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Article

Global research patterns in corporate social responsibility within electronic commerce: A bibliometric analysis

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Abstract: This study examines the importance of corporate social responsibility (CSR) in e-commerce literature by locating and collecting data from academic publications. By doing a search using specific terms such as “e-commerce,” “electronic commerce,” and “corporate social responsibility” in a prominent online publisher’s database from 2001 to 2023, our analysis reveals the increasing importance of CSR matters in the field of e-commerce. Multiple levels of observation have identified this growing trend (conceptual, geographical, and technological). This article primarily focuses on providing a conceptual framework that provides the economic reason for the increasing interest in corporate social responsibility (CSR) issues in the field of electronic commerce. While there are several ethical and social aspects that can account for this interest, this research specifically explores the complementary justification.

Keywords: decision-making; grounded theory; local authority; moral heuristics; public sector

1. Introduction

This paper delves into the vital realm of corporate social responsibility (CSR) within the dynamic landscape of e-commerce. CSR involves weaving social and environmental considerations seamlessly into a company’s everyday operations and interactions with stakeholders. It stands as a widely embraced approach where companies aim to harmonise economic, environmental, and social objectives effectively. Successfully navigating this terrain requires the involvement of various stakeholders, including global logistics companies, e-commerce corporations, regulatory authorities, labour unions, consumers, and non-governmental organisations (NGOs) [1,2]. Companies must understand the wider range of industries and cooperate with a varied group of individuals and organisations, all striving to reduce negative factors in both their own operations and the external environment [3]. The sustainability concerns in e-commerce encompass issues of responsibility, handling intricate products and services, and addressing performance indicators on a worldwide level.

The proliferation of medium- to large-scale multinational firms has stimulated an increasing recognition of yearly reports, sustainable strategies, and revised codes of conduct. These endeavours demonstrate a growing awareness of the need for e-commerce to be sustainable, taking into account social norms, religious duties, and customary practices [4,5]. These programmes assist organisations in implementing eco-friendly practices, reducing environmental impact through effective logistics, and adhering to corporate social responsibility (CSR) standards, all while taking into account the triple bottom line of social, environmental, and financial concerns [6].

This study has two main goals: Firstly, to examine the present significance of corporate social responsibility (CSR) and sustainable e-commerce in the existing body of literature; secondly, to provide an economic perspective that elucidates the increasing interest in CSR practices. In order to accomplish this, the study investigates scholarly articles that analyse e-commerce tactics, using datasets from 2001 to 2023. The study specifically concentrates on the occurrence of the terms “e-commerce” and “corporate social responsibility” in the abstracts or titles of these articles. The investigation seeks to discern patterns that indicate the growing significance of CSR in electronic commerce. The main objective is to evaluate the increasing prevalence of CSR as a fashionable word in scholarly literature and its growing significance as a matter of concern.

The paper adheres to a systematic framework, commencing with an exhaustive examination of existing literature on corporate social responsibility (CSR) practices in the field of logistics. It employs a systematic approach to assessing documents as a tool for identifying patterns and offering possible interpretations. Although the literature review does not expressly concentrate on corporate social responsibility (CSR) in electronic commerce, the following sections explore the methodology and data analysis of the study and ultimately provide an economic rationale for the increasing importance of CSR issues in logistics. This encompasses a conceptual framework illustrating how CSR policies exert influence on a firm’s financial value.

Upon scrutinising research on corporate social responsibility, a discernible surge in global recognition of CSR by corporations becomes apparent. Companies worldwide are progressively acknowledging their responsibility to champion sustainable and socially conscious practices, particularly in the realm of e-commerce. The integration of technology and business ethics in e-commerce offers a distinct framework for comprehending firms’ corporate social responsibility (CSR) initiatives.

According to Milton Friedman’s 1970 essay, the main goal of CSR is to ensure ethical and socially responsible treatment of all stakeholders and promote human development [7]. In 1999, there was a notable development in the business world with the introduction of corporate codes of ethics, triple-bottom-line reports, and public relations campaigns that aimed to define socially responsible corporate activity. At the time, these behaviours were seen as symbolic [8]. This impact extends to areas like profitability, growth, and operational efficiency. Furthermore, corporate social responsibility can lead to a reduction in capital expenses, thereby making a collective contribution to the overall value of the company [9,10]. During the 1980s, scholars placed a high value on corporate social performance as a result of growing public apprehension towards social matters [11]. During the 1990s, this phenomenon became widespread on a global scale [12]. Surveys suggest an increasing focus on social problems in the field of electronic commerce. The trend is underscored by doing a content study of literature on sustainable practices [13], providing an insightful review of socially responsible sourcing [14], and utilising network analysis to demonstrate the increasing emphasis on CSR issues in e-commerce literature [15].

2. Methodology

We undertook a methodical investigation to uncover the significance of work that focuses on corporate social responsibility (CSR) activities. Our quest for insights was guided by a systematic approach (see **Table 1**), which can be described as a precise methodology that involves locating existing studies, selecting and contributing to them, analysing and synthesising data, and reporting the evidence in a manner that enables clear and reasonable conclusions to be drawn about what is known and what is not known. By utilising a systematic review as our selected approach, our objective was to gather unaltered data regarding the frequency of corporate social responsibility (CSR) in literature, specifically focusing on the e-commerce sector.

Table 1. Selection criteria for articles.

Steps 2 and 3: Choosing the criteria	Description
Keywords	Corporate social responsibility, electronic commerce, e-commerce
Language & document type	English peer-reviewed academic journals
Time interval	2001–2023

The objective of our study is not to offer a comprehensive analysis of the CSR literature but rather to utilise a systematic review to illuminate its prevalence. Our research utilised a six-stage classification approach to examine the importance of CSR in e-commerce literature. This approach allowed us to establish a structured foundation for our analysis.

At first, we discovered a crucial data point in 2001 from the initial e-commerce and CSR documents we came across during our search. To ensure high standards, we omitted conference proceedings, work in progress, and technical reports from our analysis [16–18]. In order to achieve thorough and extensive coverage, we enhanced our search of academic literature by focusing specifically on English peer-reviewed publications, utilising platforms such as Scopus [19]. The appendix complements our research by providing comprehensive bibliographic information for each reviewed publication, guaranteeing transparency and lucidity [20].

The third phase entailed a thorough examination of publications from Scopus, covering a time period of twenty-three years starting in 2001. Every selected paper was subjected to meticulous examination, with the writers evaluating the information contained in the titles, abstracts, and main text to ensure its relevance and credibility [21,22]. Expanding upon the systematic review, the fourth phase involved organising our research materials by categorising 917 articles from seven prominent databases according to the journal of publication, year of publication, geographic area, industry, and authors.

The fifth step was the analysis of the importance of CSR literature, with the objective of understanding present patterns and potential implications for future studies. The final step entails presenting a conceptual framework that provides a formalised approach to economic reasoning that has the potential to elucidate the observed trends in the empirical data. Below is a concise overview of our approach, as depicted in **Figure 1**.

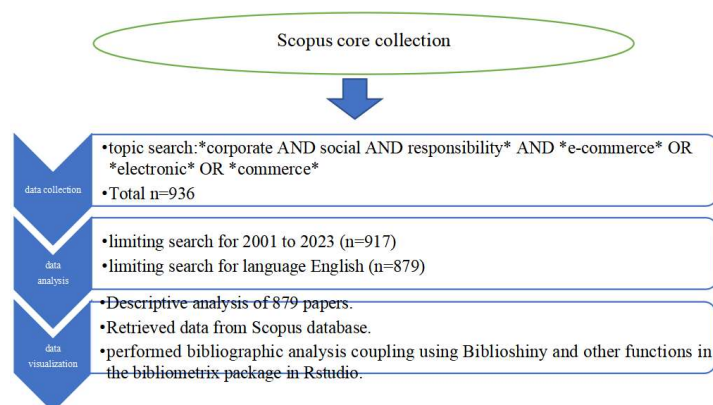


Figure 1. The selection strategy.

This bibliometric approach effectively handles data connected to publications, producing a strong empirical methodology. Our main goal is not to conduct a typical literature review but instead to analyse and categorise the growing amount of information about CSR issues in e-commerce. We will use a unique approach that differs from prior surveys on this topic. In the following section, we will show our data analysis.

2.1. Data presentation

The document's type, year, subject matter, number of authors, citations, keywords, and source type were all established by an analysis of the collected data (see **Table 2**). The data were presented in the form of frequencies and percentages for quantitative analysis.

Table 2. Main information.

Main information about data	
Timespan	2001–2023
Sources (journals, books, etc.)	552
Documents	871
Annual growth rate %	17.79
Document average age	7.08
Average citations per doc	23.24
References	1
Document contents	
Keywords plus (ID)	3966
Author's keywords (DE)	2156
Authors	-
Authors	2032
Authors of single-authored docs	195
Authors collaboration	-
Single-authored docs	221
Co-authors per doc	2.66
International co-authorships	22.85

The number of articles published annually is rising: from 2001 to 2023, 917 articles were published. The number of articles published annually after that shows a decreasing pattern (**Figure 2**).

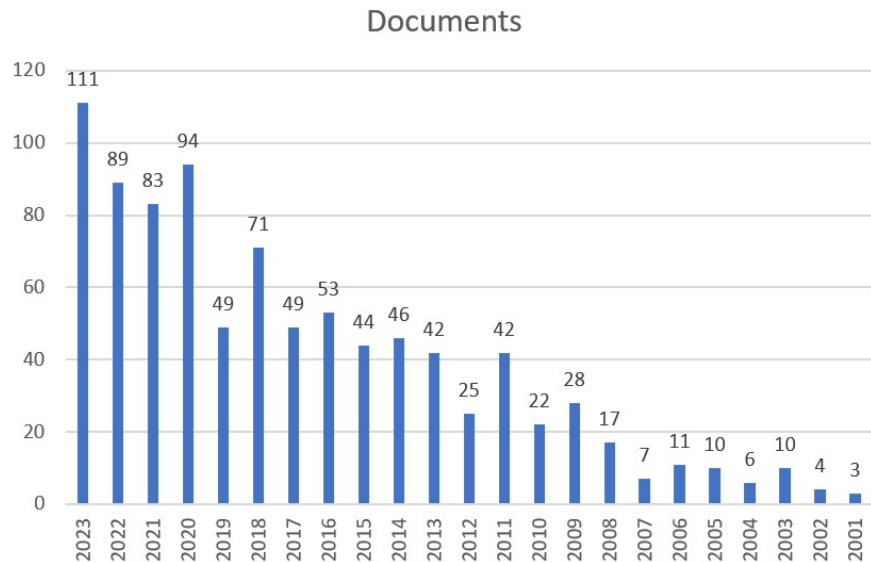


Figure 2. Number of research papers.

2.2. Productivity analysis

Productivity refers to the quantification of an author's output in terms of the number of papers they have published within a specific timeframe, or the number of articles published inside a journal during that same timeframe. **Figure 3** indicates that out of the 879 research papers published over the specified period, the top three journals in this field for published studies are the Journal of Cleaner Production, Environmental Science and Pollution, and the International Journal of Environmental Research.



Figure 3. Productivity of journals.

2.3. Authors' performance analysis

According to **Table 3**, the first three authors, which represent 50% of the 879 research papers published during the period, NA NA have a total article of 28% out of 100%, and Zhang have a total article of 13% out of 100%, so the first three authors mostly perform for their publication. The top 10 authors in this field published their papers.

Table 3. Authors performance analysis.

Authors	Articles	% Total article
NA NA	20	28%
Zhang Y	9	13%
Li J	6	9%
Li Z	6	9%
Kraak VI	5	7%
Li X	5	7%
Wang X	5	7%
Zhang X	5	7%
Alas R	4	6%
Chen S	4	6%

Figure 4 shows the author's output over a period of time. The number of articles is indicated by the size of the circles; larger sizes correspond to more publications. A darker colour denotes more citations, and the colour of the circles represents the total number of citations per year.

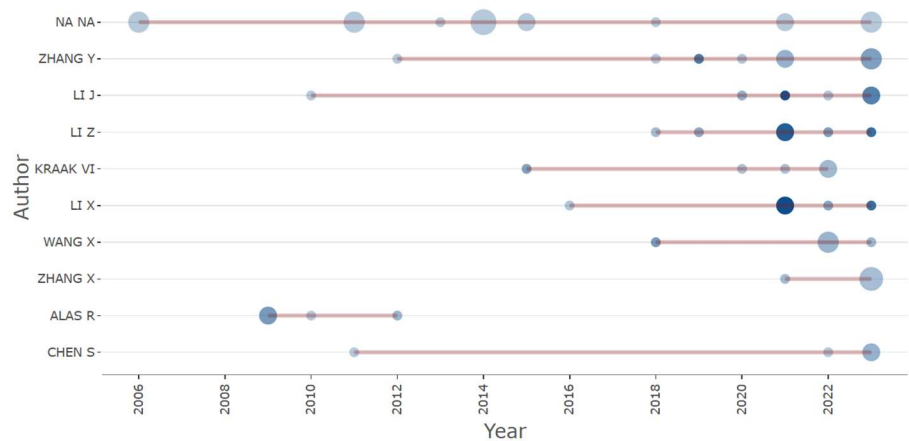


Figure 4. Authors' production over time.

2.4. Keyword analysis

Figure 5 depicts the substantial growth of electronic trade over time. This suggests that a multitude of researchers have shown a keen interest in it. Both the concepts of “corporate social responsibility” and “e-commerce” are experiencing a surge in popularity. This indicates that the study of e-commerce and the practical implementation of corporate social responsibility have led to a rise in consumer inclination towards utilising e-commerce platforms, with a notable exponential trend.

The term map visually represents the complex nature of user acceptability, which involves various domains such as CSR, human factors, and sustainable development.

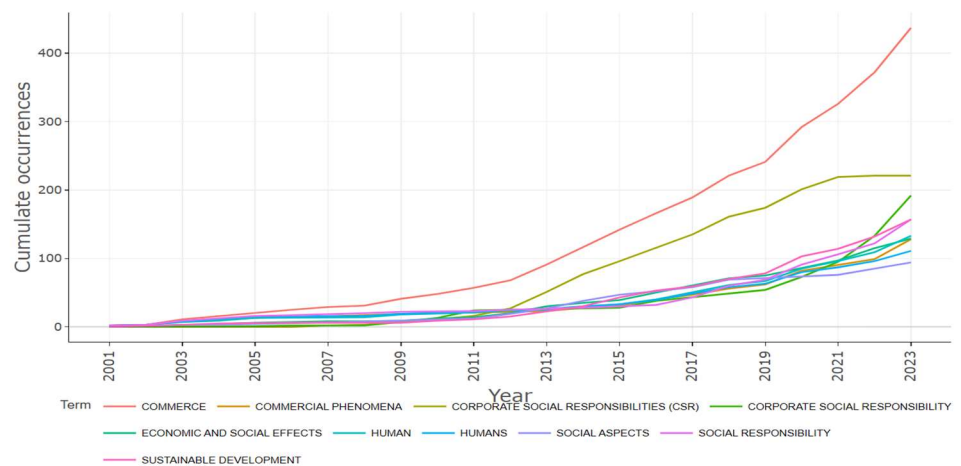


Figure 5. Words' frequency over time.

Figure 6 demonstrates that corporate social responsibility (CSR) and trade continue to be prominent subjects in the research articles being examined. In addition, the terms “CSR,” “sustainable development,” and “commercial phenomena” have been included and acknowledged. Previous searches utilising these terms together have yielded a result.



Figure 6. Word map of keywords.

The motor motifs are depicted in Figure 6. The search field is located in the upper right corner of the graph and is crucial due to its complete execution and strong associations with other themes. The primary concepts, which serve as the foundation of the particular publication series, are shown in the bottom left corner of the chart. Although they possess a low density, they exhibit a significant level of centrality [23,24]. Subjects exhibiting a high density and a low centrality can be characterised as having a high density and a low centrality, which can indicate different yet well-developed characteristics.

The thematic map analysis revealed that the main themes were sustainability, e-commerce, and corporate social responsibility, each with a particular emphasis. The field of e-commerce research has focused extensively on the topics of e-commerce and corporate social responsibility [25,26].

2.5. Potential directions for further study

The objective of our article was to analyse the complexities of corporate social responsibility (CSR) in e-commerce using bibliometric methods (see **Figure 7**). As academics negotiate the changing environment, we anticipate that our investigation will act as a starting point for new initiatives, connecting current areas of knowledge and addressing specific research requirements. Important areas for future research encompass the “last mile” obstacle in environmentally friendly business-to-consumer e-commerce distribution, as well as the wider effects of e-commerce on eco-friendly logistics, sustainability, and reverse logistics in electronic markets.

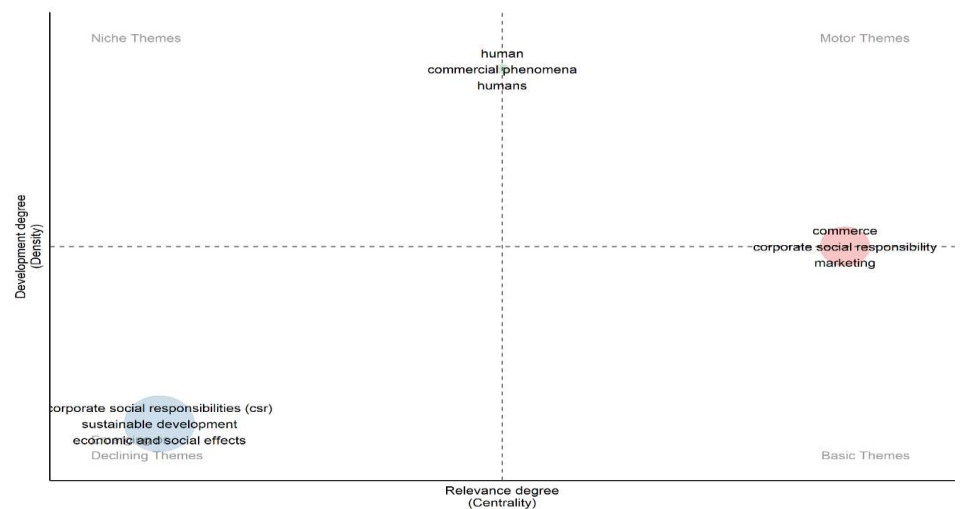


Figure 7. Thematic map of publications.

An essential question is how to evaluate the environmental sustainability and competitiveness of e-commerce supply networks [27]. With the rapid growth of global e-commerce, the issue of packaging sustainability has become increasingly important due to factors such as waste management and potential trade-offs. In order to attain sustainability in e-commerce, it is crucial to comprehensively evaluate social, environmental, and economic concerns, aiming for a state where the benefits outweigh the drawbacks. Investing in advanced digital marketing tactics can enable e-commerce enterprises to efficiently target customers, thereby minimising product returns and mitigating the burden on reverse logistics and the environment.

Further investigation into the concepts of social responsibility and social sustainability in the field of e-commerce is necessary. The convergence of sustainable development goals and their influence on e-commerce offers a compelling opportunity, prompting the creation of economically viable business models that capitalise on recent developments in artificial intelligence.

3. Conclusion and limitations

The growth of e-commerce has shown significant acceleration, particularly during the pandemic, and this trend is projected to continue [28]. Nevertheless, the increase in online sales is accompanied by a gradual environmental impact, leading customers to expect businesses to adopt eco-friendly methods [29]. Businesses face

difficulty finding a harmonious equilibrium between creating sustainable earnings and satisfying customer demands for environmental responsibility.

We were tasked with performing a literature analysis on consumer behaviour and sustainability in the field of e-commerce. Through an extensive search of the Scopus database, a total of 104 scholarly publications were identified. These articles were published between 2001 and April 2022 and involved a total of 342 different authors. This research explores precise data, providing insights on yearly paper manufacturing, influential scientific journals, highly-referenced articles, prolific writers, and frequently used keywords in publications.

Although our bibliometric analysis yields significant insights, it is imperative to recognise its limitations. Initially, our data collection exclusively relied on publications sourced from the Scopus database, which may have resulted in the exclusion of contributions from other databases. Furthermore, certain pertinent research may have been omitted, despite our exhaustive search criteria. Furthermore, despite our diligent attempts to conform to the objectives of the bibliometric analysis, subjectivity remains an inherent aspect of the analysis [30]. Furthermore, the act of referencing a piece of work can be impacted by a multitude of circumstances that extend beyond its academic worth [31], hence questioning the absolute dependability of citation counts for certain studies [32]. To summarise, this study aims to provide fresh views on corporate social responsibility (CSR) in the field of electronic commerce (e-commerce), urging scholars to integrate these viewpoints into their next attempts.

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Conflict of interest: The authors declare no conflict of interest.

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Article

Social enterprises transformation and its effects on socio-economic development in developed and developing countries

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Abstract: In the twenty-first century, the idea of social enterprises influencing global socio-economic growth has gained much attention and has momentous implications for the modern economy. Both emerging and developed countries frequently observe its considerable impact on their economy as social enterprise transformation has such a wide-ranging effect on socioeconomic growth. The purpose of this study is to present evidence of the impacts of global social enterprise transformation on global socio-economic development. However, there are no official statistics available on the effects of the transformation of global social companies on global socio-economic development. The debate in this research demonstrates how social enterprise transform like a collaboration between the private, public, and civil sectors, continually honing their approach to their goals, based on the review of several case studies of social enterprises from around the world. Revamp, acquisitions, and improved performance are all efforts to achieve sustainable societal progress in the fields of economics, culture, and politics. The results indicate that social enterprises transformation causes the socio-economic development of the world. Our results also suggest that social enterprise transformation impact and outcome are more significant in developed countries than in developing countries.

