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Research article

Construction of urban low-carbon development and sustainable evaluation system based on the internet of things

Haochun Guan

Faculty of General Education, Huaqiao University, Xiamen, 361021, Fujian, China

A R T I C L E I N F O

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A B S T R A C T

Low-carbon (LC) cities are the cities that people long for today. LC environmental protection plays a very important role in people's health. The construction of a city in LC is a great cause that contributes to the present and benefits the future. In this study, we propose a development and sustainability evaluation system for building low-carbon cities based on the Internet of Things (IoT). The study is novel in that it considers key areas such as urban planning, environmental issues and solutions, and how the Internet of Things can optimize low-carbon logistics and smart grids, with the aim of promoting the formation of low-carbon city models. This comprehensive approach not only presents problems and solutions in low-carbon urban planning but also focuses on how the Internet of Things can be used as a key technology to promote low-carbon urban development. The urban development of LC was constructed with a sustainable evaluation system, so that people could experience the life of LC. Through the investigation of the degree of atmospheric pollution of LC cities using the Internet of Things, this article found that the highest degree of atmospheric pollution was 30. The highest degree of atmospheric pollution in cities in LC without IoT was 53. The severity of water pollution in cities in LC using IoT technology ranged from 10 to 25, while those without IoT ranged from 30 to 60. The degree of soil pollution in LC cities using IoT technology was concentrated in 10–30, while those without using IoT were concentrated in 30–50. Through these experimental data, it could be seen that IoT technology could reduce environmental pollution, thus achieving the effect of LC cities. This shows that the use of IoT technology in LC cities was highly feasible.

1. Introduction

LC cities are currently a prominent topic of discussion and delight the imaginations of people around the world. The concept of LC cities, short for "Low-Carbon" cities, has gradually gained traction among the populace. People harbor a deep yearning for the LC lifestyle, envisioning medium-sized cities that are environmentally friendly and pristine, capable of fostering both health and happiness. Consequently, there is an ongoing surge in scholarly endeavors aimed at comprehensively understanding LC cities.

As public interest in LC cities continues to increase, so does the volume of research dedicated to unraveling their intricacies. Liu C, for instance, espoused the view that LC policies are not merely geared towards fostering economic development, but also towards mitigating the impacts of climate change. He posited that LC policies foster a symbiotic relationship between economic industrial structures and foreign investments, thus achieving mutually beneficial growth. Despite the promotion of regional innovation by LC policies, Liu cautioned that innovation might not produce immediate results [1]. Similarly, Xin L stated that the promotion of green

E-mail address: ghc15475@hqu.edu.cn.

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and LC development has become a global consensus, but lamented the dearth of studies exploring the scientific nuances and repercussions of LC development [2]. Chen L, on the other hand, emphasized that the primary environmental challenge lies in carbon emissions arising from urbanization. He advocated for stringent measures to curb the growth of urban carbon emissions as part of experimental policies aimed at achieving carbon neutrality [3]. Colenbrander S shed light on the prevalent misconception that LC development is inherently more expensive than high-carbon development, a belief that often hampers opportunities for sustainable growth, especially in resource-constrained environments [4]. It is posited that integrating LC city construction with the Internet of Things (IoT) could potentially catalyze more comprehensive LC development, thereby fostering cities' transformation towards greater sustainability.

The integration of IoT technology has immense potential for comprehensive management of urban infrastructure and effective control of pollutant emissions. Kobayakawa T underscored the significance of policies that aim to reduce carbon intensity in energy production, particularly in sectors such as industry, energy, and transportation. Such policies, if implemented effectively, could drastically minimize carbon dioxide emissions per capita, thus contributing to environmental sustainability [5]. Guo S characterized the LC pilot city project as a crucial policy experiment designed to implement the tools and measures essential to achieve the LC development goals at the local level. However, certain scholars expressed reservations about the extent to which local pilot initiatives aligned with the central government's expectations for policy innovation [6]. Zhang L P emphasized the pivotal role of LC development in addressing the challenges posed by climate change. Understanding the dynamics of the implementation of LC development offers valuable insights for policy makers striving to monitor and enhance the trajectory of LC in cities [7]. Zhang Y raised concerns about the effectiveness of global efforts directed toward the development of the LC economy, highlighting a lack of a comprehensive understanding of its efficacy [8]. Zhang J highlighted the growing importance of establishing intelligent and environmentally sustainable models for the development of green industries amidst the rapid expansion of the global LC economy and the industrial IoT landscape [9]. In this context, the amalgamation of IoT technology with LC cities emerges as a dominant trend. With robust IoT support, cities in LC are poised to enhance their environmental credentials and foster sustainability on a broader scale. This synergy not only enhances the efficiency of city operations, but also facilitates the realization of environmentally friendly urban environments, aligning with the evolving aspirations of contemporary society.

