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Article

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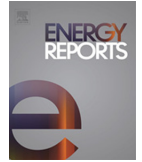
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Shared bicycle study to help reduce carbon emissions in Beijing

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Abstract

The shared bicycles had become an important choice for Beijing citizens to travel “the last kilometer” on a daily basis. By replacing buses and cars, sharing bicycles can reduce urban carbon emissions, and only occupy a small area of parking space, thus improving urban land use efficiency. A comprehensive field survey was conducted on 45 subway stations and 174 exits of the Metro Line 10. Through the method of mathematical statistics and graph analysis, the change of the number of shared bicycles on the subway line 10 in the middle of the day was studied. At the same time, the needs and characteristics of the user types and actions were analyzed. Based on the characteristics of the surrounding land, this paper studies the rationality and potential of reducing carbon emission by sharing bicycle are studied and provides data support for the government to increase the parking space of shared bicycles.

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Keywords: Reduce carbon emissions; Shared bicycle; Subway station

1. Research significance

There were nearly 11 million registered users of shared bicycle products in Beijing, accounting for nearly half of Beijing’s resident population. In the first half of 2018, the average daily cycling volume of shared bicycles reached 1.42 million passengers, and the cumulative trip reached 400 million kilometers. Bicycle sharing are important choices for Beijing citizens to travel “the last kilometer” on a daily basis, and are of great significance to the development of Beijing’s urban public transportation system. In order to meet such a huge demand, operating companies spread 1.9 million shared bicycles in the streets of the city. If no bike sharing, people from the subway exit need to transfer to other means of transportation to reach their destination [1]. For example, in Beijing, 8% people choose to ride a private bike, 22% people choose to take buses, 29% people choose to take cars and only 44% people choose to walk. Taking buses or taxis will consume fossil energy and produce a lot of carbon emissions, which will aggravate the heat island effect and air pollution in Beijing.

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In the important node area of urban public transport transfer, the problems such as the choice of parking and transfer areas have become more and more serious, because there is not enough land for car parks. The Beijing Metro Line 10 is circular and has the function of connecting people in all directions of Beijing's central city. It is the backbone line in the Beijing Metro Line Network. There are 45 stations in the ring line, and there are various types of soil use along the line. The average daily passenger flow reached 11 million people, and the source of flow of people was complex. By encouraging people to use shared bicycles around Metro Line 10, it can effectively reduce Beijing's carbon emissions. This study will encourage city managers to make further policies to increase the supply of shared bicycles in the area near the metro entrance.

2. Research method

A comprehensive field survey was conducted on 45 subway stations and 174 exits of the Metro Line 10. In the field survey, representative 8 am–12 am, 12 am–16 pm, 16 pm–20 pm, 20 pm–8 am sampling time period were used to count the number and spatial distribution of shared bicycles for each subway exit. According to the daily life of Beijing citizens, 8 am–12 am time period reflect the use after the morning peak, 12 am–16 pm time period reflect the use after work at noon, 16 pm–20 pm time period reflect the situation before the evening peak use, 20 pm–8 am time period reflect the situation after night use.

First of all, the method of mathematical statistics and graph analysis reflects the change in the number of shared bicycles on the 10th subway line in the middle of the day. At the same time, the paper analyzes the characteristics of the type of shared bicycle users, and calculates the actual reduction of carbon emission.

The calculation formula for carbon emission E is:

$$E_i = NLP_iG_iC \quad (1)$$

$$N = b_1ar \quad (2)$$

$$L = vt \quad (3)$$

In formula (1), E_i is the transfer connection method (bus, car). N is the number of passengers used. L is the average travel distance. P_i is the kilometer fuel consumption of the i th travel mode. G_i is the proportion of the i th travel mode. C is the carbon emission conversion factor, and in Beijing the value of C is average 0.627 kg/L. If the bus is used as the travel mode, the value of P is 30 L/100 km, and the value of G is 0.22. If the car is used as the travel mode, the value of P is 10 L/100 km, and the value of G is 0.29.

In formula (2), b_1 is the total number of shared bicycles, a is the average activity of shared bicycles, and r is the daily turnover rate of shared bicycles. In Beijing, the value of a is average 0.5, and the value of r is average 1.7.

In formula (3), v is the average speed of the shared bicycle, and t is the average usage time of the shared bicycle. In Beijing, the value of v is average 5 m/s, and the value of r is average 10 min.

Secondly, the paper analyzes the characteristics of the surrounding land of the subway gate and studies the rationality of the space distribution of the shared bicycle in the subway gate of Line 10. With the subway entrance as the center of the circle, a circle with a diameter of 100 m was set as the research area. By placing a reasonable number of shared bicycles in green areas or squares instead of invading normal car and bicycle traffic spaces, planning the parking and transfer areas for future shared bicycles [2]. In order to encourage low-carbon travel, through communication with government departments, the shared bicycles to be supplied in the future can properly occupy the square and green space near the subway entrance.

$$b_2 = m/(1.6 * 1.6)qc \quad (4)$$

In formula (4), b_2 is the number of predicted shared bicycles can be increased in the future. m is the space area where placed new shared bikes. q is the maximum number of bicycles placed in the space unit area. Through field test, up to 8 shared bicycles can be placed in the area of basic research unit. 1.6 m is the length of the shared bicycle, which is used to determine the basic research unit area. c is the space occupancy coefficient. C is the space occupancy coefficient. For square space, the maximum value of space occupation coefficient C is 0.1, and the minimum value is 0.05. For green space, the maximum value of space occupation coefficient C is 0.02, and the minimum value is 0.01.

