contributed to 92.1 percent of the total GHG emission based on a service life of 50 years. They calculated rail traction emission factor using the estimated total CO_2-e emission, and the annual passenger volume and average riding distance provided by Shanghai's urban rail for the year 2012. They found that Shanghai's urban rail system emitted 23.4 g CO_2-e per passenger-km when only traction energy was considered. As the emission factor of electricity was 820 g CO_2-e per kWh in Li et al.'s (2018) paper, Shanghai's urban rail consumed 0.029 kWh per passenger-km or 0.102 MJ per passenger-km for rail traction system. Li et al. (2018) also reported that there were approximately 2.3

billion passengers traveling in average 12 km in 56.1 million train-km and each train had six cars in 2012, meaning that rail load factor was 82 persons per train-car.

2. Method

Sustainability is about meeting the current needs without compromising the ability of future generations to meet their own needs (US EPA, 2019; WCED, 1987). Hence, an organization or system has to devote its efforts to align economic gains with the interests of environmental protection and social well-being. Hence, the study adopted a triple bottom line approach (Elkington, 2013; To and Lee, 2017a) and focused on identifying and evaluating the environmental, economic, and social performance of an urban rail system. Additionally, as system performance would vary depending on the usability and the continual changes of system parameters; we collected a 10-year operational data and financial performance of an urban rail system – Hong Kong's MTR urban rail system.

2.1.Sustainability indicators

Different sets of indicators have been used to measure the sustainability of activities, systems, cities, and countries depending on the contexts (Beames et al., 2014; Finkbeiner et al., 2010; Mickwitz and Melanen, 2009). For urban rail systems, it is a general consensus that they consume a significant amount of electricity in their operation (Kenworthy, 2008; Li et al., 2018; Mulley et al., 2017; Saxe et al., 2017). Hence, Hong Kong's MTR energy efficiency in terms of kWh per passenger-km or MJ per passenger-km and GHG emission in terms of CO_2-e per passenger-km were chosen as its environmental indicators. Clift and Wright (2000), and Wagner (2010) suggested that economic value added or Tobin's q can be used as an economic indicator in sustainability assessment. Economic value added is defined as the difference between a firm's operating income after taxes and the opportunity cost of the capital invested in the firm (Clift and Wright, 2000; Stewart, 1998). Hence, it is a measure concerning a firm's ability to produce an economic profit that is determined by return in excess of the cost of capital. However, when market sentiment and a long-term view such as sustainability are considered, Tobin's q is more appropriate because it is known as a reliable measure of a firm's growth opportunities and ability to create long-run firm value (Wagner, 2010). Tobin's q is defined as the ratio of the market value of a firm to the replacement of the firm's assets (or total asset value of the firm). In the study, we calculated Tobin's q based on the data from MTR's annual reports which provided its market value and total asset value at the end of each year. We used MTR's operating margin – an operating performance as another proxy economic indicator. Social indicators may include employment, income, public safety, public accessibility, education, and health (Noll, 2004; US Department of Commerce, 1973). For Hong Kong's MTR as a public organization, we used percentage of Hong Kong's total employment and percentage of total public transport as social indicators. Percentage of Hong Kong's employment is calculated by dividing the number of MTR's employees including all staff in its operations, projects, corporate management, and supporting units by Hong Kong's total labor force. Percentage of total public transport is calculated by dividing MTR's passenger-trips by total public transport in terms of passenger-trips for each year. Table 1 summarizes sustainability indictors, the units of measurement, and sources of the data.

Table 1. Sustainability indicators of an urban rail system

Dimension	Indicator	Unit	Sources of data
Environmental	Energy efficiency	kWh (or MJ) per passenger-km	MTR[i]
	GHG emission	CO_2-e per passenger-km	MTR
Economic	Tobin's q	dimensionless	MTR
	Operating margin	percentage	MTR
Social	Employment	percentage of the total	MTR, CENSTATD[ii]
	Public transport	percentage of the total	MTR, TD[iii]

Notes:
[i] MTR – MTR's annual reports and sustainability reports
[ii] CENSTATD – publications from Hong Kong Census and Statistics Department
[iii] TD – publications from Hong Kong Transport Department

2.2.Data collection

Data were collected from MTR official website. As one of the largest public utilities in Hong Kong, MTR has been listed on the Hong Kong Stock Exchange since 5 October 2000. MTR officially merged with KCRC on 2 December 2007. Hence, MTR started reporting total electricity consumption for Hong Kong's urban rail system since 2008. For this reason, we collected MTR's operational and financial data from its annual and sustainability reports during the period of 2008-2017 (the latest one available in public with full operational data). Additionally, we obtained Hong Kong's labor force and population data from the Hong Kong Statistics and Census Department (CENSTATD, 2019a, 2019b) and Hong Kong's total public transport data from the Hong Kong Transport Department (TD, 2019). Table 2 presents MTR key operational and financial data during the period of 2008-2017.

