An environmental benefit analysis of bike sharing in New York City

Abstract: Bike-sharing systems provide the public with more transport choices. To elaborate more effectively and comprehensively bike sharing's prospective contribution to urban sustainable development, a quantitative estimation of bike sharing's environmental benefits is performed through a case study of New York City's bike-sharing systems. Using a long-term series of big data, the environmental benefits of bike sharing in New York City are evaluated from a spatiotemporal perspective. Data on a total of 48 million bicycle trips between January 2014 and December 2017 are analysed. During 2014-2017, bike travellers saved 13,370 tonnes of oil equivalent, and decreased 30,070 tonnes of carbon emissions and 80 tonnes of nitrogen oxides. Evaluation of gender dynamics reveals that men produced greater environmental benefits through the bike-sharing initiative.

Keywords: bike-sharing systems, big data, energy consumption, carbon emissions, nitrogen oxides, gender

1. Introduction

The popularity of private motor vehicles and a well-developed transport network system have led public to rely strongly on motorised travel modes (Khreis et al., 2016; Morton, 2018). Carbon emissions from transportation represent approximately a quarter of human activities, and fossil energy consumption from transportation negatively impacts the environment. Therefore, governments of various countries pay great attention to the transportation industry and have taken measures to reduce the carbon emissions during transportation (Aamaas and Peters, 2017). To accelerate the development of sustainable transportation methods, many governments promoted the use of shared bicycle systems (Chen et al., 2020). For example, bike-sharing systems proved popular in the US. In 2016, the number of participants exceeded 28 million, an increase of 25 per cent over 2015. The total number of shared bicycles closely aligns with the total number of American rail trips (Wang et al., 2018). International environmental protection organizations are demanding the promotion of vehicles that contribute to environmental sustainability – including bicycles and low-energy-consuming electric vehicles – with the intention to reduce urban pollution indexes and improve traffic safety (Dora et al., 2000). To achieve these aims, cities can either provide subsidies to private owners of bicycles and low-energy automobiles, or they can promote sharing economy solutions such as bike-sharing and ride-sharing schemes through a variety of schemes (Mi and Coffman, 2019), which are becoming increasingly popular with younger consumers. Austwick et al. (2013) and Zhang et al. (2015) point out that bike sharing leads to a significant drop in CO_2 emissions, reduces the use of fossil fuels, and provides people with a practical mode of transport. Bocken et al. (2014) add that the bike-sharing system is key to reduce levels of pollution and car use, as well as providing people with a healthy means of transport and supporting the drive to use alternative energy sources. These benefits are enabled by alternatives to commute by automobile and to greater public transit use for all types of journeys (Caulfield et al., 2017; Shaheen et al., 2013). Sharing bicycles as a means of transport provides travel convenience for citizens. Such systems can effectively reduce traffic congestion and reduce environmental pollution.

Many scholars have explored and analyzed the bike-sharing systems in different cities. Scott and Ciuro (2019) provide a practical case study of Hamilton bike-sharing systems. They analysed the city’s climate, time variables and road transport hub. They found that when the bike sharing stations near the university, it would attract more users. Pfrommer et al. (2014) focused on the Barclays bicycle rental programme. Due to a combination of improved vehicle redistribution between users and better price incentives, shared mobility systems allow more efficient operation of transport within cities. Bicycle sharing system initiatives lead to a drop in rush hour traffic, fewer people fighting for parking spaces downtown and rush hour bottlenecks and congestion caused by heavy traffic. Frade et al. (2015) found that communities which have adopted a bike-sharing system have found it an excellent alternative and supplement to the car, and ideal for commuting. Half of Nice Ride's members reduced the number of trips they made in cars thanks to a bike-sharing system (Pfrommer et al.,2014) and if this becomes a widespread activity, communities will have less congested roads, use cars less frequently, thereby making it easier to travel through urban areas.

