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Rethinking Industrial Heritage Tourism Resources in the EU: A Spatial Perspective

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Abstract: Industrial heritage serves as a poignant testament to the historical narrative of industrial civilization. The European Route of Industrial Heritage (ERIH) is a pan-European network that connects industrial sites and museums to enhance public awareness of the significance of the industrial heritage sector and to promote sustainable development practices in urban areas through collaboration and cooperation between these sites. The ERIH is crucial in promoting economic, cultural, and social values associated with industrial heritage and creating opportunities for tourism and education in Europe. Taking the ERIH as the research object, the nearest-neighbor index, kernel density, geographic detector, and other methods are used in this study to explore the spatial distribution characteristics and influencing factors of European industrial heritage. The results of this study have implications for urban and regional planning endeavors aimed at advancing sustainable urban development. Furthermore, they contribute to cultivating a sense of place and identity by identifying and preserving industrial heritage institutions while fostering social cohesion and community identity practices. The results show that (1) the spatial distribution of European industrial heritage presents a cohesive distribution, and the spatial distribution is uneven; (2) the spatial distribution of European industrial heritage forms "dual cores, dual centers, one belt, three zones and multiple scattered points"—the center of gravity shows a trend of "first north and then east" and the north–south movement is relatively small; and (3) a combination of natural and social factors shape the spatial distribution of industrial heritage. Natural conditions, such as altitude, topography, and hydrological characteristics, influence the distribution patterns of industrial heritage sites. Meanwhile, human factors, including infrastructure level, cultural tourism potential, and social development, play a pivotal role in determining spatial distribution patterns. Among these factors, the socio-economic level exhibits the strongest influence, with an explanatory power of 0.763. The results of this study can contribute to the conservation and tourism practices regarding industrial heritage sites, thus promoting sustainable urban development practices.

Keywords: European Route of Industrial Heritage; European industrial heritage; industrial heritage; spatial distribution characteristics

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1. Introduction

As a crucial urban cultural asset, the preservation of industrial heritage institutions holds an immensely significant position in the pursuit of the cultural heritage of cities [1]. Despite its relatively short survival time compared to other cultural heritage institutions, the impact of the Industrial Revolution on the evolution of human society has been immense, affecting the domains of economy, society, and culture [2]. Thus, the industrial heritage sector serves as valuable historical evidence that reflects the development of human culture in the past few centuries. Industrial heritage conservation and protection practices represent a shared societal interest [3]. However, the industrial upgrading process has led to the pressing challenge of industrial heritage preservation, which has resulted in critical issues in the sector, such as the abandonment or demolition of these sites [4].

Moreover, sustainable development has gained significant momentum in the field of environmental pollution, energy crisis, and urban shrinkage, aiming to address the competing interests of economic growth and environmental conservation [5]. Consequently, the research conducted on sustainability has expanded from the environmental, ecological, and social domains to encompass cultural dimensions, too [6]. Specifically, cultural and creative industries, cultural tourism, and heritage preservation are critical drivers of areas that include sustainable economic growth, poverty eradication, innovation, and employment. Notably, UNESCO's 2030 Agenda for Sustainable Development emphasizes the pivotal role of the field of cultural heritage in achieving sustainable development goals [7]. Therefore, industrial heritage is a significant component of cultural heritage, attracting considerable attention in the research of heritage sustainability owing to its accessibility in terms of geographic location, architectural space flexibility, and unique cultural values [8]. The preservation and repurposing of industrial heritage sites are essential activities for transmitting urban culture and enhancing spatial quality, thereby establishing sustainable urban development measures [9].

The study of industrial heritage can be traced back to industrial archaeology, which aimed to document and preserve relics from the Industrial Revolution [10]. At present, the research conducted on industrial heritage primarily focuses on four main aspects: assessing its value, determining conservation methods, renovating buildings, and developing industrial tourism [8,11–14]. Industrial heritage conservation focuses on the authenticity and integrity of a specific site [15]. For example, some points argue that renewing equipment without altering the production process would not affect the integrity of the industrial heritage site [16]. It is widely acknowledged, at present, that the integrity of industrial heritage is reflected in the physical integrity of the production site and its social activities [17]. In recent times, there has been a shift in the focus of industrial heritage conservation research from the ontology of heritage to the users, with an increasing emphasis being placed on community conservation and public participation aspects, as well as the dissemination of industrial heritage education in the community [18]. This shift has been accompanied by the adoption of new forms of technology, such as unmanned aerial vehicles (UAVs), simulation technology, and virtual reality, which have greatly facilitated the collection of information that would have been difficult to obtain using traditional methods [19–21]. These emerging technologies have opened up new possibilities for documentation, interpretation, and engagement with industrial heritage, thereby expanding the scope of industrial heritage conservation research [22]. A post-use evaluation can assess the sustainable value and user satisfaction of industrial heritage renovation projects, offering recommendations for renovation designs [23]. The conversion of industrial spaces into tourist spaces is a successful strategy for the adaptive reuse of industrial heritage sites. Industrial tourism is deemed to generate novel cultural resources and cultural spaces. The starting point for industrial tourism research is the tourists themselves [24]. Industrial tourism research focuses on the tourists, with investigations conducted from multiple perspectives, including improvements in tourist satisfaction, the enrichment of perceptual experiences, and the evocation of emotional resonance. These results provide valuable guidance for the design and restoration of industrial heritage sites in research.

The research shows that reusing industrial heritage sites is an important pathway for urban renewal [25]. However, some research has focused on this aspect at the micro-level and relied on the results of other case studies, with a narrow geographic scope often limited to a single country or city [13,26,27]. The research has mainly been analyzed from the perspectives of different disciplines, such as archaeology, architecture, and sociology. Thus, there is a relative lack of analysis of industrial heritage in the literature from a macro-spatial perspective. With the rise in big data in the industry, some scholars have conducted spatial analyses at the national, city, and heritage-type levels. However, there is still a lack of research that has been conducted on the spatial analysis of the industrial heritage sector at a more macro-level, especially in the EU, where there many industrial heritage sites exist [28].

Additionally, the analysis of the factors influencing the spatial distribution of industrial heritage sites lacks further in-depth examinations. Based on these considerations, this study utilizes the ERIH list as a representative research sample and employs geographic analysis methods to scrutinize the spatial distribution patterns and evolutionary traits of industrial heritage sites located across Europe. By delving into the underlying mechanisms influencing the spatial distribution of industrial heritage institutions, this study offers valuable insights that contribute to ideas for the preservation and repurposing of industrial heritage sites, facilitates sustainable land-use practices, and furthers urban renewal initiatives in the field.

This paper is structured as follows: Section 2 provides an in-depth analysis of the ERIH, highlighting its historical background and significance; Section 3 details this study's data collection procedures and analytical techniques; in Section 4, the results of the analysis are presented and described in detail; and Sections 5 and 6 summarize and evaluate the results that we obtained and outline the possibilities for future research conducted in the field.

2. The European Route of Industrial Heritage (ERIH)

2.1. Industrial Heritage in Europe

The Industrial Revolution of the 18th century transformed Europe from a primarily agricultural economy into a global manufacturing powerhouse [29]. This period's physical artefacts and structures, including factories, mills, canals, railways, mines, and other industrial sites, constitute Europe's industrial heritage. In addition to their historical significance, these sites also hold cultural and artistic values, serving as a testament to the ingenuity and skill of Europe's industrial pioneers and providing a tangible link to the past for future generations [30]. Europe's industrial heritage is ubiquitous in every corner of the continent. It encompasses the factories located in the UK's Midlands, the steel mills of GE's Ruhr Valley, the coal mines of PO, and the textile mills of IT (for the abbreviations of countries, see Appendix A). The technological advances achieved during the Industrial Revolution, such as the creation of the steam engine, the Bessemer process, and the spinning jenny, have had an enduring impact on the modern industry worldwide [31]. European industrial heritage is a significant part of the continent's cultural and economic history [32]. Its preservation is important for historical and cultural reasons and its potential to promote economic development and tourism [33]. At present, many sites are at risk of neglect or development pressures; therefore, it is crucial to find ways to safeguard them for future generations [34–36].

2.2. The ERIH Process

The European Route of Industrial Heritage (ERIH) represents a comprehensive network encompassing many industrial heritage sites located across Europe. This transnational initiative serves the paramount purpose of advocating for the promotion and conservation of Europe's industrial heritage. By accentuating these sites' historical, cultural, and economic importance, the ERIH seeks to illuminate their pivotal role in shaping the trajectory of European civilization. The ERIH was established at the end of the last century to promote industrial heritage conservation measures and enhance its tourism potential [37,38]. In the year 1999, the Council of Europe called on its member states to participate in the "Europe, a Common Heritage" campaign to raise public awareness of the value of European heritage [39]. The German Society for Industrial Culture proposed a pan-European network concept to support the campaign, which the State of North Rhine-Westphalia accepted [40]. The ERIH received EU funds from the EU Interreg II C Northwest Europe Program [41]. Organizations from four countries (UK, BE, DE, and NL) joined and submitted the Pan-European Network Master Plan in 2001 [42]. The program aims to preserve European industrial heritage by developing transnational initiatives, promoting public participation, and stimulating local tourism [43]. The anchor network is one of the most important tools used in the industry to promote the ERIH concept. Europe has 46 countries, of which 24 have become members of the ERIH, accounting for 52% of all of the countries located in Europe [44]. The ERIH underwent certification by the Council of Europe's Cultural Routes in 2019, signaling a developing recognition of the significance of preserving and promoting a country's industrial heritage as a valuable cultural asset (Figure 1) [45].

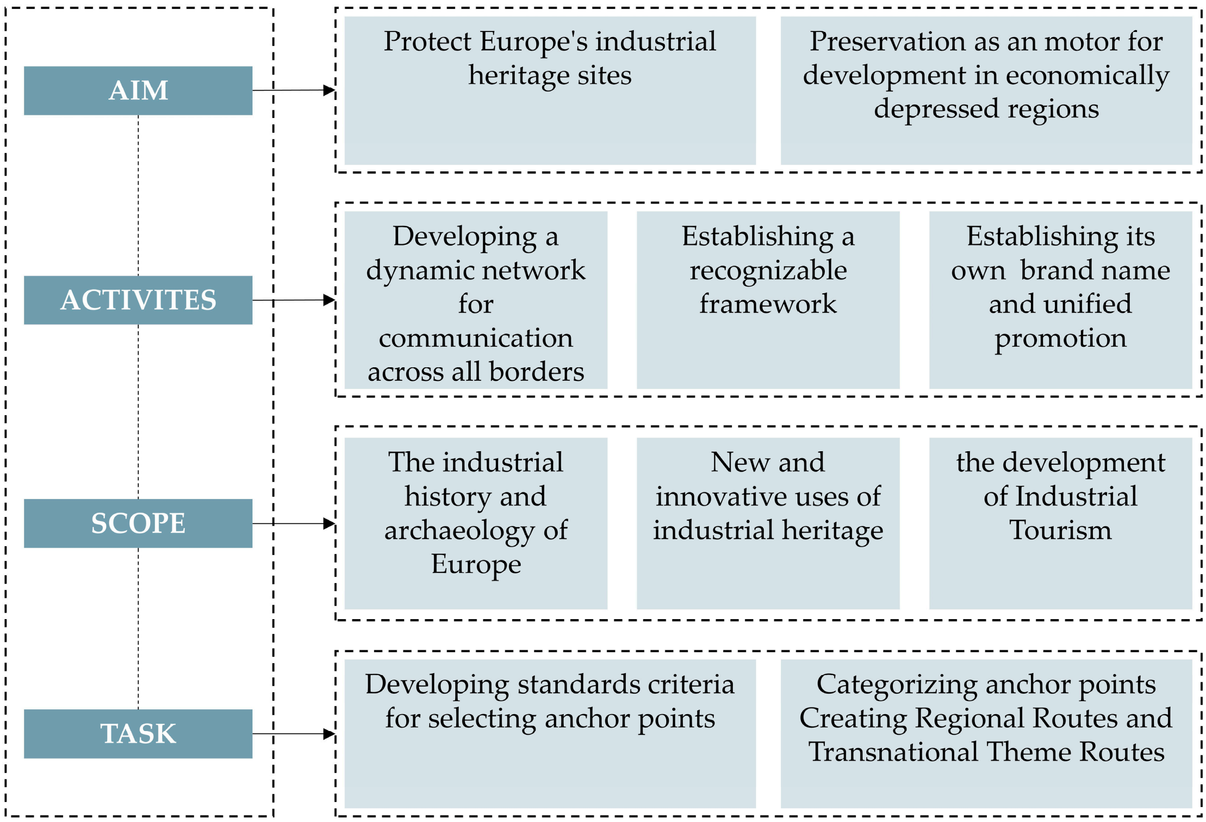


Figure 1. Working layout of the ERIH.

