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Chapter: Advancing Digital Transformation through Information and Innovation Management

PATHWAYS FOR DRIVING INDUSTRIAL PROGRESS UNDER THE SUSTAINABLE DEVELOPMENT GOALS FRAMEWORK

Jing Jiang
E-mail: christinejiang2@Hotmail.com
ORCID:
Affiliation: School of Economics and, Management, Wenzhou Universtiy of Technology, China
ROR: https://ror.org/03dd7qj98

Annotation. Advancing the 2030 sustainable development agenda, global industrialization faces challenges like resource shortages, climate change, and inequality, while technological innovation and green transformation offer opportunities. The pursuit of sustainable industrialization represents a complex and systematic process. Existing studies have primarily examined single-factor impacts on industrialization, with limited systematic analysis of diverse paths and interactions among multiple elements. To explore the complex relationship between industrialization and the Sustainable Development Goals (SDGs), drawing on unified growth theory and the global value chain, and using panel data from the United Nations database covering the period from 2016 to 2023, the “joint effects” promoting industrialization and the “interactions” among different SDGs were analyzed through a fuzzy-set qualitative comparative analysis (fsQCA). Results indicate that industrialization is the outcome of multiple condition combinations and is not adequately explained by a single or a few explanatory variables. Four configurations are identified as significantly promoting industrialization: the Education–Environmental protection double core type, the Health-Environmental protection double driving type, the Health-Education collaboration type, and the Comprehensive Education-Equality-Environmental integrated type. Responsible consumption and production, quality education, and good health and well-being are identified as key elements of industrialization. Under varying conditions, a substitute or complementary relationship is observed between education and health, whereas trade-offs are found to be necessary between affordable clean energy and industrialization. Differences in priorities and challenges are revealed in the industrial development paths of industrialized economies, emerging industrial economies, and other developing economies .The conclusions obtained from this study expand the applications of the SDGs, enrich methodological tools for industrialization, and offer practical recommendations for various countries.

Keywords: industrialization, sustainable development goals, Fuzzy-set qualitative comparative analysis, joint effects, interactions.

JEL classification: Q00, Q01, Q50, Q56, Q58.

Introduction

The world has been undergoing major reforms, such as a profound energy transition, the Fourth Industrial Revolution, population structural transformation, and global rebalancing. These changes have brought

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many new challenges and have forced countries to seek a balance between economic growth and sustainable development. As the key power to promote economic growth and innovation, create new employments, reduce poverty and hunger, build a more equal society, and cope with climate changes, industries are viewed as the main engine to realize the Sustainable Development Goals (SDGs) of the United Nations (UN) (UNIDO, 2024). However, effectively integrating the multi-dimensional development goals of economy, society, and environment into the industrialization process while promoting environmental protection and social well-being remains a complicated and severe global challenge (Samašonok, Išoraitė, 2023).

Industrialization has historically been an important development process for economically developed countries and is a central goal for many developing countries. Previous studies mainly measured and compared industrialization through per capita gross national product (GNP) (Palomo *et al*., 2007), the proportion of the tertiary industry in the industrial structure (Rothbarth and Clark, 1941), urbanization level (Gu *et al*., 2015), and the net output ratio of consumer goods to capital goods sectors (Hoffmann, 1958). These studies usually equate industrialization narrowly with the economic growth led by industries, and they emphasize quantifiable economic indicators while ignoring the complicated influences of the society and environment. With the rapid development of information technology and profound changes of social structure, traditional industrialization theories fail to interpret its current trends. Modern industrialization not only focuses on economic growth efficiency but also takes social equity and environmental sustainability into account.

The United Nations Industrial Development Organization (UNIDO) emphasizes that inclusiveness and sustainability are core elements of industrialization. This approach emphasizes the coordinated economic, social, and environmental development (UNIDO, 2015) while also addressing the challenges that arise from the single perspective of traditional industrialization studies. Previous studies often viewed inclusiveness and environmental sustainability as constraints against industrialization (Claros Garcia, Von Sperling, 2010, Worrell *et al*., 2001), and they ignored their positive effect on the industrialization process. Modern industrialization balance advantages and disadvantages while maintaining economic growth, promoting social inclusiveness, and environmental sustainability (UNIDO, 2020). This opinion has received extensive support from all members of the UN and was reflected in the 17 SDGs passed in 2015 (UN, 2015). Nonetheless, existing studies mainly focus on the influences of single factors on industrialization, which fails to reflect the complexity of the process comprehensively (Rybalkin *et al.,* 2023; Majewska, Bełtowska, 2023). The single-factor analysis method restricts a deep understanding of the diversity of industrialization paths and their internal mechanisms. Hence, a systematic comprehensive analysis of the factors influencing industrialization under the SDG framework remains unexplored. Exploring the joint effects of different elements has important theoretical and practical significance for uncovering industrialization paths and understanding the differentiated influences among countries. This study aims to fill in this research gap and investigate the joint effects among different elements and their influence on the selection of industrialization paths. In the SDG framework, this study systematically analyzes multiple influencing factors of industrialization and reveals their interaction mechanisms. Moreover, it discusses how countries can apply the industrialization paths consistent with sustainable development by balancing economic, social, and environmental goals. Additionally, this study aims to provide theoretical support and empirical references for countries to formulate sustainable industrialization strategies tailored to their national conditions, thus improving the quality and benefits of industrialization in the context of globalization.

Unified growth theory (UGT) emphasizes the interaction of elements like technology, population, education, and income in national development and explains the transition from stagnation to growth. Global value chain (GVC) theory concerns the distribution of value creation in global production activities. Together, UGT and GVC provide a systematic and comprehensive framework to study the factors influencing national industrialization from domestic and international perspectives, respectively. From a configurational perspective, this study integrates the antecedent elements of industrialization systematically, explores the industrialization driving paths in different countries. Influenced by globalization and the innovation capabilities of countries, industrialization usually involves deep integration of technological progress, resource allocation, education level, and GVC. The interaction between external and internal structural factors can form diversified industrialization paths, thus influencing the overall process and economic benefits. This study focuses on two hierarchical problems: (1) Path problem. Based on the latest research on industrialization, this study examines industrialization development paths through fuzzy-set qualitative comparative analysis (fsQCA) by considering population, technology, education, income, equality, and environmental protection. It identifies the complexity of the causes and effects driving industrialization across different countries. (2) Policy suggestions. Based on the exploration of industrialization paths, this study provides specific policy suggestions tailored to different paths by combining practical cases and data analysis. The core goal of this study is to formulate effective industrialization transformation strategies for different countries and help them realize better economic growth and sustainable development (Streimikiene, 2022; Dat, Hung, 2023).

The following three marginal contributions are made by this study:(1) Based on UGT and GVC theory, an analysis framework for the influencing factors of industrialization is established from the perspectives of internal motivation and external regulation. This framework enriches the theoretical foundations to industrialization paths. (2) This study identifies the „equifinality" phenomenon of industrialization through a qualitative analysis and examines the universality and applicability of the driving factors of global industrialization. The findings provide important guidance for countries pursuing industrial development. (3) Addressing different conclusions and debates in existing research concerning industrialization and SDGs, this study develops a new framework of interpretation. In particular, it proposes the coexistence of substitutional and complementary relationships in interpreting the influencing mechanism of education and health on industrialization. This proposal expands the application scope of the SDG framework.

