Research on the construction of carbon emission evaluation system of low-carbon-oriented urban planning scheme: taking the West New District of Jinan city as example

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ABSTRACT
Carbon emissions caused by human activities are closely linked to the process of urbanization, urban land use and traffic system are two important factors that may influence it. On the basis of clarifying the space structure of low-carbon eco-city, this paper constructing an evaluation system of urban carbon emission from four dimensions: construction land compact, traffic carbon emission potential, road network accessibility, and public transportation accessibility. Based on the evaluation system, the author took the West New District of Jinan city as an example, evaluated urban planning scheme by using several spatial models such as landscape pattern index, Spatial syntax, POI (Point of Interest) kernel density analysis, and OD (Origin Destination) matrix in support of GIS (Geographic Information System) and RS (Remote Sensing) techniques.

In the global context of global warming leading to global climate change and local extreme climate causing frequent disasters, as a city that accounts for 80% of global emissions, the city is facing intense pressure on resource constraints and ecological environment. China’s high-carbon emission areas are mainly concentrated in urban areas, industrial manufacturing intensive coastal areas, and some energy production bases like Inner Mongolia and Shanxi (Development Research Centre of the State Council 2009; Liu, 2015). The urban growth model of the epitaxial growth has been difficult to adapt to the development needs under the new situation, and the urban development model is faced with the choice of transformation. Low-carbon model and ecological concept have become the most significant theme of human sustainable development in the twenty-first century, and become a new development direction to cope with climate change, resource constraints, and ecological environment challenges. In this context, how to construct a carbon emission evaluation system of low-carbon-oriented urban planning program has become an important way to reduce carbon emissions and achieve the development goal of low-carbon Eco-city. Many scholars at home and abroad have carried on relevant research to low-carbon city and city carbon emission, the existing research has basically covered each aspects from the policy theory to the technical practice. At the policy level, the research mainly focuses on the connotation, the pattern and the correlation between the low-carbon city and the low-carbon economy, and guides on the direction of China’s economic development (Leqin & Rui, 2009; Quan, Xingping, & Guowei, 2010; Zhangping & Yintai, 2008). At the same time, some scholars have pointed out the current situation of the acceleration of urbanization in China, starting from the point of view of low carbon, to explore the possibility and necessity of the low-carbon urbanization in China, and to put forward the development principles and patterns of low-carbon urbanization (Yixin, 2009). At the technical practice level, the research mainly focuses on the analysis of the relevant factors of carbon emission in cities and the measurement of carbon emissions in the process of urban development, especially in urban energy consumption carbon emissions and urban transport carbon emissions. On the basis of referring to the IPCC carbon emission inventory or other related models, some scholars obtain various energy emission factors through actual measurements or other people’s research, and adopt different carbon emission models and accounting mechanisms, to carry out the measure of the total carbon emission in cities (Jin, Li-Ping, & Bin, 2012; Qian, 2011; Weilin & Xianjin, 2008; Jing, Xian-Jin, Ying, & Xing-Yu, 2010), the preparation of the carbon emission inventory in the national conditions (Rong-Qing & Xian-Jin, 2010; Ya-Jie & Yong, 2015), the study of the means of assessment (Yu, Zhe, Fei, Suo-Cheng, & Ze-Hong, 2013; Yu-Hong, 2015), and the analysis of the driving factors of urban carbon emission (Cao-Cao et al., 2014; Rui & Zheng, 2013).
In the aspect of transportation carbon emission, the relevant scholars have compared models in other fields such as LMDI (Ming & Hai-Lin 2010), DSGC, Laspeyres complete decomposition model into the introduction of the urban traffic (Jie, 2015; Zheng, Feng, & Dan, 2008), to measure urban transport carbon emission, calculate the carbon emission factor of urban traffic (Hansen & Rosen, 1990; Huo, Zhang, & He et al., 2011), or to establish the urban low-carbon traffic pattern index based on the OD cost matrix model (Määttä-Juntunen, Antikainen, & Kotavaara et al., 2011; Wen-Yue, Tao, & Xiao-Shu, 2015a; Xiao-Shu, Wen-Yue, & Xiao-Yan, 2015).