3. Segment study

3.1. Eastern business section

The eastern section of Metro Line 10 has 9 subway stations and 40 subway Gates, which are mainly connected to large office business groups in the eastern part of Beijing. The style of the city is dominated by high-rise modern buildings. The space for walking and cycling is rich, and the urban green space is relatively concentrated and banded. The linear distribution of the main road of the East Third Ring Expressway at the exit of the subway station is basically located in the public green space at large intersections, or in the paving square of large commercial shopping areas. The status quo of shared bicycles is mostly parked on the outside of the sidewalk, occupying 1/3 of the width of the sidewalk, affecting the normal pedestrian flow. The statistics of land-use types within 50 m around the subway entrance are as follows Fig. 1. City squares and urban green spaces can accommodate this part of the space for shared bicycle parking, and have a certain amount of growth potential.

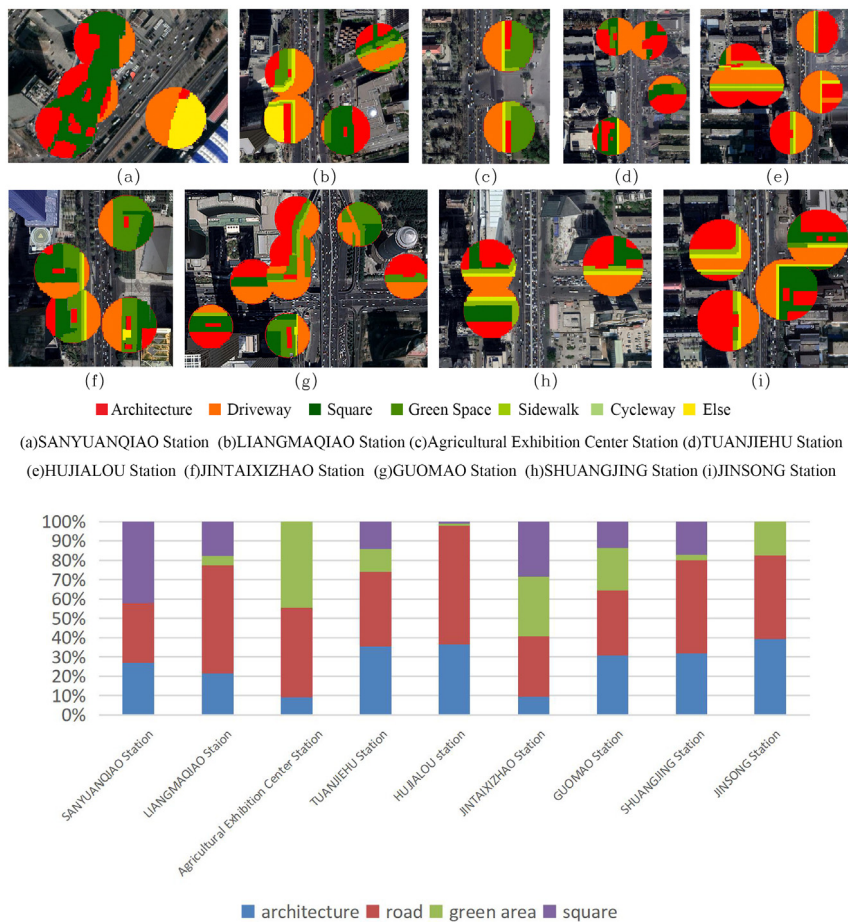


Fig. 1. The land-use types around the eastern subway entrance . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Due to the high housing prices in the area, a large number of local shopping malls and office workers live outside the area. Most of the residents living in the area do not work in shopping malls and office buildings in the area. Since the subway exit is far from the bus station, the sharing of bicycles is mainly commuter white-collar workers and young people [3]. The number of bicycles riding away from the subway station is comparable to the number of bicycles riding to the subway station, and it has a dynamic balance. However, in the use time of shared bicycles, it has the characteristics of large peak traffic in the morning and evening, and small traffic in the afternoon. Recycle the shared bicycle properly at 12 am–16 pm and place it in other places where there is a need (Fig. 2).

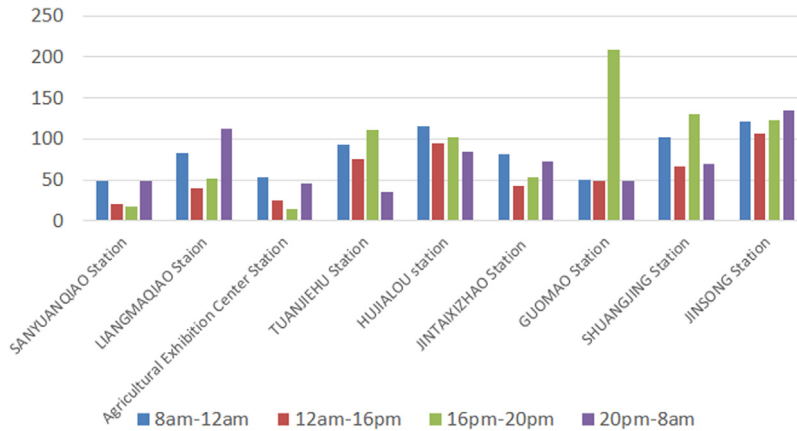


Fig. 2. The number of shared bicycles in eastern subway stations.

