


Article

Investigating Environmental Efficiency Upgrading Path of Construction Waste Based on Configuration Analysis

Clyde Zhengdao Li ¹ , Xinyi Ling ¹, Mingyang Jiang ^{2,*} and Peiying Xie ¹

¹ Key Laboratory for Resilient Infrastructures of Coastal Cities, Ministry of Education, Shenzhen University, Shenzhen 518060, China; clyde.zhengdao.li@szu.edu.cn (C.Z.L.); 2100474003@szu.edu.cn (X.L.); 1900474001@szu.edu.cn (P.X.)

² Department of Building and Real Estate, The Hong Kong Polytechnic University, Kowloon, Hong Kong

* Correspondence: ming-yang.jiang@connect.polyu.hk; Tel.: +852-56225521

Abstract: The rapid development of urbanization and large-scale engineering projects have led to the output of a large quantity of construction waste, which also puts great pressure on the environment. Environmental efficiency, as one of the criteria for measuring sustainable development, can be used to measure the impact of enterprises, industries, or regions on the environment when creating economic value. This research takes 30 provinces in China as samples and uses configuration analysis and fuzzy-set qualitative comparative analysis (fsQCA) methods to analyze the combined effects of factors affecting the environmental efficiency of construction waste generation, to find upgrading paths to improve environmental efficiency. The results indicate that five configurations can promote provinces to achieve high environmental efficiency, which can be classified into three types: population density, technological innovation, and policy economy. These three configurations reveal the comprehensive impact of systematic correlations among population, technology, policy, and economic factors on environmental efficiency improvements. This research provides a certain theoretical reference for exploring the influencing factors of environmental efficiency and provides theoretical guidance for selecting different paths to improve the environmental efficiency of construction waste in regions with different social conditions.

Keywords: construction waste; environmental efficiency; configuration analysis; fuzzy-set qualitative comparative analysis (fsQCA)



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1. Introduction

For the past few years, the rapid urbanization of China has brought about large-scale development and the construction of engineering projects [1]. Construction sites generate a lot of construction waste in a short period [2]. According to statistical data, the annual average emissions from construction waste in China in recent years are around 2 billion tons, accounting for up to 40% of all solid waste in the city [3]. Combined with the statistics from the relevant departments of the Chinese government, construction waste production topped 3 billion tons in 2020 [4]. The vast majority of construction waste was transported to the suburbs or rural areas without any treatment, using open-air stacking or landfill methods for disposal, which occupies a lot of valuable land resources [5]. The generation of construction waste has caused a significant burden on the environment [6], including resource and energy consumption, dust and noise pollution, waste gas and water emissions, and land resource occupation, which is mainly manifested in the following ways: Firstly, the pre-construction project requires a large number of building materials to be put into production, and the production of building materials consumes certain resources and energy, and emits greenhouse gases [7]. Secondly, the operation of machinery and equipment during the collection, sorting, and transportation of waste also consume energy and emit greenhouse gases. Finally, the disposal of construction waste, whether it is

piled up, landfilled, or illegally dumped, will take up land space and destroy the original moisture and fertility of the land [8].

In the context in various countries around the world of active energy conservation and carbon emission reduction [9], China is also vigorously developing a green economy and implementing carbon peaking and carbon neutrality goals [10]. The construction industry is one of the important pillars of China's national economy, so promoting green construction has been the most urgent task, as enhancing the environmental efficiency of construction waste output cannot be delayed [11]. How to reduce construction waste and minimize its negative impact on the environment is an urgent problem. Initially, attention was focused on cleaning to ensure a clean and hygienic urban environment, but as the amount of waste increased, it was recognized that cleaning, transporting, and direct landfilling alone can no longer effectively resolve the conflict between waste and the environment, until the term "reduction" was first mentioned in the Circular Economy Promotion Law promulgated in 2008 [12]. As an important concept in the field of solid waste management, the most recognized concepts in the academic world are the three interpretations of quantification: reduction in waste generation, reduction in waste disposal, and reduction in waste emissions. It can be seen that quantification is several separate actions whose goal is to reduce the amount of waste at each stage of its occurrence.

