Construction of Smart Carbon Monitoring Platform for Small Cities in China Based on Internet of Things

He Zhang[1], Jianxun Zhang[1], Rui Wang[1](✉), Qianrui Peng[1], Xuefeng Shang[1], and Chang Gao[2]

[1] School of Architecture, Tianjin University, Tianjin, China
326047221@qq.com
[2] Urban Planning Institute of Tianjin University, Tianjin, China

Abstract. The rapid development of the Internet of Things has promoted the construction of smart cities around the world. Research on carbon reduction path based on Internet of Things technology is an important direction for global low carbon city research. Carbon dioxide emissions in small cities are usually higher than in large and medium cities. However, due to the large difference of data environment between small cities and large and medium-sized cities, the weak hardware foundation of the Internet of Things and the high input cost, the construction of a small city smart carbon monitoring platform has not yet been carried out. This paper proposes a smart carbon monitoring platform that combines traditional carbon control methods with IoT technology. It can correct existing long-term data by using real-time data acquired by the sensing device. Therefore, the dynamic monitoring and management of low-carbon development in small cities can be realized. The conclusion are summarized as follows: (1) Intelligent thermoelectric systems, industrial energy monitoring systems, and intelligent transportation systems are the three core systems of the monitoring platform. (2) The initial economic input of the monitoring platform can be reduced by setting up IoT identification devices in departments and enterprises with data foundations and selecting samples by using classification and stratified sampling.

Keywords: Internet of Things · Smart city · Low carbon city · Intelligent control of carbon emission · Real-time monitoring · Small cities in China

1 Introduction

The Internet of Things (IoT) is an information network, which connects information from any object in the world to the Internet through information sensing devices such as radio frequency identification (RFID), function sensors, global positioning systems, laser scanners, etc., for intelligent identification, monitoring and management of objects [1]. It is estimated that in 2020, 30 billion information sensing devices will be put into use, including some information-sensing devices such as vehicles embedded in electronic

X. Wang et al. (Eds.): 6GN 2020, LNICST 337, pp. 263–277, 2020.
https://doi.org/10.1007/978-3-030-63941-9_20

software and household appliances [2]. The real-time monitoring platform based on Internet of Things technology realizes early warning and decision making by using identifiable, capturable and sharable data, which is able to achieve the storage, query, analysis, mining and understanding of massive sensing data through Internet technology.

Intelligent low-carbon technology based on the Internet of Things is an important direction for the research of global low-carbon cities. Exploring and advancing the way to achieve smart carbon control has become the epoch topic of for government and urban designers [3]. For example, through RFID (Radio Frequency Identification) technology and the development of an electronic environmental protection sign system, cars can be classified and controlled according to different emission standards, on the basis of which, a low-carbon traffic zone is established to gain an aim of low-carbon traffic, energy conservation and emission reduction [4]. In addition, some scholars have proposed a future urban low-carbon community model supported by digital infrastructure and data management systems, which constitutes a smart, sustainable and inclusive growth strategy through cloud computing and IoT [5].

In China, a county or county-level city with an urban population of less than 500,000 is called a small city. According to the study, carbon emissions in small urban areas with low levels of urbanization are usually three times higher than those in big cities [6]. However, the low-carbon technology based on Internet of Things technology has not yet been launched in small cities in China. On the one hand, the technical system needs to be further improved. On the other hand, it is also affected by the differences in carbon emissions pathways in small cities and the limitations of the economic foundation. Firstly, the main influencing factors of carbon emissions in large cities such as traffic congestion and high population density are not applicable to small cities. However, the carbon emissions generated by industrial enterprises account for 50% of carbon emissions in small cities. Therefore, in the small-city smart city-controlled carbon monitoring technology, the objects and data collected by the Internet of Things perception layer are quite different from those of large cities. Secondly, as the economic development level of small cities in China still has a large gap with big cities, the new generation of mobile broadband network technology, internet technology and digital management technology have not been fully popularized in households and businesses. It leads to the results that the perception of real-time data on carbon emissions still requires a large number of hardware devices such as sensor technology, micro-electro-mechanical systems and so on, while the investment of this equipment will cause the economic cost burden of small cities. Therefore, the smart city carbon control method based on the Internet of Things in small cities still needs to consider both the precision monitoring and the economic cost.

The purpose of this paper is to build a smart low-carbon monitoring platform applied to small cities in China based on Internet of Things technology. It mainly solves two major problems: 1) constructing a real-time monitoring system to monitor carbon emission data from carbon sources in Chinese small cities; 2) initially implementing a smart carbon monitoring platform for small cities with lower cost hardware investment.