LC cities can help people live better. Cities with too much environmental pollution are not suitable for people to live in. Therefore, the concept of LC and environmental protection needs to be instilled in everyone's mind and then put into practice. In this way, the city's LC can do better and better. This paper studied the development of LC cities based on IoT. It was to improve the LC level of cities through IoT technology. This paper tested several key points of pollution in the experiment, hoped to prove that IoT was really effective for urban LC. This paper tested the air pollution, water pollution, and soil pollution of LC cities using IoT technology. Through the experimental data, it was found that the level of pollution was lower than that of those without IoT technology. This showed that the use of IoT technology in the LC cities was very good and suitable for comprehensive promotion.

The outline of the paper is as follows. The first part is the introduction and background, introducing the concept of low-carbon city, and why the urban low-carbon development and sustainable evaluation system based on the Internet of Things is needed; the second part discusses how to build a low-carbon iot city development system; the third part is the low-carbon city experiment based on the Internet of Things; the fourth part is the conclusion part, which summarizes the contribution and potential of iot technology to urban low-carbon development, and puts forward suggestions for further research and implementation of low-carbon urban planning.

2. Construction of urban LC development system of the IoT

2.1. Introduction to LC cities

LC city refers to grasping the direction of urban planning and promoting the formation of a LC model in the process of reasonable urban planning. The planning of the city of LC includes the transportation system and related economic sectors. Today, many countries have combined the concept of LC with urban planning practice and have achieved some results. In urban planning and construction, it is also necessary to pay attention to the impact of economic development on the environment, and the problem between the economy and the environment cannot be ignored.

2.2. Environmental problems and solutions in cities

The increase in economic activities would lead to deterioration of environmental quality [10]. The environmental problems in cities are mainly reflected in air quality. With the continuous development of industry and the rapid growth of the population, air pollution has become very serious, especially the emission of motor vehicle exhaust, which has a huge impact on air quality and seriously affects the lives of people in cities. The burden of disease and death caused by environmental pollution challenges public health around the world [11]. Especially in developing countries, the kidneys are vulnerable to environmental pollutants, because most environmental toxins are concentrated by the kidneys during filtration [12]. The complexity and dynamics of the environment make it extremely difficult to directly predict and track pollution [13].

With the development of industrialization and technology in the world, pollutants in modern society are increasing exponentially and the impact of pollution on public health is well known [14]. The environmental problems in cities are also reflected in water pollution. With the accelerating process of urbanization, the urban industry would have a great impact on the urban environment. In some densely populated areas, the problem of the destruction of water resources would be more serious, so water pollution is very important [15].

The solution to environmental problems in cities is to improve public transport. Automobile exhaust emissions would produce a greenhouse effect. In the construction of LC cities, it is necessary to reduce unnecessary traffic first, and strengthen the concept of LC travel of the masses, so as to use more shared bicycles or electric vehicles for travel.

The solution to environmental problems in cities is to vigorously develop new energy. With the rapid development of industrialization, people cannot live without energy, and the economic development of energy demand is also very huge. To reduce carbon emissions in LC construction, the most effective way is to change the use of energy types. For urban buildings and construction of public equipment, the use of non-hazardous materials is advocated, which can reduce environmental pollution [16]. When purchasing materials, local manufacturers are selected as much as possible and materials are recycled as much as possible to reduce the consumption of resources. Recyclable resources should be used responsibly, which can improve the ecological quality of the city and reduce pollution. Industrialization is an important part of the economic development of any country. Industrialization has a significant impact on carbon emissions [17]. The interaction between environmental pollution and economic growth determines whether developing countries can achieve the goal of green growth [18].

The solution also includes industrial planning, which includes promoting the transformation of traditional industries to realize the transformation from traditional industries to new modern industries. It also includes promoting the development of new industries and eliminating industries that are not suitable for the times, which would build new industries that are suitable for the times.

2.3. *Features of the LC city planning*

LC city is one of the urban planning, but LC city is a relatively new type of LC construction, which has both the characteristics of traditional urban planning and the content different from traditional urban planning. The planning of LC cities is based on tradition, so the coordination of various elements in traditional cities needs to be referred to. The LC function of cities should be built, and the LC cities should be built. The concept of LC cities needs to be advocated, which requires LC city planners to advocate for the construction concept of LC cities.

2.4. *Implementation of LC urban planning*

In the urban planning process, there needs to be a relatively perfect and standard urban planning indicator to plan LC cities. However, due to the regional and cultural differences between cities, different indicators need to be formulated according to different cities when formulating indicators.

The role of urban planning is to coordinate interests within the city as much as possible, so there are many factors in urban planning and design. In the implementation of urban planning, it is necessary to study the policies of LC cities. By formulating the planning policies of the LC cities, urban planning can be assessed and evaluated. Those who do well in urban planning would be rewarded, while those who do not do well would be punished. In the implementation of urban planning, it is also necessary to strengthen the supervision of different organizations in the city on urban carbon emissions and the promotion of ideas, in order to create a better LC city. The implementation of urban planning also includes a comprehensive assessment of the implementation process of LC cities. Through these assessments, effective implementation measures can be summarized to guide future urban construction. The implementation of urban planning is also reflected in the follow-up study of the LC planning schemes, that is, the statistics of all aspects of urban construction. The carbon emissions of LC cities should be adjusted and managed.