The existing literature on bike-sharing systems is vast, but studies focussing on the long-term environmental benefits of shared bicycle’s studies are very limited. Therefore, this paper aims to quantitatively evaluate the environmental benefits of shared bicycles in New York. The driving trajectory of shared bicycles undergoes analysis from a spatial perspective, and the use of big data analysis obtains the energy consumption saved by using shared bicycles. This research primarily makes two contributions. Firstly, data covering four years helps explore the environmental benefits of shared bicycles. Using a longer period of data as the basis for analysis can provide more accurate estimates. Secondly, the study introduces gender as mode of analysis and separately calculates the environmental benefits of shared bicycles used by men and women to provide data support for future research.

2. Literature review

2.1 The environmental benefits of bike-sharing systems

Bike-sharing systems is one of the most energy-efficient forms of transport available at present, so bike-sharing schemes will play a major role in minimising carbon emissions and other types of pollutants (Circella et al., 2016). A rise in the number of people using bike-sharing schemes will provide a solution to the first and last-mile issues which undermine public transit systems, and eradicate the need for short one-way fossil-fuel powered journeys. In 2013, bike-sharing systems users rode 560,424 miles, and in the process saved the atmosphere from being polluted by 1,028,836 pounds of CO_2 emissions in Sacramento (Muarer, 2011). Investing in bicycles results in substantial savings for communities. This means that bicycling and bike-sharing systems play a role in protecting the environment, since the fall in carbon emissions leads to less air pollution and thus tackles the globate climate change issue facing all of us.

Bike-sharing programmes have been adopted in many countries around the world, making contributions to the urban environmental benefits (Rojas-Rueda et al., 2012). In New York City, the number of people using bike sharing has gradually increased. The use of bicycles can increase the amount of exercise, reduce environmental pollution (Dora et al., 2000). Bike sharing can promote the sustainability in cities, by reducing vehicle emissions and reducing air pollution. Some researchers focus on estimating environmental benefits in a specific city, like Shanghai, China (Zhang and Mi, 2018). They found that when users use shared bicycles in Shanghai can saved 8,358 tonnes of gasoline. Nitrogen oxides and carbon dioxide were reduced by 64 tonnes and 25,240 tonnes, respectively. From a spatial perspective, Shanghai is a densely populated city, the environmental benefits are more significant. In addition, according to the United States Census Bureau (2014), London and Washington D.C. have 36 per cent and 46 per cent of residents respectively go to work by car, but the car mode substitution rate calculated through the bike-sharing programme is a low 2 per cent and 7 per cent, respectively. If these short car journeys were replaced by bicycle rides, this would make an enormous impact on congestion and lower pollution levels.

Participation in the shared bicycle programme can both positively and negatively impact the urban environment. The production of bicycles requires raw materials, such as steel and aluminium products. A large amount of aluminium (55.43 per cent) and rubber (16.27 per cent) are used in the production process, and the environmental pollution caused by the creation of raw materials cannot be ignored (Mao et al., 2021). An additional study found that the ageing, underutilisation and increase of shared bicycles will harm the environment (Zheng et al., 2019). In view of these findings, it is clear that the formation of an effective and sustainable bicycle production and transportation industry will reduce the negative impact on the environment (Leister et al., 2018). According to Mao et al. (2021), the positive environmental impact during the use phase will offset the negative impact caused by the production and recycling of shared bicycles.

2.2 Temporal variables and spatial variables

Distinct time periods may influence engagement in bike sharing initiatives. Faghih-Imani et al. (2016) identified a time variation effect on the number of bicycles used in Montreal, Canada. Found in other research, bicycle flow peaked in the morning and evening. Compared with the morning peak time, the evening peak time was longer, and bikers travelled longer distances.

Significantly, the frequency of bike sharing increased on Friday and Saturday nights. Moreover, Gebhart and Noland (2014) identified daily variations between peak and non-peak periods for bike-sharing systems use in Washington, DC, along with seasonal variations (accounting for weather and darkness variables). Usage peaks in the morning and afternoon on weekdays, indicating that such programmes are commonly used as a means of commuting (O'Brien et al., 2014).

