ISSN 2616-5902 Vol. 8, Issue 2: 85-98, DOI: 10.25236/AJBM.2026.080212

Research on the Low-carbon Transformation Path of Chaozhou's Ceramic Industry under the Dual Carbon Goals——Based on Innovative Carbon Reduction Technologies

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Abstract: *With the increasingly severe issue of global climate change, China has put forward the ambitious goals of "carbon peaking and carbon neutrality", marking that the development model of the economy and society will undergo a widespread and profound systemic transformation. Against this backdrop, as a representative of traditional manufacturing industries that are high in energy consumption and emissions, the ceramic industry is facing unprecedented pressure to make a low-carbon transformation. Chaozhou, known as the "Porcelain Capital of China", has a long history in its ceramic industry, which is characterized by a distinct cluster. It serves as a pillar industry for the local economy and an important guarantee for employment and people's livelihood. However, behind its prosperous development, the long-term reliance on an energy structure dominated by coal and natural gas has led to a prominent problem of "double high" in total carbon emissions and intensity, which has become a key and difficult area for the region to achieve its dual carbon goals. Therefore, this paper takes Chaozhou ceramic manufacturing enterprises as the research object, assesses the carbon reduction technology paths and their effects for different ceramic categories, studies the urgency and new directions of transformation, quantifies carbon reduction technologies as the core driving force, identifies the core obstacles in the transformation process, and establishes a "transformation path" to provide a decision-making model.*

Keywords: *Chaozhou ceramics, dual carbon goals, carbon emissions, carbon reduction technologies*

1. Introduction

1.1 Research Background and Significance

In the Neolithic Age, the ancestors of the Chaoshan people had already begun the history of pottery making. The 18 ancient kilns in Hutoupu, Puning, are densely distributed with early Chaozhou ceramics, forming the largest Neolithic kiln complex discovered in China, witnessing the early exploration of pottery-making by our ancestors. During the Northern Song Dynasty, the Chaozhou kilns entered their first golden age. In the kiln sites around the Bi Jia Mountain, hundreds of kilns were constantly working every night. By the Ming and Qing dynasties, the craftsmanship of Chaozhou ceramics had further advanced. Relying on the development of the Maritime Silk Road, they were exported overseas, bringing "Chaozhou-made" ceramics into homes around the world. This porcelain-making technique has been passed down without interruption. From the Republic of China era to modern times, it has continuously absorbed new elements in its development. It constantly draws on the elegance of Central Plains porcelain, integrates the techniques of Chao-Shan wood and stone carvings, and incorporates the essence of molding, painting, embroidery and other crafts. [1]

In recent years, due to the rising costs of raw materials and labor, the disruption of sea transportation and the reduction of foreign orders, the development pressure has been multiplied. Meanwhile, as the country's "dual carbon" policy advances, the problems of high energy consumption and large emissions have also become the main obstacles for the transformation and upgrading of Chaozhou's ceramic industry. Under Article 6. 4 of the Paris Agreement, the global carbon market mechanism will officially come into operation in 2025, replacing the Clean Development Mechanism with a unified international carbon credit trading system. This will enable countries to achieve their nationally determined contributions through carbon credit trading and enhance the sustainable

ISSN 2616-5902 Vol. 8, Issue 2: 85-98, DOI: 10.25236/AJBM.2026.080212

development contributions and overall global emissions reduction of emission reduction projects. [2][3]The ceramic industry, as a high energy-consuming sector, is one of the major carbon emission sources in the building materials field. According to data from the International Energy Agency, the global ceramic industry (including refractory materials and bricks and tiles) emits over 400 million tons of carbon dioxide annually. Among them, the annual emissions of the EU's building and sanitary ceramics industry are approximately 19 million tons, with fuel combustion accounting for 66%, electricity and process contributing 18% and 16% respectively; the annual emissions of this industry in China are about 15 million tons. [4]Therefore, in response, intelligence and sustainability together form the core strategy for the development of developed countries. Digitalization has become a key strategic approach for industrial transformation. Representative initiatives include Germany's "Digital Future Initiative", the United States' "Advanced Manufacturing Partnership Program" and Digital Manufacturing Innovation Centers. [5]Therefore, applying innovative carbon reduction technologies to address the low-carbon transformation of the ceramic industry is the direction and demand for the ceramic industry in Chaozhou. As the ceramic industry is a high-emission sector, the General Office of the National Development and Reform Commission proposed in 2013, in accordance with the "Twelfth Five-Year Plan" Outline, that domestic ceramic manufacturing enterprises should refer to this guideline to standardize the calculation and reporting of greenhouse gas emissions. [6]The emissions produced during the ceramic firing process are the main source of pollution in the entire production process. Therefore, when analyzing the core driving forces of innovative carbon reduction technologies, particular attention should be paid to this aspect.

1.2 Research Status at Home and Abroad

At present, the evaluation framework for innovative carbon reduction technologies has not been unified. Therefore, this paper focuses on the existing research to construct a multi-dimensional evaluation approach and systematically compare the cost-effectiveness of different technological paths that are lacking.

1.2.1 Research on the Application and Evaluation of Traditional Carbon Reduction Technologies

Although scholars at home and abroad have extensively explored various alternative technologies for energy conservation and emission reduction in ceramic production, the overall research framework for its emission reduction pathways still has room for improvement. Firstly, the current research's shortcomings mainly lie in the lack of systematic assessment and comparison of the emission reduction potential and costs of various technologies, especially breakthrough technologies. On the other hand, a large number of discussions oriented towards clean production have conclusions that deviate from the core requirements of decarbonization goals and lack specificity. One study cited the ceramic tile factory as an example, confirming that clean production, through process optimization, energy substitution and waste recycling, not only achieves energy conservation and emission reduction but also enhances economic benefits, providing an effective technical path and evaluation method for the low-carbon transformation of traditional high-energy-consuming industries. [7]Furthermore, a few research conclusions suggest that economic pressure has become a key driver for the application of carbon reduction technologies, and there must be a shift towards fundamental process innovations that can significantly enhance energy efficiency and reduce overall costs. [8]

In conclusion, although existing studies have affirmed the dual benefits of emission reduction and economic improvement brought by cleaner production and process innovation, they generally lack a systematic assessment of the potential and costs of breakthrough technologies.

