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Review Article

Impacts of intelligent transportation systems on energy conservation and emission reduction of transport systems: A comprehensive review

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ABSTRACT

With the development of smart cities, new requirements have been put forward for the control of carbon emissions (CEs) in the transportation system. Intelligent transportation systems (ITS) provide a solution to the problems of traffic congestion and CEs caused by the rapid increase in the number of vehicles. This work aims at the impact of ITS on the energy conservation and emission reduction (ECER) of transportation networks. This work screened more than 100 pieces of relevant literature on ECER from Google Scholar and classified and analyzed them one by one. First, the development of the transportation system is studied. The monitoring of the transportation network is developing in a brilliant direction, from the initial induction coil detector to the current ITS. Then, the realization path of the ECER transportation system is studied from three aspects: transportation, transportation organization and management, and energy upgrading and replacement. Finally, the impact of ITS on ECER in different transportation domains is summarized. The results indicate that the traffic system has undergone traditional video surveillance and has become increasingly intelligent. Visually presenting traffic data in the management system plays a very influential role in alleviating traffic congestion and vehicle ECER. However, selecting the best vehicle parameters is necessary to realize ECER for the transport system. At the same time, the implementation of these energy-saving measures requires the traction and promotion of government policies in order for ECER transportation to fulfill its potential role.

Contents

1. Introduction

In the era of policy traction and technology promotion, smart global transportation has ushered in a historical development opportunity. On the one hand, the intelligent traffic management model

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formed by new technology innovations such as big data, the Internet, Artificial Intelligence (AI), and blockchain provides a wealth of application scenarios [1]. On the other hand, governments at all levels in different countries have successively issued relevant policies on transportation power, new infrastructure, digital transportation, etc., to provide guarantees and guidance for the high-quality development of smart transportation. The transportation industry is one of the three major sources of CEs in the world. According to the data of the Ministry of Communications, the annual economic losses caused by traffic congestion are as high as 20% of the disposable income of the urban population. In 2020, China's CEs in the transportation field accounted for 15% of the national end CEs, while in the entire transportation field, road traffic CEs accounted for 90% [2]. In the context of realizing the Dual Carbon (Peak Carbon Dioxide Emissions and Carbon Neutrality) goal, smart transportation has started a green and low-carbon transformation. Real-time monitoring of traffic flow, congestion index, delay index, etc., through the intelligent transportation system (ITS) can reduce traffic congestion, improve traffic efficiency, and reduce CEs [3].

Product applications and solutions in the smart transportation field have gradually become a critical position for public transportation to promote scientific and technological emission reduction. Correct perception and acquisition of traffic information can be all-round. People can obtain continuous and full coverage of information on vehicle status, traffic operation status, and traffic behavior status to realize the so-called panoramic traffic. At the same time, the development of ubiquitous mobile Internet, new vehicles, big data, etc. in the transportation system has dramatically improved the efficiency of transportation operations [4]. Connectivity and the Internet have also brought about new forms of transportation and new modes of service [5]. Accelerating the establishment of a low-carbon road transportation system and changing the extensive development mode of the industry is a major strategic task for the development of road transportation at present and in the future [6]. For example, the goal of energy conservation and emission reduction in transportation can be achieved through organizational management and emission reduction, that is, through scientific organization and management of transportation infrastructure and drivers. Besides, the introduction of advanced ITSs to reduce the no-load rate and energy consumption per mileage to improve road transportation efficiency. ITS can help realize the informatization and visualization of road transportation and the intelligentization of urban traffic management. It is a feasible and effective measure for energy-saving and emission-reduction goals in the transportation field [7].

Therefore, this work studies the realization path of energy conservation and emission reduction (ECER) of the transportation system . The study found that the ITS plays a crucial role in the ECER of the transportation system. Finally, the current situation is investigated and summarized from the application of ITS in different industries. This work can provide a research basis for the formulation of ECER policies and traffic congestion control in the transportation system.

2. An overview of the development history of the transportation system

ITS combines improvements in information technology and systems, communications, sensors, controllers, and advanced mathematical methods with the traditional world of transportation infrastructure [8]. Over the past few decades, ITS has been developed and deployed to improve traffic safety and mobility, reduce environmental impact, promote sustainable transportation, and increase productivity [9]. This work conducts a literature review to screen nearly one hundred papers related to ECER from Google Scholar to investigate precisely the current status of ECER in ITSs. Figs. 1 and 2 show the visualized literature network diagrams.

There is a big gap between the overall level of urban traffic in various countries and the ideal situation due to the unreasonable structure of urban road network, imperfect road function, imperfect road system, lack of traffic management facilities, and low management level [10]. The acceleration of urbanization and the rapid increase in the number of cars have led to increasingly serious urban congestion problems, frequent traffic accidents, and aggravated noise pollution and air pollution. These issues have severely challenged urban traffic carrying capacity and operational efficiency [11]. Under such circumstances, cities have begun to actively build ITSs.

The advantages of the ITS are reflected in several aspects. (1) It integrates information technologies such as the Internet of Things (IoT), cloud computing, big data technology (BDT), and mobile Internet to build an intelligent traffic dispatching system. Real-time traffic services are provided by capturing and processing traffic information using information technology [12]. (2) The ITS strengthens the connection and cooperation between people, vehicles, roads, and the environment while improving road capacity, reducing traffic accidents, and improving transportation efficiency and safety by alleviating traffic congestion and reducing pollution. (3) The ITS makes full use of traffic information as an application service, which can improve the operation efficiency of existing traffic facilities [13]. There is no doubt that intelligent transportation will have broad market opportunities in the future [14].

On the one hand, there is widespread road congestion and imbalance between traffic supply and demand in cities of various countries. The contradiction among city, population, and transportation has become even more prominent, providing soil for the construction and development of the ITS. All these problems need to rely on the vigorous development of intelligent transportation to improve the current urban traffic situation and achieve a virtuous circle of development. In addition, innovations and breakthroughs in new technologies, such as AI, Cloud Computing, and IoT, have provided product research and development directions for many transportation companies. With the help of high-tech advantages, the transportation software and hardware facilities have been continuously advanced in the direction of intelligence. Under this background, the industry as a whole is in a growth stage, and the demand for intelligent transportation is growing clearly and has broad space. On the other hand, governments of various countries are also playing an active role in promoting ITS construction. For example, China's Outline for Building a Strong Transportation Country clearly stated that it is necessary to vigorously develop intelligent transportation, promote the deep integration of new technologies, such as AI, Internet, Big Data, blockchain, and supercomputing with the transportation industry, and contribute to the construction escort of ITS.

The development of transportation systems has gone through many stages. Traditionally, the inductive loop detector [15,16] can detect vehicles according to the induced current in the loop of crossing vehicles. The pneumatic pipe [17,18] detects vehicles as per the pressure change in the pipeline. These devices have collected key information like traffic flux and spot speed. Nevertheless, due to the high realization cost and the impact on traffic in the implementation process, these techniques have failed to spread quickly, especially in crowded areas. With maturing Wireless Sensors and Imaging Technologies, cameras and Radio Frequency Identification (RFID) scanners [19,20] mostly lend to traffic data acquisitions. Cameras are mounted at different traffic network hotspots to record traffic scenes. Then, the special-purpose image processing software analyzes the collected video to determine the traffic flow, speed, vehicle type, and other information. Later, Automatic License Plate Recognition (ALPR) [21,22] and matching are widely used. Combined with the traffic data obtained by RFID, the traffic information at different times can be extracted.

Later, the advent of video traffic monitoring acquired traffic data cheap and convenient. Traffic image processing is widely used to detect traffic conditions and determine traffic control strategies in ITS. However, these traffic images always contain privacy-relevant data, such as vehicle registration numbers and faces. The abuse of this data threatens the privacy of vehicle drivers, passengers, pedestrians,

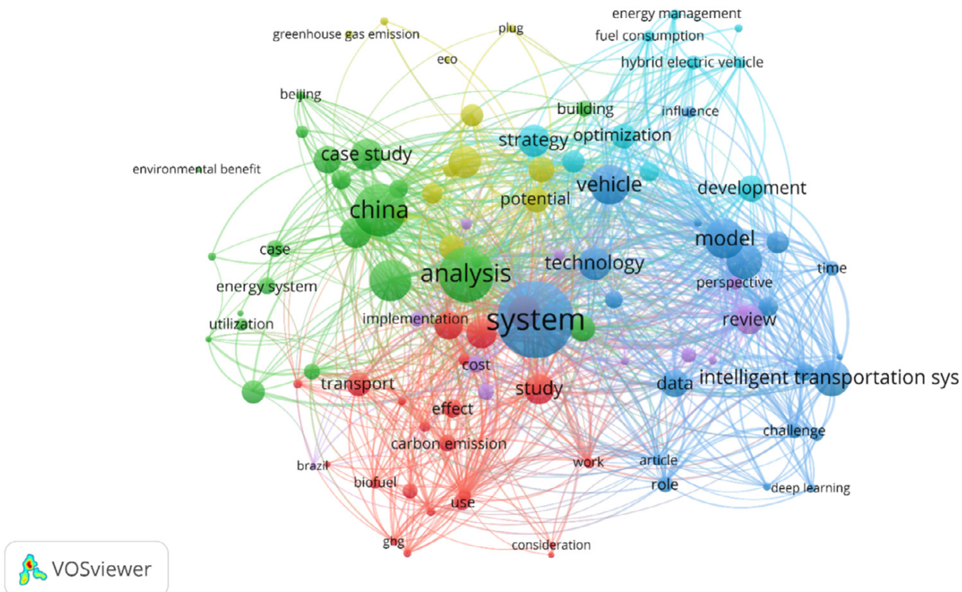

Fig. 1. Visual document network map 1. Image source: Self-painted by the author.