The remainder of this study is organized as follows: Section 1 develops the theoretical framework of analysis, reviews the literature related to the influencing factors and paths of industrialization, and establishes a theoretical basis for this study. Section 2 describes the research method and provides a comprehensive overview of the sample selection, data sources, variable definitions, and research design. Section 3 presents the empirical analysis, combines the conditions of industrialization based on the SDGs, and carries out multiple case studies. Section 4 discusses the results of the analysis. Section 5 draws the conclusions, policy implications, research limitations, and future research directions.

1. Theoretical Analysis and Theoretical Framework Construction

1.1 Literature Review

Existing related studies have discussed the influencing factors of industrialization, selection of industrialization paths, and the relationship between industrialization and SDGs.

Research on influencing factors of industrialization. Technological progress is extensively viewed as the core factor of industrialization. In the 19th century, Germany and the United States achieved successful industrialization through new technologies and products. In the 20th Century, Southeast Asian countries achieved industrial growth by „learning and introducing technologies" (UNIDO, 2021). Technological progress significantly influences industrialization, productivity, and economic growth, particularly through innovations in automation and artificial intelligence (AI) (Acemoglu, Restrepo, 2018). An inverted U-shaped relationship exists between technological progress and economic growth in emerging markets. Continuous digitalization introduces skilled biases, thus challenging the competitiveness of developing countries in traditional labor-intensive industries (Clifton *et al.*, 2020). Additionally, social factors, such as population structure (Haraguchi *et al.*, 2019), educational level, social capitals, and policy environment play a critical role in industrialization (Lucas, 1988). In countries with centralized power, governments have stronger ability to facilitate the rapid and comprehensive industrialization (Gerring *et al.*, 2022, Haraguchi *et al.*, 2019).

Research on industrialization paths. (1) Principle lines of industrialization. Global industrialization paths are sensitive to historical background, economic policy, social structure, and geographic area. After two centuries of industrialization diffusion, two principal lines of global industrialization have emerged: the „Western road" related to capital-energy intensive industries and the „East Asian road" of labor-intensive industrialization based on high-quality labor resources (Sugihara, 2007). (2) Different industrialization patterns. The leading-industrialization pattern has achieved rapid high-quality economic growth with abundant professional human resources at the cost of the environment. The crossing-industrialization economic growth pattern has promoted resource-saving and environmentally friendly service industries with high economic potentials through elites and technological progresses (Huang *et al.*, 2020). (3)Combination of industrialization and other factors. The social, economic, population, and trading structural changes have nonlinear relations with renewable energy sources (Su *et al.*, 2022). Unidirectional causal links exist among industrialization, foreign direct investment, and economic growth (Appiah *et al.*, 2023).

Research on SDGs. a) Relations among SDGs. The interaction among SDGs and their influence on policy planning attracts extensive attention. Machine learning identifies the strongest collaboration among SDGs 3, 4, and 7 (Asadikia *et al.,* 2021). The correlations of SDGs are also explored through the product space method. A revolutionary collaboration between SDGs 4, 15, 1, and other SDGs is noted (Gong *et al.,* 2024). Influences of AI on SDGs become increasingly prominent, and AI-based innovations positively affect SDGs 1, 3, and 5 in most countries (Nahar, 2024). b) Relations between industrialization and SDGs. Industrialization is the impetus to drive sustainable development (UNIDO, 2020). The collaboration of SDGs is usually stronger than the balancing effect, although negative correlations and noncategorical correlations are observed in some cases (Pradhan *et al.,* 2017). Developing countries are struggling with the contradiction between economic growth and sustainable resource utilization during industrialization (Eisenmenger *et al.,* 2020). In the background of Industry 4.0, additive manufacturing, big data analysis, cloud computing and AI, and machine learning are five factors that drive sustainable manufacturing (Agarwal, Ojha, 2024). Technological progress and international environmental agreement positively influence sustainability (Nasrollahi *et al.,* 2020).

SDGs have attracted extensive scholarly attention, and abundant research results have been achieved since they were proposed. Despite the considerable knowledge gained and theoretical contributions, existing studies still have limitations: (1) Influencing factors: Although existing studies discuss the antecedents of industrialization, most of them use large-sample regression tests and logical deductions.

Studies on specific factors under these antecedents are lacking. (2) Industrialization paths: Although some studies identify the capital-intensive and labor-intensive classical paths, research on how these paths develop joint effects across different countries and generate diversified influences remains insufficient. Moreover, a deep discussion on the interaction of multiple factors is absent. (3) Relationship between SDGs and industrialization: Although the synergistic and trade-off relationships among several SDGs are recognized, conclusions are mixed and even contradictory because of limitations in research samples and periods. Hence, the relationship between industrialization and core SDGs warrants further discussions under different combinations of influencing factors.

1.2 Theoretical Framework Construction

In the context of globalization and sustainable development, comprehending the driving factors of economic growth and industrial upgrading is particularly important. UGT and GVC theory interpret industrial progresses from the perspectives of internal motivation and external regulation, respectively. From the perspective of internal motivation, UGT discusses the long-term evolutionary relationships among population, technology, and income and explains the fundamental driving factors of industrialization (economic growth). This theory emphasizes that long-term economic growth depends not only on capital and labor inputs but is also rooted in the improvement of population quality and continuous process of technological innovation and diffusion. Education and population optimization facilitate technological progress and enhance productivity. These processes influence income distribution and social well-being, ultimately driving the transition from stagnation to modern economic growth (Galor, 2005). From the perspective of external regulation, GVC theory emphasizes the division of labor and integration mechanism in global production activities and the equality of opportunity and environmental management elements reflected in different links (Gereffi *et al*., 2005, Gereffi, Lee, 2012). According to GVC theory, global production networks enable enterprises, industries, and countries to acquire externalities in technologies, capital, and institutional innovation. However, they also face a dynamic balance between competition and cooperation. Participation in GVC significantly promotes sustainable development (Osabohien *et al*., 2024) and improves energy efficiency through industrial and energy optimization (Luo *et al*., 2024). The combination of UGT and GVC theory provides multidimensional perspectives for studying the internal and external factors influencing industrialization that considers SDGs, thus offering theoretical support to the comprehensive understanding of sustainable practices during the industrialization of different countries.

Effects of population on industrialization. Demographic transition has similar modes with industrial revolutions, and population growth is closely related to industrial development (Lima *et al*., 2024). The ultimate goals of economic development are improving the quality of human life and extending life expectancy (Tong *et al*., 2002). Industrialization exerts multiple effects on population health. It not only causes health and environmental deterioration (Lima *et al*., 2024) but also may improve population health through economic growth (Ying *et al*., 2022). SDGs, such as SDG 3, cover human health and well-being except for the economic layer. Social development and health can progress hand in hand without the need for trade-offs between the two (Pradhan *et al*., 2017). Realizing SDG 3 requires cooperation of multiple departments because some optimal health determinants (e.g., income, poverty, and natural environment) are beyond the administration of the health department (Khayatzadeh-Mahani *et al*., 2019). When expanding health coverage and providing health services, priority needs to be given to communities with poor economic and environmental conditions (Chapman, 2016).

Effects of technology on industrialization. Technological progress is the core driving force of industrialization, which facilitates further development of technologies. As industrialization deepens, demands for clean energy increase gradually. This challenge is not only important during industrialization; it also presents an important opportunity for sustainable development. It highly agrees with SDG 7. Technological innovation is crucial to energy acquisition and green growth, and it facilitates the sustainability of environment and positive economic development (Wang *et al*., 2021). The differences across countries in technology-driven industrialization paths are significant. Rich countries promote technological applications by integrating Industry 4.0, whereas poor countries realize technology transfer through policies and strategies to offset technological gaps (Khayatzadeh-Mahani *et al*., 2019, van Vuuren *et al*., 2017, Liu *et al*., 2024).