Through the calculation of formula (1) (2) (3) (4) introduced in the second chapter, we can get the carbon emission reduction of shared single car at the Easter station of the ring line of Metro Line 10. By optimizing the parking space of shared bicycles and increasing the supply of shared bicycles, more carbon emissions can be reduced (Figs. 3, 4). Guomao Station is the largest subway station in the eastern section, with 8 exits, and its service scope includes the largest CBD area in Beijing. Not only is the number of shared bicycles far higher than that of other stations, but there are many open spaces around the subway station entrance, and the number of newly added shared bicycles is large. The relevant calculation data is shown in Table 1, but not in the lattice diagram.

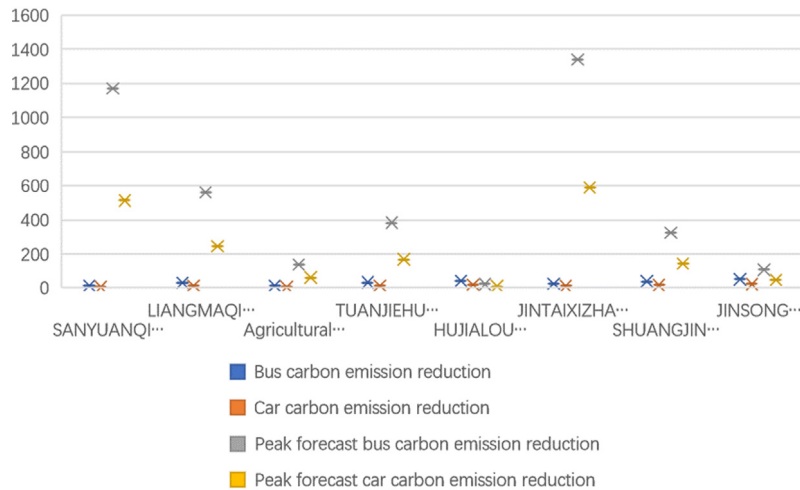


Fig. 3. Maximum potential to reduce carbon emissions around the eastern subway station.

3.2. South living section

The Southern section of Metro Line 10 has 9 subway stations and 32 subway outlets, which mainly connect with a large number of residents in the southern part of Beijing, as well as some universities and transportation hubs. The urban landscape is dominated by modern residential buildings, and the urban green space is evenly distributed and abundant. Most of the subway station exits are located in the core of large residential groups and are the main traffic nodes for residents to travel daily. Due to the low daily traffic volume of lifestyle roads and the limited width of sidewalks and bicycle lanes, shared bicycles are mostly parked on the side of bicycle lanes, occupying 1/2 or all bicycle lanes, affecting normal bicycle traffic. The statistics of land use types within a range of 50 m around the

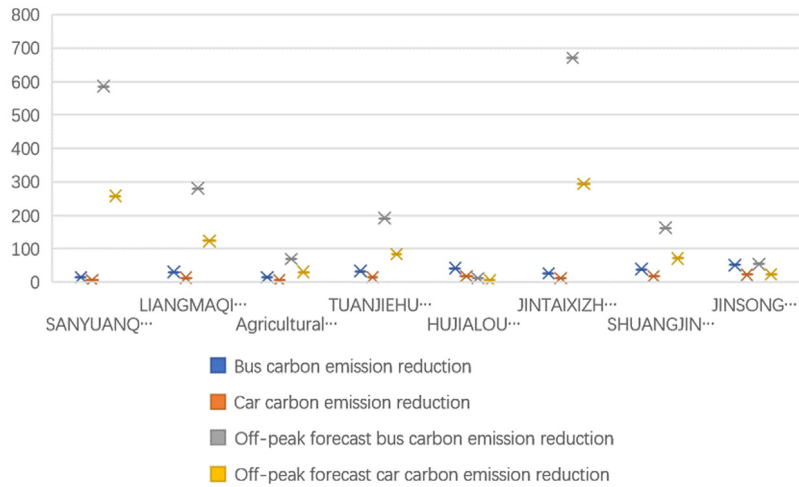


Fig. 4. Minimal potential to reduce carbon emissions around the eastern subway station.

Table 1. Carbon emission reductions (kg).

Eastern subway station	Current carbon emission reduction	Forecast the maximum potential value of carbon emission reduction	Predicting the minimum potential value of carbon emission reductions
SANYUANQIAO Station	20	1 685	843
LIANGMAQIAO Station	43	806	403
Agricultural Exhibition Center Station	21	199	100
TUANJIEHU Station	48	551	275
HUJIALOU Station	60	33	17
JINTAIXIZHAO Station	38	1 929	965
GUOMAO Station	54	8 862	4431
SHUANGJING Station	56	467	234
JINSONG Station	73	155	78
Total	414	14 689	7345

subway entrance are as follows Fig. 5. Due to the small paved area of the square, a shared bicycle parking area should be opened up in urban green spaces. However, the parking lot can basically only meet the current demand for shared bicycle parking, and the growth potential is small.

The use of the crowd is mainly commuter residents, students, there is a clear morning and evening peak traffic, midday traffic is small characteristics. However, due to a single destination, shared bicycles crowded from the interior of the residential area to the subway station during the early peak hours, causing congestion; Late peak hours left the subway entrance and headed for the interior of the residential area, resulting in insufficient numbers. At the same time, due to the high capacity of residential areas, a subway station serves multiple residential groups, and the arrival and concentrated departure of the subway mouth sharing bicycle tidal type. There is a greater demand for the sharing of bicycle storage areas in the subway mouth, and a three-dimensional parking lot or semi-underground parking lot needs to be arranged (Fig. 6).