2.3. The ERIH System

The ERIH uses a route system that includes sites, anchor points, and regional and theme routes. The site is an important example of European industrial history and is fundamental to the ERIH's route system. The anchor points are vital nodes in the ERIH, framing the entire route system, and there are 110 anchor points, at present, covering the full range of industrial development in Europe. These anchor points are attractive destinations for industrial tourism and provide visitors with a thrilling industrial heritage experience. The regional routes connect points that have influenced the European industry and reflect the character of each European region's industrial development process. The ERIH has 21 regional routes in countries such as DE, the UK, NO, and ES, with DE having the most regional routes (11 routes) (Table 1). Based on the data obtained from the homepage, the ERIH's theme routes cover 15 major categories, including power, chemistry, communication, mining, paper, iron and steel, textiles, and transportation, further divided into 52 subcategories (Table 2).

Table 1. Representative regional routes in the ERIH.

Country	Name	Introduction
AT	Regional Route Styrian Iron Trail	The Anchor Point Erzberg Mine is the pre-eminent open cast-iron ore mine in Central Europe, which serves as a testament to the region's rich history of mining and smelting.
CZ	Regional Route Moravian-Silesian Technical Trail	The Moravian-Silesian region is a key industrial area of Central Europe, dominated by coal mining, steel production, and automotive industries.
DE	Regional Route Berlin	Berlin, known as the "City of Electronics", has been a key player in the industrialization process since the mid-19th century, with Siemens being one of the largest electronics companies in the world, founded in 1847.
	Regional Route Hamburg Metropolitan Region	Hamburg is an important seaport, and the maritime industry has shaped the region's industrial culture "waterside landscape", including shipyards, fish processing plants, docks, lighthouses, and bridges.
	Regional Route North Hessen	Mining, weapons, and textile industries dominate the Hessen region.
	Regional Route Ruhr	The Ruhr region in GE has historically been recognized as a significant heavy industrial area, with numerous coke plants, pits, steelworks, and chemical factories. The "Route of Industrial Heritage" in the Ruhr region serves as the core network of this tourist attraction.
LU	Regional Route Minett Tour	The Red Rock Region in LU has witnessed the country's industrial growth, with the steel industry driving the economy since the mid-19th century.
NL	Regional Route Euregio Meuse–Rhine	The Euregio Meuse–Rhine region, comprising GE, the NE, and BELG, holds historical significance as a key player in Europe's early industrialization process, earning the reputation of the "melting pot of Europe".
PL	Regional Route Silesia	The province of Silesia has a rich history of mining dating back to the Middle Ages and became a prominent player in the European mining industry during the Industrial Revolution.
ES	Regional Route Asturias	Asturias has been widely recognized as the country's epicenter of the coal industry, attributed to its abundant coal reserves.
UK	Regional Route South Wales	In the 19th century, Wales underwent significant industrialization, focusing on steel, tinplate, and coal production. At present, the remnants of this industrial heritage have been transformed into an industrial landscape.

Table 2. Representative regional routes in the ERIH.

Theme Routes	Subcategories
Application of power	Electricity; gas; nuclear; oil; peat; steam; water; wind
Chemistry	Chemistry
Communication	Mass media; printing; telecommunication
Housing	Entrepreneurs' mansions; planned industrial villages; workers' housing
Industrial architecture	Adaptive re-use; industrial architecture of the 20th century; outstanding industrial architecture
Industry and war	Industry and war
Iron and steel	Furnaces; goods from iron and steel
Landscapes	Landscapes
Mining	Black coal; brown coal; ore; metal; slate
Paper	Paper
Production and manufacturing	Armament; beer; building materials; ceramics, porcellane; glass; cutlery; engineering; food; drink; fishing; agriculture; tobacco; gold; silver; jewelry; clocks; coins; leather; wood; timber; other
Salt	Salt
Service and leisure industry	Service and leisure industry
Textiles	Clothing (and other textile) manufacturing; cotton; linen; flax; hemp; jute; silk; wool
Transport	Aviation; motor vehicles and roads; railway rolling stock and railways; ships; harbors; rivers and canals; street tramways and omnibuses
Water	Drinking water; sewage disposal; power from water

3. Data Sources and Research Methods

3.1. Data Sources

The industrial heritage data utilized in this study were obtained from the official site of the ERIH (https://www.erih.net/ (accessed on 6 May 2023)), one of Europe's most significant industrial heritage resource databases [46]. As of May 2023, the ERIH lists 2221 industrial heritage sites in 52 countries or regions, with 110 "anchor points" of exceptional historical importance, 21 regional industrial heritage routes, and 18 thematic routes of European industrial heritage. The data for GDP [47], total kilometers of railways [48], urbanization rate [49], number of international tourist arrivals [50], population density [51], and power consumption [52] were obtained from World Bank open data (https://data.worldbank.org.cn/ (accessed on 3 June 2023)).

To analyze the results from a geographic perspective, the research data were obtained using the geographic coordinate picker in Google Earth to calibrate the geospatial coordinates of industrial heritage sites. Subsequently, the relevant data were imported into ArcGIS 10.2, an advanced software tool used to perform data analysis and map creation developed by the Environmental Systems Research Institute (ESRI) in the United States. The spatial coordinates in ArcGIS 10.2 were then matched and projected to create a spatial database of European industrial heritage sites and to visualize them on a map (Figure 2).

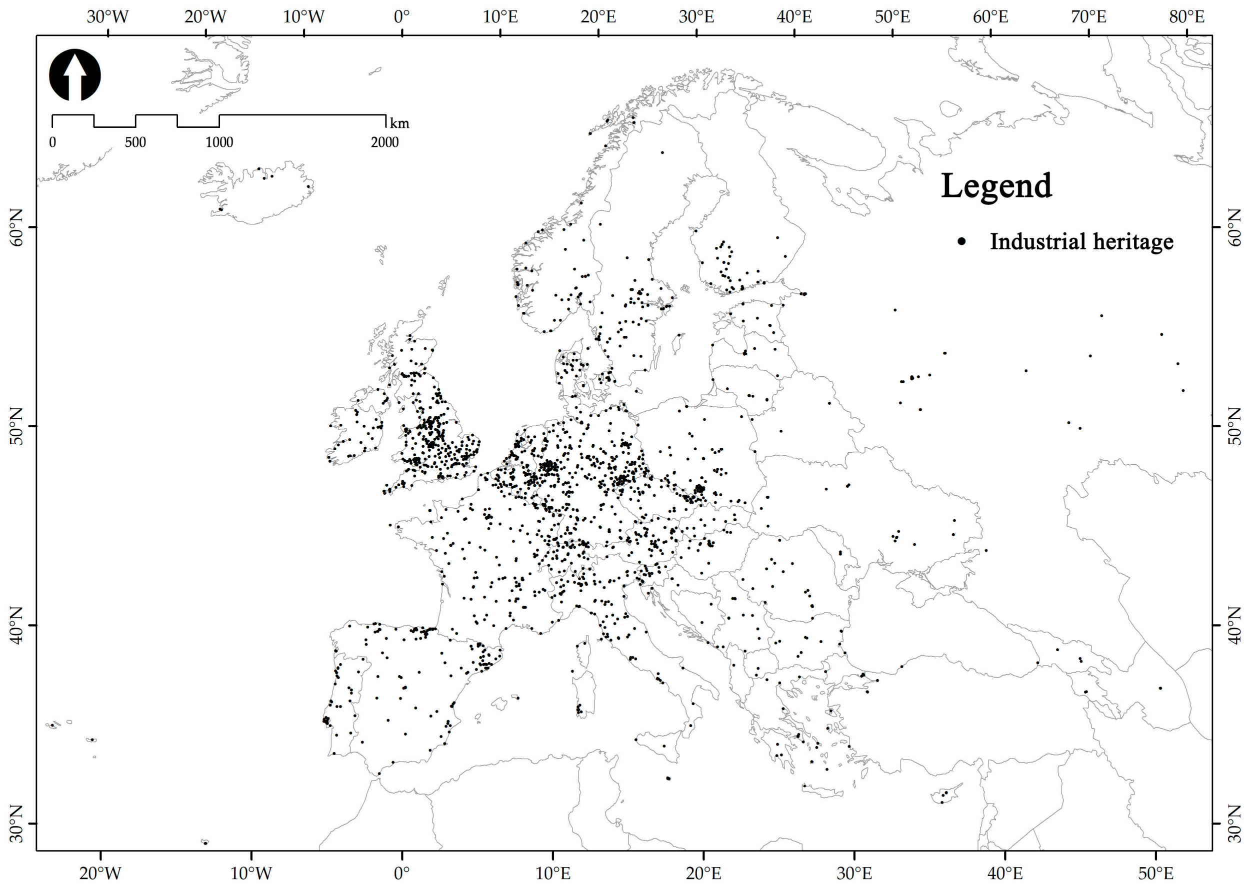


Figure 2. Geographical distribution of industrial heritage in Europe based on the ERIH.

3.2. Research Methods

To comprehensively examine the distribution characteristics of the European Route of Industrial Heritage, this study adopted well-established indices and models that are widely accepted in geospatial research. By utilizing these tools commonly employed in the field, this study conducted a thorough analysis of the spatial distribution characteristics of the ERIH and investigated the various factors that influenced this distribution. The nearest-neighbor index was used to analyze the spatial distribution type of the ERIH, while a kernel density estimation was applied to investigate its spatial distribution density. Moreover, the imbalance index and Gini coefficient were utilized to assess the spatial distribution difference in the ERIH, and GeoDetector was also employed to quantify the impact of specific factors on its distribution (Figure 3).

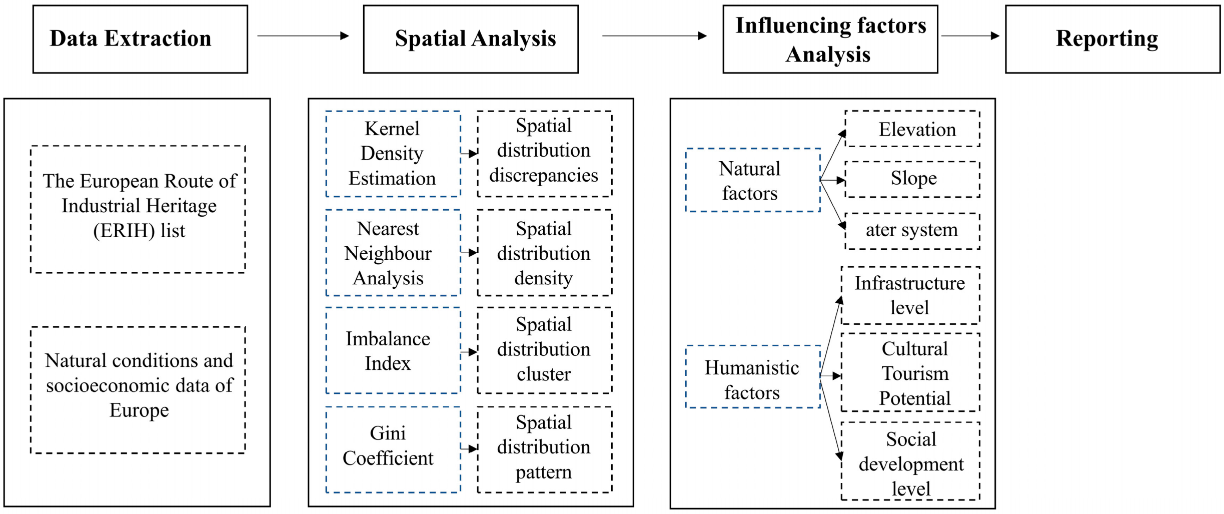


Figure 3. Research framework diagram.