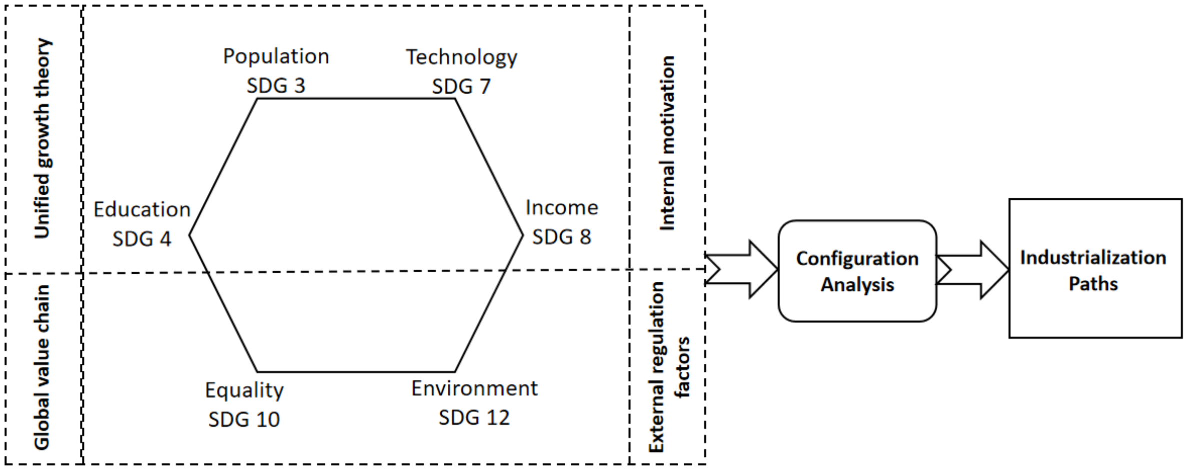
Effects of education on industrialization. SDG 4 is the key means to realize sustainable development. Contributions of high-quality education and lifelong learning are extensively accepted by the international society. The manufacturing industry proposes a high requirement on capitals and skills, so skill training needed by industrialization relies on education, including formal education and vocational training (UNIDO, 2020). Capitals, skills, experiences, and efforts of people are the greatest wealth of the world. Human capital input bring wealth and fast economic growth (Kim *et al*., 2018). Even in the current informationalized global economy, advanced knowledge and human capital are more important than basic elements (Porter, 1990). High levels of manufacturing achieve lower levels of educational attainmen (Donaldson, O'Keefe, 2013).

Effects of income on industrialization. SDG 8 is particularly important because of the slow and imbalanced economic development at present. Although the annual growth rate of global per capita GNP has been increasing continuously, the growth speed of many developing countries has slowed down. The global unemployment rate in 2023 reached as high as 5.7%. The ranking of Germany in terms of per capita income declined sharply after WWII because of early industrialization, indicating that the initial benefits of industrialization were achieved at the cost of long-term benefits (Berbée *et al*., 2024). Although economic globalization decreases income inequality among high and middle-income countries, it intensifies the inequality among low-income countries (Villanthenkodath *et al*., 2024). The effects of industrialization on income distribution are influenced by the comparative advantages of countries worldwide, especially in labor-intensive and capital-intensive industries (Auty, 1993). SDG 8 is one of goals that have the greatest positive influences on other SDGs (Weitz *et al*., 2018). Besides, UNIDO believes that the manufacturing industry can provide considerable formal employment opportunities for young people. Nonetheless, some studies demonstrate that industrialization may intensify income inequality (Erman, te Kaat, 2019).

Effects of equal opportunity on industrialization. Equal opportunity presents a complicated variation trend around the world, which is clearly verified in SDG 10 (Piketty, 2014). The global inequality declined significantly over the past decade, which was mainly benefited from the industrialization of poor countries promoted by economic globalization. However, some scholars believe that this phenomenon is attributed to the slowing growth of rich countries (Pandian, 2024). Income differences across countries rather than inequality in a country is the main determinant of global inequality (Milanovic, 2011). Although economic globalization reduces inequality among countries to an extent, it intensifies inequality in a country, which triggers the complicated discussions on the overall influences of global inequality (Hung, 2021). The gap between the Global North and Global South may further widen after public health events. The industries in the Northern Hemisphere continue to develop, whereas industrial outputs of some countries in the Southern Hemisphere may experience difficulties reaching the global average level (Hung, 2021).

Effects of environmental management on industrialization. The external regulation mechanism influences production behaviors through policies, laws, and motivation measures, thus promoting the sustainable transformation of production mode. For SDG 12, the sustainable consumption and production mode specifically refers to the green and efficient product use and production process (Keskin *et al.*, 2013). Generally, SDG 12 is to decrease resource consumption, degradation, and pollution for consumption and production while improving quality of life, thus increasing the net benefits of economic activities. However, balancing SDGs and maintaining economic benefits is difficult under the profit orientation (Zahra *et al.*, 2009). At the country level, industrialized or rich countries seem to undertake many responsibilities. For example, the agricultural policies of industrialized countries need to consider the benefits of middle- and low-income nations. Besides, rich countries increase productivity and resource efficiency and then provide beneficial experiences to developing countries in technological development and policy formation (Movilla-Pateiro *et al.*, 2021).

The collaboration of internal motivation and external regulation facilitates the sustainable development of industrialization. Population growth and industrial expansion not only offer sufficient labor forces and enormous market demands (Shen, 2022) but also facilitate technological innovation (Beaudry, Green, 2002) to meet the changing production and consumption needs. Technological progress improves production efficiency (Qiu *et al.*, 2023), facilitates the extensive applications of green technologies (Wang *et al.,* 2021), further enhances the environmental management (Aaldering *et al.*, 2019), and achieves the economy–environment coordinated development. The increasing education level enhances skills and knowledge reserves of labor forces (Korber, 2019), which support the high-tech industrial development and facilitate income growth, thus improving quality of life and social well-being (Kim *et al.*, 2018, UNIDO, 2021). Moreover, the increasing income offers more resources to enterprises and the government for technological innovation and environmental protection (Aldieri *et al.*, 2019, Xu *et al.*, 2021). However, it may intensify social inequality because of the unequal income distribution (Berbée *et al.*, 2024, Erman, te Kaat, 2019). Regarding external regulation, improving equal opportunities is conducive to narrow the socioeconomic gap and assures the equal participation of different groups in the industrialization process, thus promoting the overall stability and harmony of the society (Piketty, 2014, Hung, 2021). Environment management guides global enterprises to apply sustainable and low-carbon production modes by formulating and implementing environmental protection policies. This approach not only standardizes behaviors of enterprises but also forms synergistic effect with technological progress and education improvement, preventing economic development at the cost of the environment (Keskin *et al.*, 2013, Movilla-Pateiro *et al.*, 2021). On the one hand, these external factors standardize the operation mode of internal motivations. On the other hand, they facilitate economy–environment coordinated development through institutional guarantee. To sum up, internal motivation factors like population, technology, education, and income lay a solid foundation for industrialization by facilitating economic and social development. External regulation factors like equal opportunities and environmental management assure the fairness and sustainability of industrialization through the institutional and policy frameworks. The internal motivation factors and external regulation factors supplement each other to realize SDGs. Based on the internal motivations (education, population, technology, and income) in UGT and external regulation (equal opportunities and environmental management) in GVC, this study builds a research model to explore their joint effects from the perspective of configurations (*Figure 1*).



