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# Analysis and Case Study of National Economic Evaluation of Expressway Dynamic Wireless Charging

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**Abstract:** As the transportation industry develops new forms of energy and electrification, expressway dynamic wireless charging has become an attractive technology that has the potential to completely solve a range of anxieties associated with electric vehicles. The main objective of this paper was to analyze the economic feasibility of dynamic wireless charging projects on highways. First, the roadside cost of dynamic wireless charging was estimated in terms of equipment, construction, and maintenance costs. Then, various indicators of the national economy of expressway dynamic wireless charging were analyzed. Finally, using the GM (1,1) model, a prediction model for evaluating the associated economic benefits is proposed in this study. As a case study, a national economic evaluation of retrofitting a dynamic wireless charging infrastructure on the Guiyang to Xinzhai Expressway was calculated with the following results: the economic internal rate of return (EIRR) is 11.27% to 29.11%, the economic net present value (ENPV) is 321.59 million RMB to 733.51 million RMB, the economic benefit to cost ratio (EBCR) is 1.02 to 1.32, and the payback period is 3.15 years to 6.35 years. All indicators are higher than the benchmark value for the national economic evaluation, and the sensitivity analysis results are also higher than the benchmark. The results of this paper show that the project is economically feasible and has certain economic benefits. From the perspective of economic benefits, it is necessary to provide more effective information for investors and decision-makers to build dynamic wireless charging highway projects.

**Keywords:** dynamic wireless charging; economic benefits; national economic evaluation

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## 1. Introduction

Expressway transportation is one of the main methods of freight transportation. In 1988, China's first expressway was completed and opened to traffic. By the end of 2021, the total mileage of China's expressways will be 117,000 km, ranking first in the world [1]. With the development of the economy and continuous improvements in terms of expressway construction, the traffic volume of expressways is increasing daily.

The rapid development of expressways has also brought about vast problems in terms of oil consumption and carbon dioxide emissions that cannot be ignored. With the second largest oil and gas consumption in the world, China relies on imports for 70% of its oil. Of the nearly 700 million tons of oil consumed, automobile consumption accounts for 55%. In recent years, China has vigorously developed new energy sources and improved its energy structure [2]. To respond to the national call for energy conservation and emission reductions and a reduction in the oil consumption of automobiles, the development of electric vehicles (EVs) has become one of the fields that China attaches great importance to and actively promotes. EVs play an important role in reducing greenhouse gas emissions, improving energy security, and meeting future energy demands [3,4].

EVs can reduce China's dependence on oil and actively respond to China's "dual carbon" policy. At present, EVs are categorized as pure battery electric vehicles (PEVs) [5], hybrid electric vehicles (HEVs) [6], plug-in hybrid electric vehicles (PHEVs) [7], battery replacement electric vehicles (BREVs) [8], and road power electric vehicles (RPEV) [9]. Table 1 lists the characteristics of these different EVs. As shown in Table 1, PEVs and BREVs rely on batteries, but the cost of batteries is high, resulting in the high cost of such vehicles; HEVs are expensive to purchase and consume a lot of fuel over long-term use, which is not conducive to energy conservation and emission reductions; BREVs mean that electric vehicles are charged by replacing batteries, but the standards of battery replacements are not uniform, and the initial investment is relatively large; compared with the first four, RPEVs have high levels of endurance, safety, and environmental protections, but the implementation of their technology is relatively difficult.

**Table 1.** The characteristics of different EVs.

| Vehicle Type | Characteristics |
|---|---|
| PEV | Depends on battery, high cost |
| HEV | The cost of the car is expensive, and the long-term driving does not save fuel |
| PHEV | Batteries are expensive and difficult to charge |
| BREV | Depends on battery, high cost |
| RPEV | Safe, environmentally friendly, but technically difficult |

Dynamic wireless charging technology for road EVs has the advantages of being convenient to use and involving no direct electrical contact and an unlimited charging time [10]. At present, most research is focused on the transferred power, efficiency, and coil optimization of dynamic wireless charging projects, but fewer studies focus on economic feasibility analysis of these projects [11,12]. In 1997, the University of Auckland in New Zealand cooperated with the German company Kang wen to design the world's first wireless charging bus, with a transferred power of 30 kW and a frequency of 13 kHz. Engineers at Oak Ridge National Laboratory in the United States studied the transmission characteristics, electromagnetic radiation, and dielectric loss of dynamic wireless charging technology [13]. In 2013, researchers from the Korea Advanced Institute of Science and Technology (KAIST) conducted research on dynamic wireless charging technology and named electric vehicles that "recharge while driving" online electric vehicles (OLEV) [14,15]. In 2017, Qualcomm laid a test track with a length of 100 m in Paris, France, and realized the wireless charging of a small electric box truck with a charging power of 20 kW [16].

In the context of dynamic wireless charging expressway construction, to determine whether a new project is feasible requires a national economic evaluation. National economic evaluations contain indicators of the economic internal rate of return (EIRR), economic net present value (ENPV), economic benefit-cost ratio (EBCR), and payback period [17]. National economic evaluations are used to evaluate the feasibility and economic benefits of projects from the perspective of the state and society and are mainly dependent on the relevant economic policies promulgated by the state and the specific market conditions, as well as the actual implementation, of the project. Using limited funds to obtain maximum benefits, projects are chosen according to the results of national economic evaluations. Expressways are a quasi-public property. To ensure the unity of social and economic benefits of expressways, it is necessary to carry out national economic evaluations on new expressway projects. National economic evaluations of expressways is conducive to maintaining the national and social interests of any new project. A national economic evaluation of an expressway forms the basis for studying the feasibility of a new project. Whether the construction of a new high-speed highway project commences or not depends on the results of national economic evaluations.

Dynamic wireless charging technology is over 100 years old, and some articles have also studied its economics. In 1990, the PATH team built a high-power rail with an output of 60 kW and an air gap of 7.6 cm at a cost of about 1 M$/km [14]. In 2009, the KAIST research group in South Korea founded the OLEV project, which achieved a system output power of 60 kW, an air gap of 20 cm, and a maximum efficiency of 83% [15]. The cost of the KAIST research group was one-third the cost of the PATH team project. This paper considers the actual development of highways in China, proposes a scheme of laying dynamic wireless charging coils on highways to charge electric trucks, and uses the national economic evaluation method to evaluate the associated costs and benefits. Based on a national economic evaluation, combined with the GM (1,1) model and the dynamic wireless expressway revenue model proposed in this study, the income from a dynamic wireless charging expressway over the coming year was predicted.

The purpose of this paper was to analyze a national economic evaluation of an expressway dynamic wireless charging project and comprehensively analyze its national economics through a cost, benefit, and future economic forecast of an expressway dynamic wireless charging project. The contributions of this paper are as follows:

The highway dynamic wireless charging project analyzed in this paper is, to certain extent, innovative. Although there are many studies on wireless charging and dynamic wireless charging, few studies specifically analyze the cost of wireless charging. In particular, there is a relatively small amount of research on the costs of highway dynamic wireless charging projects. This paper analyzes the equipment, construction, and maintenance costs of an expressway dynamic wireless charging project. Firstly, the cost of the transmitter coil of the expressway dynamic wireless charging project was analyzed. The relationship between the coupling coefficient and the size of the transmitter coil and that between the air gap and the transmission power were analyzed as well as the relationship between the coupling coefficient and the coil cost. Secondly, the construction cost of the project was considered, as were the maintenance costs. This paper predicts the future maintenance cost of this project based on the relationship between other expressways opened to traffic and their maintenance cost over the years.

The national economic evaluation is used to evaluate projects' benefits. Previous studies of expressway benefits mainly include transportation cost benefits, mileage shortening benefits, time-saving benefits, and so on. Combined with the characteristics of dynamic wireless charging on expressways, this paper mainly analyzes the benefits in terms of reducing transportation costs, increasing highway revenue, and reducing carbon emissions. It clearly shows the superiority of the highway dynamic wireless charging project.

To ensure the credibility of the national economic evaluation of the project, a sensitivity analysis was carried out based on the national economic evaluation. In the two extreme cases of a 30% reduction in income and a 30% reduction in benefits, the indicators of the national economic evaluation were all satisfied with the requirements, demonstrate the feasibility of the project.

Finally, this paper predicts the income of the expressway dynamic wireless charging project according to the future annual traffic volume and toll of the expressway, and an income prediction model is proposed in this paper. From the perspective of the economic, energy saving, and emission reduction aspects of dynamic wireless charging projects, the research in this paper has important theoretical and practical significance.

The structure of the rest paper is set as follows: Section 2 introduces dynamic wireless charging technology, how to apply dynamic wireless charging technology to an expressway, and how to choose a suitable expressway for renovation; in Section 3, the costs of the project, including its direct and maintenance costs, are analyzed; in Section 4, a benefit analysis of the project is carried out from three points of view: reducing the transportation cost benefit, increasing the expressway revenue benefit, and reducing the carbon emission benefit; in Section 5, an actual case study of an expressway dynamic wireless charging project is analyzed in terms of its benefits, national economic evaluation, and future benefits; in Section 6, the research results of this paper are summarized and some suggestions for future research are put forward.

## 2. Dynamic Wireless Charging Expressway

### *2.1. Dynamic Wireless Charging*

Dynamic wireless charging technology can reduce the weight of the vehicle battery pack, extend the cruising range, and effectively meet the requirements of electric vehicle charging times and space while only using existing road resources [18]. It should be noted that a certain amount of battery is needed for vehicles to maintain a certain distance when vehicles drive on non-charging road. As shown in Figure 1, a dynamic wireless charging system for electric vehicles mainly consists of two parts: the transmitting side and the receiving side. The transmitting side mainly includes transmitting coils, high-frequency inverters, and compensation networks. The receiving side mainly includes receiving coils, compensation networks, AC-DC rectifier filters, battery packs, etc. In a dynamic charging system, the transmitting coils identify the location of the receiving coil and then enable the transmitting coils near the receiving coils. When there are no vehicles, the transmitting coils are not enabled to avoid wasting energy.

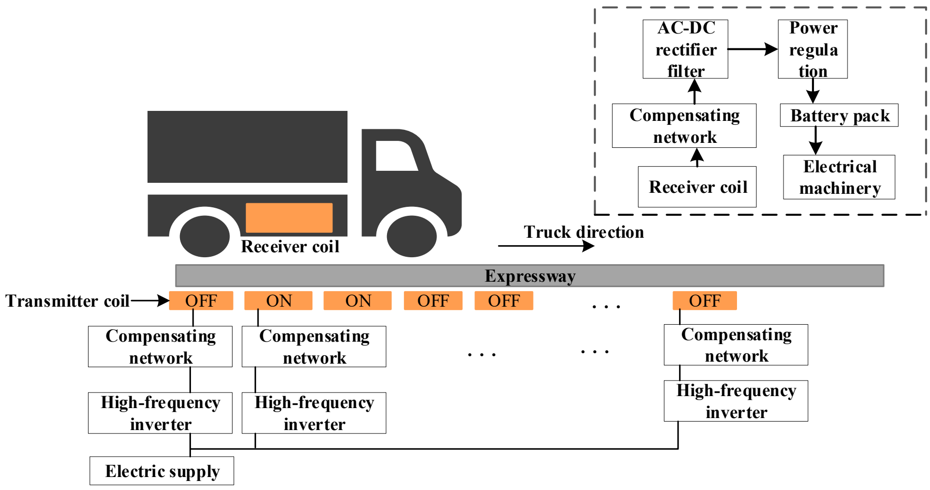



**Figure 1.** Dynamic wireless charging schematic.

### *2.2. Selection of Expressway*

In a dynamic wireless charging expressway project, the selection of an expressway is very important and needs to be determined first. Expressway transportation mainly includes passage and freight transportation, using cars and trucks, respectively. Among them, freight always uses the expressway for long-distance transportation. Compared with cars, the trucks used for freight transportation always have enough installation space under the chassis, which is easier to retrofit. Additionally, multiple receiving coils can be installed under trucks to increase the received power. Therefore, we chose an expressway mainly used for freight transportation as the research object. The selected expressway should have the following characteristics:

- Choose an expressway that has a large volume of freight transportation.
- Choose an expressway where the trucks have fixed routes, which can reduce the mileage of trucks in non-charging areas.

Figure 2 shows a schematic diagram of the expressway with transmitting coils. Using suitable geometry, the transmitting coils are continuously laid on the expressway. By using proper receiving coils, the coupling ecoefficiency and transmission efficiency between the coils can be improved [19]. Concerning China's expressways, two-way four-lane and two-way six-lane are common layout styles. In the initial project design, it was required to transform one lane in each direction into a dynamic wireless charging road, as shown in Figure 2.

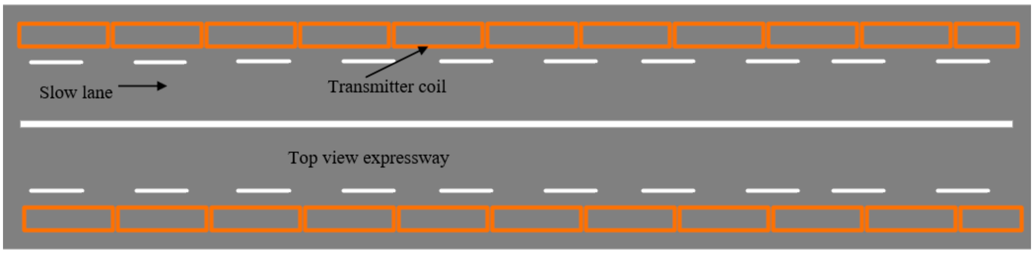



**Figure 2.** Schematic diagram of the laying of the transmitting coil of the expressway.

## 3. Project Cost (Two-Way Construction Configuration)

The construction quality of road engineering takes account of the construction period, cost, quality, and environment [20]. The costs mainly include direct costs (material costs, construction costs) and maintenance costs. To simplify the analysis process, the downtime cost of the expressway construction was included as part of the construction cost, with the upgrade cost of the vehicles and the reduction of batteries being ignored in this study.