1.2.2 Advanced Low-Carbon Technologies and Frontier Explorations

At present, in existing research, there is mention of "environmental-economic" integrated life cycle assessment. This is a cutting-edge systematic analysis method. Firstly, it quantifies the environmental benefits and economic costs and benefits brought by different improvement strategies throughout the entire life cycle simultaneously. On the other hand, it reveals the trade-offs and synergies between environmental performance and economic benefits, providing more decision-making support value for enterprises and managers with scientific basis. [9]However, at present, there is no optimal technical path that can achieve the best balance between emission reduction effects and cost control, which remains the core difficulty for the low-carbon transformation of Chaozhou ceramics.

Therefore, this study conducts an empirical analysis to systematically assess the actual "cost-effectiveness" of different innovative carbon reduction technologies in the context of Chaozhou, thereby identifying a localized transformation path that takes into account both environmental benefits

ISSN 2616-5902 Vol. 8, Issue 2: 85-98, DOI: 10.25236/AJBM.2026.080212

and economic feasibility.

2. The Path of Ceramic Innovation and Carbon Reduction in the Predicament of Small and Medium-sized Enterprises

In the face of the urgent transformation that the Chaozhou ceramic industry is confronted with under the "dual carbon" goals, its path selection should be based on the unique industrial reality. Currently, three types of ceramics have formed differentiated carbon reduction paths. Firstly, daily-use porcelain has become a benchmark for emission reduction thanks to technologies such as electric kilns. Construction porcelain is seeking breakthroughs in scale by relying on thinning and photovoltaics. Art porcelain, on the other hand, is exploring personalized carbon reduction through 3D printing and other means. Secondly, the local industrial chain is complete and policy support is clear, but the core predicament of small and medium-sized enterprises being "weak and miscellaneous, few and lacking, poor and inferior" seriously restricts the release of technological potential. Finally, this chapter aims to deeply analyze this contradiction and explore innovative carbon reduction paths that fit local realities.

2.1 Current Situation and Evaluation of Carbon Reduction Technologies in Chaozhou's Ceramic Industry

At present, the three types of ceramics use different carbon reduction technologies respectively (see Figure 1).

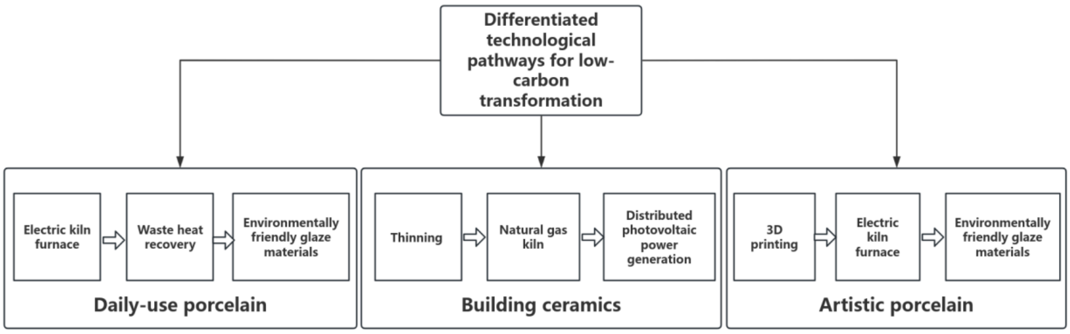

Figure 1 Carbon reduction technologies used for the three types of ceramics respectively

The specific carbon reduction technologies corresponding to each type of ceramic are summarized in Table 1. The daily-use porcelain sector has become a "benchmark area" for carbon reduction in Chaozhou's ceramics industry. Its technological combination has achieved a relatively optimal balance in terms of emission reduction, economy and maturity. Electric kilns directly use electrical energy, achieving zero carbon emissions at the production end from the source. If combined with the future increase in the proportion of green electricity, the potential for emission reduction is huge. Secondly, the accompanying waste heat recovery system can utilize the waste heat generated during the cooling process of the kiln for drying the greenware or heating the workshop, significantly enhancing the overall energy utilization efficiency and further reducing energy consumption costs. Meanwhile, the application of eco-friendly glazes has reduced the emission of heavy metals and other pollutants during the firing process. Due to its clear technical path, relatively simple equipment modification, stable operation, and low maintenance costs, this technology has the highest acceptance and popularity among small and medium-sized enterprises in Chaozhou, demonstrating excellent economic viability and maturity. It provides a replicable transformation model for other ceramic categories.

Table 1: Capacity Utilization Rate of Chaozhou's Ceramic Industry and Macroeconomic Indicators in 2024

Indicator	2024 Data	Year-on-Year Change
Actual GDP growth rate	4.6%	-0.1%
Industrial capacity utilization rate	75.1%	-
Capacity utilization rate of the ceramic industry	60%	-
Real estate development investment	7,868 billion yuan	-10.1%
Sales area of newly built commercial housing	702.84 million square meters	-17.1%
Sales revenue of newly built commercial housing	6888 billion yuan	-22.7%

Data source: China Ceramics Network

ISSN 2616-5902 Vol. 8, Issue 2: 85-98, DOI: 10.25236/AJBM.2026.080212

The carbon reduction path of architectural ceramics is highly dependent on the scale effect, and its core technologies have different focuses in terms of emission reduction. Thinning reduces the raw material usage per unit product, directly lowering the energy consumption and emissions throughout the entire process of mining, transportation, and firing from the source. However, this technology is limited by the strength requirements of the products and is restricted in specific product scenarios such as load-bearing wall and floor tiles. Upgrading traditional coal kilns and gas kilns to more efficient natural gas kilns is a key step in reducing carbon emission intensity at present, and the cleanliness of their emissions is far superior to that of coal. The application of distributed photovoltaic power can provide green electricity for large-scale factories and effectively offset the high electricity consumption during the production process. However, the current challenge lies in the relatively high initial investment for photovoltaic systems, as well as the need for complete factory rooftops and stable grid connection conditions, which impose requirements on enterprises' funds and sites, and thus its potential has not been fully unleashed.