*Source:*created by the authors.

Figure 1 **Conceptual Model of Antecedent Configurations of Industrialization**

2. Methodology

2.1 Data Source and Sample Selection

In the fsQCA method, the number of conditions need to be controlled when choosing the condition variables because the number of configurations increases exponentially with additional variables (De Meur, Rihoux, 2002). For example, three condition variables have eight combinations (2^3), and six condition variables have 64 combinations (2^6). The rest can be calculated in the same way. Therefore, repeated trials are needed in this study to find the reasonable balance point between the numbers of cases and condition variables. Generally, four to seven condition variables suffice for 10–40 cases (Rihoux, Ragin, 2009).

The definition of industrialization in this study follows the definition of UNIDO.This classification standard has been extensively used to comparative analyses of industrial activity growth and structure, and the data are sourced from UNIDO.With the theoretical framework this study, six SDGs are chosen as condition variables. The research samples are determined through the following screening standards. First, 218 country members classified by UNIDO according to industrialization development stages are selected. To guarantee research comprehensiveness and data reliability, countries with substantial information missing are excluded. Countries without data for two or more condition variables are deleted. The selected cases are similar and need to have sufficient background or features to assure representativeness of analysis. In addition, diversity of cases is essential to reflect the maximum heterogeneity of cases. Following the aforementioned screening steps, relevant data of 132 countries from 2016 to 2023 are acquired, sourced from the United Nations SDGs database.

2.2 Variable Settings and Descriptions

2.2.1 Outcome variable

The outcome variable was industrialization (INDUS). Manufacturing value added per capita (MVA) is an appropriate indicator to measure the industrialization level (UNIDO, 2024). MVA reflects the gap between the industrial production level and the population size of a country. Therefore, MVA is selected as an outcome variable of industrialization. Besides, the traditional dichotomy, which classifies countries into industrialized and developing categories, fails to effectively capture the complex diversity of the global economy. As a result, the UNIDO proposed a more refined classification method to further divide developing countries according to industrialization stages. Ultimately, five groupings are established (*Table 1*).

Table 1. Grouping by Stage of Industrialization

Country groups		US dollar
1	Industrialized economies	MVApc (adjusted) ≥ 2500
2	Emerging industrial economies (except China)	2500 > MVApc (adjusted) ≥ 1000
3	Emerging industrial economy（China）	
4	Other developing economies	All others (except LDSs)
5	Least developed countries (LDSs)	Based on UN's official list

Source: United Nations Industrial Development Organization.

2.2.2 Condition variables

There are 169 indicators across 17 goals included in the SDG**s.** Each of the six goals in this study contains several targets and multiple indicators (*Table 2*). According to the literature review, six SDGs are chosen as condition variables in this study,namely: decent work and economic growth (DW), reduced inequality (RI), good health and well-being (HW), high-quality education (QE), affordable clean energy (ACE), and responsible consumption and production (RCP).Entropy method is an objective method for assigning weights based on information entropy. It measures the importance of indicators by analyzing dispersity of data, thus determining weights of decision indicators effectively and improving the objectivity and scientificity of decisions (Kong *et al*., 2020). The weights of the indicators under the chosen SDGs are calculated using the entropy method in this study. The specific steps are as follows:

Step 1: Normalization. Suppose there are *k* countries, *n* years, and *m* indicators. The *j* th indicator value of Country a in Year *i* is Y_{aij}(*a* = 1, 2,..., *k* ; *i* =1, 2, ..., *n* ; *j* = 1, 2, ..., *m*). Considering the inconsistency of original data units and degree of variation, this study employs the maximum–minimum normalization method to map data into the 0–1 range (Eq. 1 and 2). This approach decreases experimental errors and assures scientific and objective empirical results.

Positive indicators:

$$X_{aij} = \frac{Y_{aij} - Y_{\min}}{Y_{\max} - Y_{\min}} \tag{1}$$

Negative indicators:

$$X_{aij} = \frac{Y_{\max} - Y_{aij}}{Y_{\max} - Y_{\min}} \tag{2}$$

Step 2: Calculate the weight of the j th indicator value of Country *a* in Year *i* (P_{aij}) (Eq. 3).

$$P_{aij} = \frac{X_{aij}}{\sum_{a=1}^{k}\sum_{i=1}^{n} X_{aij}} \tag{3}$$

Step 3: Calculate the information entropy of the *j*th indicator (e_j) (Eq. 4).

$$e_j = -\frac{1}{\ln n}\sum_{a=1}^{k}\sum_{i=1}^{n}\left(P_{aij}\ln P_{aij}\right) \tag{4}$$

Step 4: Calculate the utility value of information (g_j) (Eq. 5).

$$g_j = 1 - e_j \tag{5}$$

Step 5: Calculate the weight of the *j*th indicator (W_j) (Eq. 6).

$$W_j = \frac{g_j}{\sum_{i=1}^{n} g_j} \tag{6}$$

Step 6: Calculate the evaluation indicator of an SDG of Country *a* in year *i* (F_{ai}) (Eq. 7).

$$F_{ai} = \sum_{j=1}^{m} W_j \times X_{aij} \tag{7}$$

Table 2. List of Condition Variables

Goals	Targets	Indicators
SDG8 Decent work and economic growth（DW）	12	17
SDG10 Reduced inequality (RI)	11	10
SDG3 Good health and well-being (HW)	13	28
SDG4 Quality education (QE)	10	11
SDG7 Affordable and clean energy (ACE)	5	6
SDG12 Responsible consumption and production (RCP)	11	13

Source: United Nations.

2.3 Research Designs

fsQCA is an effective tool to explore the “joint effect” and “interactions”. Ragin (Ragin, 1987, 2000, 2008), Fiss (Fiss, 2007, 2011), and Schneider and Wagemann (Schneider and Wagemann, 2012) have made remarkable contributions to the research and invention, concept determination and practical application of qualitative comparative analysis (QCA). In 2007, Fiss proposed the QCA method based on set theory and Boolean operations, which can explore interactions (including complementarity, substitution, and suppression) of antecedents (Fiss, 2007). It has been extensively applied to various fields of social sciences in recent years. Compared with traditional research methods, fsQCA enables scholars to be closer to the complicated reality of problems (Fainshmidt *et al.*, 2020). fsQCA was introduced into international business research by Pajunen to analyze the attraction of countries to foreign direct investors (Pajunen, 2008). The causal relationship between conditional configurations and results is reviewed by fsQCA through direct case comparison based on the overall research perspective. This study attempts to answer which condition combinations can cause the expected results.

fsQCA is chosen for four reasons in this study. First, QCA has flexible requirements on sample size and data source and is applicable to situations with excessive or insufficient sample size as a research tool combining quantitative and qualitative analyses (Stokke, 2007). Second, QCA is applicable to causal complexity analysis. Traditional regression analysis requires no collinearity among variables to recognize the net effect of different variables. However, QCA concerns the interaction, joint effect, and combination effect of factors based on the theory of structures (Greckhamer, 2011), and it can interpret specific complicated outcomes reasonably through combination analysis of antecedents (Korczynski, Evans, 2013). Third, QCA is conducive to promote the interaction between theory and cases. Interpreting QCA research results requires integration with theoretical knowledge, involving both inductive and deductive reasoning. Finally, fsQCA is significantly superior to other QCA technologies in processing the situation when causal conditions are used as continuous variables (Schneider and Wagemann, 2012). fsQCA can reflect subtle influences caused by different degrees of changes of condition variables more accurately (Rihoux, Ragin, 2009).