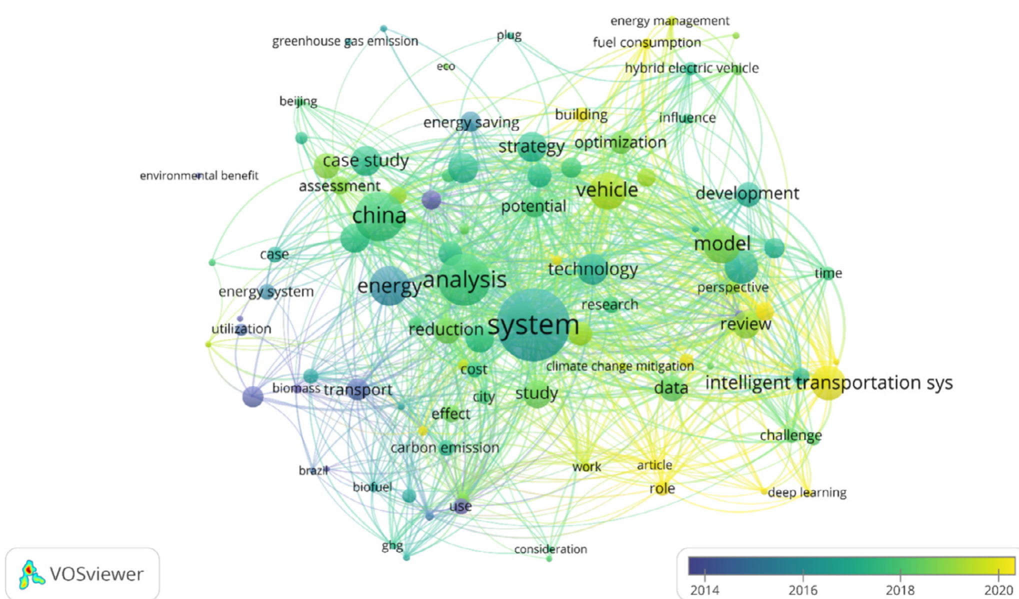

Fig. 2. Visual document network map 2. Image source: Self-painted by the author.

etc. [23]. Therefore, it is still not possible to fully intelligently control traffic flow. For instance, Wan et al. (2020) [24] noted that there are typically thousands of cameras deployed in it, so analyzing the live video streams from these cameras is critical for public safety. The high mobility of ITS allows for increased coverage and quick assistance to users and neighboring networks and also reduces the performance of the overall system due to fluctuations in the radio channel. Fig. 3 exemplifies the bus intelligent dispatching system based on the Third Generation Mobile Communication (3G) video monitoring on the bus.

According to Fig. 3, the ITS can help the bus run more reasonably and visually through the intelligent scheduling of bus video monitoring. Later, due to the increasing popularity of smartphones and advanced communication technologies, Global Position System (GPS) [25,26] data, Bluetooth, and WiFi components' media access control addresses [27,28], and mobile phone data can be used to analyze traffic conditions and even travel behavior. At present, in many first- and second-tier cities, intelligent transportation projects have begun to be planned and will account for a larger proportion of the development of the transportation industry in the future. Modern ITS combines computers, big data, Fifth Generation (5G) technology, and information systems. Sensor technology, electronic control systems, fuzzy control mechanisms, and AI are comprehensively applied to transportation, management, control, and vehicle manufacturing. They help to form a safe, efficient, and energy-efficient integrated transportation system. It also helps solve the problems existing in traditional transportation, reduces the pressure of road construction, and improves road infrastructure construction.

In addition, Deep Learning (DL) and big data algorithm can further improve the intellectualization of transportation applications. They can meet the data-driven demands from the amount and availability of data in ITSs. BDT and DL algorithms have found broad applications. For example, signal recognition and object detection usually adopt DL models. So are traffic flow forecasting, travel scheduling, routing strategy, and vehicle and road safety. Many scholars' research has

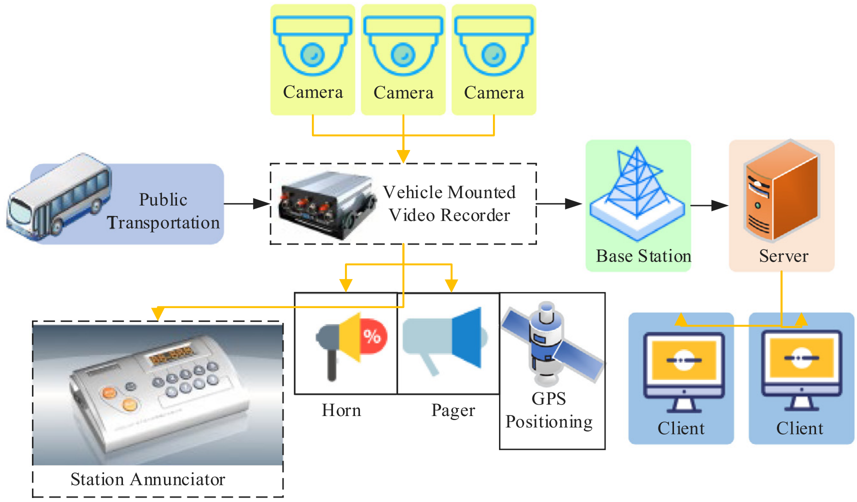

Fig. 3. Example of bus intelligent dispatching system. Image source: From the Internet.

involved this field. For example, Chaturvedi and Srivastava (2016) [29] proposed a new ITS using the cellular network. They estimated the edge-end speed under dynamic traffic conditions based on GPS probes and available ITS architectures. The proposed system processed the wrong vehicle location data obtained from the cellular network in real-time to calculate the edge-end vehicle flow, foothold, and traffic jam, within a 10% mean deviation. The communication and storage requirements of the proposed ITS and the utility of the traffic information were verified.

For another example, Lv et al. (2020) [30] improved the ITS using the DL algorithm and simulated the system. Statistically, the researchers analyzed the data transmission rate, precision, and dynamic path planning. The results showed that the successful propagation was 100% in data transmission performance. Among all the comparison models, the reported system's prediction precision was the highest with increased iteration times. Following the route guidance strategy analysis, they reasoned that the proposed strategy could effectively mitigate and timely evacuate traffic jams.

Likewise, recent developments in edge computing and content caching in wireless networks enable ITS to provide high-quality services to vehicles. However, various vehicle applications and time-varying network states make it difficult for ITS to allocate resources efficiently. AI algorithms can identify various time-varying characteristics of the Internet of Connected Vehicles, enabling them to implement intent-based networking to address the above challenges. Ning et al. (2020) [31] developed an intent-based traffic control system. It dynamically coordinates edge computing and content caching to improve mobile networks by studying deep reinforcement learning for connected cars envisioned by 5G commercial profits operation. Experimental results based on real traffic data showed that the system performs well and effectively.

DL technology has a broad range of applications in the field of transportation. As mentioned above, DL algorithms are often utilized to improve data transmission and vehicle scheduling schemes to alleviate traffic congestion. In addition, intelligent traffic control has an important impact on the efficiency of scheduling urban traffic flow. For instance, Lv et al. (2020) [32] used the back-propagation neural network to design an intersection vehicle traffic model and adopted the earliest deadline-first dynamic scheduling algorithm based on an intelligent traffic control system model to improve the communication network of the controller's local area network (LAN). Finally, they evaluated the effectiveness of the model and the improved controller LAN bus communication network. The results showed that the neural network model can predict the transit time of vehicles at intersections with an error of less than 10%. It can be seen that the application of AI technology in the ITS can improve the efficiency of vehicle scheduling and the efficiency of the communication system, which is of great significance for improving the communication performance and scheduling efficiency of the transportation system.

Due to the high mobility of vehicles and the heterogeneity of future IoT-based edge computing networks, how to obtain Quality of Service (QoS) superior to the future generation network (i.e., edge computing platform) in the future multimedia transmission process is very challenging. Therefore, Sodhro et al. (2020) [33] developed a QoS-aware, green, sustainable, reliable, and usable algorithm. It has been validated on an extensive real-time dataset of vehicles to demonstrate its superiority over conventional techniques' performance, making it a potential candidate for multimedia delivery on adaptive edge computing platforms. Moreover, Gao et al. (2020) [34] reported that in a dynamic traffic environment, the situational assessment of traffic could accurately predict and evaluate the situational risk within the prediction range and provide an accurate situational risk assessment outside the prediction range.

It can be seen that the ITS is an inherent element of the construction of a smart city to achieve ECER for the transportation system. In the ITS, road network optimization and vehicle flow monitoring led by AI and DL algorithms will become the focus of the research. In the future, in addition to the data acquired by sensors and cameras in the transportation network, public opinions and opinions collected online (for example, on social networks) can help to understand the situation and performance of the urban transportation system. The degree and severity of traffic problems can be comprehensively estimated through the social network data marked in time and space, combined with the actual traffic conditions, which is of great help to urban transportation ECER.