Keywords: socio-economic development; social-enterprise; transformation; NGO; BRAC; Bangladesh

1. Introduction

We are experiencing many social and financial problems across the globe. Sometimes social problems are the reason for financial problems, and financial problems are the reason for social problems. The social, economic, and environmental aspects of development continue to present the biggest difficulties in the twenty-first century. Governments, international organizations, businesses, and civil society can meet only one-third of the requirements for addressing global goals focusing on human and sustainable development [1]. The majority of the world's nations face the challenge of creating a model that combines sustainable economic development with a social vision that incorporates millions of poor people into the system and its benefits [2]. Social enterprises are voluntary to address social causes, and they emerge as tools for tackling complex, indivisible social problems that corporate business organizations find difficult to cope with alone. Over the past few decades, there has been a noticeable dynamic in many regions of the world around the idea of social enterprise. To address social issues, social enterprises mostly use non-governmental approaches based on the market. The social enterprise frequently demonstrates that it is “a business” and provides funding for a variety of organizations and activities with a social focus. A social enterprise is defined as a business with primarily social objectives whose surpluses are primarily reinvested for that purpose in the business or the community,

rather than being driven by the need to maximize profit for shareholders and owners, by the UK government's Social Enterprise Unit (SEU). However, the phrase "social enterprise" was first coined in the 1970s to describe nonprofit company ventures that were beginning as a way to provide disadvantaged populations with employment possibilities [3]. Social enterprises' main goals are to address society's expanding, multifaceted challenges, and the lack of resources also necessitates collaboration [4]. Collaboration between the public, commercial, and nonprofit sectors, as well as social enterprise transformation, are essential for attaining sustainable social development in the fields of economy, culture, and politics [5]. It focuses on improving social welfare by adopting non-economic objectives [6]. Social enterprises are continuously refining their approach to their objectives. The implementation of re-branding strategies, acquisitions, and enhanced performance measures are all undertaken to enhance the operational effectiveness of social enterprises. Through rigorous training and extensive practice, social businesses have demonstrated the ability to effectively assess the impact they have on various institutions over an extended period of time. The outcomes of these efforts have proven to be quite noteworthy. The transformation of social enterprises contributes to the socio-economic growth of many nations. Social companies are required to function within a distinct corporate framework, which subsequently influences both social and economic progress. Hence, it generates economic advantages and societal value for the community. Social enterprises are organizations that operate to promote pro-social objectives such as wealth creation, cooperation, and community development. Their primary goal is to generate social value, which can be understood in terms of intangible assets such as happiness, general well-being, and economic sustainability. Therefore, social companies play a significant role in fostering socio-economic growth.

To address social and financial issues, it has examined cross-sector alliances and collaboration between businesses and social enterprises. In the framework of a subsistence marketplace, the development of cross-sector collaboration, the partners' contributions, and the consequences and social transformation impact of the social alliances have also been explored. It has established the metrics for evaluating the effects and results of collaboration. Concerning Sakarya, the review of social change and impact aspects studies the social transformation influence they have on society [7]. Through the social innovation process, a social enterprise could develop the empowering local community that leads to success, which has been narrated by Maguiree in the case study of the Ixtlán Group, a social enterprise located in the community of Ixtlán, in the Southern State of Oaxaca, Mexico [8]. From a gender perspective, this paper contributes to exploring the mechanisms of success for women in highly marginalized indigenous communities. It illustrates how private entities, such as social enterprises, through social innovation can foster local development and contribute to superseding poverty, marginalization, and emigration. Social enterprises in Kosovo have aimed at human development and social integration of citizens by creating job opportunities for young people, which play an enormous role in the socio-economic development of Kosovo, as narrated in the article by Loku [9]. Without a shared perspective on the transformation of social enterprises and their impact on socioeconomic growth in both developed and developing nations, more investigation is required. By examining social enterprises' transformation in a hostile environment

and from many angles, this paper closes this gap. This article examines how numerous social enterprise transformations have affected socioeconomic development in developed and emerging nations. Both a literature review and an empirical analysis were done. The findings in this study offer a substantial contribution to the body of literature, and their implications may be beneficial to local and national governments as well as policymakers.

1.1. Social enterprise transformation, socio-economic development, and impact

The concept of social enterprise is not new; however, the term was first introduced in the early 1970s to define nonprofit business activities to create job opportunities for underprivileged groups in the course of their journey [10]. According to conventional commercial and non-profit thinking, the idea of social entrepreneurship is novel and distinct from both of these. It is the combination of different elements of social purpose, financial performance standards of business, and market orientation [11]. The majority of the segments of society that are typically left out of social and economic activity were served by social enterprises. The strengthening of cooperatives and the rediscovery of non-profit organizations and work-integration associations as suppliers of social services. It is different from conventional enterprises in the way of doing business and also from public agencies in the way of providing social services. Social enterprises engage in a continuous pursuit of activities that exhibit both the entrepreneurial attributes of the non-profit sector and the innovative qualities of the cooperative movement. The concept of social entrepreneurship can be distinguished from the definition of social enterprise, which encompasses entities that do not engage in entrepreneurial operations but primarily focus on advocacy or re-distributive functions. This includes public institutions and for-profit firms involved in social projects.

A group found a social enterprise with a specific institutional structure, well-defined social goals, and a well-defined social mission. The activity carried out by the social enterprise is of public concern and must be managed in an entrepreneurial manner, while a constant equilibrium between the social and economic dimensions must be maintained. As agents of change, social enterprises may be perceived as more focused on addressing the requirements of the most vulnerable segments of society. Social enterprises can implement innovative solutions suitable for addressing social problems because they place a greater emphasis on the dimension of general interest, which includes, among others, welfare, health, education, employment, and housing, whereas traditional non-profit organizations overlook these factors. When government funding for nonprofits was reduced, the terms social enterprise and social enterprise began to be used interchangeably [12].

Social responsibility and a long-term strategy focused on addressing social needs are two aspects of the nature of social companies. In a participatory democracy, where citizens are best positioned to dedicate themselves to the social and economic growth of their communities, social enterprises have demonstrated their ability to promote cutting-edge forms of democratic involvement and empowerment [13]. The process of changing completely the character or appearance of something to improve it is

called transformation [14]. A process of transformation in social enterprises accompanies socio-economic development. Social development refers to the systematic efforts aimed at establishing a fair and impartial society by ensuring the equitable allocation of economic opportunities and social services. This process also entails addressing power disparities, thereby fostering the active participation of various institutions, ranging from national governments to diverse civil society organizations [15]. Through policies and initiatives that improve the capacities of people, families, and communities, the processes of society, institutions, and systems are being altered. The focus of social development is on concerns of equality, social justice, and involvement among disadvantaged and marginalized communities across all nations. It is feasible to create a balanced social and ecological system that is intimately linked to human rights, social justice, and environmental justice by fostering sustainable development and climate change adaptation through social development [16].

1.2. Impact of social enterprise transformation and outcomes on socio-economic development

Impact means to have an influence on something or the action of one object coming forcibly into contact with another. The impact is described as “significant or long-lasting changes brought about by a specific action or series of actions in people's lives” [17]. The impact is a series of outcomes from a series of institutional inputs. Definitions of impact refer to the ultimate results of organizational inputs that make sustainable changes in the system. Impacts are the consequences of some action that alters how the system generally copes with the changes. Outcomes refer to the results of inputs. Outcomes are defined as the ultimate results of some action that is taken to make some changes. The impact of social enterprise transformation leads to socio-economic development. Social enterprise transformation leads to sustainable development in the cultural, political, and economic spheres [18].

Social impact assessment includes the process of assessing, estimating, monitoring, and managing the intended and unintended social consequences in advance, both positive and negative, of planned interventions. That are likely to follow from specific policy actions or project development and any social change processes invoked by those interventions, particularly in the context of appropriate national, state, or provincial environmental policy legislation [5]. The primary variables along which social influence may be gauged are community and institutional structures, community resources, political and social resources, individual and family changes, and population characteristics [19].

The result of a special event or activity regarding the economy is called economic impact. Economic impact is defined as the net change in an economy due to a special event or activity [20]. To ascertain the impacts of a change in economic activity on a specific location, economic impact analysis is crucial [21]. The implications for government services and revenues, financial and physical capital, employment, output, income and wages, and growth are significant focal points in the majority of economic impact analyses [22]. The scope of impact can be examined from many levels within the social system, namely micro, mezzo, and macro. At the macro level, the entirety

of global society can be considered a collective entity. At the mezzo-level, nation-states and regional political or military alliances can be viewed as distinct subsystems. At the micro-level, subsystems can be identified as individuals, local communities, associations, firms, families, or friendship circles [23]. Social business transformation's effects on the cultural, political, and economic arenas could eventually result in systemic changes [24]. With demands for responsibility from stakeholders and financial agencies, social businesses are concerned with monitoring and demonstrating success in tackling social problems [25]. A wide variety of tools have been developed for social performance assessment. Measures of performance for the social and financial sectors, however, are limited. Analysis and measuring social and financial impact are very difficult.

1.3. Research objectives

A qualitative research methodology was followed in this present study with secondary data sources from several research papers, publications, reports, newspaper articles, newsletters, booklets, and internet reports on social enterprises that related to this study and reviewed it to find some goals. The objectives of this research are:

- 1) to analyze the transformation of social companies on a worldwide scale;
- 2) to determine the impact that this transformation has on the socioeconomic development of the globe;
- 3) to carry out an analysis of the activities performed by international social enterprises.

2. Research methodology

This study was carried out using a qualitative research approach. In the beginning, an enormous contents and document analysis was conducted at the time of this paper. The majority of the data used in this review is from secondary sources. For this study, a variety of social enterprise-related research papers, publications, reports, newspaper articles, newsletters, booklets, and internet reports were examined. This investigation has been carried out from home because it was not feasible to visit libraries or other locations to get information. It is being attempted to locate the pertinent article to supplement this research by using a variety of search engines, such as Google Scholar, ERIC, and Science Direction, amongst others. The time frame is from 2000 to 2023 (see **Table 1**); however, the study has included several papers published before the mentioned period as references.

Table 1. Inclusion and exclusion criteria.

Category	Description
Time	2000–2023
Key Words	Socio-economic development, Social-enterprise, Transformation, NGO, BRAC, Bangladesh
Search Engines	❖ Google Scholar (353)
	✓ Research Article-336
	✓ Review Article-17
	❖ Eric (59)
	✓ Research Article-41
	✓ Review Article-18
	❖ Science Direct (32)
	✓ Research Article-29
	✓ Review Article-3

The terms that fell under the review framework have been briefly explained in **Table 2**.

Table 2. An overview of the various phenomena examined within the encompassing framework of social entrepreneurship.

Terms being researched	Descriptions	Key authors
Social enterprise	Organizational structures that adhere to cooperative principles. The private organizations dedicated themselves to tackling social issues, assisting the needy and providing goods that, in their view, were improperly distributed by government agencies or the free market.	Borzaga and Defourny [26]
Entrepreneurial non-profit organizations	NGOs that take part in commercial operations to generate cash and improve financial sustainability.	Fowler [27]; Frumkin [28]; Boschee [29]; Mair and Martí [30]; Sharir and Lerner [31]; Vega and Kidwell [32];
Leadership	Based on social entrepreneurship, leadership takes into account everything but the traditional concept of a leader. This fosters a sense of shared purpose among the social entrepreneurs and attracts further participants.	Holt [33]; Almeida [34]; Boschee [29]; Drayton [35]; Touboul & Roulet [36]; Martin and Osberg [37]; Sharir and Lerner [31]; Zahra et al. [38]; Hossain [39]; Henton et al. [40]
Social Innovation	Innovation, when viewed broadly, includes methods and technologies used for social good.	Alvord et al. [5]; Phills et al. [41]
Social Ventures	Business ventures that provide a product or service that creates social or environmental benefits, such as the production and distribution of biodegradable water bottles.	Dorado [42]; Sharir and Lerner [31]
Institutional entrepreneurs	People or groups that change institutional structures and social structures hamper development.	Mair and Martí [43]; Martí and Mair [44]
Community entrepreneurship	Entrepreneurial activity benefits and is acted upon by the community. For instance, a hamlet growing and selling fair trade coffee.	Peredo and Chrisman [45]; Johannisson and Nilsson [46]

* Compiled from Mair [47].

2.1. Access to finance and borrowing

Social companies contribute significantly to alleviating poverty and expanding economic opportunity, but they face significant challenges in getting access to funding. Social enterprises mostly rely on their financial resources from a variety of sources, such as the public sector, philanthropic organizations, impact investors, and traditional financial institutions. Another source of funding for social entrepreneurs is grants from foreign donors and organizations. The social enterprise model enables them to plan fundraising events and other activities, which are crucial for them to be able to support themselves financially. However, this approach frequently presents challenges for social entrepreneurs. The predetermined funding requirements set by traditional financial providers are too stringent for social companies to comply with. Finance providers lack information and comprehension of the risks and rewards involved in making investments in social companies. Other difficulties include the acceptance of society, many stakeholders in their industries, and bureaucracy. Additionally, social enterprises with female founders confront additional difficulties and social pressure. Many social enterprises use “boot-strapping” strategies, which frequently struggle to scale up. To attract more investment, social entrepreneurs must improve their ability to communicate with potential funders and sources of financing. Due to their significant position as suppliers of services or goods to the public sector, social enterprises frequently get subsidies. The use of social enterprises as “investees”

is a fairly recent development nonetheless. Social companies are expected to generate both a financial and a social return on investment for their investors. Social enterprises are not well-known or understood by traditional funding companies. Additionally, a lot of investors have a conservative and established risk-return mindset. As a result, there is frequently an inadequate amount of private money. The absence of a legislative framework, the lack of incentives for investing in social enterprises, and regulatory obstacles all serve to exacerbate these issues. Due to their size and demand, the majority of social companies only require a minimal amount of investment. Because social companies have high transaction costs relative to the amount of funds provided and the expected financial return, financial intermediaries are hesitant to finance them. The current rate of investment return for social companies is also somewhat low in comparison to regular business rates and timelines when taking into account the level of capital payback. Depending on the size and type of a social enterprise, different financial resources are required. Additionally, different countries offer different options for social companies to meet their requirements.

2.2. Factors of sustainability and success of social enterprises

The requirement for social enterprise success is to create enough money to cover costs; this means that there is no need to routinely infuse liquidity and that social companies are not dependent on contributions for their operations. No matter what individuals will be working on, social companies will remain sustainable even for the duration of a global recession because of their guiding beliefs. In addition, the following elements contribute to the longevity and success of social enterprises:

Reinvestment of profits: In contrast to conventional business entities, social enterprises are not obligated to distribute dividends to their investors, even in cases where they operate within a “profit-seeking” legal framework. This affords social companies the option to reinvest a significant portion of their income into the business.

Dedicated workforce: Social companies have prioritized social goals and emphasized the importance of the values of justice and equality. As a result, social enterprise employees and volunteers are more devoted, driven, and loyal.

Devoted consumers: Social enterprises seek to improve society and increase the value of the goods and services they produce. Due to their social goals, social companies may develop a loyal and patriotic customer base that is unaffected by competition based on monetary worth.

Additional resources: Social businesses, being socially owned entities, address a range of social issues and consequently allocate their profits and services towards the betterment of society. This characteristic can serve as an advantageous factor for investors and grant organizations, providing them with additional value. Social investors have recently demonstrated a strong interest in social entrepreneurs, who have subsequently been presented with excellent financing alternatives. Social aims also foster a significant influx of volunteers who are eager to provide their abilities and expertise as a means of contributing. Communities and agencies, driven by their social objectives, exhibit a willingness to allocate resources, such as complimentary tools or facilities, and actively engage in fundraising efforts to support social entrepreneurs.

Supporting networks and cooperation: Social companies have been successful in building support networks within society, which is a prerequisite for their optimal development in the face of a competitive market. Social companies frequently have little employment competition, and employees desire to influence the community due to social objectives. By establishing social enterprises and improving the standard of living and services, people can take advantage of social amenities and benefits. Third-sector groups as well as social entrepreneurs are supported by significant regional and global networks. Social enterprise activities can expand globally, and their services can be expanded to numerous fields such as environmental protection, social aid, education, and the general promotion of human values [48].

2.3. Creation of social value

The underlying concept behind the establishment of social enterprises stems from the existence of diverse societal issues that conventional enterprises are incapable of addressing. The generation of social value is a consequential and esteemed facet of social companies. The emergence of social companies can be attributed to societal challenges, leading to their primary focus on generating social value while also ensuring financial sustainability. Irrespective of the nature of the enterprise, social enterprises possess the capacity to generate societal value by effectively addressing its demands and difficulties. Consequently, they contribute to the development of economic value for society. Numerous scientists hold the perspective that economic value can be regarded as a form of social worth, whereas others maintain that social value is entirely distinct from economic value. However, there is a range of viewpoints that fall within the spectrum between these two extremes. Evaluating the societal worth of various activities and undertakings, as well as comprehending the essence of social value itself, is a challenging endeavor. Hence, the task of justifying the adequacy of social value generated by social enterprises based on the resources employed for their creation has significant challenges. Hossain et al. posit a dual outcome resulting from social entrepreneurship. The primary objective is to generate societal value, which can be quantified through intangible resources such as wealth, happiness, and overall welfare. Additionally, the generation of economic value serves as a crucial factor for the sustainability and profitability of the social enterprise venture, enabling the social entrepreneur to effectively utilize this resource [49]. Auerswald notes that the concept of social value is very broad and can include financial, reputational, and ethical aspects, consumer surplus, capacity building, and other positive externalities [50].

2.4. Innovation in social enterprises

As “innovative activities and services motivated by the goal of satisfying a social need,” social innovation is described as [51] takes place in a variety of organizational structures, from profit-driven businesses (such as those that engage in corporate social responsibility initiatives) to hybrid organizations and social enterprises [52]. Since social enterprise is a type of social innovation, society benefits from it. The core purpose of social enterprises is to provide ground-breaking programs and remedies for pressing societal issues. Social entrepreneurs are referred to as the new catalysts for

change. Innovative thinking is crucial for social enterprises to fulfill their social missions. Social change is understood to be implemented by the execution of quick activities, services, and incremental ideas, and social enterprises are motivated by this purpose. The local public system gives significantly less consideration to kinds of innovation that have the potential to address social issues but are not given enough consideration. In terms of funding, social entrepreneurs are looking for innovations that would guarantee their access to resources while also generating social value. Social firms regularly engage in this zeal to innovate. It is a constant process of learning, development, and discovery rather than just a flash of innovation. Of course, innovation is essential to success when there is a chance for uncertainty and a chance of failure. Social enterprises need to develop risk management skills and often have a high level of uncertainty tolerance. Social entrepreneurs view project failure as a teaching opportunity rather than an unavoidable tragedy. The growing interest in social enterprises and social innovation in recent years is unequivocal proof of the weakness and failure of the predominately profit-oriented corporate paradigm.

2.5. Sample descriptive and analysis of data

Hertie School contributed to a pioneering international study. According to the study, the major contributors to Europe's economy are social enterprises. They conserve an intense responsibility to their social mission while strongly anchored in market realities. It is also evident from the study that German social enterprises have made strong collaboration patterns and important innovations in products and services. Therefore, they can contribute to the development of the social sector. The 107 social enterprises surveyed in Germany offered training opportunities and employed 7500 people who gained access to the labor market in 2014. Through the activities, over two billion euros were generated and helped nearly 900 people. According to the German country report of the study, the prime focus of German social enterprises is on health care (15%), education and research (22%), employment and training (25%), and community development. German social enterprises cover a wide range of development activities and thus contribute to the socio-economic development of the country [53].

The Great East Japan Earthquake, which occurred on 11 March 2011, caused a great earthquake disaster in the Tohoku region of Japan. After the natural disaster, Miyagi Co-op, the member co-op of Co-op Tohoku, one of the prominent social enterprises in Japan, has been involved in various support activities. It has rendered its services to disaster victims and taken part in the reconstruction of disaster-stricken areas. It has also provided disaster relief supplies, shopping support, and support for Megumino-Oyster producers, holding "Fureai Salon" (a small gathering). It has contributed to the sales of products made by handmade groups in the Tohoku region [54]. The Fukushima nuclear disaster that occurred on 11 March 2011 has created new challenges for the country. The energetic social enterprises of Japan have been reinforced to catch the wreckage. A large number of workers from various social enterprises and consumer co-ops are taking part in the reconstruction of disaster-stricken areas and working extensively to reedify communities, lives, and neighborhoods. Social enterprises in Japan work increasingly in disaster zones [55].

Research division manager at the training organization Entrepreneurial Training for Innovation Communities (ETIC), Koumei Ishikawa, has narrated that a social enterprise in Miyagi has built a new transportation system, mainly with buses for the residence, because most people lost their vehicles in the recent earthquake and tsunami. Other social enterprises have implemented e-learning programs for children who are unable to get to school and training facilities for locals to be able to teach students and employ themselves [56].

The mission of the multi-award-winning social venture Cafédirect is to support small-scale coffee growers in underdeveloped nations. It is the development of innovative, superior business practices. Cafédirect is a 100% fair-trade coffee firm that, to date, has contributed more than £6 million back into farmer communities. This fund is invested through a charity run by farmers, and it benefits farming communities. The company's overall goal is to improve the standard of living for smallholder farmers in underdeveloped nations. Rebranding, acquisitions, and improved profitability, along with ethical and just corporate practices, are the outcomes. In a disadvantaged area of the UK, Community Shop, the first social supermarket chain, has begun operating. In places with the greatest need, it has provided extra food to its members at steep discounts. Through its members' purchases and sales, which increased the community's power, it has helped to create more resilient people and communities. Every member that walks through the doors is engaged, inspired, and connected by the social enterprise. The impact of Community Shop's ongoing strategy modifications is exceptional. It is noteworthy how learning fosters improvising planning and development, which is manifested in various ways. It produces significant growth, has great relationships with both customers and suppliers, and helps the UK's socioeconomic development. Amey is a social enterprise from the UK that invests in and maintains the infrastructure and services that are important to the nation, such as engineering, facilities management, utilities, transport, and environmental services. It contributes to the creation of smarter, safer, more sustainable, and better places to live, work, and travel through designing and building. By providing top-notch multi-professional training to the maternity industry, Baby Lifeline Training Ltd. aims to protect the safety of mother and child. Training content is constantly updated and modified to encourage the best clinical practice and communication. The outcomes improve, and care is given to pregnant women and their unborn and newborn babies [57].