2.4 Calibration

In fsQCA, each condition (one of six SDGs in this study) and result (industrialization) are viewed as a set. Each case has one membership score in these sets. According to Fiss, the calibration depends on theories and practical external knowledge or standards, and three critical values are set: full membership, full non-membership, and cross-over point (Fiss, 2011). Based on existing theories and experience practices, condition variables are calibrated in this study according to the direct calibration method (Ragin, 2008). The applied degrees of membership are 5% for full non-membership, 50% for cross-over point, and 95% for full membership. Specific standards are shown in *Table 3*. For outcome variables, different countries undergo varying industrialization stages, and five critical values are divided. In this study, calibration is implemented at the threshold of 100%. Specifically, 1 represents the industrialized countries, 0.75 represents emerging industrial countries (except China), 0.5 represents the emerging industrial country China, 0.25 represents other developing countries, and 0 represents the least developed countries. In a follow-up robustness test, the threshold is set 95% for validation.

Table 3. Calibration Anchors of Variables in Configuration Analysis

Variables		Full membership	Cross-over point	Full non-membership
Outcome Variable	INDUS	1	0.5	0
Condition Variables	DW	0.9669	0.8208	0.4081
	RI	0.8696	0.5639	0.2298
	HW	0.9493	0.680435	0.2292
	QE	0.6921	0.0019	0
	ACE	0.9065	0.2496	0.0020
	RCP	1	0.5799	0.0199

Source: authors' own results.

3. Result Analysis

3.1 Necessity Analysis

According to the steps of QCA, it is necessary to first test whether a single condition constitutes a necessary condition for industrialization. In view of set theory, the necessity analysis of a single condition tests whether the outcome set is the subset of a condition set. In fsQCA, if a condition is always related with the outcome, it is considered a necessary condition of the outcomes (Ragin, 2008). After calibration, the conditions of outcomes and all variables (the suffix *fz* represents the calibration variables) are shown in *Table 4*.

Table 4. Analysis of Necessary Conditions

Condition	Indus		~Indus	
	Consistency	Coverage	Consistency	Coverage
HW*fz*	0.804	0.899	0.470	0.434
~HW*fz*	0.494	0.530	0.890	0.789
QE*fz*	0.596	0.861	0.426	0.507
~QE*fz*	0.658	0.582	0.883	0.643
DW*fz*	0.632	0.655	0.692	0.592
~DW*fz*	0.606	0.705	0.596	0.572
RI*fz*	0.717	0.763	0.598	0.525
~RI*fz*	0.554	0.626	0.731	0.681
ACE*fz*	0.447	0.519	0.781	0.749
~ACE*fz*	0.784	0.813	0.498	0.426
RCP*fz*	0.731	0.791	0.472	0.422
~RCP*fz*	0.465	0.517	0.766	0.702

Note: ~ indicates the absence of a condition.

Source: authors' own results.

Consistency is the standard to judge the reliability of necessary conditions. When consistency is higher than 0.9, the condition is a necessary condition of the outcome (Young, Park, 2013). According to the test results of the necessary conditions of industrialization (*Table 4*), the consistency levels of all conditions are lower than 0.9. This indicates that no single factor constitutes a necessary condition for industrialization or non-industrialization. Thus, industrialization is often the collaborative result of multiple factors rather than a single factor under complicated conditions.

3.2 Sufficiency Analysis

Configuration analysis mainly evaluates the sufficiency of outcomes caused by a combination of multiple conditions. The sufficiency of configurations is measured by the consistency. The sufficiency of configurations is measured by consistency values, which can accept a certain minimum standard. However, the calculation method differs from that of necessity analysis. At present, the general sufficiency consistency threshold is no less than 0.75 (Schneider, Wagemann, 2012). Two main factors are considered when determining the consistency threshold and frequency threshold to ensure reliability and accuracy. First, the frequency threshold needs to cover at least 75% of the observation cases. Second, the minimum proportional reduction in inconsistency (PRI) needs to exceed 0.8 to recognize the potential contradictory combination. Based on these practice standards, this study finally determines the consistency threshold at 0.8 and the frequency threshold at 1.

This study investigates the complex relationships between six SDGs and industrialization, and as a result, counterfactuals are not analyzed in detail. “Present or Absent” is chosen as the standard to determine in what state the six SDGs lead to industrialization. The three types of solutions—complex, intermediate, and parsimonious—represent different levels of complexity. With reference to existing related studies, the analysis focuses on the intermediate solution, supplemented by the parsimonious solution (Fiss, 2011). The influences of the four configurations generated by six SDGs on industrialization selection are analyzed, and the results are presented in *Table 5*. The solid circles indicate the presence of conditions, while the cross-over circles denote their absence. The blanks express the fuzzy state, indicating that the condition may be present or absent. The large circles represent core conditions (parsimonious solution and intermediate solution coexist), and small circles show auxiliary conditions (only present in intermediate solution). Coverage, a key indicator of empirical correlation, is comparable to R^2 in regression analysis (Fiss, 2011). Coverage ranges from 0 to 1, reflecting the extent to which each solution or the entire solution interprets the outcome. Coverage of the overall solution refers to the membership proportion of outcome variables interpreted by the complete solution. Raw coverage refers to the outcome membership proportion that each causal path can interpret, whereas the unique coverage refers to the proportion of cases that are covered by only one solution in samples. Consistency, which also ranges from 0 to 1, measures the degree to which members of a solution belong to the outcome subset (Ragin, 2008). A low consistency means that the solution has a low correlation with other solutions with high consistency. Balancing coverage and consistency is critical to producing reliable and significant results. Generally, the solution is viewed significant if consistency is higher than 0.8 and highly dominant if consistency exceeds 0.9.

Table 5. High Industrialization

Conditions	1a	1b	2a	2b	3	4
HW			●	●	●	●
QE	●	●			●	●
DW	⊗			●		
RI		⊗	●			●
ACE	⨂	⨂	⨂	⨂	⨂	
RCP	●	●	●	●		●
Consistency	0.979048	0.972521	0.976201	0.975986	0.97569	0.97028
Raw coverage	0.353239	0.282829	0.447407	0.381856	0.48542	0.37721
Unique coverage	0.004104	0.00648	0.04406	0.02473	0.07721	0.02408
Solution coverage		0.646543				
Solution consistency		0.954712				

Note：●Core condition is present, ⨂Core condition is absent, ●Auxiliary condition is present, ⊗ Auxiliary condition is absent. A blank space indicates that the condition may be either present or absent.

Source: authors' own results.

Four configurations that promote national industrialization are identified, and the corresponding results are presented in *Table 5*. The consistency of both single and overall solutions exceeds the acceptable threshold of 0.75. Specifically, the overall solution consistency reaches 0.95, with a fuzzy membership value of 0.646 covering industrialization. Based on the overall solution consistency, these four configurations are closely related to industrialization. However, in terms of coverage, these solutions cover most subsets of industrialization.