Spatial variables, capturing elements of urban planning and the built environment, significantly affect bike-sharing systems usage. Bachand-Marleau et al. (2012) employed BIXI data to analyse the contexts in Vancouver, Canada, and Seattle, USA. With assistance from government and city advisory agencies, potential station locations were identified in these cities. The survey results demonstrated that bicycle station infrastructure, surrounding land use and the built environment affect the usage of bike-sharing programmes. Wang et al. (2015) replicated this research, determining that cycle path planning is imperative for encouraging consumer uptake. Ultimately, they found that when cycle paths are planned effectively, the bike-sharing initiative usage rate will markedly increase. Nair et al. (2013) undertook an investigation in Sao Paulo, Brazil. Statistical analysis identified a positive correlation between the number of bicycles used and travel between each terminal. However, a negative correlation was found for train stations with high traffic. Therefore, Buck and Buehler (2012) concluded that having docks close to public stations would attract more shared bicycle customers. The higher incidence of bicycle passengers was connected to areas with high job density and around food vendors. Cao et al. (2019) used the kernel density estimation method to analyse the spatial distribution of shared bicycles. From the perspective of spatial distribution, the distribution of shared bicycles correlates with the urban public transport system. The location, 500m away from the bus station and 1.5km away from the subway station, will act as the main distribution area of the shared bicycle system. The number of shared bicycles stored varies according to the distance of the city's bus system. In addition, According to the research results of Jahanshahi et al. (2020), there exists inequality in the distribution of shared bicycle sites. People with higher education and income levels tend to be close to shared bicycle facilities, as do young people's communities. Barbour et al. (2019) confirmed this view and found that super-users are more likely to be young men residing close to bike-sharing systems stations with an income level under $75,000. Therefore, urban planners and policy-makers need to optimise the spatial distribution of shared bicycles to promote the sustainable development of urban shared bicycle systems.

3. Data and methods

3.1 Bike-sharing systems and data collection

New York City's bike-sharing service, Citi Bike, is the largest such program in the USA. Since its launch in May 2013, it has expanded to become a fundamental component of New York City's transport infrastructure. The bikes can be unlocked at one station and returned to any other station in the system, making them ideal for various trip purposes, whether for school/work commuting or leisure activities. Firstly, the bike-sharing system value approach considers how the business model meets a specific customer need - for example, by offering 'the last mile' solution, encouraging tourists to use energy-efficient and environmentally friendly travel modes. Secondly, the profit formula is also used by researchers to determine how companies generate profit, whether through a pay-per-ride approach, subscriptions or advertising. Thirdly, studies can concentrate on key processes, which allow the service proposition to be realised, and this includes features such as the maintenance and relocation of bikes (Boons et al., 2013). The trip data used here are publicly available and easily downloaded from the program's official website (https://www.citibikenyc.com/). The data provide detail on basic trip attributes, such as trip duration, start/end time, start/end stations, station ID, the longitude and latitude of the start/end stations, bike ID, and user type. The data adopted in this paper cover a four-year period (between January 2014 and December 2017), with a total of 48.23 million trips. Of these trips, 11.17% were taken by customer users (those holding a 24-hour pass or 3-day pass), while 88.83% were taken by subscribed users (annual members). The total number of bike trips, the total number of stations and the total duration of bike trips steadily increased between 2014 and 2017, while the mean trip duration remained relatively stable over the years (Table 1).

Table 1 Basic description of bike trips taken in bike-sharing systems in New York City.

	2014	**2015**	**2016**	**2017**	**2014-2017**
Average trip duration (minutes)	14.19	16.13	15.99	16.58	15.9
Total number of bike trips (million)	8.08	9.94	13.85	16.37	48.23
Total number of bike stations	332	492	653	811	870
Total duration of bike trips (years)	218.12	305.07	421.09	516.11	1460.39

3.2 Methods

3.2.1 Estimating trip distances and locations

To estimate the environmental advantages, the first stage involves analysing the location of the bicycle stations and the number of people the stations serve. The bike-sharing data include trip distance, trip origin and destination stations' longitudes and latitudes. To provide a more accurate estimation of bike station locations, the steps of the station location estimation are as follows.