The Indian sanitation industry was revolutionized by the social enterprises of Mahatma Gandhi and Bhindeshwar Pathak. There were other social enterprises engaged in the issue that also had an impact locally. The majority of Indian households (approximately 69%) that live in rural areas like Kameshwaram, a typical coastal village along the Indian Ocean in the State of Tamil Nadu, lack access to adequate sanitation. A Franco-Indian social enterprise that is registered as a non-profit and works to improve sanitation in India. It had a good reputation for innovation in India's sanitation system and was well-connected. As a result, it was able to secure funding from UNICEF and the state government as part of the overall Sanitation Campaign program. In Kameshwaram, it was able to construct and open about 150 urine-diversion toilets. For this achievement, the Kameshwaram Panchayat was awarded the Nirmal Gram Puraskar [58]. The Indian government awarded the prize for complete

sanitation coverage to Kameshwaram in 2007, based on the assumption that such sanitation campaigns would shortly ensure the city's complete sanitation coverage. In the post-liberalization period (after 1991), international organizations such as UNICEF and the World Bank (as indicated on their websites) have also expanded their activities in India. International organizations such as Water Aid, GIZ, BORDA, and WASTE3, among others, are extraordinarily proactive in promoting sanitation and are creating additional business opportunities for Indian social enterprises in the sanitation sector [59]. Sanitation coverage has a direct impact on environmental security and health, which has an interrelation with labor productivity and income generation and thereby economic growth and regional development [60].

In Egypt, there are no official databases or statistics on social enterprises. Social enterprises in Egypt and their contribution to the creation of formal employment possibilities. The main activities of some social enterprises include recycling, cleaning the Nile and other areas in Egypt, and raising awareness of environmental issues. They also provide their services in the environmental sector, education sector, training, and capacity building with a declared social impact: sharing more knowledge, educating people, and changing the culture. Some social companies provide supportive products and offer training to promote the empowerment of both men and women. The social enterprise works on promoting Egyptian traditional crafts and avoiding their disappearance [61].

3. Discussion

As the objectives of this study are to explore the transformation of social enterprises globally, find the impact on global socio-economic development, and analyze the actions of international social enterprises, this study went through several research papers, publications, reports, and so on, which is not sufficient to reach the goal. Besides, this research has a major limitation in its design in that it could not manage any formal interviews with the key persons of the organizations, which may raise the question of the reliability and validity of the research.

Along with that, though it chose the period to pick up the materials from 2000–2023, some articles are taken before 2000 as the topic of those articles is very closely discussed and the findings are very compatible with this study. However, as the research is exploratory, no primary field research was undertaken. The study has some limitations, which may provide room (see **Table 3**) for future research by upcoming researchers.

Table 3. Research gap and proposed research questions.

Research gap	Proposed research questions
There is no clarity or consensus regarding the concept of social entrepreneurship and its components.	Expurgate and identify key concepts and elaborate on social entrepreneurship's essential elements.
In developing regions why hasn't social entrepreneurship caught on?	Look into the expansion of social entrepreneurship and its contribution to social development in developing nations.

In this research paper, the existing knowledge was analyzed and rearranged in a dimension that provided novelty in this paper. With all its faults and lacking, this paper

will add additional knowledge to the ample existing literature. It would also contribute to weed out the competing and conflicting conjecture of social enterprises.

4. Limitations

As this paper was done from home, the proper method of qualitative research could not be followed. Not all the necessary and proper information and reports could be provided here. There are too many reports and papers regarding social enterprises, so sources of information sometimes give different statistics on the same matter. The WTO is a trade-rule-providing institution. However, in the face of worldwide restrictions on exports, it had little to do without the cooperation of the members. It has tried to do its best to extract the activities of the WTO during this grave situation, though this may not seem enough. In addition, the selected articles do not follow the appropriate time zone.

5. Conclusion

The purpose of this article was to shed light on social enterprise transformation and how it affects both developed and developing nations' socioeconomic development. Social companies can serve as catalysts for innovation within a corporation, even though they cannot guarantee social benefit. Social enterprises are created voluntarily to address social issues, and they act as vehicles for addressing intricate, interconnected social issues that corporate and commercial organizations find challenging to handle on their own. Socioeconomic enterprises are changing from traditional activities to cutting-edge ones to address this issue. It facilitates collaboration across the public, business, and nonprofit sectors as they continuously improve how they approach their goals. Rebranding, acquisitions, and improved performance all contribute to both developed and developing nations' socioeconomic progress. The Sustainable Development Goals (SDGs), commonly referred to as the Global Goals, were endorsed by the United Nations in 2015. The fundamental objectives of the Global Goal are to end poverty, protect the environment, and guarantee that by 2030 everyone can live in peace and prosperity. The following primary goals make up the SDGs: No poverty, no hunger, good health and well-being, high-quality education, gender equality, and access to clean water and sanitary facilities are among the goals. Stable institutions, justice, and peace [62]. Though access to financial resources is a great challenge for social enterprises, they can attract grants from international donors and organizations, philanthropic foundations, impact investors, and mainstream financial institutions. Social enterprises' robust financial resources give them the chance to reinvest a large portion of their income back into the company. Through a variety of initiatives and inventiveness, social enterprises can provide social value and contribute to socioeconomic growth. The managerial vision, actions, skills, and high-caliber inventions of a social enterprise will determine its long-term effects. For knowledge, technology, and innovation to effectively stimulate adoption for long-term social impact, social enterprises must be eager.

The COVID-19 pandemic has recently been viewed as a new obstacle to the growth of social companies, which hurts their profitability and the financial prospects that are available. The importance of social enterprises has increased during the

COVID-19 epidemic, particularly in the health and services sectors. The establishment of a package of financial resources, legal frameworks, and regulations, as well as the provision of incentives for social enterprises that can play a significant role in the socio-economic development of both developed and developing countries, are the best ways for the world's leaders to ensure the sustainability of these enterprises.

Given all the limitations and restrictions, it seems appropriate to conclude that there is still a need for and a place for passionately driven social enterprises with “emotional commitment” as a long-term vision of development and dedication, which are essential to optimize long-term socio-economic development.

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Article

Commercialization: A hatch in the sociological diagnosis of our time

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Abstract: Max Weber feared a social future dominated by rational specialists “without spirit”. He considered this development a possible outcome of the interplay between all-embracing commercialization (marketization, monetization) with the rationalization (bureaucratization) of structures and processes in industrialized societies. Another observation of Weber concerned the ongoing replacement of medieval religious values with secularized-rationalist and profit-oriented ones. The predominance of such values usually fosters work productivity but also raises profound questions about the changing specifics of money. They have become central to the value systems at local, regional, and global levels. Weber was pessimistic concerning the fate of commercialization. Edward A. Ross substantially contributed to the study of commercialization as part and parcel of his efforts to put a sociological diagnosis on American society after WWI. He selected and analysed a dozen constructive and destructive cases of commercialization. Talcott Parsons studied the phenomenon in detail and called it “instrumental activism”. George Ritzer’s study on McDonaldization as a rationalization process is an effort to put a sociological diagnosis on global society. There are open questions concerning the capacity of contemporary societies and individuals to manage innovations for coping with commercialization. The empirical reference for the discussion is SpaceX, led by Elon Musk.

Keywords: commercialization; instrumental activism; technological innovation; organizational innovation; SpaceX

1. Introduction

Commercialization is the increasing subjection of any calling or function to the profit motive [1]. The public mind cannot be united in its judgment about the complicated phenomenon that is Elon Musk. His achievements—as an entrepreneur, investor, designer, engineer, producer of electric cars, and spacecraft—are respected. He is admired as the richest man in the world. Millions of young people idolize Musk as a self-made man. Given his unusual drive for success and the variety of his success stories, it would be reasonable to interrogate the broader relevance of his deeds. The crucial questions in this large and complex context read: Is Musk actually the person who best represents the spirit of this time? What are the causes of his intense motivation for initiating and implementing innovations? And, last but not least, why are the voices criticizing his ideas, decisions, and practical activities so numerous and forceful?

The answers should take into account the scientific and societal relevance of Elon Musk’s ideas and practices. No doubt, a strong element of his motivation is a desire for better quality of life among all people, societies, and human civilization. This is a motive that pops up throughout the latest of Elon Musk’s biography [2]. Another strong motivation could be seeking out paths towards personal and societal development and realization. Last but not least, a very important clue for

understanding his decisions and actions can be found in the analysis of his financial status and dynamics. According to Current Affairs, Musk owned assets worth \$222 billion in December 2023 [3]. This vast amount of wealth in various forms evidences the first position occupied by Musk in the ranking of rich people worldwide.

It is exactly this variety of striking achievements that provokes deep economic, political, and cultural suspicion about the originality or true value of Musk's ideas and practices. Some are due to the destructive effects on many creative and sensitive personalities. Some criticisms are a normal element of the discourse relating to tensions and contradictions in all areas of social life [4]. Lessons from history teach us that every innovation provokes such accompanying reactions. It is the task of innovators to proactively initiate or support the overcoming resistance from conservative traditional forces. The situation is not so simple, however. There is critical pressure for realistic planning in R&D and avoiding displays of false optimism in promises for great achievements in space research [5]. Deep respect is needed for the diligent efforts at upgrading the rules for economic exchange to the law, even in cases of very important innovations [6].

Taking a generalist stance, one may draw two preliminary conclusions from the discussion above. Both conclusions deal with the same subject matter but come from different points of view. The first fundamental issue concerns the core value orientation of actors' decisions and actions. The second refers to the appearance, functioning, and change of social structures. According to the sociological tradition founded by Max Weber, both processes are primarily guided by rational calculations in industrialized societies. More precisely, the overriding strategic orientation is dominated by money. Following ideas of Weber, Talcott Parsons studied the phenomenon and called it instrumental activism. It is a pattern of thinking and acting that leads individuals to dedicate themselves to activities that rationally seek "to maximize human control over the conditional elements of the life situation" [7]. The spread of instrumental activism is a process with deep roots in social evolution but most typical for the capitalist organization of economies and societies. It has two key parameters. The first is commercialization, defined in the sociological tradition as "the organization of something in a way intended to make a profit" [8]. The second is consumerism in the sense that consumption is perceived as desirable even far beyond the necessities. Starting from Western Europe, the dominance of capitalist value-normative and practical arrangements dispersed in every direction across the globe. Thus, it became a global trend shaping the orientation, decision, action, and evaluation of the actions of individual and collective actors [9] in contemporary societies. Here, the research interest is focused on the component "commercialization" of the "spread of instrumental activism" global trend. Under the present-day conditions of global markets characterized by fierce competition, the commercialization issues are of the utmost relevance for individuals and societies.

2. (Dis)Continuity in the study of commercialization

The historical background of conceptual work on commercialization is the maturation of modern industrial societies. Comparative analyses of scattered ideas could be of substantial help in this regard.

2.1. Max Weber: Threatening prospects of commercialization

Max Weber [10] noticed an important peculiarity of the industrialization process in Western Europe. The intellectual and organizational innovation of Protestantism affected technological development and the relationships between industrialization, economic development, politics, and religion in the region. Protestant ideology and activities have changed the value preferences in favour of the well-organized and efficient work. The rising efficiency of work was most visible in the continent's fast-growing industrial centres. The conclusion was clear: actors' participation in industrial expansion brings affluence. The strict following of religious values brings mental comfort. Therefore, per Weber, inner-worldly ideas about successful work gradually replaced traditional out-worldly religious values and norms. The emphasis on diligence, discipline, frugality, and rational calculation in ascetic Protestantism contributed to the profound enhancement of efficiency in the organization of work and, consequently, of all action fields. Functional equivalents of Protestantism can be identified in contemporary societies too [11].

The explanation for these complex processes is like the resolution of a complicated practical puzzle. Facing the challenge, Max Weber was strategically justified in his focus on the determination of changing organizations. Observations and conceptual analysis led him to the conclusion that entrepreneurs belonging to the Protestant religious community were gradually internalizing a new value-normative system that gave priority to rationally organized hard work and savings for investment. Thus, the most influential individuals and collective actors were these entrepreneurs as bearers of the spirit and practice of rational preparation and materialization of scientific, technological, organizational, etc., innovations. The continuous search for innovations is necessary in building and maintaining a full-fledged capitalist society. Weber explains: "... capitalism is identical with the pursuit of profit, and forever renewed profit, by means of continuous, rational, capitalistic enterprise. For it must be so: in a wholly capitalistic order of society, an individual capitalistic enterprise which did not take advantage of its opportunities for profitmaking would be doomed to extinction" [10]. The numerous parameters of capitalism (capitalist society), starting with the rational division of labor and reaching the culture of modern book-keeping comprise an association Weber called commercialization [10]. These capitalist value-normative arrangements spread to all directions worldwide. Max Weber praised the constructive effects of the rationalization of social relations and processes initiated by the ascetic Calvinist Protestantism. The major gains were the increased transparency in decision-making and the implementation of decisions, as well as the rise of productivity in all activities. At the same time, he was afraid of potentially pathologic effects from the spread of ascetic Protestantism. The newly developed historical situation might become dominated by "Specialists without spirit, sensualists without heart; this nullity imagines that it has attained a level of civilization never before achieved" [10].

2.2. Edward Alsworth Ross: Commercialization today and tomorrow

Weber's type of argumentation was unusual for the founding fathers of American sociology. However, most of them were quite creative in resolving methodological

and theoretical issues. For instance, the author of the first comprehensive book for academic instruction in the USA, *Foundations of Sociology* (1905), Edward Alsworth Ross, published a widely discussed and cited article with the provoking title “Commercialization—Increasing or decreasing?” [1]. At that time, the question might have been entirely understandable. Today the answer is quite clear. Commercialization (monetization, marketization) has conquered all action spheres, from the economy and politics through education, mass media, and health care to sports, sciences, and the arts worldwide. This could not have come about without a radical change to the status and functions of money. Georg Simmel, Emil Durkheim, and others provided the evidence that individuals over the course of millennia have been integrated in societies to a large extent by uniting visions about sacred ultimate values. The shared idea of the sacred helped define identities, situations, and solidarity. Max Weber elaborated on the topic by analysing a historical shift from the dominance of out-worldly religious values towards inner-worldly spirituality. Traditional religious values were replaced by the values of a new secular religion: striving for acquisition and accumulation of wealth and making money to make money [12]. The multidimensional task has become the guiding factor in the orientations, decisions, and actions of individuals dealing with specific cases of commercialization in different action fields. Most European sociologists have argued that the process was full of tensions and conflicts, as Weber did.

The same problem appears in Ross’s studies on commercialization, but it was seen and dealt with from the opposite point of view. His basic assumption was that American society was very well integrated: “Using the ancient test relations as a dial face, the onward movement in humanity, sympathy, and charity is most cheering” [1]. Therefore, there were no reasons for serious domestic tensions or conflicts. As to international challenges, they were even less relevant for commercialization in the United States in the 1920s. This position sharply contrasts with Max Weber’s critical assessments of both the achievements and failures of commercialization in Western Europe and North America during the first two decades of the 20th century. It was a period including the years of the “Great War”. Without its critical assessment, one could hardly understand the long-term accumulation of potential conflicts in the social fabric of US society. These conflicts caused the national drama of the Great Depression.

When being critical about fundamental issues in Ross’s understanding and study of the phenomenon of commercialization, one should recognise and respect his scientific achievements in this area. A major reason for the potential applicability of his approach to the topic of commercialization is his ability to demonstrate the large variety of dimensions within the social phenomenon under scrutiny. Briefly presented, according to Ross, there are a number of different manifestations. They range from interactions between producers and consumers to balance their diverging interests till the exploitation of younger sculptors by the well-established ones, as well as from the commercialization of the newspaper business till the commercialization of entertainment and recreation. Ross completes the description of these and more cases of identified commercialization with efforts to briefly explain the causes and consequences of each specific case [1].

As seen from a contemporary point of view, Ross’s efforts to identify and explain

a series of observable phenomena representing commercialization in his local environment were pioneering achievements. He identified such phenomena quite precisely:

- deepening social distance between producer and consumer along with declining responsibility on both sides;
- growing differentiation between principals and subordinates in major concerns;
- increasing prominence of capital in the practice of art or professions tending to subordinate artistic or professional conscience to profit;
- newspaper publishing where the capital factor constantly outweighs the service factor;
- lawyers in corporations having to judge according to the corporation interest;
- sculptors of great repute taking credit for the work of young, unknown men and reaping for themselves the proceeds and the honor;
- commercialization of entertainment and recreational activities.

Ross has developed interesting ideas about the constructive and destructive effects of commercialization practices. He assumes that among the representatives of some professional groups as “clergyman, teacher, judge, official, artist, and journalist, it is expected that lust of gain will be quite subordinated to the obligation to render a vital service” [1]. This implies that the representatives of these professional groups would be less involved in practices of commercialization. This is not a widely shared idea in contemporary societies. To the contrary, most people in advanced societies are convinced that exactly judges, officials, and journalists are particularly prone to sell information or influence. Moreover, it is nearly common knowledge that politicians and business people are champions in abusing their social positions and the rules of objectivity and ethical responsibility in favour of the gains from commercialization.

There is a theoretical and methodological difference between Ross’s ideas and the modern efforts to develop and apply conceptual frameworks for systematic description and explanation of the variety of manifestations of commercialization. Ross dealt with each case of commercialization separately. Currently the trend is to study the particular phenomena of commercialization in comparison and by using overarching conceptual frameworks. Still another important difference concerns the concentration of Ross’s analysis and argumentation on the microsocial level of commercialization. A contemporary research project cannot neglect the macrosocial dimension of commercialization. Currently, this means that special attention should be paid to global economic, political, and cultural processes related to commercialization. The third difference concerns the expectation of Ross that the issues concerning the negative social and moral effects of commercialization. Its current multiple causes bring about a large variety of effects.

2.3. George Ritzer: McDonalidization as successful commercialization

Thus, after having analysed the sociological classic studies on commercialization, the most natural question appears: What is the continuity of this debate in contemporary sociology? Or, is there any continuity at all? The questions are of rhetorical nature. In the preface to the tenth edition of his bestseller “The McDonalidization of the World” George Ritzer repeats his intention to continue Max

Weber's efforts to prepare a diagnosis of his contemporary times [13]. His intention turned out to be an impressive reality: "McDonaldization is the process by which the principles of the fast-food restaurant are coming to dominate more and more sectors in American society as well as of the rest of the world" [13].

There are four principles under scrutiny [13]:

- efficiency in the sense of "finding and using the optimum method for getting from one point to another";
- calculability in the sense of "an emphasis on quantity, often to the detriment of quality";
- predictability in the sense of offering foods which are "highly predictable foods that vary little from one time and place to another";
- control by means of technology, in the sense that "technologies currently dominate employees, but increasingly they will be replacing them".

These principles and the interpretation of their content and functioning by George Ritzer are a typical example of efficient transmission of social scientific knowledge to wider audiences. Ritzer's book is very well placed in the continuity and change of social reality and sociological knowledge. This mostly concerns the rationalization process identified by Max Weber as an all-embracing process in modern societies. It was a brilliant idea for George Ritzer to continue Weber's studies by checking their validity under present-day conditions. He has selected the impressive rise of the McDonalds chain of fast-food restaurants for the purpose of managing to combine ideas that are stressing the continuity and discontinuity of his vision of this fundamental social innovation. McDonaldization is a proper candidate, as it relates to key ideas by Max Weber on social rationalization. Selecting McDonald's Corporation for dealing with present-day social rationalization is compatible with the analysis of rather specific cases of social interaction, which brings about better quality of commercialization and social innovation. However, in most cases, the discussions about social innovations have concepts involved in local interactions. They concern ideas about the management of both rationality and irrationality in the rationalization processes.

The problem situation includes the capacities of individuals, groups, and organizations to balance rational and irrational practices. Official standpoints notwithstanding, average people usually know if the intended or implemented changes are expected to be favourable for them or not. The Internet has the power to spread knowledge but also institutional measures against destructive Internet. It happens that both tendencies reach the very core of commercialization. In everyday life, this activity fosters politeness and skills to resolve issues by means of negotiations and mutual understanding. However, another side of the business also fosters hypocrisy, false friendliness, and skilled strategies and tactics for maximum profit accumulation according to the circumstances.

George Ritzer's analyses show nearly on every page that profit was and remains the major motivation for radical reforms in the organization of fast-food restaurants. This is a case dealing with mature innovation wherein profit is the guiding idea behind the preparation for improving the results of reforms already carried as well as potential future reforms. The organizational openness and proven financial stability of the potential study case were and are the issues in the support of a new generation. There

are factors for the readiness of financial support to projects under the conditions of financial stabilization. As seen from another point of view, one may respect these achievements while holding profound doubts concerning aims which focus on financial success but neglect environmental protection or health care. Some traditional habits have been tested in the context of the need for healthy food. The chain restaurants may offer a menu that is incompatible with the home-made local food. Still others have tried to homogenize by excluding cultural diversity after making careful cost-benefit calculations. McDonald's fast-food restaurants have certainly been successful in uniting production and consumption as well as work and leisure.

With all due respect to these achievements owing to McDonald's business strategy and practice, one should respect the achievements of other individuals, groups, and organizations as well. Some of them have offered even more impressive solutions in larger contexts. The works of Taylor [14] should be remembered first and foremost. The problem is not in a lack of citations. Taylor and his methods of measurement and organization of work were mentioned in Ritzer's book on "McDonaldization of Society" several times. Taylor's impact on the introduction, maintenance, and permanent improvement of assembly lines in Ford's factories was fully recognized.

But the bold emphasis on the pioneering achievements of the fast-food chain is intellectually unfair and practically misleading. The structure and functioning of the McDonalds restaurants literally copied the structure and functioning of the assembly lines in industry as invented and practically realized in the Ford T Model production by the tandem of Henry Ford and Fredrick W. Taylor. Therefore, to define global changes in major social structures and behavioral patterns as due to the organizational changes in McDonald's fast-food restaurants provokes a rather different standpoint. It takes for granted that these profound changes in structure and behavior came about primarily due to radical innovations in the organization of industrial production. The real breakthrough was the invention and massive expansion of assembly lines in car production and, later, in the electronics industry, with the production of electronic components, electronic devices, etc. In all these structural changes, commercialization of products was the central achievement well in advance of the commercial kitchens [13].