The carbon reduction technology for art porcelain demonstrates a high degree of personalized adaptability. The advantages of electric kilns and eco-friendly glazes are similar to those in the field of daily-use porcelain, providing a precise and clean firing environment for small-batch and multi-variety creations. It is particularly worth mentioning that 3D printing technology, through digital modeling and additive manufacturing, can precisely control the amount of raw materials used, almost eliminating the waste generated from carving and trimming, and fundamentally reducing material consumption and solid waste. However, its potential for reducing emissions is currently limited by two major factors. On the one hand, 3D printing in the field of art porcelain is still mainly applied to model making or specific categories, and has not yet formed large-scale industrialized application, resulting in a relatively high unit cost of emission reduction. On the other hand, this new technology has a conceptual conflict with traditional craftsmanship that emphasizes manual skills and "artisan spirit" . Many artists and collectors believe that digital production weakens the uniqueness and value of artworks, which makes the promotion of 3D printing technology in the core art porcelain field face resistance.

To sum up, the decarbonization technologies for the three major types of products in Chaozhou's ceramic industry have presented clear and differentiated paths. Firstly, daily-use porcelain has established a "benchmark" position in terms of emission reduction effect, economy and technological popularity through the mature combination of electric kilns, waste heat recovery and environmentally friendly glazes. Secondly, architectural ceramics rely on economies of scale, focusing on thinning, natural gas kilns and distributed photovoltaics. Their emission reduction effects are significant but are constrained by the high threshold of product scenarios and photovoltaic matching. Although art porcelain has demonstrated a high degree of personalized adaptability and potential for waste reduction at the source in electric kilns, environmentally friendly glazes and 3D printing technology, its emission reduction potential has not been fully realized due to the insufficient scale of 3D printing and the conflict of concepts with traditional craftsmanship. Overall, the current status of carbon reduction technologies in the Chaozhou ceramic industry is generally positive but unevenly developed. In the future, precise breakthroughs should be made for the specific bottlenecks of different product categories.

2.2 Current Effects of Carbon Reduction Technologies' Application

At present, the ceramic industry in Chaozhou has been in the leading position in energy conservation and consumption reduction. Through innovative measures and planning standards, it has successfully improved energy utilization efficiency and reduced resource consumption. Chaozhou City is establishing and improving a system for the recycling and reuse of ceramic waste, supporting enterprises in carrying out the circular utilization of ceramic waste. Five ceramic waste disposal sites and four resource recovery and processing centers have been built. Ceramic waste can basically be disposed of harmlessly and reused.

In terms of the industrial chain, a complete industrial chain is the cornerstone of the "dual carbon" transformation of Chaozhou's ceramic industry. During its development, Chaozhou's ceramic industry has formed a relatively complete industrial chain. In addition, the ceramic production in Chaozhou is equipped with complete facilities and processes. From the upstream industry to the downstream industry, a mature production process system has been formed. All the production links and related supporting facilities of the products can be completed promptly and quickly locally.

In terms of policy guidance, the Chaozhou Municipal Government attaches great importance to the low-carbon development of the Chaozhou ceramic industry. It has already issued a guiding document,

ISSN 2616-5902 Vol. 8, Issue 2: 85-98, DOI: 10.25236/AJBM.2026.080212

clearly stating that it will promote enterprises to switch the energy used in kilns from coal to clean energy such as electricity or natural gas, and support enterprises in building photovoltaic projects on their rooftops, hoping to achieve self-sufficiency for the enterprises. [10]In terms of difficulties and challenges, although the carbon reduction practices of the Chaozhou ceramic industry have achieved remarkable results, the full play of its actual effects still faces two major practical challenges. First of all, there are a large number of small and medium-sized enterprises that dominate the market. Due to the high initial investment, they find it difficult to apply key technologies such as electric kilns and distributed photovoltaic power generation. This has to some extent delayed the overall emission reduction process of the industry. Secondly, the photovoltaic projects that have been completed are subject to intermittent power generation due to weather conditions, which has highlighted the issue of unstable power generation. This directly restricts the actual substitution effect of clean energy for traditional energy and affects the stability and measurability of carbon reduction effects. To break through the bottleneck and promote the achievements of carbon reduction to a deeper level, systematic measures need to be taken in the future. Enterprises are currently eagerly awaiting the adoption of new models to precisely address the financial pain points of small and medium-sized enterprises. On the other hand, enterprises should actively explore integrated solutions of "photovoltaic + energy storage", and by equipping with energy storage facilities to smooth out power output, effectively enhance the consumption rate of green electricity and the stability of power usage. Ultimately, by focusing on building a number of "zero-carbon benchmark factories", a replicable and scalable comprehensive emission reduction model can be formed. This will lead by example and drive the Chaozhou ceramic industry to achieve a qualitative leap from energy conservation in individual links to low-carbonization throughout the entire chain.

To sum up, although the Chaozhou ceramic industry has established a systematic carbon reduction framework through technological innovation, a complete industrial chain and policy guidance, the financial pressure on small and medium-sized enterprises and the stability of green electricity remain the main challenges. In the future, the industry needs to leverage financial innovation, "photovoltaic + energy storage" and zero-carbon benchmarks and other measures to promote a deep low-carbon transformation throughout the entire industrial chain.

2.3 Analysis of Key Factors Affecting Technology Application

Under the "dual carbon" goals, the application of innovative carbon reduction technologies is the core driving force for the transformation of the Chaozhou ceramic industry. However, its comprehensive promotion and in-depth penetration are facing key constraints from three aspects: enterprise structure, talent support, and the innovation ecosystem.

Firstly, the "weak and fragmented" structure of enterprises fundamentally restricts the scale and efficiency of technology application. The industrial ecosystem of Chaozhou's ceramic industry is composed of thousands of small, medium and micro enterprises, and its inherent "small, scattered and weak" pattern brings about dual challenges. On the one hand, the limited scale of funds makes it difficult for them to bear the initial investment and operating costs of electric kilns, distributed photovoltaic systems and carbon management systems, thus falling into a predicament of "willing to transform but unable to invest" . On the other hand, enterprises are geographically scattered and the parks are far apart. This physical separation makes it impossible for them to share centralized energy supply, pollutant treatment facilities and a unified carbon accounting platform as large integrated parks do. This greatly increases the management costs and technical difficulties of the entire industrial chain in reducing carbon emissions in a coordinated manner, and fundamentally weakens the scale benefits and feasibility of implementing innovative carbon reduction technologies.

