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Path selection and mechanism innovation of improving railway energy efficiency – from foreign experience and Chinese practice

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Abstract

Purpose – Under the dual pressure of resources and environment, many countries have focused on the role of railways in promoting low-carbon development of integrated transportation and of even the whole society. This paper aims to provide a comprehensive study on methods to improve railway energy efficiency in other national railways and achievements made by China's railways in the past practice, and then to propose ways in which in the future China's railways could rationally select the path of improving energy efficiency regarding the needs of the nation's ever-shifting development and carry out the re-engineering for mechanism innovation in energy conservation and emission reduction process.

Design/methodology/approach – This paper first studies other national railways that have tried to promote the improvement of railway energy efficiency by the ways of technology, management and structural reconstruction to reduce energy consumption and carbon emissions. Among them, the effect of structural energy conservation and emission reduction has become more prominent. It has become the main energy conservation and emission reduction measure adopted by foreign railway sectors. The practice of energy conservation and emission reduction of railways in various countries has tended to shift from a technical level to a structural one.

Findings – Key aspects in improving energy efficiency include re-optimization of energy structure, re-innovation of energy-saving technologies and optimization of transportation organization. Path selection includes continuing to promote electrified railway construction, increasing the use of new and renewable energy sources, and promoting the reform of railway transportation organizations.

Originality/value – This paper provides further challenges and research directions in the proposed area and has referential value for the methodologies, approaches for practice in a Chinese context. To achieve the expected goals, relevant supporting policies and measures need to be formulated, including actively guiding integrated transportation toward railway-oriented development, promoting innovation in energy-saving and emission reduction mechanisms and strengthening policy incentives, focusing on improving the energy efficiency of railways through market behavior. At the same time, it is necessary to pay attention to new phenomena in the railway industry for track and analysis.

Keywords China's railways, Energy efficiency, Energy consumption structure, Transport organization optimization, Electrification, New energy, Renewable energy

Paper type Research paper

1. Introduction

Since the beginning of the 21st century, under the dual pressure of resources and environment, many countries have started to re-examine issues of integrated transportation structure. In recent years, civil society, citizens and decision makers have become much more aware of the role of rail transport as a key factor in achieving sustainable development and reducing the effects of climate change. While adopting adjustment and optimizing measures, those countries have paid attention to role models of the railway in transportation energy

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conservation and emission reduction because it is socially accepted that railway, especially high-speed rail, is more energy-efficient and environmentally friendly than other competing transport modes; moreover, the increase in train speed also contributes to the increase of the efficiency of the transport system (Franco & Marcos, 2022). In China, railway has been highly valued and has developed rapidly in the most tangible form. In 2016, the State Council of the People's Republic of China approved the Medium and Long-term Railway Network Plan (period set for 2016–2025, long-term outlook to 2030). One of its key points is to expand the original "Four North-south and Four East-west" high-speed rail lines to the "Eight North-south and Eight East-west," painting a more ambitious blueprint for the future development of Chinese railway (National Development and Reform Commission, 2016). By the end of 2021, the total operating mileage of railways had reached 150,000 km, including 40,000 km of high-speed railways. Through the remarkable achievements of China's railway, especially that of the high-speed rail in recent years, we believe that significant improvements in daily rail travels will be further voiced through such a plan, will fully exert the railway in boosting the Chinese economy and will take the key role in promoting the social development.

Improving energy efficiency is becoming the most important aspect of the rail sector's strategies to reduce CO_2 emissions and, of course, offers significant business benefits as well as reducing costs. How to improve energy efficiency of railways? In general, there are two paths. One is to improve the transportation efficiency, and the other is to decrease the energy consumption. Then, in the new epoch of development, how to further improve the energy efficiency of China's railways, take full advantage of railways as green and environmentally friendly transport and further promote the development of integrated transportation with low-carbon and sustainable development? Based on the reference of foreign railway energy conservation and emission reduction, this paper analyzes the potential spaces of China's railway energy conservation, locates the key elements of energy efficiency improvement and proposes a roadmap for China's railways energy conservation and emission reduction in the future and the relevant supportive policies and measures for the implementation of the energy conservation strategy.

2. Experience from foreign railway energy efficiency and emission reduction

Energy efficiency offers huge potential for cost savings – a 1% improvement in energy efficiency will save several million euro per year for most railways (UIC, 2022), and is also the most direct way to reduce CO_2 emissions and secure strong environmental performance in support of the Union Internationale des Chemins de fer-Community of European Railway (UIC-CER) Sustainability Strategy. In recent years, many successfully concluded projects have delivered promising results in terms of energy efficiency such as Railenergy, CleanER-D, Energy Consumption, Parked Trains, MERLIN, etc., and further important projects such as Shift2Rail are underway.

Technical innovation and policy optimization have further promoted railway energy efficiency and achieved the development of low-carbon green railways. Experience from foreign countries has a certain degree of universality, and it is worth learning from for China's railway sectors.

2.1 Energy efficiency of foreign railways

2.1.1 Railway energy consumption and carbon emission in European Union countries. In the European Union (EU), the transport sector accounted for 28.3% of total energy related CO_2 emissions and 28.1% of total final energy use in 2015. The transport sector is the largest contributor to energy related CO_2 emissions in the EU28. As for the rail sector, it only accounted for 2.9% of CO_2 emissions from transport, and for 2.1% of transport final energy demand. Furthermore, the carbon emission of railway passenger transport was 38.1%

lowered per passenger-km between 2005 and 2015, and the carbon emissions of freight transportation was lowered 31.2% per freight ton-km in the same period. The trend of low-carbon energy consumption became more and more obvious. By 2030, the European railways will reduce their specific average CO_2 emissions from train operation by 50% compared to base year 1990 (UIC, 2014).

The results above are derived mainly from two aspects. One was the better energy consumption structure, and the other was improved technology of energy saving. The energy consumption structure of EU28 railways primarily consists of oil, coal, biofuels and electricity. The structure had altered more quickly the year before. According to the information provided by the International Unions of Railways (UIC, 2017), the use of oil products (diesel) in the railway fuel mix continued to decrease, dropping from 40.4% of railway final energy consumption in 2005 to 31.8% in 2015, while electricity increased to 67.6%, of which the share of renewable energy in the electricity mix more than tripled, rising from 6% to 21% between 2005 and 2015. The German government initially planned to further increase the share of renewables in electricity to 50% by 2030, 65% by 2040 and 80% by 2050 (IEA, 2020).

Energy efficiency activities in European railway companies are concerning non-traction energy efficiency – ranging from new lighting systems, heating management, cooling and ventilation over intelligent control of energy efficient equipment, improved energy requirements for contractors to energetic overhaul of buildings (IZT & Macroplan, 2012).