1. The space structure of low-carbon eco-city

 Scholars at home and abroad have studied the relationship between carbon emissions and spatial planning in the process of urbanization, and proposed low-carbon urban planning characterized by “low emission, high energy efficiency, high efficiency and high carbon sequestration.” Newman (1987) in its empirical study shows that compared with the economic development level, the level of traffic and land compactness more can affect the city’s carbon intensity, high-density mixed function of the compact city can effectively reduce the city carbon emissions, urban morphology, function mixing and multi-center layout all reduce the carbon emission by shortening the distance of transportation. Based on the FEE-MAS model, Long Ying (2011) has assessed the energy consumption of urban commuter traffic in different forms, and found that the energy consumption of urban traffic is low in the compact form. Kockelman (1997), Leck (2006), and other scholars believe that such factors as the accessibility of public transportation, land use diversity will impact on urban transportation, high degree of accessibility, high degree of mixing area residents choose more low carbon means of transportation.

Efficient spatial structure, organization and morphology, efficient development and utilization of land resources, high benefit transportation system planning, and management are important spatial planning approaches to realize low-carbon orientation. Among them, the construction land compact (CLC), traffic carbon emission potential (TCEP), road network accessibility (RNA), and public transportation accessibility (PTA) are the most important factors. The spatial structure of low-carbon Eco-city is embodied in four aspects: (1) The urban construction land is compact and functional; (2) the number of function centers and public service centers is suitable, and the layout is reasonable; (3) the grade of urban road is reasonable, the density of road network meets the demand of city form and function; (4) public transit priority, the site distribution is reasonable and wide covered.

2. Construct an evaluation system of urban planning carbon emission

According to the estimation of carbon emission in urban planning program, the following assumptions are put forward: (1) the natural and social conditions of similar land in cities are close to homogeneous distribution; (2) there are no significant class differences between residents’ demand and consumption; (3) the same service facilities are selected when residents get all kinds of services to reduce traffic time; (4) road conditions and speed limits are similar in the same grade of road, and there is no scale and quality difference between the various service facilities provided by the city public center. On the basis of the above assumptions, the evaluation system of urban carbon emission is constructed from four dimensions: the CLC, TCEP, RNA, and PTA (Figure 1).

2.1 Construction land compact

Landscape shape index (LSI) and Shannon’s diversity index (SHDI) were used to measure the shape compactness and functional compactness; the shape compactness is the degree of compactness of urban construction, and the functional compactness reflects the diversity and mixing of urban functions.

2.2 Traffic carbon emission potential

According to the current distribution of the functional center and the layout of the urban planning scheme, select the appropriate public center, with the help of ArcGIS network analysis platform, to build the blocks to the OD matrix of public center and to estimate the shortest traffic time of each block or block to the nearest public center carbon emissions. To some extent, it reflects the pattern of urban residents’ traffic carbon emissions.

2.3 Road network accessibility

Abstract the planned road network into the Segment Map of the spatial syntax, taking the length of the road as the weighting factor, measuring the research of regional road integration and the road network density. According to measurement results, analyze whether the road structure has the potential to build a low-carbon traffic community.

2.4 Public transportation accessibility

With the help of ArcGIS analysis and network density analysis tools, through the analysis of kernel density distribution of urban transit stations and the
accessibility walking area to the transit stations, to evaluate the accessibility of public transport system in the planning area and to reflect the low-carbon traffic potential of the urban community.