Through the calculation of formula (1) (2) (3) (4) introduced in the second chapter, we can get the carbon emission reduction of shared single car at the Southern station of the ring line of Metro Line 10 (Table 2). By optimizing the parking space of shared bicycles and increasing the supply of shared bicycles, more carbon emissions can be reduced (Figs. 7, 8).

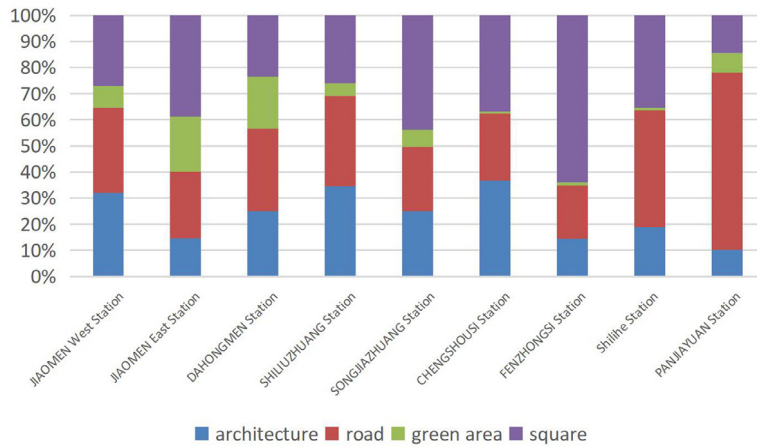
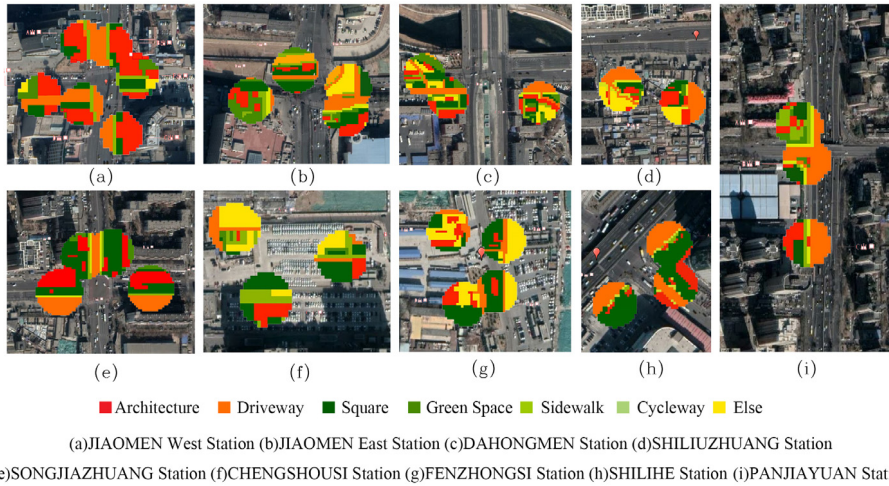


Fig. 5. The land-use types around the southern subway entrance . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

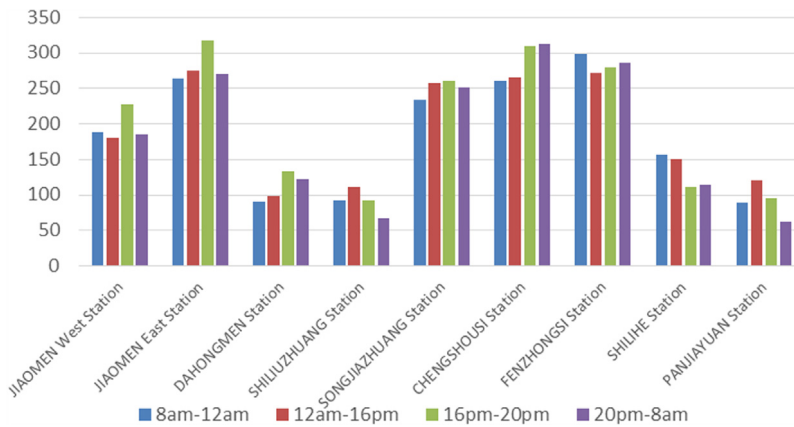


Fig. 6. The number of shared bicycles in southern subway stations.

Table 2. Carbon emission reductions (kg).

Southern subway station	Current carbon emission reduction	Forecast the maximum potential value of carbon emission reduction	Predicting the minimum potential value of carbon emission reductions
JIAOMEN West Station	119	642	321
JIAOMEN East Station	171	558	279
DAHONGMEN Station	67	278	139
SHILIUZHUANG Station	55	201	101
SONGJIAZHUANG Station	152	673	337
CHENGSHOUSI Station	174	414	207
FENZHONGSI Station	173	958	479
SHILIHE Station	81	398	199
PANJIAYUAN Station	56	179	90
Total	1048	4301	2150

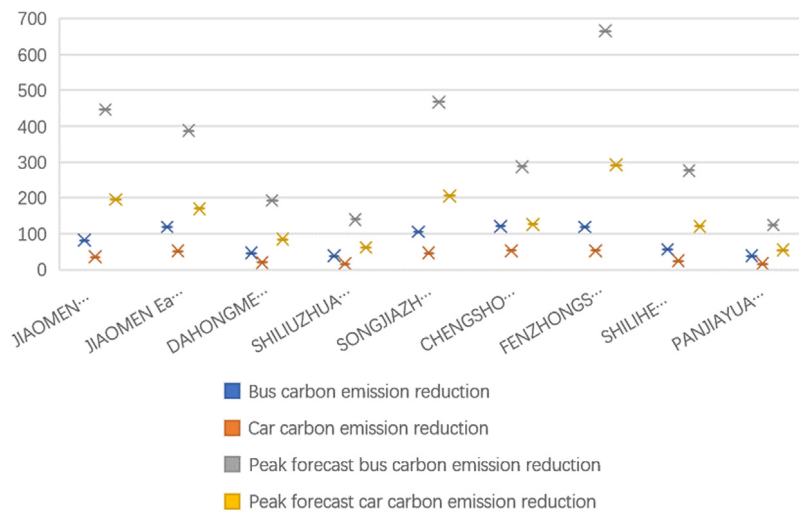


Fig. 7. Maximum potential to reduce carbon emissions around the southern subway station.