Some phenomena worthy of discussion can be found through a comprehensive comparison of the relationships among different configurations. (1) RCP demonstrates a high level of collaboration with industrialization progress. As the core condition, RCP appears most frequently, highlighting its vital role in the sustainable development of industrialization and resource optimization management.However, RCP alone is insufficient to drive industrialization, as it requires collaboration with other conditions to achieve sustainable industrial development. As a result, RCP needs to collaborate with QE, HW, and ACE to achieve its maximum efficacy in different configurations. (2) QE is the key factor that facilitates industrialization. QE is present in the four configurations, showing its core role in industrialization. Education promotion not only strengthens the quality and skills of labor forces but also facilitates innovation and technological application, thus accelerating the industrialization process. Although QE is crucial, it still relies on other conditions like RCP to effectively promote sustainable industrial development in different configurations. (3) HW is the guarantee and outcome of industrialization. HW is present in three configurations. It improves the productivity of labor forces and strengthens social stability and sustainability of economic development. Nonetheless, HW relies on collaboration with other conditions like RCP and QE to promote the sustainable development of industrialization effectively in different configurations. (4) ACE faces significant challenges and trade-offs in the context of industrialization. ACE is absent in all configurations except Configuration 4, indicating a certain conflict between this condition and industrialization, necessitating trade-offs during the industrialization process. The absence of ACE suggests that industrialization may depend on traditional energy sources, posing challenges to environmental sustainability. (5) QE and HW exhibit complementarity or substitutability in the process of industrialization. During the sustainable development of industrialization, QE and HW are two critical internal driving forces. By analyzing different configurations, QE and HW may form substitution or complementarity under different contexts. Such complex relationships between QE and HW profoundly influence the selection and ultimate outcomes of industrialization paths.

At the national level, significantly positive correlations among the SDGs in most countries are observed, which exceed negative correlations. This observation indicates that the SDG agenda has a promising foundation. The proportion of synergies in the SDGs is significantly higher than trade-offs (Pradhan *et al.*, 2017). Through fsQCA, this study effectively identifies four main industrialization paths, and the equifinality and multiple co-occurrence features of industrialization are reflected. Compared with existing related studies, these four configurations are thoroughly analyzed (*Figure 2*) and further interpreted using specific cases.

1a	1b	2a	2b	3	4
QEfz*~DWfz*~ACEfz*RCPfz	QEfz*~RIfz*~ACEfz*RCPfz	HWfz*RIfz*~ACEfz*RCPfz	HWfz*DWfz*~ACEfz*RCPfz	HWfz*QEfz*~ACEfz	HWfz*QEfz*RIfz*RCPfz
Poland	Mexico	Belgium	Qatar	Korea	UK
Italy	Malaysia	UK	Bahrain	UK	Italy
Turkey	Turkey	Australia	UAE	France	Australia
Algeria	Egypt	Germany	Singapore	Italy	Canada
France	Morocco	Italy	Mexico	Japan	France
Germany	Bulgaria	Greece	Oman	USA	Germany
Argentina	Tunisia	Cyprus	Maldives	Spain	Japan
Belgium	Algeria	Slovenia	Australia	Australia	China
Hungary	Cuba	France	Japan	Poland	Thailand
South Africa	Lithuania	Czechia	Luxembourg	Mexico	Argentina

Industrialized economies
Emerging industrialized economies
Other developing economies

Source: authors' own results.

Figure 2. **Top 10 CountriesRepresented by Each Configuration**

Configuration 1a (QE*fz*~DW*fz*~ACE*fz*RCP*fz*) and Configuration 1b (QE*fz*~RI*fz*~ACE*fz*RCP*fz*) share the same core condition and both highlight the critical roles of QE and RCP in promoting industrialization. Hence, this path is called the "Education–Environmental protection double core type." In Configuration

1a, education not only lays the foundation for sustainable development but also improves overall social quality. However, it lacks income growth as an auxiliary condition. Despite advantages in education and environmental protection, economic stagnation may limit the potential for long-term sustainable development. Configuration 1a is applicable to industrialized countries, emerging industrialized countries, and other developing countries, showing its strong universality. However, economic growth in Configuration 1a is insufficient, which may lead to unequal resource allocation and socioeconomic development bottlenecks, thus hindering the comprehensive realization of SDGs. Configuration 1b (QE*fz*~RI*fz*~ACE*fz**RCP*fz*) lacks the auxiliary condition of RI. It mainly appears in emerging industrial countries (e.g., Mexico and Malaysia) and other developing countries (e.g., Egypt and Cuba). Measures to reduce inequality in Configuration 1b are insufficient, leading to challenges in addressing unequal social and income distribution. These countries fail to solve the unequal social and income distribution problems effectively during the rapid economic development. Emerging industrial countries and developing countries often face challenges such as limited resources, weak policy enforcement, and complex social structures. These challenges hinder efforts to promote responsible consumption and production while achieving social equity and reducing inequality. The characteristics of Configuration 1b indicate that, in pursuing industrialization and sustainable development, emerging industrial countries and developing countries need to strengthen the balance between social equity and income distribution to achieve comprehensive SDGs.

Configuration 2a (HW*fz*RI*fz*~ACE*fz*RCP*fz*) and Configuration 2b (HW*fz*DW*fz*~ACE*fz*RCP*fz*) share the same core factors, with HW and RCP serving as the core causal conditions. Thus, this path is referred to as the "Health–Environmental protection double driving type." These two configurations have the constraint of ACE but different auxiliary conditions. In Configuration 2a, RI serves as the auxiliary condition and is primarily applied by industrialized countries, reflecting their unique advantages and challenges in pursuing sustainable development. HW lays a solid foundation for sustainable social development. Industrialized countries usually possess perfect medical systems and high quality of life, which improves the happiness of their people and strengthens the productivity of labor forces and overall social stability. Moreover, the RCP mode is conducive to decrease resource waste and environmental pollution and promote circular economic development. Industrialized countries usually have advanced technologies and management experiences in these aspects. They can implement green supply chain and environmental protection laws and regulations effectively to promote sustainable economic growth. However, the absence of ACE restricts these countries to achieve progresses in energy transformation and carbon emission reduction. Reliance on traditional fossil fuels not only increases greenhouse gas emissions but also impedes the achievement of climate goals and SDGs. Although RI, the auxiliary condition in Configuration 2a, is conducive to promote the comprehensive sustainable social development, industrialized countries still have to exert efforts in narrowing the income gap and improving social inclusiveness continuously to assure that all groupings can share the outcomes of sustainable development. In Configuration 2b, the auxiliary condition DW is mainly present in Middle East countries and some Asian industrialized countries. The absence of ACE is also a constraint in Configuration 2b. For example, some Middle Eastern countries, such as Qatar and the UAE, rely on traditional energy due to abundant fossil fuel resources, leading to high carbon emissions and increased environmental pressure. Although Asian industrialized countries, such as Singapore and Japan, excel in economic growth and technological innovation, their rapid industrialization poses challenges related to resource consumption and environmental pollution.

In Configuration 3 (HW*fz*QE*fz*~ACE*fz*), HW and QE are core elements. Therefore, this path is referred to as the "Health–Education collaboration type." The UN Educational, Scientific, and Cultural Organization points out that good quality education is the basis of health and well-being. Moreover, individuals with higher education levels often make better decisions and choices regarding health-related problems than those with lower education levels. New technology enhances the efficiency of health intervention measures and disseminates knowledge to a broader audience. The health benefits associated with education are not limited to the early stages, and lifelong learning provides essential opportunities in a fast-changing society. This interaction between health and education has particularly great potential in developing countries. The relationship between health and education is bidirectional. Poor health condition often restricts the improvement of educational achievement, whereas high-quality education can improve health level effectively. Configuration 3 demonstrates a close relationship between the acquisition of high-quality education and better health conditions, as evidenced in industrialized countries. In particular, the synergistic effect between education and health is prominent during industrialization, as observed in many countries, such as Korea, the UK, France, Germany, Japan, among others.