2.1.2 Railway energy consumption and carbon emissions in the USA. Similar to the EU28, the transport sector of the USA is also the largest contributor to its energy-related CO_2 emissions, and the rail sector accounted for very low proportion of CO_2 emissions and final energy demand from the transport sector. In 2015, the transport sector accounted for 35.1% of energy-related CO_2 emissions and for 41.5% of final energy consumption. The other sectors accounted for 20.3, 18.0, 17.2, 6.3 and 3.1%, respectively. From the transport sector, the railway accounted for 2.4% of CO_2 emissions and for 2.0% of transport final energy demand. But different from the EU, the pattern of railway energy consumption in the USA appears to be slow. For example, the use of oil products (diesel) in the railway fuel mix decreased slightly from 95.8% in 2005 to 94% in 2015. Over the same period, there was a slight increase in the share of electricity and biofuels. One of the main reasons is that electrication of the US railway lines remains very low. The majority of energy consumed by the US railway is used for freight service. The energy efficiency of the US freight rail has increased by 50% because of improved heavy-haul transportation and better locomotive technology since 1980. Energy consumption per freight ton-km (kJ/tkm) decreased by 15.4% from 2005 to 2015.

2.1.3 Railway energy consumption and carbon emissions in the Japan. In Japan, the transport sector is not the largest contributor to its energy-related CO_2 emissions. In 2015, the transport sector accounted for 19.1% of energy-related CO_2 emissions, following the sectors of manufacturing industries and construction (33.3%) and commercial and public services (22.5%), but it is the second largest consumer, with 24.5% of final energy demand. The rail sector accounted for 5.0% of transport CO_2 emissions, up from 4.2% in 2010. Despite this increase, railway final energy consumption decreased over the same period, accounting for 2.4% of transport final energy demand in 2015. The main reason was that energy consumption per passenger-km decreased by 15.6% between 2005 and 2015, and energy consumption per freight ton-km decreased by 13.7% in the same period.

2.2 Practical experience of energy conservation and emission reduction in foreign railway industry

The EU countries, the USA and Japan have accumulated a large amount of experience in energy conservation and emission reduction in railway development, which can be summarized in three aspects.

2.2.1 Energy conservation and emission reduction at the technical level. Energy-saving and emission reduction strategies of foreign railways are mainly reflected in the following fields:

(1) *Production and manufacturing*. For example, lightweight transportation equipment, including vehicles, bogies and electric equipment, etc. Many countries have put much effort in developing the lightweight quality of high-speed trains. For example, the body weight of Shinkansen has been reduced to 537 kg per seat, and the suburban railway in Copenhagen has been reduced to 360 kg per seat. Usually, there are two ways to reduce the weight of a train body: one is to reduce its weight of components, and the other is to optimize the overall design for its structure. It is necessary to pursue the optimal weight layout of the components of the train body while ensuring the strength.

(2) *Locomotive energy and fuel saving technology*. Firstly, the regenerative braking technology is suitable for train operation modes with multiple stops. For example, the total energy consumption of intercity rail transit can be reduced from 30% to 15%, which has great potentials for energy saving. Furthermore, fuel additives or other alternative energy techniques, such as replacing fuel with natural gas and hydrogen fuel, can be adopted. On July 25, 2022, Alstom CoradiaiLint hydrogen fuel train officially started commercial operation and its assessment. According to the company's operating plan, 27 trains of the same kind will be put into operation in the west of Ammayne, Frankfurt, from December 2022. Finally, new modes of locomotives can be used to replace old locomotives.

(3) *Develop heavy-haul transportation technology*. Heavy-haul transportation technology has been scaled up abroad. The extension of heavy-haul transportation abroad is expanding progressively, not only in vast continental countries like the USA, Canada, Australia, etc., but also on the traditional passenger-freight mixed trunk railways in Europe.

2.2.2 Energy conservation and emission reduction at the management level. First of all, the railway companies were imposed low-carbon environmental protection requirements from the regulatory level. For example, the British government and railway regulatory authorities put forward more demanding energy-saving and environmental protection requirements on railway infrastructure and renovation, even vehicle manufacturing requires more energy-efficient and environmentally friendly designs.

Secondly, specific requirements were also applied in the training of locomotive drivers as operation technology is an important factor affecting the energy consumption of locomotives. Therefore, professional staff training also makes visible eco-friendly outcomes.

2.2.3 Energy conservation and emission reduction at the structural level. Optimizing the structure of energy consumption through energy replacement to achieve low- or zero-carbon energy, instead of carbon or high-carbon energy, mainly increases the share of natural gas, renewable energy and nuclear energy in energy consumption. It also reduces the proportion of coal and oil used in the whole process. Compared to technical and management methods, the effect of structural energy conservation and emission reduction is more prominent, and it has become the main source of energy conservation and emission reduction for foreign railways.

2.3 Enlightenment from the experience of foreign railway energy conservation and emission reduction

The practices discussed above have concentrated in technical, managerial and structural levels. Nevertheless, the structural level is also a pivotal medium, which provides context for energy conservation and emission reduction.

(1) Vigorously promote the technology innovation in energy saving of railway transportation equipment and transformation. This is an important means of implementing a low-carbon strategy from a technical perspective, so foreign railways place great value on energy conservation and emission reduction in this field, and have obtained substantial progress. China's railway needs to improve the function of equipment manufacturing and design, as well as pay attention to the continuous innovation of energy-saving technologies, collaborative improvement in energy efficiency.

(2) Re-engineer the process of the regulatory supervisions. China Railway will still be under large-scale construction for a period of time. It is critical to enhance the supervisory practices targeting low-carbon and environmental protection from planning, construction and operation. At the same time, we should utilize market mechanisms for indirect supervision, focus on using the power of the market to promote railway decarbonization and establish a long-term mechanism, e.g. introducing carbon-trading into the energy-saving management of the transportation industry to increase industrial awareness. This is a fundamental strategic measure to building a low-carbon and environmentally friendly railway.

(3) Structural emission reduction focuses on substituting electricity for oil and renewable energy for coal and kerosene. Improving railway electrification rate is an important way to develop low-carbon railway transportation abroad, it is also the most realistic way for China's railway to improve energy efficiency under current conditions. Regarding the experiences of other national railways, new and renewable energy has been mainly used in the non-traction field, and the main purpose is to replace the use of coal and kerosene, which is also an important experience in optimizing the structure of energy consumption (Zhou, 2016a, b).

3. Potential for China's railway to improve energy efficiency

Chinese railway has made a significant increase in energy efficiency in recent years (see Figure 1). On the whole, the trend of the comprehensive energy consumption per unit transport workload and comprehensive energy consumption of major businesses is decreasing on an annual basis. Moreover, the improvement of this kind of energy efficiency is realized when the traffic volume has been greatly improved while the total energy consumption has decreased or increased slowly. To some extent, there is of great

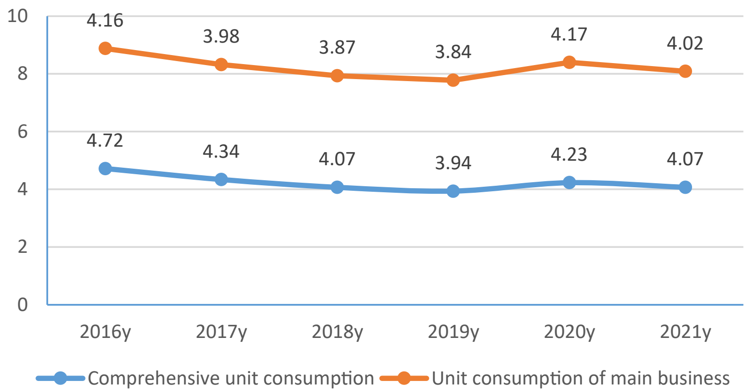

Figure 1.
Comprehensive energy consumption per unit transport workload and comprehensive energy consumption of main business of China's national railways (unit: ton standard coal/million ton km)

potential for prospective development in this field. If China's railway can continuously develop energy-saving ideas, promote technical methods, management innovation, institutional environment, investment and construction, it will inevitably further promote the optimization of energy consumption structure of the railway, improve the technology and the level of energy management and conservation, maximally excavate the potential of railway energy conservation and emission reduction, thus making a big step forward toward its low-carbon goals.