Under the development model of the new age, it is necessary to improve development efficiency based on environmental protection. The 17 Sustainable Development Goals (SDGs) of the 2030 agenda are a set of global development goals set by the United Nations aimed at addressing the most pressing global development challenges. It mentions the goal of making cities and human settlements inclusive, safe, resilient, and sustainable, as well as the goal of taking urgent action to address climate change and its impacts. To achieve the goal of sustainable development in the construction industry, it is necessary to consider the loss of resources during the construction process and the impact of resources on the environment. In this research, the environmental efficiency of construction waste output is defined as the ratio of the economic value obtained in the process of production activities in the construction industry to its corresponding environmental impact, in which the environmental impact is expressed by the amount of construction waste generated. Shen et al. [13] analyzed the impact of industrial agglomeration on industrial environmental efficiency in China, using a spatial panel model, and the results showed that there was a U-shaped relationship between industrial agglomeration and industrial environmental efficiency in China. Lu et al. [14] measured environmental efficiency from the perspective of local leaders and used a two-step analysis method of the meta-boundary and stochastic boundary. The results showed that the term of office of the mayor had an inverted-U-shape relationship with environmental efficiency. Mayors who are highly educated, young, and environmentally conscious can enhance environmental efficiency. And the experience of the mayor in official conversations can also contribute to environmental efficiency. To investigate the main factors affecting the environmental efficiency of construction waste generation, this research adopts the fuzzy-set qualitative comparative analysis (fsQCA) proposed by Ragin, a method that combines fuzzy mathematics with qualitative comparative analysis [13]. Compared to case studies or multiple regression, fsQCA aims to identify combinations of configurations that lead to higher or lower levels of environmental efficiency, thus effectively explaining the causes of differences in the environmental efficiency of construction waste generation.

This research not only identifies the core elements affecting the environmental efficiency of construction waste generation but also obtains the configurations affecting the environmental efficiency of construction waste generation. This research provides a reference for regions to select the configurations to enhance the environmental efficiency of construction waste generation, and in addition, provides a theoretical significance for the development of environmental efficiency. This research first conducted a literature review on the environmental efficiency of construction waste and then elaborated on the research methods and specific research steps used in this study. After collecting data, empirical

analysis was used to obtain the configuration results of the influencing factors that affect the environmental efficiency of construction waste generation. Finally, the results were analyzed and suggestions were given, as well as the shortcomings of the research.

2. Literature Review

2.1. Environmental Efficiency of Construction Waste Management

The rapid growth of urbanization causes a construction site to produce a large surplus of construction waste in a short time. The process of generating construction waste consumes a notable amount of natural resources and energy, and at the same time emits greenhouse gases, occupies a large surplus of arable land and forest land, and has an obvious impact on the environment. The implementation of construction waste reduction and resource utilization can reduce the quantity of construction waste generated and create certain environmental benefits. Marzouk et al. [14] constructed a dynamic model of construction waste management through the use of STELLA v3.0 software for analysis. The results revealed that the recycling of construction waste can significantly reduce the emission of greenhouse gases, energy consumption, and the use of landfills. It can also reduce Global Warming Potential (GWP) at the same time. Ibrahim et al. [15] explored how the waste management of an engineering project affects the environment from the perspective of sustainable development, and the final results confirmed that recycling and reusing construction waste can not only increase economic benefits but also enhance environmental benefits, such as saving the number of landfills for construction waste and reducing carbon emissions.

Hossain et al. [16] compared the environmental benefits of different construction waste management systems in Hong Kong, using the Life-cycle assessment (LCA), and concluded that off-site sorting and direct land-filling would have a significant influence on the environment, while on-site sorting could achieve better environmental benefits. Wang et al. [17] used the Life-cycle Assessment (LCA) to explore the environmental impact of 1 ton of construction waste in Shenzhen, China, from the perspective of willingness to pay. The results revealed that recycling and utilization would bring significant environmental impacts. The results indicate that recycling can bring certain environmental benefits. Most scholars have used the LCA method to explore the recycling and disposal effects of construction waste after it has been generated, with little research on preventing construction waste generation. Therefore, Llatas et al. [18] established an environmental benefit model based on a full lifecycle assessment to simulate the amount of construction waste generated in both preventive and non-preventive situations. The research results showed that preventive situations can effectively reduce the output of construction waste, and the efficiency of construction waste recovery and treatment is significantly higher than that of non-preventive measures.