Ritzer's detailed discussion of the rise, advantages, and irrationalities of the rationalization process [13] of the commercial (or commercialized) kitchen is a good starting point for a well-focused discussion. Its conceptual core is the building of a generalized and well differentiated concept of commercialization by basically following the definition cited at the beginning. The best way to dive into the details of commercialization as a concept is to link it to specific structures and processes. There is no better candidate for that purpose than social innovations. Bureaucratization (Max Weber's preference) is a perfect case for testing the analysis and argumentation behind the intricacies of commercialization. The research interest of Ross is also focused on commercialization as a major social process. Referring back to Weber's example of social change, George Ritzer takes the development of effective commercialization in the form of innovative fast-food restaurants as the core of the discussion. In all these rather specific cases, the central issue is money in a wide variety of manifestations. Money and the market calculations have become the most influential organizational

factors for stability and the profound social changes dominated by instrumental activism, or, in this version, of commercialization.

Thus, the value-normative and behavioural shift from ultimate religious value orientations to instrumental market-based orientations caused tremendous advances in the human command over the natural and social world. In present-day global society, instrumental activism predominates with a view to the specifics of this historical type of society. In this controversial context, the concept of commercialization might be particularly useful in efforts to improve the capacities of individual and collective actors to manage technological and organizational innovations. The variety of opinions reflects the relevance of issues, which are being presented as constructions of relationships. One of the topics for discussion concerns the content of the stages of innovation and the key notion of processes. Therefore, the decisions about the aims, means, content, and stages of the innovations will be further identified, described, and explained in the paradigm of social interaction [15]. The scheme will guide the analysis of the gigantic innovation that is being implemented by Elon Musk's company SpaceX program for flight to Mars (see **Figure 1**):

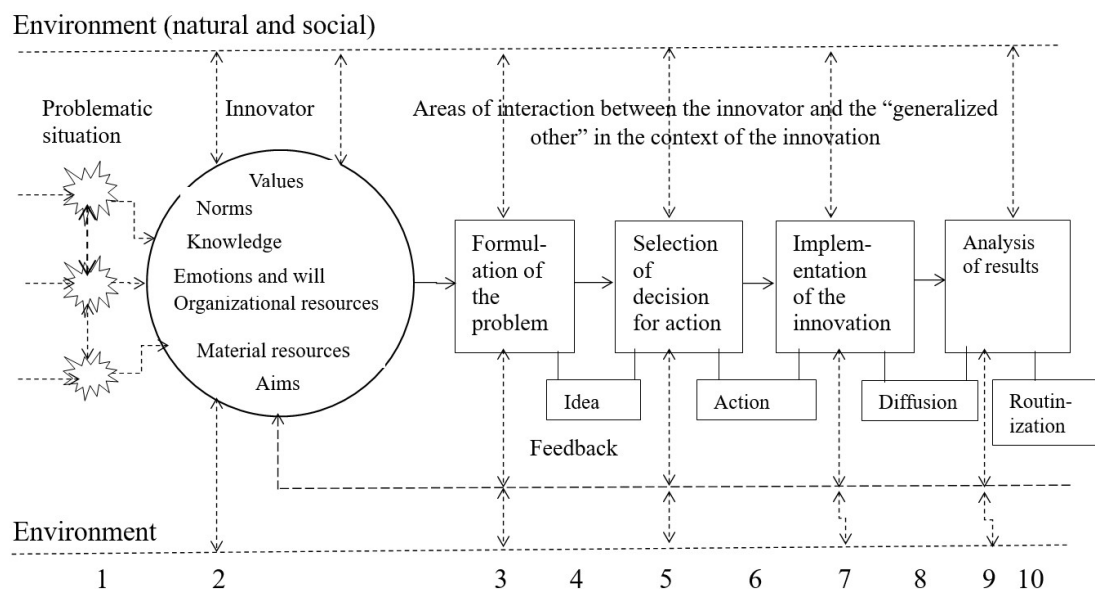


Figure 1. Key indicators of commercialization in the innovation process.

Source: Author's design.

Legend:

- 1: A potential innovator registers a problematic situation,
- 2: The potential innovator identifies and compares research problems,
- 3: The innovator identifies the most promising research problem (from his/her point of view),
- 4: The innovator develops ideas about the problem's resolution,
- 5: Preparation for problem solving through a cognitive and/or practical innovation,
- 6: Action for problem solving,
- 7: Problem resolved,
- 8: Diffusion of the cognitive and/or practical results of the commercialized innovation,

- 9: Analysis of results and recommendations,
- 10: Routinization.

The numerous innovations suggested and implemented by Elon Musk will be further analyzed by using a soft version of constructivist approaches to dynamic phenomena.

3. Elon Musk: Ambitions, achievements, and failures in SpaceX commercialization

In contrast to the time of Max Weber, today the vast majority of European and North American entrepreneurs typically see issues of religiosity as private, without any direct impact on their professional activities as a rule. This is the background of the secularized rules of professional conduct followed by Elon Musk [2]:

- 1) Question every cost,
- 2) Have a maniacal sense of urgency,
- 3) Learn by failing,
- 4) Improvise.

Weber interpreted the economic achievements and failures in industrialized societies prior to the First World War as monetary processes in the first place. To make the point clear enough, a brief analysis of the relationships between entrepreneurs, their employees, and markets will be made in secular terms. The value-normative situation in Musk's companies can be best exemplified by Musk's colourful language [2]: "Then he (Elon Musk) threw a metal ball at one of the Armor Glass windows, to show it wouldn't break. To his surprise, it cracked. 'Oh my fucking God!' Musk said. 'Well, maybe that was a little too hard.'"

3.1. A potential innovator registers a problematic situation

At the beginning of the 21st century, NASA and the Russian space agency were in deep crises. The tremendous size and weight of the space rockets then in use posed fundamental problems. Their fuel was heavy, expensive, and thus inefficient. There was an urgent need to re-use parts of launch vehicles, primarily the rocket engines. In the USA, a special problem was caused by the necessity to introduce new models of efficient vehicles in order to replace Space Shuttle Columbia. The Russians could serve American programmes with somewhat outdated rockets but were out of funding for new projects. So, the very talk about manned flights to Mars seemed to be meaningless. At the same time, new actors (mostly China) more and more frequently made clear their aspirations for taking part in the colonization of outer space [16]. New strategies, new technologies, and new organizational forms were needed for coping with the multidimensional critical situation. In their search for solutions, NASA's experts started to consider the potentials of public-private partnerships in efforts to intensify the study of outer space and to exploit its resources.

At the same time, the talented young workaholic Elon Musk was searching for a promising field of professional realization. The public debate about the study and exploitation of outer space did correspond to his ambitions and talents as researcher, designer, engineer, and entrepreneur. The focused efforts to colonize Mars as a symbolic part of outer space were intriguing. As a potential innovator, Elon Musk was

aware of the high intensity of complex problems facing a return trip from Mars. The possibility of failure in his efforts to resolve the immense task was overwhelming, since the young man didn't have any specialized knowledge or relevant skills to apply. The risk of being involved in an accident was extremely high. However, due to his participation in the first version of PayPal's software, Musk received his first million dollars. They could be invested in research and development. Having no secured institutional support or funding, Elon Musk relied on information about launch vehicles from the public library in Palo Alto.

3.2. The potential innovator identifies and compares research problems

The strategic task was overcoming the delay in the colonization of Mars. This delay had many reasons, related to several determinants of social interaction. The intended long flights and particularly the required repairs in outer space provoked a series of discussions about the environmental effects on the crew, travelling specialists, and tourists [17]. The relevance of economic factors could be best exemplified by the experience of Russia. Having been one of the two leading actors in space launches decades earlier, during the 1990s the country was practically out of the business because of financial reasons. As to the political determination of space flight, it was indeed present in all decisions and in all stages of the implementation of these decisions. The same held true for the cultural impacts of knowledge, values, and norms. The ultimate goal was humanistic—to secure a safe habitat for humankind in case of a catastrophe on Earth. The instrumental goal was and remained building less expensive rockets by reducing their weight and by producing reusable launch vehicles. Lighter rockets could support the budget of the SpaceX project by allowing larger cargo for longer space flights. The intention for self-fulfillment was an intrinsic part of the motivation [2].

3.3. The innovator identifies the most promising research problem (from his/her point of view)

Collecting information about the problem areas announced by NASA for research and management, Musk noticed that the problem area of “flights to Mars” was hardly being covered by any projects. On the occasion of the establishment of his SpaceX company, intended to prepare flights to Mars, Musk formulated the point in programmatic style: “I wanted to hold out hope that humans could be a space-faring civilization and be out there among the stars” [2]. A strong will and motivation for achievement lurked behind this statement. The choice of building and using spacecraft was well founded, considering Musk's personal qualities. He had been influenced by the predominant interest of young people from his generation towards software. However, like some others, he had experience and a genuine interest in working on hardware too. This balance of personal interests was a very important asset in the building of launch rockets.

3.4. The innovator develops ideas about the problem's resolution

The first strategy suggested by Musk for the development of the rocket project was focused on building a single spacecraft for the flight to Mars. A reduction in

weight compared to the then-used launch rockets would be the major problem to resolve. The rockets themselves had to have a lower weight so that the available additional space could be used for carrying heavier cargo. Arguments against this strategy were manifold—starting from accusations of economic inefficiency up to the immense technological challenges. Musk and his followers decided on a different resolution to the problem with a two-step programme. The first step consisted of the design, production, and use of a series of orbital launch vehicles that grew increasingly larger in size and included reusable parts.

Implementing this strategy, SpaceX became the champion among fierce competition for increasing the efficiency of aggregates and modules of spacecraft. In the conceptual framework of innovations, Elon Musk's time for dramatic performance was over. Knowingly or not, he followed the principles of Protestant rationalism, "focused on one key metric: what it cost to get each pound of payload into orbit. That goal of maximizing boost for the buck would guide his obsession with increasing the thrust of the engines, reducing the mass of the rockets, and making them reusable" [2]. His programme's similarity with the principles and practices of Western European Protestantism was made easier because of his particular socialization and personal preferences: "... most techies who came of age in the 1990s gravitated to software more than hardware. They never knew the sweet smell of a soldering iron, but they could code in ways that made circuits sing. Musk was different. He liked hardware as well as software. He could code, but he also had a feel for physical components, such as battery cells and capacitors, valves and combustion chambers, fuel pumps and fan belts" [2].

3.5. Preparation for problem solving through a cognitive and/or practical innovation

The organizational preparation of the project for return flights to Mars started with the establishment of the company SpaceX. It was basically funded by Elon Musk's private capital. Two trips to Russia were intended to identify prototypes and organize a creative transfer of knowledge and skills. The most fundamental cognitive issue concerned the project's strategy for organizational division into two parts. The decision was chiefly made according to financial calculations. The strategic task of return trips to Mars could be understood as an effort to build one big spacecraft to use for the trip. The second strategy was preferred by Musk, who argued in favour of the gradual construction of larger and larger launch vehicles. This was for several reasons. Thus managed, the project would become economically profitable by using the produced rockets for supplying international stations, space tourism, putting satellites into orbit, and helping with the design and construction of the large spacecraft intended to fly to Mars and back. The first elements of the company's infrastructure, logistics, and training of personnel were designed, and construction had begun or was on the agenda. In this way, the Falcon 9 rocket was used to bring supplies to the International Space Station. The Dragon version of the same rocket was used for transporting the station's team. The Starlink network is the best organized system of some 4000 satellites, which provides the most comprehensive picture of events taking place on the surface of the Earth. Starship testing is regarded as the final stage in preparation

for a manned flight to Mars. The construction and use of this spacecraft would complete the SpaceX programme.

3.6. Actions for problem solving

Elon Musk is a talented organizer. He managed to attract dedicated young people for participation in all stages of work on the SpaceX project. The young people were highly creative and responsible people to listen to his suggestions. Though some may have seemed irrational, they turned out to be quite innovative. Most of these employees did not leave the company in a crisis situation. They proved themselves serious enough. The first three Falcon models failed. Between 2008 and 2009, SpaceX was on the brink of bankruptcy, and the workload was extremely high. Only Musk's stamina and inventiveness saved jobs. Finally, after the successful Falcon 9 test in 2009, recognition came in all its desirable forms. The rockets, having passed testing, were offered services covering the demand of telecommunication satellites or the supply of food to the International Space Station.

All activities for resolving the problem were carried out under strict financial control: "Musk was laser-focused on keeping down costs. It was not simply because his own money was on the line, though that was a factor. It was also because cost-effectiveness was critical for his ultimate goal, which was to colonize Mars. He challenged the prices that aerospace suppliers charged for components, which were usually ten times higher than similar parts in the auto industry" [2]. Musk had personal control over product quality: "From the very beginning of his career, Musk was a demanding manager, contemptuous of the concept of work-life balance. At Zip2 and every subsequent company, he drove himself relentlessly all day and through much of the night, without vacations, and he expected others to do the same... With his weak empathy gene, he didn't realize or care that correcting someone publicly—or, as he put it, 'fixing their fucking stupid code'—was not a path to endearment." [2].

3.7. Problem resolved

Elon Musk had to cope with a fundamental problem that concerned the strategy of SpaceX: his firm decision about the advantages of dividing the task to prepare for the return flight to Mars in two stages. The decision was empirically tested, and the conclusion is unmistakably clear. The strategy to focus on rocket building first was confirmed in a most impressive way. Twenty years since SpaceX was established, the company has 294 rocket launches under its belt. Some 256 of these launches were followed by successful landings. Currently, there are 9 different models of rockets offered by SpaceX for market supply. In this way, the burning need for spacecraft has been radically satisfied. The various SpaceX offerings may serve the needs of most individual clients. Major demand comes from potential satellite clients or satellite-driven services. SpaceX is in an excellent position to answer it on a large scale, with the company's fleet of 4000 satellites and intentions to upgrade that number to 40,000. This unique capacity is a strong asset against the competition but also a kind of curse, considering the complicated state of international relations at present. "If Musk had been the type of person who could pause and savor success, he would have noticed that he had just brought the world into the era of electric vehicles, commercial space

flight, and reusable rockets. Each was a big deal” [2].

3.8. Diffusion of the cognitive and/or practical results of the commercialized innovation

The spread of patterns for the design, construction, and use of orbital launch vehicles developed and tested in the SpaceX project have been most impressive. These long-term and globally relevant achievements make the project attractive and have been the subject of dissemination and diffusion. This applies to the multidimensional innovation of public-private partnerships as well. Competitive interest in colonizing the space will not decline. Thus, the ideas and practices of Musk and his staff will continue to intensify in their spread.

3.9. Analysis of results and recommendations

The start of the SpaceX programme by Elon Musk signalled a decisive move from discussions on the possibility of space travel to Mars to practical colonization of the planet. The aim seemed to be clear to the young, talented, and ambitious leader. But he had no specialized knowledge or skills. The fact that Elon Musk managed to overcome this barrier by introducing a series of technological and organizational innovations should be carefully analysed by decision-makers in the fields of secondary and university education. Rationally guided creativity is not an illusion. One should not expect that the extreme creativity of Elon Musk could be doubled or quintupled by recruiting trainees for courses on creative design and project management. However, markets do positively react to all manner of innovations, even those limited to precision or slightly changing colours.

It is surprising to notice how isolated the struggles of the talented and ambitious young industrialist and entrepreneur Elon Musk were with the local and state administration, according to his biography. This phenomenon might be due to the readiness of Musk to adapt to the requirements of administrators. Another explanation has to do with the way Elon Musk has argued with policymakers by stressing the national and international relevance of his work. Undoubtedly, the most rational policy recommendation is for mutual respect towards SpaceX. It should transfer into optimum relationships between local and state administrations and innovators from all action areas, in all action spheres, and in all age groups.

3.10. Routinization of the innovation

The routinization of the breakthroughs achieved by Musk’s SpaceX in the field of rocket building and use is widely known. SpaceX launch vehicles supply the ISS, offer space tourism, install satellites, and provide subscriptions to use Musk’s satellite network. One may take it for granted that there will be intensive public interest in the return flights to Mars promised by Musk. These achievements will be celebrated and routinized in the flights which will follow the same route. Likewise, specialists will routinize the memories of this historical event in museums and academic lectures.

4. Concluding remarks

The achievements made by SpaceX as a company and personally by Elon Musk

are unique. Even in spite of a highly unlikely forthcoming bankruptcy for the company, the multidimensional constructive experience of SpaceX deserves study and dissemination. The experience is a public asset since Musk's ideas are future-oriented and highly competitive. As seen from a different point of view, Musk's personal story as a successful, self-made man is a strong source of motivation for creativity, responsibility, and hard work. This last point is particularly relevant for the value-normative and practical unity of the analysed efforts to put a diagnosis on contemporary societies by paying special attention to processes and structures of the commercialization (monetization) of social life.

Both similarities and differences in the views of Max Weber, Edward Ross, George Ritzer, and Elon Musk are related to intellectual traditions, impacts of the local context, and personal preferences. In the context of the broader social environment, Musk's interests, knowledge, and action were very substantially determined by the challenges of technological development. More precisely, he managed to turn these challenges into a factor fostering inventiveness, innovation, flexibility, risk-taking, responsibility, and good habits for communication and cooperation with other people or organizations. This story is a perfect example of rewarded abilities to properly read and understand the requirements of the economic situation. The outcome is that SpaceX is by far the global leader among private companies serving the market for spacecraft. Due to his extreme sensitivity to the volatility of markets and ability to take calculated risks, Elon Musk succeeded in building a highly respectable technological and economic empire. However, Musk's readiness to take on intense, calculated risks might just as easily meet unpredictable technological, economic, political, and cultural circumstances similar to the critical situation for SpaceX in 2008. Depending on circumstances, the resilience of economic systems based on commercialization might be rather strong or limited. The same holds true for the resilience of political systems thriving on the same basis. The events related to Musk's decision to withdraw his fleet of satellites from military activities are a clear signal as to how powerful the political determination of the technological and economic situation might be. In interviews, he used to repeat the point about the potential implications of value-normative integration.

The integration of a society based on commercialization could reach great heights under certain circumstances. Such a general situation might allow individuals like Elon Musk the freedom to be distinctive and extraordinarily productive. The open concerns about the limits of commercialization might be supported by relevant economic, political, and cultural actors. With his obsession to carefully identify real and potential sources of profit and drive to work hard in order to increase the capital to be invested for a new cycle of accumulation, Elon Musk seems to be the ideal capitalist entrepreneur, according to Weber's vision: "Man is dominated by the making of money, by acquisition as the ultimate purpose of his life. Economic acquisition is no longer subordinated to man as the means for the satisfaction of his material needs" [10]. Such an identity would not be fully adequate for Musk because it would only correspond to the central part of his activities. His biography and particularly his interviews present a person with a strongly humanistic value-normative identity, as well as a rich emotional life. Musk is not a Frankenstein-like character in the sense of "specialist without spirit" or "sensualist without heart".

Although some groups of specialists with educational backgrounds in the natural sciences clearly see social problems requiring technological solutions, this is not the dominant vision in contemporary advanced societies. The profiles of emblematic leaders in technological development worldwide [18] do not correspond to Weber's pessimistic vision about the worldview of the people who were expected to guide the commercialization of today.

Ross has organized his article as a juxtaposition of the still strongly commercialized action spheres and examples of already de-commercialized ones. These examples include the de-commercialization of marriages (no more payments for brides), de-commercialization of religion (church services are offered free of charge), and de-commercialization of government (the introduction of fixed taxes). In all these specific cases, individuals and institutions developed more sophisticated mechanisms for replacing the traditional forms of commercialization. One would be on sound ground to say that commercialization is present or directly dominates on every structural level and in all action spheres in contemporary societies. That is why the definition of commercialization suggested by Ross has tremendous potential for guiding studies and management of contemporary and future science and society.

The continuity of key ideas from Max Weber's intellectual heritage through George Ritzer's study on the McDonaldization of society concerns the causes, content, and consequences of social rationalization. This continuity has been regularly stressed in Ritzer's own writings as well as in the secondary literature [19]. The vision of self-improving rationalized market exchange links Ritzer's conception of society's McDonaldization with Elon Musk's philosophy and practices of rationalization in the design, production, marketization, and use of spacecraft as well as electric cars and trucks. However, Weber dealt with the organizational rationalization of economic, political, and cultural structures predominantly on a regional (Western Europe) or partly global (world religions) level. George Ritzer specified the idea of rationalization by focusing on its four parameters, applying this conceptual scheme in the study of processes that allow for the same pattern of explanation. Most of them, if not all, belong to the area of consumption and services. The ideas of organizational rationalization initiated by Elon Musk concern production processes first and foremost.

The conclusion is obvious. Instrumental activism in the form of commercialization (monetization, marketization) is a strong global process with a plethora of manifestations. Core processes of rationalization in the form of commercialization are present in all such manifestations, particularly in innovations. Specific conceptualizations should be prepared for local iterations of commercialization. This double-sided approach should be specially applied in the study of complex processes like Elon Musk's SpaceX programme.

The specifics of the rationalization of R&D in the implementation of the innovation under SpaceX might be briefly presented in this way:

- Specific demand for the new product was identified;
- A timeline for commercialization, in the sense of the innovative product's first contact, was created;
- Elon Musk carefully coordinated the aims of each strategy with the financial resources available;

- This coordination was tested at the start and end of each stage of the project;
- Financial coordination occurred between SpaceX, Tesla, Boring, SpaceX Dragon, Falcon Heavy, and Super Heavy Starship.

There have been tensions between the ideas and practices of Elon Musk, on the one side, and rapidly changing contemporary dynamics due to the interplay of rational and irrational decisions and processes, on the other. His statements about the future have been quite optimistic, yet his readiness to take risks has been too strong from time to time. His reactions to the remarks and actions of colleagues also tend to be rude. The puzzle is fundamental: What are the moving forces behind the development of present-day national societies and global societies? Answers have been attempted in a plethora of ways. Some of them are notoriously one-sided by stressing one or several key factors. Most often, this is a technological breakthrough on the basis of scientific progress. Another preference concerns the growth of scientific knowledge and its impact on rationalization of all activities. Large-scale changes in social structures and action patterns accompany or follow major innovations in the economy, politics, and culture. Destructive potentials determine the present-day critical situation of global commercialization. Elon Musk has presented them in an interesting way: “From 2007 onwards, until maybe last year, it’s been nonstop pain. There’s a gun to your head; make Tesla work; pull a rabbit out of your hat; then pull another rabbit out of the hat. A stream of rabbits is flying through the air. If the next rabbit does not come out, you’re dead. It takes a toll. You can’t be in a constant fight for survival, always in adrenaline mode, and not have it hurt you. But there’s something else I’ve found this year. It’s that fighting to survive keeps you going for quite a while. When you are no longer in a survive-or-die mode, it’s not that easy to get motivated every day” [2]. Generalizations about the critical global situation sound ever more disappointing: “We’re entering a ‘new world disorder’. We can no longer afford to focus on the big issue at hand because there are many interrelated issues at play” [20].