3. The current situation of ECER implementation in ITS

Speeding up the establishment of a low-carbon road transportation system and changing the extensive development mode of the industry are the major strategic tasks for the development of road transportation at present and in the future. Therefore, it is necessary to sort out the ECER paths of the road transportation industry. They can be summed up into three types: technical emission reduction, organizational management emission reduction, and energy upgrading and substitution.

3.1. Technical emission reduction

The technical emission reduction in the transportation field is based on the traditional transportation energy consumption structure and improves the energy utilization efficiency through the progress of transportation energy saving technology. Various road vehicles are the main body of transportation energy consumption [35]. China's overall energy, including the energy utilization efficiency of the road transportation industry, is relatively low compared with other countries. For example, in 2021, the total energy consumption of China's transportation, warehousing, and postal industries reached 439.09 million tons of standard coal (according to China Statistical Yearbook 2021), accounting for 9.01% of the total industry consumption of 4,874.88 million tons, while the energy consumption elasticity coefficient was only 0.96. This is mainly affected by factors such as technology, personnel skills, energy prices, and the degree of transport organization. Therefore, there is still a large space for technical energy conservation in the global road transportation industry.

Technical emission reduction measures mainly include: developing energy-saving and environmentally friendly vehicles, adopting new energy-saving processes, new technologies, new equipment, and new materials within the transportation industry, or forcibly eliminating high-consumption and low-efficiency means of transportation.

Many experts and scholars have studied the ECER of the transportation system in the direction of transportation. Peng et al. (2015) [36] developed an assessment model for the ECER potential of urban passenger transport (UPT) using the tool of "long-distance energy alternative planning". They also assessed the emission reduction potential of final energy consumption, Greenhouse Gas (GHG) emissions, and pollutant emissions in the urban passenger transport sector from 2010 to 2040. The results showed that due to the promotion of public transport, emission standard regulation is the most effective measure to reduce air pollutant emissions in all cases, and green energy promotion is particularly effective for reducing nitric oxide.

The power of transportation has gone through different stages, such as the train system has undergone the evolution of steam locomotives, diesel locomotives, and electric locomotives, corresponding to the consumption of coal, diesel, and electricity, respectively. In the process, fuel consumption for rail transport is replaced by coal and oil power generation. Liu and Lin (2021) [37] re-derived and revised the elasticity of the substitution formula between fuels and made reasonable and scientific choices for the ridge regression parameters in the econometric model. The empirical results suggested that, in the railway sector, the elasticity of substitution between coal and oil, coal and electricity, and oil and electricity is about 2.2084, 1.0628, and 0.9202, respectively. It can be seen that a bottom-up model based on the detailed and microscopic activity of a transport fleet has become the tool of choice for many researchers because it has a finer level of resolution and has the potential to more accurately represent fuel consumption and emissions based on fleet composition. production [38].

Commercialized 5G technology can provide reliable and efficient connectivity for motor vehicles to achieve efficient ECER [39]. Green development is of particular interest to a range of industries around the world (one of which is air transport). Besides, the low-carbon economy has developed into an emerging and essential way to address global competition. The International Civil Aviation Organization, the European Union, and other intercontinental or local companies have set higher ECER targets for air transport. Under this circumstance, green and low-carbon design becomes inevitable and one of China's air transport industry's sustainable development (SD) models [40]. As China's largest mode of transportation, road traffic is vital in reducing congestion and emissions. Lu et al. (2020) [41] introduced Bayesian Structural Equation Modeling (SEM) to understand the intrinsic relationship between aggregate demand, structure, and technology as factors affecting the road traffic system. The results demonstrate that the influence of aggregate demand is the most significant among all the influencing factors. At the same time, there is an indirect effect on the interaction between latent variables. In this case, the flow structure is the most crucial factor.

The deployment of renewable electricity and electric vehicles presents a synergistic opportunity to accelerate the decarbonization of China's power and transport sectors. Li et al. (2021) [42] used the SWITCH-China model to assess the potential impact of EVs. The model, which aims to meet emission limits in its power sector while integrating the electrified transport sector, calculated that the cost of integrating electric systems ranging from 228 to 352 USD per EV could put countries around the world firmly on a path to meet carbon cap targets. In addition to this, energy-efficient train operation was considered an effective way to reduce the operating cost and CEs of the subway system. Reducing traction energy and increasing renewable energy are two important ways to save energy, which are closely related to train schedules and driving strategies [43–45].

Against the high CE in the tourist cities' green transportation ECER methods, Zheng et al. (2020) [46] proposed a new method of green transportation based on Grey Correlation Analysis (GCA). They built the green transportation energy demand-oriented prediction and GHG emission calculation model, calculated the GHG emissions of vehicles, and selected the best vehicle ECER parameters. The experimental data showed that the proposed method was more effective in ECER than the traditional method, saving energy up to 93% and emitting GHG of just over 210 tons. Therefore, the proposed ECER method for green transportation in tourism cities had an excellent effect. Zhang et al. (2020) [47] leveraged the extensive ITS infrastructure deployed in Nanjing, China (6,600 km) to provide high-resolution, multi-source traffic data on the road network. Compared to traditional emission inventories, ITS data are an improvement and can reveal significant temporal and spatial heterogeneity in traffic dynamics, which can significantly influence traffic emission patterns. Suleiman et al. (2019) [48] proposed a new method for assessing the predictive validity of PM10 and PM2.5 concentrations in traffic using a machine learning-based model and a reduction scheme.

The main literature findings are summarized in Table 1:

Table 1 shows that transportation vehicles-oriented ECER focus on optimizing the energy utilization rate. Developing ES NEVs and improving energy utilization are the two major directions of the technological ECER path. Regarding fuel power technology, the diesel thermal engine is more efficient and exhausts fewer emissions than the gasoline engine, and the technology maturity is high.

3.2. Organizational management of emission reduction

The organization and management of emission reduction is the area with the greatest energy conservation potential and the most opportunities among all the recent emission reduction paths, but it is also the area with the most difficulty in saving energy [49]. The greatest energy-saving potential is that there are the most problems in urban transportation in various countries, such as management systems, policies and regulations, planning, technology, operation, and management mechanism. Improvements in one or several aspects will improve road transportation. Efficiency has a positive impact, which leads to the improvement of the urban traffic environment and efficiency [50]. The external diseconomy caused by urban traffic jams has become a global problem, promoting Public Transport Priority (PTP) in many nations.

ER is the most difficult because China's UTM is relatively decentralized. Local governments have a different understanding of the importance of traffic ECER [51]. The factors related to ER organizational management are very complex. The research on the potential of organizational management and ER needs to grasp the main elements and feedback loops as the simplification and representation of the real system and then make a quantitative analysis of these influencing factors [52]. There is no unified and clear understanding of the Smart City system, which may affect their evaluation/planning and lead to misleading construction [53].

Smart cities are characterized by complex self-organization and follow a sustainable and healthy evolutionary model. Many scholars have given research conclusions on the management of organizational emission reduction. Touratier-Muller et al. (2019) [54] conducted the

Table 1
Summary of research achievements on technological emission reduction.

Year + Author	Research methods	Research results	Summary and analysis
Peng et al. (2015)	A potential evaluation model was developed for ECER of UPT using the Remote energy alternative planning tool.	Due to the promotion of public transport, energy consumption and carbon dioxide emissions in 2040 can be reduced by 22% and 22.6%.	Emission standard regulation is the most effective measure to reduce air pollutant emissions under all circumstances, and green energy promotion is especially effective in reducing NOx and PM particulate matter emissions. Among them, vehicle population supervision is the most effective implementation.
Liu and Lin (2021)	The fuel substitution elasticity formula is derived and revised. The selection of ridge regression parameters in the econometric model is reasonable and scientific.	The substitution elasticity of kerosene, coal-electricity and oil-electricity in China's railway sector is about 2.2084, 1.0628 and 0.9202, respectively.	great significance to the development of China's rail transit system and the energy conservation and emission reduction of railway transportation.
Lu et al. (2020)	The future development of CE structure and CEs related to road transport is analyzed.	If we consider the indirect effects caused by the interaction between latent variables, the traffic structure becomes the most important factor, with a combined influence coefficient of −1.63.	Quantity and structure should be emphasized in the short term to achieve China's energy conservation and emission reduction targets, while technology is critical in the long term.
Zheng et al. (2020)	A new GCA-based ECER method for green transportation in tourist cities is proposed.	Compared with the traditional method, this method can effectively reduce the emission and energy consumption, the energy saving rate can reach 93%, and the minimum GHG emission is 210 tons.	The new method of green transportation energy-saving and emission-reduction in tourist cities based on the grey correlation degree has a good energy-saving and emission-reduction effect on green transportation energy-saving and emission reduction methods in tourist cities.
Zhang et al. (2020)	The authors demonstrated how to effectively utilize ITS and other traffic data to develop link-level and hour-based dynamic vehicle emission inventories.	Due to the detailed analysis of road network traffic, the dynamic emissions inventory captures two types of emission hotspots.	The ITS data-driven emissions management system combined with atmospheric models offers the potential for future dynamic air quality management.
Suleiman et al. (2019)	The authors proposed a The authors presented a new method for assessing the predictive validity of PM_{10} and $PM_{2.5}$ concentrations in traffic using a machine learning-based model, as well as a scaling-down scheme.	The observed prediction error is tiny, such as the average normalized average gross error of 0.2.	Well-trained artificial neural networks and boosted regression tree models can be successfully applied to the concentration prediction of PM_{10} and $PM_{2.5}$ in traffic. Additionally, they can be used to measure the effectiveness of particulate reduction programmes in transportation.

in-depth semi-structured interviews with 14 companies (shippers and carriers) across France, providing clear insights into the attitudes of middle and small-sized enterprises (SMEs). The results show that most SMEs are adopting sustainable strategies and implementing measures to achieve a greener supply chain driven by internal initiatives and customer expectations. From the perspective of small and medium-sized shippers and carriers, the French government's policy to reduce CEs from freight transport has had a significant impact on the emissions of SMEs. This phenomenon indirectly demonstrates the effectiveness of organizational management in reducing emissions for ECER.