3.3. Northern university section

The northern section of the Beijing Metro Line 10 has 49 subway stations in 12 subway stations. It mainly connects to the northern high campus of Beijing, and is represented by Zhongguancun as a science park, some residential areas and hospitals. The urban landscape is dominated by university cities, and urban green areas are distributed along roads. Most of the subway stations are located at urban traffic nodes and are close to bus stops. Lifestyle road traffic is relatively large, sidewalks and bicycle lanes are narrow, and there are fewer large paved squares. The status quo of shared bicycles is mostly parked on the outside of the sidewalk, which has a greater impact on normal pedestrian flow Fig. 9. The statistics of land use types within 50 m around the subway entrance are as follows, which can make full use of the space potential of the Zonal city park and set up shared bicycle parking points.

The main users are young students, white-collar workers and residents of the region. Due to the small daily travel needs of students, white-collar workers and local residents take more developed ground buses and private cars, and the number of shared bicycles is relatively small. However, there is a large flow of travel on weekends, and the distribution of shared bicycles presents the characteristics of tidal flow in universities and subway stations (Fig. 10).

Through the calculation of formula (1) (2) (3) (4) introduced in the second chapter, we can get the carbon emission reduction of shared single car at the Northern station of the ring line of Metro Line 10. By optimizing

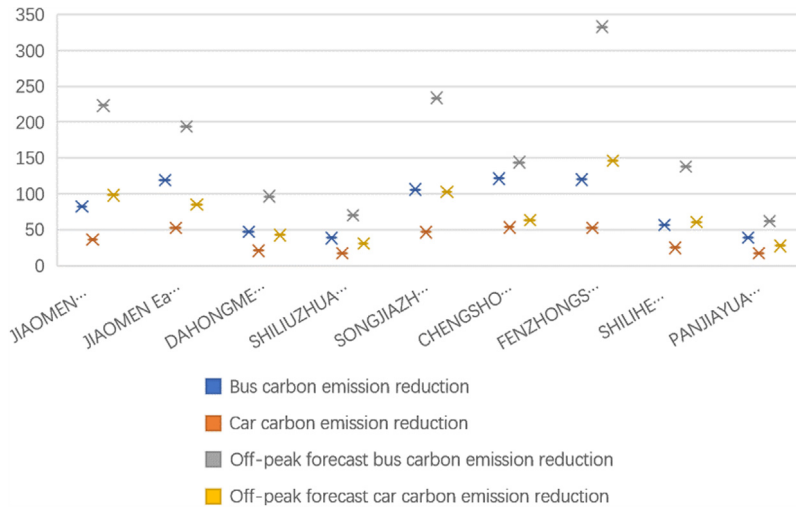
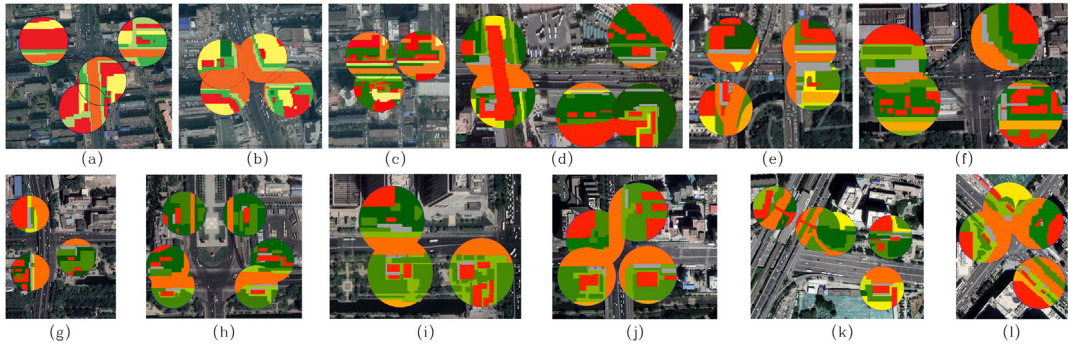


Fig. 8. Minimal potential to reduce carbon emissions around the southern subway station.