Therefore, the contemporary entrepreneur is expected to have learned about the many dimensions of social reality [21]. In this respect, Elon Musk demonstrates a striking ability to avoid monocultural strategies for private and professional realization and development. Knowledgeable modern entrepreneurs are very willing to lead the rational management of technological and organizational processes. In this sense, they are the authentic legacy of Weber’s vision about the desirable future organization. The condition is general and specialized education. In all European societies, the general level of education is attained under weakened state supervision. Some additional education and training in the area of commercialization would be a fine enhancement of citizens’ professional knowledge and skills. However, one should not forget Karl Mannheim’s warning: “The more we think about the best forms of planning, the more we might arrive at the decision that the most important spheres of life one should deliberately refrain from interference, and that the scope for spontaneity should rather be kept free than distorted by superfluous management” [22].

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Article

Factors that influence choice of residence by urban informal settlement dwellers in an intermediate city: A case study of Enugu, Nigeria

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Abstract: The consequences of urbanization in Sub-Saharan Africa are poverty, insecurity, and the growth of informal settlements. These settlements are characterized by overcrowding, tenure insecurity, a lack of basic services and amenities, and many other deprivations. The current study looks at the social and environmental problems faced by residents and the factors responsible for their choice to reside in an informal settlement in Enugu using the survey research method. Primary and secondary data were utilized in the study. Whereas the former source includes a structured questionnaire and observations, the latter source comprises relevant literature. A total of 111 questionnaires were distributed to household heads in five selected informal settlements in Enugu. The data set was collated and analysed using descriptive and inferential statistics. Principal component analysis was used to classify and determine the factors influencing the choice to reside in an informal settlement. The study revealed that six factors influence the choice of residence in informal settlements: government/political influence, social integration/services, housing/employment, infrastructure accessibility, livelihood costs and security/economy. The factors accounted for 72.11 percent of the factors influencing the choice to reside in an informal settlement. The major social challenges faced by residents are gambling, drug abuse, and overcrowding. The study recommends that low-cost housing that is affordable should be provided for the low-income group that characterizes informal settlements in Enugu metropolis.

Keywords: informal settlement; residence decision; poverty; social challenges; residential location

1. Introduction

By 2018, more than half of the world's population lived in urban areas. This population is expected to increase to 68% by the year 2050. The increase in urban population has led to the urbanization of poverty, inequality, and the growth of informal settlements [1]. The poor are the major inhabitants of informal settlements in the city and live with many deprivations and bear the greater burdens of urban environmental risks because of the situation in which they are forced to live [2]. The urban poor are faced with daily challenges that include limited access to employment opportunities and income, inadequate and insecure housing and services, violent and unhealthy environments, little or no informal social support system, and limited access to adequate health and education opportunities [3,4]. This condition refers to a dynamic condition of vulnerability or susceptibility to risks. The situation is even more worrisome in the developing countries of South-Asia and Sub-Saharan Africa, where poverty reduction has been uneven as these countries lagged behind in achieving the Millennium Development Goal [5,6].

Informal settlements are known by a number of different names, some of which are slums, low-income settlements, semi-permanent settlements, shanty towns, spontaneous settlements, unauthorized settlements, unplanned settlements, uncontrolled settlements, etcetera. Most of the urban poor populations in developing countries live in informal settlements [7–9]. In Africa, almost two-thirds of the urban population resides in informal settlements [10]. Sub-Saharan Africa is reported to have the largest proportion of urban slum dwellers, at about 71.9% [11]. Reasons have been given as the cause of informal settlement development and growth in different parts of the world [4,7,12–14]. The formation of slums has been blamed on discriminatory urban regulations and public spending that fail to deal with housing problems of the poor [4,15,16]. Therefore, the proliferation of informal settlements in urban areas can be said to be an inevitable consequence of the lack of regional planning, rapid urbanization, and high cost of housing [14,17]. Informal settlements provide a convenient place for migrants seeking economic opportunities in major cities [7]. They develop makeshift houses in and around the cities where there are vacant and unclaimed parcels of land [14].

Enugu, an intermediate city located in the hinterland of Nigeria, has twenty-three informal settlements. These settlements are characterized by most of the problems discussed above about slum areas in developing countries (social, economic, environmental, and, in some cases, physical problems). Despite the situations in the slum areas highlighted above, many people still make the decision to live in informal settlements in Enugu. This paper raises the question of why individuals make the decision to reside in informal settlements. This research is aimed at ascertaining the social and environmental challenges faced by residents and determining the factors that influence their choice of residence in informal settlements in Enugu metropolis, southeast Nigeria.

2. Theories of residential location

There are many classical theories of residential location: The utility maximization theory, for example, the studies of Alonso [18]. This theory suggests that people will seek to minimize commuting costs by selecting a house location that provides greater accessibility to their workplace. Hoang and Wakely [19] and John et al. [20] criticized and modified the theory. Robert Park [21] and his associates advanced the Human Ecology Theory, which looks at how people and communities interact with their immediate physical and social environments, including where they choose to live. The dynamic nature of urban settings and the impact of social and environmental influences on human behavior are highlighted by human ecology theory. A contributor to Human Ecology Theory is the concentric zone model by Burgess, which imagines cities as a series of concentric rings extending outward [22]. The second concentric zone is made up of mostly older homes and tenement houses. This area is often characterized by poverty, ill-kept properties, and slum or near-slum conditions [23]. Others that have expanded this theory are Wirth [24], Hawley [25], and Özerdem [26]. This theory was also used in analyzing residential location choices and the influence of social and economic factors in Beijing, China [27].

Again, the Rational Choice Theory is a theoretical framework that seeks to

explain human decision-making by assuming individuals act in a rational and self-interested manner. This theory has been used to analyse decisions about where to live, taking into account variables such as housing costs, amenities, proximity to jobs, and bounded rationality. In the same vein, social network theory provides a theoretical framework for understanding how social relationships and networks influence individuals' behaviours, decisions, and choices. The influence of social networks on residential location choices is evident in the argument that individuals tend to associate with others who are similar to themselves in terms of various characteristics, such as socioeconomic status, ethnicity, or lifestyle preferences [28]. The role of social networks in providing emotional and instrumental support to individuals was highlighted in the context of residential location choices, where individuals considered the availability of social support networks, such as family or close friends, when deciding where to live [29].

The Push-Pull Theory posits that individuals make decisions regarding residential location based on a combination of push and pull factors, originally developed in the context of migration studies. In the context of informal settlements, push factors refer to the negative conditions or circumstances in individuals' current residential areas that drive them to seek alternative housing options. For example, individuals may be pushed away from their current location due to poor living conditions and a lack of access to essential services [3]. On the other hand, pull factors are the positive attributes or opportunities that informal settlements offer, which attract individuals to choose these locations as their residential areas. The push-pull theory recognizes that both push and pull factors operate simultaneously and interact to shape individuals' decision-making processes.

3. Literature review

Several studies have been carried out to determine the factors that influence household choice of residence in different parts of the world. Many studies focused on central cities, large metropolises, and suburban areas. Studies have been carried out on the social, economic, physical, environmental, infrastructure, and religious attributes of location decisions. A study carried out to determine the most influencing factors of residential location preferences used nine factors that people consider while making a choice for a residential location [30]. These factors are: distance from work place; cost of building or land; distance from city centre/market; community preferences; distance from school; availability of recreational facilities; water supply and transportation; security; development trend; and surrounding environment. The analysis revealed that workplace location is the most governing criterion in deciding residential location from the majority of urban dweller's perspectives [30].

Studies have looked at the various geographical and economic factors of residential location choice. One of such studies found household income, race, household size, number of vehicles in the household, type of housing, and household structure to be the most influencing factors [31]. In addition, distance to work, distance to shopping destination, availability of social facilities, security, cultural attachment, income, access to employment opportunities, and ratio of housing cost to income were also found to influence residential location choice [32,33]. In the same vein, when the

environmental factors were examined, it was found that physical/environment factors, facilities and amenities, security factors, and community/socio-economic factors influence the choice of residential neighborhood to a reasonable extent [34]. The study also noted that each family chooses from the housing available at any given time to maximize their utility, but the factors that affect the complex selection process are unknown [34]. In assessing the social factors that influence residential area preference, 11 variables were used. Then factor analysis was used to extract two components: socio-demographic and urban infrastructural factors, from these 11 variables. The study concluded that these two factors influence residential area preference [35]. Also, other studies examined various factors associated with housing choice and found that socio-economic factors and the ease of commuting within the metropolis are the key factors [36,37]. Another study on the role played by different housing attributes in residential choice preference used fourteen variables. These fourteen variables were reduced to two components: dwelling and accessibility attributes as influencing factors [38]. Ease of transport and availability of transportation facilities, services, and amenities have also been found by studies to influence household choice of residential location [39,40]. These studies found proximity to health centres, low pollution levels, and access to public transportation and taxi stations as influencing location choice. This is to say that residents strive to minimize commuting cost and maximize home-based non-commuting time [40].

The push-pull theory has been used to analyse the dynamics of residential location choices. In South African informal settlements, push factors such as limited access to services, crime, and poor infrastructure were identified alongside pull factors such as improved housing options, social networks, and proximity to economic opportunities [41]. Similarly, the relationship between socioeconomic status and the factors considered in making residential location decisions in Port Harcourt metropolis, Nigeria, was examined using push and pull factors. The study found home ownership, crime/security, an increase in income, rent and availability of infrastructure, and proximity to industrial land uses to be among the eleven important push factors, while security, income, home ownership, electricity, water, affordable rent, size of dwelling, and social status are among the prominent pull factors [42]. Again, house price, housing environment, housing location, accessibility, and transportation services were found as push factors [37].

In studying environmental attributes considered in residential location decisions along coastlines, the physical and environmental factors of residential location decisions were used. The result showed that out of the 15 variables examined, environmental attributes contributed 39.78% of the over 70.76% of the factor loadings. The environmental attributes considered by households in residential decisions are neighborhood, critical dwelling, and socio-economic attributes [43]. Similarly, a study that assessed environmental influence found preference for places near urban parks than nearness to work [44]. A study based on the discrete choice model found that there exists a complex household sorting pattern that is initiated by sociocultural, socioeconomic, accessibility, and neighbourhood composition because African households tend to develop strong ties to their origins [45]. Another study found that stakeholders' relations have direct and positive influence on residential choice [46]. Race was also confirmed as a very influential factor [31]. Also, religious and cultural

factors were found to be influential in terms of residential location preferences in Iskandar Malaysia [47].

A few studies have been carried out on why households choose to live in informal settlements. One of such studies was carried out on factors that urban residents of informal settlements consider in location choice in Dar es Salaam, Tanzania. The study argues that with income limitations, the urban poor rely on other non-economic resources to enable their residential location decisions. The result of the study showed that 1) proximity and access to livelihood opportunities; 2) proximity to relatives and/or friends and familiarity with the area; and 3) convenience in terms of low living costs, cheap rental rooms, and access to vacant land are the most prominent factors influencing location decision-making. The study suggested that the urban planning process should aim towards empowering and capitalizing on social capital and close-knit networks of marginalized urban citizens [48]. Also, in trying to bridge the gap in literature on the residential location choice of informal settlement dwellers, the case study approach was used to investigate factors that inform households' decisions to live in Kumasi's peri-urban settlements, based on households' likelihood of changing residences in the future and their stated residential location preferences. The study found that family relations, relatively low land prices and house rents, as well as workplace proximity, were the most significant reasons underpinning households' choice of the peri-urban settlements [49]. In Nigeria, the movement pattern of slum dwellers, factors influencing their residential choices, and reasons for the people to remain in Lagos were investigated. The findings of this study showed that migration to Lagos was the major reason for population growth and, hence, slum development. It was also found that slums in Lagos serve as a sinkhole and a final destination for slum dwellers [50]. Another study looked at residential location choice among informal settlers in Port Harcourt, Nigeria, using thirteen factors. It found that seven factors—living close to family or friends, low rent/cost of housing, livelihood opportunities, commuting cost, proximity to work, nearness to children's school, and personal reasons—were the main determinants [51].

From the literature reviewed, many variables influence the choice of residence in urban areas. Twenty-three variables were identified from the literature reviewed that influence choice of residence. These variables are used in determining the residential location choice of informal settlement residents in Enugu. Most of the existing studies used a few variables to determine residential choice. It is also apparent that there is a dearth of studies on factors that determine the choice of residence in informal settlements in Nigeria, especially in the intermediate cities of the hinterland. Most of the existing studies focused on residential location choice in formal and planned residential areas. This gap in the literature provides the ground for this study. Therefore, the specific objectives of this study are to (1) ascertain the social and environmental challenges faced by residents in the informal settlements and (2) determine the factors influencing the choice of residence in these informal settlements.

4. The case study city

The city of Enugu is located approximately between latitude 06°21 and 06°30 north of the equator and longitude 07°26 and 07°37 east of Greenwich meridian. It

covers an approximate area of 200 km² and is situated on an elevation of 254 m above sea level. Enugu City was founded in 1909 by a British as a result of the discovery of coal in the Udi escarpment. Enugu is the capital city of Enugu State, located in the hinterland of Nigeria (see **Figures 1 and 2**). It has a population of over one million inhabitants. Enugu is made up of three local government areas. It has thirty-two planned residential layouts. It has remained an administrative headquarters since 1929. It has six tertiary institutions and is a commercial and industrial centre.

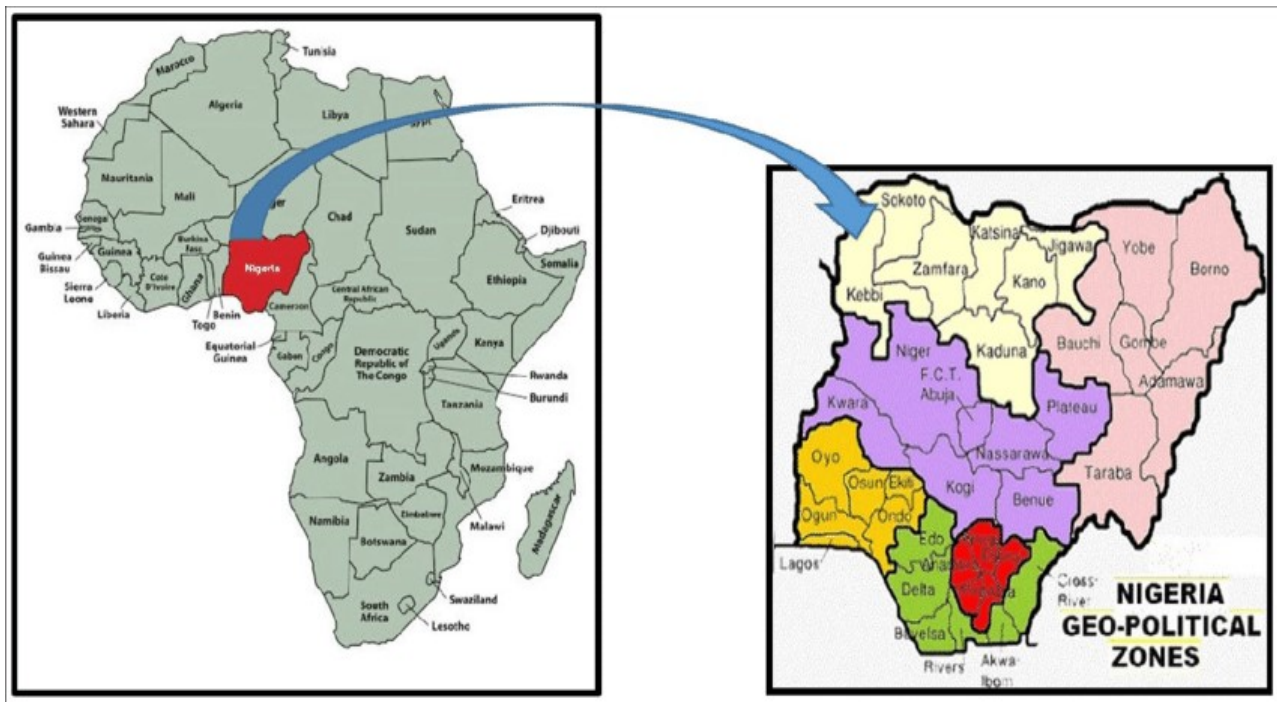


Figure 1. Map of Africa showing Nigeria [52].

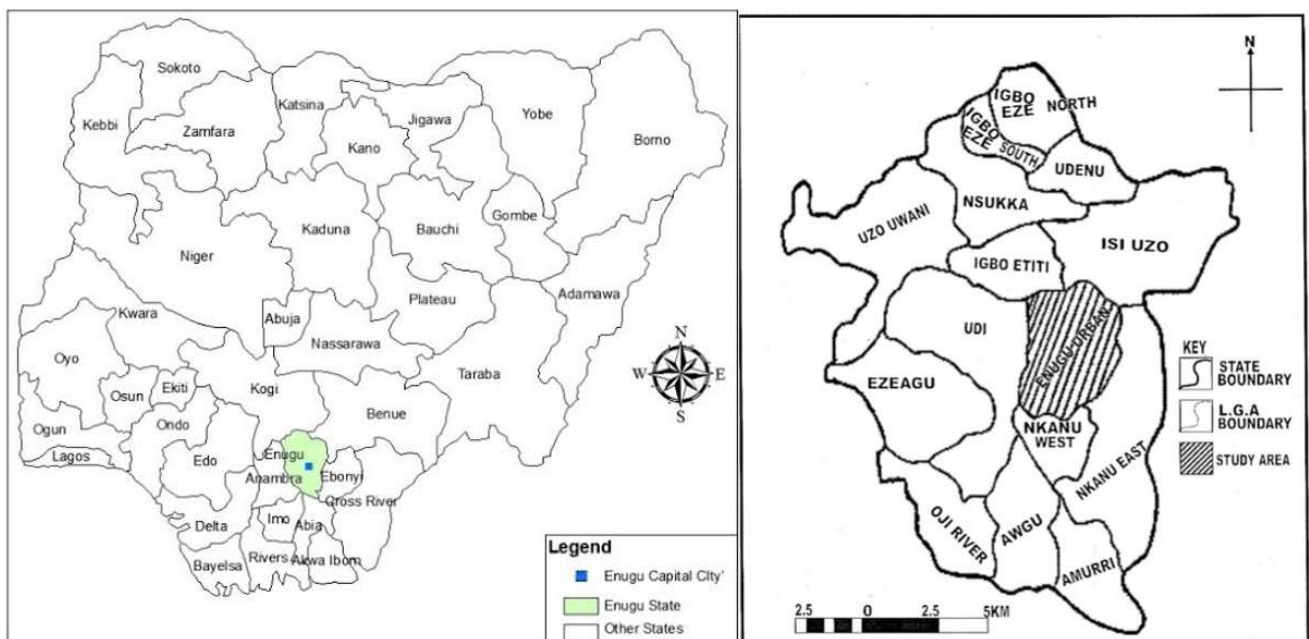


Figure 2. Map of Nigeria showing Enugu state and map of Enugu state showing Enugu metropolis [52].

Informal settlements sprung up within or around planned residential layouts. Enugu has about 23 informal settlements located within the metropolis (URP 581). Four of the settlements are located in Enugu North Local Government Area (LGA), three in Enugu South, and sixteen in Enugu East LGA. Many people in Enugu live in these informal settlements. They primarily engage in unskilled labour, artisan work, and unofficial economic activities like hawking, street trade, etcetera. Very few of the residents are civil servants. Due to a lack of continuous upkeep of the buildings, streets, and drainage systems, deterioration has occurred [23].

5. Materials and method

The research was carried out using the survey method. Both primary and secondary data were utilized in the research. Primary data were collected with the aid of a structured questionnaire, which contained two sections. Five informal settlements were randomly selected from the existing 23 informal settlements. One settlement from Enugu South, 2 from Enugu East, and, also, two from Enugu North LGAs. This was done to capture informal settlement(s) from each of the three local government areas that make up Enugu Metropolis. The selected settlements are Onuato, Ugbowa, Ugbo-Odogwu, Ngenevu, and Ikirike (see **Figure 3**).

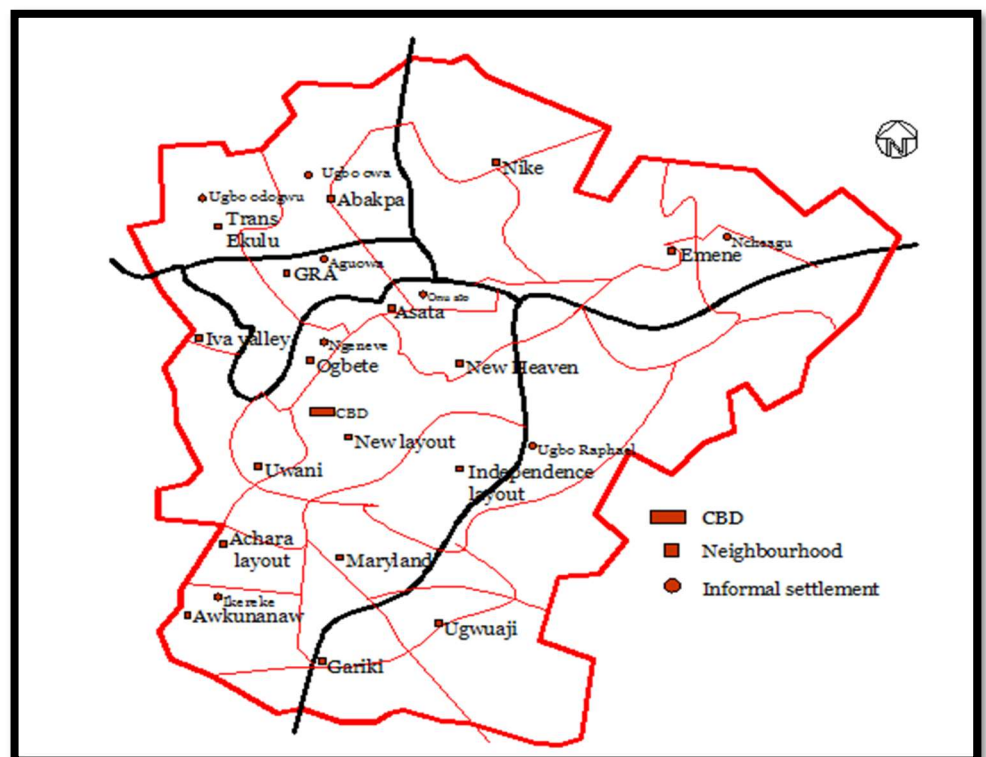


Figure 3. Map of Enugu metropolis showing location of informal settlements [53].
Note: modified by researcher.