The same effect is also reflected in the study of Lamba et al. (2019) [55]. Their study proposed a mixed integer nonlinear procedure for supplier selection. At the same time, the authors determined the correct lot size in a dynamic setup with multiple cycles, multiple products, and multiple suppliers with a view to reducing the overall supply chain costs and the associated CE costs. They considered three different carbon regulation policies and constructed a model to optimize the overall supply chain costs and associated CE costs.

With terrestrial and coastal operations relying on fossil fuels, ports are unavoidable centers of anthropogenic emissions. It is also difficult to design and implement decarbonization measures to mitigate global warming and environmental impacts by reducing GHG emissions in ports and other areas. Alamoush et al. (2022) [56] identified and analyzed policy tools and implementation plans for ports to reduce GHG emissions and ultimately help to encourage port polluters (port, land, and shipping operators) to adopt technical and operational measures. The results showed that the implementation plan faced various challenges. Port policymakers, the public, or port authorities can take steps to reduce GHG emissions while maintaining business integrity. However, monitoring emissions determines the best fusion implementation. Collaboration between ports, maritime stakeholders, and port decision-makers is recommended to excessively implement these measures and establish justice.

Moreover, Yan et al. (2020) [57] conducted secondary qualitative data analysis on previous attempts to describe the development of Smart Cities to recognize the most potent aspects verified in related research. According to the results, the self-organization theory built the Smart City's panoramic model. The International Maritime Organization agreed to reduce the total GHG emissions of international shipping in 2018. Cariou et al. (2019) [58] discussed that shippers and logistics suppliers designed cargo routing strategies based on a carbon-efficient Supply Chain environment. The research further explained the importance of integrated traffic management in different cities.

It can be seen that the most difficulty in organizing and managing energy conservation is that the management of urban transportation in various countries is relatively scattered. Besides, local governments have different understandings of the importance of transportation energy conservation and emission control. The factors associated with the organizational management of emission reductions are complex. Therefore, the study of the potential for administrative management emission reduction needs to capture the principal elements and feedback loops as a simplification and representation of the actual system and then quantify and analyze these influencing factors.

3.3. Energy upgrade and replacement

Energy upgrading and substitution promote such NEV technologies as pure electric vehicles and hydrogen fuel cells. They cooperate with the planning and construction of supporting infrastructures, such as gas filling and charging. Then, these technologies change the CE structure of vehicles to improve energy efficiency and reduce emissions [59]. According to the technology development, test application at this stage, and the availability of various alternative fuels, the main alternative fuels include natural gas, Liquefied Petroleum Gas (LPG), alcohol fuels (methanol, ethanol), electric energy (fuel cell), hydrogen, dimethyl ether, and biomass energy (biodiesel). The alternative path of energy upgrading of vehicles undoubtedly has the greatest ER potential [60, 61]. However, the NEV technology may not achieve a major technological breakthrough in a certain period, with a relatively high cost.

In the transportation system, in addition to automobiles, there are also non-motorized vehicles [62–64]. Neves & Brand (2019) [65] investigated whether replacing short car trips with walking and cycling is likely to reduce GHG emissions, the extent to which high-quality walking and cycling infrastructure are likely to influence daily travel decisions, and the impact of changing the spatial and temporal nature of local trips on overall GHG emissions from motorized travel. The study found that active travel has a huge potential to replace short-distance car travel, considerably impacting the CEs of personal travel.

A successful transition from traditional to renewable energy sources can help mitigate climate change and regional development. Yang et al. (2021) [66] established a long-term energy replacement planning system to study the environmental and socioeconomic impacts of renewable energy development by forecasting energy consumption and associated GHG emissions across industries over the period 2016–2050. The results demonstrated that the city's GHG emissions would peak in 2030 under the integrated scenario, with a 13.23% reduction in energy consumption compared to the traditional energy scenario. Compared with traditional energy sources, renewable energy sources showed competitive advantages in terms of GHG emission reduction, employment opportunities, and economic costs. By 2050, the total number of employees in the integrated scenario will reach 150,000, which is 1.71 times that of traditional energy sources.

Urbanization and Smart City construction profoundly impact transportation CE [67]. PTP has been an easier resort to reduce urban transportation CE in many cities. Technology upgrading to continuously reduce vehicles' CE and emissions are urgent. Chang et al. (2019) [68] predicted that hydrogen fuel cell vehicles were the automotive sector's future because they effectively reduced traffic CE and lightened metropolitan pollution. In addition to hydrogen fuel, biogas-based fuel could also be used as a substitute for automotive energy. The new era of high-tech innovations has driven nations worldwide to upgrade biogas to vehicle fuel. Recently, attention to liquefied biogas has also increased for heavier transportation. Biogas could also be gasified into raw materials for other fuels, such as Fischer–Tropsch fuel, methanol, dimethyl ether, and hydrogen. Dahlgren (2022) [69] outlined that biogas could produce vehicle fuels. The technological maturity and possibility of biogas as fossil alternatives in transportation systems were deduced. So far, the only fuel used in biogas for commercial production was compressed and liquefied methane. Thus, biogas has great application potential in transportation [70].

Globally, more countries have introduced biomethane as a transportation fuel alternative to benefit the environment. Ling and Brekke (2019) [71] applied the Life Cycle Assessment (LCA) in comparing the environmental performance of biogas used as a bus transportation fuel with natural gas, electric fuel bus, biodiesel, and fossil diesel. The biogas alternatives' sensitivity was analyzed to verify some basic hypotheses. It was observed that the contribution of biogas to the assessed environmental impact categories was relatively low. Regarding the nature of available energy resources, CE was one of the most demanding issues in Smart Cities. Instead of ER design and biological implementation, energy efficiency has become the main concern of Smart City life. Wang et al. (2021) [72] proposed an ER comprehensive planning framework for a sustainable Smart City to improve energy efficiency and performance. The reported energy efficiency planning involved the primary and secondary strategies for improving energy efficiency in modern cities and has been used to develop the latest energy efficient systems and regulatory measures for Smart Cities. The main literature achievements are summarized in Table 2:

In Table 2, using RE (hydrogen energy and biogas) instead of traditional gasoline and diesel can reduce the air pollution caused by the exhaust gas emission from petrochemical energy. Besides, with a certain fuel substitution algorithm, RE can help vehicles carry out planned and more accurate fuel substitution. Future plans should pursue feasible low-carbon approaches and common interest strategies related to industrial transformation and RE substitution and carry out the transformation of energy utilization in the transportation system.

4. Application status of ITS in ECER of different transportation fields

ITS management and control based on integrated monitoring of urban rail transit have been applied in different fields of transportation systems [73]. Fig. 4 reveals an example of its application in integrated transportation management and control.

As can be seen from Fig. 4, the comprehensive management and control of the traffic system require the cooperation of many parties. Today, expressways have entered an era of rapid development of informatization construction. Many countries have completed the construction of large-scale informatization projects such as transmission backbone networks and provincial comprehensive management platforms. Besides, the informatization level of comprehensive provincial management has reached a certain level. In comparison, the information management level of road sections is slightly backward, and the monitoring capability of the road network needs to be improved. The section-level intelligent traffic management and control system focuses on the need for daily monitoring and management of expressways. It can also realize full-time and all-round monitoring and monitoring at the section-level, timely manages and controls the comprehensive operation situation, and finally achieve the goal of "guaranteeing smooth flow, strengthening management, and increasing efficiency".

4.1. Transportation industry

The transportation industry includes road transportation services, marine transportation services, air transportation services, and pipeline transportation services. With the accelerated urbanization in China, the emergence of e-commerce has led to higher growth in consumer spending in the transportation sector than in society as a whole. As a result, it is one of the fastest-growing sectors in terms of consumer spending [51]. As the field accounting for the largest proportion of CE in the transportation industry, the road transportation industry has shown a rapid growth trend in recent years [74]. It can be predicted that the proportion of CE in the road transportation industry in the future may still increase. Road transportation ECER will face complex challenges. The challenges of energy conservation and emission reduction in different The challenges of ECER in various service sectors of transportation are described in the following two aspects: road transportation and maritime transportation.