### *3.1. Direct Costs*

Direct costs refer to various costs associated with the entire project and those that contribute to the formation of the project during project implementation, including material costs and construction costs (labor costs and machinery costs) [21].

#### 3.1.1. Material Costs

The material costs consist of coil costs, electronic power converter costs, and asphalt costs. Among them, the coil costs are significant and needed to be calculated first. In this study, identical rectangular coils were used as the transmission coils, and schematic diagram is shown in Figure 3. $L$ and $W$ represent the length and width of the coils and $K$ represents the width of the wires, whose value is 200 mm.

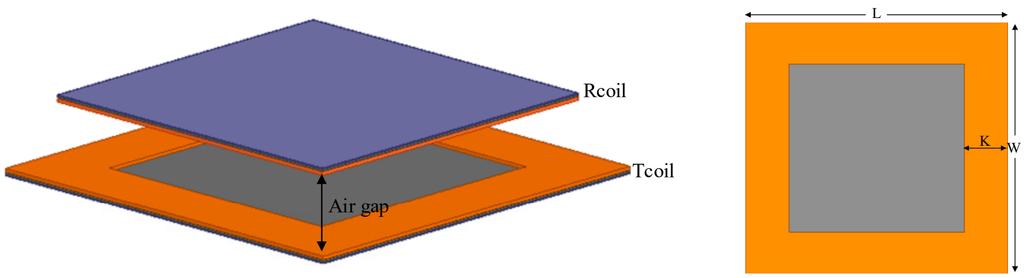



**Figure 3.** Coil schematic.

When $L$ and $W$ are the same, the coupling coefficients under different coil sizes are obtained through a simulation, with the results being provided in Appendix A.

As shown in Table 2, the larger the coil size, the higher the coupling coefficient. However, a larger coil size may increase the coil cost. Considering the coupling coefficient and the coil cost, the dimension of the transmission coils was set as 1500 mm × 1500 mm in this study.

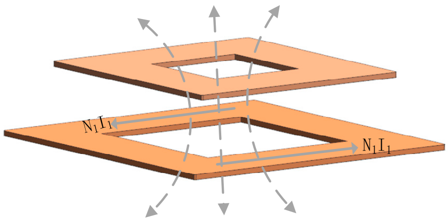
**Table 2.** Coupling coefficient under different coil sizes.

| **L/W (mm)** | 800 | 900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **k** | 0.391 | 0.421 | 0.453 | 0.502 | 0.519 | 0.529 | 0.540 | 0.547 | 0.556 | 0.562 | 0.568 | 0.572 | 0.575 |

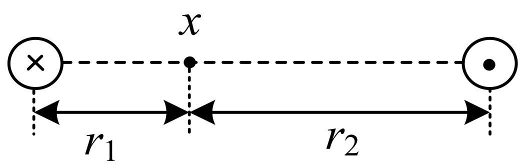
A simplified transmitting coil is a hollow conductor without ferrite cores and is installed along the charging rail. The current direction of the coil is shown in Figure 4a. $N_1$ is the number of turns, and $I_1$ is the current. The magnetic field strength at any point $x$ on the horizontal line of the wires is shown in Figure 4b. The magnetic field strength $H_x$ can be calculated as:

$$H_x = H_1 + H_2 = \frac{N_1 I_1}{2\pi r_1} + \frac{N_1 I_1}{2\pi r_2} \tag{1}$$

where $r$ represents the magnetic field radius.




(**a**)




(**b**)

**Figure 4.** (**a**) Schematic diagram of current direction; (**b**). Magnetic field strength at point $x$.

According to the principle of magnetic field strength, the magnetic flux density at the point $x$ can be obtained:

$$B_x = \mu_0 H_x = \frac{\mu_0 N_1 I_1}{2\pi}\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \tag{2}$$

where $B_x$ is the magnetic flux density at point $x$, $\mu_0$ is the free space permeability, and the value is $4\pi \times 10^{-7}$.

If the horizontal length of the coil is $d$, the magnetic flux density at $r_1$ can be calculated.

$$B_x(r_1) = \frac{\mu_0 N_1 I_1}{2\pi}\left(\frac{1}{r_1} + \frac{1}{d - r_1}\right) \tag{3}$$

If we assume that the width of the wire is $1/5$ of the horizontal length, the total flux density at $B_x(r_1)$ can then be calculated by integrating the magnetic flux density from $0.1d$ to $0.9d$, as follows.

$$\int_{0.1d}^{0.9d} B_x(r_1) d_{r_1} = \int_{0.1d}^{0.9d} \frac{\mu_0 N_1 I_1}{\pi r_1} d_{r_1} \approx 0.7 \mu_0 N_1 I_1 \tag{4}$$

In practical applications, it should be ensured that the maximum magnetic flux density passing through the magnetic core does not exceed a certain value $B_{\max}$, as shown in Figure 5, to ensure that the loss of the magnetic core will not cause a large drop in the system transmission efficiency.

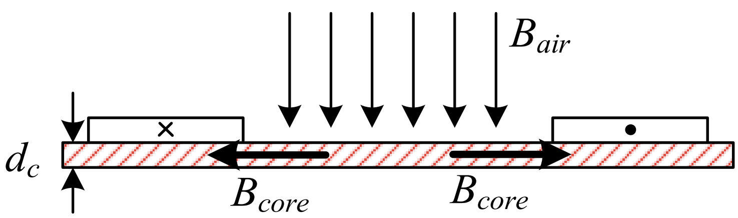



**Figure 5.** The magnetic flux density of the magnetic core.

The magnetic flux density passing through the magnetic core can be calculated as:

$$B_{core} \approx 0.35 \mu_0 N_2 I_2 / d_c < B_{\max} \tag{5}$$

where $d_c$ is the height of the magnetic core, whose value should be adjusted to meet the requirement of transferred power and maximum magnetic flux density.

In this study, the length of the receiving coil is $L_r$, the width of the receiving coil is $W_r$, the length of the transmitting coil is $L_t$, the width of the transmitting coil is $W_t$, and the coupling coefficient between the transmitting coil and the receiving coil is $k$. With the resonant frequency of 85 kHz, the received power $P$ can then be obtained as:

$$P = 0.7k\mu_0\omega N_1 N_2 I_1 I_2 L_r \tag{6}$$

When the size of the receiving coil is fixed and the length of the transmitting coil does not change during the dynamic wireless charging process, the coupling coefficient $k$ is mainly dependent on the transmitter coil width $W_t$, air gap and transferred power $P$. With a change in the transferred power, the thickness of the magnetic core changes. A diagram of the magnetic flux density distribution under different power and different thicknesses is provided in attachment A. Figure 6 shows the coupling coefficient under different coil widths, air gaps, transferred powers, and core thicknesses when the receiving coil size is 1500 mm × 1500 mm and the transmitting coil length $L_t$ is 1500 mm.

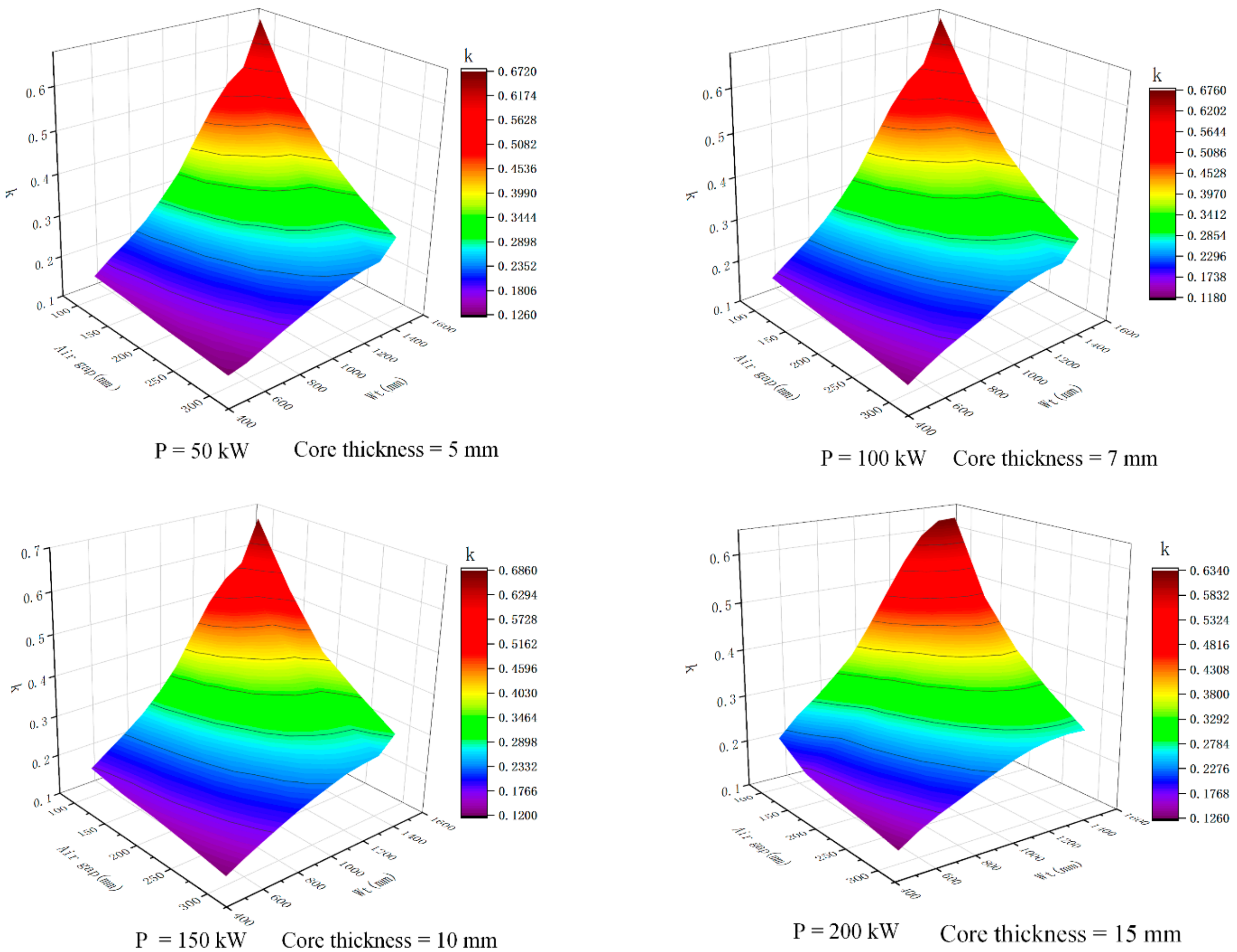



**Figure 6.** Coupling coefficient at different powers, air gaps, and $W_t$ measurements.

Based on the simulation results shown in Figure 6, we can conclude that:

- To ensure the ferrite magnetic flux density $B_{\max} \leq 0.2T$, the thickness of the magnetic core should increase with an increase in the transferred power and the coupling coefficient should increase with increasing core thicknesses, appropriately.
- The coupling coefficient mainly depends on the coil width $W_t$ and increases significantly when $W_t$ increases.

With the given $B_{\max}$, $Lr$, and $dc$, the amount of Litz wires needed in the receiving coil can be obtained from equation 5. With the transferred power and coupling coefficient k shown in Figure 6, the amount of Litz wires needed in the transmitting coils can be obtained from equation 6. According to the sizes of the coils, the amount of magnetic core and aluminum shielding plate can then be obtained. The Litz wire is made of aluminum. By using the market prices of ferrite and aluminum, the total cost of the coils at different $Wt$, $P$, and air gaps can then be obtained. The detailed calculation process is shown in attachment $B$, and the total coil cost is shown in Figure 7.

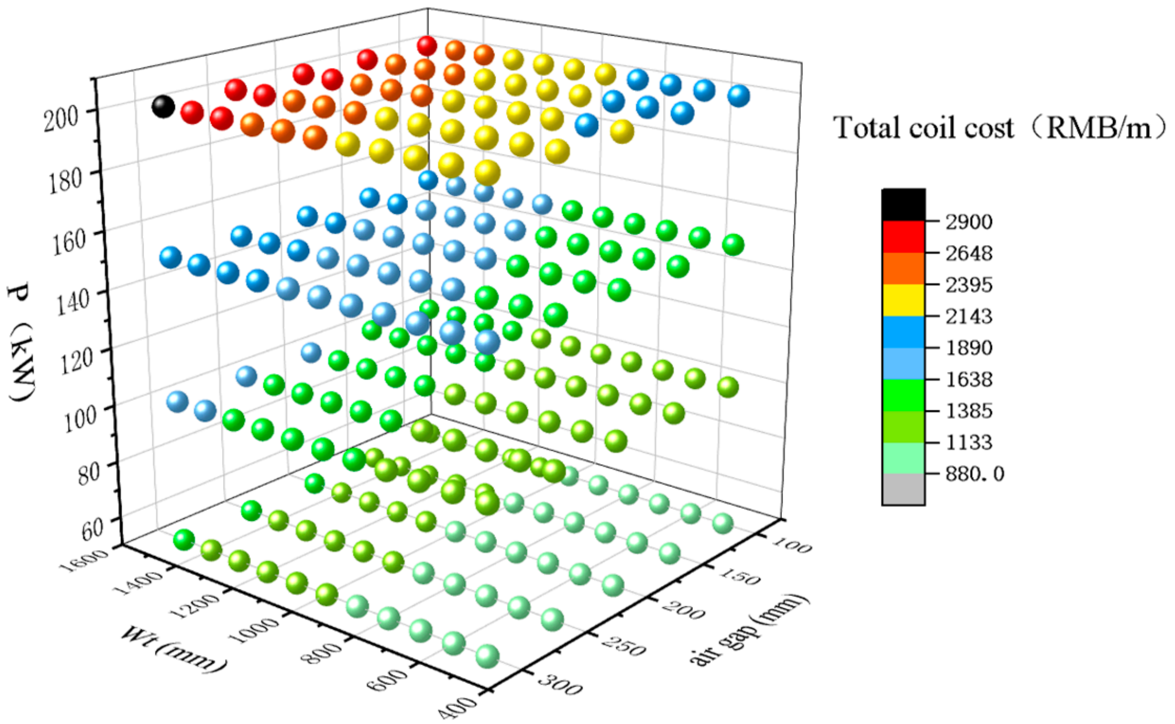



**Figure 7.** The total cost of the coils under different powers, coil widths, and air gaps.

We can conclude from Figure 7 that:

- The total coil cost varies with the transferred power, air gap, and transmitting coil width $W_t$. When the air gap and $W_t$ are fixed, the coil cost increases with increasing transferred power.
- The range of the coil cost is large. When the air gap is 100 mm and the $W_t$ is 400 mm, the total coil cost varies from 888 RMB/m to 1948 RMB/m, while the transferred power increases from 50 kW to 200 kW.
- The lowest coil cost is achieved when $P$ = 50 kW, $W_t$ = 500 mm, and the air gap = 100 mm, which is 888 RMB/m; the highest coil cost is achieved when $P$ = 200 kW, $W_t$ = 1500 mm, and the air gap = 300 mm, which is 2903 RMB/m.