2.4.1. *Problems and solutions in urban planning in LC*

At present, there are still many problems in urban planning in LC, such as unreasonable land resource planning. With the continued progress of urbanization, more and more land resources are used, which requires renewed attention to planning and utilization of land resources. At present, there is still a waste of land. The land is not fully used and the green plants in the cities are gradually replaced by cement. Existing problems are the lack of a complete indicator system and standards. Although many cities have paid attention to the construction of LC cities, they have not been well implemented in practical work. LC city construction is extremely complex, and many steps need the guidance of scientific theory, so the actual work would be lacking in implementation.

The solution to the problem of LC urban planning includes the recycling of energy, which is a requirement of sustainable development. Therefore, it is necessary to find and explore renewable energy as much as possible in urban LC construction. The solution is to

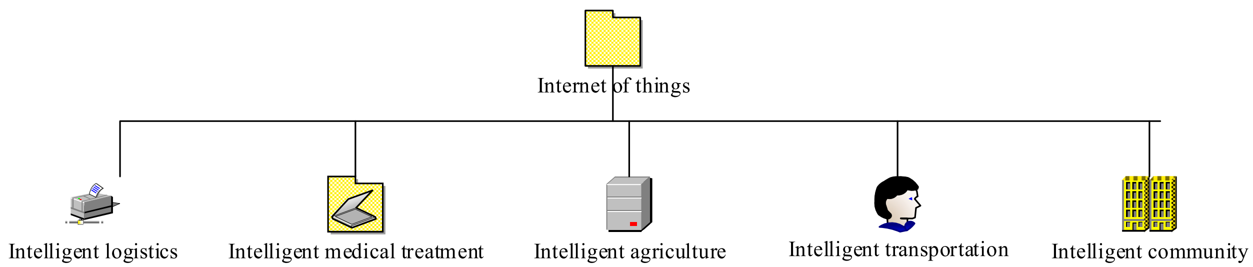


Fig. 1. The application field of the IoT in LC cities.

reasonably arrange urban space and build an industrial LC system. Nowadays, the per capita resources are relatively small and people live in crowded cities. Therefore, some crowded cities can be reasonably arranged, and the concept of green and LC economic construction can be established to reduce the greenhouse effect of cities. In the urban construction process, it is also necessary to continuously increase the forest planting area and build a good LC economic industrialization system in combination with urban development.

2.5. Impact of the IoT on urban LC development

2.5.1. Role of IoT in promoting LC logistics

The fields where IoT can be used in cities in LC are shown in Fig. 1.

In the construction of LC cities, LC logistics is a key point. The IoT has been widely used in smart home, intelligent transportation, and other fields. The application of IoT in logistics can promote the development of logistics LC. To achieve the development of LC in the logistics industry, it is necessary to optimize the logistics industry management process. Through scientific management, the cost of logistics can be reduced, to reduce carbon emissions and achieve the LC effect. Through the technology of the IoT, it can optimize the packaging, handling, and other processes of logistics, and effectively solve the problem of control and tracking of the business process of the logistics industry, so as to optimize the logistics management process.

IoT can drive the informatization and automation of LC logistics infrastructure, because IoT technology can effectively identify shelves and vehicles. Through IoT reading and writing devices for vehicles and warehouses, it can identify logistics handover information at the time of collection, which improves LC logistics automation. Improvement in automation would not only reduce the cost of logistics but would also drive the LC development of the logistics industry.

The IoT can organically link the warehouses of different companies for unified deployment and management, increasing the scope of logistics services and expanding the storage space of goods. IoT technology used in the logistics warehouse can improve the level of management of the warehouse and reduce the cost of the warehouse.

If the IoT wants to improve the development of LC logistics, it needs to find the right promotion and application to implement it. The application of IoT to LC development is a long-term process, which requires greater promotion in logistics applications while introducing IoT technology. Only in this way can IoT technology be well promoted in the logistics development process. There is also the need to strengthen research on the technology of IoT. The IoT is still an emerging industry. Although experts have done a lot of research on IoT, the depth and breadth of research on IoT is still insufficient. Therefore, in order to better use the IoT in the logistics industry, it is necessary to further study and strengthen the IoT technology. If the IoT is to be better used in logistics, it also needs the government to do a good job of coordination. The LC development of the IoT technology is a big project that needs the support of the government. Only by doing a good job of coordination can the development speed of the IoT be accelerated. It is also necessary to strengthen the construction of professional teams. The IoT has a high demand for technical personnel. Therefore, to promote the LC development of the logistics industry with IoT technology, it is necessary to focus on the cultivation of talents. Therefore, the government should formulate a talent cultivation plan to cultivate talents to promote IoT technology.