The rest of the paper is organized as follows. The second part briefly reviews the existing related research. The third part puts forward the construction of the smart station monitoring platform based on IoT. The fourth part takes Changxing as an example to explore the actual construction steps of the monitoring platform. The fifth part discusses how to implement a low-cost, high-precision, intelligent carbon-based system based on a limited source of perceptual data.

2 Literature Survey

The carbon control monitoring in small cities mainly relies on the continuous development and renewal of carbon emission estimation and measurement technology. It is mainly divided into three research stages: 1. the first stage, the calculation method of energy consumption carbon emissions based on IPCC calculation method; 2. the second stage, the carbon emission coefficient estimation based on big data; 3. the third stage, the real-time carbon emission measurement method with IoT as the core.

Since direct data on CO_2 emissions is difficult to obtain, most scholars often use existing energy consumption data and estimate it according to the calculation method provided by IPCC [7]. This is also one of the most common method. The 2006 IPCC guidelines for national greenhouse gas inventories provide two methods for estimating carbon dioxide emissions based on energy consumption. Firstly, the departmental analysis method, also known as top-down, uses the energy consumption data of transportation, industry and so on with their related emission coefficients for conversion. For example: (Yanchun Yi) obtained data on energy consumption in 108 prefecture-level cities in China, such as: raw coal, fuel coal, and fuel oil data, and introduced the carbon emissions measurement model of the 2007 IPCC (Formula 1) to calculate urban carbon emissions and analyze urban carbon emission levels and their influencing factors [8]. Secondly, the per capita consumption law, also known as bottom-up, uses data of natural gas, gas and others from urban residents to estimate carbon dioxide emissions. (Chou-Tsang Chang) Some scholars obtained data on gas consumption and electricity consumption of households in eight administrative districts of the Taichung metropolitan area in Taiwan, and converted gas and electricity consumption data based on carbon dioxide conversion coefficient to estimate the carbon dioxide emissions of city buildings [9]. In China, the energy consumption data from relevant departments can only be obtained in large and medium-sized cities, which are constituted with administrative units of prefecture-level cities, while the data of small cities including counties as administrative units are usually unavailable. Therefore, the carbon emission estimation of small cities adopts a top-down energy consumption decomposition method, which is based on the departmental analysis method to estimate the total carbon emissions of the production, living, and transportation sectors of the prefecture-level cities, to estimate the carbon emission of different parts, including economic output value, total population, and traffic road mileage. Etc.

With the development of network big data technology and the popularity of remote sensing technology, carbon emission estimation methods are experiencing a revolution. Many scholars have explored the estimation methods of total carbon emissions based on real-time population, occupational and commuting data, urban nighttime lights data, and car ownership number. Among them, the research on the estimation of carbon emissions from transportation and residential carbon emissions are the most common direction. In the carbon emission estimation of transportation, based on the interaction mechanism between carbon emissions and different elements, including residents' transportation [6, 10, 11], urban occupational residence balance and urban built environment factors, to determine the carbon emission impact coefficient under different factors, and then estimate the carbon emissions. Among the methods for estimating carbon emissions in residential life, the most commonly used method is according to night lighting data. For example, a recent study validated and simulated urban carbon dioxide emissions based on nighttime light image data from 327 prefecture-level cities in China [12]. The above method provides a new idea for carbon dioxide measurement and control methods in small cities in China.

In recent years, with the rapid development of Internet of Things technology, smart low-carbon technology has formed a cross-disciplinary research field with urban intelligent infrastructure research. By implanting inductive equipment, including urban infrastructure of electricity, energy and transportation, and mobile communication facilities, it is possible to monitor, analyze, and intelligently guide urban low-carbon operations and form an early warning mechanism. Among them, the research on the Internet of Things technology for car carbon emissions is of a great number. Somne studies suggest that the Bus Stop Interface (BSI) can be installed at a specific bus stop, and the optimal driving route can be generated according to the driver's destination selection, thereby reducing traffic time [13, 14] and road congestion time to reduce traffic carbon emissions. At the same time, the application of smart grid technology also provides a real-time monitoring method for the fine management of carbon emissions [15]. Thus, it can be further applied to low-carbon logistics [16], low-carbon energy conservation [17] and so on.

The continuous updating of carbon emission measurement technology provides many methods to support the control and monitoring of carbon emissions in small cities. However, each method has certain limitations in carbon monitoring in small cities: 1) Estimation techniques based on IPCC and big data methods can cover major consumer sectors of carbon emissions. However, due to the characteristic of static data, its timeliness is low, and it is difficult to support the application field of real-time monitoring; 2) Based on the carbon emission monitoring technology of Internet of Things technology, Real-time monitoring and refined management of carbon emissions can be achieved. However, it has high requirements for mobile internet and smart grid technology and hardware, and it still cannot achieve comprehensive coverage in the carbon accounting of the living and production sectors. Combining the advantages and disadvantages of the above methods, taking into account the practical basis and economic cost of the application of IoT technology in small cities, this paper introduces a real-time data monitoring and correction method for the IoT, based on traditional carbon emission measurement method, to initially construct a smart city carbon monitoring system and application platform for small cities.