3. The basic situations of the West New District of Jinan city

3.1 The regional situation

The West New District of Jinan city is located in the northwest of Jinan City, east to the second ring road, west and north to the Yellow River, south to the Wufeng Mountain, stretch across three administrative divisions of Jinan city including the Shizhong District, the Huaiyin District, and the Changqing District. Two new city district including the West Railway Station area and the University Science and Technology Park, the ecological zone in the West New District of Jinan city and the old Town of Changqing, some other urban and rural areas such as Dangjia Town and Gushan Town are all contained. The total area is about 450 sq. km (Figure 2). Before the construction of the West New District, the urban construction land was organized on both sides of Changqing old Town and the 220 national highway. The population density was relatively low, and the economic development was relatively backward. Affected by the terrain and the status of land for construction, the planning of the
West New District of Jinan city is multi-core layout, taking the West Railway Station of Jinan city, the University Science and Technology Park and wetlands in the Western District of Jinan as the core, to form the business center, science center, and ecological conservation center, respectively. At the same time, the government plans to co-ordinate the transport network of the West New District and the urban area of Jinan, to build an integrated public transport system to provide infrastructure support for the future development of the Western New District (Figures 3 and 4).

3.2 Low-carbon model

Based on the spatial efficiency of carbon emission and the carbon capture of non-construction land in the West New District of Jinan city, the carbon effect of the West New District can be divided into three regions: (1) High density and high emission areas such as the West Railway Station area. The construction density and development intensity are high, the Greenland, Wetlands, and other ecological patches with carbon sink function are lacking in this area. (2) Low impact and low emission areas such as the areas with Dangjia

![Figure 3. The master plan of the West New District of Jinan city.](image)

![Figure 4. The road traffic planning of the West New District of Jinan city.](image)
Town, the University Science and Technology Park and the old Town of Changqing District as core for the urban construction land. The core of these areas has a certain intensity of construction, but far less than the West Railway Station area, and surrounded by large green patches. (3) High-carbon sequestration and zero emission areas including the hilly area on the south side of the West New District, the farmland on the west and the wetlands in the Western District on the north. The intensity of construction in these areas are minimal, and have large areas of green patches that can provide ecological services for the city (Figure 5). In this paper, according to the guiding status and overall planning guidance, the West New District is divided into seven research area, respectively as the area of the West Railway Station, the University Science and Technology Park, the old Town of Changqing District, Duandian Town, Dangjia Town, Pingan Dian Town, and Gushan Town (Figure 6).

4. Construction land compact of the West New District of Jinan City

4.1 Shape compactness

The LSI measure calculates the degree of complexity of the patch shape by calculating the degree of deviation between the shape of the entire landscape patch and the square of the same area. When the patch shape is square, the LSI value is 1, and the LSI value increases when the shape of the landscape patches deviates from the square. The formula is shown as the following:

$$\text{LSI}_i = \frac{0.325E_i}{\sqrt{A_i}} \quad (1)$$

In the formula, LSI, is the landscape shape index of section $i$; $E_i$, is the outer contour length of urban construction in section $i$; $A_i$, is the urban construction land area of section $i$.

Based on ArcGIS, the exterior contour vector data of urban construction were gridded, and calculate the LSI of landscape level (Table 1).

The results showed that the LSI values of the seven areas from north to south have increased, and the West Railway Station area is the most compact form, followed by the old Town of Changqing District. The LSI indexes of the University Science and Technology Park, the Dangjia Town and the Gushan Town are all above 3.0, it indicate that the shape of two Town’s urban construction land is more irregular. Combined with the analysis of its topography and land use status, it is found that the topography of the west railway station, the old Town of Changqing District, the section of Duandian Town and Pingan Dian Town are relatively flat. Among them, the West Railway Station area was built on the ground floor, and the regular layout pattern led the outer contour of the construction land to the square. The old Town of Changqing District possessed a obvious grid like characteristic, and also the compactness of construction land was also higher. Duandian Town and Pingan Dian Town areas along the provincial highway and have obvious strip layout, the compactness of the construction land were slightly lower.