4.1.1. Road transport services

The severe situation of ECER in transportation requires the national transportation authorities to think deeply about the current extensive development mode of the road transportation industry relying on expanding transportation capacity. It is also essential to study and judge the development trend of ECER in the road transportation industry in various countries. Moreover, it is necessary to deeply explore the contribution potential of technical means, management means, and resource integration to energy conservation and emission reduction of road transportation. At the same time, it is feasible to use the primary role of the transportation industry authorities in energy conservation law enforcement and energy conservation supervision and management functions in the industry [75]. In recent years, countries have introduced a series of energy alternative policies, aiming to achieve a fundamental change in the way of energy development [76]. They aim to speed up the establishment of a low-carbon road traffic intelligent

Table 2
A Summary of research achievements on ECER.

Year + Author	Research methods	Research results	Summary and analysis
Neves & Brand (2019)	The authors conducted an in-depth observational study of 50 residents in Cardiff, Wales.	Active travel has enormous potential to replace short-distance car travel, with a considerable impact on the carbon footprint of a personal journey.	The combination of data collection methods developed and employed will also help inform future research on the broad environmental impacts of active travel, including the "co-benefits" of improved air quality, reduced noise, and reduced fossil fuel use.
Yang et al. (2021)	The authors proposed a long-term energy alternative system model.	Under the comprehensive scenario, Zhangjiakou's GHG emissions will peak in 2030, and energy consumption will be reduced by 13.23% compared with the BAU scenario.	Renewable energy has competitive advantages in terms of GHG emissions reduction, employment opportunities, and economic cost compared to traditional energy sources.
Chang et al. (2019)	The impact of urban development on energy consumption in public and private transportation from 2013 to 2015 is analyzed; the use of hydrogen fuel cell vehicle alternatives in urban public transportation is used as a scenario.	Urban economic development can effectively reduce public transportation.	Hydrogen fuel cell vehicles can effectively reduce the energy consumption and pollution emissions of urban traffic during the operation.
Dahlgren, (2022)	The study outlined how biogas can be used to produce automotive fuel.	Compressed and liquefied methane is the only fuel commercially produced using biogas	The most promising short-term renewable energy biogas fuel is the expanded use of compressed and liquefied biomethane as biogas.
Wang et al. (2021)	An ER-integrated planning framework was proposed to improve energy efficiency and performance.	The integrated planning framework provides a numerical model for selecting energy efficiency methods to optimize economic and environmental impacts.	Considering the nature of the energy resources available, energy consumption is one of the most challenging issues in these smart cities.
Lyng and Brekke (2019)	The authors used a life cycle assessment approach to compare the environmental performance of biogas as a transport fuel for buses with natural gas, electric buses, biodiesel, and fossil diesel.	The contribution of biogas to the assessed environmental impact categories is relatively small.	GHG emissions depend on assumptions, such as system boundaries, transport distances, and methane leakage

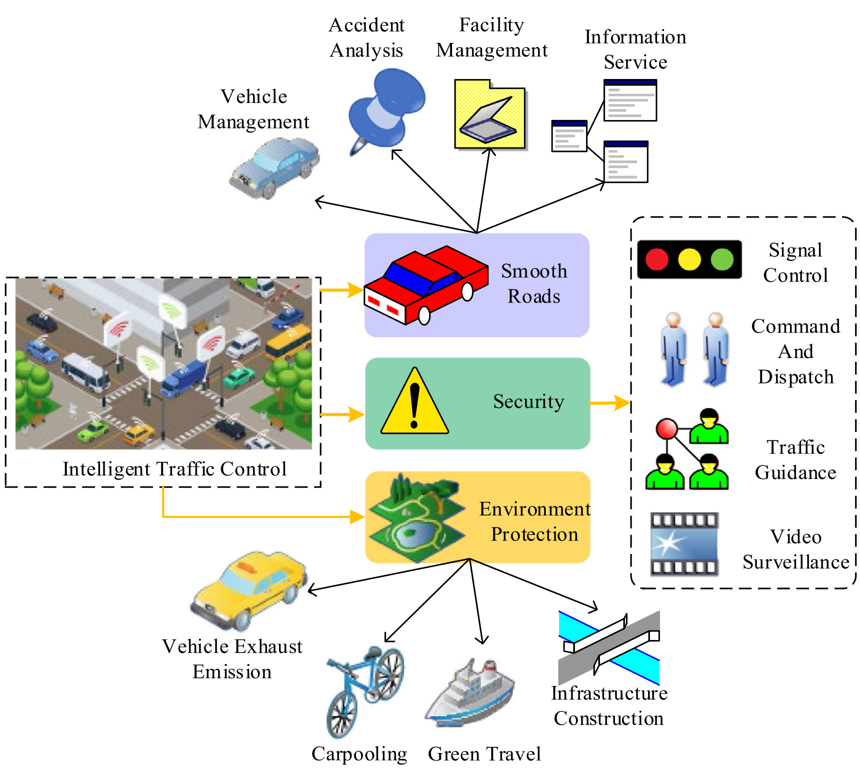

Fig. 4. Comprehensive traffic control solution. Image source: The Internet.

management system and change the extensive development mode of the industry.

Many scholars have realized ER research through ITS in the context of Smart Cities. Chen et al. (2017) [77] reported that intelligent mobile solutions had four main steps to achieve ER, and each step required some institutional, technical, and physical conditions. Users could reduce CE per kilometer by reducing traveling and changing traveling modes in the short term. ITS was essential to manage traffic jams and reduce vehicle emissions and EC, but its effectiveness has not been directly quantified under actual driving conditions. Meanwhile, in-vehicle networks can provide numerous in-vehicle data services, Liu et al. (2020) [78] conducted a comprehensive investigation on the resource allocation scheme for two dominant in-vehicle network technologies such as dedicated short-range communication and cellular-based in-vehicle networks.

In addition, road transport, as a critical climate change factor, contributes to environmental pollution to a large extent. Liu et al. (2021) [79] investigated the potential impact of dynamic wireless power transfer systems on URN, with a particular focus on charging and EC. They constructed an eco-driving model to reduce CE and proposed a dynamic wireless power transfer system layout suitable for charging eco-friendly autonomous vehicles at signalized intersections. Studies show that as the market penetration of self-driving cars increases, the ER effect of self-driving and human-driven cars will increase significantly. With complete market penetration of autonomous vehicles, the average CE of all cars can be reduced by 62%. These data suggest that ecological driving behavior can positively influence the ECER of urban transportation systems.

Transportation, including the movement of goods and people, plays a prominent role in the burning of fossil fuels and the emission of air pollutants. Ecological methods and bias applications for networked vehicles at signalized intersections have been extensively studied. They can effectively reduce the emission of EC, GHG, and other standard pollutants [80]. Hou et al. (2018) [81] proposed a two-stage method for joint optimization of traffic signal length and oncoming vehicle speed. The approach was designed to minimize the efficiency of all vehicles passing through independent intersections. Specifically, an intersection-level dynamic programming algorithm was proposed to calculate the optimal signal length by considering vehicle arrival time and energy distribution. The system improves intersection performance in different traffic conditions. Unlike traditional timing and drive signal control strategies, this algorithm can reduce CEs by 31% and queue length by 95%, respectively.

Hu et al. (2020) [82] developed a model-predictive multi-objective control framework for hybrid electric vehicles to study the interplay between fuel economy, vehicle exhaust emissions, and workshop safety. Specifically, a controller was developed to optimize vehicle speed and engine torque to improve fuel economy and reduce exhaust emissions while ensuring safety on the shop floor. The engine emission model and its impact on energy management were considered in the optimization. The controller is evaluated under different driving conditions, such as city driving and highway driving, and if implemented correctly, the controller can optimize fuel emissions well.

In addition, using the trajectory data of taxis in a city can accurately estimate the time required for a given trajectory in the transportation system, which is a very challenging task. The trajectory information in the historical data is not available. Overuse or inaccuracy of adjacent trajectory information does not improve the prediction accuracy of query trajectories. Qiu et al. (2019) [83] proposed a neighbor-based DL method for travel time estimation called the Nei-TTE method. This technique divides the entire trajectory into multiple disjoint segments and uses a time-level approximation of historical trajectory data. The model captures the features of each road segment and utilizes the trajectory features of adjacent road segments as the interaction of road network topology and speed. The experimental results showed that the performance of this model is significantly better than the existing models. This study reveals the critical role of DL in intelligent transportation.

Additionally, integrating data-driven applications with transportation systems has played a key role in recent transportation applications. haydari & ylmaz (2022) [84] discussed state-of-the-art traffic control applications based on Deep Reinforcement Learning (DRL), especially DRL-based traffic signal control applications, which have been widely studied in reality. Chen and Jiang (2019) [85] pointed out that high-speed trains have become one of the most critical and advanced branches of intelligent transportation. Their reliability and safety are immature, and they cannot keep up with other aspects. Multi-step traffic prediction of road networks is the key to the successful application of ITSs. Zhang et al. (2019) [86] proposed a new DL framework called the attention graph convolutional sequence-to-sequence (Seq2Seq) model to capture the complex non-stationary temporal dynamics and spatial correlations in multi-step traffic condition prediction. The spatiotemporal dependencies are modeled in the DL framework by the Seq2Seq model and the graph convolutional network, respectively. Furthermore, an attention mechanism based on the Seq2Seq architecture and a newly designed training method were proposed to overcome the difficulty of multi-step prediction and further capture the temporal heterogeneity of traffic patterns.