Table 2. Key operational and financial data during the period of 2008-2017

Dimension	Size	Year 2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Operational [i]											
Passenger-trip: city & cross-boundary	billion	1.299	1.313	1.399	1.470	1.540	1.586	1.661	1.691	1.700	1.750
airport express	billion	0.011	0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.016	0.017
Passenger-km travelled: city & cross-b.		10.4	10.7	10.9	10.9	10.9	11.0	11.0	11.0	10.9	10.8
airport express		29.4	29.5	29.4	29.4	29.0	29.0	28.6	28.4	28.4	28.5
Revenue car-km: city & cross-boundary	million	245.8	247.9	253.1	254.4	260.9	269.2	273.8	284.5	287.8	301.5
airport express	million	19.9	19.7	19.8	19.7	23.1	23.2	23.2	23.2	23.3	23.2
- *Total passenger-trips* [ii]	*billion*	*1.309*	*1.323*	*1.410*	*1.482*	*1.553*	*1.600*	*1.676*	*1.707*	*1.716*	*1.767*
- *Total passenger-km travelled* [ii]	*billion*	*13.82*	*14.34*	*15.57*	*16.37*	*17.16*	*17.84*	*18.69*	*19.06*	*18.99*	*19.38*
- *Total revenue car-km* [ii]	*million*	*265.7*	*267.6*	*272.9*	*274.0*	*284.0*	*292.4*	*297.0*	*307.7*	*311.1*	*324.7*
- Electricity consumption	GWh	1290.3	1297.0	1314.7	1323.8	1369.5	1371.9	1417.3	1486.0	1487.4	1573.2
Financial [iii]											
- Total assets in HKD	billion	159.3	176.5	181.7	197.7	206.7	215.8	227.2	241.1	257.3	263.8
- Total debt in HKD	billion	57.9	66.0	59.7	65.8	63.8	63.2	63.8	71.0	107.9	97.5
- Market capitalization in HKD	billion	101.7	153.5	163.3	145.5	176.7	170.2	185.2	225.0	222.6	275.2
- Operating margin in percent (for rail)		48.1	47.3	50.2	49.7	49.2	48.6	47.5	47.0	47.7	45.7
Others											
- MTR's rail employees [iv]	thousand	10.9	11.5	12.2	12.8	13.6	14.5	14.9	15.4	15.8	15.6
- Public transport passenger-trips [v]	billion	4.173	4.136	4.245	4.343	4.421	4.508	4.569	4.599	4.608	4.632
- Hong Kong's labor force [vi]	thousand	3637.2	3660.3	3631.3	3703.1	3782.2	3855.1	3871.1	3903.2	3920.1	3946.6

Notes:

[i] MTR provided annual data for its urban rail system and light-rail system separately in its sustainability reports. MTR urban rail system includes domestic/city lines, cross-boundary service (Hong Kong's side), and airport express but it excludes light-rail network. MTR only provided total annual electricity use for railway operations covering the usage for its rolling stocks, platforms, concourses, depots as well as the administrative works for its urban rail operations.

[ii] Parameters in italics were calculated based on MTR's published data.

[iii] MTR's financial data were obtained from MTR's annual reports.

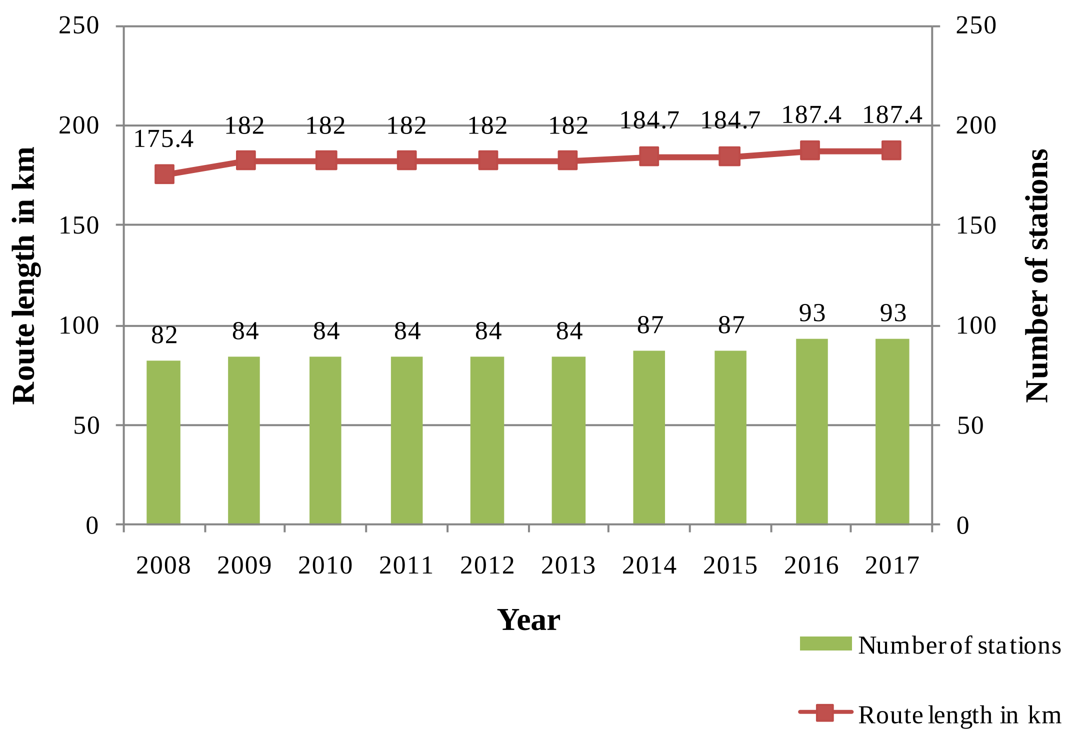
[iv] MTR's rail employees include operations, projects, corporate management, and supporting staff.