3 Proposed Framework

3.1 System Framework with the Linkage of "Long Term Data – Real Time Data"

Based on the IPCC-based carbon inventory method, the carbon emission consumer departments of small cities mainly include public power and heat, industrial production processes, transportation, service industries, and residential lives. The power and heat energy consumption in the service industry and the residential life department has been calculated in the public power heat department, and other energy consumption such as gas is negligible. Therefore, the two departments are eliminated. The main departments that jointly monitor "long-term data-real-time data" in small cities are identified, which are the thermal power sector, the industrial sector, and the transportation sector. On this basis, a real-time data acquisition system is constructed based on the revised requirements of long-term data. They also constitute the three major systems of the framework of the intelligent carbon monitoring platform, which are thermal-electricity monitoring system, energy monitoring system of industrial process and transportation monitoring system (Fig. 1).

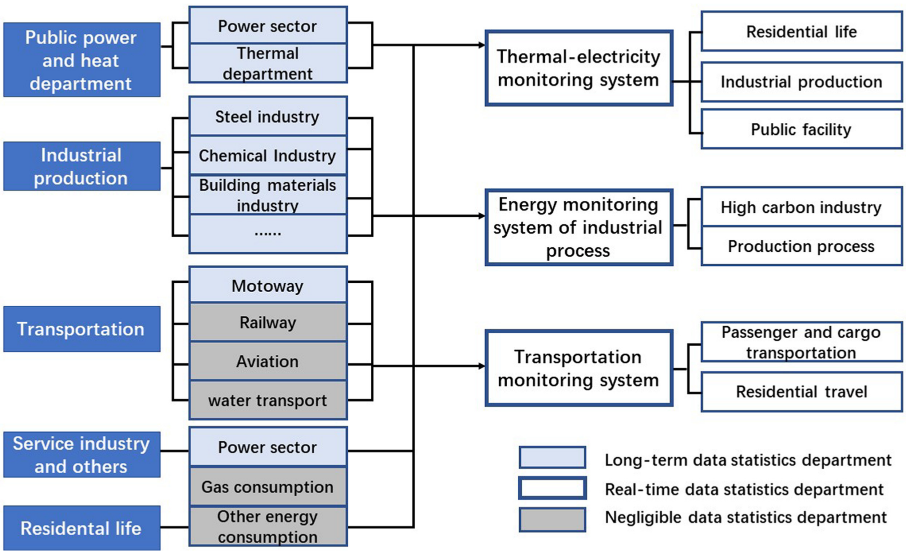

Fig. 1. "Long-term data - real-time data" linkage of carbon monitoring system framework

Thermal-electricity monitoring system is a real-time monitoring system based on sensing devices such as smart power meter and intelligent heat meter. It includes three major systems: residential life, industrial production, and public facilities. The carbon emission estimation results of long-term data are corrected in real time through real-time data of three systems.

Energy monitoring system of industrial process is to realize the correction of industrial process carbon emission measurement results through variable calculation, based on real-time data monitoring of material consumption and energy consumption data in industrial technology processes.

Transportation monitoring system includes passenger and cargo transportation systems and resident travel systems. The passenger and cargo carbon emission monitoring system is a real-time monitoring of the emission with magnetic the induction equipment and cameras monitoring the emission standards of passenger and freight vehicles, vehicle load and transit time in real time. Through the monitoring of fueling in town gas stations, the carbon emissions of residents in small cities are estimated.

3.2 Collection Method of Basic Environmental Data

It takes a long time for smart sensing devices based on individuals, families or vehicles to be popularized in small cities. Considering the feasibility of the implementation of the Internet of Things in small cities, data collection should be carried out in management departments and enterprises with certain data foundations. Based on the sociological survey method of sample sampling, the real-time fluctuation estimation technology of carbon emission is realized (Table 1).

Thermal-Electricity Monitoring System. Residential life system: Sampling methods for different capacity and different social structure settlements in small cities by sampling method. According to the proportion of the population, the sample cell is taken, the smart meter and the smart heat meter are replaced, and the sample data is collected to realize the real-time estimation of the residential thermal energy consumption.

Industrial production: Industrial enterprises above designated size are the main group of industrial land. Therefore, smart meters and smart heat meter systems are installed in such enterprises to realize real-time estimation of electric energy consumption of industrial enterprises.

Public service facility: Public service facilities are divided into city level, community level and neighborhood level. Urban-level public service facilities such as city-level hospitals, schools, and shopping malls account for more than 70% of electricity and heat energy consumption. Therefore, intelligent thermoelectric system monitoring is carried out only for city-level public service facilities. Then through the coefficient conversion, the overall facility energy consumption is obtained.