With a transferred power of 50 kW, the cost ratios of various materials under different air gaps and $W_t$ measurements are shown in Figure 8.

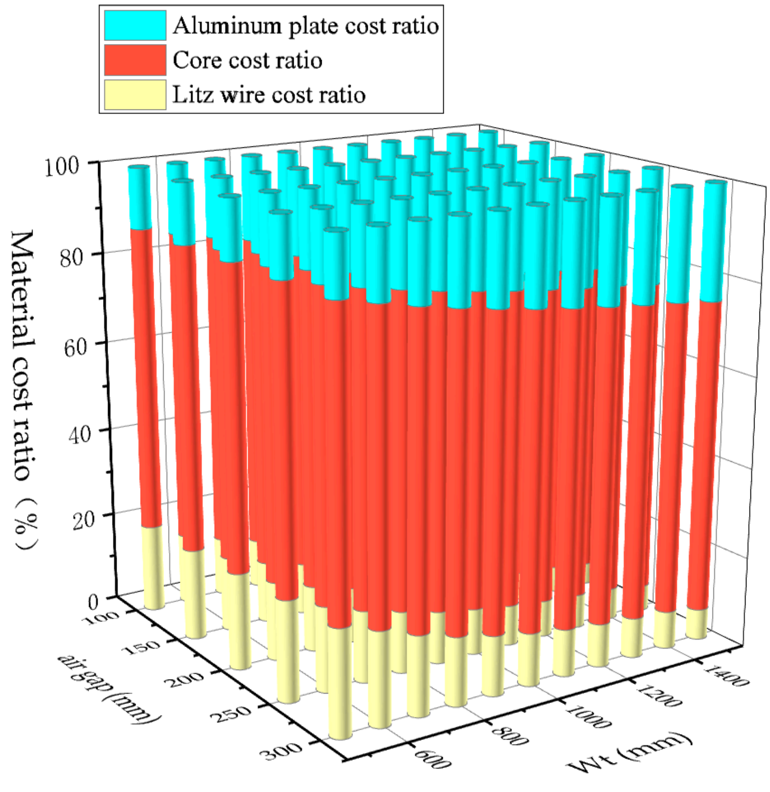



**Figure 8.** Various material cost percentages.

We can conclude from Figure 8 that:

- Among the three material costs, the core cost accounts for the highest proportion, with an average proportion of 68.9%, and the aluminum plate cost accounts for the lowest proportion, with an average proportion of 14.9%.
- With a given air gap, the coupling coefficients shown in Figure 6 increase with an increasing *Wt*, resulting in a decrease in the Litz wire cost; additionally, the surface area of the coil also increases, leading to an increase in the core cost and aluminum plate cost.
- With a given $W_t$, the coupling coefficients shown in Figure 6 decrease with an increasing air gap, resulting in an increase in the Litz wire cost. Since the surface area of the coil remains unchanged, the costs of the magnetic core and aluminum plate remain unchanged, but the associated cost ratio decreases, as shown in Figure 8.

It should be noted that the coil cost is obtained with aligned coils. During the dynamic charging process, misalignment conditions are inevitable, which can affect the coupling coefficients and further reduce the transferred power and efficiency. To ensure the received power, complex coupler structures such as DD/DDQ coils and BP couplers have been introduced to improve misalignment tolerance [22]. Additionally, the receiver coil turns are always increased to achieve the same level of transferred power. All these methods will increase the actual coil cost accordingly.

In the literature, when designing a 50 kW high-power wireless charging coil, the current density was increased from 2.4 A/mm$^2$ to 4.8 A/mm$^2$ [23]. Without increasing the size of the coil, the power density was increased by 2.5 times, and the transmission efficiency of the 50 kW power coil was 97.7%. As shown in Appendix B, the current density of the coil in this paper was 2 A/mm$^2$. To combat the offset problem, the current density can be appropriately increased to reduce the power loss. After the vehicle position is offset, the primary side current can be increased to increase the primary side magnetic field strength to maintain the same power.

In addition to the coil cost, the material cost also includes the cost of the electronic power converter and the cost of the asphalt for laying the road. Traditionally, the cost of a 30 kW inverter in the laboratory is about 2000 RMB/m. The key components that result in most of the inverter cost are electronic power devices, and the main electronic power devices of the inverter analyzed in this paper are shown in Table 3. For large-scale applications, the cost of the inverter can be further reduced [14]. The cost of asphalt is 100 RMB/m. Considering the coil cost shown in Figure 7, the specific cost of each material was obtained, as shown in Figure 9. The material cost of a dynamic wireless charging expressway can be as low as 2988 RMB/m and as high as 5000 RMB/m.

**Table 3.** Primary inverter electronic power components.

| Module | Main Components | Price (RMB) | Quantity | Total Price (RMB) |
|---|---|---|---|---|
| Main Power Switch Module | F4-23MR12W1M1-B11 | 1000 | 1 | 1000 |
| Drive Module | ISO5852DW | 10 | 6 | 60 |
| Control Module | MCU | 100 | 1 | 100 |
| Capacitance | MKP-LL | 220 | 2 | 440 |
| Others | | | | 800 |
| Total | | | | 2000 |

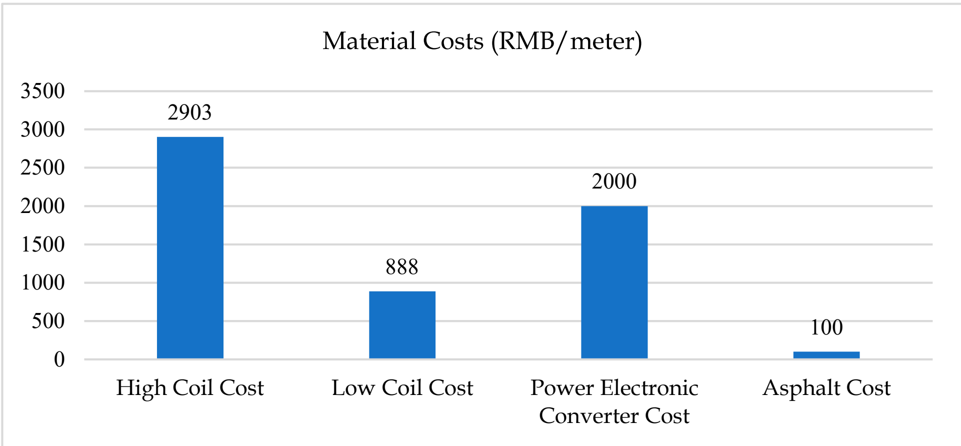



**Figure 9.** Material costs.

#### 3.1.2. Construction Costs

The total cost of a dynamic wireless charging expressway comprises a material cost and a construction cost. The construction cost, which consists of labor costs and machinery costs, accounts for 17% of the project cost, which is approximately 500~780 RMB/m. The construction cost increased with the downtime cost. Here, we set the total construction cost to account for 22% of the project cost, which is approximately 646~1009 RMB/m. Therefore, the total cost of a dynamic wireless charging expressway is at its lowest 3.60 million RMB/km and at its highest 6.00 million RMB/km.

### *3.2. Maintenance Cost*

Using reasonable and scientific methods to maintain the expressway can prolong its service life. Therefore, a dynamic wireless charging expressway requires regular maintenance in terms of the transmitting coil, which, if faulty or damaged, needs to be replaced. The maintenance cost of an expressway is mainly related to the number of years of traffic. As shown in Table 4, data on the number of years in which different expressways have been open to traffic and the average annual maintenance costs are collected, and an analysis of this relationship is provided in Figure 10. The black dots are the specific data collected. The dotted line is the growth trend of the average annual maintenance cost with the number of years in operation. A large-scale inspection of a dynamic wireless charging expressway should be carried out every year, and the damaged coils should be replaced to reduce the requirements for manpower and material resources and ensure the normal operation of the dynamic wireless charging expressway.

**Table 4.** The number of years in operation and the average annual maintenance fee.

| Expressway | Years in Operation | Average Annual Maintenance Cost (10,000 RMB/km) | Expressway | Years in Operation | Average Annual Maintenance Cost (10,000 RMB/km) |
|---|---|---|---|---|---|
| 1 | 5.5 | 8.743 | 6 | 4.6 | 6.214 |
| 2 | 5.4 | 7.116 | 7 | 6 | 7.535 |
| 3 | 3.8 | 6.059 | 8 | 4.9 | 8.642 |
| 4 | 6.5 | 8.752 | 9 | 2.6 | 3.878 |
| 5 | 6.1 | 9.26 | 10 | 8.1 | 11.266 |

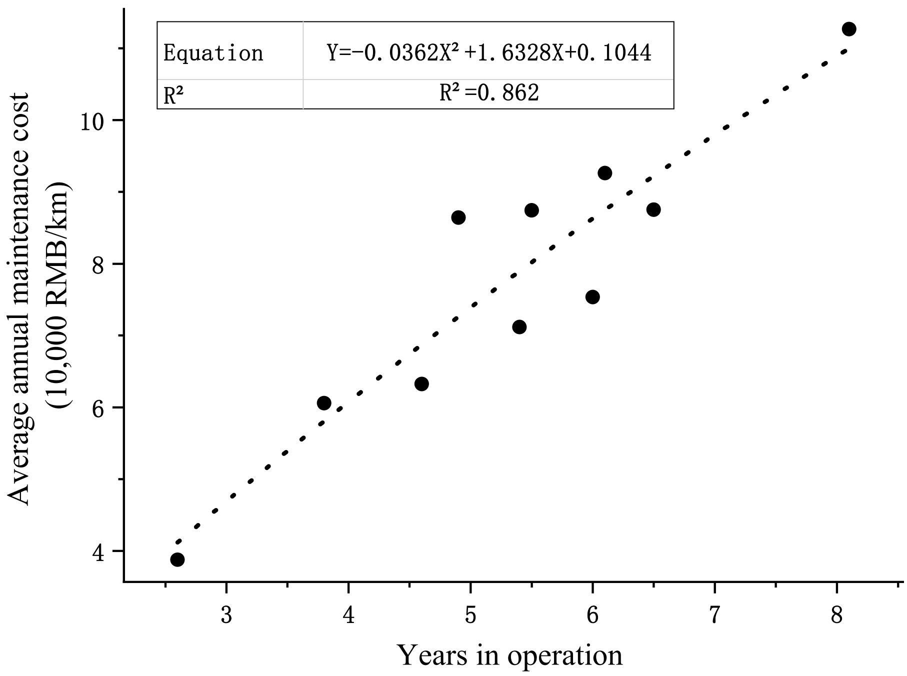



**Figure 10.** The relationship between the average annual maintenance cost and the number of years of operation.

## 4. Project Benefit

### *4.1. Reduce Transportation Cost*

The project's benefit includes three parts: a reduction in transportation costs, an increase in the expressway's revenue, and a reduction in carbon emissions. The transportation cost refers to the cost of completing the transportation of goods, including two aspects: one is the station cost, and the other is cost of transportation [24]. The station cost mainly includes the loading and unloading of goods and the cost of using docks, which is not related to this project. Transportation costs on the road mainly include fuel consumption, daily maintenance and repair costs, tire maintenance costs, road tolls, traffic accident costs, and other costs [25,26]. JGT B01 2014 "Technical Standards for Expressway Engineering" stipulates the division of vehicles based on the rated load, and the traffic revenue of new energy trucks on dynamic wireless charging expressways is decided according to this standard.

The truck transportation cost is mainly dependent on tolls, fuel consumption, daily maintenance and repair costs, and car purchase costs. If the truck driver works for 20 days a month, at 8 h a day, and at 80 km per hour, he can drive for approximately 160,000 km a year on average. The transportation cost $C$ is divided into the original expressway truck transportation cost $C_W$ and the dynamic wireless charging expressway transportation cost $C_Y$, which can be calculated as follows:

$$C_{Wi} = (T_{Wi} + M) \times L \tag{7}$$

$$C_{Y\mathrm{i}} = T_{Yi} \times L \tag{8}$$

where $C_{Wi}$ is the original expressway transportation cost of the i-type truck [ten thousand RMB/year], $C_{Yi}$ is the transportation cost of the dynamic wireless charging expressway of i-type truck [Ten thousand RMB/year], and $T_{Wi}$ is the toll of the original expressway i-type truck [RMB/km], $T_{Yi}$ is the toll of the i-type truck on the dynamic wireless charging expressway [RMB/km], M is the fuel consumption [RMB/km], and $L$ is the total mileage of the truck [km]. The fuel costs of different trucks are shown in Table 5.