Step 1: Extract all cyclable roads in New York City from OpenStreetMap. Road extraction is realised using OSMnx, the Python package will be used to download administrative boundary outlines and road grids from OpenStreetMap.

Step 2: Construct road networks using the Network Analysis function provided by ArcGIS, the most widely applied commercial GIS software.

Step 3: Extract the specific location of the bicycle parking station from ArcGIS and the number of people at each station. Analyse the concentrated area of the bicycle docking stations according to OpenStreetMap.

3.2.2 Assess the energy savings and environmental benefits of the bike-sharing system

The main purpose of this paper is to assess the environmental benefits of using shared bicycles. Therefore, we need to evaluate the total amount of gasoline and diesel oil consumption saved by the use of shared bicycles. In general, travel distances and travel times often result in commuters choosing different modes of travel. According to Joachim (2010) travellers may choose different modes of transport for different travel distances, energy consumption can be calculated (Table 2). In this calculation, walking and using shared bicycles are considered to be zero consumption and have no negative environmental impact. In the US, citizens by considering differences based on culture, population density, climate, etc., are more likely to take a car within the long distance. Gasoline and diesel oil are consumed during transport and use, so we assess the energy consumption of gasoline and diesel oil exploitation and distribution. Different vehicles are used according to different driving distances, and we set different thresholds to calculate the energy consumption of a vehicle (Table 3).

Table 2 Modal split by trip distance.

Km	On foot	Bicycle	Bus	Car
≤ 0.2	94%	5%	0%	1%
0.2-0.4	81%	11%	0%	7%
0.4-0.6	64%	19%	0%	17%

0.6-0.8	38%	19%	1%	40%
0.8-1	56%	21%	1%	21%
1.0-1.5	25%	19%	3%	53%
1.5-2.0	18%	17%	5%	60%
2-3	10%	14%	7%	68%
3-5	4%	9%	10%	77%
5-7	1%	6%	11%	81%
7-10	1%	4%	12%	82%
10-20	0%	2%	10%	87%
> 20	1%	1%	13%	85%

Data source: Joachim (2010).

Table 3 Basic parameters of energy consumption calculation.

Symbol	**Indicator** **Unit**	**Bus**	**Data source**	**Car**	**Data source**
P	Fuel consumption L/Km	0.006	PENNSTATE, 2012	0.088	ANDC, 2017
ρ	Fuel density Kg/L	0.85	SpeightJ, 2011	0.72	SpeightJ, 2011
λe	Exploitation efficiencies /	0.93	Ou et al., 2010	0.87	Yu et al., 2017
λt	Transport efficiencies /	0.99	Ou et al., 2010	0.95	Yu et al., 2017
CO_2	Carbon dioxide emission factor Kg/Kg	3.09	IPCC, 2006	2.93	IPCC, 2006
NO_x	Nitrogen oxide emission factor Kg/Kg	0.055	Ježek et al., 2015	0.006	Ježek et al., 2015

The energy consumption of a vehicle is calculated as

$$N = \begin{cases} \frac{d \cdot p_1 \cdot \rho_1}{\lambda_{e1} \cdot \lambda_{t1}} \\ \frac{d \cdot p_2 \cdot \rho_2}{\lambda_{e2} \cdot \lambda_{t2}} \end{cases} \quad (1)$$

N refers to the energy expended by the vehicle, d refers the commute distance (unit: km), p_1 (unit: L/km) refers to the bus's diesel consumption per unit commute distance, p_2(unit:L/km) indicates private car petrol consumption per unit commute distance. ρ_1 refers to the bus density of the diesel oil (unit: kg/L), and the ρ_2 means the car density of the gasoline (unit: kg/L). The λ_{e1} and λ_{t1} express the diesel oil efficiency of exploitation and transportation. The λ_{e2} is used to indicate gasoline mining efficiency, and the λ_{t2} symbol is used to indicate the efficiency of gasoline transport. In this study, we pay attention to the CO_2 and NO_X emissions, which are calculated according to the following formula. E is the emissions of vehicle gasoline and diesel oil consumption, and f_i is the emission factor of CO_2 and NO_X.