[v] Data were obtained from various issues of the Monthly Traffic and Transport Digest published by the Hong Kong Transport Department.

[vi] Data were obtained from Labor Force published by the Hong Kong Census and Statistics Department.

3. Results and Analysis

MTR's urban rail system had nine city lines and an airport express with 82 stations and a total route length of 175.4 km in 2008. It expanded slightly to eleven lines with 93 stations and a total route length of 187.4 km in 2017. Figure 1 shows the route length and number of stations over the past decade.



Note: South Island Line commenced service in December 2016, adding four new stations to MTR's urban rail system.

Figure 1. Route length and number of stations during the period 2008-2017.

Figure 2 shows that the number of passenger-trips of MTR urban rail system continuously increased from 1.309 billion in 2008 to 1.767 billion in 2017. This implies that MTR handled an average of 4.84 million passenger-trips per day in 2017. In 2017, MTR urban and cross-boundary services carried 1.75 billion passenger-trips with an average travel distance of 10.8 km while its airport express carried 17 million passenger-trips with an average travel distance of 28.5 km. Thus, MTR urban rail system handled 19.38 billion passenger-km travelled in 2017, increasing from 13.82 billion passenger-km travelled in 2008. The total electricity use for railway operations was 1573 GWh in 2017, increasing from 1290 GWh in 2008 as shown in Figure 2.

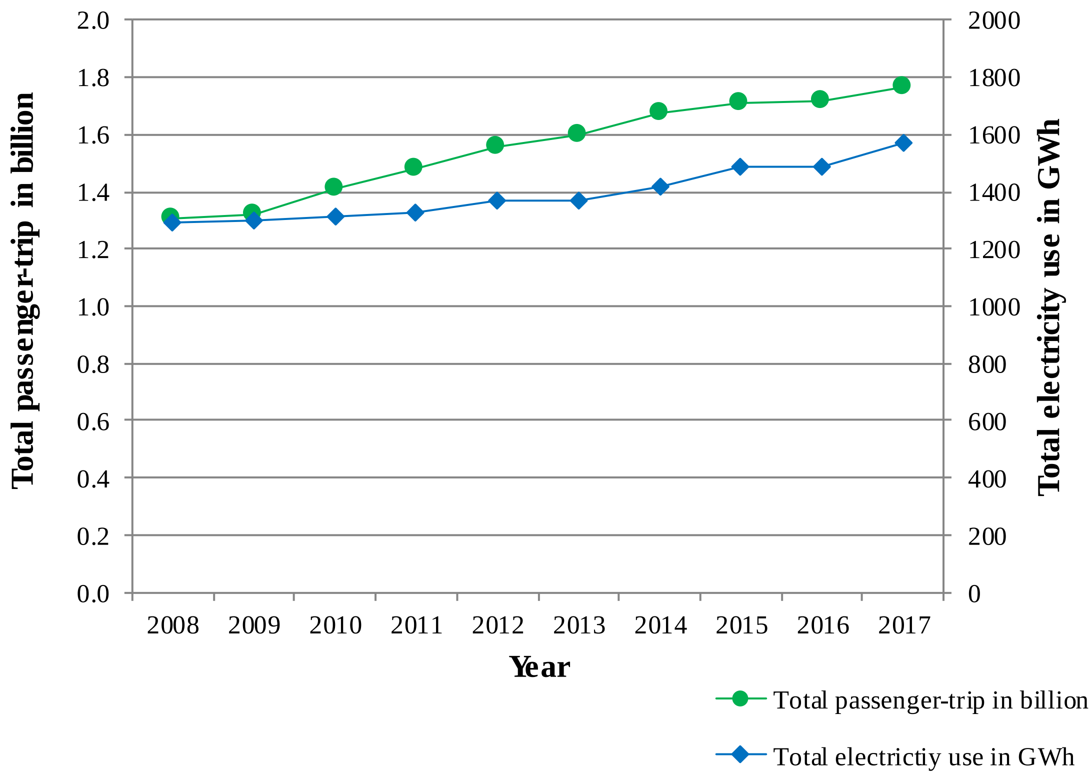


Figure 2. Total passenger-trip and electricity use during the period 2008-2017

3.1.Environmental performance

Energy efficiency was determined by dividing the total electricity use by the total passenger-km handled by MTR in each year for the period of 2008-2017. It was found that MTR had an energy efficiency of 0.081 kWh per passenger-km in 2017, improving from

0.093 kWh per passenger-km in 2008. GHG emission due to the operation of MTR urban rail system was calculated by multiplying its energy efficiency by emission factor of electricity consumed in Hong Kong which varied from year to year (To and Lee, 2017). It was found that MTR urban rail system produced 0.055 kg CO_2-e per passenger-km in 2017, decreasing from 0.071 kg CO_2-e per passenger-km in 2008. Figure 3 shows MTR environmental performance from 2008 to 2017.