**Table 5.** Dynamic wireless charging expressway toll standard.

| Car Model (i) | Truck Category | M | $T_{Wi}$ | $T_{Yi}$ |
|---|---|---|---|---|
| 1 | Small electric truck | 0.65 | 0.45 | <1.1 |
| 2 | Medium electric truck | 1.01 | 0.90 | <1.91 |
| 3 | Large electric truck | 1.413 | 1.462 | <2.875 |
| 4 | Extra-large electric truck | 2.102 | 2.138 | <4.24 |

The cost of expressway tolls is one of the main aspects of transportation costs. Expressway toll standards have been different at different times. New dynamic wireless charging expressways need to formulate new toll standards. The formula for calculating a standard charge for dynamic wireless charging expressways is as follows:

$$T_{Y\mathrm{i}} = T_{W\mathrm{i}} + \lambda M \tag{9}$$

where $\lambda$ is the income coefficient and the value range is $\lambda < 1$, which not only ensures the income of the expressway but also reduces the transportation cost of the truck driver.

Compared with static charging trucks, dynamic wireless charging trucks reduce the weight of the battery and bypass the need to install large-capacity battery packs. In terms of daily maintenance costs, traditional trucks need to regularly replace maintenance oil, three filters, spark plugs, and other components as well as replace the brake fluid every two years and change the transmission gear oil every year. The associated maintenance cost is close to 30,000 RMB/year. The structure of a dynamic wireless charging truck is simpler than that of a traditional refueling truck, and most of the time the battery is shallowly charged and discharged during the dynamic wireless charging process. The cycle life is increased and is close to being maintenance-free. According to the "Regulations on the Standard for Compulsory Scrap of Motor Vehicles", the service life of a truck is generally 15 years. The 15-year income of truck drivers can be obtained by using the following equation

$$R = [(C_{Wi} + S) - (C_{Yi} + S)] \times 15 \tag{10}$$

where $R$ is the income benefit in 15 years [ten thousand RMB] and $S$ is the maintenance cost [ten thousand RMB].

### *4.2. Increase Expressway Revenue Benefit*

The income of the expressway is mainly related to the traffic volume. The dynamic wireless charging expressway toll standard is shown in Table 4, together with the traffic volume of each vehicle type, and, thus, the revenue benefit of the expressway can be calculated as:

$$\Delta Q = \sum_{\mathrm{i}=1}^{n} V_i \times T_{Yi} \times n - \sum_{\mathrm{i}=1}^{n} V_i \times T_{W_i} \times n \tag{11}$$

where $\Delta Q$ is the income benefit of the expressway after the construction of the new project [ten thousand RMB], $V_i$ is the monthly/annual traffic volume of truck models; $n$ is the mileage of the proposed dynamic wireless charging expressway [km].

### *4.3. Lower Carbon Emissions Benefits*

The development of the transportation industry has led to problems such as the increased consumption of fossil fuels, greenhouse gas emissions, traffic congestion, and noise pollution [27,28]. However, when being driven the carbon emissions of an electric vehicle is approximately zero. The carbon emissions of the vehicle during the driving process can be calculated as follows:

$$E = \sum_{i}^{n} m \times \rho \times j \times F_i \times I_i \tag{12}$$

where $E$ is the carbon emission [mg]; $m$ is the annual diesel consumption of the truck [L]; $\rho$ is the diesel density [kg/L]; $j$ is the default net calorific value of diesel [MJ/kg]; $F_i$ is the emission factor based on the net calorific value [mg/MJ]; $I_i$ is the characteristic factor; $\rho$ = 0.84 kg/L; $j$ = 43 MJ/kg; $F(CO_2)$ = 74,100 mg/MJ; $F(CH_4)$ = 3 mg/MJ; $F(N_2O)$ = 0.6 mg/MJ; $I(CO_2)$ = 1, $I(CH_4)$ = 1; and $I(N_2O)$ = 1.

## **5. Case Analysis**

Based on the above discussions, we took the Guiyang-Xinzhai Expressway as an example. According to the national economic evaluation parameters stipulated by the state, the social refractive index of this project is 8%, and the trade expense rate is 6%. The Guixin Expressway is designed and constructed as a full interchange, two-way, four-lane expressway, with a designated speed of 80 km/h and a total length of 260 km. Table 6 shows the collected truck traffic volume of the Guixin Expressway over the past 10 years. If each lane of the Guixin Expressway was transformed into a dynamic wireless charging lane, the total construction cost of the project would be approximately 936 million RMB to 1.56 billion RMB.

**Table 6.** Guixin expressway 2010–2020 truck flow meter (unit: 100,000 vehicles).

| Years | Small Electric Truck | Medium Electric Truck | Large Electric Truck | Extra-Large Electric Truck | Total |
|---|---|---|---|---|---|
| 2010 | 9.20335 | 4.14656 | 5.90630 | 1.83872 | 21.09508 |
| 2011 | 8.97132 | 3.87113 | 4.83986 | 2.34854 | 20.03085 |
| 2012 | 10.25494 | 4.19009 | 4.94149 | 3.12496 | 22.51148 |
| 2013 | 11.94710 | 4.39946 | 5.59139 | 3.83666 | 25.77461 |
| 2014 | 13.26713 | 3.87552 | 5.30127 | 4.52386 | 26.96778 |
| 2015 | 13.51392 | 3.53149 | 4.78404 | 4.84820 | 26.67765 |
| 2016 | 13.75422 | 3.81275 | 5.08454 | 6.47008 | 29.12159 |
| 2017 | 14.93093 | 4.01737 | 5.17986 | 9.73920 | 33.86736 |
| 2018 | 15.41392 | 4.21882 | 5.16826 | 10.79225 | 35.59325 |
| 2019 | 14.69306 | 4.01318 | 4.42245 | 11.67002 | 34.79871 |
| 2020 | 16.29994 | 4.25822 | 9.62136 | 4.02998 | 34.20950 |
| total | 142.2498 | 44.33459 | 60.84082 | 63.22247 | 310.64771 |

### *5.1. Project Benefit Results*

#### 5.1.1. Reduced Shipping Cost

Figure 11 shows the 15-year transportation costs for truck drivers when $\lambda$ ranges from 0.5 to 0.8.

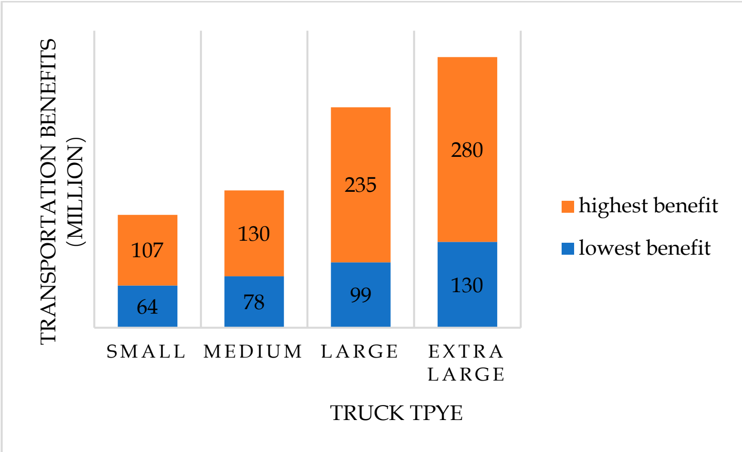



**Figure 11.** 15 Years of transportation cost-effectiveness for truck drivers.

It can be seen from Figure 11 that after the construction of the dynamic wireless charging expressway, the transportation cost of small trucks is reduced by 20% to 36%, the transportation cost of medium trucks is reduced by 40% to 50%, the transportation cost of large trucks is reduced by 14% to 32%, and the transportation cost of extra-large trucks is reduced by 13% to 27%.

5.1.2. Expressway Revenue Benefit

If the toll standard of Guixin Expressway is charged according to the standard shown in Table 5, and taking account of the traffic volume of each vehicle model in Table 6, the revenue benefit of the Guixin Expressway can be obtained from Equation (11), with the results being shown in Figure 12.

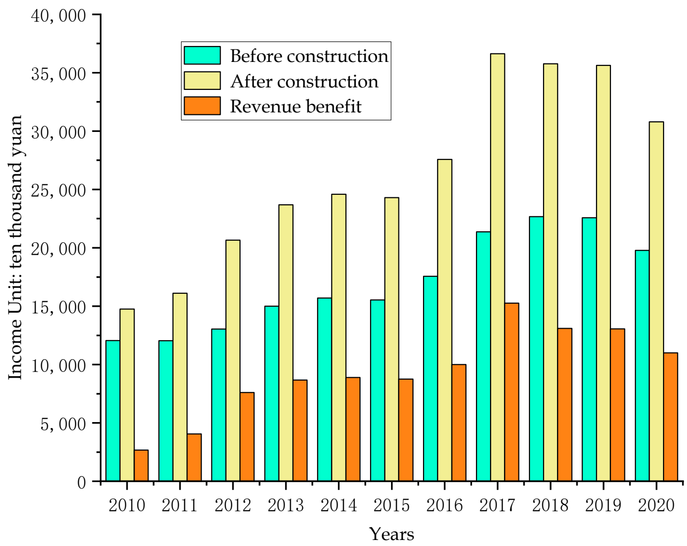



**Figure 12.** Revenue of Guixin Expressway, 2010–2020.

Upon completion of new project of the Guixin Expressway, the toll standard of the expressway would be increased by 50~70% from the original toll standard. Based on the truck traffic data collected from 2010 to 2020, with this toll standard for the dynamic wireless charging project, the Guixin Expressway would increase its revenue by 22% to 70%.

5.1.3. Lower Carbon Emissions Benefits

With the traffic volume of each vehicle model provided in Table 6, the gas emitted by traditional fuel trucks is shown in Figure 13, where the primary gas emission is $CO_2$

emissions. Each small truck emits 47.6 t per year, each medium truck emits 74.049 t per year, each large truck emits 100.495 t per year, and each extra-large truck emits 148.1 t per year. If new energy trucks are used and charged via the dynamic wireless charging lanes of the expressway, the average annual $CO_2$ emissions of each truck would be reduced by 92 t.

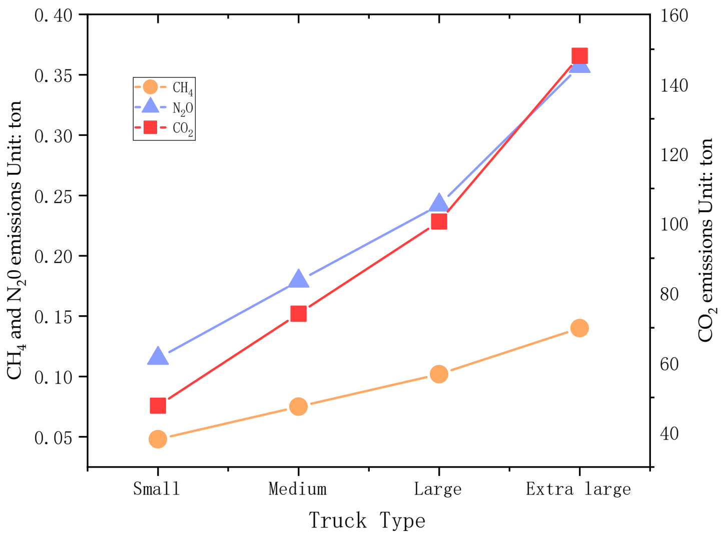



**Figure 13.** Lower carbon emissions benefits.

### 5.2. National Economic Evaluation Results

The national economic evaluation indicators of the dynamic wireless charging project of Guixin Expressway were calculated according to the national economic evaluation method. Figure 14 analyzes the highest and lowest costs in terms of EIRR and EPVN under different λ values.

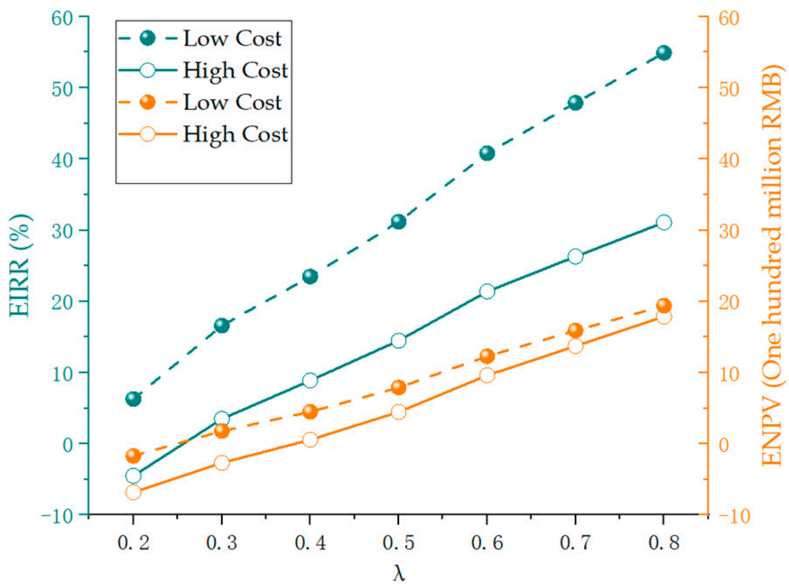



**Figure 14.** The highest and lowest cost EIRR and EPVN for different λ values.

We can see from Figure 14 that the EIRR and ENPV values increase with an increasing $\lambda$, with the growth trend for EIRR being more obvious.

Table 7 analyzes the national economic evaluation results for the lowest construction cost and the highest construction cost of this project, where $\lambda$ = 0.5.

**Table 7.** National economic evaluation result.

| Result | EIRR (%) | ENPV (Ten Thousand RMB) | EBCR | Payback Period (Years) |
|---|---|---|---|---|
| High cost | 13.56 | 39,081.25 | 1.26 | 5.10 |
| Low cost | 29.11 | 73,351.60 | 1.31 | 3.15 |

The national economic evaluation results for the Guixin Expressway dynamic wireless charging project are all within the standards, and the dynamic wireless charging project for the expressway is feasible in terms of the national economic evaluation. Since the data of national economic evaluation are mostly predictions, which include uncertainties, a sensitivity analysis of the national economic evaluation results can enhance the accuracy of the evaluation results. Sensitivity analysis of high cost and low cost is shown in Tables 8 and 9.