Some scholars have researched the environmental benefits of construction waste in Shenzhen, China. Ding et al. [19] constructed a new dynamic model based on system dynamics and the theory of planned behavior and simulated a project in Shenzhen through Vensim 64 bit version software. The simulation concluded that about 30% of construction waste would not be generated if the relevant departments implemented reduction management, thus reducing environmental pollution and the management cost of construction waste for the relevant enterprises. Li et al. [20] measured the environmental impacts of construction waste resource utilization by selecting four construction waste resource utilization projects in Shenzhen, using a full life cycle assessment methodology, and collecting data from the mobile resource utilization process and energy consumption of each project.

2.2. Theory of Environmental Efficiency

Environmental efficiency originated in the 1990s with the concept of resource environmental efficiency proposed by the German scholars Schaltegger et al., who defined it as the ratio of economic growth to environmental pollution in the production process. Then, in 1992, the World Business Council for Sustainable Development (WBCSD) defined environ-

mental efficiency as the ratio of the economic value of products and services that satisfy human needs to the environmental load, which can also be understood as the economic value per unit of environmental load. As academics have increasingly focused on the issue of environmental efficiency, several scholars have defined the concept of environmental efficiency. Kuosmanen et al. [21] considered that environmental efficiency refers to the proportion of economic benefits achieved in the actual production process and its negative effects on the environment. Tenente et al. [22] believed that environmental efficiency refers to the minimization of pollutants in principle when the inputs and desired outputs remain unchanged.

By organizing and researching the related literature, this study defines environmental efficiency as the proportion of the total amount of construction profits and taxes obtained in the process of production activities in the construction industry to the environmental impact it causes. Environmental factors are added to the process of production activities in engineering corporations to calculate the input–output proportion, in which the environmental impact is indicated by the production of environmental pollutants. The input indicators selected for this study include labor, capital, and resource consumption, the desired output is the total profit tax of the construction industry, and the non-desired output indicator is selected as the quantity of construction waste generated. The more construction waste generated, the lower the environmental efficiency, and vice versa, the higher the environmental efficiency.

Through existing research, it was found that scholars have implemented a range of studies on construction waste management and environmental efficiency from different perspectives. This reflects the importance of research on the theme of construction waste management and environmental efficiency. However, existing research on environmental efficiency focuses on energy, government power, and the level of marketization, and does not pay much attention to the impact of construction waste on environmental efficiency.

3. Research Methodology

3.1. Theoretical Model

As early as the 1980s, American sociologist Ragin proposed qualitative comparative analysis (QCA) based on set theory and Boolean algebra [13]. By using Boolean algebra to express logical relationships, this method combines the advantages of both qualitative analysis, where the analysis is based on cases, and quantitative analysis, where the study is based on quantities. In the continuous development and progress of the QCA method, Ragin also proposed fuzzy-set qualitative comparative analysis (fsQCA) based on the original methodology, which is a research methodology integrating fuzzy mathematics and qualitative comparative analysis [23]. The fsQCA method also integrates fuzzy sets and truth values, allowing for the continuous assignment of antecedent and outcome variables during qualitative comparative analysis, and the affiliation of variables can be any number between 0 and 1, which can be used for studies with continuous changes in the raw data. Subsequently, these data were converted into truth tables to ensure that the dominance of truth tables in qualitative data analysis was utilized, thus giving the method the dual attributes of both qualitative and quantitative analysis.

This research takes 30 provinces in China as samples, using configuration analysis and fsQCA methods to explore the comprehensive effects of factors affecting the environmental efficiency of construction waste generation. At the same time, it analyzes the configuration modes that can enhance the environmental efficiency of construction waste generation in China, and finds the key factors and corresponding configuration modes to enhance the environmental efficiency of construction waste generation in various provinces.

The concrete steps for using the fsQCA method are as follows:

- (1) Select variables: Based on the research question, the outcome variable and antecedent variable were selected. In this research, the environmental efficiency of construction waste generation was chosen as the outcome variable, and the antecedent variable was selected using the PEST analysis method.