3.1 Improvement of the external energy conservation policy environment

Energy saving of the railway industry is subject to the external institutional environment, and its continuous improvement will build on Chinese railways to save energy. The Chinese government has always placed great value on the energy-saving policy, and has striven to provide a sound and well-grounded policy environment for energy saving and emission reduction in diverse industries. However, due to various factors, it still requires further improvement, mainly in two aspects:

(1) Policies to encourage new and renewable energy development. China's renewable energy has been developed rapidly in past years, but it still has a way to go in terms of effective convergence of transmission and distribution in the renewable energy electricity generation. China Railway has been committed to using new and renewable energy in replacing traditional energy in recent years, and achieved positive results. Nevertheless, it needs to improve external energy-saving policies to make further breakthroughs.

(2) The current energy conservation and emission reduction mechanism in China. For a long period of time, China has been focusing on controlling total amount of energy consumption, mainly initiated by the state's developmental concerns, and energy-using sectors are often in a state of passive energy saving. Therefore, it is necessary to improve the current energy conservation mechanism by means of introducing the market mechanism. Under the guidance of related policies, industrial players could make an active and voluntary shift toward the energy conservation of energy-using sectors. China has already obtained certain preliminary results in the carbon market pilot. Since the launch of the national carbon market on July 16, 2021, the overall operation of the market has been stable. The first batch of 2,162 key emission units in the power generation industry, covering about 4.5 billion tons of carbon dioxide emissions, is the world's largest carbon market. By the end of July 15, 2022, the cumulative trading volume of carbon emission quota (CEA) in the national carbon market had exceeded 194 million tons, far exceeding the trading volume of the EU and the South Korea markets in the same period, ranking the first in the global carbon market, with a cumulative turnover of nearly ¥8.5bn. Over the past year, the cumulative number of enterprises participating in trading has exceeded half of the total number of key emission units, and the market quota fulfillment rate has reached more than 99.5%. It is estimated that after the coverage of eight industries in the future, the total quota of the national carbon market is expected to expand to seven billion tons. According to the carbon price level in 2021, the cumulative trading volume is expected to reach ¥100bn by 2030. China's carbon trading pilot has generally achieved the expected results. The introduction of the carbon market is conducive to the railway transport enterprises for achieving greater energy-saving economic benefits. From the perspective of external factors, it is beneficial for railway transportation enterprises to actively participate in carbon emissions trading, taking advantage of the industry's low-carbon characteristic to increase carbon revenues.

Considering internal benefits, it will help with further energy saving and emission reduction for enterprises, effectively control of carbon emissions, prevent energy waste, improve the level of energy efficiency and reduce energy cost.

3.2 Expanding space for railway energy conservation and emission reduction

Through continuous efforts, the energy efficiency level of China's railways has been at the forefront of the world. Unit consumption is the most important indicator of energy efficiency. Taking the year 2013 as an example, we may have the unit consumption of passenger transport and that of freight transport of the main railway countries, including EU28, the USA, Russia, Japan and China are about as follows: 360 kj/pkm, 170 kj/tkm; 1,000 kj/pkm, 190 kj/tkm; 240 kj/pkm, 90 kj/tkm; 150 kj/pkm,195 kj/tkm; 90 kj/pkm, 140 kj/tkm (UIC, 2017). It can be observed that China's railways have the lowest energy consumption and therefore the highest energy efficiency, and it is far lower than the average level of the unit consumption of the global railway (145 kj/pkm, 140 kj/tkm). However, comparing to the practical experience of energy conservation and emission reduction abroad, there still remain areas to be improved as in the two areas in the following discussion.

3.2.1 Development in the field of railway heavy-haul transportation. Railway heavy-haul transportation technology has been recognized internationally as the future direction of railway freight transportation development, and is also considered as an important way for railway energy conservation and emission reduction. In recent years, China's railway heavy-haul transportation has been developed rapidly. The heavy-haul transportation technology innovation represented by the Daqin line has ranked among the world's top list, but overall, there is still room for improvement. The International Heavy-Haul Association successively revised the heavy-haul railway criteria three times in 1986, 1994 and 2005, respectively. According to the requirements in the 1994 version, the heavy-haul railway must meet at least two of the following three criteria: (1) the minimum train freight is 5,000 t; (2) the axis mass is at or above 25 t; (3) the annual traffic volume on the line with a length of at least 150 km is not less than $2,000 \times 10^4$ t. At the 2005 International Heavy Load Association Council, the new heavy-duty railways applying for the International Heavy-Haul Association are required to meet at least two of the following three criteria: (1) the train mass is not less than 8,000 t; (2) the axis mass is above 27 t; (3) the annual traffic volume on the line with a length of at least 150 km is not less than $4,000 \times 10^4$ t (Tong, 2012). According to these criteria, China's Daqin Line has met the new heavy-haul railway standards set by the 25th International Heavy-Haul Association, and the other main lines such as Shuohuang, Beijing-Guangzhou, Beijing-Shanghai and Beijing-Harbin can only meet the 1994 standard. It can be seen that there is still a lot of room for overall improvement.

3.2.2 Improvement in structural optimization. Improvement in structural optimization alludes to two aspects: the optimization of energy consumption structure and transportation structure.

The energy consumption structure of China railways have been continuously optimized in recent years and made relatively obvious progress. It has evolved from the coal-based to the oil-based. Nowadays, it combines oil and electricity as the mainstay. The structure of energy consumption has undergone qualitative changes. This is also the most optimized energy consumption structure in the field of comprehensive transportation. From Table 1, during the "5th Five-Year Plan," China's national railway energy consumption was made up of 8.44% of fuel, 1.24% of electricity and 90.32% of coal. By the end of the "11th Five-Year Plan" (from the start of 2010), it had been evolved to 43.98% of fuel, 27.49% of electricity and 28.53% of coal. The consumption structure has undergone great changes, but mainly in terms of quantity, and the proportion of electricity is close to the proportion of coal. The accelerating progress of adjustment of energy consumption structure began in the "11th Five-Year Plan," mainly reflected in the "12th Five Year Plan," reaching a qualitative leap. By 2012, the proportion of electricity greatly exceeded the coal and was close to the fuel weight. In addition, since the consumption of new and renewable energy is not currently counted for energy consumption, the actual energy consumption structure should be more optimized. In recent years, the use of new and renewable energy by railways has been expanding (Zhou, 2016a, b). However, compared with the energy consumption structure of the EU countries, there still remains a gap, mainly in the proportion of new and renewable energy, natural gas and nuclear energy, especially the electricity power structure. At present, China's railway power is mainly based on coal-powered electricity due to the current state of power structure in the country as a whole. This means that China's railway still has a lot to improve in terms of energy structure optimization. Table 2 shows the long-time historical changes of energy consumption structure of China's railway from 1980 to 2012.