3.2.1. Kernel Density Estimation

Kernel density estimation is a nonparametric density estimation method. It represents the pattern of spatial points by analyzing the spatial density of the study object [53]. In this study, the kernel density estimation method was used to visually reflect the aggregation state of the ERIH. The formula for the kernel density estimate is

$$f_n(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - X_i}{h}\right) \quad (1)$$

where $f_n(x)$ represents the kernel density estimate value of the ERIH; n is the number of the ERIH; $k\left(\frac{x-X_i}{h}\right)$ denotes the kernel function; $(x - X_i)$ denotes the distance from the valuation point x to the sample X_i; and h denotes the bandwidth.

3.2.2. Nearest-Neighbor Analysis

The nearest-neighbor index method is one of the most effective methods used in research to study the spatial distribution of point elements [54]. In this study, the ERIH was abstracted as a point element, and its distribution type was determined by calculating its nearest-neighbor index. The formula is as follows:

$$R = \frac{\overline{Do}}{\overline{De}}\ ; \quad \overline{Do} = \frac{1}{n}\sum_{i=1}^{n} d_{min}\ ; \quad \overline{De} = \frac{0.5}{\sqrt{n/A}} \quad (2)$$

where R is the nearest-neighbor index; $\overline{Do}$ is the average of the distance between the nearest points in reality; $\overline{De}$ is the average between the nearest points in theory; and A is the study area. If $R < 1$, the point elements are aggregated; if $R > 1$, the point elements are randomly distributed; if $R = 1$, the point elements are uniformly distributed.

3.2.3. Imbalance Index

The imbalance index reflects the equilibrium degree of the distribution of the study object within different regions [55]. The imbalance index was used to analyze the differences in the spatial distribution of the ERIH, while the Lorenz curve was applied to further verify the equilibrium of the regional distribution. The formula is as follows:

$$S = \frac{\sum_{i=1}^{n} Y_i - 50(n+1)}{100n - 50(n+1)} \tag{3}$$

where S is the imbalance index; n is the number of the country (region); and Y_i is the cumulative percentage of the number of industrial heritage sites within each country (region) to the total in the area. Considering that $0 \leq S \leq 1$, if $S = 0$, it indicates that the ERIH is evenly distributed in the region; if $0 < S < 1$, it indicates that the ERIH is not evenly distributed; and if $S = 1$, the industrial heritage sites are all concentrated in the specified region.

3.2.4. Gini Coefficient

The Gini coefficient can be used to measure the differences in the spatial distribution values of geographic elements [56]. In this study, the Gini coefficient was used to measure the spatial distribution of the ERIH in the geographic subdivisions. The formula is as follows:

$$G = \frac{-\sum_{i=1}^{N} P_i \ln P_i}{\ln N} \tag{4}$$

$$C = 1 - G \tag{5}$$

where G is the Gini coefficient, N is the number of regions, P_i is the proportion of the number of industrial heritage sites in the region i to the total number in the entire region, and C indicates the uniformity of the distribution. The Gini coefficient is between 0 and 1, with a larger coefficient indicating a higher degree of concentration.

3.2.5. GeoDetector

GeoDetector is a statistical method used in the research to analyze the drivers of spatial heterogeneity of geographical elements [57]. This study applied the model to analyze the magnitude of the explanatory power of the factors influencing the spatial distribution of industrial heritage sites located in Europe. The formula is as follows:

$$q = 1 - \frac{1}{N\sigma^2} \sum_{i=1}^{L} N_i \sigma_i^2 \tag{6}$$

where L represents the stratification of factors influencing the spatial distribution of industrial heritage sites, N_i represents the number of industrial heritage sites in strata i, N represents the total number of industrial heritage sites, and σ^2 and σ_i^2 represent the variance in industrial heritage density in strata i and the entire region, respectively. The value range of q is [0,1]. The higher the value, the stronger the explanatory power of the factor for the spatial distribution of the industrial heritage site, and vice versa. If q is 0, this factor is unrelated to the spatial distribution of the industrial heritage sites.

4. Results

4.1. Overview of the Study Subjects

The European Industrial Heritage Route concept originated in 1999, and the association was officially registered in 2008 following an initial development phase of five years [41]. The ERIH has over 2200 sites, and the database is continually expanding. Upon sorting and conducting a statistical analysis of the existing list, it was discovered that the sites were scattered and concentrated in 52 countries or regions (Table 3). DE has the highest number of sites at 423 (accounting for 19.05% of the total). In contrast, AL, LI, and VA have the lowest number of sites, with only one industrial heritage site listed in the ERIH. The distribution of industrial heritage sites in various countries varies considerably.

Table 3. Statistics of the regional distribution of industrial heritage sites in Europe.

No.	Country or Region	Amount	Proportion (%)	Cumulative Proportion (%)	No.	Country or Region	Amount	Proportion (%)	Cumulative Proportion (%)
1	DE	423	19.05	19.05	27	RS	11	0.50	95.68
2	UK	399	17.96	37.01	28	TR	11	0.50	96.17
3	FR	181	8.15	45.16	29	LV	8	0.36	96.53
4	ES	125	5.63	50.79	30	LT	8	0.36	96.89
5	IT	115	5.18	55.97	31	LU	8	0.36	97.25
6	PL	92	4.14	60.11	32	HR	7	0.32	97.57
7	SE	76	3.42	63.53	33	AD	6	0.27	97.84
8	BE	71	3.20	66.73	34	CY	6	0.27	98.11
9	NL	66	2.97	69.70	35	IS	6	0.27	98.38
10	AT	60	2.70	72.40	36	BY	5	0.23	98.60
11	CZ	60	2.70	75.10	37	GE	4	0.18	98.78
12	NO	56	2.52	77.62	38	AZ	3	0.14	98.92
13	CH	48	2.16	79.78	39	MT	3	0.14	99.05
14	PT	47	2.12	81.90	40	MD	3	0.14	99.19
15	FI	41	1.85	83.75	41	AM	2	0.09	99.28
16	RU	37	1.67	85.41	42	BA	2	0.09	99.37
17	DK	36	1.62	87.03	43	KZ	2	0.09	99.46
18	HU	35	1.58	88.61	44	ME	2	0.09	99.55
19	IE	32	1.44	90.05	45	MK	2	0.09	99.64
20	GR	23	1.04	91.09	46	SM	2	0.09	99.73
21	SL	19	0.86	91.94	47	AL	1	0.05	99.77
22	UA	18	0.72	92.75	48	GI	1	0.05	99.82
23	RO	16	0.72	93.47	49	XK	1	0.05	99.86
24	EE	14	0.63	94.10	50	LI	1	0.05	99.91
25	BG	12	0.54	94.64	51	MC	1	0.05	99.95
26	SK	12	0.54	95.18	52	VC	1	0.05	100.00
						Total	2221	100.00	100.00

4.2. Spatial Structure Characteristics

4.2.1. Spatial Distribution Pattern

If the European industrial heritage points are abstracted as point elements, their distribution patterns in a geographical space can be divided into three types: uniform, random, and cohesive. Using the spatial analysis tool in ArcGIS 10.2 to calculate the nearest-neighbor index for European industrial heritage sites, the average nearest-neighbor index R = 0.34 < 1, and it passes the 1% significance test (p-value = 0.0000). It can be observed that the distribution of European industrial heritage sites generally presents a cohesive distribution pattern.

4.2.2. Spatial Distribution Density

This research used the kernel density tool in ArcGIS10.2 to estimate the kernel density values of European industrial heritage sites and used the natural breakpoint classification method to divide the kernel density values into six categories, extremely high, sub-high, high, medium, sub-low, and low densities (Table 4), thus forming a kernel density map of the spatial distribution of European industrial heritage sites (Figure 4). It generally presents a distribution pattern of "dual cores, dual centres, one belt, three zones and multiple scattered points".

Table 4. Kernel density analysis of industrial heritage sites in Europe.

Density Classification	Distribution Patterns	Country or Region	Amount	Kernel Density Zone
Extremely high density	dual cores	* UK	399	19.46–28.51
		IE	32	2.58–5.37
		* DE	423	19.46–28.51
		BE	71	13.54–19.45
		NE	66	13.54–19.45
		LI	1	0.68–2.57
Sub-high density	dual centers	* CZ	60	8.95–13.53
		AT	60	5.38–8.94
		SL	19	5.38–8.94
		HR	7	0.68–2.57
		* PL	92	13.54–19.45
		HU	35	5.38–8.94
		SK	12	5.38–8.94
High density	one belt	* CH	48	8.95–13.53
		LU	8	8.95–13.53
		FR	181	5.38–8.94
		IT	115	2.58–5.37
		SM	2	2.58–5.37
		MC	1	0.68–2.57
		VA	1	0.68–2.57
Medium density	three zones	* ES	125	5.38–8.94
		PT	47	2.58–5.37
		AD	6	0.68–2.57
		GI	1	0.68–2.57
		* RS	11	0.68–2.57
		GR	23	0.68–2.57
		RO	16	0.68–2.57
		BG	12	0.68–2.57
		TU	11	0.68–2.57
		BY	5	0.68–2.57
		BA	2	0.68–2.57
		MK	2	0.68–2.57
		ME	2	0.68–2.57
		AL	1	0.68–2.57
		XK	1	0.68–2.57
		* DK	36	2.58–5.37
		SE	76	2.58–5.37
		NO	56	2.58–5.37
		FI	41	2.58–5.37
		EE	14	2.58–5.37
		LV	8	0.68–2.57
		LT	8	0.68–2.57
Sub-low density	multiple scattered points	RU	37	2.58–5.37
		UA	18	2.58–5.37
		CY	6	0.68–2.57
		IE	6	0.68–2.57
		GE	4	0.68–2.57
Low density	multiple scattered points	AZ	3	0.68–2.57
		MT	3	0.68–2.57
		MD	3	0.68–2.57
		AM	2	0.68–2.57
		KZ	2	0.68–2.57

* Represents the core of the zone.

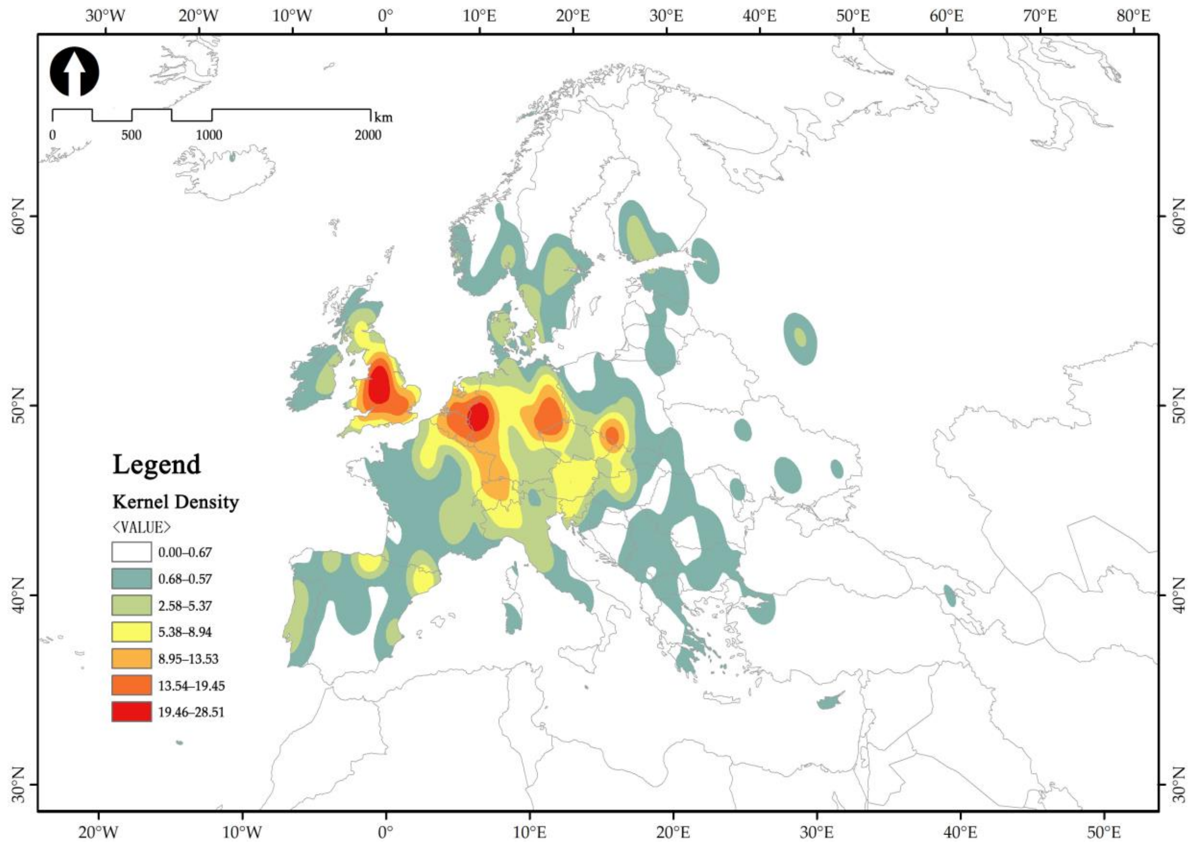


Figure 4. Spatial kernel density distribution of industrial heritage sites in Europe.