$$E = \begin{cases} d \cdot p_1 \cdot \rho_1 \cdot f_i \\ d \cdot p_2 \cdot \rho_2 \cdot f_i \end{cases} \quad (2)$$

Our sample data are from a company that divided the final result of energy consumption by the Citi company's market share (41%) to more fully assess the environmental benefits of the bike-sharing programme in New York City (from 2014-2017). We calculate the energy consumption of different vehicles based on different driving distances.

4 Results

4.1 Assessing the spatiotemporal characteristics of bike-sharing programmes

The New York City's basic characteristics relevant to the bike-sharing programme are demonstrated in Fig. 1, including bicycle platforms, urban road construction, the majority of building locations and river orientation. The bike station locations are displayed in ArcGIS, which shows a clear concentration of bicycle platforms in the Manhattan area (Midtown and Lower Manhattan). Roads were extracted from the OpenStreetMap, a pervasively adopted free spatial data source, using Boeing's (2017) OSMnx tool. Manhattan contains New York City's business district and the world's financial centre. Its population is very large given that the area has the highest density of employment places, with business, finance and catering all concentrated there. From a spatial point of view, New York is a densely populated city. Close to bus stations, subway stations, and shared bicycles around large shopping malls are frequently used. From a spatial point of view, New York represents a densely populated city. Shared bicycles are in frequent use around bus stations, subway stations and large shopping malls. This finding bears similarities with the work of Buck and Buehler (2012), who believe that areas with high-density work transportation and food service attract travellers to use shared bicycles. In addition, in the downtown area where the environmental benefits prove more significant, travellers in city center areas demonstrate greater willingness to use shared bicycle systems. Promoting participation in the plan provides a solution to urban environmental pollution.

Furthermore, in Fig. 1, blue, green, yellow and red signs represent the number of bicycles rented across Manhattan. Red signs, representing the largest number of trips, are particularly concentrated within the vicinity of city centre. This shows that shared bicycle use has become a widespread means of travel to public transport locations. Many of the existing bike-sharing systems run into problems trying to balance supply and demand, particularly during peak commuting times, or if their bike stations are located near bus stops or metro stations which experience heavy commuter traffic. One of the solutions is to use lorries to pick up and drop off bikes, to meet demand, or to introduce incentives which will make it more likely that users will move bikes to less occupied stations

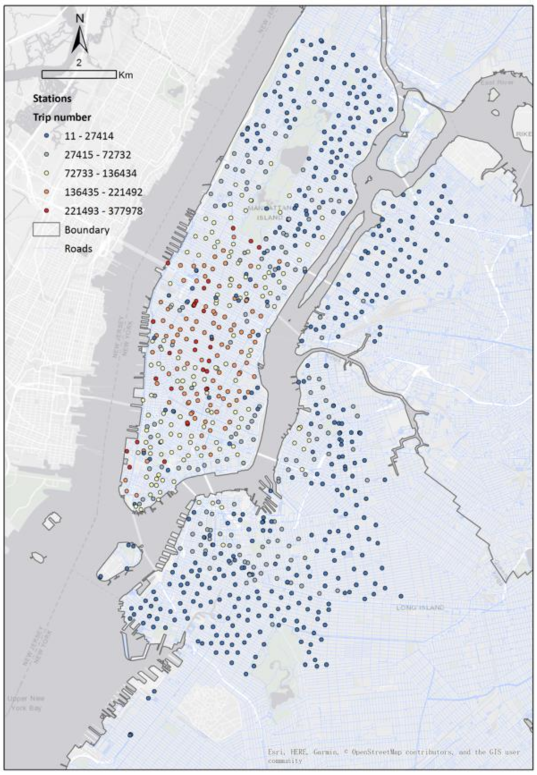

Fig. 1. New York City's bike sharing distribution.