The table above does not include other sorts of energy resources such as gas and heat power, etc. With those included, the energy structure can be illustrated as in Table 3 which suggests a rapid increase of the other resources.

In terms of transportation structure, China's railway transportation efficiency ranks first in the world (Wang, 2002; Jiao, 2007), and the phenomenon of mixed running of passenger and freight on existing railway lines has been greatly improved, but there is still a certain distance from the ideal goal for passenger and freight sub-line operation. It is a main direction of railway development to actualize passenger and freight separate transportation on busy railway trunk lines in the future, which is conducive to improving transportation efficiency and energy efficiency. There are a large number of existing railways with passenger-freight joint lines in China, and the transformation volume of sub-line transportation is also relatively

Field of activity	Recommended efficiency measure	Subsystem saving potential
Lighting	• Intelligent control • Replacement of less efficient lighting	• 10–30% • 10–40%
Heating and cooling	• Improved insulation of buildings • Intelligent control including temperature setting • Modern heat pumps (A+)	• 10–30% • 10–20% • Up to 30%
Powered equipment	New efficient drives and pumps (A+) plus intelligent control	10–40%
Lighting	• Intelligent control • Replacement of less efficient lighting	• 10–30% • 10–40%

Table 1. Different measures produce non-traction energy efficiency

Time period	Oil	Electricity	Coal
"Fifth Five-Year" plan (1980–1984)	8.44	1.24	90.32
"Sixth Five-Year" plan (1985–1989)	12.51	2.13	95.35
"Seventh Five-Year" plan (1990–1994)	20.25	4.01	75.74
"Eighth Five-Year" plan (1995–1999)	31.67	6.90	61.43
"Ninth Five-Year" plan (2000–2004)	48.61	10.29	41.10
"Tenth Five-Year" plan (2005–2009)	49.62	13.36	37.01
"Eleventh Five-Year" plan (2010)	43.98	27.49	28.53
2011	41.92	31.81	26.27
2012	39.56	35.15	25.29

Source(s): According to the relevant data from the railway department

Table 2. Historical change of energy consumption structure of China's railway (%)

large. Therefore, as a whole, there is great potential to improve the optimization of China's railway transportation, which will also help with the structure reduction in railway energy conservation.

4. Strategic choices for energy efficiency improvement of China's railway

Along with the rapid development of China's comprehensive transportation, how to effectively exert the internal and external effects of railway energy conservation and low-carbon characteristic has gradually risen to the strategic level. Therefore, the future plan and the specific path to improve its energy efficiency also need to be planned from a strategic perspective.

4.1 The strategic focus of China's railway energy conservation and emission reduction

Through the analysis of the current situation, China's railway energy conservation and emission reduction is experiencing a strategic shift. First of all, it gradually shifts the focus from traction energy consumption to non-traction energy consumption. For a long period of time, the focus of China's railway energy conservation and emission reduction was concentrated on the development of electrified railways. Rapid development in electrified railway has greatly improved railway capacity as it is characterized by the use of high-power locomotives and shortened interval transport time; comprehensive use of resources, especially renewables, which reduce fuel consumption; and lower transport and maintenance costs, thus increasing labor productivity. Therefore, electrified railway significantly contributes to energy efficiency. In 2015, China's railway electrification rate has exceeded 60%. This target task was five years ahead of the tasks proposed in the original "medium- and long-term railway network plan." In the next five years, the development of electrified railways is still the main task for China's railways. According to the revised "medium- and long-term railway network plan," China's railway electrification rate would reach 70% by 2020. At present, China's railways entered the top-ranking group of the world's highest electrification rate, far exceeding the long-established developed countries in railway industries such as France, Russia and Germany, and become powerful in electrified railway.

At present, the workload of electric traction in China's railways accounts for about 80% of the total traction workload of locomotive. From the perspective of future development, although it is still room to improve the electrification rate, the space for increasing electric traction workload will be limited due to the rising construction cost of electrified line and extreme weather during operation such as blizzard. On the contrary, between 2010 and 2015, the proportion of non-traction energy consumption of railways has increased from 42.9% to 53.40%, which has exceeded the proportion of traction energy consumption. In particular, non-traction energy consumption is mainly based on coal. Regarding the macro-environment,

Year	Oil	Electricity	Coal	Other resources
2012	38.1	34.1	24.4	3.4
2013	35.3	37.5	23.3	3.9
2014	32.6	41.3	21.4	4.7
2015	29.0	45.6	19.6	5.8
2016	28.0	50.1	15.2	6.7
2017	26.9	55.8	9.8	7.5
2018	25.0	60.9	5.5	8.6
2019	23.0	65.5	2.5	9.0
2020	22.5	67.0	1.6	8.9

Table 3.
Recent energy consumption structure change of China railway (%)

one of the main tasks of China's energy conservation and emission reduction in the future is to effectively reduce the coal consumption. Therefore, gradually substituting new and renewable energy for coal in the current non-traction energy consumption of railways is one of the main tasks that needs to be done to reduce emissions in the long term.

The second change is to switch from traditional high-carbon energy source to the lower carbon and to replace the traditional energy source with new and renewable energy, and only by this way can we truly enter a period of low-carbon development period. Energy conservation and emission reduction are interdependent with certain differences. To some extent, energy conservation means reduction in emission; however, when it comes to a certain way, the effect of emission reduction is often very different. In the case of fossil energy, even if it is energy-saving, there are limits to the effect of emission reduction. If new energy and renewable energy are used instead of fossil energy, the emission reduction effect will be very significant. Therefore, energy conservation must not only achieve energy efficiency improvement in a traditional sense, but also achieve low the carbonization and carbon-free.

4.2 Key points to improve China's railway energy efficiency

Focusing on the shift of the key points of energy saving and emission reduction of China's railways in the future, the following sections will describe the main ideas of improving energy efficiency of Chinese railways.

4.2.1 Further optimization of energy consumption structure. Structural energy conservation and emission reduction is the most fundamental strategic demand for the low-carbon development of China's railway transportation. The optimization of China's railways energy consumption structure requires continuous improvement of the proportion of electricity in energy consumption, which is a major strategic demand for low-carbon development of China's railway transportation in the future.

From the perspective of traction energy structure, the key to optimization is to improve the level of railway electrification. Based on the past practical experience, increasing the electrification rate can effectively promote the further optimization of the railway energy consumption structure.

From the perspective of non-traction energy consumption structure, it mainly uses new and renewable energy to replace boiler coal and fuel for heating. At the same time, new and renewable energy can be used for cooling to reduce power consumption. In non-traction energy consumption, building energy consumption accounts for a large proportion. Building energy conservation mainly includes energy saving and emission reduction of large stations, office buildings, dispatching buildings, employee apartment buildings, bathhouses, etc., with an emphasis on large stations. In recent years, with increasing coverage of high-speed railways, the number of large stations has increased rapidly, and this part of energy consumption accounts for a large proportion of non-traction energy consumption. In addition, the energy consumption of large marshalling yards is relatively large. These places can be considered to promote energy-saving lamps. For future development, new and renewable energy can be used for distributed electricity generation and for replacing coal power in these areas step by step.