- (2) Calibrate variables: Different qualitative breakpoints were set to convert the raw data of variables into fuzzy membership scores between 0 and 1. Among them, there were three anchor points: complete membership points (fuzzy membership = 1), cross-membership points (fuzzy membership = 0.50), and completely non-membership points (fuzzy membership = 0).
- (3) Check the necessary conditions: Because the fsQCA method studies the impact of the combination pattern of antecedents on the outcome variable, it is necessary to conduct a necessity analysis of the antecedent variable after determining the anchor points of the antecedent and outcome variables. If necessary conditions exist, they need to be removed to avoid it affecting the research results.
- (4) Establish the truth table: we imported the calibrated data into fsQCA v3.0 software and constructed a 2^n row truth table, where “n” denotes the number of antecedent variables and each row denotes different combinations that may affect the final results. Therefore, this research set the frequency and consistency threshold of the results, removed combinations that did not meet the conditions, and obtained the final truth table.
- (5) Analyze the combination of conditions and results: By using fsQCA software, complex solutions, concise solutions, and intermediate solutions can be obtained simultaneously, due to the inclusion of eligible “logical residuals” in the mediation solution and the preservation of the necessary conditions for the outcome variable. Therefore, the intermediate solution is superior to the other two solutions in general. In addition, it is necessary to define the type of antecedent variable. If the antecedent variable occurs in the configuration of intermediate and simplified solutions, then that antecedent variable is the core condition and has a strong causal relationship with the results; if the antecedent variable only occurs in the configuration of the intermediate solution, then the antecedent variable is an edge condition and has a weaker impact on the results.

3.2. Data Collection

3.2.1. Data Sources

There are a total of 34 provinces, municipalities, and autonomous regions in China (hereinafter referred to as provinces), but there are differences in economic development, pollution control, and many other aspects among different provinces. Therefore, the environmental efficiency of different provinces will also vary. In this study, 30 provinces in China (excluding Tibet, Hong Kong, Macao, and Taiwan) were taken as research samples, and panel data from 2011 to 2020 were collected as data values of antecedent variables, including per capita GDP, the permanent population, urban population ratio, standard mileage of highways, and patent application authorization data. These data were all sourced from the China Statistical Yearbook for each year from 2012 to 2021. The land area data were sourced from the China Administrative Region Network www.xzqy.net/ (accessed on 4 February 2022).

3.2.2. Variable Selection

Based on the research questions, the environmental efficiency of construction waste generation (EE) was selected as the outcome variable in this study, and the factors affecting the environmental efficiency of construction waste generation were selected as the antecedent variables. Referring to the research of Liu et al. [5], the results of the environmental efficiency of construction waste output in each province were obtained separately by setting input–output indicators and using the Slacks-based Measure (SBM) model to measure the environmental efficiency.

The configuration perspective that the organization should take a holistic idea cannot be analyzed in isolation: there may be a variety of factors affecting the environmental efficiency of construction waste generation. Therefore, there is a need to introduce some other factors that may have effects on the problem of construction waste generation into

the model to control the impact of the experimental variables outside the experimental variables. In this research, to explore the effects of factor combination configurations on the environmental efficiency of construction waste output, the antecedent variables were selected based on PEST analysis [24]. PEST analysis is a widely used method of political–legal factors (P—Political) which is mainly composed of four types of external environmental factors: political–legal (P—Economic), economic (E—Economic), social–cultural (S—Social), and technological (T—Technological). Based on this, this study selected the policy intensity of construction waste (PI) [25] as the political–legal factor, economic development (ED) [26] as the economic factor, population density (PD), urbanization level (UL), and freeway density (FD) [27] as the social–cultural factor, and technological innovation (TI) [28] as the technological factor. The selected influencing factors above constitute the antecedent variables of this study.

The selected antecedent variables are described as follows:

- (1) Policy intensity of construction waste (PI): In the process of construction waste management, the initial step is to constrain relevant aspects from the perspective of policies and regulations, so that the government can carry out macroeconomic regulation and achieve the purpose of guidance. The strength of policy intensity will also have a certain effect on construction waste management.
- (2) Economic development (ED): The better the economic development level of a region, the more attention it pays to the environmental problems of the city. This can significantly improve the problem of construction waste management in the process of engineering and construction. In this research, per capita gross domestic product (GDP) is used as an indicator of the level of economic development.
- (3) Population density (PD): Population density can represent the standard of economic development and land scarcity of a region. Since the haphazard dumping of construction waste takes up a certain amount of land resources, regions that emphasize the more significant problems of construction waste generation may be regions with less available land resources. Therefore, population density can be used to consider the environmental efficiency problem of construction waste generation. Population density data are measured using the proportion of the resident population to land area.
- (4) Urbanization level (UL): In the progress of urbanization development, the number of engineering projects is also growing rapidly. A large quantity of construction waste may be generated, which poses a serious threat to the environment and puts a lot of pressure on the ecological environment. The proportion of the urban population is selected as a measure of the urbanization level in this study.
- (5) Freeway density (FD): Freeway density reflects the degree of transportation accessibility of a region. Its increased level can reduce the cost of delivery of construction waste and the cost of engineering and construction, thus reducing the landfill of construction waste. This factor may have a positive impact on the environmental efficiency of construction waste generation. In this research, the ratio of standard freeway mileage to land area was used to measure the freeway density indicator.
- (6) Technological innovation (TI): Technological innovation is the staple driving force for technological processes, which helps to enhance the level of economic development and is essential for improving environmental efficiency. In this research, the quantity of patent applications was chosen as a measurement of scientific and technological innovation.