Secondly, the scarcity and insufficiency of human resources fundamentally undermine the intellectual foundation for the application and iteration of technology. Talent is the executor of technology application and the source of innovation. The shortage of funds in small, medium and micro enterprises makes it difficult for them to offer competitive salaries and complete career development channels, and they are unable to establish effective mechanisms for talent introduction and retention, resulting in a severe shortage of professional talents in energy conservation technology and carbon management fields. Furthermore, the unique Chao-Shan culture and dialect environment have set up an invisible communication barrier for the incoming technical and management talents, deepening the estrangement between the "local circle" and the "outsiders", making it difficult for talents to truly integrate. Eventually, this leads to a vicious cycle of "not being able to attract and retain". Without a stable talent pool, not only will the most cutting-edge carbon reduction technologies be left unoperated, but even the existing technical equipment will be unable to achieve its optimal performance.

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Ultimately, the poor and inferior innovation capacity has, in the long run, restricted the endogenous impetus for technological application and the industrial value. The long-term shortage of funds and talents eventually trickles down to the innovation level of enterprises, resulting in a "low-end lock-in" effect. Due to the lack of investment in research and development and high-end talents, enterprises find it difficult to carry out original product and process development, and can only get trapped in homogeneous competition mainly based on imitation and price wars. This has led to the product added value remaining at a low level, with a meager profit margin, which in turn further reduces the funds available to enterprises for green technology research and application, thus forming a negative cycle that is hard to break free from. More importantly, many business managers have an insufficient understanding of the strategic value of R&D and innovation. Their short-term profit-seeking mindset far outweighs their long-term green development perspective. They view carbon reduction technologies as "costs" rather than "investments". This lag in perception is a deeper and more stubborn application barrier than the shortage of funds.

In conclusion, this study, from the perspective of innovative carbon reduction technologies, has identified three key factors that restrict the low-carbon transformation of the ceramic industry in Chaozhou. The "weak and fragmented" corporate structure restricts the large-scale application of technology, the "scarce and deficient" talent resources affect the effective implementation of technology, and the "poor and inferior" innovation ecosystem hinders the value enhancement of technology. The three factors are intertwined to form barriers to transformation. Only by systematically resolving these predicaments can the technological potential be transformed into the driving force for emission reduction, and can the industry achieve high-quality development under the "dual carbon" goals.

3. Enterprise Performance Differentiation and the Low-carbon Transformation Path of the Ceramic Industry

In the face of the current severe situation in the Chaozhou ceramic industry - with a capacity utilization rate of only 60%, significantly lower than the industrial average, a continuous decline in the production and sales volume of traditional ceramic tiles, and a performance differentiation phenomenon where the majority of enterprises experience a double decline in revenue and profits - the low-carbon transformation of the industry has become an urgent matter. Data shows that market demand is shifting from traditional ceramic tiles to new materials such as large-format slabs, and the downward pressure on the real estate market has further intensified the urgency of the transformation. Against this backdrop, the performance divergence among enterprises not only reflects the competitive landscape of the market but also reveals the inevitability of low-carbon transformation. Only by breaking through the path dependence of high energy consumption and high emissions through innovative carbon reduction technologies can enterprises gain a competitive edge in the industry reshuffle and achieve sustainable development.

3.1 Data Analysis of the Capacity Utilization Rate of Chaozhou's Ceramic Industry and Macroeconomic Indicators in 2024

The industrial capacity utilization rate is an indicator that measures the actual utilization degree of industrial production capacity. It is usually expressed as the ratio of actual output to potential maximum output. This indicator can reflect the production efficiency of industrial enterprises within a certain period. When the utilization rate of industrial capacity shows high capacity, it indicates that the production capacity is close to saturation and the economic activity is high. When the data shows a low capacity utilization rate, it may reflect insufficient demand or overcapacity problems.

The capacity utilization rate of the ceramic industry refers to the ratio of the actual output to the designed production capacity of ceramic manufacturing enterprises within a specific period. High capacity utilization during production indicates that ceramic enterprises are operating at near full capacity, with resources being fully utilized. Low capacity utilization may indicate weak market demand, low production efficiency or an unreasonable capacity structure. It is necessary to enhance it through technological upgrading, market expansion and capacity adjustment.

In Table 2, the maximum value of 0.751 in 2024 is the highest, indicating that the overall capacity utilization level of the industrial sector is higher than that of the ceramic industry. The capacity utilization rate of the ceramic industry is 60%, not only lower than the industrial average of 75.1%, but also in the middle position among the three indicators, reflecting a relatively obvious problem of overcapacity in the ceramic industry, and having a weak correlation with the macroeconomic growth rate of 4.6%. The real estate market is the main area experiencing year-on-year contraction, and the decline in sales volume and sales area is much greater than that in the investment sector. Meanwhile, the fluctuation in the macroeconomic growth rate is extremely small. It can be seen that the downturn in the real estate sector is the main source of pressure on the current economy and may have a direct impact on the ceramic industry.

Table 2 Basic Indicators of Capacity Utilization Rate and Macroeconomic Indicators of Chaozhou Ceramic Industry in 2024

Basic indicators						
Name	Sample Size	Minimum Value	Maximum Value	Mean	Standard Deviation	Median
Data for 2024	3	0.046	0.751	0.466	0.371	0.600
year-on-year change	4	-0.227	-0.001	-0.125	0.097	-0.136
Indicator	6	1.000	6.000	3.500	1.871	3.500

Data source: China Ceramics Network

3.2 Data Analysis of Production and Sales of Chaozhou Ceramics Industry (2023-2024)

Table 3 Production and Sales Data of Chaozhou Ceramics Industry (2023-2024)

Indicator	2023	2024	Year-on-Year Change
Ceramic tile output	6.73 billion square meters	6.118 billion square meters	-9.2%
Ceramic tile export volume	618 million square meters	546 million square meters	-11.6%
Ceramic tile export value	4.856 billion US dollars	4.152 billion US dollars	-14.5%
Rock plate output	228.5 million square meters	240 million square meters	5%
Rock plate demand volume	195.95 million square meters	205 million square meters	4.6%

Data source: China Ceramics Network

According to Table 3 Production and Sales Data of Chaozhou Ceramics Industry (2023-2024), it can be concluded that the total output of ceramic tiles decreased from 6.73 billion square meters in 2023 to 6.118 billion square meters in 2024, representing a decline of 9.2%. This reflects changes in market demand, an increase in production costs or intensified industry competition. The export volume dropped from 618 million square meters to 546 million square meters, a decrease of 11.6%. The export volume dropped from 4.856 billion US dollars to 4.152 billion US dollars, a decrease of 14.5%. This indicates that the international market's demand for ceramic tiles is decreasing, or that the export value has dropped due to factors such as price competition and exchange rate fluctuations. The output of rock plates increased from 228.5 million square meters to 240 million square meters, representing a growth of 5%. The demand for rock plates increased from 195.95 million square meters to 205 million square meters, representing a growth of 4.6%. This reflects the increasing popularity of rock slabs as a new type of material in the market, or due to their advantages in terms of performance, aesthetics, etc., they have replaced traditional ceramic tiles in some application fields.