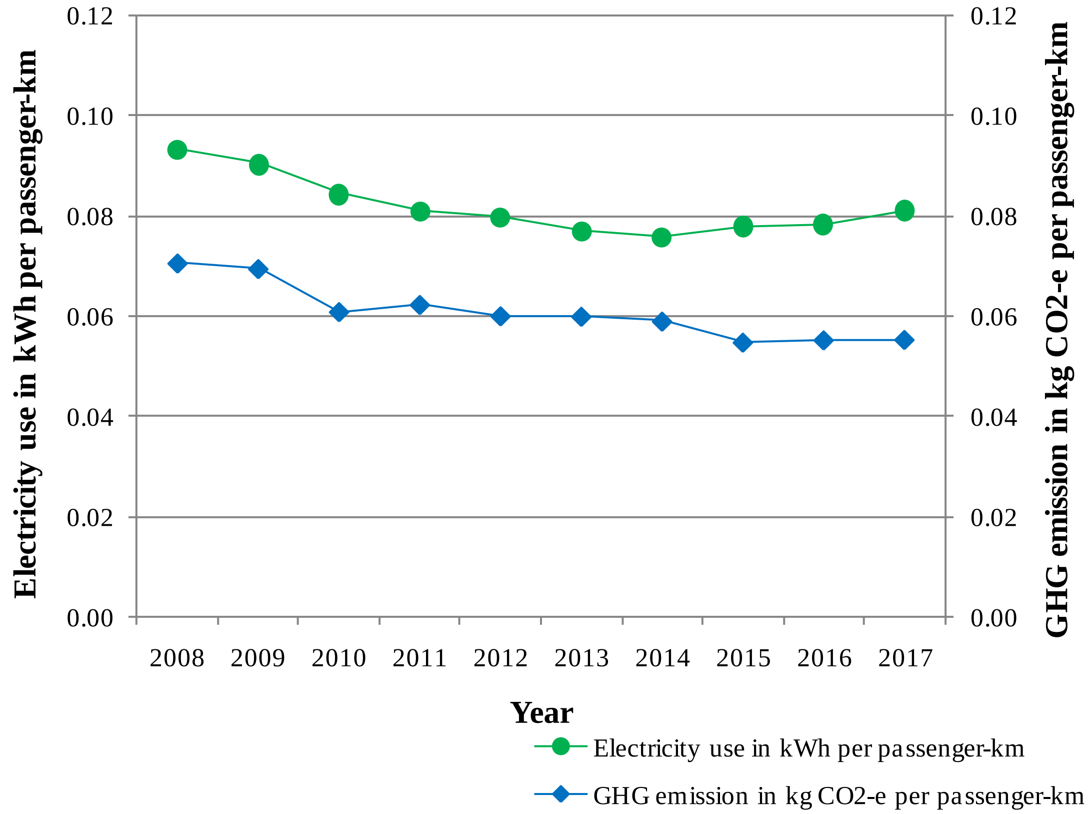


Figure 3. MTR environmental performance during the period 2008-2017

A more detailed observation in Figure 3 reveals that MTR electricity use per passenger-km decreased continuously from 0.093 kWh per passenger-km in 2008 to 0.075 kWh per passenger-km in 2014. It then increased slightly back to 0.081 kWh per passenger-km in

2017. Additionally, GHG emission per passenger-km also decreased from 0.071 kg CO_2-e in 2008 to 0.059 kg CO_2-e in 2014. After that, GHG emission further dropped to 0.055 kg CO_2-e in 2017. It should be noted that Hong Kong's fuel mix for electricity generation had changed slightly by using more natural gas as primary energy source and importing more power from the Daya Bay Nuclear Power Plant since 2015. The detailed numerical values of MTR's environmental performance were summarized in Table 3.

Table 3. MTR sustainability performance during the period of 2008-2017

		Year									
Dimension	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Environmental											
- Electricity use	kWh per passenger-km	0.093	0.091	0.085	0.081	0.080	0.077	0.076	0.078	0.078	0.081
- GHG emission [i]	kg CO_2-e per passenger-km	0.071	0.070	0.061	0.062	0.060	0.060	0.059	0.055	0.055	0.055
Economic/financial											
- Tobin's q	dimensionless	0.638	0.870	0.899	0.736	0.855	0.789	0.816	0.933	0.865	1.043
- Operating margin	percentage	48.1	47.3	50.2	49.7	49.2	48.6	47.5	47.0	47.7	45.7
Social											
- Public transport	percentage share	31.5	32.1	33.3	34.2	35.2	35.6	36.8	37.2	37.3	38.2
- Employment	percentage share	0.301	0.313	0.335	0.347	0.358	0.376	0.386	0.394	0.403	0.396

Note:
[i] Emission factor of electricity consumption varied from 0.681 to 0.780 kg per kWh during the period of 2008-2017 because Hong Kong's power companies used different proportions of coal, natural gas, and heavy oil to generate electricity every year (To and Lee, 2017b). Additionally, the amount of imported electricity from Daya Bay Nuclear Power Plant varied from year to year (To and Lee, 2017b).

We also calculated MTR electricity use in terms of kWh per revenue-car km which has been used to compare energy consumption and GHG emission by alternative urban transport systems (Wang, 2011). Figure 4 shows GHG emission due to the electricity consumed in Hong Kong and MTR electricity use per revenue-car km from 2008 to 2017.