**Table 8.** National economic evaluation results (High cost).

| Result | EIRR (%) | ENPV (Ten Thousand RMB) | EBCR | Payback Period (Years) |
|---|---|---|---|---|
| 10% more cost | 13.85 | 51,305.46 | 1.16 | 5.35 |
| 10% less benefit | 13.61 | 44,614.91 | 1.12 | 5.41 |
| 20% more cost | 11.82 | 35,705.46 | 1.06 | 5.77 |
| 20% less benefit | 14.11 | 43,115.25 | 1.02 | 5.98 |
| 15% more cost and 15% less benefit | 11.27 | 32,159.95 | 1.12 | 6.35 |

**Table 9.** National economic evaluation results (Low cost).

| Result | EIRR (%) | ENPV (Ten Thousand RMB) | EBCR | Payback Period (Years) |
|---|---|---|---|---|
| 10% more cost | 27.92 | 64,051.61 | 1.21 | 3.45 |
| 10% less benefit | 22.48 | 56,656.45 | 1.22 | 3.75 |
| 20% more cost | 19.86 | 54,651.61 | 1.10 | 3.71 |
| 20% less benefit | 18.51 | 39,961.28 | 1.10 | 3.84 |
| 15% more cost and 15% less benefit | 16.01 | 34,308.86 | 1.23 | 4.10 |

When the project construction cost is high, the sensitivity analysis results are within the national economic evaluation standard, which indicates that the project construction will have stable economic benefits in the future.

### *5.3. Future Economic Prediction*

#### 5.3.1. Traffic Volume Prediction

The expressway toll charges are dependent on traffic volume, vehicle type, mileage, charging standards, and national policies [29]. The future annual toll revenue of dynamic wireless charging expressways can be predicted by combining multiple factors such as traffic volume, toll standard, toll mileage, and toll models [30]. Traffic volume forecasting methods mainly include the regression forecasting method, exponential smoothing method, grey forecasting method GM (1,1), growth curve trend extrapolation method, elastic coefficient forecasting method, and the gravity model forecasting method, etc. In this paper, the grey prediction method GM (1,1) model was used to predict the future traffic volumes of different types of trucks. The main feature of grey prediction is that the model does not use the original data series but the generated data series. Its core system is the grey model (GM), which is a method which involves accumulating the original data to obtain an approximate exponential law and then modeling [31]. The grey prediction method has strong regularity and can predict future developments.

The model building process is as follows:

Let the reference data be listed as:

$$x^{(0)} = (x^{(1)}, x^{(2)}, \ldots, x^{(n)}) \tag{13}$$

One accumulation generates a new data column:

$$\begin{aligned} x^{(1)} &= (x^{(0)}(1), x^{(0)}x(1) + x^{(0)}(2), \ldots, x^{(0)}(1) + \ldots + x^{(0)}(n)) \\ &= (x^{(1)}(1), x^{(2)}(2), \ldots, x^{(n)}(n)) \end{aligned} \tag{14}$$

Set up the differential equation:

$$x^{(0)}(k) + az^{(1)}(k) = b, k = 2, 3, \ldots, n \tag{15}$$

Modeling:

$$\frac{dx^{(1)}}{dt} + \overset{\wedge}{a}x^{(1)} = \overset{\wedge}{b} \tag{16}$$

Further solve the time response function:

$$\overset{\wedge}{x}^{(1)}(k=1) = (x^0(1) - \frac{\overset{\wedge}{b}}{\overset{\wedge}{a}})e - \overset{\wedge}{a}k + \frac{\overset{\wedge}{b}}{\overset{\wedge}{a}} \tag{17}$$

Build the model as:

$$\hat{V}_{\mathrm{i}}^{(0)}(\mathrm{t}+1) = \left(V_{\mathrm{i}}^{(0)} - \frac{\hat{\mathrm{b}}}{\hat{\mathrm{a}}}\right)\mathrm{e}^{-\hat{\mathrm{a}}\mathrm{t}} + \frac{\hat{\mathrm{b}}}{\hat{\mathrm{a}}}, \mathrm{t} = 0, 1, \ldots, n-1, \ldots, \tag{18}$$

Entering the truck traffic volume data for the Guixin Expressway from 2010 to 2020 in Table 6 into the GM (1,1) model, the small truck traffic volume prediction model can be obtained as $y = 160.546e^{0.0617837t} - 151.346$, the medium truck traffic volume prediction model is $y = 1312.52e^{0.00301685t} - 1308.37$, the large truck traffic volume prediction model is $y = 94.5678e^{0.0457103t} - 88.6618$, and the extra-large truck traffic volume prediction model is $y = 34.0753e^{0.182078t} - 32.2373$.

### 5.3.2. Revenue Prediction

Considering the predicted value for truck traffic volume, the Guixin Expressway revenue in the next 10 years can be calculated by using the following equation (the results are shown in Table 10):

$$Q_{Wi} = \sum_{i=1}^{n} V_i \times T_{Wi} \times n \tag{19}$$

**Table 10.** Guixin expressway revenue forecast (Unit: Billion RMB).

| Years | Small Electric Truck | Medium Electric Truck | Large Electric Truck | Extra-Large Electric Truck | Total |
|---|---|---|---|---|---|
| 2021 | 1.8751 | 0.5419 | 1.0135 | 1.2552 | 4.6857 |
| 2022 | 1.9946 | 0.5432 | 1.0609 | 1.5635 | 5.1622 |
| 2023 | 2.1218 | 0.5452 | 1.1584 | 1.7362 | 5.5616 |
| 2024 | 2.2570 | 0.5468 | 1.1146 | 1.9277 | 5.8461 |
| 2025 | 2.3999 | 0.5485 | 1.2128 | 2.1405 | 6.3017 |
| 2026 | 2.5530 | 0.5502 | 1.2738 | 2.3767 | 6.7537 |
| 2027 | 2.7157 | 0.5519 | 1.4464 | 2.6389 | 7.3529 |
| 2028 | 2.8894 | 0.5535 | 1.3958 | 2.9302 | 7.7689 |
| 2029 | 3.0735 | 0.5552 | 1.4610 | 3.2536 | 8.3433 |
| 2030 | 3.2696 | 0.5568 | 1.5293 | 3.6213 | 8.9770 |

Table 10 shows the revenue of Guixin Expressway over the next 10 years. According to the number of years of operation and maintenance cost in Figure 7, the profit of Guixin Expressway in the next 10 years was obtained, as shown in Figure 15.

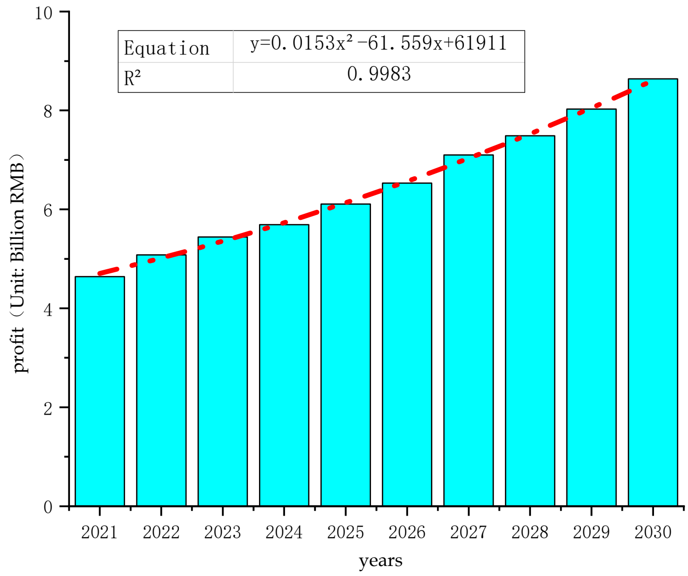



**Figure 15.** The future profits and the number of Guixin Expressway.

As shown in Figure 15, the blue bars represent annual profits, and the red dotted lines represent profit growth trends. The profit of the Guixin expressway dynamic wireless charging project increases year by year. The relationship between the profit and the number of years of operation is: $y = 0.0153x^2 - 61.599 + 61911$.

## 6. Conclusions

This paper studies the national economic evaluation of expressway dynamic wireless charging projects and draws the following conclusions:

Firstly, for truck drivers, electric vans offer lower transportation costs than traditional vans. Electric trucks have lower purchase and operating costs than traditional refueling trucks. Dynamic wireless charging trucks can reduce the transportation costs of truck drivers by 35~48%. The reduction in transportation costs will encourage more electric trucks to be put into highway operation in the future.

Secondly, the dynamic wireless charging highway is a green and environmentally friendly way of travel, in line with the principle of harmonious coexistence between man and nature. The dynamic wireless charging expressway can reduce carbon emissions. Pure electric trucks travel roughly 160,000 km a year, and each vehicle can reduce greenhouse gas emissions by 92 t per year.

Although the initial investment required for a dynamic wireless charging highway project is large, the project has economic benefits later on. Under the sensitivity analysis of national economic evaluation, the investment payback period is 3.05~6.35 years, and various national economic evaluation indicators are also higher than the benchmark values, indicating that the project will have stable economic benefits in the future. The economic income of the dynamic wireless charging high-speed Guixin Expressway was predicted for the next ten years. Excluding the maintenance cost, the profit over the next ten years will be 464 million RMB/year to 864 million RMB/year, with this forecast only being for the traffic revenue of trucks, indicating that the economic benefits of dynamic wireless charging expressways are substantial.

Other research groups, those mentioned in the introduction, have also carried out economic research on dynamic wireless charging lanes, and the research results of this paper were compared with other groups. The research cost of the PATH team was 1 M/km, and the research cost of the KAIST team was one-third of that of the PATH team, being approximately US$330,000/km. The research cost of this paper is 3.60 million yuan/km to 6.00 million yuan/km. This cost is half that of the PATH team. The initial investment for the dynamic wireless charging lane project in this paper is large, but, like the research results of the KAIST team, the project has huge benefits further down the line and has good economic benefits. Combined with the results of this national economic evaluation, the construction of dynamic wireless charging highways in China would result in substantial economic gains.

Finally, the coil studied in this paper is a conventional rectangular array coil, and the coupling mechanism is relatively simple. To improve the misalignment tolerance of the dynamic wireless charging system, complex coupler structures and coupling mechanisms require further study. Additionally, the control strategies for the charging system are also important to ensure the received power and transmission efficiency. It is hoped that subsequent research can enrich the coupling mechanism, making estimation of the coil cost more accurate and the national economic evaluation results closer to the actual figures.

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**Data Availability Statement:** The data presented in this study are available on request from the first author.

**Conflicts of Interest:** The authors declare no conflict of interest.

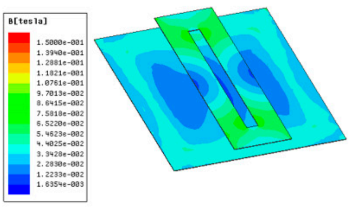
## Abbreviations

The following symbols/abbreviations are used in this manuscript.

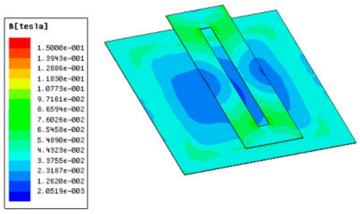
| | |
|---|---|
| GM (1,1) | Grey forecasting method |
| EIRR | Economic internal rate of return |
| EBCR | Economic benefit to cost ratio |
| EVs | Electric vehicles |
| PEV | Pure battery electric vehicles |
| HEV | Hybrid electric vehicles |
| PHEV | Plug-in hybrid electric vehicles |
| BREV | Battery replacement electric vehicles |
| RPEV | Road power electric vehicles |
| $L$ | Length of the coils |
| $W$ | Width of the coils |
| $K$ | Width of wires |
| $I$ | Current |
| $N$ | Number of turns |
| $H$ | Magnetic field strength |
| $B$ | Magnetic field strength |
| $P$ | Power |
| $M$ | Fuel consumption |
| $R$ | Income benefit |
| $S$ | Maintenance cost |
| $E$ | Carbon emission |

# Appendix A

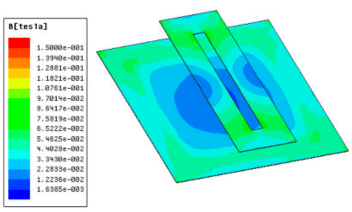
P = 50kW Magnetic flux density distribution map (Core gapickness5mm)



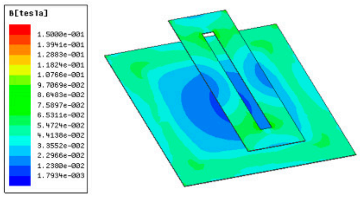
1500× 500mm air gap = 100mm



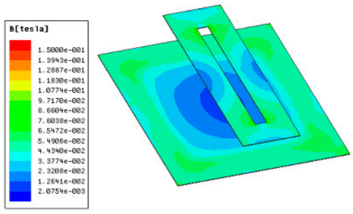
1500× 500mm air gap =150mm



1500× 500mm air gap = 200mm

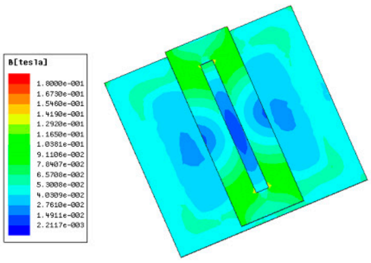


1500× 500mm air gap = 250mm

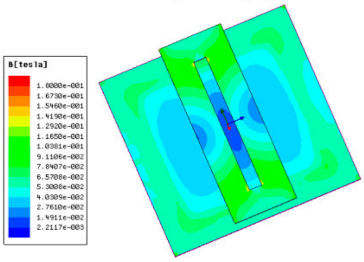


1500× 500mm air gap = 300mm

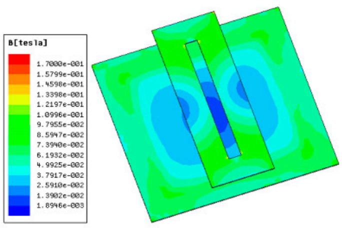
P = 100kW Magnetic flux density distribution map (Core gapickness7mm)