Table 4 Pearson Correlation Data of Production and Sales in Chaozhou's Ceramic Industry (2023-2024)

Pearson Correlation - Triangle Line Format				
	2023	2024	Year-on-year change	Indicator
2023	1			
2024	1.000**	1		
Year-on-year change	-0.754	-0.754	1	
Indicator	0.500	0.500	-0.942*	1
* p<0.05 ** p<0.01				

Data source: China Ceramics Network

According to the Pearson correlation data in Table 4 Pearson Correlation Data of Production and Sales in Chaozhou's Ceramic Industry (2023-2024), there is an extremely strong positive correlation that is highly significant. It can be demonstrated that the core indicators of ceramic products (such as the output and export volume of ceramic tiles, the output of large-size slabs, etc.) show a highly consistent trend in 2023 and 2024. The year-on-year change is moderately negatively correlated with the data of 2023. This means that the higher the indicator value in 2023, the lower the year-on-year growth rate of change will be in 2024. Through Pearson correlation analysis, the year-on-year changes of ceramic tiles and rock plates show a significant negative correlation (-0.942*), indicating that market demand or production capacity is shifting from traditional ceramic tiles to rock plates. As a product with high potential for low carbon, rock plate is expected to become an important direction for the

ISSN 2616-5902 Vol. 8, Issue 2: 85-98, DOI: 10.25236/AJBM.2026.080212

low-carbon transformation of the ceramic industry in Chaozhou. The output, export volume and export value of ceramic tiles have been continuously declining from 2023 to 2024, and they are negatively correlated with the base of 2023. It can be concluded that the downward pressure on traditional products is not only due to short-term fluctuations, but may also be related to long-term factors such as market saturation and restrictions imposed by low-carbon policies. Therefore, enterprises need to reduce carbon emissions and enhance their competitiveness. The year-on-year decline in the export volume and value of ceramic tiles (-11.6% and -14.5% respectively) was greater than the decline in production (-9.2%), and the export data for 2023 showed a negative correlation with the year-on-year change in 2024, indicating a more pronounced contraction in demand for traditional ceramic tiles in the export market.

3.3 Data Analysis of Key Enterprises' Operations in Chaozhou's Ceramic Industry (First Three Quarters of 2024)

Table 5: Key Operating Data of Major Enterprises in Chaozhou's Ceramic Industry (First Three Quarters of 2024)

Company Name	Revenue (billion yuan)	Year-on-Year Change	Net Profit (billion yuan)	Year-on-Year Change
Dongpeng Holdings	46.84	-18.27%	3.09	-50.95%
Mona Lisa	35.72	-21.41%	1.41	-57.85%
Arrows Home	48.32	-8.49%	0.32	-88.87%
Huidar Sanitary Ware	24.75	-5.97%	0.93	+100%
Keda Manufacturing	85.64	+21.85%	7.03	-65.19%

Data source: China Ceramics Network

According to the data in Table 5, the operating data of major enterprises in the Chaozhou ceramic industry (first three quarters of 2024), the revenue of Keda Manufacturing increased by 21.85% year-on-year, indicating a growth trend. This suggests that the enterprise has strong competitiveness and business expansion capabilities in the market, with an expanded market share or increased business volume. However, among them, Dongpeng Holdings, Mengna LiSa, Arrows Home Furnishing, and Weida Sanitary Ware all experienced negative year-on-year revenue growth. Among them, Mengna LiSa saw the largest decline, at -21.41%, indicating that these enterprises faced issues such as intensified market competition, reduced product demand, and ineffective sales strategies in the first three quarters, leading to a decline in business volume. Huidat Bathware's net profit increased by 100% year-on-year, achieving a significant growth. The analysis suggests that this is due to its optimization of cost structure, enhancement of product added value or exploration of new profit channels. The net profits of other enterprises all decreased year-on-year, with Arrows Home Furnishing experiencing the largest decline, reaching -88.87%. Among them, Keda Manufacturing saw a significant decline of -65.19%, which reflects that these enterprises are facing pressures such as rising costs and fierce market competition during their operation, leading to a substantial drop in net profits.

As shown in Table 5, which was analyzed through SPSS, the data analysis of the correlation among different enterprises reveals that there are significant differences in their performances in terms of revenue and net profit. Although Keda Manufacturing's net profit declined year-on-year, its revenue increased and its net profit scale remained relatively large. Overall, its business condition is relatively good. However, Arrow Home's revenue decline was relatively small, but its net profit dropped significantly, indicating problems in cost control or product pricing. The decline in revenue and net profit of most enterprises indicates that the entire industry is facing certain challenges, such as weak market demand and intensified competition. However, the significant increase in the net profit of Huidar Sanitary Ware is either due to the effective business strategies adopted by the individual enterprise during a specific period or the manifestation of some positive factors in the industry on it.

4. Application Practice and Verification of Thin-film Technology and New Energy in Chaozhou Porcelain Industry

In response to the technological path demands for the low-carbon transformation of the Chaozhou ceramic industry, this chapter focuses on two innovative directions: thinning technology and the application of new energy, for in-depth analysis. Through verification with enterprise-level data, it is found that the thickness of the product is significantly negatively correlated with the effect of emission reduction. The thinning technology has become an effective path for energy conservation and carbon reduction. Meanwhile, the application of new energy sources such as photovoltaic power generation

ISSN 2616-5902 Vol. 8, Issue 2: 85-98, DOI: 10.25236/AJBM.2026.080212

has demonstrated significant benefits in terms of reducing standard coal consumption and carbon dioxide emissions. However, there are obvious differences in the implementation effects among various enterprises. Research shows that integrating thinning process innovation with the optimization of new energy systems to build a "technology-energy" collaborative carbon reduction model can provide a low-carbon transformation solution that is both economically viable and environmentally beneficial for the ceramic industry in Chaozhou.