When discussing the construction of low-carbon urban development and sustainability assessment systems, the huge impact of Internet of Things (IoT) technologies on low-carbon city (LC) planning and implementation was highlighted. As an advanced technological solution, the Internet of Things can promote the decarbonization of urban transport systems, energy management, and logistics operations, thereby improving the quality of the city's environment and the quality of life of residents. Before continuing to explore the application of the Internet of Things in the construction of low-carbon cities, it is necessary to explore how the Internet of Things specifically affects urban planning and management. By connecting various smart devices and systems, the Internet of Things can collect, process, and analyze data from multiple parts of a city in real time. These include, but are not limited to, data on energy consumption, traffic flow, air quality index, and water usage. Through the analysis of these data, urban planners and managers can more accurately understand the actual situation of urban operation, and then make more targeted adjustments and improvements. For example, in transportation planning, iot technology can help enable intelligent transportation systems to reduce vehicle congestion and emissions by monitoring traffic flow and road conditions in real time, optimizing signal control and route planning. In terms of energy management, the concept of smart grids and smart buildings can be combined with iot technology to enable more efficient energy use and reduce unnecessary waste, while improving the access and utilization of renewable energy by optimizing the energy supply chain. The potential of iot to increase the level of low-carbon urban development is also reflected in its optimization of urban logistics and supply chains. Through intelligent tracking and management technologies, iot can help logistics companies achieve more efficient warehouse management, distribution route planning, and vehicle scheduling, thereby reducing energy consumption and carbon emissions. In addition, the Internet of Things can also promote intelligent management of urban waste, through the intelligent waste collection and classification system, improve resource recycling rate, and reduce carbon emissions in the waste treatment process. In order to fully leverage the role of the Internet of Things in the construction of low-carbon cities, all aspects of government, business, and society need to cooperate, including the development of policies and regulations conducive to the application of iot technology, increasing investment in iot research and development, and raising public awareness of the importance of low-carbon lifestyles. These efforts, combined with the application of iot technology, can effectively promote low-carbon urban development and move toward a sustainable future.

2.5.2. LC smart grid of the IoT

The IoT can intelligently communicate all links of the power grid system, such as energy resource development, transmission, and power sales, to achieve accurate power supply. The IoT can monitor the distribution network in real time. It can monitor information such as the power measurement of each meter of the transformer and the power consumption of large users. It can also locate the fault area to determine the fault area. The fault section is isolated from the nondistribution area, so that the power supply function can be restored quickly. If a trip is detected, the closing operation can also be performed quickly. These IoTs can reduce the unnecessary power consumption of a smart grid, thus achieving the effect of LC.

2.5.3. LC intelligent transportation of the IoT

Intelligent transportation is a traffic-oriented service system based on modern electronic information technology. Its characteristics are collection, processing, and analysis as the main line, which provides diverse services for traffic participants. Intelligent transportation includes traffic flow monitoring, intelligent parking space management system, and Internet of Vehicles. Among them, traffic flow monitoring can improve vehicle traffic capacity. The intelligent parking space management system can let car owners know the situation of the destination parking space via mobile phones and then choose the way of travel, which can reduce carbon emissions. The Internet of Vehicles can reduce costs to manage vehicles.

2.5.4. LC smart home with IoT

The IoT can realize access control. The access control system combined with fingerprint and face can save the user's record of each access and can automatically call the elevator. The IoT can also improve home security, because the smart home has an alarm function, which is connected to the community security center and can alert in time. The smart home also has the function of automatic meter reading, which can collect data from water and electricity meters and contact the community management center to transmit the data. It can also carry out visual intercom and see the image of visitors through the screen, so as to open the door indoors. It can also perform remote control on the network. Through the network, the situation and news can be learned at home, and safety precautions can be taken. Before going home, the air conditioner and water heater can also be turned on in advance. The powerful IoT has improved the quality of family life and achieved LC.

2.5.5. LC smart community of IoT

The intelligent community can identify the owner's identity and intelligently manage vehicle access. The security guard only needs to watch the intelligent monitoring, instead of patrolling everywhere. Intellectualization of the community adopts the two-layer network platform of the control network and the management information network, that is, the comprehensive management of the community and the comprehensive monitoring management. These two management can make the community management in order to achieve LC.