### 4.2 Functional compactness

The essence of SHDI measure is to calculate the sum of the product of each patch’s proportion to the total landscape area and its logarithm, and then take its negative values to reflect the landscape heterogeneity in the region composed of these various patches. When there was only one patch in the range of study, the SHDI value was 0. As the patch type increased and the patch areas tended to be similar, the SHDI value increased. The formula is shown as the following:

$$\text{SHDI}_i = -\sum_{k=1}^{n} [P_{ik} \times \ln(P_{ik})] \quad (2)$$

In the formula, SHDI, is the Shannon diversity index of $i$ area, and $P_{ik}$ is the proportion of patch $k$ in $i$ area, which occupies the total area of landscape.

Based on ArcGIS, the outer contour of seven areas is used as masks to extract independent raster data of per area, and the calculate SHDI under the landscape level (Table 2).

The results show that the difference of functional compactness between seven areas are quite small. From the perspective of land use diversity, the seven areas are more diverse and can meet the daily needs of residents. Among them, Duandian Town Area’s land types are the most diverse and its function compactness is the biggest, because of its medical function and Industrial and logistics functions. Followed by the West Railway station Area, University Science and Technology Park is mainly based on education and supporting business. Its functions are single and its function compactness is lowest.

### Table 1. The LSI value of each area of the West New District of Jinan city.

| The name of each area | The West Railway Station | The old Town of Changqing District | The University Science and Technology Park | Pingan Dian Town | Gushan Town | Duan Dian Town | Dang Jia Town |
|----------------------|--------------------------|----------------------------------|------------------------------------------|-----------------|-------------|---------------|--------------|
| LSI value            | 1.495                    | 2.232                            | 3.074                                    | 2.463           | 3.569       | 2.692         | 3.381        |
5. TCEP in the West New District of Jinan city

5.1 Public service center identification

According to the Overall Planning of the West New District of Jinan city, the location of the public center with a high density and vitality in the West New District of Jinan city by the combination of the current situation. Referring to the POI classification of Baidu, the domestic mainstream electronic map supplier, extract six types of POI data: residence, business services, health care, style and leisure, company, and external traffic, to make data cleaning and coordinate conversion (Wen-Hao & Ting-Hua, 2015). Based on Kernel density analysis tool of ArcGIS to perform Kernel density analysis by category. According to the method of natural discontinuity classification, the Kernel density grids were divided into four levels, to make equal weight stacking after classification and identify four more accurate public service centers: the west side of the West Railway Station, Changqing Old Town Center, University Town Commercial Street, Jinan University West Campus at second ring south road (Figure 5).

5.2 Residents’ TCEP

Reference to the relevant research (Wen-Yue et al., 2015a), the carbon emissions potential in each service area is estimated:

\[ TCE_{ik} = D_{ik} \times TCEF \]  

(3)

\[ TTCE = \sum_{m} \sum_{i} nk \times TCE_{ik} \]  

(4)

TCE_{ik} is the carbon emission potential from the center point “k” to the nearest public service center “i” in the grid; TTCE is the overall TCEP value for urban construction land of the West New District; D_{ik} is the optimal path length from the center point “k” to the public service center “i” in the grid; TCEF is a carbon emission factor for urban traffic, generally related to the models, speed, traffic conditions and so on.

Referring to Huo H (2011)’s study on the comprehensive measure of carbon emission factors of urban traffic in Jinan city. Valuing TCEF = 246g/km (Huo et al., 2011) and calculating the carbon emission potential of residents (Figure 6, Table 3).

On the whole, the carbon emission patterns of the residents show a clear circle structure around the four centers in the West New District of Jinan city. The public center areas have been built more residential areas and densely populated which are located in the old district of Changqing, the West Railway Station area, University Science and Technology Park and Dangjia Town. Their potential carbon emissions are lower than other areas. With the planning of a more intensive road network, they have the potential to develop into a low-carbon community. However, because of the distance from the public center is far and the density of the road network is small, the potential value of carbon emissions are higher in...
the banded layout of Pingan Town, Duandian Town area, and the group layout of Gushan Town.