Energy Monitoring System of Industrial Process. There are large differences in carbon emissions from production processes in different industries. Therefore, energy consumption monitoring is selected for industrial enterprises whose energy consumption accounts for more than 20% of all industrial processes in small cities. Energy consumption monitoring devices and material total monitoring device are arranged in the production process that generates carbon emissions for real-time monitoring purposes.

Transportation Monitoring System. Passenger and cargo transportation: With the highway entrance and exit and section speed monitoring equipment, the speed, fuel consumption standard, driving history of passenger and freight cars are collected. And through the highway traffic flow ratio coefficient, real-time carbon emissions data of transit passenger and freight systems in small cities are estimated.

Table 1. Data attributes and acquisition methods of long-term data and real-time

Carbon monitoring system	Long-term data		Real-time data		
	Data attribute	Data Sources	Subsystem	Acquisition method	Data attributes and devices
Thermal-electricity monitoring system	Power energy consumption	Statistical data	Residential living	Stratified sampling	**Electricity and heat energy consumption:** Intelligent power meter Intelligent heat meter
	Thermal energy consumption	Statistical data	Industrial production	Stratified sampling	
			Public service facility	Classification sampling	
Energy monitoring system of industrial process	Energy consumption of raw materials and process streams	Statistical data	Subsystem by industry type (energy consumption accounting for more than 20% of all industries)	Classification sampling	**Industrial consumption energy consumption:** Energy consumption monitoring device Material total monitoring device
Transportation monitoring system	Passenger and cargo transportation	Data decomposition estimation	Passenger and cargo transportation	High speed station data acquisition	**Speed, fuel consumption standard, driving history:** Geomagnetic sensor, camera device
	Residential travel	Sample survey	Residential travel	Gas station data collection	**Amount of gasoline:** Oil quantity monitor

Resident travel system: Real-time monitoring and daily statistics on the amount of gasoline in small city gas stations. Estimate the dynamic trend of carbon emissions from residents' travel through the amount of gasoline. The amount of gasoline in small city gas stations is monitored in real time and daily statistics. And we use the trend of gasoline volume to replace the trend of carbon emissions in car travel.

3.3 Carbon Emission Measurement Correction Method Based on Real Time Data

Typical sample collection and departmental integration methods are selected for real-time data. The carbon emission method is different from the traditional static data calculation method, and it is difficult to perform simple calculation using superposition. Therefore, this paper uses the coefficient of variation method to perform real-time dynamic data monitoring based on traditional carbon emission measurement results.

Public Power and Thermal Department. Estimate the total carbon emissions of energy consumption in public utilities and thermal systems respectively. The calculation method is as follows:

$$CE_{Ph} = \sum\nolimits_{j=1}^{2} CE_{rj}(1 + R_{rj}) + \sum\nolimits_{j=1}^{2} CE_{ij}(1 + R_{ij}) + \sum\nolimits_{j=1}^{2} CE_{pj}(1 + R_{pj})$$

Among them, CE_{ph} is the revised real-time total carbon emissions for the public electric power department. CE_{rj}, CE_{ij}, and CE_{pj} respectively represent the basic carbon emission values of residential, industrial, and public services, and they all use the calculation method provided by IPCC to estimate the static energy consumption data of each department. R_{rj}, R_{ij}, and R_{pj} are respectively calculated coefficients of real-time monitoring data of the three departments, and the calculation method is as follows:

$$R_r = \sum\nolimits_{1}^{n} \frac{\Delta CER \cdot r_n}{P_n} / \sum\nolimits_{1}^{n} \frac{CER \cdot r_n}{P_n};$$

$$R_i = \sum\nolimits_{1}^{n} \Delta CEI / \sum\nolimits_{1}^{n} CEI;$$

$$R_p = \alpha\left(\sum\nolimits_{1}^{n} \Delta CEP / \sum\nolimits_{1}^{n} CEP\right);$$

Among them, ΔCER, ΔCEI, ΔCEP represent real-time energy consumption changes of the three sectors, n is the number of samples, r_n is the proportion of population in different types of residential areas, and α is the energy conversion coefficient of total public service facilities and urban public service facilities.