3.3. Data Analysis

3.3.1. Variable Measurement and Calibration

The fsQCA method is suitable for studies with a sample size between 10 and 60 [29]. In this research, the data on the results of environmental efficiency measurements and its impact factors in 30 provinces in China were selected to meet the requirements of the fsQCA method for sample size. The environmental efficiency of construction waste generation

was used as the outcome variable, and the intensity of construction waste policy, economic development level, population density, urbanization level, freeway density, and science and technology innovation were used as the antecedent variables.

The most critical aspect in the study of the problem using the fsQCA method is the calibration of the variables, which denotes the process of assigning pooled affiliation to all the antecedent and outcome variables of the study object, with the calibrated pooled affiliation ranging from 0 to 1 [30]. In the process of calibrating the variables, there is a need to define the three anchor points of the variables: the full affiliation point, which represents a fuzzy affiliation value equal to 1, the full unaffiliated point, which represents a fuzzy affiliation value equal to 0, and the crossover point, which represents a fuzzy affiliation value equal to 0.50. Based on the qualitative criteria given by the existing research [31], the values chosen for this study were the 95% quartile as the full affiliation point, the 5% quartile as the full unaffiliated point, and the median as the cross-affiliation point. In addition, the value of environmental efficiency of construction waste itself is a value between 0 and 1, so no calibration is needed [32]. Only six conditional variables, construction waste policy intensity, economic development level, population density, urbanization level, freeway density, and technology innovation, were calibrated. Indicator descriptions and anchors for the antecedent variables are shown in Table 1.

Table 1. Anchors for the antecedent variables.

Variable Label	Measured Variable	Anchor Point		
		Full Affiliation Point	Cross-Affiliation Point	Unaffiliated Point
PI	Policy Intensity of Construction Waste	17.16	3.02	0.75
ED	Economic Development	159,872.45	58,499.00	39,647.00
PD	Population Density	2511.26	286.69	12.25
UL	Urbanization Level (of a city or town)	88.34	62.65	51.250
FD	Freeway Density	1210.87	360.43	41.30
TI	Technological Innovation	593,918.10	67,979.00	6352.35

3.3.2. Analysis of Necessary Conditions

According to the steps of the fsQCA analysis, the necessity assessment is carried out in all research cases once the anchors of the antecedent and outcome variables have been determined. When the assessment is conducted, if there is an antecedent variable that is a condition that will bring out the appearance of the outcome, then this antecedent variable must appear in the outcome configuration to avoid its presence from influencing the outcome. Therefore, it can be eliminated from the subsequent qualitative comparative analysis. This study analyzed the necessary conditions for each antecedent variable based on the calibration data of the outcome variables and antecedent variables in the previous section. According to the research of Ragin, a conditional variable must have a consist value greater than 0.9 in the necessary conditions analysis for the outcome, and only then can this variant be regarded as a necessary condition for the emergence of the outcome [13]. Therefore, the fsQCA software was used to perform the consist analysis to obtain the consist value of each antecedent variable to the outcome variable.

Based on the above analytical calculations, the results of the necessity analysis are expressed in Table 2.

Table 2. Necessity analysis of individual antecedent variables.

Antecedent Variable	EE		~EE	
	Consist	Degree of Coverage	Consist	Degree of Coverage
PI	0.57	0.77	0.66	0.61
~PI	0.72	0.76	0.76	0.54
ED	0.63	0.80	0.65	0.56
~ED	0.65	0.73	0.76	0.58
PD	0.55	0.78	0.61	0.60
~PD	0.72	0.73	0.78	0.54
UL	0.61	0.77	0.66	0.56
~UL	0.65	0.74	0.73	0.56
FD	0.56	0.76	0.64	0.59
~FD	0.70	0.74	0.74	0.54
TI	0.52	0.77	0.60	0.61
~TI	0.74	0.73	0.77	0.52

Note: ~ represents the INVERT in AND-OR-INVERT.