4.2.3. Spatial Distribution Discrepancies

According to Formula 3, after calculating and analyzing the data presented in Table 3, the imbalance index S = 0.728704 and 0 < S < 1 indicate that each region's distribution is unbalanced. The Lorenz curve was drawn according to the cumulative proportion of different countries or regions (Figure 5), which showed an upward convex trend. The industrial heritage of DE, UK, FR, and ES alone reached 50.79% of the total, further showing the unbalanced distribution of industrial heritage sites in Europe.

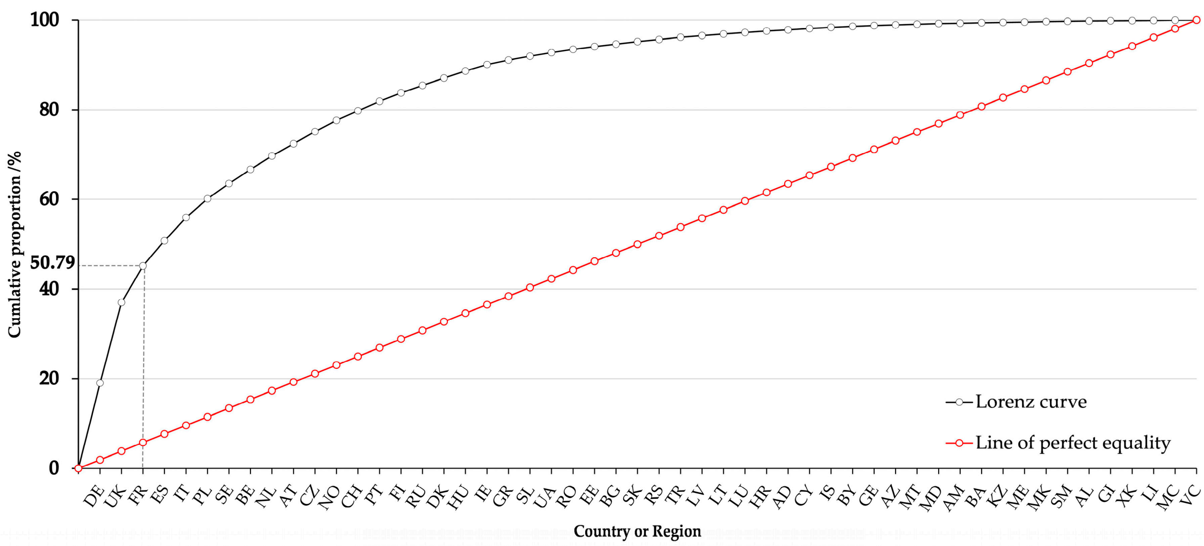


Figure 5. The Lorenz curve of the spatial distribution of industrial heritage sites in Europe.

4.2.4. Spatial Distribution Cluster

In this study, Europe was divided into five geographical divisions regarding the United Nations' geographical divisions, northern Europe, eastern Europe, western Europe, southern Europe, and Others, and the number of industrial heritage sites located in each geographical division were counted (Table 5). Specifically, the most concentrated area of industrial heritage distribution in Europe was western Europe, accounting for 38.67% of the total. The Others region had the smallest share, accounting for only 1.26%. It can be observed that the distribution of industrial heritage sites in Europe is uneven.

Table 5. Statistics for the distribution of industrial heritage sites located in various administrative divisions.

No.	Administrative Division	Amount	Proportion (%)	Cumulative Proportion (%)	Imbalance Index	Gini Coefficient
1	**Western Europe** (AT, BE, FR, DE, LI, LU, MC, NL, and CH)	859	38.67	38.67	0.69	0.68
2	**Northern Europe** (DK, EE, FI, IS, IE, LV, LT, NO, SE, and UK)	676	30.44	69.11	0.71	0.63
3	**Southern Europe** (AL, AD, BA, HR, GI, GR, IT, XK, MT, ME, MK, PT, SM, RS, SL, ES, and VA)	368	16.57	85.68	0.78	0.63
4	**Eastern Europe** (BY, BG, CZ, HU, MD, PL, RO, RU, SK, and UA)	290	13.06	98.74	0.53	0.83
5	**Others** (AM, AZ, CY, GE, KZ, and TR)	28	1.26	100	0.41	0.89
	Total	2221	100.00	100.00		

The Gini coefficient of the spatial distribution of five geographic divisions was analyzed in this study to determine the degree of uniformity in the distribution of European industrial heritage sites at the geographic division level. Based on Formulae (4) and (5), we calculated that $G = 0.74$, and the distribution uniformity $C = 0.26$. The results show that the distribution of European industrial heritage sites has a strong agglomeration and a low uniformity of distribution.

4.3. The Characteristics of Time and Type Distribution

4.3.1. Temporal Distribution of Industrial Heritage Sites in Europe

(1) Distribution of the Construction Time

A statistical analysis conducted on the construction time of industrial heritage sites located across Europe was conducted in this study to assess the intricate processes and patterns involved in forming industrial heritage areas. This meticulous examination that we conducted aimed to foster a profound comprehension of the temporal dynamics underlying the development of industrial heritage sites in the region. This research performed a statistical analysis to successfully determine a timeline for industrial heritage construction sites in Europe (Figure 6). To better understand the evolution of industrial heritage sites over time, this study divided the study period into three main periods: the years before 1000, 1000–1699, and 1700–2019. Within the 1000–1699 time period, every 100 years was considered as a separate interval, while within the 1700–2019 time period, every 20 years was considered as a separate interval. Our analysis revealed a rapid increase in the number of industrial heritage sites from the year 1760 onwards. However, from 1920 onwards, the number of sites gradually declined at a yearly rate.

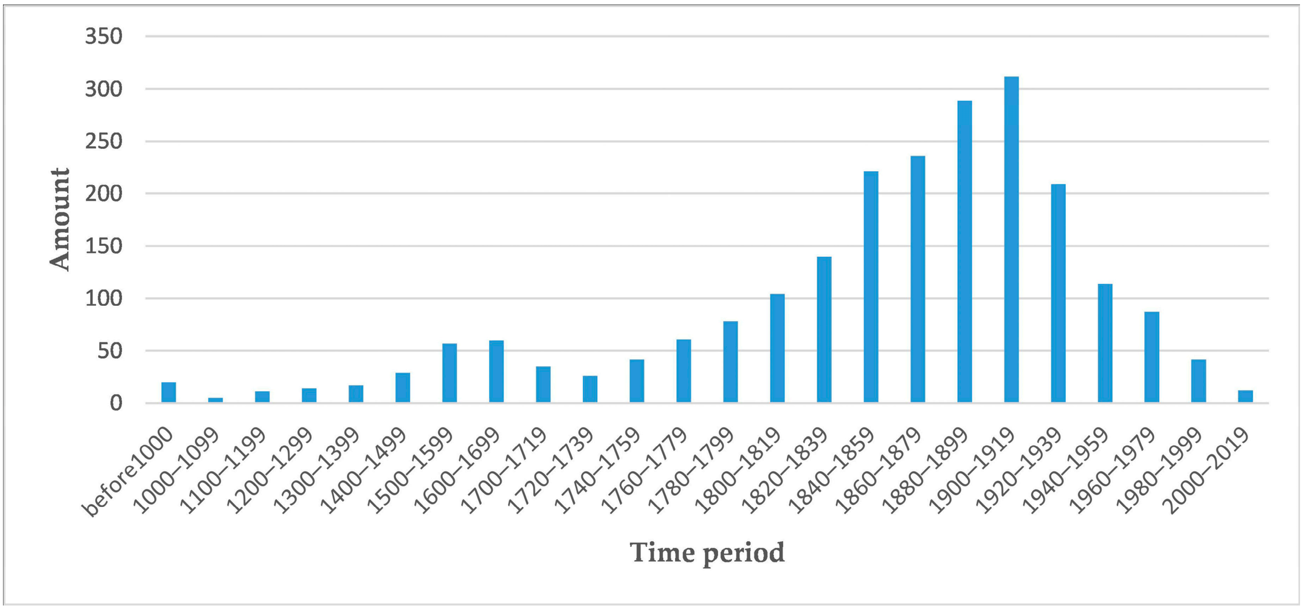


Figure 6. Statistics for the construction time of industrial heritage sites in Europe.

(2) Temporal Evolution Pattern Features

The well-known standard deviation ellipsoid method used in spatial analysis tests was used to quantitatively explain the centrality and directionality of the spatial distribution of the ERIH from a spatial perspective. The center of gravity of industrial heritage site distributions in Europe showed a trend of "first north and then east", and the spatial distribution became increasingly more discrete. According to the stages of the Industrial Revolution, this paper divided the European industrial heritage sites into four chronological stages: the years pre-1759, 1760–1869, 1870–1945, and post-1946. The center of gravity of the ellipse was predominantly located in western DE during the pre-1759 period (Figure 7). Additionally, the ellipse presented a turning angle of 74° and its long axis ran along the northeast–southwest direction, signifying that the spatial distribution of European industrial heritage prior to 1759 mainly followed this direction. From 1760 to 1869, the center of gravity of European industrial heritage shifted toward the north direction, specifically in northwestern DE, close to the border of DE and BE. The ellipse rotation angle increased, 89°, and the ellipse's major axis rotated 15° clockwise, close to the positive east–west direction distribution, indicating that in 1760–1869, the spatial distribution of industrial heritage tended to occur east–west. From 1870 to 1945, the center of gravity of the ellipse distribution moved eastward, and the rotation angle of the ellipse was 83°. In the post-1946 era, the center of gravity of the ellipse shifted toward the southeast direction, and the angle of rotation of the ellipse tended toward 90°. In summary, the concentration of European industrial heritage sites has gradually weakened over time, and the change in the southeast direction is greater. The center of gravity of the distribution showed a trend of "first north and then east".