4.1.2. Maritime transportation and other transportation services

The operation of the transportation system is not simple. Transportation systems exhibit spatial and temporal characteristics at different scales under different conditions brought about by external sources such as many social events, holidays, and weather. However, it is challenging to model the interactions of different factors, design generalized representations, and subsequently use them to solve specific problems. These situations are just a few of the difficulties facing modern ITSs. Veres & Moussa (2019) [87] presented a survey highlighting the role that role modeling techniques within the field of DL play in ITSs. They focused on how practitioners formulated problems to address these different challenges and outlined the architecture and problem-specific considerations used to develop solutions. This research can help bridge the gap between the machine learning and transportation communities, illuminating new areas and considerations for the future.

Too much emissions are a vital component in the transportation system. Yang et al. (2020) [88] utilized a portable emission measurement system for actual driving and emission measurements. They found that the use of speed guidance significantly reduced the two test vehicles (light-duty gasoline vehicles and heavy-duty vehicles) by reducing starting frequency and vibration Diesel trucks fuel consumption and pollutant emissions and the proportion of time between acceleration and idling.

In intelligent mobility, the management of relationships between recognized enterprises and service customers relies heavily on deploying compelling ITS applications to form a unified collaboration with customers. KadłUbek et al. (2022) [89] proposed the selected ITS applications in the research, divided into six applications as the logistics customer service-oriented optimization scheme for freight enterprises. These applications were crucial in vehicle support. They improved transportation's energy efficiency, reducing transportation's negative impact on the natural environment, reducing transportation time, and increasing connectivity and comfort.

In addition to road transport, maritime transport is also a critical component of CEs. Growing global trade poses increasing challenges for intelligent maritime mobility, which is an important branch of ITSs. It is particularly imperative to develop efficient technologies to improve the performance of intelligent maritime transport. Most existing integrated berth allocation and quay crane allocation projects assume that all equipment will be available for a period of time. However, there are often time-consuming quay crane maintenance activities in seaports. Li et al. (2022) [90] studied a new dual-objective optimization model that integrates berth assignment and quay crane assignment with preventive quay crane maintenance activities. The two goals were to minimize the total turnaround time of the vessel and the total penalty cost of timely and late maintenance of quay cranes, which can effectively reduce CEs.

In addition to maritime transport, the CEs of air transport also need attention. Lo et al. (2020) [91] pointed out that although aircraft size increases total emissions, it reduces emissions per Available Seat Kilometers (ASK), while route distance increases total emissions and reduces emissions per ASK. Technological advances have reduced CEs per ASK with an estimated elasticity of −0.06%.

Table 3
Application status of ITS in the transportation industry.

Year + Authors	Research achievements
Chen et al. (2017)	According to the research, intelligent mobile solutions have four main steps to save energy. Each step required some institutional, technical, and physical conditions.
Yang et al. (2020)	It was found that using speed guidance significantly reduced the CE and emissions of the two test trucks. The time ratio of acceleration and idling was reduced by reducing the starting frequency and vibration.
Kadłubek et al. (2022)	The selected ITS application was proposed as an optimization scheme for logistics customer service of highway freight enterprises.
Liu et al. (2021)	The dynamic wireless power transmission system's potential impact on urban road networks was studied, with special attention to the impact of charging and EC. An ecological driving model aiming at reducing CE was constructed.
Hou et al. (2018)	A two-tier method was proposed to optimize the traffic signal lighting interval and vehicle-approaching speed jointly. The research aimed to minimize the total CE of all vehicles crossing through isolated intersections.
Cheng et al. (2020)	The specific-purpose longitudinal data set on road traffic was integrated, and a large federally supported ITS program was deployed in 99 urban areas in the United States between 1994 and 2014.
Zhang et al. (2019)	The socio-economic development and CE of Beijing were analyzed. The LEAP-Beijing medium and long-term prediction model of GHG emissions was established.

With all possible efforts, the Chinese government has promised to peak GHG emissions by 2030. As the "frontier" of China's Reform and Opening Up, its capital has put on the agenda on the "13th five-year plan" to peak local GHG emissions by 2020. Zhang et al. (2019) [92] analyzed the socio-economic status and CE of the Chinese capital and established the LEAP-Beijing medium and long-term GHG emission forecasting model. These scenarios were used to calculate the GHG emission volume in Beijing and estimate how the Carbon Peak timepoint changed with the impact of different policies. The main research findings are summarized in Table 3:

As can be seen from Table 3, a proliferation of attention has been paid to saving energy and reducing emissions in the road transport industry in various countries. Experts and scholars have proposed various application schemes for ITSs. The research on ECER of road transportation is in the initial stage of breaking through the advocacy of ideas and policy recommendations. Next, it is essential to strengthen the quantitative evaluation of the implementation effect of the ECER means of transportation and analyze the ECER situation under the combined means. These operations can improve the reference value of theoretical research to decision-making departments and promote the scientific and refined level of decision-making in the process of promoting road transportation systems based on the low-carbon ITS.

4.2. Low CE of urban transportation

SD is a global concern on which environmental pollution and haze diffusion have a significant effect. Urban transportation mainly refers to social vehicles and UPT. Low-carbon urban transport requires vehicles to operate in a green and eco-friendly way. An example of a green and low-carbon transportation solution is shown in Fig. 5:

Using ITS in scheduling and monitoring social vehicles and UPT has attracted scholars' attention. As a new business model of sharing economy, shared travel has been reshaping how domestic residents travel. Yi and Yan (2020) [93] extracted 2018 data and other statistical data from DiDi travel to verify the impact of shared travel on EC, emissions, and transportation structure nationwide. It was revealed that the substitution effect of shared travel encouraged ECER, with 371,000 ER and 518,000 tons of CO_2 ER. Thus, a shared travel platform could prioritize the traffic structure, promote the popularization of electric vehicles, and obtain better cost returns.

Automobile exhaust emissions contributed terribly to CEs and haze diffusion. The sharp increase in cars also makes the energy supply increasingly tight. Peng et al. (2020) [94] discussed how to use intelligent navigation technology based on data analysis to reduce the overall CEs of road network vehicles. They used Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) to enhance Support Vector Regression (SVR) to predict traffic flow prediction. Finally, the exhaust emission prediction model was proposed based on road conditions and vehicle fuel consumption. The low-CE navigation algorithm based on spatial optimization dynamic path planning algorithm was constructed. The outcome showed that the proposed method significantly reduced the overall CEs of road network vehicles. It was conducive to constructing low-carbon ITS and Smart Cities.

As HEVs provide a viable solution to reduce energy consumption and environmental emissions, autonomous vehicles are expected to be powered by hybrid systems compared to other alternatives [95,96]. Phan et al. (2020) [97] studied the HEVs with a large number of uncertainties and ambiguities in the road environment and driver behavior. They also built a fuzzy logic controller to solve the uncertainty of driving conditions. The scheme can reduce energy consumption and emissions to the environment and ease traffic congestion. Many ITSs need to be developed to reduce traffic congestion and improve the efficiency of public transport. Fig. 6 illustrates an example of vehicle static transportation and management service platforms in the smart city.

Lee and Chiu (2020) [98] implemented a signal-control ITS to support multiple Smart City traffic applications. The research entailed emergency vehicle signal preemption, public traffic signal priority, Adaptive Traffic Signal Control (TSC), ecological driving support, and information broadcasting. Importantly, the Roadside Unit (RSU) controller was the core of the proposed signal-control ITS. The system architecture, middleware, control algorithm, and peripheral modules were discussed in detail. They were compatible with the existing TSC devices and could be deployed quickly and cost-effectively. So far, developing countries have not introduced RSUs. The Internet connection interferes with integrating communication devices in Smart Cities and the IoT in remote areas. In this regard, Zaheer et al. (2019) [99] proposed an intelligent vehicle network framework for Smart Cities to temporarily select routes using the real-time data received from adjacent vehicles. The framework used the on-board self-organizing network to realize the ITS. The framework transmitted vehicle data through the Vehicle to Vehicle (V2V) communication network. Vehicles in the network shared information to calculate the traffic jam index. The experiments showed that the travel time was shortened by 33.3% to the traditional fixed route selection algorithm.

Additionally, different route guidance strategies also impact the traffic pollution emissions of ITSs. Cui et al. (2019) [100] introduced the Nagel Schreckenberg cellular automata model into six routing guidance strategies and applied them in three different dual routing scenarios. Different vehicle operation modes were used to simulate the relationship between traffic emissions, emissions per vehicle, unit flux

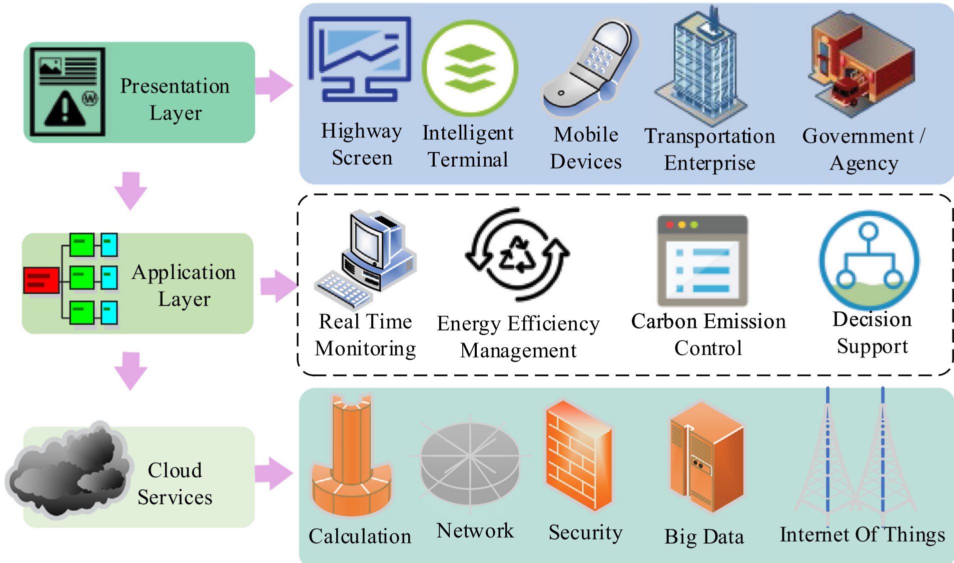

Fig. 5. Examples of green and low-carbon transportation solutions. Image source: The Internet.