It should be noted that there are certain risks in the use of the Internet of things, including security vulnerabilities, privacy issues,

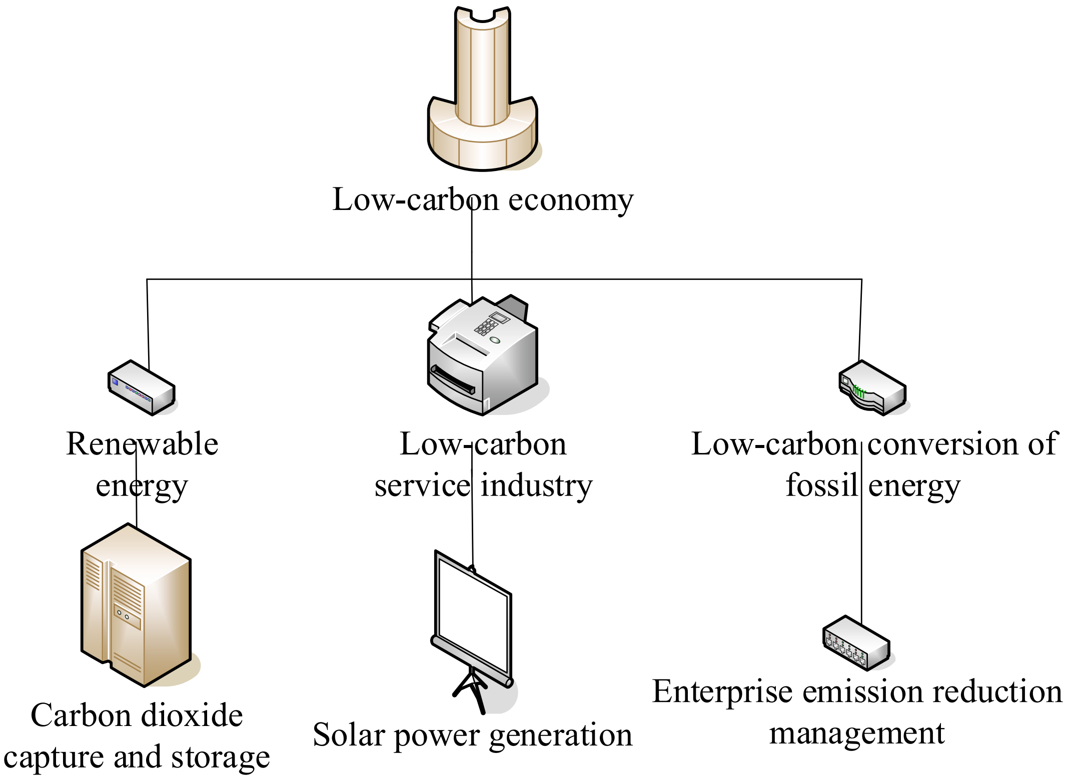


Fig. 2. The Development Direction of the LC economy.

interoperability difficulties, etc., need to consider the challenges of device management, data processing, legal regulation and other aspects to ensure sustainable and secure applications.

2.6. Impact of IoT on the LC economy

Low carbon, which means low carbon, refers to a paradigm shift in reducing greenhouse gas emissions and mitigating environmental impacts. In the context of the LC economy, the focus is on significantly curbing the consumption of high-carbon energy sources such as coal and oil. This has been achieved through technological innovation, institutional reform, industrial restructuring, and renewable energy development. Oriented by the principles of sustainable development, the goal is to promote economic growth while minimizing the carbon footprint and protecting the integrity of the environment. This approach to economic development embodies the essence of sustainability and aims to meet the needs of present generations without compromising the ability of future generations to meet their own needs. By prioritizing the reduction of greenhouse gas emissions and the adoption of cleaner, more sustainable energy alternatives, the LC economy sets a trajectory for long-term viability and resilience. In terms of economic efficiency, the letter-of-credit economy presents several compelling advantages. First, by transitioning from high-carbon energy sources, companies can reduce operating costs associated with resource extraction, transportation, and emission reductions. In addition, investments in renewable energy infrastructure and energy-efficient technologies can lead to long-term savings and improve competitiveness in the global market. The LC economy offers a more sustainable and resilient model of economic growth than previous approaches centered on dependence on fossil fuels and resource-intensive industries. Encourage innovation and entrepreneurialism in areas such as renewable energy [19], clean transportation, and sustainable agriculture [20], driving job creation and economic diversification. However, it must be acknowledged that the transition to an LC economy may require upfront investment and transition challenges. Businesses and industries accustomed to traditional practices may need support and incentives to adopt sustainable technologies and practices. Additionally, policymakers must navigate regulatory frameworks and market dynamics to ensure a smooth transition to low-carbon solutions. Overall, while the LC economy represents a promising path to sustainable development, its success depends on collaborative efforts between governments, businesses and communities. By fostering innovation, promoting investments in clean technologies, and fostering a culture of environmental stewardship, the LC economy has the potential to create a more prosperous and sustainable future for all. The development direction of the LC Economy is shown in Fig. 2.

2.7. Investigation on the sustainable evaluation system of LC cities of the IoT

Sustainable development must be important in the development of the times. The development direction of sustainable LC cities is in three levels: The first is the natural level, which means to be close to the environment and to develop without damaging the ecological environment. Only in this way can sustainable development be achieved; the second is the citizen level, which means that the spiritual and cultural construction of citizens should be paid attention and the urban space should be created that is more conducive to physical and mental health of people, which is conducive to sustainable development. The third is the social level, which means taking the resource-saving road and helping to improve the social, economic, and cultural level, so as to make LC cities more sustainable.