In Configuration 4 (HW*fz*QE*fz*RI*fz**RCP*fz*), QE, RI, and RCP are all core elements. Hence, this path is referred to as the "Comprehensive Education–Equality–Environmental integrated type." QE plays an important role as the auxiliary condition. Countries including the UK, Italy, Austria, Canada, China, and Thailand train numerous high-quality talents and promote technological innovation and economic development by establishing a perfect education system. Furthermore, these countries implement effective social policies and welfare systems and improve social fairness and cohesion, aiming to reduce social inequality. RCP is promoted by policy support and technological innovation, which facilitates green economic growth and environmental protection. HW provides a strong foundation for social stability and high productivity, laying the groundwork for the effective implementation of core conditions. Configuration 4 demonstrates how these countries achieve coordinated development across the economy, society, and environment through the synergistic effects of education, social equality, and environmental protection measures. Therefore, this configuration highlights the comprehensive advantages of pursuing sustainable development.

3.3 Robustness Test

A robustness test is conducted by adjusting consistency (increased from 0.8 to 0.81) and modifying the calibration mode (replacing 100% with 95%). The configurations obtained after robustness adjustments remain consistent with the original condition configurations.Based on the two QCA robustness test criteria, the conclusions of this study are confirmed to be robust (Schneider, Wagemann, 2012).

4. Discussions

By integrating the antecedents and outcomes of six SDGs into a unified framework, this study identifies four industrialization paths for different countries and conducts an in-depth analysis of the internal driving factors and external regulatory mechanisms of industrialization. According to the findings, industrialization is the collaborative result of multiple antecedents in the SDG framework, which ultimately leads to the formation of four distinct industrialization paths. Paths of different countries exert varying influences on subsequent industrialization. This study offers new perspectives for exploring industrialization within the SDG framework, as detailed below.

First, the necessity of single conditions for six major industrialization factors and the sufficiency of condition configurations under SDGs are presented in *Tables 4* and *5*, respectively. The results further highlight the complexity of sustainable industrialization. Few related studies have addressed this topic, highlighting the novelty of this research.This study demonstrates that sustainable industrialization is the collaborative result of multiple factors and that a single influencing factor cannot form the necessary conditions of industrialization. Industrialization is a complex system under the SDG framework and is influenced by multiple factors. Moreover, this study offers a comprehensive framework for countries to achieve sustainable industrialization by further exploring the joint effects of these factors.

Second, a comparative analysis of different configurations reveals that RCP, QE, and HW collectively promote the sustainable development of industrialization. However, they have to cooperate mutually to promote industrialization effectively. (1) RCP can still promote industrialization even in the presence of information asymmetry and weak relationships between DW, significant economic growth, and RI. Industrialized countries place significant emphasis on this goal in practical operations, while developing countries aim to achieve it primarily through awareness programs and policy guidance. This phenomenon demonstrates that responsible consumption and production have been widely recognized, indicating a promising foundation for this goal. (2) QE also promotes industrialization. Through substantial education investment and policy support, education can mitigate a country's disadvantages and enhance its strengths. Education can promote industrialization even under the absence of HW or DW. The interaction between industrialization and education exerts a significantly positive effect. The high-quality education system and talent system are key factors during the industrialization of developed countries. Many developing countries devote themselves to breaking the cycle of poverty through education. For example, China has emerged as the fastest-growing industrial economy by making significant investments in education. (3) HW facilitates industrialization by increasing population health level and other auxiliary conditions of a country. Industrialized countries often view health as a priority and implement a paradigm shift in their medical systems to provide citizens with improved healthcare and quality of life. The physical health of citizens forms the foundation for productivity growth, creating a virtuous cycle that facilitates industrialization. (4) ACE is absent in all configurations except Configuration 4, suggesting a potential conflict with industrialization and the necessity of trade-offs during its implementation. Given the lack of clean energy, industrialization may rely on traditional energy sources, thereby posing challenges to sustainable environmental development. Hence, the supply of ACE needs to be balanced with industrialization efforts to ensure environmental sustainability. (5) QE and HW represent complex relationships as internal motivational factors. Both can effectively overcome information asymmetry and uncertainty, which may occur during industrialization. They can exert stronger core influences when coexisting in relevant configurations, particularly in early industrialized countries. A substitutional relationship between health and education is observed in certain cases. This substitutability is evident not only in industrialized countries but also in developing countries.

Third, a configuration analysis of six factors is shown in *Figure 2*. According to the results, four major configurations under SDGs are identified: Education–Environmental protection double core type, Health–Environmental protection double driving type, Health–Education collaboration type, and Comprehensive education–Equality–Environmental integrated type. Based on the industrialization progress of 132 countries over the past seven years, results consistent and inconsistent with previous studies have been obtained in this study. (1) Industrialized countries rely on high-level health and education systems, aiming to achieve coordinated development across the economy, society, and environment by reducing social inequality and promoting a green economy. However, clean energy shortage remains a key problem to be solved urgently. Although industrialized countries have significant advantages in technological innovation and policy formulation, how to integrate existing resources and emerging clean energy technologies effectively during transformation is a severe challenge. Moreover, public acceptance and participation in green energy transformation significantly influence the effectiveness of policy implementation. (2) Although emerging industrial countries prioritize education and responsible consumption to facilitate rapid industrialization, social and income inequality continue to restrict the sustainable development of industrialization. Therefore, these countries need to enhance relevant policies to promote social inclusiveness. With rapid economic growth, these countries face dual challenges: achieving equitable distribution of social resources while maintaining economic activity. In addition, emerging industrial countries need to cope with the environmental pressure brought by urbanization, decrease the negative effects of industrialization on environment through green technologies and sustainable urban planning, and ensure the win–win development of economy and environment. (3) Other developing countries face insufficient economic growth, which, despite efforts to improve education and technology, restricts their potential for sustainable development. Insufficient economic growth not only restricts infrastructure construction and public service improvement but also negatively affects the enhancement of technological innovation and education quality. Unlike previous studies on industrialization, this study focuses on the differences in industrialization paths across countries, provides detailed analyses, and offers a comprehensive perspective to deeply understand the industrialization of various nations.

Moreover, the antecedent configurations of sustainable industrialization and industrialization paths further illustrate the relationships among different layers during the transformation of antecedents. For example, the necessity and sufficiency analyses reveal that a single factor is insufficient to independently promote industrialization. Sustainable industrialization requires the collaboration of multiple factors. This finding emphasizes the complexity of sustainable industrialization as a form of system engineering and highlights the importance of a multidimensional synergistic effect. This study significantly contributes to understanding the differences among countries in their industrialization paths and their influence on the path selection of others. Moreover, this study finds that joint effects, rather than simple causal relationships, exist between sustainable industrialization factors and paths. This study fills research gaps and offers a comprehensive depiction of the antecedents and outcomes of sustainable industrialization. In summary, this study provides valuable insights for practices and policy formulation related to the SDGs.

Conclusions and Implications

Main Findings

Recently, countries have begun to recognize the critical role of the manufacturing industry in economic development, thereby initiating a new wave of industrialization. However, industrialization is a long complicated process. Understanding the principles of industrialization remains a significant challenge due to its lengthy and varied history. To address the challenges of ‘equifinality’ and ‘differentiated effects’ in sustainable industrialization, this study introduces a research framework grounded in UGT and GVC perspectives. Based on the analysis of the United Nations SDG database, 132 countries were selected. Diversified industrialization paths and their varying impacts on different countries were analyzed using fsQCA. The following major conclusions are summarized:

First, six major influencing factors of industrialization are included in the SDG framework. According to a configuration analysis of these six factors, this study finds that sustainable industrialization is characterized by four major configurations or development paths. Each path represents the collaborative outcome of multiple interacting factors within the SDG framework. These four major configurations or development paths are the Education–Environmental protection double core type, Health–Environmental protection double driving type, Health–Education collaboration type, and Comprehensive Education–Equality–Environmental integrated type. This study provides a new interpretation of the industrialization process from a holistic perspective and significantly extends existing research on industrialization within the SDG framework.