From the results, it is clear that the consist value of the antecedent variables on the outcome variables was less than 0.90, indicating that no condition of necessity leads to the environmental efficiency of construction waste, but which also indicates that the environmental impact on construction waste is also not determined only by a specific element, and it is necessary to analyze a combination of influencing factors to determine that a configuration of the results may exist.

3.3.3. Constructing the Truth Table

Transforming the data after performing the calibration into sample values of pooled clear affiliation generates 2^n combination paths, with n being the number of conditioning variables. In this study, six antecedent variables were chosen, so 64 combination paths were generated. When fsQCA software was used to develop the histogram analysis, considering the relatively small total number of samples, the frequency threshold was installed to 1. At the same time, based on the existing studies, the raw consist and PRI consists of the different truth table rows were sorted, and the values with natural truncation were determined as the raw consist threshold and the PRI consist threshold [33]. After sorting the raw consist of the truth table rows in this study, it was found that the raw consist values of the first 12 rows were all greater than 0.92, while the raw consist scores from the 13th row onwards were significantly lower than 0.89, and the raw consist appeared to be naturally truncated at the value of 0.92. Therefore, 0.92 was selected as the raw consist threshold. Similarly, the PRI consist was sorted and found to be naturally truncated at the value of 0.91, and 0.91 was selected as the PRI consist threshold. The truth table constructed is shown in Table 3.

3.3.4. Conditional Configuration Analysis

An fsQCA analysis will generate complex, parsimonious, and intermediate solutions with different degrees of simplification. These three solutions are not only different in sophistication but also different in apocalypse and generalization. The complex solution is the most stringent, but the conclusion is usually more complex and less generalizable. The simple solution is the most lenient, but the conclusions are usually simpler, and many research conclusions are likely to conflict with the actual situation, so it is less enlightening. The positioning of the intermediate solution is actually between the complex solution and the simple solution, so it can be interpreted as the “logical remainder” of the conditions, and in the simplification of the process will also retain the necessary conditions, so the conclusion can be a more comprehensive description of the problem and is more enlightening and generalizable.

Table 3. Configuration truth table analysis.

PI	ED	PD	UL	FD	TI	Number	EE	Raw Consist	PRI Consist	SYM Consist
0	1	1	0	0	1	1	1	0.98	0.94	0.94
0	0	1	0	0	0	1	1	0.97	0.93	0.93
1	1	1	0	0	1	1	1	0.97	0.92	0.92
0	0	0	0	1	1	1	1	0.97	0.91	0.91
1	1	0	1	0	0	1	1	0.97	0.93	0.93
1	1	1	1	1	0	1	1	0.96	0.91	0.91
0	1	1	1	0	0	1	0	0.95	0.89	0.89
1	0	0	1	0	0	1	0	0.94	0.87	0.87
1	0	0	0	0	1	1	0	0.94	0.83	0.83
1	0	1	0	1	1	2	0	0.93	0.83	0.83
0	1	0	1	0	0	1	0	0.93	0.83	0.85
0	0	0	1	0	0	2	0	0.92	0.82	0.82
0	1	1	1	1	1	3	0	0.89	0.76	0.76
1	0	0	0	1	0	2	0	0.89	0.76	0.76
1	1	1	1	1	1	6	0	0.88	0.74	0.74
0	0	0	0	0	0	5	0	0.85	0.71	0.75

In order to compare and analyze the importance of each antecedent variable and its impact on the final result in depth, this study used a Ragin logic scheme table to organize the final results and grouped all configurations of intermediate solutions based on core conditions [34]. The results are indicated in Table 4.

Table 4. Environmental efficiency configuration of construction waste generation.