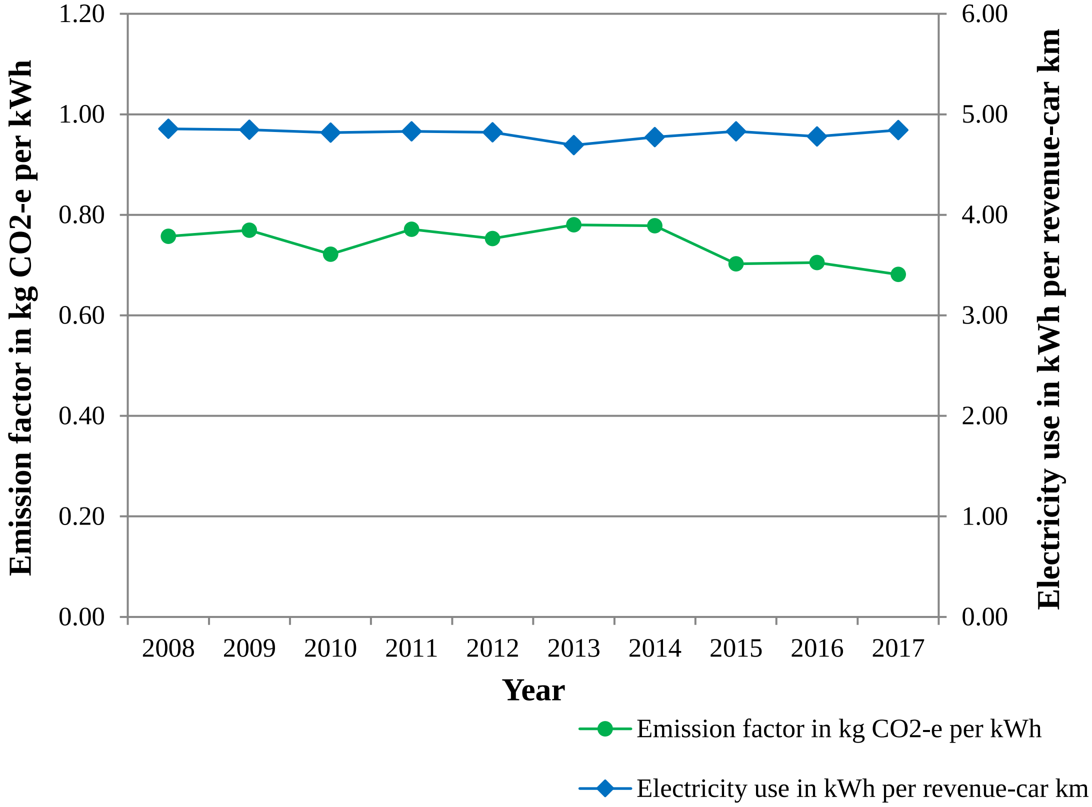


Figure 4. Emission factor of electricity and MTR electricity use in terms of kWh per revenue-car km during the period 2008-2017

A more detailed observation in Figure 4 identifies that GHG emission per kWh electricity consumed in Hong Kong varied between 0.722 and 0.780 kg CO_2-e per kWh from 2008 to 2014. GHG emission per kWh electricity consumed then decreased to around 0.70 kg CO_2-eq per kWh in 2015 and 2016, and further decreased to 0.681 kg CO_2-e per kWh in 2017. MTR electricity use per revenue-car km changed very slightly during the period of 2008-2017. It ranged from 4.69 to 4.86 kWh per revenue-car km with a mean value of 4.81 kWh per revenue-car km and a standard deviation of 0.05 kWh per revenue-car km.

3.2.Economic performance and social performance

According to MTR's annual reports, the firm's market value and total asset value were HKD 101.6 billion and HKD 159.3 billion, respectively at the end of 2008. The calculated Tobin's q for 2008 was 0.638, meaning that MTR was undervalued by the market. MTR's market value increased to HKD 275.2 billion while its total asset value increased relative slowly to HKD 263.8 billion in 2017, resulting in a Tobin's value of 1.043 in 2017. Figure 5 shows MTR's market value and total asset value from 2008 to 2017.