4.1 Data Analysis on the Implementation Effect of Thin-Type Technology in Chaozhou's Ceramic Industry

Table 6 Implementation Effects of Thin-Type Technology in Chaozhou's Ceramic Industry

Enterprise Name	Thin Product Thickness (mm)	Energy Saving Effect (%)	Emission Reduction Effect (%)
Dongpeng	5.8	16%	15%
Mona Lisa	3	25%	20%
New Pearl	4	20%	18%
Marco Polo	4.5	18%	17%

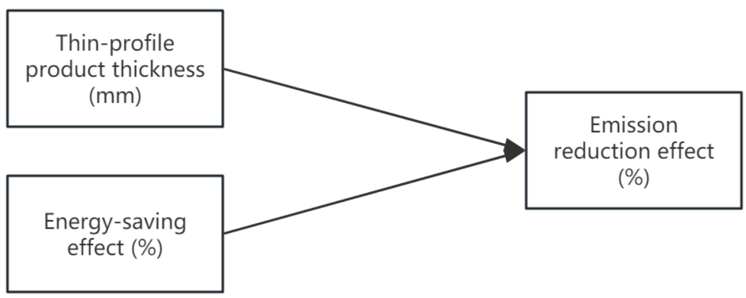
Data source: China Ceramics Network

Generally, thinning products require advanced production processes and technical support. In Table 6 Implementation Effects of Thin-Type Technology in Chaozhou's Ceramic Industry, Monalisa is able to achieve a thinner product thickness, which indicates that it has advantages in material research and development, forming technology, and other aspects. Thinner products may require less energy during production processes such as firing, thus achieving better energy-saving effects. During the product usage stage, due to its own characteristics, it is more conducive to reducing energy consumption and pollutant emissions. When enterprises invest differently in technological research and development, it will lead to performance differences in products. Enterprises that invest more resources in the research and development of thinning technology, such as Mengnalisha, may achieve more remarkable results in energy conservation and emission reduction. In contrast, enterprises with relatively less technological investment have relatively weaker performance in these two aspects.

Table 7 Results of Linear Regression Analysis on the Implementation Effects of Thinning Technology

Linear Regression Analysis Results - Simplified Format				
	Regression coefficient	95% CI	Collinearity diagnostics VIF	Tolerance
Constant	0.206* (32.810)	0.194 ~ 0.218	-	-
Thickness of thin products (mm)	-0.013* (-21.800)	-0.015 ~ -0.012	11.198	0.089
Energy-saving effect (%)	0.138 (7.413)	0.101 ~ 0.174	11.198	0.089
sample size		4		
R^2		1.000		
Adjust R^2		1.000		
F value		F (2,1)=4695. 389,p=0.010		
Note: Dependent variable = Emission reduction effect (%)				
D-W value = 2.875				
* p < 0. 05 ** p < 0. 01 (t values are in parentheses)				

Data source: China Ceramics Network



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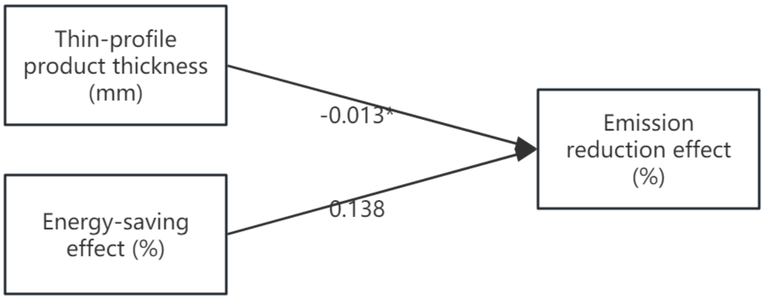

Data source: China Ceramics Network

Figure 2 Model of the Implementation Effect of Thinning Technology

Table 8 Summary of the Model for the Implementation Effects of Thinning Technology

Model Summary (Intermediate Process)						
R	R 2	Adjusted R^2	Root Mean Square Error (RMSE)	DW Value	AICValue	BICValue
1.000	1.000	1.000	0.000	2.875	-51.366	-53.207

Data source: China Ceramics Network

Based on the analysis of the linear regression results for the implementation effect of thinning technology in Table 7, the regression coefficient is -0.013 and $p < 0.05$, indicating a significant negative correlation between the thickness of thin products and the emission reduction effect. The path analysis model is shown in Figure 2. Under the condition that other factors remain unchanged, for every 1mm increase in the thickness of thin products, the expected reduction in emissions is estimated to decrease by 0.013%. The original data in Table 6 shows that the Mona Lisa product has the thinnest thickness (3mm) and its emission reduction effect is 20%, while the Dongpeng product has the thickest thickness (5.8mm) and its emission reduction effect is 15%. This is consistent with the relationship presented by the regression results, indicating that an increase in the degree of product thinning helps to enhance the emission reduction effect. The model summary, including the Durbin-Watson value, is presented in Table 8. The VIF values for both the thickness of thin-profile products and their energy-saving effects are 11.198, with a tolerance of 0.089 each. Generally speaking, a VIF greater than 10 indicates a serious multicollinearity problem. It can be analyzed that this is because thin-profile products often adopt more advanced production processes and technologies, which also contribute to improving energy-saving effects.

4.2 Data on the Application of New Energy and Energy-saving Equipment in the Chaozhou Ceramics Industry

Table 9 Data on the Application of New Energy and Energy-saving Equipment in the Chaozhou Ceramics Industry

Enterprise Name	Photovoltaic Power Generation (10,000 KWH)	Reduced Standard Coal (tons)	Reduced Carbon Dioxide (tons)
Dongpeng	4560	5604	27041
Mona Lisa	8166	32700	81400
New Pearl	6000	24000	60000
Marco Polo	5000	20000	50000

Data source: China Ceramics Network

Analyzing the content of Table 9, it is evident that enterprises with higher photovoltaic power generation have significantly greater reductions in standard coal and carbon dioxide emissions. However, enterprises with lower power generation have relatively smaller emission reduction volumes. This indicates that the photovoltaic power generation volume is the core factor determining the emission reduction effectiveness of enterprises. Through relevant calculations, it can be found that the amount of standard coal and carbon dioxide reduced per 10,000 KWH of photovoltaic power generation varies among different enterprises, which is related to their energy structure, power generation efficiency or calculation methods for emission reduction. However, the overall trend still supports the positive correlation between power generation and emission reduction.