A total of 111 questionnaires were distributed to heads of households in the selected settlements. Questionnaire distribution was according to the population of the settlement. Onuato 24, Ugbowa 21, Ugbo-Odogwu 25, Ngenevu 22, and Ikiriki 19 questionnaires. Simple random sampling was used to select households to be sampled

(each household head had an equal chance of being selected).

The data collected through the questionnaire centered on household choice of residential location and social and environmental challenges faced by informal settlement residents. Statistical Package for Social Sciences (SPSS) was used to analyse the data. A five-point Likert scale was used to determine the importance of the factors that influence choice of residential location. Principal component analysis (PCA) was used to identify and classify the determinants of residential location choice in informal settlements in Enugu. PCA is a statistical technique that converts a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components using an orthogonal transformation. It classified the 22 likely determinants of residential location choice into components based on their factor loading. PCA is expressed mathematically as:

$$F = \sum W_j X_j = W_1 X_1 + W_2 X_2 + \dots + W_n X_n$$

where

$W_1 - W_n$ = factor weights; $X_1 - X_n$ = original variable.

6. Results

6.1. Environmental and social challenges of residents in informal settlements in Enugu

From the observations made by the researchers, informal settlements in Enugu are besieged with most of the environmental challenges associated with slum settlements in other African and Nigerian cities. Poor house quality, waste disposal and drainage problems, poor access roads, etcetera [4,7,15,17]. These challenges were obvious even from observations. See **Figures 4 and 5**.



Figure 4. Building and road condition in Ugbo-owa.



Figure 5. Waste water from residence flowing on to the street at Ikirike and Onu-Asato.

The respondents were asked the most pressing social challenges in their settlement. Their response is shown in **Table 1**. Gambling is the highest social challenge with 34.1%, followed by drug abuse 29%, overcrowding 21.2%. While insecurity and prostitution have the lowest percentages of 9.8% and 5.9%, respectively (see **Table 1**). This suggests that the major social challenges facing residents of informal settlements are gambling, drug abuse, and overcrowding, whereas insecurity has been controlled through the use of local vigilante groups and neighborhood watch. The issue of security was confirmed during the researcher's field survey.

Table 1. Social challenges of informal settlements in Enugu.

Social challenges	% response
Insecurity	9.8
Overcrowding	21.2
Drug abuse	29.0
Prostitution	5.9
Gambling	34.1

6.2. Factors influencing choice of residence in informal settlement

Having understood the social and environmental problems of informal settlements in Enugu, respondents were asked why they chose to live in an informal settlement. Their responses are shown in **Table 2** below. The descriptive statistics of 23 variables influencing residential location choice are shown in **Table 2**. The mean scores were used to rank the variables, with an average mean score (MS) of 2.691. The result suggests that 12 variables strongly influence household choice of residence in informal settlements in Enugu metropolis. They are in descending order: cost of living (4.42), cost of housing and land tenure (4.40), income (4.24), poverty (4.14), security and safety (4.05), employment opportunities and livelihood (3.57), business interest (3.11), family ties (3.00), proximity to work, city centre and transportation (2.91), access to basic infrastructure (water, sanitation, and electricity) (2.79), social cohesion and ethnicity (2.65), accessibility to social amenities and services (2.62).

Table 2. Factors that influence choice of residence in informal settlements in Enugu city.

Variables	Mean values	Rank
Cost of living	4.42	1
Cost of housing and land tenure	4.40	2
Income and affordability	4.24	3
Poverty	4.14	4
Security and safety	4.05	5
Employment opportunities and livelihood	3.57	6
Business interest	3.11	7
Family ties	3.00	8
Proximity to work, city centre and transportation	2.91	9
Access to basic infrastructure (water, sanitation, electricity)	2.79	10

Table 2. (Continued).

Variables	Mean values	Rank
Social cohesion and ethnic/religious communities	2.65	11
Accessibility to social amenities and services	2.62	12
Environmental hazards and risks	1.87	13
Land use policies and urban planning	1.81	14
Current political situation of the country	1.81	14
Government interventions and regulations	1.78	16
Inconsistency in land and plan legislation	1.77	17
Rigid building regulation for informal houses	1.76	18
Inadequate housing policy	1.68	19
Corruption in relation to land	1.67	20
Inefficient public administration and procedure provision by the leaders	1.59	21
Problem of legal land provision	1.57	22
Average mean score	2.691	-

However, the most influential ones are cost of living, cost of housing and land tenure, income, poverty, safety, and security, all having $MS \geq 4.0$. This is in agreement with other works on factors influencing the choice of residence in slums [42,50]. Also, employment opportunities and livelihood, business interest, and family ties are the second most influential factors in this study but are ranked first in [51]. Proximity to work, city centre and transportation, access to basic infrastructure, social cohesion and ethnicity, and accessibility to social amenities and services were ranked (9th, 10th, 11th, and 12th). This is also in variance with the study that found proximity to city centre the most influential factor in Ilorin [32], but in agreement with [39,40,36,37]

Ten variables got an MS of (<2.0). This implies that these 10 variables do not have a significant influence on the choice of residence in the study area.

6.3. Determinants of choice of residence

The results of the PCA analysis classified the identified variables that influence the choice of residence in informal settlements into six components. Component 1 loaded significantly on 10 variables as distinct from other variables that determine choice of residence. These are rigid regulation for informal settlement houses (0.931), corruption in relation to land (0.895), inefficient public administration and procedure provision by the leaders (0.892), inconsistency in land and plan legislation (0.885), inadequate housing policy (0.881), the current political situation of the country (0.880), the problem of legal land provision (0.864), land use policies and urban planning (0.837), government interventions and regulations (0.680), and environmental hazards and risks (0.526). It has an eigenvalue of 7.495 and explains 34.066% of the determining variables of residential location choice in informal settlements in Enugu. Component 1 is an index for government/political influence on the choice of residence in informal settlements. The defining variable is rigid regulation for informal settlement houses.

Component two loaded significantly on four variables. They are social cohesion and ethnic communities (0.836), accessibility to social amenities and services (0.782),

business interest (0.680), and family ties (0.493). The component has an eigenvalue of 2.492, explains 11.327% of the determining variables, and is therefore classified as one of the factors influencing the choice of residential location in informal settlements. Component two is an index for social integration/services influencing choice of residence in informal settlements in Enugu. The defining variables of the component are social cohesion and ethnic/religious.

Component 3 is significant and loaded on two factors as distinct from other determinants of residential location choice in informal settlements in Enugu. These are the costs of housing and land (0.795) and employment opportunities and livelihood (0.708). The component has an eigenvalue of 2.066 and explains 9.390% of the variability of choice of residential location. It is therefore classified as one of the factors influencing choice of residential location in informal settlements. Component three is an index for housing/employment influence on choice of residence in informal settlements in Enugu. The defining variable of the component is the cost of housing and land.

Component 4 is significantly loaded on two variables. They are proximity to work, city centre and transportation (0.858) and access to basic infrastructure (water, sanitation, and electricity) (0.845). This component has an eigenvalue of 1.530 and explains 6.955% of the variability. It is therefore one of the factors influencing the choice of residential location in informal settlements. Component 4 is an index for the influence of infrastructure/accessibility on the choice of residence in informal settlements in Enugu. The defining variable of the component is proximity to work, city centre and transportation (0.858).

Component 5 is significant and loaded on two variables. They are cost of living (0.742) and poverty (0.730). It has an eigenvalue of 1.205 and explains 5.479% of the variability in determining the choice of residential location. Component 5 is an index for livelihood cost influencing choice of residence in informal settlements in Enugu. The defining variable of the component is the cost of living (0.742).

Component six is significant and loaded on two variables. They are security and safety (0.613) and income and affordability (0.607). It has an eigenvalue of 1.009, explains 4.993% of the determining variables, and is therefore classified as one of the factors influencing the choice of residential location in informal settlements. The component is an index for security/economy influencing choice of residence in informal settlements in Enugu. The defining variable is security and safety (0.613). In all, the six identified determinants that influence choice of residence in informal settlements in Enugu are government/political, social integration/services, housing/employment, infrastructure/accessibility, livelihood cost, and security/economy. They accounted for 72.211 percent of the determinants of residential location choice in informal settlements (see **Table 3**).

Table 3. Determinants of choice of residence in informal settlements in Enugu.

Component	Determinants	Factor	Eigen value (% variance)	Loading
1) Government/Political	rigid building regulation for informal houses	0.931	7.495	34.066
	Corruption in relation to land	0.895		
	Inefficient public administration and procedure provision by the leaders	0.892		
	Inconsistency in land and plan legislation	0.885		
	Inadequate housing policy	0.881		
2) Social integration/Services	Social cohesion and ethnic communities	0.836	2.492	11.327
	Accessibility to social amenities and services	0.782		
	Business interest	0.680		
	Family ties	0.493		
3) Housing/Employment	Cost of housing and land tenure	0.795	2.066	9.390
	Employment opportunities and livelihood	0.708		
4) Infrastructure Accessibility	Proximity to work, city centre and transportation	0.858	1.530	6.955
	Access to basic infrastructure (Water, electricity, sanitation)	0.845		
5) Livelihood costs	Cost of living	0.742	1.205	5.479
	Poverty	0.730		
6) Security/economy	Security and safety	−0.613	1.009	4.993
	Income and affordability	0.607		
Total				72.211

Source: Result of principal component analysis using Statistical Package for Social Sciences.

7. Discussion

Principal component analysis was used to compress the variables into six components, and each component influences the choice of residence in informal settlements.

Government/political influence have total eigenvalues of 7.495 and 10 factors, explaining 34.066% of the determining variables. It consists of rigid building regulations for informal houses, corruption in relation to land, inefficient public administration and procedure provision by the leaders, inconsistency in land and plan legislation, inadequate housing policy, the current political situation of the country, problems of legal land provision, land use policies, and urban planning, government interventions and regulations, and environmental hazards and risks.

The variables that make up this component according to how they influence the people's choice ranked between 13 and 22 (see **Table 2** above). This suggests that this component, although it has the highest factor loading due to the high correlation of its variables, is the least influencing component affecting choice of residence in informal settlements in Enugu metropolis. Hence, it agrees with the claim that these factors are the push factors which chase people away from the formal areas [7,15].

Social integration/services have eigenvalues of 2.492 and consist of 4 factors. It explains 11.327% of the determining variables and is therefore one of the factors influencing choice of residential location in informal settlements. It comprises of social cohesion and ethnic communities which implies that some people choose to live

in informal settlement because of the presence of a member of their ethnic group or religion. The majority (91%) of the respondents are immigrants from neighbouring villages and towns. This finding is in agreement with works that opined that social ties, religion, stakeholder's relations, race, and culture, as well as social connection and prestige, are important factors that influence choice of residential location [28,29,31,34,44,47,49,51,46]. Accessibility to social amenities and services is the second variable under this component. Some of these informal settlements are close to some social amenities, such as health centre, private and public primary and secondary schools. However, some of these social amenities are not functioning effectively and are not enough to service the population. This is in agreement with works that found informal settlements to be characterized by a lack of critical social amenities, bad housing facilities, and an unsafe environment [7,15]. Business interest is another factor. From the questionnaire and interview, it was found that the majority of the respondents are petty traders. Many of them have their businesses within the settlement, and that contributes to the reason for either choosing or retaining their respective settlements. Implying that people will continue to stay in slums as long as their needs are met [50]. Family ties is another important factor supporting that living close to family and friends is a factor affecting choice of residence in informal settlement [31,46,48,49,51]. The factor social integration/services is in agreement with the Rational Choice theory, which posits that housing costs, amenities, proximity to jobs, and bounded rationality influence residential location choice, and also with the social network theory, which says that individuals tend to associate with others who are similar to themselves [28,29].

Housing/employment has an eigenvalue of 2.066 with 2 factors. It explains 9.390% of the determining variable and is one of the factors influencing choice of residence in informal settlements in Enugu metropolis. One of the factors is the cost of land. Some of the respondents secured land and erected structures due to the low cost of land in the informal settlement. This supports the findings that many of the people who have lived long in slums are the owners of their houses [50]. Employment opportunities and livelihood are another factor. Some of the dwellers have employment opportunities and sources of livelihood in and around the informal settlements. This factor agrees with the Human Ecology Theory, which looks at how people and communities interact with their immediate physical and social environments, and also the Rational Choice Theory.

Infrastructure accessibility has eigenvalues of 1.530 with 2 factors. It explains 6.955% of the determining variables and therefore influences choice of residence in informal settlements in Enugu metropolis. They are: proximity to work, city centre and transportation. These have been found as influencing factors [30,49,50]. Access to basic infrastructure (water, sanitation, electricity) in the survey of the five informal settlements was found to be poor. Lack of potable water (a problem peculiar to the entire city) and very poor sanitation abound. The availability of electricity in the informal settlements is a parameter for choosing a settlement [42]. This factor is in agreement with the Utility Maximization Theory, which suggests that people will seek to minimize commuting costs by selecting a house location that provides greater accessibility to their workplace [40] and the Rational Choice Theory.

Livelihood cost factors have eigenvalues of 1.205 and 2 factors. It explains

6.955% of determining variables, and it is one of the factors influencing choice of residence in informal settlements in Enugu metropolis. It has cost of living as a factor. Lower cost of living in informal settlements is a pull factor, and high cost of living is a push factor from the formal areas. Poverty is a critical factor that influences the choice of residence in informal settlements [42]. This component is in line with the Push and Pull theory of residential location, which states that there are factors that either push or pull residents to a place.

Security and economy have an eigenvalue of 1.099 and 2 factors; it represents 4.993% of determining variables, and it is classified therefore as one of the factors that determine the choice of residence in informal settlements in Enugu metropolis. It comprises of the following variables: security and safety, and income and affordability. It was found that there is security and safety in informal settlements in Enugu, as against the general assumption that informal settlements are unsafe places. This is in agreement with the findings that security/safety is the most influencing factor in choice of residential location in Ibadan, Nigeria [36]. This means that residents will always make housing choices in areas they feel are safe.

8. Conclusion

The study determined the factors that influence choice of residence in informal settlements in Enugu metropolis. The data used was based on responses from residents of 5 informal settlements in Enugu. The results show that the determinant factors of choice of residence in informal settlements consist of the following: government/political influence, social integration/services, housing/employment, infrastructure accessibility, security/economy, and livelihood cost. The implication is that policymakers should bear these influencing factors when improving /upgrading informal settlements. It was also found that gambling and drug abuse are the major social challenges in informal settlements in Enugu. Low-cost housing that is affordable should be provided for the low-income group that characterizes informal settlements in Enugu metropolis. Informal settlements should not be allowed to continue to deteriorate. Policy that will not only improve the quality of the environment where people live should be formulated. This should also include the welfare, wellbeing, and psychological wellness of the residents.

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Article

Understanding regional development strategies of the European Union and China: Lessons learned for Vietnam

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Abstract: This study aims to understand the European countries and China's regional development strategies in enhancing cohesion and reducing regional disparity to serve as lessons learned for Vietnam. The study provides an overview of the approaches, priorities, and challenges faced in regional development policies pursued by the European countries and China, showcasing their respective efforts in addressing regional disparities and fostering sustainable development within their territories. From the EU's macro-regional strategies (MRS), Vietnam can adopt principles of enhanced connectivity, sustainable development, inclusive growth, and institutional coordination to create a framework promoting balanced and sustainable growth. Additionally, the EU's smart specialization strategy offers a model for fostering innovation-driven growth and regional competitiveness by encouraging regions to identify and capitalize on their unique strengths. From China's regional development initiatives, Vietnam can learn the importance of targeted interventions to address regional disparities and promote balanced development. Also, China's success in developing interconnected urban clusters or metropolitan areas-driven regional development strategies offers valuable insights for Vietnam's urban agglomeration efforts. By adopting these strategies, Vietnam can enhance its sustainable urban development, improve livability, and maximize the economic potential of its cities and towns.

Keywords: balanced development; macro-regional strategy; regional cohesion; regional development; smart specification strategy

1. Introduction

'Region' is a concept commonly used in development policy studies. The understanding and application of the term 'region' can differ based on the disciplinary perspectives, objectives, and methodologies employed. Despite differences in approach, the region is still defined with certain boundaries, a space where each activity has an interactive impact on each other.

Over the past decades, the field of research on regional development policies and regional cohesion and convergence has received much attention from researchers, practitioners, and policymakers at different levels of governance [1–4]. The pursuit of regional cohesion remains both an aspiration and a necessity. In this quest for cohesion, drawing lessons from experiences across continents becomes instrumental in comprehending the intricacies of regional development dynamics. The European Union (EU) and China have offered contrasting yet insightful paradigms in fostering regional cohesion, serving as compelling case studies for understanding mechanisms that could potentially resonate within a global context.

The EU, with its multi-country collaborative framework, exemplifies an intricate linkage of regional integration, where diverse nations with distinct socio-economic backgrounds converge under a common umbrella. The EU's experience in promoting

cohesion policies, fostering cross-border cooperation, and harmonizing development strategies across regions holds valuable lessons that might provide insights into addressing disparities and enhancing connectivity within the varied provinces and geographical regions [5,6].

Conversely, China's remarkable transformation and its approach to regional development, characterized by targeted policies, strategic investments, and infrastructural advancements, offer a contrasting perspective [2,7,8]. China's emphasis on regional connectivity through both global and local initiatives and its experiences in managing large-scale regional disparities could offer pertinent insights into potential pathways for infrastructure development, economic collaboration, and inclusive growth strategies within geographical regions.

This research endeavors to bridge geographical and conceptual gaps by scrutinizing the European and Chinese models of regional cohesion and discerning the underlying principles, policy frameworks, and implementation strategies that have contributed to fostering unity, resilience, and sustainable development within their respective contexts. By critically examining the successes, challenges, and contextual nuances of these models, this study aims to distill lessons that can inform and enrich strategies for enhancing regional cohesion within the socio-economic and environmental fabric of Vietnam.

Moreover, this comparative study seeks not only to identify transferable practices but also to acknowledge the necessity of tailoring strategies to suit Vietnam's unique challenges and opportunities. By assimilating insights from diverse regional development experiences, this research aspires to contribute to the discourse on nuanced approaches, policy frameworks, and collaborative initiatives that can fortify cohesion and catalyze sustainable progress in Vietnam.

2. Regional development strategies of the European Union

2.1. Macro-regional strategies ("MRS")

Macro-regional strategies are comprehensive frameworks established by groups of countries or regions that share common geographical features, challenges, and goals. These strategies aim to promote cooperation and integrated development across borders towards sustainable growth. In essence, MRS aims to address challenges that demand collaboration among multiple countries by adopting a comprehensive approach involving various sectors and governance levels [9].

Since 2009, the EU has pioneered macro-regional strategies such as the EU Strategy for the Baltic Sea Region (EUSBSR, 2009), the EU Strategy for the Danube Region (EUSDR, 2010), the EU Strategy for the Adriatic-Ionian Region (EUSAIR, 2014), and the EU Strategy for the Alpine Region (EUSALP, 2015) [10–13]. These four EU Strategies are conducted in 19 EU member states and 9 non-EU countries. Each strategy focuses on enhancing cooperation among countries in specific regions to address challenges like environmental sustainability, economic development, transport, and cultural exchange.

All macro strategies of the EU were developed by identifying key regional challenges and then setting out goals and subgoals to address them. These strategies were accompanied by a rolling action plan that is regularly updated according to new

needs and changing contexts [14]. For example, the EUSBSR is divided into three goals, representing the three main challenges of the region: ‘saving the sea’, ‘connecting the region’ and ‘increasing prosperity’; or the EUSAIR has four pillars, including ‘blue growth in the fisheries sector’, ‘regional connectivity in energy and transport’, ‘environmental quality’ and ‘tourism development’. The EUSDR Strategy has also identified 11 priority goals for regional development, focusing on the following aspects: transport connectivity (waterways), energy connection, environmental quality, socio-economic development, and security [15,16].

About the core principles of MRS, the study has identified four pillars for building policy interventions and instruments [6,17–20]. First, the ‘Enhanced Connectivity’ pillar highlights that infrastructure development, transport networks, and digital connectivity are pivotal components, fostering economic growth and trade among participating regions. Second, the ‘Sustainable Development’ pillar emphasises environmental protection, natural resource management, and resilience against climate change to ensure sustainable development practices. Third, the ‘Inclusive Growth’ pillar aimed at reducing disparities, promoting social inclusion, and ensuring equal opportunities for all regions involved. Fourth, the ‘Institutional Coordination’ pillar strengthens governance structures and promotes collaboration among governments, stakeholders, and institutions to facilitate effective implementation of strategies. By applying these above principles, countries/regions could seize the opportunities for synergy. It means that leveraging shared resources, expertise, and best practices among participating regions can lead to mutually beneficial outcomes.

However, there are still challenges that countries/regions need to pay attention to when developing and implementing MRS. They include (1) Coordination and implementation challenges—Managing diverse interests, aligning policies, and ensuring effective coordination among participating countries or regions can be complex; (2) financial and resource constraints—Limited funding and resources can hinder the successful implementation of macro-regional strategies; (3) monitoring and evaluation system—Continuous monitoring, assessment of progress, and evaluation of outcomes are required to gauge the effectiveness of macro-regional strategies; and (4) requirements on adaptability and flexibility—Strategies should remain adaptive to changing circumstances, evolving challenges, and emerging opportunities [20,21].