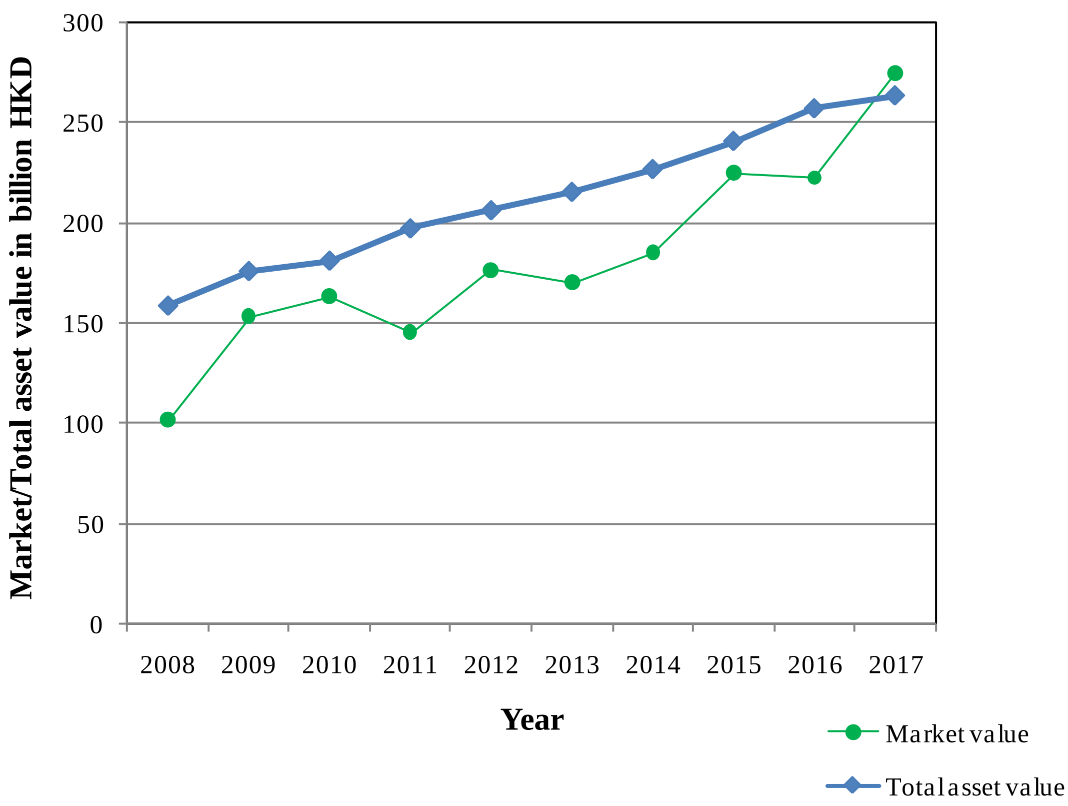


Figure 5. MTR's market value and total asset value during the period 2008-2017

Additionally, MTR's operating margin improved from 48.1 percent in 2008 to 50.2 percent in 2004, then dropped almost continuously to 45.7 percent in 2017. Table 3 presents MTR Tobin's q and operating margin from 2008 to 2017. It shows that MTR's key economic performance did not produce a consistent pattern because its Tobin's q value increased erratically from 1.002 to 1.413, depending on many other exogenous factors like the global economic outlook and the domestic market conditions.

MTR social performance had improved continuously during the period of 2008-2017. MTR carried 1.309 billion passenger-trips and employed around 11 thousand people for its rail operation in 2007. These figures increased to 1.767 billion passenger-trips and 15.6 thousand employees in 2018 as shown in Figure 6. Hence, MTR carried more and more share of public transport, increasing from 31.5 percent share of public transport in 2008 to 38.2 percent share of public transport in 2017. MTR also provided more job opportunities to people of Hong Kong. Its rail operation employed 10.9 thousand people i.e. 0.301 percent of total employment in 2008. MTR rail operation employed 15.6 thousand people i.e. 0.396 percent of total employment in 2017. MTR's social performance over the years is also presented in Table 3.

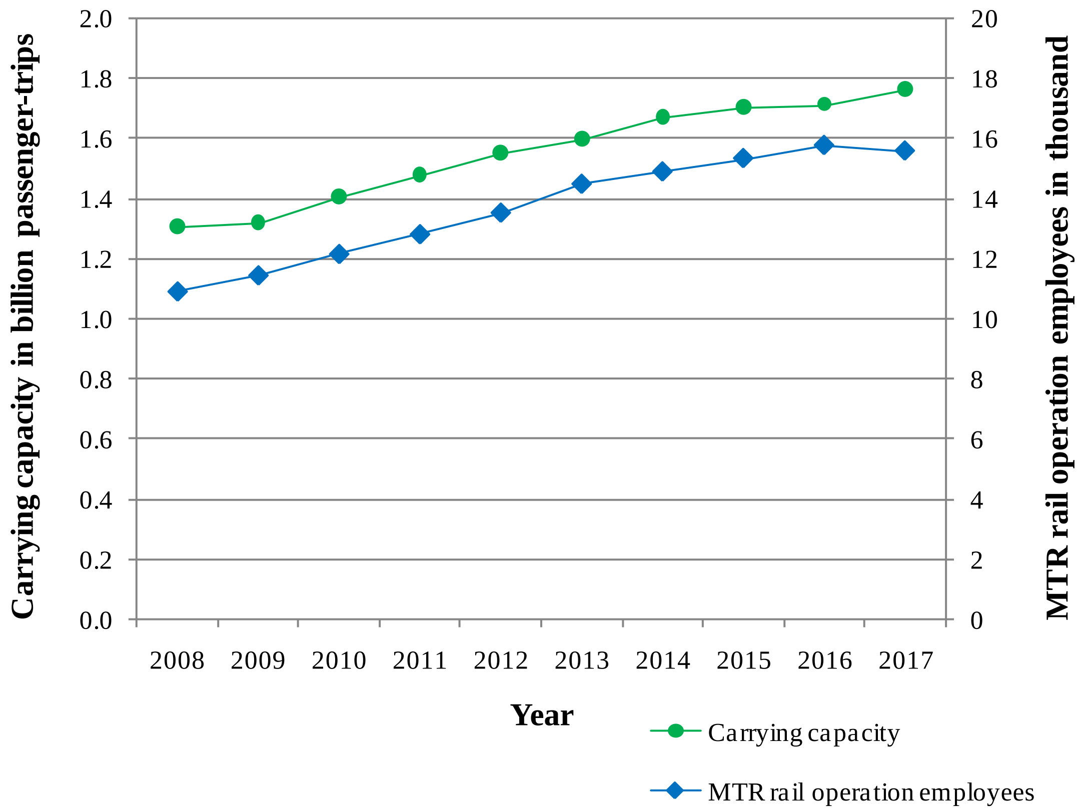
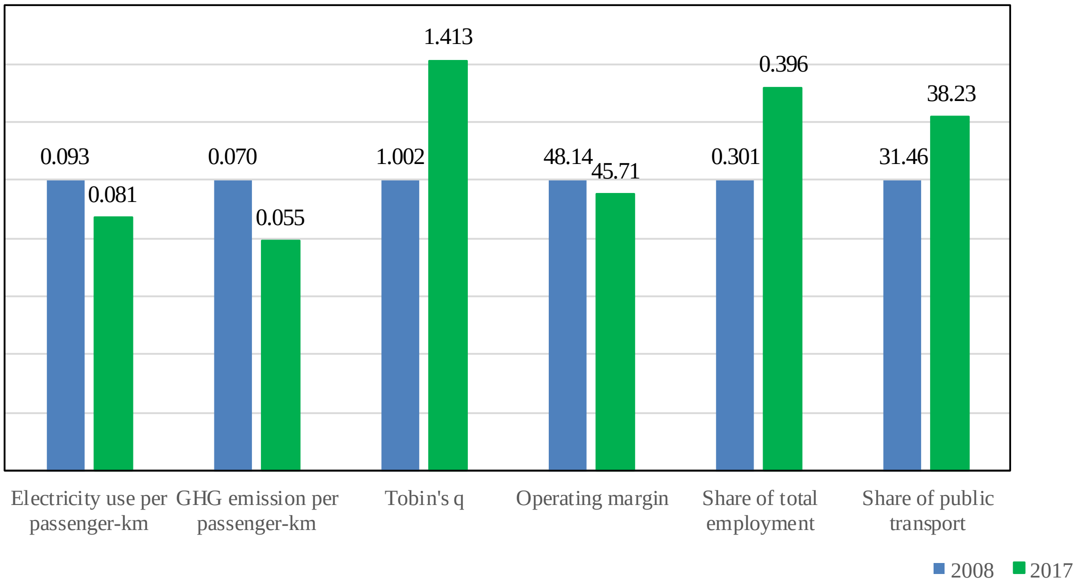