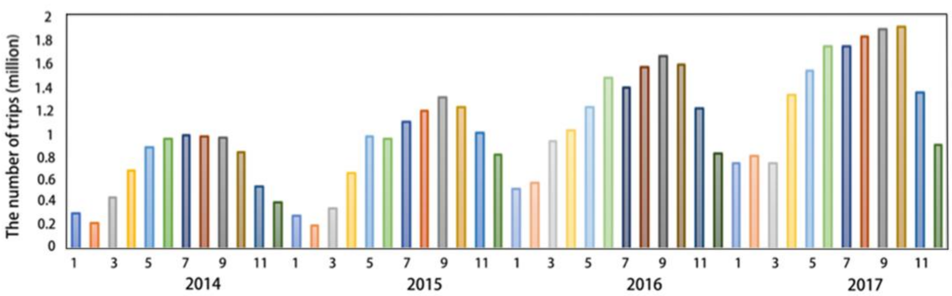

Fig. 2. The number of trips per month (from 2014-2017).

Between 2014 and 2017, the number of trips generated has steadily increased (Fig. 2). Bike sharing is used most in the summer months (June-September), whereas during winter (particularly in January-February), the number of trips declines substantially, with peak winter use not occurring until March. The low use in winter is primarily due to adverse weather conditions. Meanwhile, between 2014 and 2017, a general increase in the number of users is apparent. In 2015, the number of riders trended slightly downward starting in June and rose in September. The downward trend in June may also be related to the New York City school holidays. New York City's school holidays fall in June and July, which could lead to a drop in the number of users choosing bike-sharing systems.

The travel time spent using the bike-sharing programme was calculated according to travel statistics records (Fig. 3). As may be expected, during weekdays, the bike-sharing programme is used as a commuter tool. On workdays, two peak usage periods occur: from 8 am-9 am and from 6 pm-8 pm. The bicycle use period is longer at night than in the morning, evidencing cyclists' engagement in a broader array of activities and greater flexibility after work. Moreover, the data shows a small peak usage period around 1 pm, which likely corresponds to a minor fluctuation stemming from office employees travelling short distances to purchase lunch. More interesting data appears on the weekend, with user levels increase between 10 am and 4 pm. This result confirms the perspective of Nosal and Miranda-Moreno (2014), who found that bike-sharing is used as a means for leisure-related activities during weekends. In this regard, the peak period for commuting is from around 11 am to 7 pm. This result is attributed to weekend leisure, during which time users are more willing to use bicycle-sharing facilities as a mode of leisure transport.

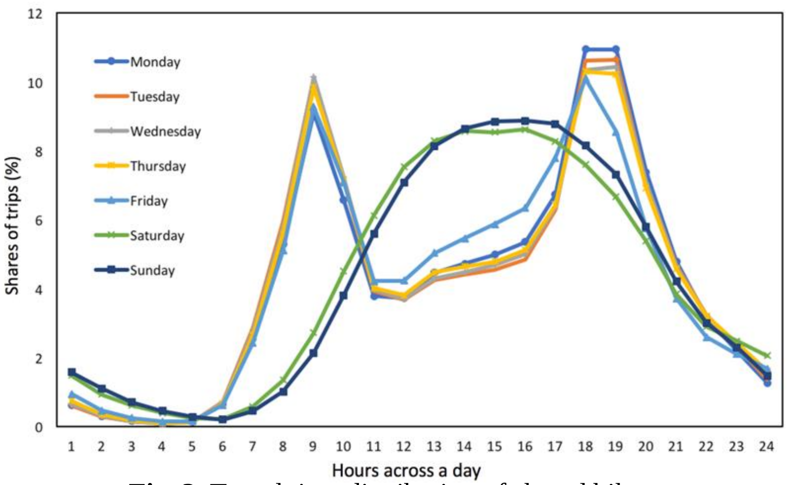

Fig. 3. Travel time distribution of shared bikes.