When evaluating LC cities, a set of reasonable data-based LC city construction methods is needed, which is also an important reference for formulating LC city development strategies. Only after a systematic analysis of the city's economy and environment can the deficiencies be made up, so as to solve the problem of LC development and build a comprehensive and coordinated LC city.

The evaluation system of LC cities is driven by LC economic development and responded by LC development policies, to establish indicators of LC output and LC consumption. To establish a LC development evaluation system with LC cities as the target, it is necessary to determine the weight of the evaluation indicators. By giving specific values to each indicator, it shows the relative importance and influence of the indicator in the evaluation system of the development of LC cities and quantifies the evaluation of LC cities. The weight assignment methods include the Delphi method and the entropy weight method. The Delphi method is to let multiple experts grade a problem and then discuss it, so as to finally reach a consensus. The limitations of the social science knowledge of experts would affect the experimental results, so this method can only make a preliminary determination of the results. The entropy weight method is used to calculate and modify the weight of each index according to the value of the index by using the information entropy. This method can be used to weight the index by combining subjective judgment with objective method, which can make the obtained data more accurate.

2.8. Evaluation of the development of LC cities with IoT

LC cities with the IoT are now under continuous construction. In the construction process, many unreasonable urban planning would be adjusted through IoT technology, which is conducive to a better realization of LC in the city. For example, in transportation, reasonable vehicle management can reduce vehicle emissions. In logistics, it can also make logistics operation more standardized and help reduce unnecessary energy consumption. IoT can have an LC effect in all areas of the city, which is very helpful for the construction of LC cities.

2.9. Application of the clustering topology fault-tolerant algorithm of IoT to the construction of LC cities

The role of the IoT in LC cities often uses the fault-tolerant clustering topology algorithm of the IoT. This algorithm can sense, collect, and process the information of the sensing objects in the network coverage area for the cooperation of the IoT, and send the information to the base station for processing after fusion.

In the algorithm, the selection probability of the cluster head is calculated as shown in Formula 1:

$$P = AB/C \tag{1}$$

In formula 1, B is the residual energy of the node; C is the maximum energy at the initial time of the node; A is the probability coefficient for the head of the main cluster.

k(i) is the probability that the i-th node becomes the cluster head node and x is the percentage of the cluster head node in all nodes. The calculation method of k(i) is shown in Formula 2:

$$k(i) = \frac{x}{1 - x(1/x)} \tag{2}$$

During the operation of sensor nodes, compared with the energy consumed during idle, reception, data fusion, and transmission, the energy consumed during the transmission phase is relatively the highest. The calculation method of energy consumed per second is shown in Formula 3:

$$e = z + ms \tag{3}$$

In Formula 3, z is the energy consumed during information transmission; m is the energy coefficient consumed at the transmission stage; s is the transmission range of the node. It can be seen from Formula 3 that the energy consumed by the node is related to the distance from the previous communication of the node. If the node uses the maximum communication radius to communicate, it can reduce unnecessary energy waste.

The maximum probability that the cluster head node loses contact with the backbone network is shown in Formula 4:

$$v = bt + b^2t^2 \tag{4}$$

In formula 4, b represents the probability that the node becomes an isolated cluster, and t represents the probability that the node in the cluster leaves the backbone network.

3. LC city experiment based on the IoT

Pollution is now a topic that people attach great importance to, and the establishment of LC cities has become people's vision. This study aims to investigate the efficacy of integrating IoT technology into LC cities for the development of low-carbon (LC) environments. The research methodology involves conducting experiments to compare pollution levels in LC cities before and after the integration of IoT technology. Seven groups of LC cities were selected for the study, some using IoT technology and others not. The study design ensures a comprehensive analysis of the effectiveness of IoT-enabled LC cities in mitigating pollution.

The study process involves several key steps:

Selection of LC Cities: The researchers identified and selected a wide range of LC cities for inclusion in the study. These cities represent various geographic regions, population sizes, and economic profiles to ensure that the results are representative and applicable in different contexts.