4.2.2 Energy conservation technology innovation. Railway energy-saving technologies mainly involve four aspects: locomotives, buildings, buses and major energy-using equipment.

(1) Locomotive energy-saving technology. It is need to research and innovate fuel-saving technology of diesel locomotive, power loss mechanism and energy efficiency improvement technology of traction power supply under the condition of train regenerative braking, energy interaction mechanism of regenerative braking between train and traction network, energy efficiency modeling technology of

train-traction network-substation coordination, loss reduction control theory and key technologies and also research regenerative braking energy utilization technology and energy consumption integrated management system.

(2) Energy saving and emission reduction technology of traction power supply equipment. That includes accelerating the development of new energy-saving locomotives, such as intelligent "New Energy Locomotive" manufactured by CRRC Dalian Company, China; researching on high-overload traction transformer technology, developing energy-saving traction transformers with a low-loss iron core and coil structure, and studying high-conductivity contact network wires based on new materials and preparation techniques.

(3) Energy-saving and emission reduction technologies for railway stations. It is needed to study station energy management and control technology, eco-green lighting technology of station yard, new and renewable energy utilization technology, water-saving technology, the applicability of intelligent lighting systems in railway stations and develop energy-saving operation intelligence for central air-conditioning of large passenger stations control systems. It is also necessary to research on green-heat source and energy-saving technology for heating in railway station house in cold and dry areas, building heat supply technology along railway under a ultra-low ambient temperature of air source heat pump and develop remote monitoring systems for air source heat pump heating. In addition, it is needed to study comprehensive energy saving and energy efficiency of high-speed railway station management mechanism and strategy, and research on air compressor heat recovery technologies, station comprehensive technologies for recycling waste through pipeline technology.

(4) Railway comprehensive energy conservation and efficiency management technologies. These include the following: to research and innovate railway energy consumption data measurement technology, energy consumption data statistics systems, energy conservation evaluation and assessment technology; to formulate energy-saving management measures suitable for production practice; and to introduce management technologies such as carbon trading mechanisms.

4.2.3 Promote the heavy load of railway freight transportation and further optimize the organization of transportation. It is a necessary path to accelerate the reform of railway transportation organization, promote the heavy load of railway freight transportation, further optimize transportation organization to reduce the energy consumption generated by trains during operation. Transportation organization optimization mainly includes scientifically and rationally laying out the train operation diagram, optimizing vehicle flow organization, improving the efficiency of dispatchers and skills and energy conservation awareness of drivers. As for heavy-haul freight railways, it is crucial to actualize heavy-haul transportation on the main railway transportation channels and make that to reach the internationally advanced level. This is a streamlined path to improving transportation efficiency by increasing the level of heavy loading. To some extent, energy conservation and emission reduction during the operation will have a relatively large impact on overall energy conservation and emission reduction. The main reason is that the energy consumption generated in train operations is relatively large. Delayed trains, longer parking times and roundabout traffic (non-shortest path operations) can result in significant energy waste. The key issue here is to deal with the relationship between safe operation and energy conservation and emission reduction. Safety issues have always been an overriding task in railway operations. How to ensure energy conservation and emission reduction during train operations on the premise of ensuring safety is also a special concern for railway energy conservation and emission reduction.

4.3 Main ways for energy efficiency improvement of China's railway

The main ways to improve the efficiency of Chinese railways in the future can be summarized into four aspects: further increase the electrification rate, make major breakthroughs in key energy-saving technologies, improve the low-carbon management system and promote the use of new and renewable energy.

4.3.1 Further improve railway electrification rate. The electrified railway has a large volume of transportation. According to the research, the volume of an electrified railway is equivalent to that of two non-electrified railways, and that of high-speed electrified railways is much larger (General Group of High Speed Railway Technology Research, 2005). In theory, the high-speed railway can transport 2 × 224,000 to 2 × 30,000 people per hour. The four-lane highway has an hourly capacity of approximately 2 × 4,800 people, and the airport's throughput per hour is approximately 2 × 6,000 people. It can be seen that the transportation capacity of high-speed railway is unmatched by modern transportation modes such as highways and civil aviation. In particular, the electrified railway has achieved full electric traction without direct carbon emissions, showing high-standard performance in emission reduction. Therefore, the most realistic way to improve railway energy efficiency reveals to be increasing the electrification rate of railways.

There are many ways to improve the electrification rate: firstly, to further develop high-speed railways, passenger special lines and intercity railways. High-speed electrification is the fundamental direction of world railway development. China's railways should make full use of the opportunities during the era of great development to advance its high-speed electrified railways sustainably, further tap on the advantages of electrified railways and achieve the maximum amount of transportation tasks with the same amount of railway mileage. Secondly, the newly built freight railway should be electrified as much as possible. Freight railways is also taking center stage in future railway development, and electrification should be considered as much as possible in planning and construction. The third is to speed up the electrification of existing lines as needed.

4.3.2 Speed up the upgrading of transportation equipment. The old and outdated railway transportation equipment needs to be updated quickly, and the new energy-saving products should be applied. Of course, there is room for further improvement of energy-saving technology in new equipment. For example, although the speed of high-speed Electric Multiple Units (EMUs) has been greatly improved, the energy consumption has become larger accordingly. If the energy consumption can be effectively reduced while maintaining at high speeds, the energy efficiency can be maximized. This is also a technical difficulty to be overcome in future research and in the development of new EMUs. It can be seen that both technological transformation and new technology research and development require breakthroughs in key energy-saving technologies.

4.3.3 Promote further improvement of the energy management system. The low-carbon development of railway transportation puts forward new and higher requirements for the existing energy-saving and emission reduction management system. First of all, higher requirements go along with monitoring energy consumption. At present, the traditional way of monitoring by instrument and manual can no longer meet the needs of future development. In the future, Chinese railway is expected to change the existing units to report on the online real-time monitoring of energy consumption. On the one hand, it can avoid the lag and passiveness of energy data reporting, and eliminate delayed, missing, unreported and false reports. On the other hand, it is also convenient for early warning energy conservation and emission reduction. On-line monitoring of energy consumption not only improves the timeliness, accuracy and scientificity of energy consumption statistics, but also greatly improves management efficiency. Secondly, higher requirements are put forward for the evaluation system for energy conservation and emission reduction. The low-carbon development of railway transportation needs to accurately assess the status quo of energy conservation and emission reduction, and conduct fair and equitable rewards and penalties according to the assessment results, so as to promote the effective development of railway energy conservation and emission reduction, and truly implement the objectives and tasks and relevant regulations. Third, a complete set of rules and regulations is needed for energy management in train operation. The most ideal goal is to actualize online monitoring of the energy consumption generated during train operation through informatization.

4.3.4 Increase the use of new and renewable energy. In the non-traction field, further efforts will be made to renovate oil-fueled and coal-fired boilers. The focus will be on the reconstruction and new construction of a large number of heat pumps, solar energy, air-source heat pumps (mainly carbon dioxide air sources) and other new and renewable energy for heating and cooling. Furthermore, those have increased the proportion of new and renewable energy in non-traction energy consumption. For the traction, it should also actively try to use photovoltaic power generation, wind power and other clean energy power generation technologies along the railway to partially replace coal-fired power generation.