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Table 10 Linear Regression Analysis Results of New Energy and Energy-saving Equipment Application in Chaozhou Ceramic Industry

Linear regression analysis results (n=4)							
	Unstandardized coefficient		Standardized coefficient	t	p	Collinearity diagnosis	
	B	Standard error	Beta			VIF	tolerance
Constant	574.225	225.524	-	2.546	0.238	-	-
Reduction of standard coal (tons)	1.476	0.009	0.739	167.999	0.004**	4.740	0.211
Photovoltaic power generation (10,000 KWH)	3.990	0.062	0.284	64.583	0.010**	4.740	0.211
R^2	1.000						
Adjust R^2	1.000						
F	F (2,1)=122454.424,p=0.002						
D-Wvalue	2.977						
Note: Dependent variable = Carbon dioxide reduction (tons)							
* p<0.05 ** p<0.01							

Data source: China Ceramics Network

In Table 10, the coefficient B is 1.476, which indicates that for every additional one ton of standard coal reduced in emissions, approximately 1.476 tons of carbon dioxide can be further reduced. The standardized coefficient Beta is 0.739, suggesting that its contribution to reducing carbon dioxide emissions is much greater than that of photovoltaic power generation, which is the main driving factor. The coefficient B = 3.990 indicates that for every additional 10,000 KWH of photovoltaic power generation, approximately 3.990 tons of carbon dioxide can be reduced. However, the standardized coefficient is relatively low, suggesting that its influence is relatively minor, which may be related to the variable's dimension or collinearity. The standardized coefficient Beta of 0.739 is much higher than that of photovoltaic power generation at 0.284, indicating that enterprises should prioritize reducing standard coal consumption through technological upgrades or energy structure adjustments rather than relying solely on photovoltaic power generation. Although the contribution of photovoltaic power generation is relatively low, as a clean energy source, it still has marginal emission reduction benefits, especially suitable for enterprises with limited space for reducing standard coal emissions. For the Mona Lisa Ceramics Enterprise, it should maintain its advantage in reducing standard coal consumption, explore the large-scale application of photovoltaic power generation, and further release the superimposed effect. For Dongpeng Ceramics, priority should be given to investing in coal-fired emission reduction technologies to rapidly enhance the reduction effect, while photovoltaic power generation can serve as a long-term supplement. For the New Pearl and Marco Polo ceramic enterprises, the proportion of investment in reducing standard coal emissions and photovoltaic power generation should be balanced to optimize cost-effectiveness.

5. Countermeasures for the Application of Carbon Reduction Technologies in Chaozhou's Ceramic Industry

5.1 Carbon Emission Data Analysis of Chaozhou Porcelain Industry

As shown in Table 1, the 60% capacity utilization rate of the Chaozhou ceramic industry in 2024 contrasts sharply with the industrial average of 75.1%. This gap not only highlights the issue of overcapacity but also reveals that the high-carbon emission operation model is unsustainable. A horizontal comparison of the data in Table 1 shows that the capacity utilization rate of the ceramic industry is at the median position among the three key indicators (0.600), which is not only far lower than the overall industrial level (0.751), but also significantly higher than the actual GDP growth rate (0.046). This "hollowing out in the middle" phenomenon indicates that the carbon emission issue in the ceramic industry has its own industry-specific characteristics and requires targeted emission reduction measures. As can be seen from Table 2, the high degree of dispersion with a standard deviation of 0.371 further confirms the extent of differentiation among different enterprises in terms of carbon emission performance. It is worth noting that in Table 1, all the indicators related to the real estate sector show a deep year-on-year decline, among which the sales of newly built commercial housing has the most severe drop of 22.7%. This "dual decline" in both volume and price in the real estate market has directly affected the total carbon emissions of the ceramic industry through the industrial chain transmission mechanism, especially in the ceramic tile category which is highly bound to traditional real estate. Table 3 data shows that the output of traditional ceramic tiles decreased by 9.2%

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year-on-year, with the export volume and export value dropping by 11.6% and 14.5% respectively. This overall decline in production and sales has objectively reduced some carbon emissions, but it also reflects the structural challenges faced by the industry.

5.2 Carbon Reduction Technology Practice Verification and Conclusion

Table 6 data reveals the remarkable energy-saving and emission-reduction effects of thinning technology. Mona Lisa's products are the thinnest, achieving a 25% energy-saving effect and a 20% emission-reduction effect. Among them, the products of Dongpeng have the thickest thickness, with energy-saving and emission reduction effects of 16% and 15% respectively. This negative correlation between thickness and emission reduction effect is further confirmed in the linear regression analysis in Table 7, with a regression coefficient of -0.013 and $p < 0.05$, statistically verifying the direct contribution of thinning technology to emission reduction. In terms of new energy applications, the data in Table 9 demonstrates the emission reduction benefits of photovoltaic power generation. Mona Lisa's photovoltaic power generation reached 81.66 million KWH, achieving a reduction of 32,700 tons of standard coal and 81,400 tons of carbon dioxide emissions. All these indicators lead the industry. The results of the linear regression analysis in Table 10 show that the contribution of reduced standard coal to carbon dioxide reduction is much higher than that of photovoltaic power generation. This indicates that energy structure adjustment has greater potential for emission reduction than simply increasing the supply of clean energy. It is worth noting that there are significant differences in the effects of the same technology application among different enterprises. Monalisa has performed outstandingly in both thinning and new energy applications, while Dongpeng has considerable room for improvement in both aspects. This reflects the differences in the implementation effects of technology among enterprises.

As shown in the model summary data of Table 7 and Table 10, the adjusted R^2 of the regression models for thinning technology and new energy application both reached 1.000, indicating that the effects of these carbon reduction technologies are highly predictable and stable, providing a theoretical basis for their large-scale promotion in the industry. The D-W values are 2.875 and 2.977 respectively, indicating that there is no autocorrelation problem in the model, which further enhances the reliability of the conclusion.