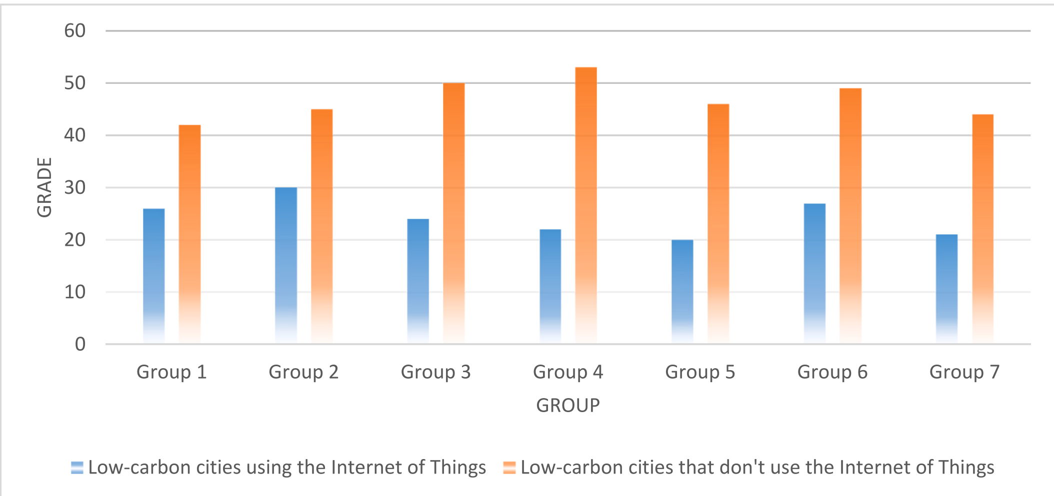


Fig. 3. Comparison of the degree of air pollution in LC cities with and without IoT.

Implementation of IoT Technology: In selected LC cities, IoT technology was integrated into various aspects of urban infrastructure and management systems. This technology enables real-time monitoring, data collection and analysis of environmental parameters, thus facilitating informed decision-making and proactive pollution control measures.

Pollution Measurement: Before and after the implementation of the IoT technology, pollution levels in the selected LC cities were meticulously measured and documented. Air pollution, water pollution, and soil pollution were evaluated using standardized measurement techniques and instruments.

Data Analysis: The pollution data collected were analyzed and compared between LC cities with IoT integration and those without. Statistical analysis techniques were used to identify trends, patterns, and significant differences in pollution levels before and after the implementation of the IoT.

Pollution Grading System: The degree of pollution in each city in LC was quantified using a grading system consisting of 100 grades. Higher grades indicate more severe pollution levels, providing a standardized metric for comparison and evaluation.

Limitations and Constraints: The study acknowledges potential limitations and limitations, such as variations in environmental conditions, socioeconomic factors, and the complexity of the dynamics of pollution. These factors were taken into account during data interpretation and analysis to ensure the robustness and reliability of the findings. Experimental results are shown in Fig. 3.

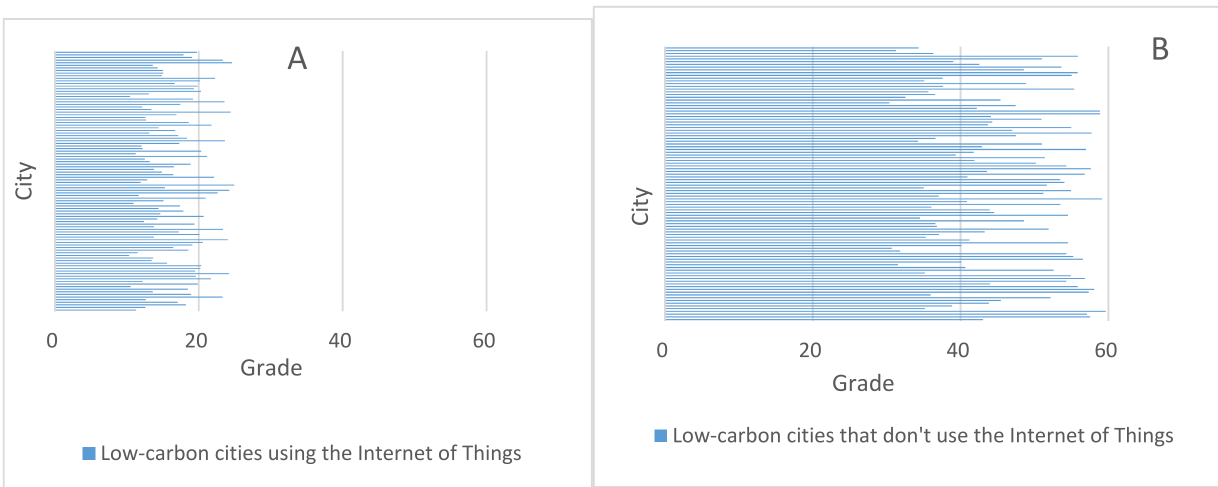
From the experimental results in Fig. 3, it could be seen that the highest level of pollution in seven groups of LC cities using the IoT was Group 2, with a severity of 30. The lowest level of pollution was Group 5, with a severity of 20. Group 4 of LC cities that did not use the IoT was the most polluted, with a pollution level of 53. The group with the lowest degree of pollution was Group 1, with a degree of pollution of 42. From these experimental data, it could be seen that the level of atmospheric pollution of LC cities using IoT was lower than that of cities without IoT. The reason might be that the IoT could regulate traffic and reduce vehicle emissions, thus reducing the level of atmospheric pollution.