5. Low-carbon roadmap of energy conservation and emission reduction in China's railway

First of all, we should make a comprehensive plan for an overall goal, the development path and stages and the phase tasks of China's railway energy efficiency improvement. On this base, we can design a more comprehensive and detailed implementation roadmap to form an optimized integrated system that includes technologies, management and structure.

5.1 China's railway energy conservation and emission reduction targets and tasks

At present, relevant departments of China's railways are working on the "14th Five-Year Plan" (2020–2025) for energy conservation and emission reduction in the railway industry, and determining the overall goal of energy conservation and emission reduction in 2025. Overall, there is still a certain potential for energy conservation and emission reduction in the railway industry. The "14th Five-Year Plan" will continue to maintain the same trend as suggested in the "13rd Five-Year Plan" and will seek to improve energy efficiency. The proposed strategies mainly include the following areas:

(1) Strengthen the basic work of railway energy conservation management. Strengthen the energy consumption measurement management of the railway industry and further improve the energy consumption statistics system. Accelerate the construction of an energy-saving monitoring organization system and improve the system capacity of monitoring. Improve the energy consumption assessment system, establish scientific and reasonable assessment indicators and continuously improve the effectiveness of incentives and constraints on energy assessment. Strengthen promotion and professional training of energy saving and improve the energy-saving awareness and overall energy-saving quality. Seek and launch more global energy conservation exchanges and cooperation, and use international advanced energy conservation concepts, technologies, mechanisms and management methods to promote the overall improvement of energy conservation management in China's railway industry.

(2) Accelerate the elimination of lagging production capacity, improve the exit mechanism of lagging production capacity and implement punitive measures according to law for institutions that have not completed the elimination of tasks. Accelerate the elimination of lagging energy-consuming equipment and inefficient transformers, air conditioners, water pumps and other products. Make full awareness of amount of energy consumption, develop an annual plan for elimination and break

down the responsibility step by step. Encourage energy-using units to develop more stringent energy consumption standards and raise the threshold on elimination.

(3) Accelerate the construction of energy-efficient railway transportation structures. Develop electrified railways, implement railway energy-saving dispatching, optimize traction power structure and continuously increase the proportion of electric traction. To promote the reloading of freight transport, China's heavy-haul transport corridors will have a network structure of the "Eight Vertical and Nine Horizontal" by 2020, and the total scale of heavy-haul transport networks will reach 3×10^4 km. Actively construct eight heavy-haul transport passages such as Beijing-Harbin, Beijing-Guangzhou, Beijing-Jiulong and Baotou-Xian, and nine heavy-haul transport passages such as Daqin, Shenshuohuang, Longhai Line and passages for water carriage system. At the same time, actively adjust the layout of transportation productivity, optimize the flow path and train formation of freight, balance the upstream and downstream traffic and continuously improve the effective transportation coefficient of freight. Strengthen the research on the energy consumption rules for passenger lines and intercity railways, and explore a new model for energy conservation in high-speed railways.

(4) Improve the railway energy management system. In accordance with the three-level energy conservation management framework of the China State Railway Group Co., Ltd. (CHINA RAILWAY), railway bureaus and local station sections, improve the energy-saving management organization system, strengthen the capacity building of energy-saving management institutions with the emphasis on the local station sections and continuously improve the level of energy-saving management. Accelerate the revision and implementation of the "Energy Conservation Law," railway energy-saving technology policies and other railway energy-saving management rules and regulations, and promote the development and implementation of railway energy-saving standards. Strengthen the energy conservation management in railway construction, and further improve the energy conservation assessment and the review system for railway fixed assets investment projects. Strengthen industry guidance, supervision and management of railway energy conservation.

(5) Implement a number of major technical projects for energy conservation. It mainly includes improving the power supply efficiency project of electrified railways, improving energy efficiency projects for locomotives and other energy-consuming equipment, promoting energy-saving and emission reduction technology for passenger trains and energy-saving projects for railway buildings.

(6) Increase energy conservation in key areas of railways. Increase investment in energy-saving technology transformation in key energy-consuming areas or energy-consuming points of railways, speed up the renewal or elimination of facilities with large energy consumption and lagging technology devices. Promote scientific research on railway energy conservation and build energy-saving demonstration projects. Strengthen the research on energy-saving technologies such as comprehensive management and control of energy consumption for large passenger stations, fuel economy for locomotives, power supply of locomotives for passenger trains, comprehensive utilization technologies for new and renewable energy and encourage enterprises to deploy advanced and mature energy-saving technologies.

(7) Vigorously promote the innovation of railway energy conservation mechanism. Focus on the implementation of contract energy management, improve environmental conditions of the railway market-oriented energy-saving mechanism, increase policy

support, encourage railway transportation enterprises to innovate energy-saving models and accelerate the transformation of railway energy-saving mechanisms. Strengthen the construction of railway energy-saving comprehensive service system; cultivate railway energy-saving technical support, information consultation, financial services, education and training and other intermediary institutions to promote the orderly development of the railway energy-saving market.

5.2 China's railway energy efficiency and emission reduction technology roadmap

According to the key points of China's railway energy efficiency, the roadmap for future energy conservation and emission reduction can be roughly sketched (Figure 2).

First of all, fully understand and grasp the status quo and main features of energy conservation in China's railway; on this basis, explore the main energy consumption equipment and distribution of energy-using from the railway units, and further summarize the key areas of energy conservation, mainly from locomotive, building (e.g. large passenger stations), passenger train and elimination of outdated equipment. Then, start from the three basic ways of energy saving, including structural energy conservation, managerial energy conservation and technical energy conservation. Some major energy-saving methods are suggested to put into practice. For example, structural energy conservation is mainly achieved by increasing the electrification rate. Managerial energy conservation is mainly through organizational optimization, evaluation and review, the implementation of statistical supervision and other means. Technical energy saving is mainly actualized through power