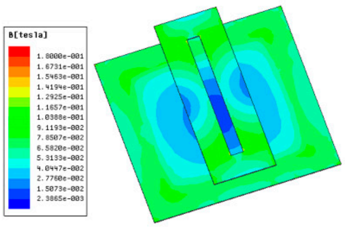
1500×500mm air gap = 100mm



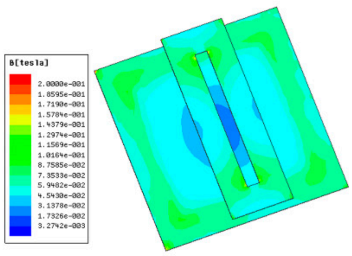
1500×500mm air gap = 150mm



1500×500mm air gap = 200mm



1500× 500mm air gap = 250mm



1500× 500mm air gap = 300mm

**Figure A1.** *Cont.*

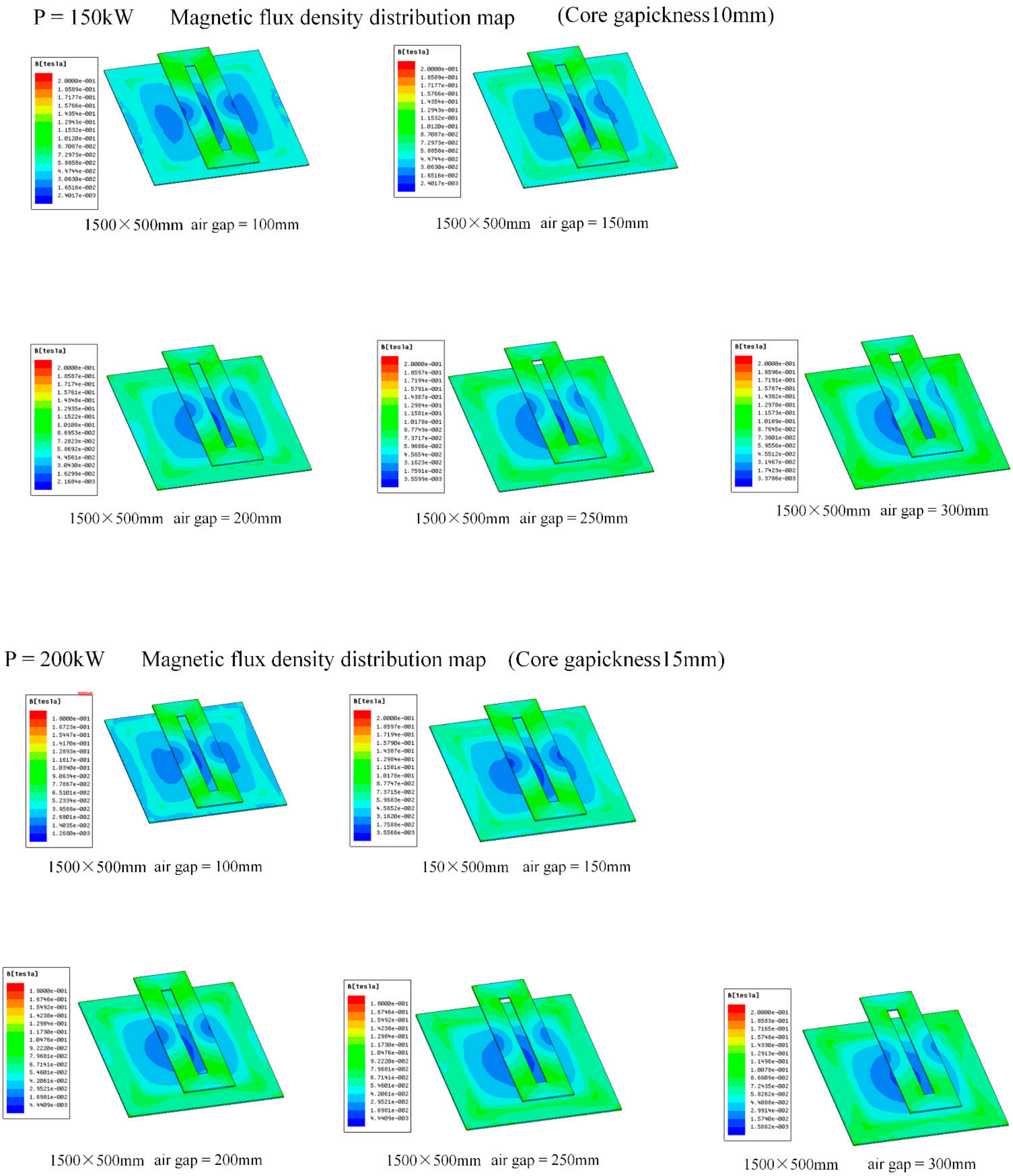



**Figure A1.** Magnetic field simulation diagram.

## Appendix B

The calculation process of the price of each material of the coil:
Litz wire cost (RMB):(Litz wire material is aluminium)

$$v = (N_1 I_1 / J) \cdot L; \; m = \rho \cdot v; \; c_1 = m \cdot p_1$$

where $v$ is volume of aluminum wire ($m^3$); $J$ is current density($A/m^2$), $J = 2\ A/m^2$; $L$ is length of aluminum wire (m); $m$ is aluminum wire weight (kg); $\rho$ is density of aluminum ($\rho_{aluminum} = 2.7 * 10^3\ kg/m^3$); $c_1$ is Leeds wire cost (RMB/m); $p_1$ is the sum of the unit price of aluminium and the unit price of aluminium processed into litz wire (RMB/kg).

Core cost:

$$c_2 = p_2 \cdot n$$

where $c_2$ is Core cost (RMB/m); $p_2$ isCore unit price (RMB); $n$ is required number of cores.

Aluminum plate cost:

$$c3 = (l \cdot w \cdot h) \cdot \rho \cdot \mathrm{p}2$$

where $c3$ is Aluminum plate cost (RMB/m); $l$ is the length of aluminum plate (m); $w$ is the width of the aluminum plate (m); $h$ is the thickness of the aluminum plate (m); $p2$ is the unit price of aluminium plate (RMB/m).

Total cost (RMB/m):

$$T = c1 + c2 + c3$$

where $T$ is total cost of coil (RMB/m).

**Table A1.** Coil specific price.

| Power (kW) | Air Gap (mm) | $W_t$ (mm) | Core Thickness (mm) | Coupling Coefficient | $N_1I_1$ | Bidirectional $N_1I_1$ | Leeds Wire Cost | Core Cost | Aluminum Plate Cos | Total Cost (RMB/m) | Litz Cost Percentage | Core Cost Percentage | Aluminum Plate Cost Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 100 | 500 | 5 | 0.1583 | 263 | 526 | 260 | 896 | 176 | 888 | 19.52% | 67.24% | 13.24% |
| | | 600 | | 0.1917 | 217 | 435 | 215 | 952 | 212 | 919 | 15.58% | 69.06% | 15.36% |
| | | 700 | | 0.2197 | 190 | 379 | 187 | 1008 | 247 | 962 | 12.99% | 69.89% | 17.12% |
| | | 800 | | 0.2534 | 164 | 329 | 162 | 1064 | 282 | 1006 | 10.77% | 70.52% | 18.71% |
| | | 900 | | 0.2973 | 140 | 280 | 138 | 1120 | 318 | 1051 | 8.79% | 71.07% | 20.15% |
| | | 1000 | | 0.3470 | 120 | 240 | 119 | 1176 | 353 | 1098 | 7.20% | 71.38% | 21.42% |
| | | 1100 | | 0.4162 | 100 | 200 | 99 | 1232 | 388 | 1146 | 5.75% | 71.67% | 22.58% |
| | | 1200 | | 0.4816 | 87 | 173 | 85 | 1288 | 423 | 1198 | 4.76% | 71.68% | 23.56% |
| | | 1300 | | 0.5330 | 78 | 156 | 77 | 1344 | 459 | 1253 | 4.11% | 71.49% | 24.40% |
| | | 1400 | | 0.5635 | 74 | 148 | 73 | 1400 | 494 | 1311 | 3.71% | 71.17% | 25.11% |
| | | 1500 | | 0.6701 | 62 | 124 | 61 | 1456 | 529 | 1364 | 3.00% | 71.14% | 25.86% |
| | 150 | 500 | | 0.1520 | 274 | 548 | 271 | 896 | 176 | 895 | 20.16% | 66.71% | 13.13% |
| | | 600 | | 0.1786 | 233 | 467 | 231 | 952 | 212 | 930 | 16.54% | 68.28% | 15.18% |
| | | 700 | | 0.2085 | 200 | 400 | 197 | 1008 | 247 | 968 | 13.59% | 69.40% | 17.01% |
| | | 800 | | 0.2358 | 177 | 353 | 175 | 1064 | 282 | 1014 | 11.48% | 69.96% | 18.56% |
| | | 900 | | 0.2708 | 154 | 308 | 152 | 1120 | 318 | 1060 | 9.56% | 70.46% | 19.98% |
| | | 1000 | | 0.3094 | 135 | 269 | 133 | 1176 | 353 | 1108 | 8.01% | 70.76% | 21.23% |
| | | 1100 | | 0.3532 | 118 | 236 | 117 | 1232 | 388 | 1158 | 6.71% | 70.94% | 22.35% |
| | | 1200 | | 0.3902 | 107 | 214 | 105 | 1288 | 423 | 1211 | 5.81% | 70.89% | 23.30% |
| | | 1300 | | 0.4215 | 99 | 198 | 98 | 1344 | 459 | 1267 | 5.14% | 70.72% | 24.14% |
| | | 1400 | | 0.4397 | 95 | 190 | 94 | 1400 | 494 | 1325 | 4.71% | 70.44% | 24.85% |
| | | 1500 | | 0.5137 | 81 | 162 | 80 | 1456 | 529 | 1377 | 3.88% | 70.50% | 25.62% |
| | 200 | 500 | | 0.1418 | 294 | 588 | 290 | 896 | 176 | 908 | 21.30% | 65.75% | 12.95% |
| | | 600 | | 0.1677 | 248 | 497 | 245 | 952 | 212 | 939 | 17.42% | 67.56% | 15.02% |
| | | 700 | | 0.1926 | 216 | 433 | 214 | 1008 | 247 | 979 | 14.55% | 68.63% | 16.82% |
| | | 800 | | 0.2178 | 191 | 383 | 189 | 1064 | 282 | 1024 | 12.31% | 69.30% | 18.38% |
| | | 900 | | 0.2435 | 171 | 342 | 169 | 1120 | 318 | 1071 | 10.52% | 69.71% | 19.77% |
| | | 1000 | | 0.2731 | 153 | 305 | 151 | 1176 | 353 | 1120 | 8.98% | 70.02% | 21.01% |
| | | 1100 | | 0.2974 | 140 | 280 | 138 | 1232 | 388 | 1172 | 7.87% | 70.06% | 22.07% |
| | | 1200 | | 0.3245 | 128 | 257 | 127 | 1288 | 423 | 1226 | 6.90% | 70.07% | 23.03% |
| | | 1300 | | 0.3437 | 121 | 242 | 120 | 1344 | 459 | 1282 | 6.23% | 69.91% | 23.86% |
| | | 1400 | | 0.3534 | 118 | 236 | 116 | 1400 | 494 | 1340 | 5.79% | 69.64% | 24.57% |
| | | 1500 | | 0.4147 | 100 | 201 | 99 | 1456 | 529 | 1390 | 4.76% | 69.85% | 25.39% |