2.2. Smart specialization strategy (“S3”)

The EU’s Smart Specialization Strategy represents a transformative and innovative approach to regional economic development and innovation policy. Introduced as part of the EU’s cohesion policy framework, S3 is designed to promote place-based, innovation-driven growth by identifying and building on the unique assets and strengths of each region [22]. The strategy emphasizes a bottom-up approach, requiring regions to engage in an entrepreneurial discovery process involving local stakeholders—such as businesses, research institutions, and civil society—to identify priority areas for investment (**Figure 1**). This ensures that the strategies are not only tailored to the specific needs and opportunities of the regions but also enjoy broad-based support and commitment from local actors.

The S3 strategies are an essential part of the EU Cohesion Policy starting after the period 2014–2021 [23]. Adapting to the characteristics of each territory, the S3 strategy is based on the following factors: (i) public-private governance and promoting business involvement; (ii) specific legal tools to support the implementation of activities; (iii) prioritizing innovation fields based on regional strengths; and (iv) impact monitoring systems.

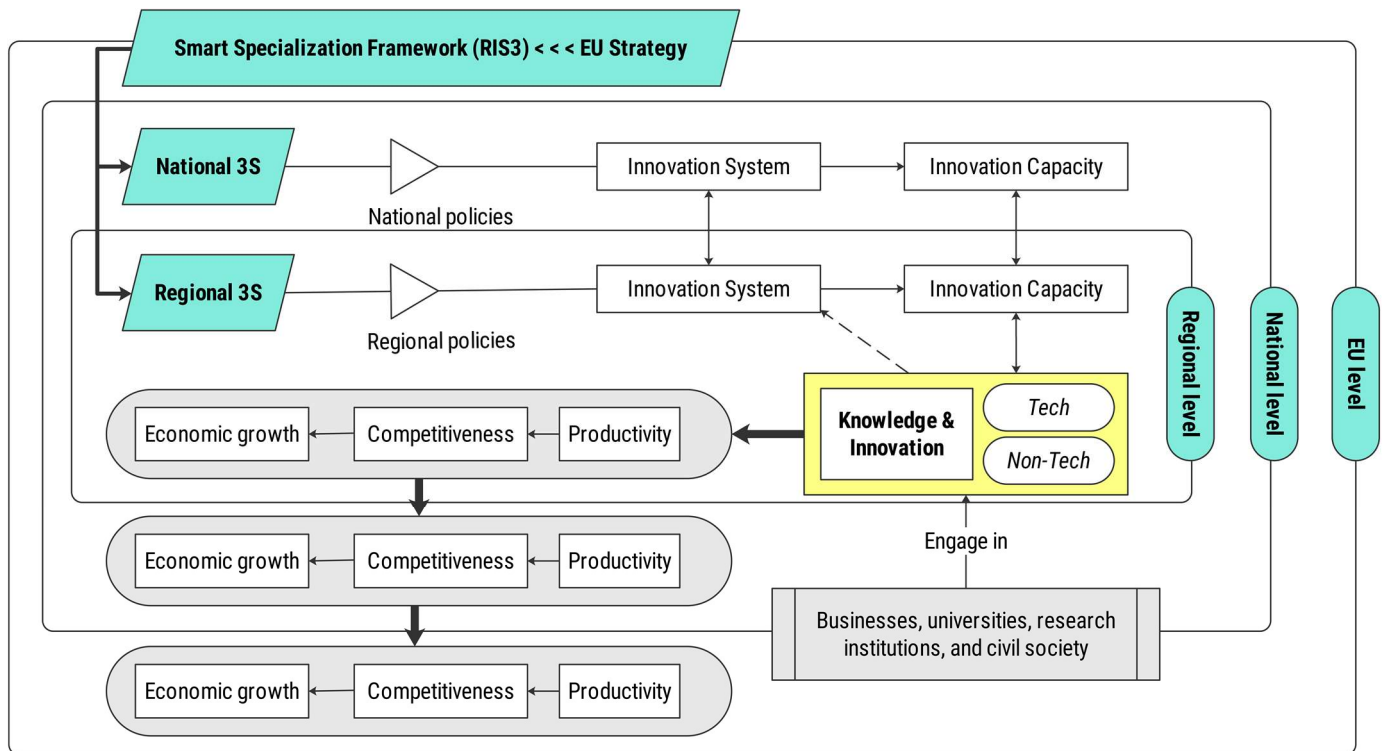


Figure 1. Conceptual framework of smart specialization strategy.

(Source: Synthesized by author, adapted from Kopczynska and Ferreira [24]).

One of the core principles of S3 is the focus on specialization. Unlike traditional, broad-based regional development policies, S3 encourages regions to concentrate their resources on a limited number of priority areas where they have the potential to excel and achieve a competitive advantage. This approach helps to avoid the dispersion of resources and enables more effective and impactful investments. For instance, regions might choose to specialize in sectors like renewable energy, advanced manufacturing, biotechnology, or digital technologies, depending on their existing capabilities and future potential. By fostering specialization, regions can develop niche markets, attract targeted investments, and create high-quality jobs, thereby enhancing their overall economic performance and resilience.

European countries have issued national and regional S3 plans, such as Ireland [25], Hungary [26], Serbia [27], and the Wallonia region in Belgium [28], and the Navarre region in Spain [22]. Since 2011, the European Commission has provided guidance on how to develop and implement S3 plans to regional and national authorities via a mechanism called the ‘Smart Specialization Platform’. The platform facilitates learning, data collection, analysis, and networking opportunities for around 170 EU regions and 18 national governments.

The implementation of S3 has led to notable successes across the EU. Regions

that have embraced the strategy have reported significant improvements in their innovation ecosystems and economic outcomes. For example, the Basque Country in Spain has leveraged S3 to become a leader in advanced manufacturing and industrial automation, creating a robust ecosystem of innovation and high-tech industries [29]. Similarly, regions in Italy, such as Emilia-Romagna, have focused on specialized sectors like automotive and agri-food technologies, driving growth and innovation through targeted investments and collaborative research initiatives [30]. These successes highlight the importance of aligning regional development policies with local strengths and opportunities, as well as the benefits of fostering public-private partnerships and cross-sector collaboration.

Furthermore, S3 has facilitated enhanced collaboration and knowledge sharing across regions, both within and beyond national borders. The EU's emphasis on inter-regional cooperation has encouraged regions to learn from each other and to engage in joint initiatives, leveraging complementary strengths and creating synergies. For example, regions specializing in renewable energy can collaborate on research and development projects, share best practices, and jointly attract investments, thus amplifying their impact. This collaborative approach not only strengthens individual regions but also contributes to the overall cohesion and competitiveness of the EU. By promoting innovation-driven growth and reducing regional disparities, S3 supports the EU's broader goals of smart, sustainable, and inclusive development.

Additionally, some regions are also adding a fourth 'S'—Sustainability to their strategies. Smart specialization strategies for sustainability (S4) aim to improve sustainability through innovation, sustainable resilience, and adaptation. S4 is therefore a tool to adapt to the post-pandemic economy, enabling regions to adapt and also take advantage of any new opportunities that open up in this new scenario.

3. Regional development strategies of China

3.1. Policy initiatives for balanced regional development

China has implemented various inbound regional development policies to foster economic growth and reduce disparities among its regions. Some of the key initiatives include: Open Up the West, Revitalize the Old Northeast Industrial Bases, and the Rise of Central China. The main features of these policies are presented in **Table 1**.

These regional development initiatives of China have brought significant changes and improvements for the lagged regions. The study has reviewed and highlighted some major policy instruments and actions taken under these initiatives [2,7,8,31] including: infrastructure investment (i.e., national investment in building transportation networks, hydropower, and telecommunications); industrial development and restructuring (i.e., modernizing traditional heavy industries and promoting technological advancement, high-tech industries); investment promotion (i.e., attracting domestic and foreign investments into lagged regions; proving preferential policies, tax incentives, and fiscal transfer); innovation, research, and entrepreneurship (i.e., encouraging public-private partnerships (PPPs), collaborations between the government, private sector, and academia to foster innovation, research, and entrepreneurship); talent retention (i.e., assigning talent to work in local government temporarily as the means to improve their administrative ability and

avoiding letting talent move to richer provinces/regions); poverty alleviation and social development (i.e., improving living standards, access to education, healthcare, and welfare, and developing a skilled workforce ready for modern industries); environmental protection and sustainability (i.e., promoting afforestation, sustainable practices in industries, reducing pollution, and addressing environmental degradation caused by previous industrial activities).

Table 1. Comparison of regional development initiatives of China.

	Open Up the West	Revitalize the Old Northeast Industrial Bases	The Rise of Central China
Year of adoption	1999	2003	2004
Targeted provinces	Gansu, Guizhou, Qinghai, Shaanxi, Sichuan, Yunnan, Guangxi, Inner Mongolia, Ningxia, Tibet, Xinjiang, and Chongqing.	Heilongjiang, Jilin, Liaoning, and five eastern prefectures of Inner Mongolia.	Shanxi, Henan, Anhui, Hubei, Hunan, and Jiangxi.
Key issues	Due to the Chinese economic reform, the economies of China's western half lagged behind economically compared to the coastal region. These regional imbalances can cause threats involving social discontent and political problems.	Northeast China was heavily affected by the restructuring of the Chinese economy and the closing and consolidation of many heavy industry state-owned enterprises. This region has the lowest ranking for GRDP growth rate in China.	Central China's development has not kept pace with the coastal region, and is not commensurate with the region's geographical advantages, population, and economic strengths.
Supporting strategies	- Infrastructure development: building transportation networks, hydropower and telecommunications. - Economic diversification: supporting agriculture, manufacturing, tourism, and technology sectors. - Investment and incentives: offering incentives and policy support to attract domestic and foreign investments. - Poverty alleviation: improving living standards, access to education, healthcare, and basic infrastructure. - Environmental protection: afforestation. - Talent retention: avoid letting talent move to richer provinces.	- Industrial restructuring: modernizing traditional heavy industries, and promoting high-tech industries. - Encouraging investment and innovation: attracting investment in key sectors, and supporting innovation and entrepreneurship. - Infrastructure development: focus on investing in transportation networks. - Environmentally sustainable development: promoting sustainable practices in industries, reducing pollution and addressing environmental degradation caused by previous industrial activities. - Social welfare and human capital development: improving social welfare, education, and developing a skilled workforce ready for modern industries. - Public-Private Partnerships: encouraging collaborations between the government, private sector, and academia to foster innovation, research, and development in the region.	- Infrastructure development: building and upgrading transportation networks, infrastructure investments aimed to attract businesses, facilitate trade, and stimulate economic activities. - Industrial transformation and upgrading: encouraging innovation, technological advancement, and developing high-tech industries, advanced manufacturing, and service sectors to diversify the regional economy. - Investment promotion: attracting domestic and foreign investments into the central regions, providing preferential policies, tax incentives, and subsidies to stimulate economic growth, and create employment opportunities. - Poverty alleviation and social development: improving social welfare, education, healthcare, and infrastructure in less-developed areas within the central provinces, ensuring inclusive growth. - Environmental protection: emphasizing on sustainable development practices and environmental protection measures to prevent pollution and ecological degradation while fostering economic growth.

Source: Synthesized by author.

3.2. Metropolitan areas-driven regional development strategy

Another noteworthy strategy of China is metropolitan urban-driven regional development, closely linked to the concept of urban agglomeration. Urban agglomeration refers to the clustering of cities around a central urban core, creating a contiguous urban area characterized by high population density, economic activity, and interconnected infrastructure. China's urban agglomeration has undergone rapid transformation over the past few decades, driven by unprecedented economic growth and extensive urbanization policies. In the 14th Five-Year Plan, China recognized three urban clusters, the Beijing-Tianjin-Hebei (Jing-Jin-Ji), Yangtze River Delta (YRD), and Guangdong-Hong Kong-Macao Greater Bay Area (GBA), as focal points to enhance the national development strategies.

These major urban agglomerations have emerged as powerful economic engines. These regions have benefited from massive infrastructure investments, including high-speed rail networks, highways, and ports, facilitating efficient movement of goods and people. The GBA region, for example, transformed from a predominantly agricultural region into a global manufacturing hub, integrating cities like Shenzhen, Guangzhou, and Hong Kong into a cohesive economic unit. This transformation has led to significant GDP contributions, high employment rates, and enhanced global trade connections.

The rapid urbanization in these agglomerations has also led to various socio-economic benefits. There has been a marked improvement in living standards, healthcare, and educational facilities, contributing to an overall increase in the quality of life for residents. Urban agglomerations have become centers of innovation, attracting both domestic and international talent and fostering a vibrant entrepreneurial ecosystem. The Yangtze River Delta, with cities like Shanghai, Hangzhou, and Suzhou, has become a leading center for finance, technology, and advanced manufacturing. These agglomerations have also seen the emergence of specialized industrial clusters, such as the tech industries in Shenzhen and the automotive sector in Changchun, further driving regional economic specialization and productivity.

However, the rapid growth of China's urban agglomerations also presents significant challenges. The influx of people into these urban areas has led to overburdened infrastructure, housing shortages, and environmental degradation. Air and water pollution remain critical issues, exacerbated by industrial activities and high population densities. Additionally, the disparities between urban and rural areas have widened, with rural regions often lagging in terms of economic opportunities and public services. Addressing these challenges requires sustainable urban planning, investment in modern technologies, and policies aimed at reducing regional inequalities. The Chinese government has recognized these issues and is increasingly focusing on creating more balanced and sustainable urban development models to ensure long-term economic stability and environmental health.

4. Discussion

4.1. The EU and China: Same but different

When comparing the regional development strategies of China and the EU,

several key differences and similarities emerge. China's approach, exemplified by policy initiatives for balanced regional development and urban agglomeration, is characterized by targeted interventions to address specific regional challenges and opportunities. These strategies often involve large-scale infrastructure investments, industrial restructuring, and urbanization initiatives aimed at promoting economic growth and reducing regional disparities. In contrast, the EU's regional development approach combines MRS with thematic strategies such as the 3S. These strategies emphasize cross-border cooperation, innovation, and sustainable development to enhance regional competitiveness and cohesion.

Governance and institutional frameworks also differ between China and the EU. Regional development in China is largely driven by top-down policies and directives from the central government, with regional governments implementing national strategies and initiatives. Decision-making authority is centralized, and there is limited autonomy for local and regional governments. On the other hand, the EU's regional development policies involve a complex governance structure, with decision-making shared between the EU institutions and member states. Regional authorities play a significant role in the implementation of EU-funded projects and programs, and there is a strong emphasis on partnership and subsidiarity.

Furthermore, the focus on innovation and specialization varies between China and the EU. While China's strategies include elements of innovation and specialization, such as the promotion of high-tech industries in urban agglomerations, the focus is often on industrial upgrading and infrastructure development to drive economic growth. In contrast, the EU's 3S places a greater emphasis on innovation-driven growth and regional specialization. This strategy encourages regions to identify and build on their unique strengths and competitive advantages, fostering collaboration between businesses, research institutions, and local governments.

Both China and the EU aim to achieve inclusive growth through their regional development strategies, but their approaches differ. China seeks to reduce disparities between urban and rural areas and promote balanced development across regions. However, there are challenges in ensuring equitable access to opportunities and resources. In the EU, place-based policies such as the European Regional Development Fund (ERDF) and the Cohesion Policy are designed to reduce disparities between regions and promote social and economic cohesion. These policies target investments in lagging regions and support initiatives to boost employment, education, and social inclusion.

Additionally, environmental sustainability and urbanization present significant challenges for both China and the EU. While China faces issues such as pollution, resource depletion, and ecological degradation in rapidly urbanizing regions, the EU emphasizes environmental sustainability and green growth through policies aimed at reducing carbon emissions, promoting renewable energy, and protecting natural resources. Sustainable urbanization is also a key priority, with initiatives to improve air quality, reduce congestion, and enhance green spaces in cities.

4.2. Some lessons learned for Vietnam

Regional development in Vietnam is a multifaceted endeavor, encompassing

strategies and policies designed to address historical disparities, stimulate economic vibrancy, and improve the overall well-being of its citizens. Against the backdrop of a dynamic and evolving socio-economic landscape, Vietnam has been crafting and implementing a spectrum of regional development policies aimed at unleashing the full potential of its diverse provinces. These policies are not mere blueprints for economic progress; they represent a concerted effort to create inclusive and sustainable growth. Specifically, Vietnam marked her efforts with the Northern Mountainous and Central Highlands Development Programs, Socio-Economic Development Plans, National Targeted Program for Sustainable Poverty Reduction [32], Strategic Infrastructure Projects (such as transportation networks, energy facilities, and digital infrastructure), and Public-Private Partnerships [33].

As of 2022, Vietnam has identified a new direction for regional development towards “Better exploit and maximize the advantages of each region in terms of infrastructure, natural conditions, economic-political position, labor force, and enhance internal and regional linkages to participate in global value chains, creating new development spaces.” as stated in the 13th National Congress of the Communist Party of Vietnam. In line with that, Vietnam has launched six resolutions for the regional development strategy in her six strategic regions, respectively [34]. However, the implementation of these strategies still has many limitations. In particular, guidelines and policies on regional integration are slow to be implemented; the role of subjects participating in regional integration, especially the central government, is still vague; and the mechanism for implementing regional integration policies has not been effective or most effective. These limitations were identified in Resolution No. 57/NQ-CP of Vietnam’s Government [35].

Within the framework of this research, I identify some policy implications for Vietnam in building its regional development policies leveraged by the EU and China’s policies as follows:

For the EU’s MRS, Vietnam stands to gain valuable insights from these strategies by incorporating four key principles into its own regional development initiatives. Firstly, the principle of ‘Enhanced Connectivity’ underscores the importance of robust infrastructure, digital networks, and efficient transport systems to stimulate economic growth. Secondly, the emphasis on ‘Sustainable Development’ guides Vietnam to prioritize environmental protection, natural resource management, and climate resilience in its regional planning. The ‘Inclusive Growth’ principle highlights the necessity of reducing disparities, fostering social inclusion, and providing equal opportunities for all regions. Lastly, the ‘Institutional Coordination’ principle emphasizes the need for effective governance structures and collaborative mechanisms, ensuring seamless coordination among various stakeholders. By aligning its regional development strategies with these principles, Vietnam can create a framework that promotes balanced and sustainable growth across its diverse regions.

Furthermore, Vietnam can learn from the EU’s smart specialization strategy in promoting innovation-driven growth and regional competitiveness. By encouraging regions to identify and capitalize on their unique strengths and competitive advantages, the EU has fostered innovation ecosystems that spur economic development and job creation. Vietnam could leverage this approach to prioritize investment in key sectors and industries where it has a comparative advantage, such

as agriculture, manufacturing, and technology. By focusing on innovation and specialization, Vietnam can enhance its global competitiveness, attract foreign investment, and accelerate its transition to a knowledge-based economy. Moreover, aligning regional development policies with smart specialization principles can help ensure that growth is inclusive and sustainable, benefiting all segments of society and contributing to long-term prosperity.

For China's initiatives, with the institutional similarities between China and Vietnam, Vietnam can extract valuable lessons from China's regional development initiatives by emphasizing key pillars crucial for successful implementation.

First, China's regional development strategies, such as 'Open Up the West,' 'Revitalize the Old Northeast Industrial Bases,' and 'The Rise of Central China,' offer lessons on the importance of targeted interventions to address regional disparities and promote balanced development. By focusing on specific regions and implementing tailored policies and investments, China has been able to stimulate economic growth, improve infrastructure, and alleviate poverty in underdeveloped areas. Vietnam could adopt a similar approach by identifying its own regions with untapped potential and implementing strategies to unlock their economic and social development.

Second, China's experience with urban agglomeration provides valuable lessons for Vietnam as it grapples with rapid urbanization and urban sprawl. China's efforts to develop interconnected urban clusters, such as the Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Guangdong-Hong Kong-Macao Greater Bay Area, demonstrate the importance of coordinated urban planning, infrastructure development, and governance mechanisms. By promoting collaboration and integration between cities, China has been able to leverage economies of scale, enhance productivity, and address common challenges such as congestion, pollution, and resource scarcity. Vietnam could benefit from adopting a similar approach to foster sustainable urban development, improve livability, and maximize the economic potential of its urban areas, e.g., Ho Chi Minh City and Ha Noi.

5. Conclusion

By understanding regional development strategies of the EU and China, this research reveals several key lessons and insights that offer valuable implications for fostering effective and sustainable regional development strategies. Here are some key takeaways:

Diverse Approaches to Regional Development: The EU and China employ diverse approaches tailored to their unique contexts and challenges. The EU emphasizes cohesion, solidarity, and multilevel governance, leveraging structural funds and smart specialization strategies. In contrast, China implements targeted initiatives addressing their specific regional challenges.

Balancing National Goals with Regional Needs: Both entities grapple with balancing national priorities with regional disparities. China's centralized governance aims to bridge the rural-urban divide and develop underperforming regions. Conversely, the EU's decentralized approach accommodates the diversity of regional needs while aligning them with broader EU objectives.

Tailoring Policies to Local Needs: Place-based policies recognize the diversity of regions and emphasize tailoring policies to address specific local needs. Smart specialization emphasizes identifying and developing a region's unique strengths and competitive advantages. Vietnam can learn to strategically leverage its own unique resources, skills, and capabilities at the regional level.

Fostering Innovation, Infrastructure, and Economic Transformation: Both the EU and China prioritize innovation, infrastructure development, and economic transformation as drivers of regional growth. They invest in technology, education, and industry upgrades to enhance regional competitiveness and stimulate economic progress.

Sustainable Development and Environmental Concerns: There is a growing emphasis on sustainability and environmental considerations in regional development policies. The EU emphasizes sustainability through its smart specialization strategies, while China increasingly integrates environmental conservation and green development into its regional initiatives to address environmental challenges.

International Cooperation and Connectivity: Both entities recognize the importance of international cooperation and connectivity for regional development. The EU focuses on territorial cooperation among member states, while China promotes connectivity and economic integration across territories and countries (e.g., via the Belt and Road Initiative).

Challenges of Inequality and Balanced Growth: Addressing regional disparities and achieving balanced growth remain persistent challenges for both the EU and China. Income inequality, environmental degradation, and disparities between urban and rural areas are among the challenges that require sustained policy attention.

Learning and Adaptation: Continuous learning, evaluation, and adaptation of regional development policies are crucial. Both the EU and China refine their policies based on experiences, changing circumstances, and emerging challenges to enhance policy effectiveness and address evolving regional needs.