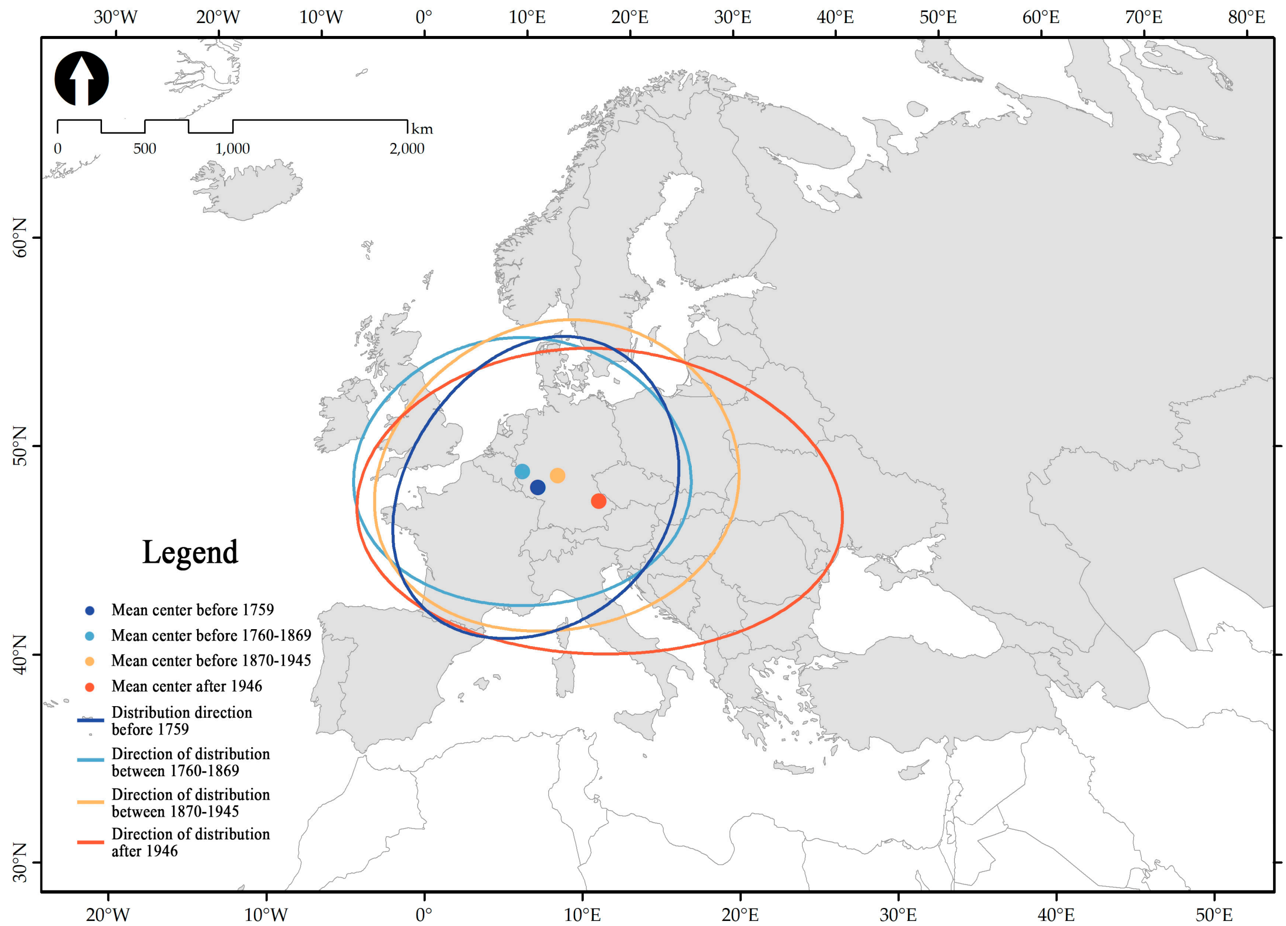


Figure 7. Standard deviation elliptic distribution of European industrial heritage sites in different periods.

4.3.2. Distribution of Industrial Heritage Types in Europe

(1) The Characteristics of Type Distribution

In order to achieve a more comprehensive understanding of the quantity and distribution of different types of industrial heritage sites, this study performed a typological analysis of the European Route of Industrial Heritage. According to the theme route of the ERIH, European industrial heritage can be divided into 15 categories and 52 subcategories (Figure 8). Transport is the most abundant in terms of categories, with 217 sites. Transport, production and manufacturing, and mining were the three sectors with the highest values, accounting for 25.75%, 23.59%, and 13.9%, respectively. Industrial architecture, chemistry, and landscapes were the three sectors with the lowest numbers, accounting for 1.22%, 7.65%, and 0.9%, respectively.

The statistical analysis we performed on the number of various types of industrial heritage sectors located in each country (Figure 9) revealed significant differences among the different countries we analyzed in our study. The statistical analysis was conducted on the number of various types of industrial heritage sectors in each geographical division (Figure 10), and we observed that a certain regional uniqueness was evident.

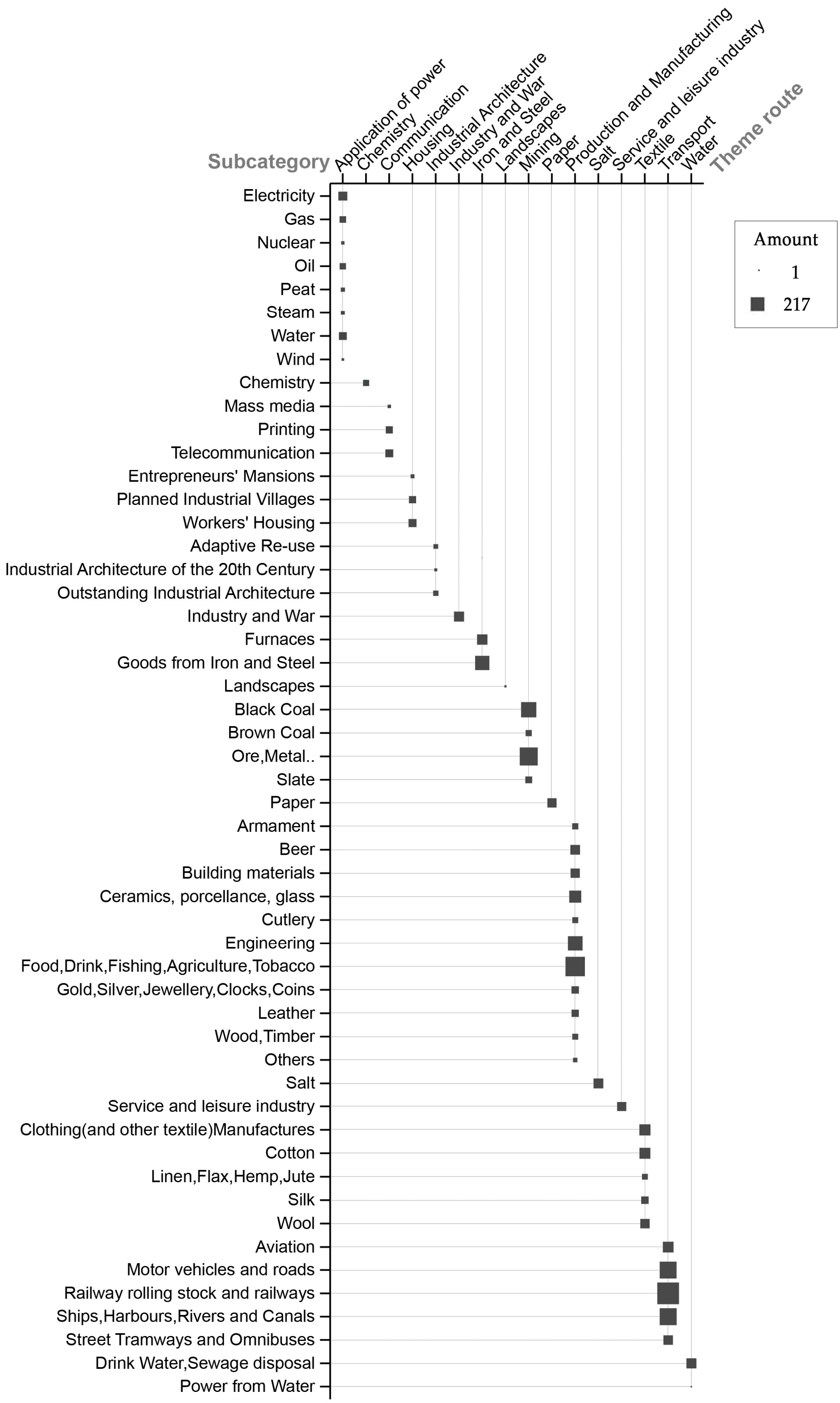


Figure 8. Classification of industrial heritage sites located in Europe.

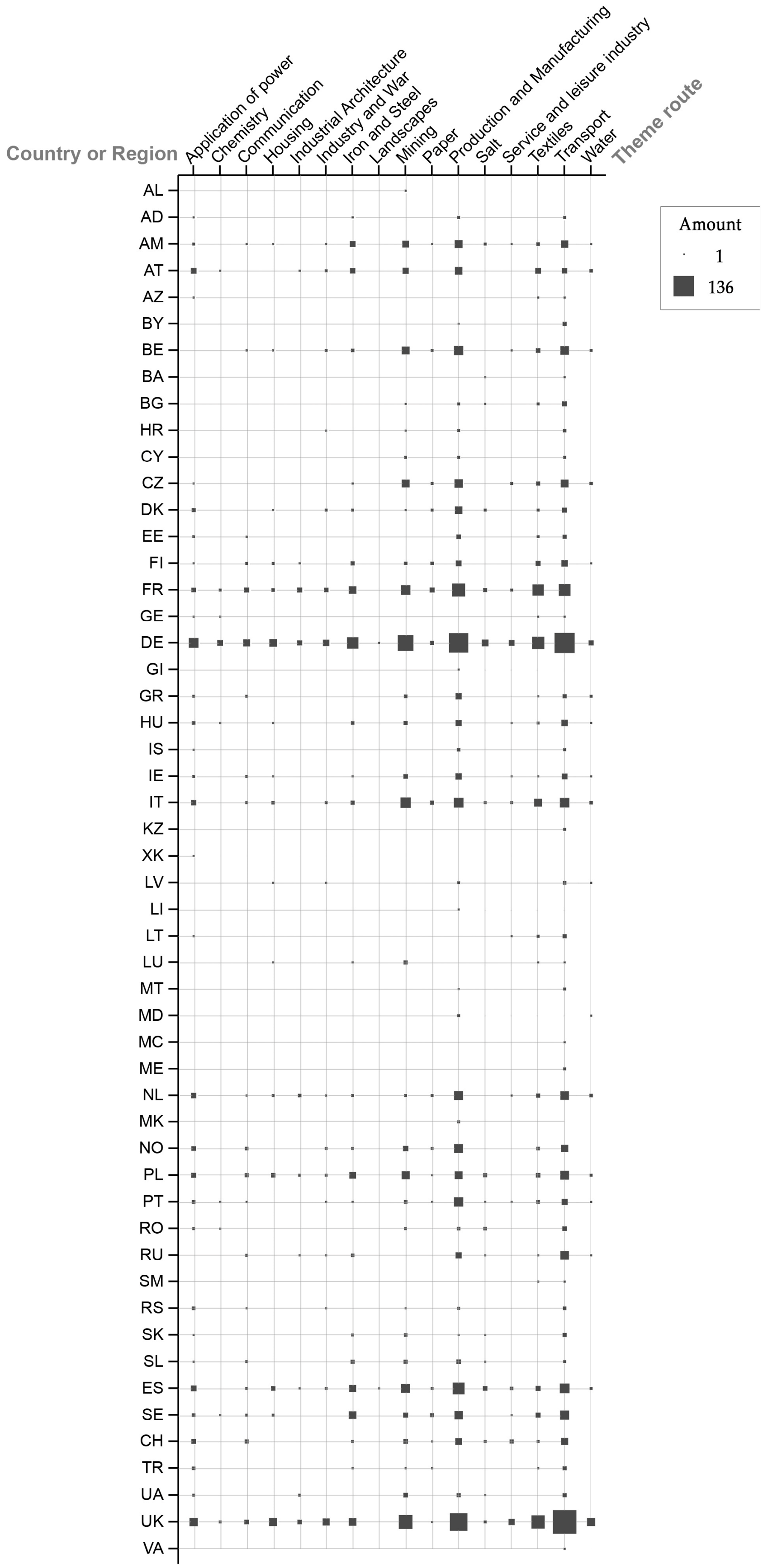


Figure 9. Regional distribution classification of industrial heritage sites in Europe.