In this experiment, the level of water pollution in cities in LC using the IoT and the level of water pollution in cities in LC not using the IoT were tested again. In this experiment, the levels of water pollution were compared between LC cities that use IoT technology and those that do not. Two LC cities were selected and 100 sampling locations were chosen within each city. The water samples were collected and analyzed for various parameters including pH, dissolved oxygen, turbidity, and chemical pollutants. Statistical analysis was conducted to assess the differences in water quality between the two types of cities. Limitations such as environmental variability, sampling bias, temporal constraints, and technological limitations were considered.The final statistical results are shown in Fig. 4.

Fig. 4A represents the degree of water pollution in cities in LC using IoT technology. It could be seen from the experimental data that the degree of water pollution was concentrated between 10 and 25. Fig. 4B represented the degree of water pollution in LC cities without the use of IoT technology, and the degree of water pollution was concentrated between 30 and 60. This showed that the degree of water pollution in LC cities using IoT was lower than that in those without IoT. The reason might be that the IoT had strict control over the urban industry, which reduced the discharge of wastewater and water pollution.

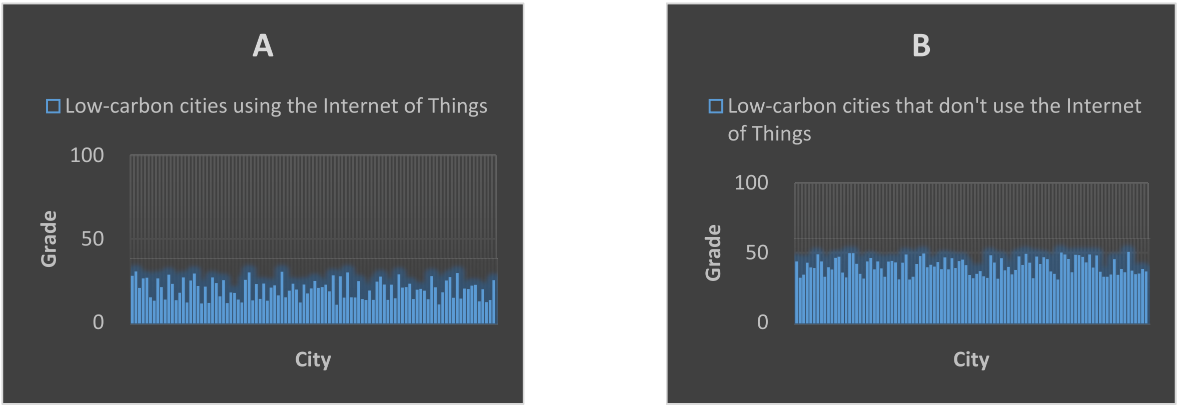
This experiment also tested the situation of soil pollution in LC cities with and without IoT. This paper selected 100 places in each of the two cities to conduct a soil pollution survey, and the soil pollution level investigated is shown in Fig. 5.

Fig. 5A showed the level of soil pollution in LC cities using IoT technology. The level of soil pollution was concentrated between 10 and 30. Fig. 5B represented the level of urban soil pollution LC without using IoT technology. The levels were concentrated between 30 and 50. This meant that IoT technology could bring less soil pollution to LC cities. The reason might be that the IoT would manage waste products reasonably. This would make it difficult for waste products to be discarded and cause soil pollution, which would greatly help to reduce urban soil pollution.



(A) Low-carbon cities using the Internet of Things **(B)** Low-carbon cities that don't use the Internet of Things

Fig. 4. Comparison of water pollution with and without IoT.



(A) Low-carbon cities using the Internet of Things **(B)** Low-carbon cities that don't use the Internet of Things

Fig. 5. Comparison of soil pollution with and without the IoT.

4. Conclusions

With the increasing severity of pollution, people gradually began to pay attention to the development of LC, which can reduce environmental pollution and bring health to people. As a new technology, the IoT can play a very good role in the construction of LC cities. Cities become intelligent and can reduce many unnecessary pollutants, thus achieving the effect of reducing pollution. This paper studied the development of LC cities based on IoT, in hopes of improving the construction of LC cities through IoT technology. This paper tested the air pollution level, water pollution level, and soil pollution level of LC cities using the IoT technology and without the IoT technology. From the experimental data, it could be seen that the level of air pollution level, water pollution level, and soil pollution level after using IoT technology were lower than those without using IoT technology, which proved that the IoT technology was suitable for the LC development of cities and could reduce pollution. Due to the length of this paper, the experiments and discussions on LC cities were still insufficient and would be improved in the future. Finally, it was hoped that the LC of the city could develop better and better and that people could lead a life that was environmentally friendly and LC.

Ethics declarations

Informed consent was not required for this study because this article does not contain studies with human participants or animals carried out by any of the authors.

Data availability statement

All data generated or analyzed during this study are included in this published article.

CRediT authorship contribution statement

Haochun Guan: Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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