Antecedent Variable	Population Density Type		Technologically Innovative Type	Policy Economy Type	
	Configuration 1a	Configuration 1b	Configuration 2	Configuration 3a	Configuration 3b
PI		⊙	⊙	●	●
ED	●	⊙	⊙	●	●
PD	●	●	⊙	⊙	●
UL	⊙	⊙	⊙	●	●
FD	⊙	⊙	●	⊙	●
TI	●	⊙	●	⊙	⊙
Concordance	0.973	0.973	0.970	0.968	0.963
Original coverage	0.326	0.358	0.321	0.276	0.292
Independent coverage	0.021	0.029	0.004	0.026	0.047
Overall consistency			0.930		
Overall coverage			0.499		

Note: According to the methodology that was used, a solid black circle (●) indicates that the condition exists, and a dotted circle (⊙) indicates that the condition does not exist, and within this, the green circle represents that it is a core condition, and the red circle represents that it is a borderline condition. A blank space indicates uncertainty; i.e., the condition does not necessarily exist.

4. Results

There were five configurations (1a, 1b, 2, 3a, 3b) for the fsQCA methodology to produce high environmental efficiency in construction waste generation, where 1a and 1b constitute second-order equivalent configurations; i.e., they have the same core conditions [35]. Configuration 3a and configuration 3b were the same. Therefore, the five configurations were categorized into three configurations: population density type, technology innovation type, and policy economy type. From the results, it can be seen that both the consist of the individual configurations and the overall consist had values greater than the raw consist threshold of 0.922. This indicates that the five configurations are sufficient conditions that lead to environmental efficiency in the generation of construction waste. The raw

coverage of the five configurations ranged between 0.276 and 0.358, which suggests that there is no situation in which a single configuration can fully explain all the cases. The independent coverage lay between 0.020 and 0.047, indicating that the environmental efficiency is influenced by a combination of antecedent variables.

Each of the upgrading paths of environment efficiency is analyzed in detail below:

(1) Population Density Type

Configuration 1a: $ED \times PD \times \sim UL \times \sim FD \times TI$ can be categorized as a population density type. In this configuration, a high population density, non-high level of urbanization, and non-high freeway density are the core conditions. Meanwhile, a high level of economic development and high-tech innovation are the peripheral conditions, and the intensity of construction waste policy is an irrelevant condition. This configuration indicates that the environmental efficiency of construction waste generation can be improved by increasing population density, economic development level, and high-tech innovation in areas with insufficient urbanization level and freeway density. In this case, the role of construction waste policy intensity in generating the high environmental efficiency of construction waste generation is not important. Configuration 1a contains two cases, Anhui and Hunan provinces, which both have a high standard of economic development and technological innovation in addition to a better population density. Although the standard of economic development and science and technology innovation are essential as marginal conditions, the other two conditions are core, but both are non-high states. One of the typical case areas is Hunan, where the level of urbanization and freeway density in 2020 are at a low to medium level, and the population density ranks high in the country. In addition, Hunan is actively pursuing economic growth, with increasing investment in fixed assets in the construction industry, increasing investment in R&D, and increasing levels of scientific and technological innovation, so that in 2020 Hunan's level of economic development and scientific and technological innovation will be at the forefront of the country.

Configuration 1b, $\sim PI \times \sim ED \times PD \times \sim UL \times \sim FD \times \sim TI$, can also be categorized as population density type. In this configuration, a high population density, non-high level of urbanization, and non-high freeway density are also core conditions, while a non-high construction waste policy intensity, non-high level of economic development, and non-high-tech innovation are marginal conditions. This configuration indicates that relying on high population density can also promote the environmental efficiency of construction waste generation when the construction waste policy intensity, level of economic development, level of urbanization, freeway density, and high-tech innovation are not strong enough. A case included in Configuration 1b was Hainan province, which relies on its high population density to achieve high environmental efficiency from construction waste. However, the intensity of construction waste policy, level of economic development, level of urbanization, freeway density, and technological innovation were not high in this configuration.

(2) Technology Innovation Type

Configuration 2, $\sim PI \times \sim ED \times \sim PD \times \sim UL \times FD \times TI$, can be categorized as high-tech innovative. In this configuration, non-high construction waste policy intensity, non-high urbanization level, and high-tech innovation are the core conditions, and non-high economic development level, non-high population density, and high freeway density can be classified as some auxiliary conditions. This configuration indicates that even if the impacts of construction waste policy intensity, economic development level, population density, and urbanization level are not high, with the help of the advantageous condition of freeway density, once the relevant departments play the role of technology innovation, the environmental efficiency of the generation of construction waste can be improved to a great extent. The case included in Configuration 2 is Jiangxi province, which, in addition to having a high level of technology innovation, also has a high freeway density. Although freeway density is a marginal condition, it is also crucial, and the other four conditions are either core or marginal, but all are non-high states. In addition, Jiangxi's construction waste policy intensity and urbanization level were low in 2020, but technology innovation

was in a higher position in the country. In the “Chinese Statistical Yearbook” related data can be seen: Jiangxi’s patent authorization for 80,239 items in 2020, and the previous year 59,150 items, a year-on-year increase of 35.7%. This shows that the level of technological innovation in Jiangxi has been steadily enhancing, and Jiangxi has laid a solid foundation for effectively improving the environmental efficiency generated by construction waste.