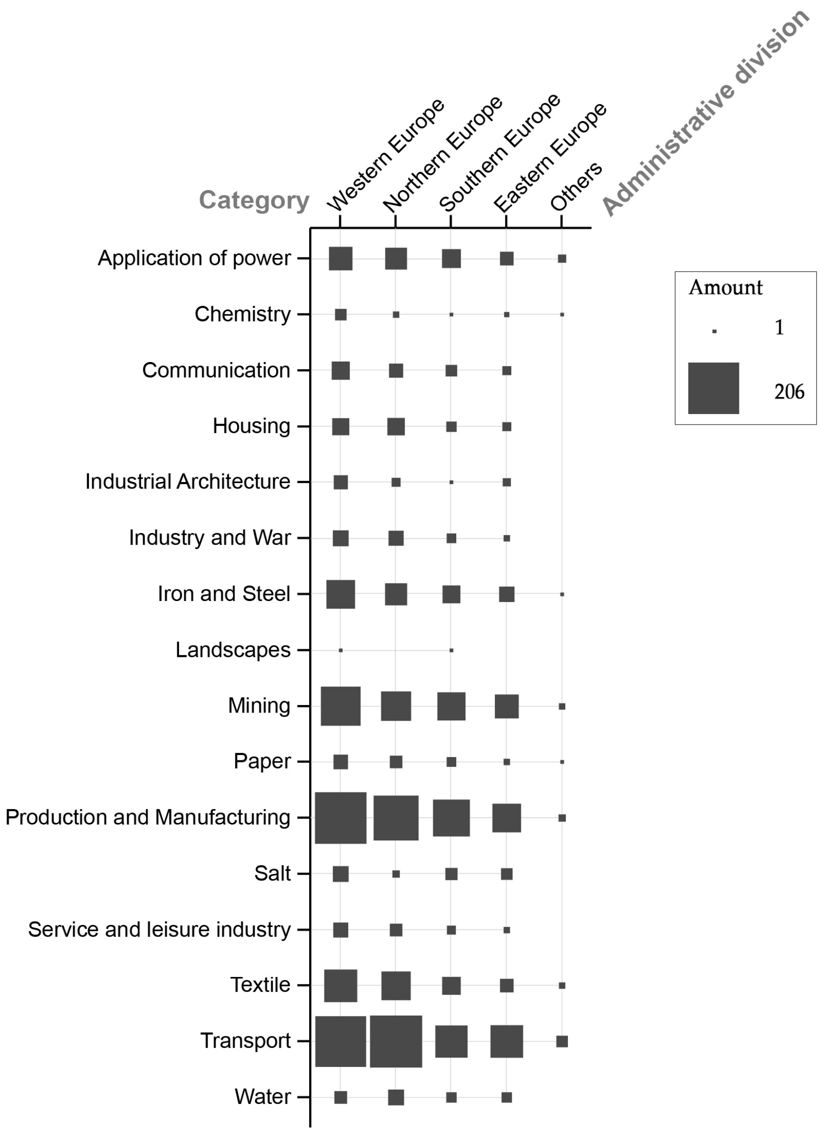
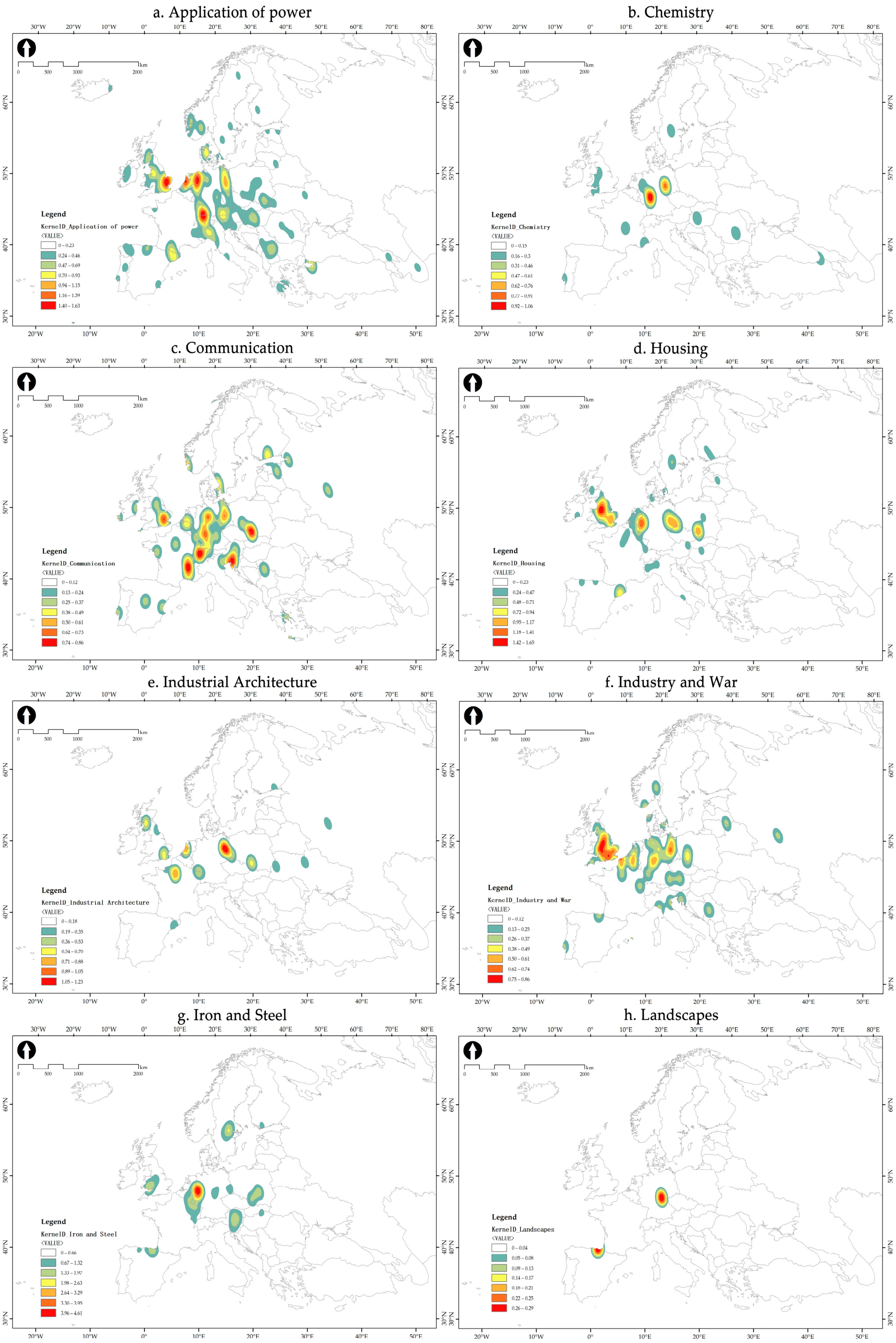


Figure 10. Classification of geographical division types of European industrial heritage institutions.

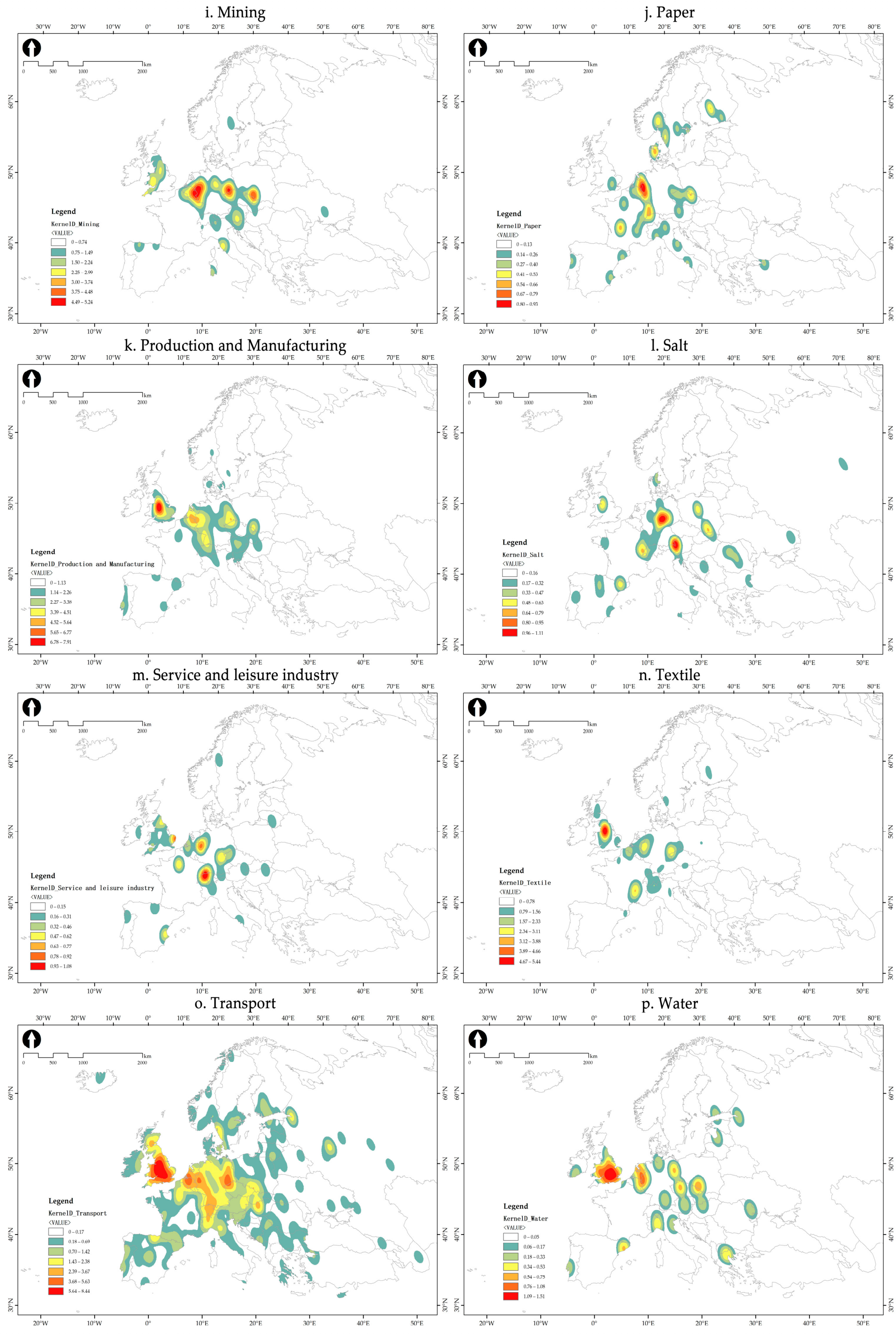
(2) Spatial distribution characteristics of different types of industrial heritage sites

In order to delineate the spatial clusters of the diverse industrial heritage types in Europe, this study utilized kernel density analysis as a methodological approach to appropriately analyze the European Route of Industrial Heritage. The spatial distribution of European industrial heritage sites varies among different types (Figure 11A,B). The application of power type exhibited a distribution pattern characterized by "four cores, two bands and multiple clusters", while the chemistry type presented a "double-core scattered" distribution. The communication type was characterized by "four continuous cores", the housing type was characterized by "single-core and three clusters", the industrial architecture type was characterized by "single-core scattered", the industry and war type was characterized by "single-core double-cluster scattered", the iron and steel type was characterized by "single-core scattered", the landscape type was characterized by "double-core", the mining type was characterized by "triple-core belt", the paper type was characterized by "single-core multi-group", the production and manufacturing type was characterized by "single-core single-group", the salt type was characterized by "double-core scattered", the service and leisure industry type was characterized by "single-core scattered", the textile type was characterized by "single-core continuous", and the water type was characterized by "double-core, one cluster, two bands".



(A)

Figure 11. *Cont*.



(**B**)

Figure 11. (**A**) Spatial distribution characteristics of various types of industrial heritage (a: application of power, b: chemistry, c: communication, d: housing, e: industrial architecture, f: industry and war, g: iron and steel, h: landscapes). (**B**) Spatial distribution characteristics of various types of industrial heritage (i: mining, j: paper, k: production and manufacturing, l: salt, m: service and leisure industry, n: textiles, o: transport, p: water).

5. Influencing Factors of the Spatial Distribution of European Industrial Heritage Sites

5.1. Selection of Influencing Factors

The spatial distribution of industrial heritage sites is affected by several factors [58]. This paper explored and analyzed natural and humanistic factors based on the existing research in the literature, considering the data's quantifiability, availability, and relevance. Among these factors, the natural factors were analyzed in this study from altitude, topography, and water system perspectives. For the humanistic factors, seven factors from three dimensions at the regional facility level, cultural tourism potential, and social development level were selected in our study as the influencing factors.

5.2. Analysis of the Natural Influencing Factors

The factors of altitude and slope represented fundamental factors that influenced the spatial distribution of industrial heritage sites [59]. Elevation played a pivotal role in determining the availability and accessibility of natural resources. At the same time, slope influenced the ease of accessing industrial sites, leading to a tendency for factories to be established in regions characterized by their gentle terrain and lower elevations. Consequently, European industrial heritage sites exhibited distinct variations across various altitudes, with a notable concentration in areas featuring low altitudes and a gentle topography. Upon superimposing the industrial heritage data onto the European elevation map, it can be observed that the industrial heritage sites with elevations ≤ 500, 500–1000, 1000–1500, and >1500 m account for 88.4%, 9.4%, 1.5%, and 0.7%, respectively (Figure 12a). The industrial heritage areas with slopes of 0–2°, 2–5°, 5–8°, 8–15°, and 15° or greater accounted for 88.3%, 9.2%, 1.8%, 0.4%, and 0.3%, respectively (Figure 12b).