(a)SUZHOUJIE Station (b)HAIDIANHUANGZHUANG Station (c)ZHICHUNLI Station (d)ZHICHUNLU Station (e)XITUCHENG Station (f)MUDANYUAN Station (g)JIANDEMEN Station (h)BEITUCHENG Station (i)ANZHENMEN Station (j)HUIXINXIJIENANKOU Station (k)SHAOYAOJU Station (l)TAIYANGGONG Station

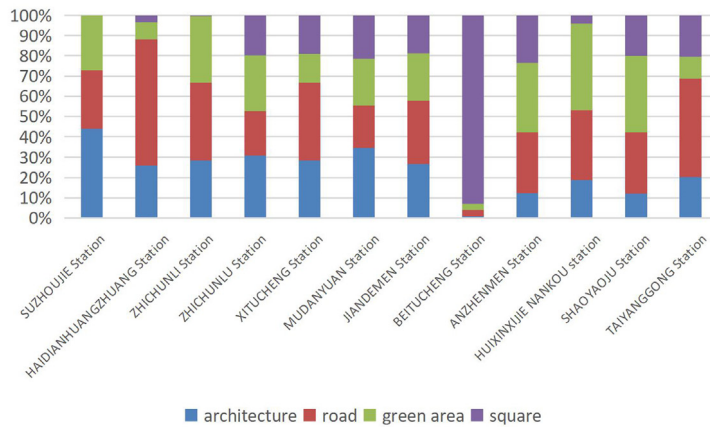


Fig. 9. The land-use types around the northern subway entrance . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

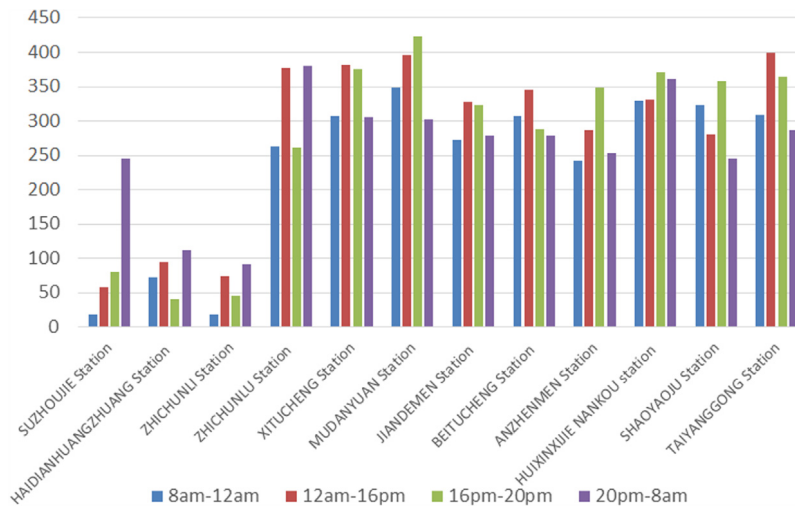


Fig. 10. The number of shared bicycles in northern subway stations.

Table 3. Carbon emission reductions (kg).

Northern subway station	Current carbon emission reduction	Forecast the maximum potential value of carbon emission reduction	Predicting the minimum potential value of carbon emission reductions
SUZHOUJIE Station	61	66	33
HAIDIANHUANGZHUANG Station	49	26	13
ZHICHUNLI Station	35	54	27
ZHICHUNLU Station	195	380	190
XITUCHENG Station	208	214	107
MUDANYUAN Station	223	227	114
JIANDEMEN Station	182	157	78
BEITUCHENG Station	144	9 553	4777
ANZHENMEN Station	171	184	92
HUIXINJIENANKOU Station	211	121	61
SHAOYAOJU Station	183	286	143
TAIYANGGONG Station	207	155	78
Total	1871	11 424	5712

the parking space of shared bicycles and increasing the supply of shared bicycles, more carbon emissions can be reduced (Figs. 11, 12). Beitucheng station is the largest subway station in the northern section, and its service scope includes many universities and hospitals. Not only is the number of shared bicycles far higher than that of other stations, but the subway station is close to a park, with a large number of newly added shared bicycles. The relevant calculation data is shown in Table 3, but not in the lattice diagram.

3.4. Western transportation hub section

The Western section of the Beijing Metro Line 10 has 53 subway stations in 15 subway stations. It mainly connects large-scale residential areas, hospital areas, and Beijing-West transportation hubs. It is the population of the central city of Beijing and the traffic tidal flow node of Fengtai, Shijingshan, Fangshan and Daxing in the west of the city. The density of surface buildings is large, the urban green space is concentrated and unevenly distributed, and the road network is dense but the road width is narrow. The status quo of sharing bicycles often occupies sidewalks and bicycle lanes, causing great congestion [4]. The statistics of land use types within 50 m around the subway entrance are as follows Fig. 13. The potential for shared bicycle parking is small. We should take full advantage of the dense urban road network to guide users to park shared bicycles on the branch roads and

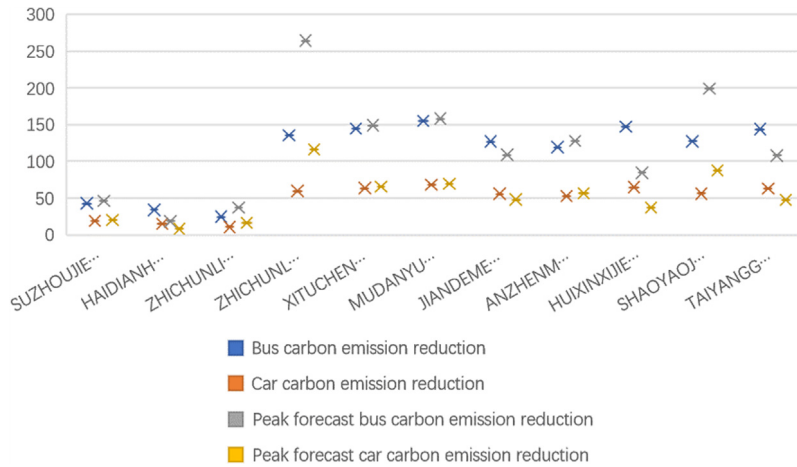


Fig. 11. Maximum potential to reduce carbon emissions around the northern subway station.