Industrial Production Department. Based on the energy consumption monitoring of the production links of typical enterprises, the real-time data of carbon emissions are obtained to correct the total carbon emissions of existing industrial production processes. The calculation method is as follows:

$$CE_{PP} = CE'_{pp}\left(1 + R_{pp}\right),$$

Among them, CE_{pp} is the real-time total carbon emissions corrected by the industrial sector. CE'_{pp} is the basic carbon emission value of industrial production processes calculated by static data. R_{pp} is the coefficient of variation calculated for real-time monitoring coefficient. The calculation method is as follows:

$$R_{pp} = \sum\nolimits_{1}^{n} (\Delta CEPP \cdot r_n) / \sum\nolimits_{1}^{n} (CEPP \cdot r_n)$$

Among them, $\Delta CEPP$ is the real-time change value of energy consumption in industrial production, and r_n is the proportion of energy consumption of enterprises in different scales.

Transportation Department. The transportation sector uses top-down traditional estimation methods for road carbon emissions. It uses highway mileage to decompose provincial and municipal transportation carbon emissions data. In addition, the carbon emissions of residents' travel are converted by the coefficient of resident car ownership. However, the above methods all result in great errors. Therefore, this paper uses the real-time energy consumption carbon emission data of passengers and freight vehicles on transit roads to replace the original road carbon emission estimation method. Meanwhile, the estimation of carbon emissions in the real-time gasoline fueling capacity of the gas station is to replace the resident car ownership.

3.4 Smart Control Carbon Monitoring Platform System

The Internet of Things usually has three characteristics. One is comprehensive sensing, that is, using sensors and other devices to acquire object information at any time. The second is reliable transmission. The sensor network is combined with the Internet to transmit object information to the Internet. The third is intelligent processing, using intelligent algorithms such as cloud computing and fuzzy recognition to analyze and process the data, and then realize intelligent control of objects [18, 19]. Based on this, this paper proposes a framework for Intelligent Control Carbon Monitoring Platform for small cities in China (Fig. 2), which mainly includes the basic environment data layer, database and information management layer, computing layer and management control layer.

Basic Environment Data Layer. The base environment data layer includes a perceptual environment, sensing devices, and long-term data ends collected by traditional methods. The sensing environment is the industry, transportation, and residential area; the sensing equipment includes various sensors, chips, cameras, etc.; the long-term data end collected by the traditional method refers to the energy consumption data collection of different departments in the unit by the carbon emission inventory method.

Database and Information Management. The database and information management are divided into two parts: database and information management. The database includes energy consumption data of the public power and heat departments, industrial production departments and transportation departments. The information management layer mainly loads, optimizes, transforms and integrates the data.

Calculation Layer. Computational layer refers to the use of cloud computing, programming models, fuzzy computing and other intelligent calculation methods to calculate and analyze the carbon emissions of energy consumption data in the database, and build a real-time measurement model of carbon emissions.

Management Control Layer. The management control layer refers to the relevant management decisions realized after data analysis. Among them, for the industrial sector it can achieve over-standard warning, control and monitoring decisions; for the transportation sector it can implement road restrictions, vehicle limit and other decisions; for the family it can achieve building energy warning, energy supply adjustment and other decisions.