Hydrological conditions are an important natural resource that also affects the spatial distribution of industrial heritage sites [60]. Water is a key resource and power source for many industrial production practices. Areas rich in water resources are ideal for food processing, paper, and hydroelectric power generation activities [61]. The linear distance from water sources directly influences the formation and development of industries and, thus, the spatial distribution of industrial heritage sites. By analyzing the major European rivers with 5, 10, 15, and 20 km buffer zones, we observed the numbers of industrial heritage sites as being 171, 60, 43, and 65, respectively (Figure 12c).

Hamburg, a typical industrial city located in northern DE, boasts distinct physical and geographical characteristics shaping its industrial development process, resulting in a legacy of abundant industrial heritage (Figure 13) [62,63]. Hamburg enjoys a strategic location at the convergence of the Elbe River and the North Sea [64], serving as a crucial nexus connecting the city to diverse inland regions and facilitating the seamless access by people to the heart of Europe [65]. This propitious combination of a gentle topography, lower altitude, and convenient water transport has established the solid groundwork for the region's industrialization activity. Over time, these industries were transformed into a fascinating industrial landscape. At present, Hamburg stands as an exemplar of urban revitalization, where numerous erstwhile industrial buildings and warehouses have been ingeniously transformed into vibrant cultural centers, art galleries, and residential spaces. This visionary metamorphosis has bestowed newfound vitality upon the city, propelling its trajectory toward urban renewal. Particularly noteworthy is the revitalization of Hamburg's waterfront, with the biennial Industrial Culture Days conducted on the waterfront serving as an immersive platform, inviting visitors to delve into and admire the rich tapestry of the region's industrial heritage.

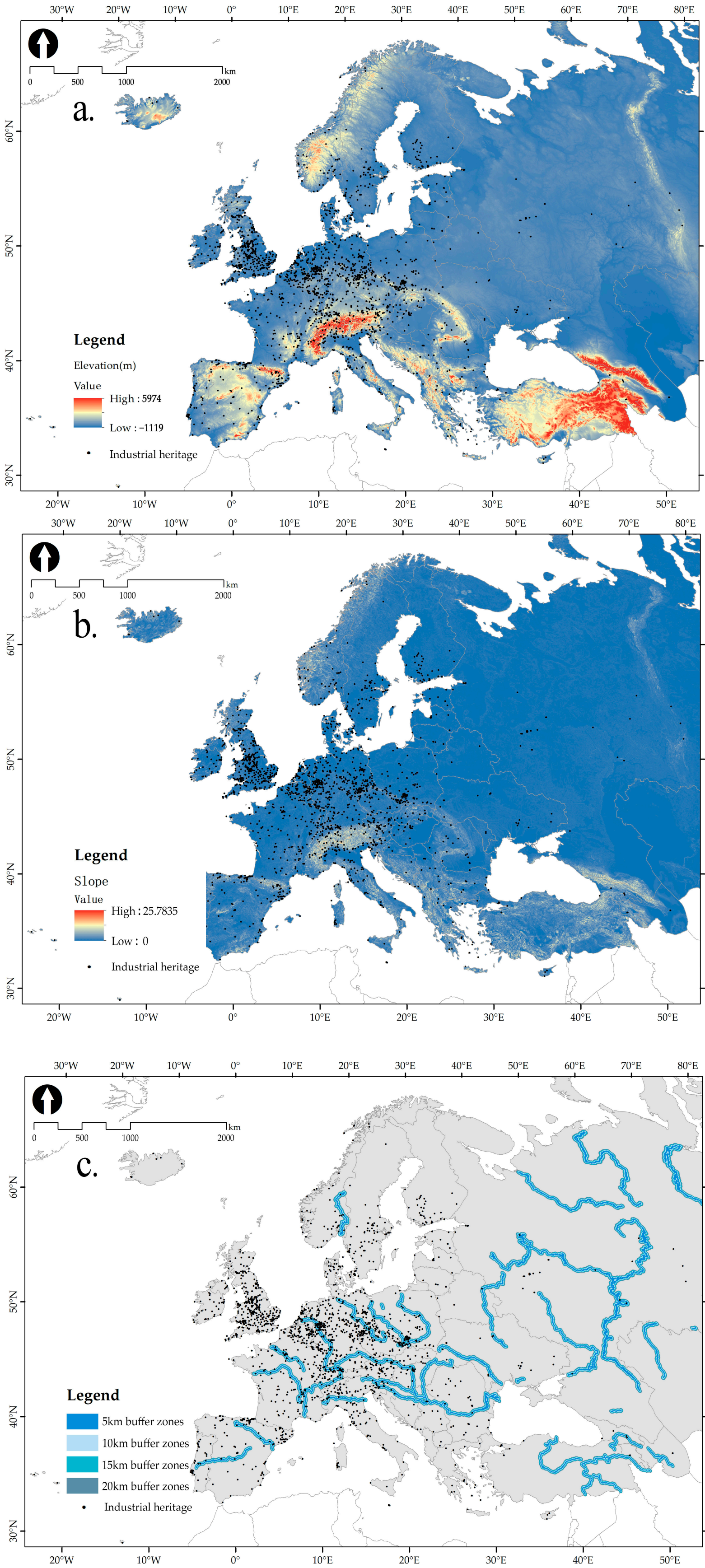


Figure 12. Analysis of the factors influencing the spatial distribution of industrial heritage sites located in Europe by natural category. (**a**) Altitude; (**b**) slope; (**c**) hydrological conditions.

Figure 13. Industrial area of Hamburg: a view of the German port museum.

5.3. Analysis of Human Influencing Factors

The spatial distribution of European industrial heritage sites was analyzed in our study using GeoDetector through a regression analysis to explore the impact of human factors on these sites (Table 6). The magnitude of influence of these factors appeared in the following order: GDP (q = 0.763) > number of world cultural heritage sites (q = 0.591) > total kilometers of railways (q = 0.457) > urbanization rate (q = 0.351) > number of international tourist arrivals (q = 0.315) > population density (q = 0.306) > power consumption (q = 0.041). Among them, GDP, the number of world cultural heritage sites, total railway kilometers, and urbanization rate were the dominant factors that influenced the spatial distribution values of industrial heritage sites located in Europe.

Table 6. Human influencing factor detection results.

	Infrastructure Level		**Cultural Tourism Potential**		**Social Development Level**		
	Total kilometers of railways	Power consumption	Number of world cultural heritage sites	Number of international tourist arrivals	GDP	Urbanization rate	Population density
q	0.457 *	0.041	0.591 *	0.315	0.763 *	0.351 *	0.306
p	0.000	0.754	0.000	0.071	0.000	0.005	0.021

Note: * *p*-values significantly correlated at the 0.01 level.

(1) Infrastructure level

Infrastructure development is a crucial determinant influencing the spatial distribution outcome of industrial heritage sites across Europe. Efficient transportation networks are pivotal in enabling the seamless flow of goods, materials, and human resources, thereby ensuring the effectiveness of supply chains [66]. Regions endowed with robust transportation systems are more inclined to attract industrial activities, resulting in an increased concentration of industrial heritage sites in a given location [67]. Additionally, the presence of energy infrastructure, such as electricity, provides the essential conditions necessary for industrial advancement, thus engendering a greater proliferation of industrial heritage [68,69]. Therefore, this study conducted a correlation analysis using total railway kilometers reflecting the transportation capacity and electricity consumption levels reflecting the power supply capacity.

The emergence of industrial heritage exhibits the strong interdependence with transportation networks [70]. The advent of steam power revolutionized the conventional modes of goods transportation activity, notably the canal system [71]. Railways were first used to transport coal. Mining engineer Richard Trevithick invented the first steam locomotive in the year 1803, and the Stockton and Darlington Railway opened in 1825 to transport coal [72]. A long-distance railway line was built between Manchester and Liverpool Port, which became an important artery of the UK industry, and the volume of goods exported increased at a steady rate [73].

Consequently, the UK's dissemination of railway technology played a crucial role in the establishment of a comprehensive European railway network. Similarly, at the turn of the 20th century, electricity replaced steam as the main power source for the industry, with power stations and electrical grids being established one after another to provide power to the industry [74]. Moreover, transportation and power facilities provide a good means for industrial development and contribute significantly to accumulating a diverse and substantial industrial heritage system [75].

The Ruhr region located in western DE is renowned for its abundant industrial heritage [76]. The interplay between the industrial development of the Ruhr region and the railway system is profound and consequential. The first DE train traveled from Nuremberg to Fürth in the year 1835 [77]. The advent of railways in the 19th century transformed the Ruhr region into a central hub of rail infrastructure, featuring an extensive network of railroad lines, stations, and marshaling yards (Figure 14) [78,79]. The railways forged crucial connections between the Ruhr region and industrial centers, ports, and markets across DE, facilitating the efficient transportation of coal from mines to factories [80]. This robust transport network played a pivotal role in driving the development and expansion of the coal and steel industries, thereby bequeathing iconic industrial heritage sites, such as Essen Industrial Park and Duisburg Industrial Park. This industrial heritage was transformed into creative workspaces that served as drivers of economic growth and urban renewal, transforming Germany's former industrial centers into modern and sustainable urban landscapes.

Figure 14. Bochum-Dahlhausen railway museum located in the Ruhr region.

(2) Cultural Tourism Potential

Tourism creates a demand for cultural heritage, including industrial heritage, which encourages the preservation and revitalization of sites that might otherwise be neglected or destroyed [81]. At the same time, the economic benefits of cultural tourism in regions with industrial heritage provide an impetus for its preservation and development [82].

Thus, cultural tourism potential can play an important role in the spatial distribution of industrial heritage sites in Europe by influencing the decisions made about promoting industrial sites [83]. Among them, the number of world heritage sites issued by UNESCO is a significant factor influencing the distribution of industrial heritage sites.

A cultural setting for the protection of industrial heritage is provided by World Cultural Heritage, an internationally recognized symbol of cultural and historical significance. Due to the brand effect of World Cultural Heritage overflow, World Cultural Heritage promotes the preservation of industrial historical sites while revitalizing, radiating, and integrating heritage resources under its purview to create better tourism experience activities. In this study, we observed that countries with many world cultural heritage sites, such as IT, ES, DE, FR, and the UK, contained more industrial heritage sites than other countries. The prosperity of culture promotes economic development and provides financial and policy guarantees for heritage conservation purposes [84]. Meanwhile, many of the world's cultural heritage properties belong to the category of industrial heritage [85]. UNESCO has designed a tourism route for industrial heritage purposes called Underground Europe, which includes underground mines, wine cellars, and underground infrastructures [86].

Renowned for its abundant world cultural heritage, IT exhibits a unique intertwining of industrial and traditional cultural heritage sites [87]. Many industrial complexes and factories are strategically located close to historical landmarks [88]. One notable example is the Centrale Montemartini, originally a power station constructed by the utility company ACEA on Via Ostiense, just beyond the boundaries of Rome's ancient walls. Although the power station ceased its electricity-generating operations in 1963, the Art Deco building has been meticulously preserved, serving as the captivating backdrop for the "Machines and Gods" exhibition (Figure 15) [89]. This exhibition's statues harmoniously coexist with the machinery that once powered the station, including a colossal 1917 turbine and a 15 m long boiler. This fusion of industrial heritage with the broader cultural landscape has significantly augmented IT's cultural heritage stature.

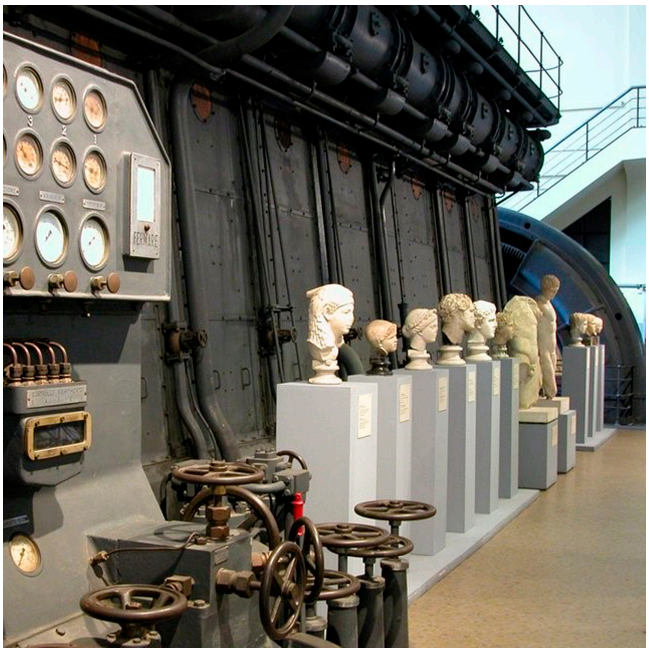


Figure 15. The Centrale Montemartini in Rome.