6. Accessibility of road network in the West New District of Jinan city

6.1 Road integration degree

In the space syntax model, the integration degree is the indicators to characterize the identifiability and accessibility of the study objects in the system. It is divided into the global integration degree (R = n) and the local integration degree (R = topological depth, rotation angle or distance) (Hillier & Qiang, 2014). According to the Overall Planning of the West New District of Jinan city, the line model of road traffic planning in the West New District of Jinan city was extracted and analyzed by the Depthmap software (Figure 7).

The results show that the highest integration degree road is the Ten West Road, which is easiest to identify and reach, and is the main road of internal transportation within the region. The high accessibility area of the whole road is the West Railway Station area and the old district area of Changqing. Among them, the West Railway Station is the concentrated distribution area of integration degree of the core road in the west new city and can meet the needs of the future high-density development. It is also conducive to the rapid distribution of large-scale passenger flow in West Railway Station. The RNA of University Science and Technology Park area is low, even lower than part of the Township built-up area, it is difficult to meet the low-carbon traffic needs of student groups and residents.

6.2 Road network density

“Node count” in space syntax is an index for measuring how many elements can any element contacted in the internal system within the study area. It can be used to characterize the intensity of elements within the study object element as the center and the radius of R. R = 3000 m was chosen to analyze the road network density of the west new district combined with the road traffic planning and the daily traffic distance of urban residents in the West New District of Jinan City (Figure 8).

| The name of each area          | West Railway Station | The old Town of Changqing District | University Science and Technology Park | Pingan Dian Town | Gushan Town | Duandian Town | Dangjia Town |
|-------------------------------|----------------------|-----------------------------------|----------------------------------------|------------------|-------------|---------------|--------------|
| Average value of traffic carbon emission potential (kg/km²) | 15.40               | 11.19                             | 15.50                                  | 28.79            | 28.36       | 32.59         | 14.10        |
| Total value of traffic carbon emission potential (kg)    | 605.88               | 298.20                            | 476.89                                 | 985.84           | 692.84      | 884.65        | 346.36        |

Table 3. The potential value of residents’ traffic carbon emission in the West New District of Jinan city.
The results showed that the density of planned road network varies greatly. The largest road network density is in the West Railway Station area and much higher than other areas. The external traffic evacuation and high-density commercial office in this area have higher requirements on the network density. The University Science and Technology park area has many mountains and hills, the topography dispersed the construction land. Universities in this area covering large areas and with regular shape, resulting in long streets and low density of the road network.

7. Accessibility of public transport in the West New District of Jinan city

7.1 Kernel density of bus station

Due to lack of plans about public transportation facilities in the Overall Planning of the West New District of Jinan city, and the basic construction is complete and most of them are carried out according to the plan in the west new district, POI data of 2016 bus station in West New City are obtained by means of network crawling, and analyzed based on kernel density analysis in ArcGIS (Figure 9).

The results showed that the bus station density of West Railway Station area is largest, followed by Changqing district and University Science and Technology Park area. From the view of spatial relations, the shape of the transit corridor has been formed between the Changqing District along the Avenue – Jingfu line. The transit corridor of Changqing District along the Ten west road, Pingan Town, Duandian Town, and the West Railway Station area have also been shaped. The distribution of high-density road network and high-density bus station in West Railway Station area provides a guarantee for the rapid evacuation of the traffic flow. The density of bus station is higher in University Science and Technology Park area. But the distribution is too concentrated and the road network density is small, so the user may walk or transit for a long time to reach other areas.

7.2 The spatio-temporal reachable domain of bus station

Based on the analysis of service area in ArcGIS network analysis tools, the road center-line is extracted and the network data set is set up. Setting the walking time (average walking speed is 1.5 m/s) is the cost factor. The 335 bus stations are set up as facilities in West New District of Jinan city, the impedance is set to walking time (in seconds), and settled into three levels: 300, 600, 900, generating the walking accessible domain of 5 min, 10 min, 15 min’ walk from each bus station (Figure 10).