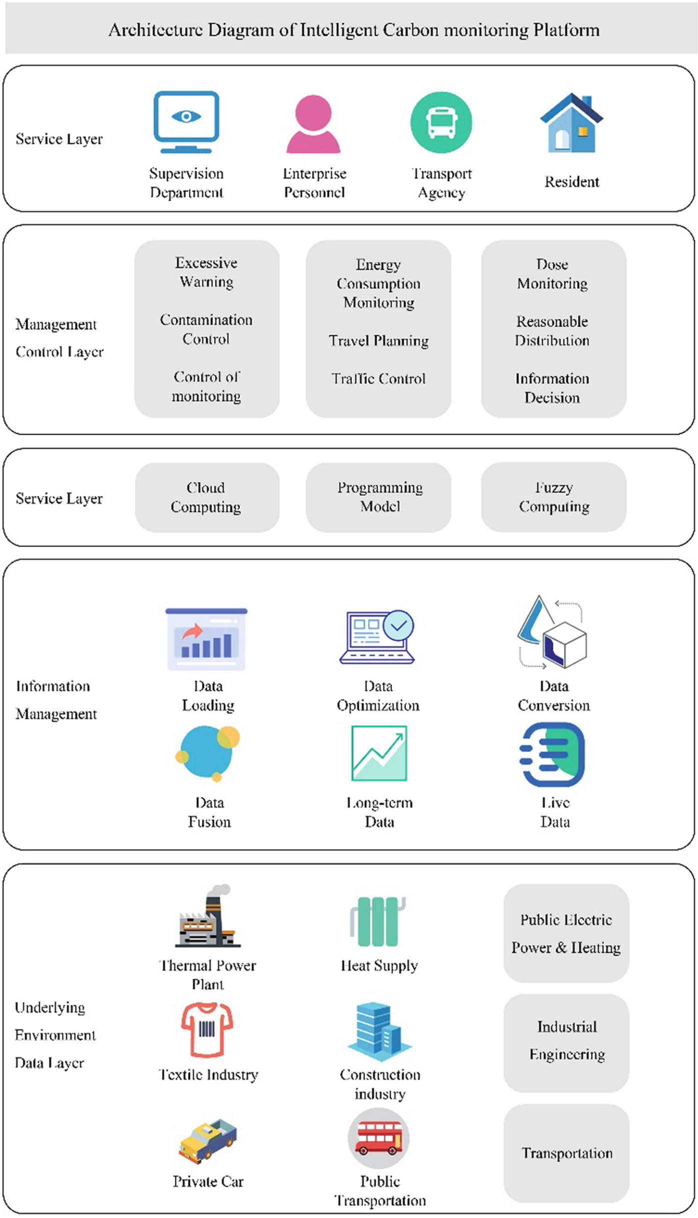

Fig. 2. The Layer of smart carbon monitoring platform system

4 Empirical Research

4.1 Empirical Introduction

The county of Changxing is affiliated to Huzhou City, Zhejiang Province. It is located on the southwestern shore of Taihu Lake between Suzhou and Hangzhou. The county governs 3 streets, 9 towns and 2 townships. The population of Changxing County is 233,200. Through the accounting of carbon emissions in Changxing County for many years, its carbon emissions are mainly concentrated in the energy industry, which is mainly based on electricity production, and the production process of building materials industry, which is mainly based on cement production (Fig. 3). And the carbon emissions of transportation and residential life are relatively low. In terms of carbon emission characteristics, Changxing has the representativeness of small cities in China.

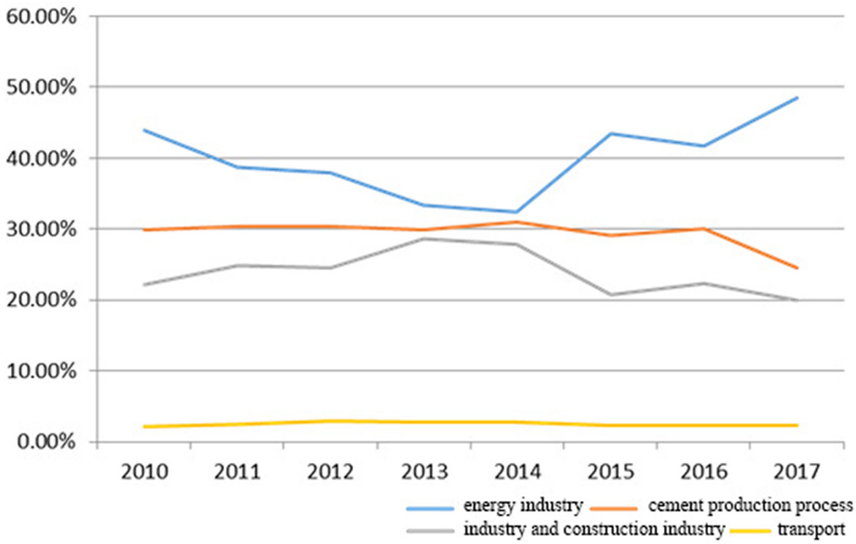

Fig. 3. Trends in carbon emission ratio of sub-sectors in Changxing (2010–2017)

4.2 Basic Environmental Data Acquisition Method of Changxing

Public Power and Heat Department. Residential life system: According to the classification method of low floor area ratio (0.8–1.1), medium floor area ratio (1.2–1.4), and high floor area ratio (>1.4), the settlement was sampled according to the proportion of the population, and finally 7 sample samples were obtained. It is proposed to install smart thermoelectric devices for the residents of the seven communities.

Industrial production system: Select 20 or more companies in different industries to install smart thermoelectric devices.

Public facility: Intelligent hotspot installations were carried out for 9 educational facilities (technical schools, secondary schools, primary schools), 8 integrated and specialist hospitals, and 7 cultural and sports facilities.

Industrial Process Department. According to the carbon emission list of Changxing County, the energy consumption of cement rotary kiln in the building materials industry accounts for 90% of the energy consumption of all industrial production. Therefore, only 9 samples of cement production enterprises are monitored for industrial process energy consumption.

Transportation Department. The intelligent monitoring equipments are installed at the super-superior station, interval speed, and camera of 18 highway entrances and exits. And oil monitoring and sensing equipment was installed at 29 gas stations in the county and townships.

4.3 Smart Carbon Monitoring Platform System of Changxing

On the basis of basic data collection, database and information management layer, computing layer and management control layer are built. The carbon emission real-time monitoring system is constructed by sensing equipment monitoring, combining carbon emission measurement correction methods with intelligent calculation methods such as data cloud calculation and fuzzy calculation. And it can simulate the future trend of carbon emissions according to the consumer sector (Fig. 4).