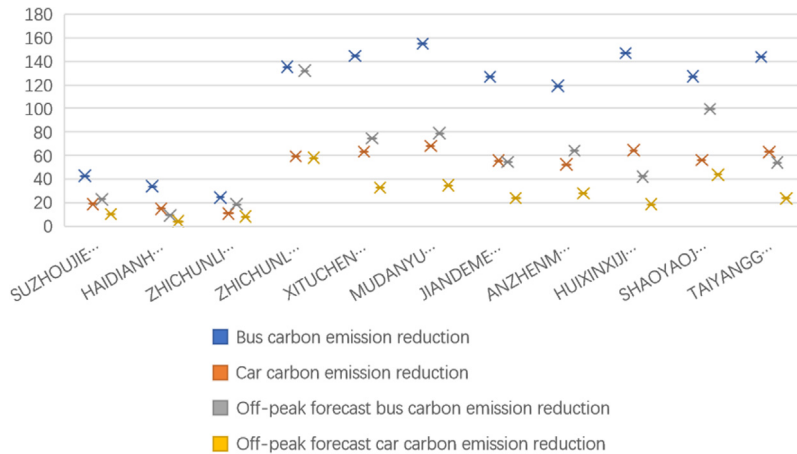


Fig. 12. Minimal potential to reduce carbon emissions around the northern subway station.

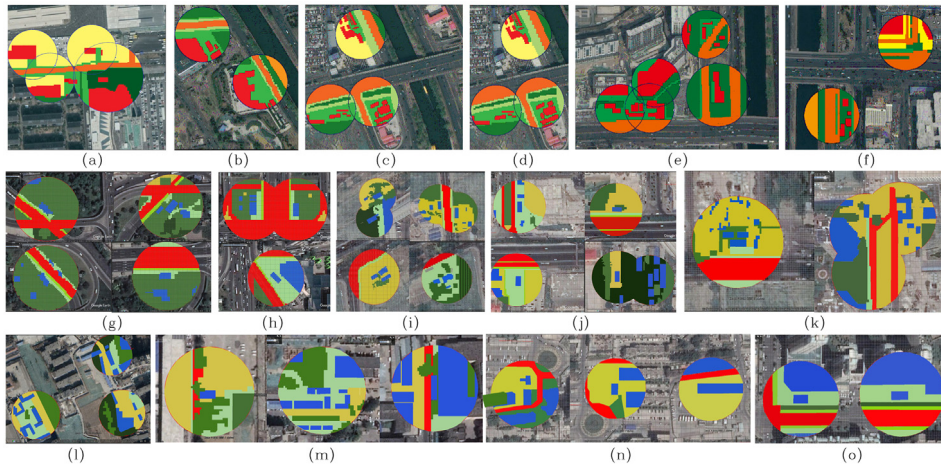
walk a short distance to the subway station. You can set up a bicycle parking area in a densely populated area to encourage walking traffic.

The use of people is mainly commuting white-collar workers. They need to cycle between subway stations and surface bus transit stations. Therefore, the use of shared bicycles in subway ports has one-way tidal migration characteristics. A large number of shared bicycles gathered in the early morning peak around the subway entrance, followed by a gradual decline in the number of trains throughout the day [5]. The number of bicycles on the subway at the peak of the evening was large, and it was necessary for operating companies to deploy vehicles from outside areas (Fig. 14).

Through the calculation of formula (1) (2) (3) (4) introduced in the second chapter, we can get the carbon emission reduction of shared single car at the Western station of the ring line of Metro Line 10 (Table 4). By optimizing the parking space of shared bicycles and increasing the supply of shared bicycles, more carbon emissions can be reduced (Figs. 15, 16).

4. Conclusion

First, through mathematical statistics and graphic analysis methods, the calculation results verify the value and potential of sharing bicycles to reduce urban carbon emissions for the scale effect, especially around the subway



■ Architecture ■ Driveway ■ Square ■ Green Space ■ Sidewalk ■ Cycleway ■ Shared Bicycle Parking Area
 (a)BAGOU Station (b)HUOQIYING Station (c)CHANGCHUNCHANG Station (d)CHEDAOGOU Station (e)CISHOUSI Station
 (f)XIDIAOYUTAI Station (g)GONGZHU FEN Station (h)LIANHUAQIAO Station (i)LIULIQIAO Station (j)XIJU Station
 (k)JIWA Station (l)FENGTAI Station (m)SHOUJINGMAO Station (n)JIJIAMIAO Station (o)CAOQIAO Station

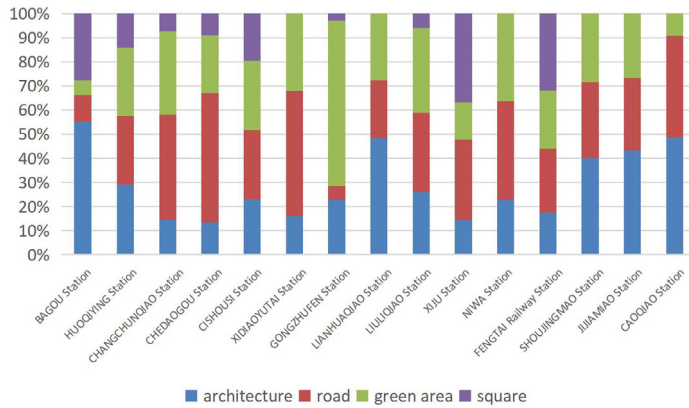


Fig. 13. The land-use types around the western subway entrance . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