The results showed that the bus station 5 min’ walk circle covers the West Railway Station of Jinan City, the main entrance of most schools in the University Science and Technology Park and along the core road. The 10 min’ walk circle basically covers the West Railway station area, Changqing old district and the core zone of Dangjia Town area. The 15 min’ walk circle basically covers the larger residential areas, schools and commercial complexes within the planning area. Some residential area is located in the outside of bus station 15 min’ walk in Duandian Town, Dangjia Town, Gushan Town, so bus travel is more inconvenient.

Figure 9. Kernel density analysis of public transport station in the West New District of Jinan city.

Figure 10. Walking accessible domain analysis of bus station in the West New District of Jinan city.
Table 4. Comprehensive evaluation of carbon emission in each area of West New district in Jinan city.

| Area Name                  | West Railway Station | The old Town of Changing District | University Science and Technology Park | Pingan Dian Town | Gushan Town | Duandian Town | Dangjia Town |
|----------------------------|----------------------|----------------------------------|---------------------------------------|-------------------|-------------|---------------|-------------|
| Shape compactness          | Higher               | High                             | Low                                   | Low               | Lower       | Medium        | Lower       |
| Functional compactness     | Higher               | Medium                           | Low                                   | High              | Medium      | Lower         | Lower       |
| Traffic carbon emission    | Low                  | Low                              | Low                                   | Lower             | Low         | High          | High        |
| potential                 |                      |                                  |                                       |                   |             |               |             |
| Road network accessibility | Higher               | High                             | Lower                                 | Low               | Low         | High          | High        |
| Accessibility of public    | Higher               | Higher                           | Medium                                | Low               | Lower       | Low           | Low         |
| transportation             |                      |                                  |                                       |                   |             |               |             |

8. Conclusion and prospect

In the Overall Planning of the West New District of Jinan city, the West Railway Station area and the University Science and Technology Park area are identified as two core growth poles. West Railway Station area encourage mixed spatial layout and low-carbon travel. Highly compact and diverse city construction land and intensive bus network can create the low-carbon community for the region and providing support for the region to become the growth pole in West New District of Jinan city. The definite positioning and relatively single service population of University Science and Technology park area result in less diversity of land use in planning. To a certain extent, near to the public service center make up the deficiency of the low density of the road network and the sparse bus station; the new residential area located in the outside of the public service center should adopt small block pattern to guide low-carbon travel, and equipped with sufficient public transport facilities to meet the needs of users. The old urban area of Changqing is a more mature city area, and the spontaneous formed land use is compact and diverse, high-density road network and supporting public transportation stations can reduce urban carbon emissions. Pingan Town and Duandian Town are far from the public center, and the bus stations density is low along the Ten Road, resulting in large traffic carbon emissions potential for residents. In order to facilitate low-carbon travel, it is better to set up bus stations and routes near the larger residential areas and residential settlements. Gushan Town and Dangjia Town’s form of construction land is dispersed which are located in the southern hilly area of Jinan. The Dangjia Town’s area road network density is high and road accessibility and traffic accessibility is better than that Gushan Town area, so the traffic carbon emissions potential is low (Table 4).

High efficiency of development and utilization of the land resources and high benefit transportation system planning and management are the important way to reduce carbon emissions. Normative low-carbon ecological space paradigm is taking shape based on spatial data as the main body. Construction land compactness, TCEP, RNA, and accessibility of public transport are important indicators of carbon emission evaluation system of urban planning program low-carbon-oriented. Urban low-carbonization relies on three aspects of the common role: reducing carbon sources, cutting carbon emissions, and strengthening carbon capture. With the development of GIS and RS as the representative of the space technology and landscape ecology and other disciplines, carbon emission evaluation system of urban planning program low-carbon-oriented should carry on comprehensive evaluation of urban spatial form, land use development intensity, traffic organization system and ecological security pattern based on the different low, carbon development mode.

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