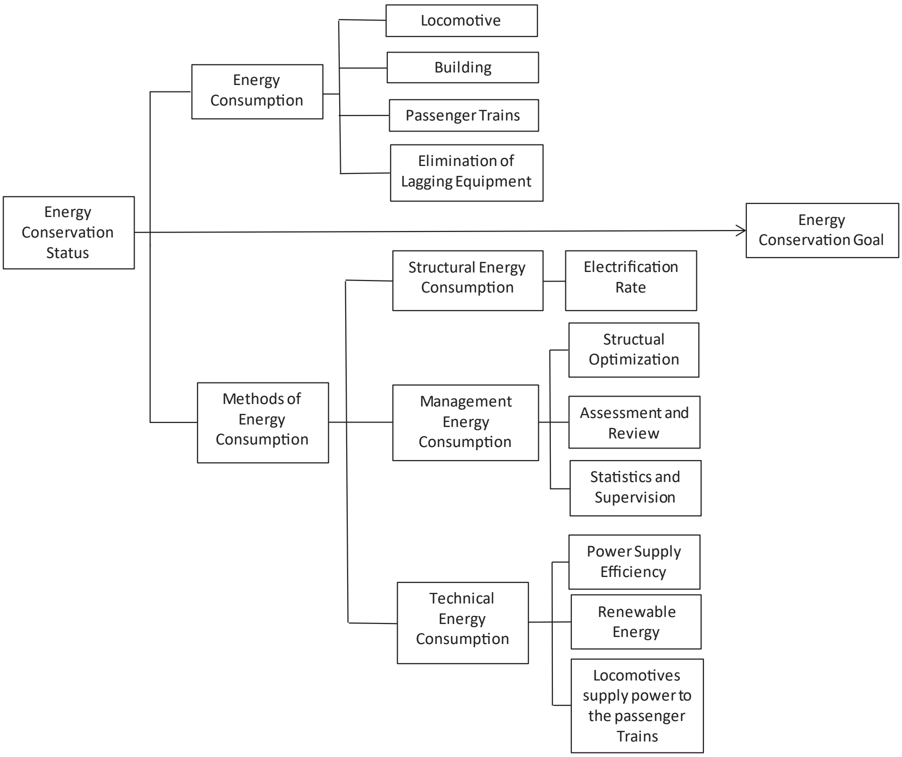

Figure 2.
Roadmap for energy conservation and emission reduction in China's railway industry

supply efficiency, new energy, locomotive power supply to passenger cars, regenerative braking, heavy-duty railway transportation, etc. By these effective means, the ultimate goal of energy conservation will be achieved.

To achieve the energy conservation roadmap, it is necessary to develop a phase plan and timetable with appropriate policy measures.

5.3 Phase plan and timetable

The characteristics of China's railway energy conservation and emission reduction development at different stages are relatively distinct. According to the change process of energy consumption structure, it can be divided into three stages. The first stage is the development based on coal-saving, which took a long time roughly from the 1950s to the mid-1980s. The main feature is reducing coal consumption for lowering carbon emissions. The development of low-carbon technology is also a technical breakthrough focusing on the efficient reduction of coal demand, mainly reflected in the reduction of locomotive and boiler coal consumption technology.

The second phase primarily focused on fuel economy, from the mid-1980s to around 2013. The main feature is reducing carbon emissions through fuel saving. The main technical features are the promotion of fuel additives and the production of new high-power diesel locomotives.

The third phase, the low-carbon development phase, which is dominated by electricity, can be set as a development period from 2013 onward. The main feature is to promote "generation of oil and electricity" and large-scale use of electric traction. The main technical features are to actualize the fundamental change of locomotive traction power structure and develop power-saving technology.

In the future, it will enter a stage of development based on the use of new and renewable energy. The main task is to replace fuel oil and coal with new and renewable energy in non-traction energy consumption, and gradually reduce the amount of coal used; in traction energy consumption, increase the proportion of new and renewable energy power to achieve carbon-free transportation of some trains.

In the developmental stage, with 2020 as the demarcation point, with the optimization of traction energy structure achieved and the electrification rate reaching 70%, China has entered the ranks of the world's best-optimized traction energy structure countries. Since 2020, the non-traction energy consumption structure has been gradually optimized. The use of coal and kerosene has been reduced to an optimal structure, which is marked by the kerosene and coal-fired boilers being replaced by new and renewable energy sources such as solar water heaters or air source heat pumps.

6. China's railway energy efficiency and low-carbon reduction policy support

According to the roadmap of design above, the national and railway industry authorities need to formulate relevant policies and measures to support its action program. Firstly, the railway industry needs policy support; secondly, energy conservation and emission reduction requires financial support. To this end, a policy design framework is required.

6.1 Strengthen policy support for China's railway development from the national level

The railway is a fundamental product of the state. Therefore, the development of railways is inseparable from the inclination and strong support of state policies.

6.1.1 Increase state financial support. Throughout the history of world railway development, the railways have received full support from the government in land acquisition, investment, taxation, subsidies and other policies during the great development period. The longest mileage of American railways reached 40 × 104 km was largely because of the funding policies for railways from the federal government and state and local governments, mainly financial supports. In recent years, the Chinese government has increased its policy support for railway development. On May 7, 2015, the National Development and Reform Commission's Opinions on Better Giving the Role of Transportation Support to Lead Economic and Social Development (Research and Development Foundation [2015] No. 969) pointed out that it was necessary to give full play to the guiding role of government fund. Financial funds should be tilted to intercity railways. Local governments are also fully aware of the huge role of high-speed railways in the development of local economies and have increased their support for railway projects. Some local governments have undertaken most of the investment for some construction projects in their regions. From the current development trend, railway investment will continue to maintain at a high level in the next few years, and the demand for fund will remain strong. This requires sustained financial support from both the central and the local governments.

6.1.2 Make good use of the railway industry development investment fund. As a financial innovation tool, railway industry investment fund meets the objective needs of railway construction and development. In 2014, China Railway Corporation formally established the China Railway Development Fund, a source of enterprise fund. The China Railway Corporation serves as the fund promoter and attracts social investors as preferred shareholders. The total fund size ranges from ¥200bn to ¥300bn per year. At present, most provinces have set or planned to set up railway industry investment funds as a platform for capital recovery in supporting railway financing, construction and operation. For example, the railway investment fund established in Jiangxi Province has a total scale of ¥15bn and with ¥5bn in the initial phase. The focus of this fund is to ensure the source of capital for railway construction in the central and western regions and to promote sustained, healthy and coordinated economic and social development.

6.2 Improve China's railway energy conservation policy system

From the perspective of the integrity and the system of energy conservation regulations, there are still some areas that need to be improved in the railway industry, mainly in the following aspects.

6.2.1 Laws and regulations can be further speeded up. The revision of railway energy conservation regulations is largely affected by the implementation of relevant national laws and regulations. For example, in monitoring energy consumption, the state initiated energy consumption monitoring management method promulgated by the State Planning Commission in 1990. It has not been revised so far and has not been able to adapt well to the current changes in the energy management. In line with this, the Ministry of Railways introduced relevant management measures in 1991. Due to the inability to adapt to the current needs of energy conservation work, it was abolished in 2012 (Railway Administration Law [2012] No. 115). Therefore, it has become a top priority to reformulate new railway energy consumption monitoring and control management methods.

6.2.2 Accelerate the introduction of a number of new energy conservation regulations. With rapid economic growth and socio-political advancement, the awareness of and the action toward railway energy conservation and emission reduction is also constantly progressing, and the fields involved are constantly expanding. However, the current management regulations are still lack of relevant content regarding energy consumption measurement and equipment management methods, contract energy management methods, etc., and the regulatory system is still underdeveloped. Therefore, it is necessary to speed up the formulation of a number of new energy conservation management regulations, including contract energy management and energy consumption measurement equipment management methods, to form an effective and complete legal system.

6.2.3 Determine the future trend of railway energy conservation legislation. To better meet the needs of the standardization and legalization of railway energy conservation work in the future, the energy conservation legislation should be incorporated into the revised scope of the future "Railway Law" as soon as possible, and the relevant provisions on railway energy conservation and emission reduction should be regulated from a legal perspective. Since the adoption of the "Railway Law" in July 1990, it was revised twice in August 2009 and April 2015, but did not cover the energy conservation and emission reduction of railways. Under the new routine circumstance, energy conservation and emission reduction should be given priority in revising the prospective "Railway Law" so that the administrators in various departments could effectively undertake and implement legal liability energy conservation and emission reduction.