(3) Policy Economic Type

Configuration 3a, $PI \times ED \times \sim PD \times UL \times \sim FD \times \sim TI$, can be categorized as policy-economic. In this configuration, a high construction waste policy intensity, high economic development level, and non-high-tech innovation are the core conditions, while a non-high population density, high urbanization level, non-high freeway density, and non-high-tech innovation play a supporting role. This configuration suggests that the combined effect of emphasizing construction waste policy intensity and economic development level can enhance the environmental efficiency of construction waste generation, even if population density, freeway density, and high-tech innovation are not prominent, aided by the advantageous conditions of urbanization level. The case included in Configuration 3a is Shaanxi province, which, in addition to having a high level of construction waste policy intensity and economic development, also has a high level of urbanization. But as a marginal condition, it plays only a secondary and minor role, and the other three conditions, one of which is a core condition and two of which are marginal, are not high.

Configuration 3b, $PI \times ED \times PD \times UL \times FD \times \sim TI$, can also be categorized as policy-economic. A high construction waste policy intensity, high economic development level, and non-high-tech innovation are also core conditions in this configuration, while high population density, high urbanization level, and high freeway density play a supporting role in this configuration. This configuration indicates that when the government pays attention to the two core conditions of construction waste policy intensity and economic development level, along with the advantageous conditions of population density, urbanization level, and freeway density, it can also enhance environmental efficiency. Configuration 3b contains one case of Chongqing, which, in addition to having high construction waste policy intensity and economic development level, has a high population density, urbanization level, and freeway density, but as marginal conditions, they only play an auxiliary and secondary role. Although science and technology innovation is a core condition, it is in a non-high state.

5. Conclusions

This study took 30 provinces in China as samples and used the fsQCA method and configuration analysis to investigate the combined effects of the main factors affecting the environmental efficiency of construction waste generation to find upgrading paths to improve environmental efficiency. This research has shown that there is no single influencing factor that can uniquely determine the environmental efficiency of construction waste. For regions with different conditions, in the case of insufficient social conditions, the environmental efficiency of construction waste generation can be improved through the interaction of other influencing factors. It conducted conditional configuration path analysis and obtained five path combinations that promote high environmental efficiency in provinces, which can be summarized in three configurations: population density, technological innovation, and policy economy. The population density type mainly utilizes high population density to play a role, combined with other auxiliary conditions to promote the improvement in environmental efficiency. The technology innovation type is based on science and technology innovation as the core condition, combined with the advantage of freeway density to enhance environmental efficiency. The policy economy type is based on the strength of construction waste policies and the level of economic progression as the core conditions, combined with other auxiliary conditions to jointly promote the improvement in environmental efficiency.

For cities with relatively weak economies, improving environmental efficiency is a complex but important challenge. This usually requires integrating strategies for efficient

resource utilization, environmental protection, and economic development. Here are some key strategies: (1) Improve energy efficiency: Encourage the use of energy-efficient appliances and building materials, and promote energy-saving lighting and high-efficiency household appliances. This can reduce energy consumption and lower the operating costs for residents and businesses. (2) Develop renewable energy: Utilize renewable energy sources such as solar and wind power to reduce dependence on fossil fuels. Although the initial investment may be high, it can reduce energy costs and improve energy security in the long term. However, this research also has certain limitations: (1) When selecting control variables for the environmental efficiency of construction waste generation, although five factors were selected through an existing literature review and PEST analysis method, the economic development level, population density, urbanization level, freeway density, and technology innovation, there may still be other factors that have effects on the explained variable. In future research, factors that affect the dependent variable can be revised. (2) In using the fsQCA method, only the environmental efficiency and influencing factors of construction waste generated in 30 provinces of China in 2020 were taken as the research subject, ignoring research on other years or representative cities. In future research, research and analysis can be conducted from the perspective of years and cities.

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