(3) Social development level

Regions that exhibit more advanced social development tend to have a more developed industrial sector, resulting in a higher concentration of industrial heritage sites [90]. Additionally, these regions possess more resources and investment opportunities to preserve and promote industrial heritage institutions, further reinforcing the existing distribution.

Consequently, the level of social development greatly influences industrial heritage's spatial distribution in Europe [91].

GDP is an important indicator used in research to measure the economic development level of a country or region [92]. The results show that GDP has the strongest explanatory power for the spatial distribution of industrial heritage existing in Europe [93]. Countries such as DE, UK, FR, and IT have high GDPs and a correspondingly abundant industrial heritage distribution. On the one hand, the significance of industrial output in relation to GDP establishes a notable correlation [94]. As the GDP of a country or region ascends, so does the level of industrial development, consequently leading to a commensurate increase in the abundance of industrial heritage sites.

On the other hand, instead of being destroyed to advance a country's economic growth, economically developed regions possess a greater capacity to preserve residual industrial heritage sites. The urbanization rate is also a pivotal indicator of a country or region's economic and social development levels [95]. With high urbanization rates, nations, such as BE, UK, NL, and DE, demonstrate regions with significant examples of industrial heritage. Urbanization is a process that is inseparable from industrialization [96]. Thus, countries with high urbanization rates often exhibit more advanced industries and a substantial industrial legacy.

London, as the capital of the UK, stands as a testament to its exceptional economic prowess, possessing one of the highest GDP figures and urbanization rates. During the era of the Industrial Revolution, London played a pivotal role in fostering the growth of diverse industries, thereby establishing a legacy of remarkable industrial heritage [97]. Multiple organizations and associations in the city, at present, are unwavering in their commitment to safeguarding this heritage [98–100]. Efforts include designating industrial sites as historical monuments and repurposing them as cultural spaces, concurrently advancing urban development while preserving their profound historical value. An exemplary illustration of this is the Tate Modern, which underwent a remarkable transformation from a 20th century power station designed by Sir Giles Gilbert Scott (Figure 16) [101]. Following the cessation of its power-generating activities in 1982, the colossal five-story turbine hall, spanning an impressive 156 m in length and standing 35 m tall, was ingeniously repurposed into a gallery space. The metamorphosis of the gallery has played a pivotal role in the revitalization of the Bankside area, morphing it into a thriving cultural hub. The Tate Modern, acting as a catalyst, has spurred economic development, magnetizing tourists, artists, and enterprises, thereby invigorating the local community.

Figure 16. The Tate Modern in London.

6. Discussion

In this study, the ERIH list was used as the research object. Based on an examination of the ERIH system, the characteristics and influencing factors of the spatial distribution of industrial heritage sites were examined (Figure 17).

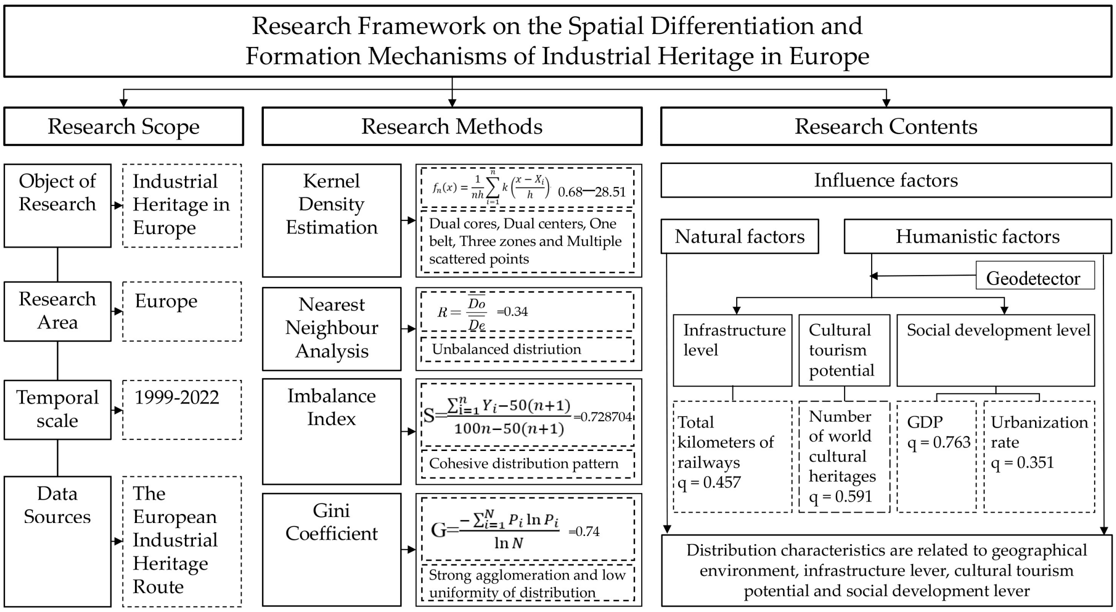


Figure 17. Research results framework.

This study explored the spatial distribution characteristics of industrial heritage areas in Europe, the birthplace of the Industrial Revolution, adopting a macroscopic perspective rather than limiting the scope of the study to a specific country or region. The comprehensive and reliable ERIH list was selected as the primary data source to ensure a rigorous analysis of the sites. By employing geographic probes as a research method, this study adopted a scientific approach when identifying the relevant influencing factors. The results of this study reveal that a combination of natural and human factors shape the spatial distribution of industrial heritage sites located in Europe. Natural geographical elements, including water systems, altitude, and topography, played a significant role in determining the location of industrial heritage sites, contributing to an uneven distribution pattern of these sites across the continent. In contrast, human and social factors, such as social development, cultural tourism potential, and infrastructure quality, facilitated the transition of industrial areas into heritage sites. The interplay between these natural and human factors underlies the formation of the distribution pattern of European industrial heritage sites at present.

The shortcomings of this study are as follows:

(1) Limitations of the research method. While the spatial distribution of industrial heritage sites was analyzed using software such as ArcGIS, the formation of industrial heritage sites was observed to be intricately influenced by larger macro-environmental factors, including institutions, policies, and laws. For instance, numerous heritage conservation organizations and institutions have been established across European countries to champion the preservation and awareness of industrial heritage. Concurrently, efforts are directed toward effecting industrial heritage education to instill an improved appreciation for its historical significance among the younger generation. Additionally, European nations are collaborating to promote industrial heritage as a shared legacy of the European industrialization era, further shaping its spatial distribution within Europe. Considering these significant socio-cultural influences, the research conducted in the future should employ qualitative methods to more

thoroughly investigate European industrial heritage preservation policies, thereby enriching the present analysis.

(2) The mechanisms that drive the spatial distribution of industrial heritage are likely to be complex and multifaceted. However, due to the data limitations, this study focused on a subset of potential factors for the analysis. For instance, the availability of mineral resources is likely to be a crucial factor influencing the distribution of industrial heritage sites; however, insufficient data prevented their inclusion in this study. Future research should strive to incorporate a wider range of variables to develop a more comprehensive understanding of the factors shaping the distribution of industrial heritage.

(3) The geographic advantages of European industries have enabled them to spread their influence across various countries via technology transfer and machine acquisition practices, thereby impacting the spatial distribution of European industrial heritage at a micro-level. Unfortunately, this study could not analyze this phenomenon in depth due to energy constraints. The research in the future should investigate the effects of technician mobility, transmission pathways of industrial technology, and the import/export of machinery and equipment on the pattern of industrial heritage.

7. Conclusions

With the help of ArcGIS software, this study performed a quantitative analysis of the spatial distribution characteristics of European industrial heritage sites (Table 7) and studied the influencing factors of the spatial distribution of these sites with the help of geographic detectors. The main conclusions are as follows:

(1) The spatial pattern of European industrial heritage sites presents the characteristics of agglomeration, the nearest-neighbor index value is 0.34, and the distribution is extremely unbalanced. It presents a distribution pattern of "dual cores, dual centers, one belt, three zones and multiple scattered points". From the perspective of the movement of the center of gravity, the center of gravity of the distribution of European industrial heritage sites shows a trend of "first north and then east", and the degree of spatial distribution is becoming increasingly more discrete.

(2) European industrial heritage is diverse; we divided it into 15 categories and 52 subcategories. In terms of its categories, the legacies of transport, production and manufacturing, and mining are the main ones. The space of different types of industrial heritage sites presents obvious characteristics of a non-equilibrium distribution, which is specifically manifested in the obvious "four-core continuous" distribution of the application of power and communication types of industrial heritage and the "three-core belt" distribution of the mining type of industrial heritage. The chemical, landscape, salt, and water types of industrial heritage have a "dual-core scattered" distribution; housing, industrial architecture, industry and war, iron and steel, paper, production and manufacturing, the service and leisure industry, and textile types of industrial heritage have a "single-core" distribution.

(3) The spatial distribution of European industrial heritage sites is affected by many factors. Among them, the natural environment is the basic factor, and altitude, slope, and hydrology affect the spatial distribution structure of industrial heritage sites to varying degrees. Among the human factors, the infrastructure level is an important one. Cultural tourism potential is an inducing factor and social development level is a dominant factor.

Table 7. The spatial indices of industrial heritage sites in Europe based on the function calculation.

No.	Function	Index
1	Nearest-neighbor index	0.34
2	Kernel density estimation	0.68–28.51
3	Imbalance index	0.728704
4	Gini coefficient	0.74

This study holds significant implications for the preservation and repurposing of industrial heritage across Europe. The spatial analysis that we conducted on industrial heritage yielded valuable insights, enabling the identification of densely concentrated industrial heritage areas, which, in turn, aided in devising conservation measures to safeguard this heritage against potential threats. Moreover, it facilitated the identification of potential tourism routes and clusters, thereby promoting local economies through industrial heritage tourism practices and revitalizing declining industrial regions. Furthermore, given the contemporary emphasis placed on urban resilience development and public health in the research, the spatial analysis conducted on the field of industrial heritage contributed to understanding sustainable practices in several ways. It facilitated the seamless integration of industrial heritage into urban development planning, effectively providing green recreational spaces for urban inhabitants and enhancing their physical and mental well-being. Additionally, the presence of industrial heritage sites reinforced urban resilience, empowering cities to withstand and navigate through disasters and crises more effectively in the post-pandemic era.

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Appendix A

Table A1. Abbreviated descriptions of country names.

No.	Country Name	Country Name Abbreviations	No.	Country Name	Country Name Abbreviations
1	Albania	AL	27	Latvia	LV
2	Andorra	AD	28	Liechtenstein	LI
3	Armenia	AM	29	Lithuania	LT
4	Austria	AT	30	Luxembourg	LU
5	Azerbajian	AZ	31	Malta	MT
6	Belarus	BY	32	Moldova	MD
7	Belgium	BE	33	Monaco	MC
8	Bosnia and Hercegovina	BA	34	Montenegro	ME
9	Bulgaria	BG	35	Netherlands	NL
10	Croatia	HR	36	North Macedonia	MK
11	Cyprus	CY	37	Norway	NO
12	Czech Republic	CZ	38	Poland	PL
13	Denmark	DK	39	Portugal	PT
14	Estonia	EE	40	Romania	RO
15	Finland	FI	41	Russia	RU
16	France	FR	42	San Marino	SM
17	Georgia	GE	43	Serbia	RS
18	Germany	DE	44	Slovakia	SK
19	Gibraltar (BOT)	GI	45	Slovenia	SL
20	Greece	GR	46	Spain	ES
21	Hungary	HU	47	Sweden	SE
22	Iceland	IS	48	Switzerland	CH
23	Ireland	IE	49	Turkey	TR
24	Italy	IT	50	Ukraine	UA
25	Kazakhstan	KZ	51	United Kingdom	UK
26	Kosovo	XK	52	Vatican City	VA

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