Figure 6. MTR's carrying capacity and number of employees during the period 2008-2017

An overview of the changes in sustainability performance is shown in Figure 7 that contrasts MTR environmental, economic, and social performance in 2008 and 2017, respectively.



Note: Sustainability performance in 2008 was used as the base year.

Figure 7. Sustainability performance of MTR in 2008 and 2017

3.3.Comparison of rail energy efficiency in different countries, cities or regions

Table 4 presents the energy efficiency of urban rail networks in different countries, cities, or regions. Kenworthy (2008) focused on energy use in different transport modes in cities and analyzed their efficiency based on the 1995 data. Besides, Kenworthy (2008) did not report load factors for different transport modes in different regions, making comparison to be rather difficult. Nevertheless, it was observed from the recent publications (Davis and Boundy, 2018; Li et al., 2018) and the present study that rail energy efficiency tended to improve when load factor increased. For example, urban rail in the U.S. had an energy efficiency of 0.50 MJ per passenger-km at a load factor of 25.8 persons per train-car. Hong Kong MTR had an energy efficiency of 0.29 MJ per passenger-km in 2017 at a load factor of 59.7 persons per revenue-car. Shanghai urban rail had an energy efficiency of 0.102 MJ per passenger-km for rail traction at a load factor of 82 persons per train-car.

Table 4. Urban rail efficiency in different countries, cities or regions

Locations	Energy efficiency (MJ per passenger-km)	Source of data	Load factor (persons/train-car)
Hong Kong, China	0.29	This study – for 2017	59.7
The U.S.	0.50	Davis and Boundy (2018)	25.8
Australia	0.46-0.56	Mulley et al. (2017)	n.a.
Toronto, Canada	1.19	Saxe et al. (2017)	n.a.
Shanghai, China	0.102 for rail traction	Li et al. (2018)	82
Higher income regions[i]			
- USA	1.65	Kenworthy (2008)	n.a.
- CAN	0.49	Kenworthy (2008)	n.a.
- WEU	0.48	Kenworthy (2008)	n.a.
- HIA	0.19	Kenworthy (2008)	n.a.
Lower income regions[i]			
- EEU	0.21	Kenworthy (2008)	n.a.
- LAM	0.19	Kenworthy (2008)	n.a.
- LIA	0.46	Kenworthy (2008)	n.a.
- CHN	0.05	Kenworthy (2008)	n.a.

Note:

[i] Kenworthy (2008) compiled his data during the period of 1998-2000 and analyzed energy use in the urban passenger transport systems of cities based on the 1995 data. He categories cities into different regions as: USA – US cities, CAN – Canadian cities, WEU – Western European cities, HIA – High income Asian cities, EEU – Eastern European cities, LAM – Latin American cities, LIA – Low income Asian cities, and CHN – Chinese cities.