6.3 Improve the mechanism of railway energy conservation and emission reduction

As mentioned above, the China's railway industry has formed a reward–penalty system regarding with incipient step forward. One of the main tasks at present is to establish a performance appraisal system for energy consumption monitoring. The reason is that energy consumption measurement is an important part of energy conservation management, promoting the measurement from the original form (manual monitoring) to the information form (online monitoring). The transformation can not only improve the timeliness and accuracy of energy consumption statistics, but also tackle real problems of energy consumption by monitoring the dynamic process of energy consumption, analyzing and diagnosing statistical data to spot the cause of excessive energy consumption and solutions to save wasted energy. The energy consumption monitoring and evaluation indicators should be reasonably set and included in the scope of performance evaluation of unit energy consumption. The energy consumption monitoring evaluation system mainly includes the evaluation system and assessment indicators. It needs to formulate the content, methods, procedures, quality standards, results identification, rewards and punishments. The evaluation indicators mainly focus on the key ones of quantitative energy consumption monitoring indicators, such as, energy consumption planning indicators, financial indicators completion status, monitoring equipment configuration rate, inspection rate, detection rate and energy consumption monitoring solution adoption.

6.3.1 Energy consumption monitoring evaluation system. The energy consumption monitoring evaluation system involves the assessment and evaluation of energy consumption monitoring stations and energy-using monitoring units, including monitoring results evaluation regulations, metering equipment management regulations, metering equipment maintenance regulations, contract energy management and personnel training programs.

6.3.2 Energy consumption monitoring and evaluation indicators. The setting of energy consumption monitoring and evaluation indicators should not only highlight key points, but also take into account other related fields. At present, the focus of energy conservation assessment is on financial and energy consumption indicators. Although they still have a restrictive effect on the quality of energy consumption monitoring, they are not direct assessment indicators. Therefore, it is necessary to develop an assessment indicator that can explicitly address energy consumption monitoring.

The evaluation indicators should encompass three levels: first, the assessment indicators of the railway bureau to the energy conservation monitoring station, including the completion of the annual energy consumption monitoring tasks, such as the number and quality of monitoring projects, personnel training and solving problems for users. With the development of network monitoring, the long-term assessment objectives should also include the statistics and analysis of energy consumption data, energy consumption diagnosis and other content into the scope of assessment. The second is the assessment of the energy-using units by the railway bureau, including the metering equipment allocation rate, the main energy-consuming equipment metering equipment, the maintenance of the metering equipment, the energy-saving monitoring information construction, the energy consumption management staffing, the technical improvement of the metering equipment, etc. Third, the energy-saving monitoring station assesses the energy-using units of the railway bureau, including the self-check rate of the metering equipment, the test results of the main energy-consuming equipment and the collection and transmission of energy-consuming data, the implementation of the recommendations required for the test results.

6.4 Encourage the introduction of market mechanisms to achieve energy conservation and emission reduction in railways

As the main body of the transportation market, China National Railway Group Co., Ltd. is giving full play to the leading role of railway energy conservation and emission reduction, meanwhile it should accelerate the cultivation of railway energy conservation technology service system, timely introduce the carbon trading mechanism and build a policy environment conducive to railway transportation enterprises to use the market mechanism to save energy.

At present, the development of relevant domestic situations has created favorable conditions for the railway industry to introduce market mechanisms to achieve energy conservation and emission reduction. The major issue that the national carbon emission trading market was launched in China in July 2021 is an important institutional innovation to control and reduce greenhouse gas emissions and to promote the green and low-carbon transformation of the economic development mode by using the market mechanism. As a low-carbon transportation industry, parts of China’s railway sectors have tried to enter the market and have achieved better results. In the future, the other railway sectors should actively participate in carbon emissions trading and use market mechanisms to leverage their low-carbon advantages and increase carbon revenues. At the same time, railway corporations should effectively control carbon emissions and better assume corporate social responsibility. As a matter of priority, it is necessary to study and propose the accounting methods for greenhouse gas emissions of Chinese railway transport enterprises to provide a sufficient basis for railway transport enterprises to enter the carbon trading market.

7. Conclusion

The improvement in Chinese railway energy efficiency is a systematic project involving a diverse range of facets such as technology, management, structure and related supporting facilities. Therefore, in the process of project implementation, it is necessary to grasp key links and supervise other fields to promote coordinated development of energy conservation and emission reduction. For future development, we need to focus on the following aspects:

(1) To further accelerate China’s railways from a national level, especially along with the fast development of high-speed railway, so as to further release external benefits of railways in low-carbon emission reduction, and take on the demonstration and leading role in the low-carbon development of comprehensive transportation. Therefore, it is necessary to actively guide the comprehensive transportation toward the development direction with railway as the axis through relevant policy support. Specific policies include financial policies for railway development, tax incentives for railway transport enterprises, the land use policy for railway construction and the transfer payment policy for railways through other modes of transportation.

(2) Promote innovation in energy conservation and emission reduction mechanisms and strengthen policy incentives. On the one hand, the innovation of energy conservation and emission reduction mechanism is to re-create the traditional mechanism; on the other hand, some new mechanisms are introduced into railway industry. From a

developmental perspective, it is necessary to introduce new energy conservation and emission reduction mechanisms, including the clean development mechanism, energy audit mechanism and post-energy assessment mechanism. From a national perspective, it is suggested that relevant departments should bring railway energy conservation and emission reduction into CDM project cooperation. On the one hand, railway management departments can use Certified Emission Reductions (CERS) generated by railway energy conservation projects to make a positive contributions to the protection of the global environment; on the other hand, they can obtain financial and technical support for the relevant enterprises of China's railways participating in CDM cooperation activities. From the perspective of the railway industry itself, it is necessary to further improve and introduce the enterprise energy audit mechanism and the post-energy evaluation mechanism for energy conservation, and promote the energy conservation and emission reduction of energy-using units through the intervention of third parties.

(3) Focus on improving railway energy efficiency through market behavior. In the past, the railway industry relied heavily on administrative organization management in promoting promote the improvement of railway energy efficiency. After China Railway Corporation has established its dominant position in the market, it should gradually change to the way addressing energy efficiency by introducing market energy-saving mechanism. Judging from the timetable for the formation of the national carbon market, the railway industry is likely to be required to fully enter the carbon trading market in the next few years. As a low-carbon transportation industry, the railway sector needs to timely formulate corporate greenhouse gas emission control plans and actively participate in carbon emissions trading, which can increases carbon revenues, control carbon emissions more effectively and better assume corporate social responsibility.

(4) Pay close attention to new phenomena in the railway industry to follow up and analyze. For example, in recent years, although the container volume has increased greatly, the proportion of absolute volume in the total freight volume is still lower. At the same time, the imbalance of railway capacity and the difference of freight demand in various regions have led to high vacancy rate to some extent. How to improve the container traffic and reduce the empty running rate of freight trains is an critical problem to be solved urgently in the future.

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