5.3 Countermeasures and Suggestions for the Application of Industrial Carbon Reduction Technologies

Based on data analysis and the conclusions drawn from practical tests, the following countermeasures and suggestions are proposed for the low-carbon transformation of the Chaozhou ceramic industry. Firstly, a technological upgrading path centered on thinning should be established. Enterprises should increase investment in thinning technology research and development, focusing on breaking through key technologies for the production of ultra-thin ceramic plates, and achieve carbon reduction at the source by reducing product thickness. The government may consider setting up a special fund for thinning technology to offer tax incentives and policy support to enterprises that are the first to achieve mass production of thin products. At the same time, a standard system for thinning the industry should be established to guide enterprises to transform from traditional ceramic tiles to thin products such as rock plates, in line with the changing trends of market demands. For leading enterprises in thin-film technology such as Mona Lisa, they should be encouraged to play a demonstration role and drive the overall progress of the industry through technology sharing. As for relatively late starters like Dongpeng, it is suggested that they accelerate technology catch-up through cooperation among industry, academia and research institutions.

Secondly, a clean production system should be established with the optimization of energy structure as the focus. Enterprises should prioritize the reduction of standard coal consumption and lower the consumption of fossil energy through technological means such as kiln and furnace renovation and waste heat recovery. On this basis, we should steadily promote the application of new energy sources such as photovoltaic power generation, with particular emphasis on improving the efficiency of photovoltaic systems and providing energy storage support, to avoid inefficient investment. For enterprises like Mona Lisa that have achieved remarkable results in the application of new energy, it is suggested to further explore the large-scale application of photovoltaic power generation. As for enterprises like Dongpeng that have relatively limited emission reduction effects, priority should be given to making up for the shortcomings in standard coal emission reduction, and then gradually increase the proportion of clean energy. The government may consider establishing a special trading

ISSN 2616-5902 Vol. 8, Issue 2: 85-98, DOI: 10.25236/AJBM.2026.080212

mechanism for green electricity in the ceramic industry to reduce the cost of new energy use for enterprises. At the same time, it should strictly set carbon emission access standards to force enterprises to adjust their energy structure.

Finally, a low-carbon transformation mechanism featuring the synergy of technology, energy and market should be established. Enterprises should organically integrate the application of thin-film technology with the optimization of energy structure, reduce energy demand through technological innovation and cut carbon emissions by replacing fossil fuels with clean energy, thereby achieving a dual effect of emission reduction. Industry associations should take the lead in establishing a low-carbon product certification system, guiding consumers to choose low-carbon ceramic products through market mechanisms, and forming a virtuous cycle where green consumption drives green production. Financial institutions can develop specialized credit products for the low-carbon transformation of ceramic enterprises, providing financial support for technological upgrades and energy projects. Through multi-party collaboration, they can jointly promote the construction of a low-carbon development model that is both economically viable and environmentally beneficial for the ceramic industry in Chaozhou. This will help the industry gain a competitive edge during the industry reshuffle and achieve sustainable development.

6. Research Conclusions and Prospects

6.1 Conclusion

This paper takes ceramic manufacturing enterprises as the research object. Mainly through the SPSS analysis method, the carbon emissions in the ceramic production process are analyzed. The main conclusions obtained are as follows:

Firstly, differentiated carbon reduction paths have initially taken shape, but the application of technologies is uneven. In Chaozhou's ceramic industry, daily-use porcelain, construction porcelain, and art porcelain have each developed distinct carbon reduction technology paths. Daily-use porcelain has become a benchmark for emission reduction by relying on electric kilns and waste heat recovery technologies. Construction porcelain, on the other hand, depends on thinning and large-scale application of photovoltaics, but is constrained by initial investment. Art porcelain is exploring personalized technologies such as 3D printing, yet it faces challenges of insufficient scale and conflicts with traditional craftsmanship.

Second, the performance divergence among enterprises highlights the urgency of low-carbon transformation, and market demand is shifting towards high-value-added products. The capacity utilization rate of traditional ceramic tiles is low, and their production and sales volumes have been continuously declining, while the demand for low-carbon high-value products such as large slabs has grown significantly. The divergence in revenue and net profit among enterprises has intensified, indicating that the high-energy-consuming and low-value-added model is no longer sustainable, and low-carbon transformation has become an inevitable choice to enhance competitiveness.

Thirdly, thinning and the application of new energy are effective paths for carbon reduction, but the driving factors are different. In thinning technology, the thickness of the product shows a significant negative correlation with the reduction effect of emissions, confirming its value in reducing carbon at the source. In the application of new energy, "reduction of standard coal" is the main factor driving the reduction of carbon dioxide emissions, while the contribution of photovoltaic power generation is relatively limited, highlighting the priority of improving energy efficiency over energy substitution.

Finally, the structural predicament of small and medium-sized enterprises hinders the promotion of advanced technologies, which requires systematic solutions. The interplay of three major factors - weak and diverse enterprises, scarce and deficient talents, and poor and inferior innovation - makes it difficult to popularize advanced technologies. It is necessary to break through the bottlenecks of funds, technology and talents through measures such as green finance, integration of photovoltaic and energy storage, and zero-carbon benchmark factories.

6.2 Outlook

This paper has studied the methods in response to the problems and achieved some interim results. However, there are still many issues that need to be further improved and refined in this paper. Future research can focus on the following aspects:

Firstly, deepen the calculation of carbon footprints throughout the entire life cycle. Current research focuses on the production stage. In the future, it can be expanded to cover the entire life cycle carbon footprint analysis including raw material extraction, transportation, and waste disposal, to establish a more complete carbon emission database and support precise emission reduction decisions.

Second, explore the collaborative benefits of multiple technology couplings. This paper focuses on thinning and new energy. In the future, the integrated application of technologies such as waste heat recovery, hydrogen energy furnaces, and carbon capture can be studied, and a multi-dimensional collaborative model of "technology-energy-process" can be constructed to optimize the cost-effectiveness of emission reduction.

The final step is to construct an interactive model of dynamic policies and enterprise behavior. By introducing system dynamics or agent models, the impact of policies such as carbon taxes, subsidies, and green electricity trading on enterprises' technology adoption behavior can be simulated, providing forward-looking basis for the design of regional industrial policies.

Acknowledgement

Fundings: 2025 National College Student Innovation and Entrepreneurship Training Program (National Level)

Project Name: Ceramic Chain Intelligence Creation: AIGC-Driven Revitalization of Chaozhou Ceramics Intangible Heritage and Topological Optimization of Supply Chain Carbon Resilience under the Perspective of New Quality Productivity

Project number: 202513719010X

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