3.4.Comparison of energy efficiency between MTR and public franchised bus

Hong Kong has five companies operating public franchised bus services. Two of the major bus companies, the Kowloon Motor Bus (KMB) Company Limited and Long Win Bus (LWB) Company Limited, are owned by Transport International Holdings Limited (TIHL) – a listed company in Hong Kong. TIHL operated in total 4,217 double-deck public buses i.e. 71 percent of the total number of public franchised buses in 2017 (TIHL, 2018). According to its 2017 Annual Report (TIHL, 2018), KMB and LWB consumed 8,552,000 GJ of diesel oil and offered 282 million vehicle-km bus services in 2017. Thus, Hong Kong's public-franchised bus was estimated to have 30.33 MJ per bus-km while MTR had

17.44 MJ per revenue-car km (or 4.844 kWh per revenue-car km). Table 5 presents energy efficiency of MTR and public-franchised bus in 2017. It shows that emission factor of MTR was 0.055 kg CO_2-e per passenger-km and that of public-franchised bus was 0.080 kg CO_2-e per passenger-km when factor load was 19.1 percent of the full capacity for both transport modes.

Table 5. Energy efficiency of MTR and public franchised bus

Item	Unit	MTR	Public franchised bus
Energy efficiency	MJ per revenue-car (or bus) km	17.44	30.33
Emission factor	kg CO_2-e per MJ electricity/diesel	0.189	0.0754[i]
Vehicle emission	kg CO_2-e per revenue-car km	3.30	2.29
Max. capacity	persons	312.5[ii]	150
Factor load	persons per revenue-car	59.7[iii]	28.7[iii]
GHG emission	kg CO_2-e per passenger-km	0.055	0.080

Notes:
[i] The Intergovernmental Panel on Climate Change (2010) indicated that emission factors of diesel oil are 74,100 kg of CO_2/TJ, 3.9 kg of CH_4/TJ, and 3.9 kg of N_2O/TJ while the global warming potential of CH_4 and N_2O relative to CO2 are 25 and 298, respectively. Hence, emission factor of diesel oil is 0.0754 kg CO2-e per MJ.
[ii] Maximum capacity of MTR train was estimated based on the data provided in MTR annual report.
[iii] The same factor load i.e. 19.1 percent was applied to MTR urban rail and public-franchised bus.

4. Discussion

MTR environmental performance in terms of energy efficiency improved from 0.093 kWh per passenger-km in 2008 to 0.076 kWh per passenger-km in 2014, but with a cost – passenger density increasing from 52 persons per revenue-car (55 persons per city line car and 16 persons per air express car) to 62.9 persons per revenue-car (67 persons per city line car and 18 persons per air express car). In 2017, MTR passenger density was 59.7 persons per revenue-car (63 persons per city line car and 20 persons per air express car) and its energy efficiency was 0.081 kWh per passenger-km. On the other hand, MTR environmental performance in terms of GHG emission improved continuously from 0.071 in 2008 to 0.055 kg CO_2-e per passenger-km in 2017 because of the improvement of energy efficiency and the increasing use of cleaner fuels in electricity production over the past few years. The value of 0.055 kg CO_2-e per passenger-km is significantly lower than the amount of GHG emission from public franchised bus at 0.080 kg CO_2-e per passenger-km for the same load factor of around 20 percent. Additionally, Davis and Boundy (2018) estimated that energy intensity was about 1.93 MJ per passenger-km by private car with a load factor of 1.5 persons per car. As the Intergovernmental Panel on Climate Change (2010) indicated that emission factors of gasoline are 69,300 kg of CO_2/TJ, 3.8 kg of CH_4/TJ, and 5.7 kg of N_2O/TJ while the global warming potential of CH_4 and N_2O relative to CO_2 are 25 and 298, respectively, emission factor of gasoline is 0.0711 kg CO_2-e per MJ. Thus, emission factor of private car is 0.137 kg CO_2-e per passenger-km, i.e. about 150 percent more than that of MTR and 71.3 percent more than that of public franchised bus.

In sum, MTR environmental performance in terms of energy efficiency and GHG emission per passenger-km would be further improved in the near future because its load factor is very likely to increase continuously due to the increase of Hong Kong's population and visitors coming to Hong Kong (MTR, 2019b). MTR economic performance in terms of Tobin's q will likely stay in line with the market performance of Hong Kong Stock Exchange but its economic performance in terms of operating margin is likely to decrease due to high operating costs. MTR social performance in terms of share of Hong Kong's total employment and share of public transport would continuously improve because more city lines are under construction and more and more people live in the vicinity of MTR stations.

5. Conclusions

Urban rail system is an important feature of a smart and sustainable city. This paper performed a sustainability assessment of MTR urban rail system based on the triple-bottom line approach. Using MTR's annual and sustainability reports over the period of 2008-2017, we found that MTR reduced its electricity use from 0.093 kWh per passenger-km in 2008 to 0.081 kWh per passenger-km in 2017, thus reducing its GHG emission from 0.071 kg CO_2-e per passenger-km in 2008 to 0.055 kg CO_2-e per passenger-km in 2017. Moreover, MTR had continually improved its social performance over the period of 2008-2017. The analyzed results showed that MTR carried a higher percent of public transport demands over the years, increasing 31.5 percent in 2008 to 38.2 percent in 2017. MTR also offered a higher proportion of job opportunities to the community as it employed about 0.4 percent of Hong Kong's labor force in 2017, increasing from 0.3 percent of Hong Kong's labor force in 2008. Nevertheless, MTR's economic performance did not show a consistent pattern. On one hand, Tobin's q values showed that MTR has been valued more positively by the market in recent years. On the other hand, MTR's operating margin for rail operation fluctuated and had a relative low value of 45.7 percent in 2017.

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