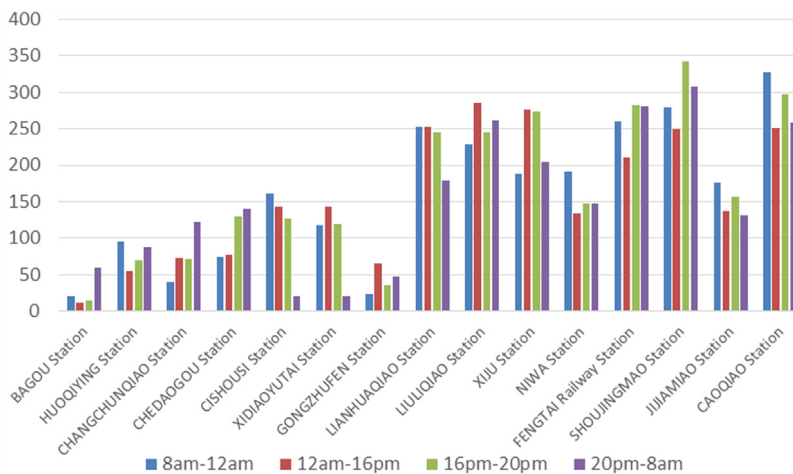
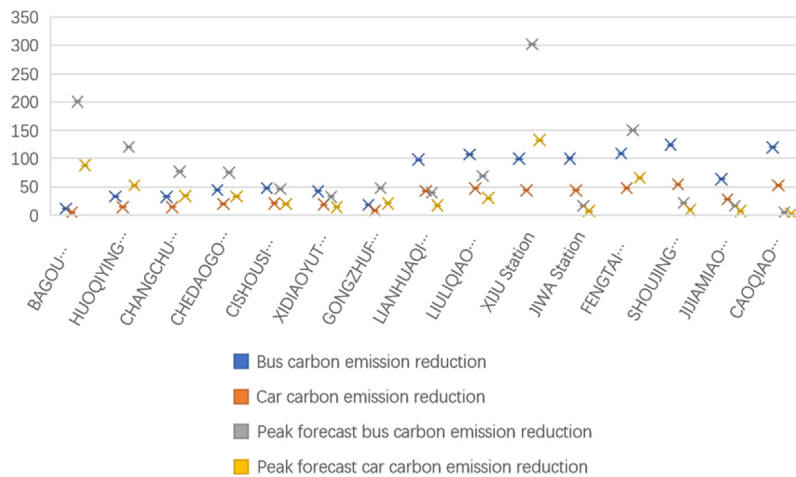


Fig. 14. The number of shared bicycles in western line MTR stations.

Table 4. Carbon emission reductions (kg).

Western subway station	Current carbon emission reduction	Forecast the maximum potential value of carbon emission reduction	Predicting the minimum potential value of carbon emission reductions
BAGOU Station	16	289	145
HUOQIYING Station	47	173	86
CHANGCHUNCHANG Station	47	111	55
CHEDAOGOU Station	64	108	54
CISHOUSI Station	69	66	33
XIDIAOYUTAI Station	61	47	23
GONGZHUFEN Station	26	69	34
LIANHUAQIAO Station	141	56	28
LIULIQIAO Station	155	100	50
XIJU Station	143	435	217
JIWA Station	144	24	12
FENGTAI Station	157	216	108
SHOUJINGMAO Station	179	31	15
JIJIAMIAO Station	92	23	12
CAOQIAO Station	172	7	4
Total	1513	1755	878

**Fig. 15.** Maximum potential to reduce carbon emissions around the western subway station.

entrance with dense public traffic. Second, combined with the characteristics of the land around the subway entrance, it can be found that the reasonable location and potential of the space distribution of the shared bicycle in the subway entrance, while the current situation is that shared bicycles occupy bicycle lanes and sidewalks. According to this study, the incremental shared bicycle parking space can be preferentially selected to use square and green space, which can effectively alleviate the problem of public space congestion. Third, there is limited land space around the stations along line 10 of Beijing Metro. The government should make policies and give priority to the setting of shared bicycle parking lot to reduce carbon emissions as much as possible.

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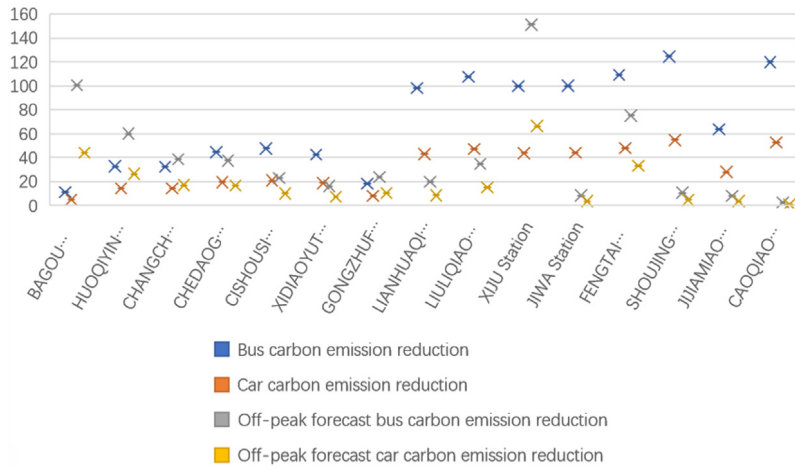


Fig. 16. Minimal potential to reduce carbon emissions around the western subway station.

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