**Table A1.** *Cont.*

| Power (kW) | Air Gap (mm) | $W_t$ (mm) | Core Thickness (mm) | Coupling Coefficient | $N_1I_1$ | Bidirectional $N_1I_1$ | Leeds Wire Cost | Core Cost | Aluminum Plate Cos | Total Cost (RMB/m) | Litz Cost Percentage | Core Cost Percentage | Aluminum Plate Cost Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 250 | 500 | 5 | 0.1347 | 309 | 619 | 306 | 896 | 176 | 919 | 22.18% | 65.02% | 12.80% |
| | | 600 | | 0.1528 | 273 | 546 | 270 | 952 | 212 | 955 | 18.80% | 66.42% | 14.77% |
| | | 700 | | 0.1745 | 239 | 478 | 236 | 1008 | 247 | 994 | 15.82% | 67.61% | 16.57% |
| | | 800 | | 0.1937 | 215 | 430 | 213 | 1064 | 282 | 1039 | 13.63% | 68.26% | 18.11% |
| | | 900 | | 0.2187 | 190 | 381 | 188 | 1120 | 318 | 1084 | 11.58% | 68.89% | 19.53% |
| | | 1000 | | 0.2381 | 175 | 350 | 173 | 1176 | 353 | 1135 | 10.16% | 69.10% | 20.73% |
| | | 1100 | | 0.2587 | 161 | 322 | 159 | 1232 | 388 | 1186 | 8.94% | 69.24% | 21.81% |
| | | 1200 | | 0.2748 | 152 | 303 | 150 | 1288 | 423 | 1241 | 8.05% | 69.20% | 22.75% |
| | | 1300 | | 0.2846 | 146 | 293 | 145 | 1344 | 459 | 1298 | 7.43% | 69.02% | 23.55% |
| | | 1400 | | 0.2916 | 143 | 286 | 141 | 1400 | 494 | 1357 | 6.94% | 68.79% | 24.27% |
| | | 1500 | | 0.3438 | 121 | 242 | 120 | 1456 | 529 | 1403 | 5.69% | 69.17% | 25.14% |
| | 300 | 500 | | 0.1271 | 328 | 656 | 324 | 896 | 176 | 931 | 23.20% | 64.17% | 12.63% |
| | | 600 | | 0.1369 | 304 | 609 | 301 | 952 | 212 | 976 | 20.54% | 65.01% | 14.46% |
| | | 700 | | 0.1546 | 269 | 539 | 266 | 1008 | 247 | 1014 | 17.50% | 66.26% | 16.24% |
| | | 800 | | 0.1728 | 241 | 482 | 238 | 1064 | 282 | 1056 | 15.04% | 67.15% | 17.81% |
| | | 900 | | 0.1888 | 221 | 441 | 218 | 1120 | 318 | 1104 | 13.17% | 67.65% | 19.18% |
| | | 1000 | | 0.2049 | 203 | 407 | 201 | 1176 | 353 | 1153 | 11.62% | 67.99% | 20.40% |
| | | 1100 | | 0.2192 | 190 | 380 | 188 | 1232 | 388 | 1205 | 10.39% | 68.14% | 21.47% |
| | | 1200 | | 0.2285 | 182 | 365 | 180 | 1288 | 423 | 1261 | 9.53% | 68.09% | 22.38% |
| | | 1300 | | 0.2372 | 176 | 351 | 174 | 1344 | 459 | 1318 | 8.78% | 68.01% | 23.21% |
| | | 1400 | | 0.2413 | 173 | 345 | 171 | 1400 | 494 | 1376 | 8.26% | 67.81% | 23.93% |
| | | 1500 | | 0.2853 | 146 | 292 | 144 | 1456 | 529 | 1420 | 6.78% | 68.37% | 24.85% |
| 100 | 100 | 500 | 7 | 0.1655 | 504 | 1007 | 497 | 1075 | 176 | 1166 | 28.44% | 61.47% | 10.09% |
| | | 600 | | 0.1962 | 425 | 849 | 420 | 1142 | 212 | 1182 | 23.66% | 64.41% | 11.94% |
| | | 700 | | 0.2266 | 368 | 736 | 363 | 1210 | 247 | 1213 | 19.96% | 66.46% | 13.57% |
| | | 800 | | 0.2617 | 318 | 637 | 315 | 1277 | 282 | 1249 | 16.79% | 68.14% | 15.06% |
| | | 900 | | 0.3055 | 273 | 546 | 270 | 1344 | 318 | 1287 | 13.96% | 69.60% | 16.44% |
| | | 1000 | | 0.3576 | 233 | 466 | 230 | 1411 | 353 | 1330 | 11.54% | 70.76% | 17.69% |
| | | 1100 | | 0.4245 | 196 | 393 | 194 | 1478 | 388 | 1374 | 9.41% | 71.75% | 18.84% |
| | | 1200 | | 0.4917 | 169 | 339 | 167 | 1546 | 423 | 1424 | 7.84% | 72.34% | 19.82% |
| | | 1300 | | 0.5429 | 153 | 307 | 152 | 1613 | 459 | 1482 | 6.82% | 72.55% | 20.63% |
| | | 1400 | | 0.5748 | 145 | 290 | 143 | 1680 | 494 | 1545 | 6.18% | 72.50% | 21.32% |
| | | 1500 | | 0.6747 | 124 | 247 | 122 | 1747 | 529 | 1599 | 5.09% | 72.85% | 22.07% |
| | 150 | 500 | | 0.1558 | 535 | 1070 | 528 | 1075 | 176 | 1187 | 29.68% | 60.40% | 9.91% |
| | | 600 | | 0.1860 | 448 | 896 | 443 | 1142 | 212 | 1198 | 24.64% | 63.58% | 11.78% |
| | | 700 | | 0.2135 | 390 | 781 | 386 | 1210 | 247 | 1228 | 20.93% | 65.66% | 13.41% |
| | | 800 | | 0.2429 | 343 | 686 | 339 | 1277 | 282 | 1265 | 17.86% | 67.27% | 14.87% |
| | | 900 | | 0.2745 | 304 | 607 | 300 | 1344 | 318 | 1308 | 15.29% | 68.52% | 16.19% |
| | | 1000 | | 0.3170 | 263 | 526 | 260 | 1411 | 353 | 1349 | 12.83% | 69.73% | 17.43% |
| | | 1100 | | 0.3578 | 233 | 466 | 230 | 1478 | 388 | 1398 | 10.98% | 70.51% | 18.51% |
| | | 1200 | | 0.3983 | 209 | 418 | 207 | 1546 | 423 | 1450 | 9.50% | 71.04% | 19.46% |
| | | 1300 | | 0.4266 | 195 | 391 | 193 | 1613 | 459 | 1510 | 8.52% | 71.22% | 20.26% |
| | | 1400 | | 0.4462 | 187 | 374 | 185 | 1680 | 494 | 1572 | 7.82% | 71.23% | 20.94% |
| | | 1500 | | 0.5329 | 156 | 313 | 155 | 1747 | 529 | 1621 | 6.36% | 71.87% | 21.77% |

**Table A1.** *Cont.*

| Power (kW) | Air Gap (mm) | $W_t$ (mm) | Core Thickness (mm) | Coupling Coefficient | $N_1I_1$ | Bidirectional $N_1I_1$ | Leeds Wire Cost | Core Cost | Aluminum Plate Cos | Total Cost (RMB/m) | Litz Cost Percentage | Core Cost Percentage | Aluminum Plate Cost Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 200 | 500 | 7 | 0.1457 | 572 | 1144 | 565 | 1075 | 176 | 1211 | 31.11% | 59.18% | 9.71% |
| | | 600 | | 0.1733 | 481 | 962 | 475 | 1142 | 212 | 1219 | 25.97% | 62.45% | 11.57% |
| | | 700 | | 0.1980 | 421 | 842 | 416 | 1210 | 247 | 1248 | 22.21% | 64.60% | 13.19% |
| | | 800 | | 0.2230 | 374 | 747 | 369 | 1277 | 282 | 1286 | 19.15% | 66.21% | 14.64% |
| | | 900 | | 0.2480 | 336 | 672 | 332 | 1344 | 318 | 1329 | 16.65% | 67.42% | 15.93% |
| | | 1000 | | 0.2769 | 301 | 602 | 297 | 1411 | 353 | 1374 | 14.42% | 68.46% | 17.12% |
| | | 1100 | | 0.3091 | 270 | 539 | 266 | 1478 | 388 | 1422 | 12.49% | 69.31% | 18.20% |
| | | 1200 | | 0.3321 | 251 | 502 | 248 | 1546 | 423 | 1478 | 11.18% | 69.72% | 19.10% |
| | | 1300 | | 0.3520 | 237 | 473 | 234 | 1613 | 459 | 1537 | 10.15% | 69.96% | 19.90% |
| | | 1400 | | 0.3611 | 231 | 462 | 228 | 1680 | 494 | 1601 | 9.49% | 69.94% | 20.57% |
| | | 1500 | | 0.4216 | 198 | 395 | 195 | 1747 | 529 | 1648 | 7.90% | 70.69% | 21.41% |
| | 250 | 500 | | 0.1347 | 619 | 1238 | 611 | 1075 | 176 | 1242 | 32.82% | 57.72% | 9.47% |
| | | 600 | | 0.1591 | 524 | 1048 | 517 | 1142 | 212 | 1248 | 27.65% | 61.04% | 11.31% |
| | | 700 | | 0.1800 | 463 | 926 | 457 | 1210 | 247 | 1276 | 23.90% | 63.20% | 12.90% |
| | | 800 | | 0.2031 | 410 | 821 | 405 | 1277 | 282 | 1310 | 20.64% | 65.00% | 14.37% |
| | | 900 | | 0.2232 | 373 | 747 | 369 | 1344 | 318 | 1354 | 18.17% | 66.19% | 15.64% |
| | | 1000 | | 0.2430 | 343 | 686 | 339 | 1411 | 353 | 1402 | 16.11% | 67.11% | 16.78% |
| | | 1100 | | 0.2632 | 317 | 633 | 313 | 1478 | 388 | 1453 | 14.35% | 67.84% | 17.81% |
| | | 1200 | | 0.2823 | 295 | 590 | 292 | 1546 | 423 | 1507 | 12.90% | 68.37% | 18.73% |
| | | 1300 | | 0.2922 | 285 | 570 | 282 | 1613 | 459 | 1569 | 11.97% | 68.53% | 19.49% |
| | | 1400 | | 0.2987 | 279 | 558 | 276 | 1680 | 494 | 1633 | 11.25% | 68.58% | 20.17% |
| | | 1500 | | 0.3469 | 240 | 480 | 237 | 1747 | 529 | 1676 | 9.44% | 69.50% | 21.05% |
| | 300 | 500 | | 0.1198 | 696 | 1391 | 687 | 1075 | 176 | 1293 | 35.45% | 55.45% | 9.10% |
| | | 600 | | 0.1429 | 583 | 1166 | 576 | 1142 | 212 | 1287 | 29.85% | 59.18% | 10.97% |
| | | 700 | | 0.1631 | 511 | 1022 | 505 | 1210 | 247 | 1308 | 25.74% | 61.67% | 12.59% |
| | | 800 | | 0.1790 | 466 | 931 | 460 | 1277 | 282 | 1346 | 22.78% | 63.24% | 13.98% |
| | | 900 | | 0.1944 | 429 | 857 | 424 | 1344 | 318 | 1390 | 20.31% | 64.46% | 15.23% |
| | | 1000 | | 0.2140 | 389 | 779 | 385 | 1411 | 353 | 1433 | 17.90% | 65.67% | 16.42% |
| | | 1100 | | 0.2304 | 362 | 723 | 357 | 1478 | 388 | 1483 | 16.07% | 66.48% | 17.45% |
| | | 1200 | | 0.2406 | 346 | 693 | 342 | 1546 | 423 | 1541 | 14.81% | 66.87% | 18.32% |
| | | 1300 | | 0.2465 | 338 | 676 | 334 | 1613 | 459 | 1604 | 13.89% | 67.05% | 19.07% |
| | | 1400 | | 0.2488 | 335 | 670 | 331 | 1680 | 494 | 1670 | 13.21% | 67.07% | 19.72% |
| | | 1500 | | 0.2926 | 285 | 570 | 281 | 1747 | 529 | 1705 | 11.00% | 68.31% | 20.69% |
| 150 | 100 | 500 | 10 | 0.1740 | 719 | 1437 | 710 | 1344 | 176 | 1487 | 31.83% | 60.26% | 7.91% |
| | | 600 | | 0.2055 | 608 | 1217 | 601 | 1428 | 212 | 1494 | 26.82% | 63.73% | 9.45% |
| | | 700 | | 0.2363 | 529 | 1058 | 523 | 1512 | 247 | 1521 | 22.91% | 66.27% | 10.82% |
| | | 800 | | 0.2702 | 463 | 925 | 457 | 1596 | 282 | 1557 | 19.57% | 68.34% | 12.09% |
| | | 900 | | 0.3131 | 399 | 798 | 394 | 1680 | 318 | 1595 | 16.49% | 70.23% | 13.28% |
| | | 1000 | | 0.3651 | 342 | 685 | 338 | 1764 | 353 | 1637 | 13.78% | 71.85% | 14.37% |
| | | 1100 | | 0.4369 | 286 | 572 | 283 | 1848 | 388 | 1679 | 11.22% | 73.37% | 15.41% |
| | | 1200 | | 0.5047 | 248 | 495 | 245 | 1932 | 423 | 1733 | 9.41% | 74.30% | 16.28% |
| | | 1300 | | 0.5542 | 226 | 451 | 223 | 2016 | 459 | 1798 | 8.26% | 74.74% | 17.00% |
| | | 1400 | | 0.5831 | 214 | 429 | 212 | 2100 | 494 | 1871 | 7.55% | 74.85% | 17.61% |
| | | 1500 | | 0.6855 | 182 | 365 | 180 | 2184 | 529 | 1929 | 6.23% | 75.48% | 18.29% |