4.2. The environmental advantages of bike sharing

In 2017, New York City emitted approximately 54 million tonnes of CO_2 into the atmosphere, of which 35% originated from the transport sector (Pasion et al., 2017). The city's population is approximately 8.6 million, and the commutes cover a total distance of over 11.5 billion miles. The government's aim is to reduce CO_2 emissions from New York City's transport sector by 45% by 2030, which is an ambitious target (Environmental Protection Agency, 2017). The EPA (2017) has suggested that travellers are willing to choose low-carbon modes of travel, such as public transport. Regardless, the optimum solution is a zero-carbon mode, such as bicycles.

Currently, although just 31% of trips in New York City as single occupants of personal vehicles, the CO_2 emissions of this commuter group account for 60% of the overall traffic volume. Notably, 74% of New Yorkers support bike sharing as a means of travel. This statistic suggests that bike sharing is the right model for supporting commuting systems in cities to decrease CO_2 emissions (O'Brien et al., 2014). We calculated the energy savings from the bike-sharing systems between 2014 and 2017. Over time, bike use has a significant positive environmental effect (Fig.4). Concerning the morning and evening peaks of transport use, bike sharing's environmental advantages are most clearly evidenced. From 2014 to 2017, the use of bike-sharing systems saved 13,370 tonnes of oil equivalent, and decreased 30,070 tonnes of CO_2 and 80 tonnes of NO_x. At 6 pm, the highest peak appeared. At this time, bike sharing saved 1,420 tonnes of oil equivalent, saving 3,950 tonnes and 8 tonnes of CO_2 and NO_x respectively.

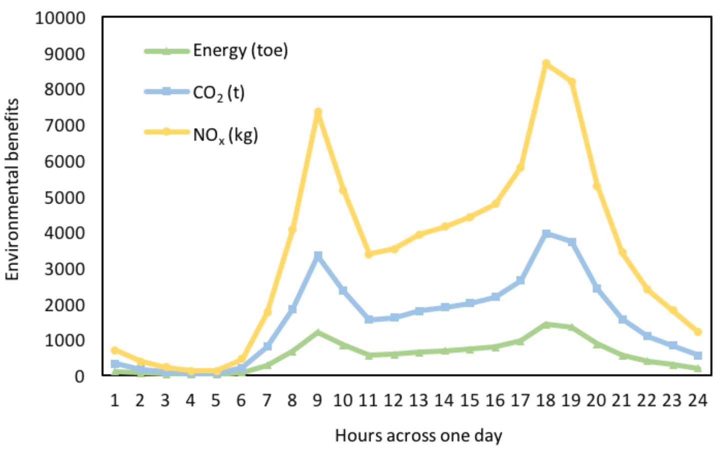

Fig. 4. Temporal distributions of the environmental benefits of bike sharing.

4.3 Environmental benefits of engaging in bike sharing by gender groups

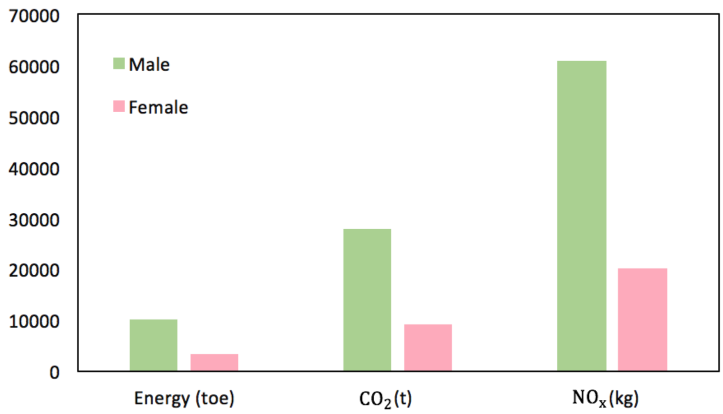

Fig. 5. Environmental benefits from female and male riders.