Second, industrialized countries achieve coordinated development across the economy, society, and environment by leveraging high-level health and education systems to promote social equity and green economic development. However, significant shortcomings in clean energy utilization persist. Although emerging industrialized countries emphasize education and responsible consumption in their efforts to accelerate industrialization, social inequality and unequal income distribution limit the potential for sustainable development. Other developing countries face insufficient economic growth despite efforts to improve education and technological capabilities. This not only hinders infrastructure development but also restricts the enhancement of public services.

Managerial Implications

Based on the four core conditions of industrialization configurations identified in this study, the industrialization paths vary significantly across countries. However, a common point in the analyzed cases is that feasible and effective industrial policy measures are essential. In particular, industrial policies are crucial to the development of countries and even a single country in the current global economic background. Under varying policy constraints, successful industrialization cases consistently demonstrate that industrial policies must be tailored to specific national contexts. On this basis, the conclusions of this study provide the following managerial implications to industrialized countries, emerging industrial countries, other developing countries, and least developed countries:

As the earliest beneficiaries of industrialization, industrialized countries have experienced sustained prosperity enabled by industrialization. However, amid the restructuring of the global manufacturing landscape, developed countries such as the USA, Germany, the UK, France, and Japan, which have experienced ‘deindustrialization,’ have initiated efforts toward ‘reindustrialization. Reindustrialization’ involves not only the strategic layout of high-end manufacturing industries but also the reshoring of low-end manufacturing sectors. It requires deploying numerous talents to high-end manufacturing industries, thus making high-quality education increasingly important. Low-end manufacturing industries need to transition away from the ‘jobless innovation’ model and achieve a balance between production and environmental sustainability. Therefore, future industrialized countries will face higher manufacturing costs and must prioritize collaboration between production and research and development, particularly in engineering and commercial innovation within the production–market interface. Simultaneously, as consumer demand shifts toward localization, digitalization, and intelligence, these trends are poised to profoundly impact energy consumption and climate change.

In the era of Industry 4.0, the manufacturing industry is anticipated to transition away from reliance on low-cost labor production. The labor cost advantages of emerging industrialized countries in the downstream of the manufacturing value chain will gradually disappear. As a result, some mid-level development countries can no longer rely on the manufacturing industry as a continuous engine of economic growth. These emerging industrialized countries need to increase investment in labor education, with a particular focus on skill training. Countries with well-established industrial systems, such as China, face dual challenges. These include the technological superiority of developed countries like those in Europe and America, and the competitive pressure of low-cost production from developing countries in Southeast Asia. These „double pressures" will further exacerbate the challenges faced by these countries. Meanwhile, consumption is gradually replacing investment as a major driver of China's economic growth. This shift will create broader opportunities for industrial development by promoting sustainable consumption upgrades. In this context, strengthening multilateral cooperation is particularly important. It not only effectively aligns with the industrialization needs of developing countries but also supports the reindustrialization efforts of industrialized countries, thereby promoting shared development on a global scale.

At present, other developing countries strive to carve out their development space in an increasingly crowded industrial environment, but achieving progress remains challenging due to rapid global changes. Hence, developing countries need to promptly explore ways to create opportunities for policy intervention and adopt successful industrial policies tailored to their specific practical contexts. The least developed countries are encouraged to strengthen communication and cooperation with UNIDO, actively seek assistance in areas such as technology transfer and management expertise, and enhance collaboration with industrialized countries in key industrial production resources. These efforts are intended to enhance their capacity and opportunities for adopting new technologies.

In particular, AI technology has become a key driver of industrial upgrading amid globalization and rapid technological advancement. The development and application of AI technology can significantly enhance the intelligence of the manufacturing industry, which is particularly critical for industrialized and emerging industrial countries. The use of AI technology not only helps address environmental and cost challenges in traditional manufacturing but also facilitates the emergence of new industries and provides fresh impetus for economic development. However, the extensive applications of AI technology also bring a series of challenges, such as changes in employment structures, data security, and privacy protection. Countries need to comprehensively evaluate the potential and challenges of AI technology when formulating industrial policies. Promoting the deep integration of AI technology with traditional industries through targeted policy measures is essential for achieving high-quality economic development.

Research Limitations and Future Directions

Similar to many associated studies, this study has certain limitations influenced by various factors. First, the results are discussed within the limitations of data sources and methods. The data for SDG indicators are still being refined, leading to limitations in the completeness of the SDG database. The limitations in the temporal coverage of the data are attributed to the impact of COVID-19 on the global economy. Second, this study needs to balance data calibration techniques with the accuracy of the results. Accurately calibrating the critical values of variables to align theoretical assumptions with practical realities is often challenging in empirical studies. Finally, industrialization is an inherently complex process. Although some industrialization paths identified in this study within the SDG framework have reference value, they are neither unique nor absolute solutions. They only provide another supplementary perspective to explore industrialization. Future studies can continue to track industrialization progress under the SDG framework and apply alternative scientific methods and models to further enrich and refine the conclusions.

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KELIAI PRAMONĖS PLĖTRAI SKATINTI PAGAL DARNIOJO VYSTYMOSI TIKSLŲ SISTEMĄ

Jing Jiang

Santrauka. Kai 2030 m. darbotvarkė dėl darnaus vystymosi toliau įgyvendinama, pasaulinė industrializacija susiduria su iššūkiais – išteklių trūkumu, klimato kaita ir nelygybe, bet sykiu atsiveria galimybės, kurias suteikia technologinės inovacijos ir žaliasis perėjimas. Tvari industrializacija – sudėtingas ir sistemingas procesas. Šiuolaikiniai tyrimai dažnai ignoruoja įvairius industrializacijos kelius ir elementų sąveikas, daugiausia dėmesio skiriama vieno veiksnio poveikiui. Šiame tyrime pritaikyta lanksčiųjų aibių kokybinė lyginamoji analizė, pagrįsta bendros plėtros ir pasaulinės vertės grandinės teorijomis, siekiant ištirti daugiamates sąlygas, kurios veikia industrializaciją, remiantis Darniojo vystymosi tikslais (DVT). Remiantis 132 šalių Jungtinių Tautų DVT duomenų baze (2016–2023 m.) nustatyta, kad industrializacija kyla iš kelių sąlygų derinių, o ne iš atskirų kintamųjų. Keturi pagrindiniai keliai, kurie skatina industrializaciją: Švietimo ir aplinkos apsaugos, Sveikatos ir aplinkos apsaugos, Sveikatos ir švietimo bendradarbiavimo ir Visapusiška švietimo, lygybės ir aplinkos integracija. Pagrindiniai elementai – atsakingas vartojimas, kokybiškas švietimas ir gera sveikata. Švietimas ir sveikata, atsižvelgiant į sąlygas, gali būti papildomi arba pakaitiniai, o švarios energijos ir industrializacijos atveju dažnai reikia kompromiso. Šios išvados padeda pritaikyti DVT sistemą, praturtina industrializacijos tyrimų metodologiją ir teikia įžvalgų dėl pasaulinės industrializacijos transformacijos ir politikos formavimo.]

Reikšminiai žodžiai: industrializacija; darnaus vystymosi tikslai; kokybinė lanksčiųjų aibių lyginamoji analizė; bendras poveikis; sąveikos.