**Table A1.** *Cont.*

| Power (kW) | Air Gap (mm) | $W_t$ (mm) | Core Thickness (mm) | Coupling Coefficient | $N_1I_1$ | Bidirectional $N_1I_1$ | Leeds Wire Cost | Core Cost | Aluminum Plate Cos | Total Cost (RMB/m) | Litz Cost Percentage | Core Cost Percentage | Aluminum Plate Cost Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150 | 150 | 500 | 10 | 0.1586 | 788 | 1576 | 779 | 1344 | 176 | 1533 | 33.87% | 58.46% | 7.67% |
| | | 600 | | 0.1904 | 657 | 1313 | 649 | 1428 | 212 | 1526 | 28.35% | 62.40% | 9.25% |
| | | 700 | | 0.2202 | 568 | 1135 | 561 | 1512 | 247 | 1547 | 24.18% | 65.18% | 10.65% |
| | | 800 | | 0.2510 | 498 | 996 | 492 | 1596 | 282 | 1580 | 20.76% | 67.33% | 11.91% |
| | | 900 | | 0.2862 | 437 | 874 | 432 | 1680 | 318 | 1619 | 17.76% | 69.16% | 13.07% |
| | | 1000 | | 0.3216 | 389 | 777 | 384 | 1764 | 353 | 1667 | 15.36% | 70.54% | 14.11% |
| | | 1100 | | 0.3669 | 341 | 681 | 337 | 1848 | 388 | 1715 | 13.08% | 71.83% | 15.09% |
| | | 1200 | | 0.4078 | 307 | 613 | 303 | 1932 | 423 | 1772 | 11.39% | 72.68% | 15.93% |
| | | 1300 | | 0.4368 | 286 | 572 | 283 | 2016 | 459 | 1838 | 10.25% | 73.11% | 16.63% |
| | | 1400 | | 0.4559 | 274 | 548 | 271 | 2100 | 494 | 1910 | 9.46% | 73.30% | 17.24% |
| | | 1500 | | 0.5375 | 233 | 465 | 230 | 2184 | 529 | 1962 | 7.81% | 74.21% | 17.98% |
| | 200 | 500 | | 0.1504 | 831 | 1662 | 821 | 1344 | 176 | 1561 | 35.07% | 57.40% | 7.53% |
| | | 600 | | 0.1793 | 697 | 1394 | 689 | 1428 | 212 | 1552 | 29.58% | 61.33% | 9.09% |
| | | 700 | | 0.2038 | 613 | 1227 | 606 | 1512 | 247 | 1577 | 25.62% | 63.93% | 10.44% |
| | | 800 | | 0.2315 | 540 | 1080 | 533 | 1596 | 282 | 1608 | 22.12% | 66.18% | 11.70% |
| | | 900 | | 0.2584 | 484 | 967 | 478 | 1680 | 318 | 1650 | 19.31% | 67.87% | 12.83% |
| | | 1000 | | 0.2860 | 437 | 874 | 432 | 1764 | 353 | 1699 | 16.94% | 69.21% | 13.84% |
| | | 1100 | | 0.3161 | 395 | 791 | 391 | 1848 | 388 | 1751 | 14.87% | 70.35% | 14.78% |
| | | 1200 | | 0.3428 | 365 | 729 | 360 | 1932 | 423 | 1810 | 13.27% | 71.14% | 15.59% |
| | | 1300 | | 0.3638 | 344 | 687 | 339 | 2016 | 459 | 1876 | 12.06% | 71.64% | 16.30% |
| | | 1400 | | 0.3738 | 334 | 669 | 330 | 2100 | 494 | 1950 | 11.30% | 71.81% | 16.89% |
| | | 1500 | | 0.4175 | 299 | 599 | 296 | 2184 | 529 | 2006 | 9.83% | 72.58% | 17.59% |
| | 250 | 500 | | 0.1371 | 912 | 1823 | 901 | 1344 | 176 | 1614 | 37.20% | 55.51% | 7.29% |
| | | 600 | | 0.1629 | 767 | 1535 | 758 | 1428 | 212 | 1599 | 31.62% | 59.55% | 8.83% |
| | | 700 | | 0.1868 | 669 | 1338 | 661 | 1512 | 247 | 1613 | 27.32% | 62.48% | 10.21% |
| | | 800 | | 0.2088 | 599 | 1197 | 591 | 1596 | 282 | 1646 | 23.95% | 64.62% | 11.43% |
| | | 900 | | 0.2284 | 547 | 1095 | 541 | 1680 | 318 | 1692 | 21.30% | 66.19% | 12.51% |
| | | 1000 | | 0.2510 | 498 | 996 | 492 | 1764 | 353 | 1739 | 18.86% | 67.62% | 13.52% |
| | | 1100 | | 0.2730 | 458 | 916 | 452 | 1848 | 388 | 1792 | 16.83% | 68.74% | 14.44% |
| | | 1200 | | 0.2897 | 431 | 863 | 426 | 1932 | 423 | 1854 | 15.33% | 69.45% | 15.22% |
| | | 1300 | | 0.2998 | 417 | 834 | 412 | 2016 | 459 | 1924 | 14.27% | 69.84% | 15.89% |
| | | 1400 | | 0.3051 | 410 | 819 | 405 | 2100 | 494 | 1999 | 13.50% | 70.03% | 16.47% |
| | | 1500 | | 0.3534 | 354 | 707 | 349 | 2184 | 529 | 2042 | 11.41% | 71.31% | 17.28% |
| | 300 | 500 | | 0.1218 | 1026 | 2053 | 1014 | 1344 | 176 | 1690 | 40.01% | 53.03% | 6.96% |
| | | 600 | | 0.1444 | 866 | 1731 | 855 | 1428 | 212 | 1663 | 34.28% | 57.24% | 8.49% |
| | | 700 | | 0.1645 | 760 | 1520 | 751 | 1512 | 247 | 1673 | 29.91% | 60.25% | 9.84% |
| | | 800 | | 0.1838 | 680 | 1360 | 672 | 1596 | 282 | 1700 | 26.35% | 62.58% | 11.07% |
| | | 900 | | 0.2020 | 619 | 1238 | 611 | 1680 | 318 | 1739 | 23.43% | 64.39% | 12.17% |
| | | 1000 | | 0.2175 | 575 | 1149 | 568 | 1764 | 353 | 1790 | 21.15% | 65.71% | 13.14% |
| | | 1100 | | 0.2316 | 540 | 1079 | 533 | 1848 | 388 | 1846 | 19.26% | 66.73% | 14.01% |
| | | 1200 | | 0.2445 | 511 | 1022 | 505 | 1932 | 423 | 1907 | 17.66% | 67.54% | 14.80% |
| | | 1300 | | 0.2510 | 498 | 996 | 492 | 2016 | 459 | 1978 | 16.59% | 67.95% | 15.46% |
| | | 1400 | | 0.2554 | 489 | 979 | 484 | 2100 | 494 | 2052 | 15.71% | 68.24% | 16.05% |
| | | 1500 | | 0.2947 | 424 | 848 | 419 | 2184 | 529 | 2088 | 13.38% | 69.72% | 16.90% |

**Table A1.** *Cont.*

| Power (kW) | Air Gap (mm) | $W_t$ (mm) | Core Thickness (mm) | Coupling Coefficient | $N_1I_1$ | Bidirectional $N_1I_1$ | Leeds Wire Cost | Core Cost | Aluminum Plate Cos | Total Cost (RMB/m) | Litz Cost Percentage | Core Cost Percentage | Aluminum Plate Cost Percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | 100 | 500 | 15 | 0.2125 | 784 | 1569 | 775 | 1971 | 176 | 1948 | 26.51% | 67.45% | 6.04% |
| | | 600 | | 0.2536 | 657 | 1314 | 649 | 2094 | 212 | 1970 | 21.97% | 70.87% | 7.16% |
| | | 700 | | 0.2852 | 584 | 1169 | 577 | 2218 | 247 | 2028 | 18.98% | 72.90% | 8.12% |
| | | 800 | | 0.3229 | 516 | 1032 | 510 | 2341 | 282 | 2089 | 16.28% | 74.71% | 9.01% |
| | | 900 | | 0.3631 | 459 | 918 | 454 | 2464 | 318 | 2157 | 14.02% | 76.17% | 9.82% |
| | | 1000 | | 0.4222 | 395 | 790 | 390 | 2587 | 353 | 2220 | 11.71% | 77.69% | 10.60% |
| | | 1100 | | 0.4876 | 342 | 684 | 338 | 2710 | 388 | 2291 | 9.83% | 78.88% | 11.29% |
| | | 1200 | | 0.5503 | 303 | 606 | 299 | 2834 | 423 | 2371 | 8.41% | 79.68% | 11.91% |
| | | 1300 | | 0.6020 | 277 | 554 | 274 | 2957 | 459 | 2459 | 7.41% | 80.15% | 12.43% |
| | | 1400 | | 0.6303 | 264 | 529 | 261 | 3080 | 494 | 2557 | 6.81% | 80.31% | 12.88% |
| | | 1500 | | 0.6323 | 264 | 527 | 260 | 3203 | 529 | 2662 | 6.52% | 80.22% | 13.25% |
| | 150 | 500 | | 0.1683 | 990 | 1981 | 978 | 1971 | 176 | 2084 | 31.30% | 63.06% | 5.64% |
| | | 600 | | 0.2033 | 820 | 1640 | 810 | 2094 | 212 | 2077 | 25.99% | 67.21% | 6.79% |
| | | 700 | | 0.2316 | 720 | 1439 | 711 | 2218 | 247 | 2117 | 22.39% | 69.83% | 7.78% |
| | | 800 | | 0.2645 | 630 | 1260 | 623 | 2341 | 282 | 2164 | 19.18% | 72.12% | 8.70% |
| | | 900 | | 0.3012 | 553 | 1107 | 547 | 2464 | 318 | 2219 | 16.43% | 74.03% | 9.54% |
| | | 1000 | | 0.3412 | 488 | 977 | 483 | 2587 | 353 | 2282 | 14.10% | 75.59% | 10.31% |
| | | 1100 | | 0.3844 | 434 | 867 | 428 | 2710 | 388 | 2351 | 12.15% | 76.85% | 11.00% |
| | | 1200 | | 0.4251 | 392 | 784 | 387 | 2834 | 423 | 2430 | 10.63% | 77.75% | 11.62% |
| | | 1300 | | 0.4546 | 367 | 733 | 362 | 2957 | 459 | 2518 | 9.59% | 78.27% | 12.14% |
| | | 1400 | | 0.4760 | 350 | 700 | 346 | 3080 | 494 | 2613 | 8.83% | 78.57% | 12.60% |
| | | 1500 | | 0.4744 | 351 | 703 | 347 | 3203 | 529 | 2720 | 8.51% | 78.52% | 12.97% |
| | 200 | 500 | | 0.1527 | 1091 | 2183 | 1078 | 1971 | 176 | 2151 | 33.43% | 61.10% | 5.47% |
| | | 600 | | 0.1880 | 887 | 1773 | 876 | 2094 | 212 | 2121 | 27.53% | 65.82% | 6.65% |
| | | 700 | | 0.2154 | 774 | 1548 | 764 | 2218 | 247 | 2153 | 23.67% | 68.68% | 7.65% |
| | | 800 | | 0.2421 | 688 | 1377 | 680 | 2341 | 282 | 2202 | 20.59% | 70.86% | 8.55% |
| | | 900 | | 0.2693 | 619 | 1238 | 611 | 2464 | 318 | 2262 | 18.02% | 72.62% | 9.36% |
| | | 1000 | | 0.2986 | 558 | 1116 | 551 | 2587 | 353 | 2328 | 15.79% | 74.10% | 10.11% |
| | | 1100 | | 0.3274 | 509 | 1018 | 503 | 2710 | 388 | 2401 | 13.97% | 75.26% | 10.78% |
| | | 1200 | | 0.3547 | 470 | 940 | 464 | 2834 | 423 | 2481 | 12.48% | 76.15% | 11.38% |
| | | 1300 | | 0.3735 | 446 | 892 | 441 | 2957 | 459 | 2571 | 11.43% | 76.67% | 11.89% |
| | | 1400 | | 0.3854 | 432 | 865 | 427 | 3080 | 494 | 2667 | 10.68% | 76.98% | 12.35% |
| | | 1500 | | 0.3826 | 436 | 871 | 430 | 3203 | 529 | 2775 | 10.34% | 76.95% | 12.71% |
| | 250 | 500 | | 0.1411 | 1181 | 2362 | 1167 | 1971 | 176 | 2210 | 35.21% | 59.47% | 5.32% |
| | | 600 | | 0.1708 | 976 | 1952 | 964 | 2094 | 212 | 2180 | 29.48% | 64.05% | 6.47% |
| | | 700 | | 0.1936 | 861 | 1722 | 851 | 2218 | 247 | 2210 | 25.66% | 66.89% | 7.45% |
| | | 800 | | 0.2185 | 763 | 1526 | 754 | 2341 | 282 | 2251 | 22.32% | 69.32% | 8.36% |
| | | 900 | | 0.2382 | 700 | 1399 | 691 | 2464 | 318 | 2315 | 19.91% | 70.95% | 9.14% |
| | | 1000 | | 0.2618 | 637 | 1273 | 629 | 2587 | 353 | 2379 | 17.62% | 72.49% | 9.89% |
| | | 1100 | | 0.2830 | 589 | 1178 | 582 | 2710 | 388 | 2454 | 15.81% | 73.64% | 10.55% |
| | | 1200 | | 0.3007 | 554 | 1109 | 548 | 2834 | 423 | 2536 | 14.39% | 74.48% | 11.13% |
| | | 1300 | | 0.3134 | 532 | 1064 | 525 | 2957 | 459 | 2627 | 13.33% | 75.03% | 11.64% |
| | | 1400 | | 0.3192 | 522 | 1044 | 516 | 3080 | 494 | 2727 | 12.61% | 75.31% | 12.08% |
| | | 1500 | | 0.3182 | 524 | 1048 | 517 | 3203 | 529 | 2833 | 12.18% | 75.37% | 12.45% |
| | 300 | 500 | | 0.1271 | 1311 | 2623 | 1296 | 1971 | 176 | 2296 | 37.63% | 57.25% | 5.12% |
| | | 600 | | 0.1535 | 1086 | 2172 | 1073 | 2094 | 212 | 2253 | 31.75% | 61.99% | 6.27% |
| | | 700 | | 0.1743 | 956 | 1912 | 945 | 2218 | 247 | 2273 | 27.71% | 65.05% | 7.24% |
| | | 800 | | 0.1919 | 869 | 1737 | 858 | 2341 | 282 | 2321 | 24.65% | 67.24% | 8.11% |
| | | 900 | | 0.2106 | 791 | 1583 | 782 | 2464 | 318 | 2376 | 21.94% | 69.15% | 8.91% |
| | | 1000 | | 0.2270 | 734 | 1468 | 725 | 2587 | 353 | 2444 | 19.79% | 70.58% | 9.63% |
| | | 1100 | | 0.2434 | 685 | 1369 | 677 | 2710 | 388 | 2517 | 17.92% | 71.80% | 10.28% |
| | | 1200 | | 0.2557 | 652 | 1304 | 644 | 2834 | 423 | 2601 | 16.51% | 72.64% | 10.85% |
| | | 1300 | | 0.2632 | 633 | 1266 | 626 | 2957 | 459 | 2694 | 15.48% | 73.17% | 11.35% |
| | | 1400 | | 0.2664 | 626 | 1251 | 618 | 3080 | 494 | 2795 | 14.74% | 73.47% | 11.78% |
| | | 1500 | | 0.2737 | 609 | 1218 | 602 | 3203 | 529 | 2889 | 13.88% | 73.91% | 12.21% |

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