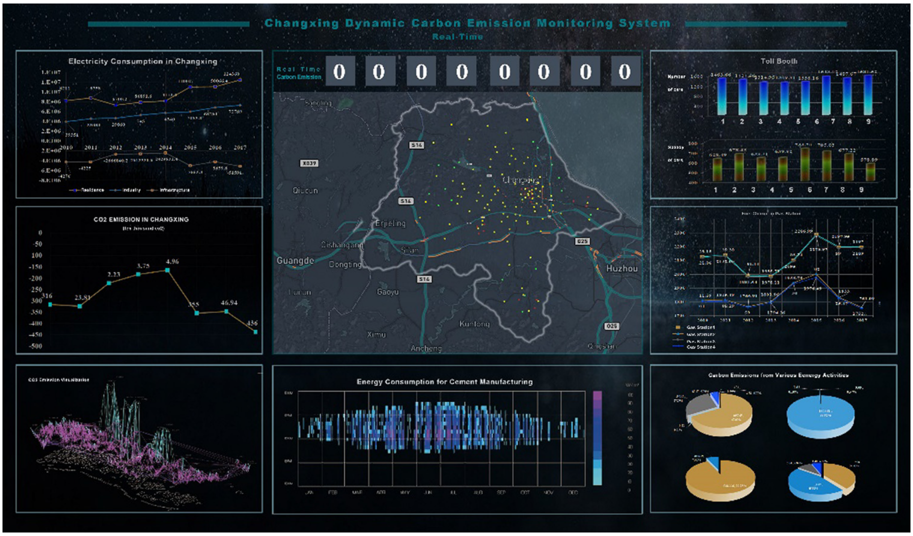

Fig. 4. Intelligent carbon monitoring platform in Changxing

5 Discussion

Based on the construction of "long-term data-real-time data" linkage control carbon monitoring system, this paper explores the real-time correction technology of traditional carbon emission measurement methods. And the intelligent control carbon monitoring platform system based on the Internet of Things was initially constructed. In this process, we mainly discuss the following issues, focusing on the characteristics and limitations of carbon control in small cities:

The small city carbon control system based on the Internet of Things technology mainly focuses on industrial thermoelectric systems, industrial production processes and transportation systems, and is quite different from large and medium cities. The focus of carbon control in large and medium-sized cities is mainly concentrated in two aspects: (1) carbon emission control brought by residential energy consumption under a large population concentration [20] and (2) carbon emission control of residential travel caused by traffic congestion [21]. The focus of carbon control in small cities focuses on (1) industrial energy consumption and carbon emissions from industrial production processes and (2) carbon emissions control for passenger and freight transportation. Therefore, low-carbon transportation and low-carbon residential Internet of Things technologies with application prospects in large cities are not very effective in controlling carbon in small cities. And increasing the IoT management and control methods for industrial processes and transit traffic is more targeted.

Selecting departments and enterprises with data foundations to collect data can reduce the input cost of the carbon monitoring platform and increase the possibility of application of IoT technology in small cities. The application of Internet of Things technology in large and medium-sized cities is often based on massive data analysis obtained from the extensive use of mobile communication devices and sensing devices [22]. However, for small cities, the data environment of their individual level is poor, and it is difficult to realize a large investment in IoT hardware devices in a short period of time. Therefore, the sensing equipment and the estimation model are deployed at the urban management department and enterprise level with a certain data foundation to avoid the dilemma of the implementation of the Internet of Things technology at the individual level in small cities.

The combination of Internet of Things technology and traditional data statistics methods is an important means of low-carbon management in small cities. Compared with small cities, the spatial structure, social structure and built environment of large and medium-sized cities show strong complex features. The perception, learning and simulation of the individual behavioral characteristics and life patterns of the Internet of Things technology make up for the gap in the management level of big cities. But for small cities, their demographic, spatial and economic structures are relatively stable and simple. And Individual IoT data environment is still immature. Therefore, the sampling method of sociology can still be used to solve the problem of unsatisfactory data environment through reasonable stratification and classification sampling. And through the combination of Internet of Things technology, real-time statistical results can be achieved.

6 Conclusion

The application of existing Internet of Things technology in low-carbon fields is often based on the superior data base, rapid economic development and low-carbon management system in large cities. However, it is not fully applicable to small cities with poor economic levels and weak data environment. In view of the above problems, this paper constructs a carbon-controlled monitoring system linked to "long-term data-real-time data", which is an exploration of the correcting method of traditional carbon emission measurement. Based on this, the intelligent carbon monitoring platform is initially constructed. This study provides a preliminary framework for the smart city carbon monitoring platform in small cities, but it still needs empirical support to explore the experience in data collection, processing and analysis.

Acknowledgments. Supported by National Key Research and Development Project (Grant No. 2018YFC0704701).