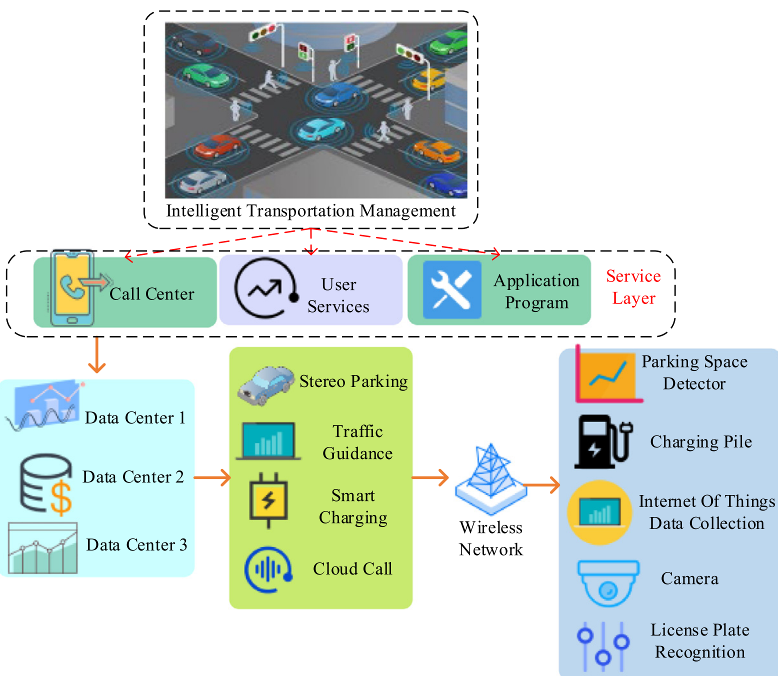

Fig. 6. Example of Smart City vehicle static transportation and management service platform. Image source: The Internet.

emissions, average driving time per vehicle, unit flux emissions, and dynamic vehicle ratio. The simulation found that the average speed and congestion coefficient-based route guidance strategy were the best. Therefore, the route guidance strategy based on the whole road traffic data was conducive to reducing traffic emissions, making the road condition simpler and smoother. Further, the strategy reduced traffic pollution emissions and improved the traffic network's efficiency.

The eco-driving assistance system encourages economical driving behavior and supports drivers to optimize their driving style to achieve fuel economy, thereby reducing emissions [101]. Energy efficiency is also one of the most relevant issues related to the autonomy of all-electric vehicles. Masikos et al. (2014) [102] devised an ER route-selecting method based on the reliable CE prediction of each road section and was implemented through Machine Learning (ML) functions. This study proposed this innovative method, the functional architecture of the implementation method, and the experimental results and explained the impact of route selection on reducing fuel consumption and CEs.

Pure Electric Vehicles (PEVs) are becoming popular with zero emissions and high energy efficiency. However, the limited mileage is one of its main weaknesses. With the rapid development of ITS, vehicle control systems can obtain various traffic information. It realizes PEV-oriented energy-efficient control to expand its total mileage. Zhang et al. (2018) [103] utilized the V2V wireless communication to predict the in-front vehicle movements within each control horizon. They established a better understanding of the future movement of the in-front vehicle. At the same time, an explicit model predictive control method was developed to achieve real-time control. The purpose was to reduce driving CE while maintaining the appropriate distance from the vehicles in front and collecting driving data using a dynamic driving simulator. The effectiveness of the explicit predictive control method was demonstrated. The simulation results showed that the proposed method improved the driving energy efficiency in most scenarios and achieved satisfactory energy-saving results.

Four-wheel Independent Drive (FWID) electric vehicles significantly improve controllability and reduce CE through better speed planning and predictive control than traditional single-axle drive vehicles. For example, Wu et al. (2019) [104] developed a model predictive control method according to the time range. Furthermore, the control tool based on the fast gradient method solved the optimization problem. Firstly, based on the road slope information, the longitudinal dynamic model of FWID electric vehicle Based on time range and distance from the horizon was established. A dynamic program control method based on a discrete distance model was proposed. Finally, the simulation was carried out under the design road conditions and the actual measured road conditions. The results showed that the time range-based model predictive control method could significantly reduce EC, close to the real-man driving experience. Compared with the dynamic program optimization method, the time-based predictive control model reduced the algorithm execution to less than 1 ms. The findings were significant for the real-time application of transportation vehicles.

The emerging information and network techniques, especially V2V and Vehicle to Infrastructure (V2I) communication, has promoted the spread of the AD vehicle concept. As a result, AD has become a practical approach to controlling the fleet by continuously providing support and guidance to drivers. The fuel consumption of trucks can be reduced by 5%–15% through longitudinal automatic driving by minimizing air resistance. Deng and Ma (2014) [105] studied the ER potential of truck exhaust through intelligent speed planning. An efficient speed control algorithm based on optimal control theory was proposed based on the assumption that real-time traffic information was available due to communication. This method was faster than the traditional dynamic programming method and was applied to analyze the ER potential of simple scheduling, including acceleration and deceleration. Numerical results showed that the ER effect was significantly improved due to the speed planning of formation. It could be further applied to more complicated formation operations.

Using the Signal Priority Strategy (SPS), Smart Cities can develop intelligent public transport but might cause personal and commercial automobiles to increase emissions, especially at crossroads. Liu et al. (2020) [106] strived to embed a crossroad CE and emission model into the SPS. A crossroad in Shenzhen, China, was surveyed on a simulation to verify the model framework. This study compared the impact of the improvement of active SPS and real-time SPS on ECER of the target intersection under the intelligent vehicle infrastructure cooperation system. The experimental finding showed that the active SPS could reduce fuel consumption and emissions by up to 13.33%.

Similarly, Edwards et al. (2018) [107] presented the Compass4D project to deploy a collaborative ITS in seven European cities and coordinate a joint assessment of technologies for the three services, with a particular focus on reality safety and environmental goals in world driving conditions. The significance of the Compass4D deployment and results provided some preliminary evidence for the effectiveness of collaborative ITSs in real-world conditions, with both light and heavy vehicles demonstrating efficiency savings of 2% ~6%. As a critical part of a smart city, ITS is the key to the SD of urban transportation considering fuel consumption and traffic efficiency.

The volume and availability of data in ITS have led to the need for a data-driven approach. Apply big data algorithms to improve the intelligence of applications in the transportation field. Big data algorithms have an extended range of applications in ITS, including but not limited to signal recognition, object detection, traffic flow prediction, travel time planning, travel route planning, and vehicle and road safety. Among them, smart sensors can be integrated with transportation infrastructure for sustainable ITS. Recent advances in ITS suggest that roads will gradually be filled with autonomous vehicles capable of driving themselves while cooperating with each other to form a sustainable transportation system. As a representative driving mode of autonomous vehicles, platooning technology has great potential to reduce fuel consumption and improve traffic efficiency.

To achieve these goals, Chen et al. (2020) [108] established a system framework for vehicle formation forming. First, the optimal speed of a platoon is determined by the optimal speed model to save the fuel consumption of the platoon. Then, according to the proposed Q-learning model, the best insertion point decision was made for the vehicles to be grouped. A collision detection model was designed to reduce the collision probability when the vehicles intend to join the queue. Numerical results showed that the proposed model could significantly improve traffic efficiency, reduce fuel consumption, and shorten formation forming time than other classical algorithms. The main research results are summarized in Table 4:

As per Table 4, traditional Autonomous Driving (AD) research and development mainly relies on single-vehicle intelligence and uses on-board sensors and computers to complete road condition perception and analysis decisions. With the intelligent control of ITS, AD enters a new stage of development. Developing a reliable and effective ECER transportation system operation model will realize automatic control, green development, and an adaptive transportation environment.

4.3. Road traffic transportation infrastructure

Transportation infrastructure includes safety facilities, road facilities, ITSs, etc. Specifically, these include signal lights, traffic signs, road markings, guardrails, isolation fences, isolation piers, noise barriers, lighting equipment, parking facilities, traffic gantry, protective nets, Guardrails, isolation fences, signs, markings, delineators, anti-glare boards, anti-fall nets, and raised spikes. The digitalization of highway infrastructure is the direction and foundation of future intelligent highway development, an indispensable technical means for creating road–vehicle coordination, and an essential element for building smart cities.