Gender also impacts on the usage of bike-sharing systems and related environmental benefits. Men saved more energy consumption via bike-sharing programmes than women (Fig. 5). Males use bicycles more often than females and spend more time riding. Males saved a total of 10,020 tonnes of oil equivalent, saved 27,800 tonnes and 60 tonnes of CO_2 and NO_x, respectively. Females saved 3,340 tonnes of oil equivalent, saved 9,260 tonnes of CO_2 and 20 tonnes of NO_x. This difference could be attributed to the bulkiness of shared bicycles: the weight of the bicycle might be too heavy for women, meaning they cannot ride flexibly. In addition, it is not safe for women to ride bicycles at night or in areas with low population density. As dockless bicycles become more common, bicycle designs should become more flexible and lighter, thus able to better accommodate female riders. According to the data, the majority of users take part in the programme. Therefore, both firm-level decision-makers and government and third-sector stakeholders in the shared bicycle system can introduce preferential policies to attract more people to participate in the project. In addition, the bicycle infrastructure correlates with the number of participants. City planners should build a strong bike-friendly infrastructure and plan clear bicycle roads with added safety protection measures for cyclists, thereby increasing the number of female users.

5. Conclusions

This paper has discussed the environmental benefits of the bike-sharing programmes in New York City from three perspectives. The majority of bike-sharing sites are located in Manhattan, and the distance between stations is relatively standardised. This is primarily to provide travellers with a convenient transport method. Between 2014 and 2017, an increasing number of users participated in the bike-sharing programme. We calculated energy emissions based on travellers' preferences for commuting modes. With regard to the time distribution of environmental benefits, peak energy conservation was achieved around 8 am and 6 pm. From 2014 to 2017, the use of bike-sharing systems saved 13,370 tonnes of oil equivalent, and decreased 30,070 tonnes of CO_2 and 80 tonnes of NO_x. This result contributes to urban traffic road management and low-carbon travel mode planning. Concerning gender dynamics, males have saved more energy through the bike-sharing programme than females, because men make a higher proportion of trips and tend to take longer rides.

The data confirmed that bicycle use as a mode for commuting can significantly diminish the urban pollutants. New York City has introduced plans for the transport sector, and citizens will be encouraged to work with city policymakers. This paper's calculations demonstrate that the shift in commuting patterns can contribute to diminishing the city's CO_2 footprint. When commuting distance is longer, people are more willing to take public transport. But using bike-sharing systems instead of public transport or cars has become a reasonable assumption. The increase in the use of shared bicycles may reduce the use of cars. The greater the proportion of bicycling that replaces previous travel by car, the greater the impact of the plan on reducing the number of rides and all related environmental benefits. Additionally, the energy conservation of males and females was calculated separately in this paper. Along with the potential physiological limitations on the wider use of bike schemes by females, further variables potentially restricting women's use should be considered, such as bicycles' comfort levels or bicycle parking locations, which could deter women from using shared bicycles at night. Therefore, the shared bicycle system requires continuous improvement to meet the needs of more users. For example, policymakers and planners need to establish a complete and dynamic regulatory system to supervise, adjust and dispatch shared bicycles to ensure the effective use of bicycles in each area. This recommendation is consistent with a recent study investigating the potential of bike-sharing to promote transport resilience in the event of mass transit outages, which is another potential indirect source of environmental benefits that could be further elaborated (Cheng et al., 2021). In the context of energy conservation and emission reduction, the shared bicycle plan has already entered the international arena.

Although this research has concentrated on the bike-sharing programme's environmental benefits, there are several avenues for further analysis. The first relates to privacy issues, as we did not obtain specific driving routes for each journey. Records are sorted only in chronological order. Secondly, regional economic development and social demographic factors affect the urban environment’s sustainable development, urban population backgrounds (for example, education and income levels) must also be considered in statistical assessments to inform future development recommendations. Thirdly, weather fluctuations deserve greater elaboration; they influence the number of users of bike-sharing systems, and may also affect the demographics of the ridership, thereby exacerbating gender-specific dynamics (Lin et al., 2020). This will provide support for the environmental benefits of using the shared bicycle system and encourage more travellers to participate in the plan.

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