References

1. Rajanpreet, K.C., Neeraj, K., Shalini, B.: Trust management in social Internet of Things: a taxonomy, open issues, and challenges. Comput. Commun. **150**(15), 13–46 (2020)
2. Sofana, R.S., Tomislav, D.: Future effectual role of energy delivery: a comprehensive review of Internet of Things and smart grid. Renew. Sustain. Energy Rev. **91**(08), 90–108 (2018)
3. Ruike, Y., Yiwei, L., Zhuangfei, G., Wang, L.: The interactive development of low-carbon city and smart city. Sci. Technol. Econ. **30**(04), 12–85 (2017)
4. Kovavisaruch, L., Suntharasaj, P.: Converging technology in society: opportunity for radio frequency identification (RFID) in Thailand's transportation system. In: Conference of the Portland-International-Center-for-Management-of-Engineering-and-Technology 2007, Portland, vol. 1–6, pp. 300–304. Springer, Heidelberg (2006)
5. Deakin, M., Reid, A.: Smart cities: under-gridding the sustainability of city-districts as energy efficient-low carbon zones. J. Clean. Prod. **173**(2), 39–48 (2016)
6. Waygood, E., Yilin, S., Yusak, O.S.: Transportation carbon dioxide emissions by built environment and family lifecycle: case study of the Osaka metropolitan area. Transp. Res. Part D Transp. Environ. **31**(08), 176–188 (2014)
7. Eggleston, H., Buendia, K., Miwa, T., Ngara, K.: Tanabe, IPCC guidelines for national greenhouse gas inventories. Institute for Global Environmental Strategies (IGES), Hayama (2006)
8. Yanchun, Y., Sisi, M., Weijun, G., Ke, L.: An empirical study on the relationship between urban spatial form and CO2 in Chinese cities. Sustainability **672**(9), 1–12 (2017)
9. Chou, T.C., Chih, H.Y., Tzu, P.L.: Carbon dioxide emissions evaluations and mitigations in the building and traffic sectors in Taichung metropolitan area, Taiwan. J. Clean. Prod. **230**(09), 1241–1255 (2019)
10. Kitamura, R., Sakamoto, K., Waygood, O.: Declining sustainability: the case of shopping trip energy consumption. Int. J. Sustain. Transp. **2**(3), 158 (2008)
11. Anne, A., Marion, V.: Urban form, commuting patterns and CO2 emissions: what differences between the municipality's residents and its jobs? Transp. Res. Part **69**, 243–251 (2014)
12. Shaojian, W., Chenyi, S., Chuanglin, F., Kuishuang, F.: Examining the spatial variations of determinants of energy-related CO2 emissions in China at the city level using Geographically Weighted Regression Model. Appl. Energy **235**(02), 95–105 (2019)

13. NodeMCU, Team: Nodemcu-an open-source firmware based on esp8266 wifi-soc (2014). http://nodemcu.com/indexen.html
14. Lakshmi, S., Nithin, S.: A Smart transportation system facilitating on demand bus and route allocation. In: International Conference on Advances in Computing, Communications and Informatics (ICACCI), Manipal, INDIA, SEP 13–16, pp. 1000–1003. IEEE (2017)
15. Dileep, G.: A survey on smart grid technologies and applications. Renew. Energy **146**(02), 2589–2625 (2020)
16. Zhiyao, L., Zilong, Z., Zizhao, H., Qi, W.: A framework of multi-agent based intelligent production logistics system. Procedia CIRP **83**, 557–562 (2019)
17. Samuels, J.A., Booysen, M.J.: Chalk, talk, and energy efficiency: saving electricity at South African schools through staff training and smart meter data visualization. Energy Res. Soc. Sci. **56**(10), 101212 (2019)
18. Jia, B., Hao, L., Zhang, C., Zhao, H., Khan, M.: An IoT service aggregation method based on dynamic planning for QoE restraints. Mob. Netw. Appl. **24**(1), 25–33 (2018). https://doi.org/10.1007/s11036-018-1135-7
19. Chen, H.M., Cui, L., Xie, K.B.: A comparative study on architectures and implementation methodologies of Internet of Things. Chin. J. Comput. **36**(1), 168–188 (2013)
20. Shanshan, S., et al.: Research on low-carbon energy management system of intelligent community. In: ICAEMAS Conference, pp. 488–489 (2014)
21. Gargiulo, C., Russo, L.: Cities and energy consumption: a critical review. J. Land Mobil. Environ. **10**(3), 259–278 (2017)
22. Mehmood, Y., Ahmad, F., Yaqoob, I., Adnane, A., Imran, M., Guizani, S.: Internet of Things based smart cities: recent advances and challenges. IEEE Commun. Mag. **55**(9), 16–24 (2017)