Smart cities are considered the future of urban living, adapting to population growth and leveraging advanced means, including electricity, water, and transportation. However, the benefits of smart cities are difficult to measure, especially in terms of economic benefits and climate change mitigation [109]. The traffic light control system divides traffic light signals into fixed durations and operates inefficiently. Therefore, it has many weaknesses, such as long waiting times, waste of fuel, and increased CEs. However, the benefits of smart cities are difficult to measure, especially economic benefits and climate change mitigation [110]. The ITS has become a critical part of smart cities and is widely adopted because it overcomes the limitations of traditional transportation systems. The existing fixed traffic light control system divides the traffic light signal into fixed durations and operates in an inefficient manner. Therefore, it has many weaknesses, such as long waiting times, waste of fuel, and increased CEs. To address these issues and improve the efficiency of traffic light control systems, Kumar et al. (2020) [111] proposed a dynamic, intelligent traffic light control system that takes real-time traffic information as input and dynamically adjusts the duration of traffic lights. Furthermore, the system operates in three modes: fair mode, priority mode, and emergency mode. All vehicles are considered to have equal priority, different classes of vehicles are given different priorities, and emergency vehicles are respectively given the highest priority.

Communication between vehicles and road infrastructure can make efficient use of road networks, reducing congestion in urban areas. Distributed control can enhance this improvement because of its light computational load and high reliability. Despite the beneficial effects on traffic, little is known about the impact of such systems on near-road air quality. Tu et al. (2019) [112] applied an end-to-end dynamic

Table 4
Application status of ITS in urban transportation.

Year+Authors	Research findings
Yi and Yan (2020)	The study extracted 2018 data, other surveys, and statistical data from DIDI travel to assess the impact of shared travel on ECER and transportation structure nationwide.
Lee and Chiu (2020)	An intelligent TSC system was designed to support many Smart City traffic applications, such as emergency vehicle signal preemption, public traffic signal priority, adaptive TSC, ecological driving support, and information broadcasting.
Cui et al. (2019)	Based on Nagel–Schreckenberg cellular automata model, six guidance strategies were applied in three different dual routing scenarios.
Masikos et al. (2014)	A new ER route method was introduced based on reliable CE prediction of each road section or potential vehicle route. The model was mainly implemented through ML algorithms.
Liu et al. (2020)	The research aimed to develop a crossroads-oriented ECER model embedded to analyze the impact of the SPS on the crossroads.
Chen et al. (2020)	A system framework of vehicle formation forming was proposed

distributed routing algorithm in interconnected and autonomous vehicles in downtown Toronto to determine whether the benefits of network throughput were associated with lower short-cut NO_2 concentrations. This new transportation-transforming technology is designed with air pollution and public health goals in mind and has benefits for alleviating traffic congestion and improving air quality.

As part of the future ITS, Internet of Vehicles (IoV) communications and services have attracted significant interest from different stakeholders [113–115]. Nevertheless, some services have strict transmission latency requirements. Multiple access or Mobile Edge Computing (MEC) has been proposed as a practical approach to implementing near-vehicle sides for such services. However, doing so gives rise to other problems. For example, where should the IoV services be distributed, especially considering the limited computing resources available on edge nodes? Therefore, Moubayed et al. (2020) [116] expressed the IoV services-oriented optimal placement strategies in a mixed core/MEC environment as a binary-integer linear programming problem. A more straightforward heuristic algorithm — greedy IoV service distribution mechanism was also designed. The results showed that the algorithm reached a close-to-optimal performance [117].

IoT-driven ITS has great potential in fast, trustworthy, intelligent, anti-theft, and long-term-oriented transportation. The IoT offers a gateway and driving force for seamless, integrated ITSs from the physical ecosystem to virtual counterparts in the digital space. Zhu et al. (2019) [118] presented a vision and work to combine AI with transportation systems to create a true IoT-based ITS. The IoT-enhanced ITSs' ubiquitous depth perception ability can instantaneously regenerate a parallel virtual transportation system mapping the physical one into the computer. That is, a real ITS and an artificial ITS exist together. The intelligent industrial environment developed on top of the new-generation network information physics system can achieve a high concentration of information resources [119]. AI development and its application in transportation have gradually begun, giving people a bright prospect of integrating AI and transportation. In particular, the application of the DL in the transportation field shows greater potential [120].

With the advent of connected cars, 5G, and IoT, vehicles and road infrastructure become interconnected and collaborative, enabling collaborative ITSs. New value-added applications can be developed by reusing and combining available heterogeneous services. Autili et al. (2021) [121] introduced an orchestration-based service composition platform: a drudgery revolution for integrated development and runtime environments. They reported how this environment could be successfully used to accelerate the reusable development of orchestration-based urban traffic coordination applications. The urban traffic coordination system uses ecological driving services to help drivers obtain the most environmentally friendly and comfortable driving experience. It can provide real-time ecological route assessment.

Collaborative ITSs based on V2I communication can address important road transport issues, such as safety and pollution. The capital required to deploy collaborative ITS services is enormous. Therefore, it is essential to clearly understand it, such as possible costs, benefits, and business models, before making an investment decision. Ognissanto et al. (2019) [122] described a tool to help national highway agencies consider deploying collaborative ITSs. They developed an investment and deployment plan for the UK's national road network as a case study. The analysis identified key factors in achieving an acceptable break-even. The findings suggested that investment costs may be higher than monetized income.

Yet, massive investment in transport infrastructure has not fundamentally changed a stubborn social and public policy problem: traffic congestion. Cheng et al. (2020) [123] integrated a road traffic-specific longitudinal dataset and deployed a large federally supported ITS project in 99 urban areas in the United States (U.S.). They looked at whether and how its affected traffic congestion between 1994 and 2014. Variance estimates suggested that the ITS program is associated with a significant reduction in traffic congestion. It saves more than 4.7 billion USD and 175 million hours of travel time in U.S. cities annually. The results showed that ITSs recommend proper travel strategies to individual commuters. ITS has helped regional departments improve urban traffic management capabilities. Empirical results support its underlying theoretical mechanism. As a result, ITS can help commuters plan their trips more efficiently, choose the best navigation routes, and optimize their work travel traffic patterns.

It can be seen that the impact of ITS depends to some extent on road supply and public transport services. The development of infrastructure in road transport systems is examined from the perspective of a parallel virtual-physical space. Meanwhile, many long-term iterative simulations are used to predict and analyze the expected outcomes of operations [124]. Clearly, IoT, wireless sensor networks (WSNs), and other promising intelligent infrastructures can help ITSs solve the problem of traffic congestion. WSN-based applications will greatly impact data-interaction costs to support high-level interconnection and information exchange. Increasing on-road vehicles lead to congestion and safety problems, whereas ITSs provide solutions to alleviate traffic jams.

5. Conclusion

Guided by the Peak Carbon Dioxide Emissions and Carbon Neutralization goals, the development of the transportation sector requires much attention to create a green and civil transportation system. ITS utilizes information and communication technologies to efficiently use existing transport infrastructure to improve transport services and reduce congestion, accidents, and air pollution. At present, the technology and policy conditions of intelligent transportation in different countries are relatively mature, and the construction has achieved preliminary results in some cities. With the continuous breakthrough of technologies such as autonomous driving, the overall smart transportation industry will usher in a wave of rapid growth. It is also expected to become a new growth point of China's economy.

However, there are still many problems. The control of the number of vehicles is a big problem for the effective control of the CEs of the transportation network. The current traffic flow control algorithm overcomes the limitations of the window traffic system, but there is still room for improvement in control efficiency and delay. In addition, various countries have differences in the construction of intelligent buildings and transportation infrastructure. They do not continue to advance with the market but will not progress after reaching a balance point. Therefore, the development pattern of future urban ITS needs to enhance the importance of urban public transportation system construction and make different layouts according to different types of urban needs. With the breakthrough of autonomous driving and other technologies, the overall intelligent transportation industry will proliferate and is expected to become a new growth point for the global economy.

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Erratum regarding previously published articles

Declaration of Conflict of Interest statements were not included in the published versions of the following articles that appeared in previous issues of Green Technologies and Sustainability.

The appropriate Declaration/Conflict of Interest statements, provided by the Authors, are included below.

1. "Impacts of intelligent transportation systems on energy conservation and emission reduction of transport systems: a comprehensive review" (Green Technologies and Sustainability, 2023, 100002) https://doi.org/10.1016/j.grets.2022.100002
Declaration of interest: The Authors have no interests to declare.

2. "Blockchain Based Smart Contract for Cooperative Spectrum Sensing in Cognitive Radio Networks for Sustainable Beyond 5G Wireless Communication" (Green Technologies and Sustainability, 2023, 100019) https://doi.org/10.1016/j.grets.2023.100019
Declaration of interest: The Authors have no interests to declare.

3. "Modeling agricultural land suitability for vegetable crops farming using RS and GIS in conjunction with bivariate techniques in the Uttar Dinajpur district of Eastern India" (Green Technologies and Sustainability, 2023, 100022) https://doi.org/10.1016/j.grets.2023.100022
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4. "Unearthing the barriers of Internet of Things adoption in Food Supply Chain: A Developing Country Perspective" (Green Technologies and Sustainability, 2023, 100023) https://doi.org/10.1016/j.grets.2023.100023
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