In conclusion, lessons learned from the regional development policies of the EU and China underscore the importance of tailoring strategies to regional contexts, balancing national and regional priorities, promoting innovation and sustainability, addressing disparities, fostering international cooperation, and adapting policies to changing circumstances. These lessons can inform policymakers in their efforts to design and implement effective and inclusive regional development strategies.

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Article

Modelling-based analytics for urban grand challenges

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Abstract: Society faces grand challenges on a number of dimensions, for example: climate change, pandemics, security and geopolitics, and social exclusion. The future development of towns and cities is key to meeting these. The availability of analytic capabilities provides foundations for developing and evaluating alternative policies and plans. An extensive range of models is available, but they have not been well-focused on these kinds of grand challenges. A significant research task, therefore, is to review the modelling developments needed to provide the necessary analytics base. We consider in turn: the building bricks; the challenge of interdependencies and high dimensionality, using Lowry's model as a framework; the integration of the elements into a comprehensive model as a basis for grand challenge analytics; and the challenges of implementation.

Keywords: climate change; pandemics; social inclusion; security; urban modelling

1. Introduction

Six decades of research underpin that part of our knowledge of cities based on mathematical and computer models. Objectives in building these include developing the science of cities and seeking to use models as an important tool in urban planning. At the present time, society faces major challenges, most of which were not understood or well-articulated through the history of urban modelling. We need to relate to, for example, sustainability and climate change, pandemics, geopolitics and security, and social exclusion. Applications of models to date have been largely in the narrower field of conventional city planning. The aim of this paper is to show how the models can be further developed to contribute both to our understanding of the major challenges and to associated policy articulation and planning. There is a considerable knowledge base that has been developed over a long period of time. We aim to show how further steps can be taken to make use of this in relation to grand challenges that are now recognised as urgent.

This is a very large task and to make this feasible, the paper will be focused on the evolution of the author's own endeavours, and the implications for future research. See Wilson [1] for the origins of this thinking, along with accounts of more recent developments in the work of Wilson [2]. It should be possible to transfer the argument, *mutatis mutandis*, to other modelling approaches and styles.

2. The building bricks

A comprehensive model of a city can be assembled from interacting submodels, aimed at handling the interdependencies that make this enterprise so challenging. The archetypal model is Lowry's [3] model of metropolis, and this continues to provide a conceptual framework for the development of more detailed, comprehensive models.

Subsequent developments have been concerned with dealing with complexity—the high-dimensional nature of the modelling challenge—and introducing explicit dynamics’ mechanisms, along with a tremendous amount of empirical work by many researchers, which has led to extensions and refinements, including handling large data sets and developing associated calibration methods.

The main elements of a comprehensive model are shown in broad terms in **Figure 1**. The migration and population (sub)models on the left-hand side represent the demographics of the system; the trade, economy, and infrastructure models on the right hand side represent the economy. These provide the framework within which people live (residence, employment, and use of services) and organisations function (delivering housing, jobs, and products or services). These elements interact through the transport and communications systems. This modelling of flows is important, ranging from migration and trade to journeys to work and to retail and various services. The flows are carried on the transport and telecom infrastructures. (There are some definitional problems: a move to a new house or job within a city is usually referred to as relocation rather than migration; and handling the ‘population’ involves both individuals and households and possibly wide family structures. The delivery of services such as health and education are sometimes referred to as ‘public services’ though the provision can be through public or private organisations (or a combination of both). We neglect these refinements in the first instance).

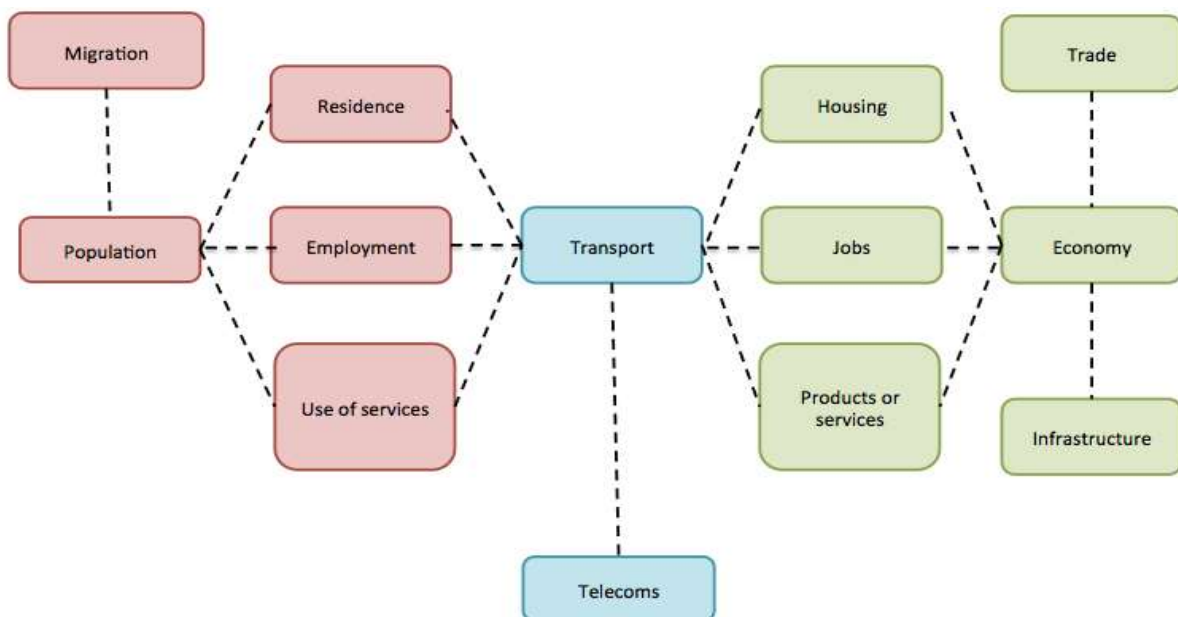


Figure 1. The main elements of a comprehensive model.

The core submodels can be therefore summarised as:

- Demographic (including migration)
- Economic (including trade and infrastructure)
- Residential location
- Housing
- Employment location
- Provision and use of services (retail, health, education, leisure, ...)

- Transport

- Telecoms

Some of these have generic model elements:

- Models of flows (spatial interaction)
- Network analysis (the infrastructure, with flows loaded on to links)
- Accounts (flow matrices, demographic and input-output accounts)
- Dynamics

As noted, the core models have been combined into general or comprehensive urban models, with Lowry's [3] simple and brilliant model capturing the main interacting elements as the precursor. Many of the models that have built on the Lowry heritage have neglected full connection to demographic and economic input-output submodels, though there have been notable exceptions to this. They have not been widely used, possibly because of the scale of effort involved in assembling them. See, for example, Echenique et al. [4], Simmonds [5], and Kim et al. [6], in the last case building on Wilson [1].

These models usually function on a steady-state or equilibrium basis, but a dynamic model for a retail system was presented in Harris and Wilson [7]—a method that can be extended to other submodels—in transport networks, for example—see de Martinis et al. [8]. This method has been tested by a number of authors, but it is not in general use. See, for example, Dearden and Wilson [9] on the dynamics of shopping centre development and gentrification in housing. It has been further developed in a new framework by Ellam et al. [10] and Gaskin et al. [11]. This has led to new calibration methods—reflecting the impact of new techniques from data science and AI. The continued growth in computing power has led to further advances, as with the Quant model (see Batty and Milton [12]). Many of the submodels are valuable in their own right for particular applications, and in specific fields such as retail and transport, they have been extensively tested and deployed (see Birkin et al. [13], Boyce and Williams [14]).

More recently, we have seen the beginnings of attempts to widen the scope of the models to contribute to the grand challenges, and we present these in Section 3. We pursue the extent to which these initiatives can be driven further in the rest of the paper. The subsystem models need to be expanded to incorporate, for example, carbon production (see Huber et al. [15]); the spread and control of infection in pandemics (see Spooner et al. [16]); more systematic applications in geopolitics and security (see Guo et al. [17]); and social inclusion, including access to health and education facilities. Modellers have not focused on social inclusion, though of course many other researchers have, notably Dorling [18,19]. The explicit incorporation of dynamics would enable the exploration of phase changes, both to identify future challenges through abrupt change and to target policy levers to support productive change. This enables the use of the models for systematic scenario exploration.

We proceed as follows: in Section 3, we explore how the model system can be developed, handling interdependence and high dimensionality as a preliminary to defining a model system that can provide the analytics basis for exploring grand challenges in Section 4. We conclude in Section 5 with a discussion of the implementation challenges.

3. Interdependencies and high dimensionality: Insights from the Lowry model

3.1. The modelling challenge

In order to develop modelling systems to contribute to the grand challenges, we need to add more depth and detail, and in some cases, new submodels. We particularly need to represent interdependence, as we will demonstrate, and hence expand comprehensive models. We can identify one interdependence chain below by way of illustration to test the potential for developing extended models.

Consider the following real challenge, albeit oversimplified but appropriate for illustration: A housing problem is usually presented as a shortage of houses. However, it can be argued that the underlying problem is an income problem—too many households with insufficient income to find or maintain accommodation. There is an income problem because there is an employment problem. There is an employment problem because there is a skills problem. There is a skills problem because there is an education problem. There is an interdependency chain: education—skills—employment—income—housing. This leads to a further complication: as well as seeking to ensure that the education system does not leave a long tail of under-skilled people, we need to recognise that to change this, it takes time. It is more complicated to model this than to predict the revenue attracted to a new supermarket. However, that is part of our agenda.

The problem of high dimensionality was considered in Wilson [20]—which led to the argument that in a relatively coarse-grained model, 10^{13} variables would be needed for a comprehensive description, something that is obviously not feasible in practice. As we expand our scope, therefore, we will need to make the necessary approximations in as optimal a way as possible. Part of this relates to data availability: we almost always have problems with missing data, and we can use such methods as biproportional fitting to fill in the gaps—see Dennett and Wilson [21] for an example in migration modelling and Caschilli and Wilson [22] on trade.

In the following subsections, we discuss first scales (3.2), and then we set up the Lowry model as a foundational example (3.3). In 3.4, we present the model in formal terms as the basis for developing extensions. This allows us to seek to build extended, comprehensive model-based analytics in Section 4.

3.2. Scales

There are three dimensions of scale to be considered: spatial, sectoral, and time. The spatial ranges from the global via the national, the city-regional, and the neighbourhood to the micro. Model-based analytics have been developed for all of these. We will largely take the city-region scale as our focus but show links to others—up to the global and down to the micro. Indeed, it is possible to model at two scales.

For sectors, there are classifications available at different levels of granularity for industry and services and for labour and government, for example. These range from the very coarse—for example, working with a ‘basic’ industry sector and a small number of ‘retail’ sectors—through to the very fine. However, the desired granularity demands easily useable data which is often only partially available. For example, fine-

scale sector data may not be available for fine-scale spatial units. At the finest scale, we can, in principle, seek data on individual organisations.

For time, we can think in broad terms of short, middle, and long runs and seek to choose what is appropriate for the systems we are modelling and their applications. We also have to decide whether to treat time as discrete or continuous—usually discrete, but we sometimes want to incorporate data on individual events in health analytics, for example, where precision is important, for example, in dealing with co-morbidities.

3.3. The Lowry model

To fix ideas, we first present the Lowry model and then convert this into something more formal. This gives us a platform for demonstrating interdependence and for extending the models in the direction of handling grand challenges. First, a recap on Lowry's variables:

A = area of land

E = employment

P = population

c = trip cost

Z = constraints

to which should be added the following to be used as subscripts or superscripts:

U = unusable land

B = basic sector

R = retail sector

H = household sector

k = class of establishment within a sector

m = number of classes of retail establishment

i, j = zones

n = number of zones

A_i^H , for example, is the area of land in zone i that is used for housing. If a subscript or a superscript is omitted, this implies summation so A_i is the total amount of land in i . There are two kinds of economic sectors: basic and retail—the latter further subdivided. Basic employment—and its spatial distribution across zones—is given exogenously. Retail employment is generated by the population. Once this simple principle of building the variables—the region's descriptors—is understood, the model can be presented in twelve equations.

The key land use equation is:

$$A_j^H = A_j - A_j^U - A_j^B - A_j^R \quad (1)$$

This captures some key hypotheses: that land for basic and retail industries can always outbid housing, so this shows land available for housing is a residual. The household sector is represented by:

$$P = f \sum_j E_j \quad (2)$$

$$P_j = g \sum_i E_{ij} f_{\text{res}}(c_{ij}) \quad (3)$$

$$\sum_j P_j = P \quad (4)$$

$$P_j \leq z^H A_j^H \quad (5)$$

This sequence generates the population through employment and begins the process of housing them. Equation (2) calculates the total population as proportional to total employment. Equation (3) allocates this population to zones, i . $f_{\text{res}}(c_{ij})$ is a declining function of travel cost from i to j , thus building in the likelihood that workers live nearer to their workplace. Equation (4) enables g in Equation (3) to be calculated as a normalising factor. The fourth equation is particularly interesting and also shows how the model is more complicated than it appears at first sight. z^H is the unit amount of land used for residences, and so this equation is constraining the numbers assigned to zone i in relation to land availability. This is one of the subtleties—and part of the trickiness—of the model: the equations have to be solved iteratively to ensure that this constraint is satisfied.

The retail sector is represented by

$$E^{Rk} = d^k P \quad (6)$$

$$E_j^{Rk} = b^k [c^k \sum_i P_i f^k(c_{ij}) + d^k E_j] \quad (7)$$

$$\sum_j E_j^{Rk} = E^{Rk} \quad (8)$$

$$E_j^{Rk} > z^{Rk} \quad (9)$$

$$A_j^R = \sum_k e^k E_j^{Rk} \quad (10)$$

$$A_j^R \leq A_j - A_j^U - A_j^B \quad (11)$$

These six equations determine the amount of employment generated in the retail sector. The total in sector k within retail is given by Equation (6), and this is spatially distributed through Equation (7). As with the residential location equation, the function $f^k(c_{ij})$ is a decreasing function of travel cost, indicating that retail facilities will be demanded relatively nearer to residences. c^k converts these units into employment. The term $d^k E_j$ represents the use of retail facilities from the workplace. b^k is a normalising factor which can be determined from Equation (8). Equation (9) imposes a minimum size for retail sector k at a location. (No school for half a dozen pupils for example!) Equations (10) and (11) sort out retail land use, the first calculating a total from a sum of k -sector uses— e^k converting employment into land—and the second specifying the maximum amount of retail land—in effect giving ‘basic’ (which has been given exogenously) priority over retail. In this case, unlike the residential case where P_i was constrained by land availability, retail employment is not so constrained. Lowry argued that, if necessary, retail could ‘build upwards’. If A_j^R from Equation (10) exceeds $A_j - A_j^U - A_j^B$, it is reset to this maximum, but employment does not change.

Total employment is then given by:

$$E_j = E_j^B + \sum_k E_j^{Rk} \quad (12)$$

This final equation simply adds up the total employment in each zone. The equations are solved iteratively, starting with $E_j^{RK} = 0$.

To develop further model-building insight as a preliminary, we can regroup these equations into four categories: accounting, aggregate relations, spatial interaction (flow) relations, and constraints.

Accounting

$$A_j^H = A_j - A_j^U - A_j^B - A_j^R \quad (13)$$

$$\sum_j P_j = P \quad (14)$$

$$E_j = E_j^B + \sum_k E_j^{Rk} \quad (15)$$

$$\Sigma_j E_j^{Rk} = E^{Rk} \quad (16)$$

Aggregate relations

$$P = f \Sigma_j E_j = fE, E = \Sigma_j E_j \quad (17)$$

$$E^{Rk} = a^k P \quad (18)$$

$$A_j^R = \Sigma_k e^k E_j^{Rk} \quad (19)$$

Spatial interaction (flow) relations

$$T_{ij} = g \Sigma_i E_i f_{res}(c_{ij}) \quad (20)$$

$$S_{ij}^k = ck[\Sigma_i P_i f_k(c_{ij}) + d^k E_j] \quad (21)$$

extracted from (7), written as

$$E_j^{Rk} = b^k [\Sigma_i S_{ij}^k + d^k E_j] \quad (22)$$

Constraints

$$P_j \leq z^H A_j^H \quad (23)$$

$$E_j^{Rk} > z^{Rk} \quad (24)$$

$$A_j^R \leq A_j - A_j^U - A_j^B \quad (25)$$

The accounting relations are statements for each main model element: land, population, and employment; these elements are linked first at an aggregate level and then through spatial interaction relationships. The constraints are Lowry's way of handling some of the problems of interdependence.

3.4. The Lowry model in formal terms

The principal endogenous variables are A_i^H , A_i^R , P_i and E_j^{Rk} and we can write them in formal form as follows.

$$A_i^H = A_i^H(P_i, E_i^B, E_i^{Rk}, A_i^U, A_i^R, A_i^B, c_{ij}) \quad (26)$$

$$P_i = P_i(H_i, \{E_j\}, \{c_{ij}\}, A_i^H, A_i^U, A_i^R, A_i^B) \quad (27)$$

$$E_j^{Rk} = E_j^{Rk}(W_j^{Rk}, \{P_i\}, \{c_{ij}\}, E_j^B) \quad (28)$$

together with the constraint equations

$$P_j \leq z^H A_j^H \quad (29)$$

$$E_j^{Rk} > z^{Rk} \quad (30)$$

$$A_j^R \leq A_j - A_j^U - A_j^B \quad (31)$$

now renumbered. In Equations (27) and (28), we have added structural variables H_i and W_j^{Rk} as measures of housing supply and 'retail' infrastructure respectively. Such terms do not appear in Lowry's model: H_i is (implicitly) taken as proportional to P_i , and W_j^{Rk} similarly to E_j^{Rk} . However, we need to recognise that these structural variables change more slowly than the activity variables, and we will model this explicitly below. Meanwhile, we can add formal equations for them:

$$H_i = H_i(P_i, \{E_j^*\}, \{c_{ij}\}, \dots) \quad (32)$$

$$W_j^{Rk} = W_j^{Rk}(\{P_i\}, \{c_{ij}\}, \dots) \quad (33)$$

It is also helpful to write the interaction Equations (20) and (21), in formal terms:

$$T_{ij} = T_{ij}(P_i, H_i, \{E_j^*\}, \{c_{ij}\}, \dots) \quad (34)$$

$$S_{ij}^{Rk} = S_{ij}^{Rk}(P_i, \{W_j^{Rk}\}, \{c_{ij}\}, \dots) \quad (35)$$

The curly brackets in Equations (32)–(35) indicate the vectors or matrices within them. The highly interdependent structure of these equations leaps out here: the endogenous variables in one equation appear as exogenous variables in the others. This is why they always have to be solved iteratively. Of course, this simply represents real-world interdependence.

We now have the framework to show how the models can be extended to contribute to meeting the grand challenges. All the submodels listed in Section 2 are implicit here. The crucial spatial interaction models have been made explicit in Equations (20) and (21) and formally in Equations (34) and (35). These have been developed in highly sophisticated and tested forms. Lowry's retail sectors are based on a very broad definition of retail to mean 'any form of interaction of people using a facility'—and so can be expanded to include education and health. It is immediately clear that the population and sector variables need much more detailed subscripts and superscripts, as indicated in the previous subsection. This can be done but creates, again, as noted, very large multi-dimensional arrays, and a full integration of these disaggregated models with microsimulation methods is called for. See Birkin and Clarke [23] and Smith et al. [24].

4. Towards an extended comprehensive modelling system: Analytics for grand challenges

4.1. Model development

We can now combine the analytics needed for the grand challenges sketched in Section 1 with the building bricks discussed in Section 2 and the insights offered by the Lowry model in Section 3.3, transformed into a formal structure in Section 3.4. The analytics base we are seeking is described as a 'modelling system' because its elements are often valuable in their own terms, and there will be variants of the comprehensive model as different kinds of approximations are made to deal with the challenges of high dimensionality.

Equations (26)–(35) provide a good starting point, first in terms of omissions and weaknesses in our usual comprehensive models: Equation (26) reminds us that we have not always dealt with 'land' effectively; Equations (29)–(31) remind us of the importance of handing constraints. However, in a broad conceptual way, Equations (27) and (28) along with Equations (32) and (33), represent the core of the model building challenge.

This takes us back to **Figure 1**: the left-hand side of the diagram represents the population and associated activities; the right-hand side represents the economy. To recap on Section 2, we have detailed demographic models that are usually applied at an aggregate scale, and similarly, good economic models—based on input-output accounts—are also applied at an aggregate scale. These provide envelopes for the more granular multi-zone models. For both the demographic and the economic models, we need fine-grained specifications of people (and households) and sectors, and there are obvious links to the activity models: life expectancy in relation to education, for example, and employment through the skills base, represented in both supply and demand terms in the input-output model.

This implies the need for disaggregation, which we now pursue. In Section 3, we have no disaggregation of person type, and the economic sectors are divided into 'basic' and a set of 'retail'. A starting point, therefore, is to define a superscript, n , to represent person type, and m to represent economic sectors. The latter replaces 'basic' and 'Rk'. This releases k to be used as a superscript for housing type. We can then

rewrite the formal model equations in these terms (and this defines the disaggregated variables in an obvious way).

$$A_i^H = A_i^H(\{P_i^n\}, \{E_i^m\}, A_i^U, A_i^R, A_i^B, \{c_{ij}^{mn}\}) \quad (36)$$

$$P_i^n = P_i^n(H_i^k, \{E_j^m\}, \{c_{ij}^{mn}\}, A_i^H, A_i^U, A_i^R, A_i^B) \quad (37)$$

$$E_j^m = E_j^m(W_j^m, \{P_i\}, \{c_{ij}^{mn}\}, \dots), m \in \{\text{retail}\} \quad (38)$$

$$P_j^n \leq z^H A_j^H \quad (39)$$

$$E_j^m > z^m, m \in \{\text{retail}\} \quad (40)$$

$$A_j^R \leq A_j - A_j^U - A_j^B \quad (41)$$

$$H_i^k = H_i^k(\{P_i^n\}, \{E_j^*\}, \{c_{ij}\}, \dots) \quad (42)$$

$$W_j^m = W_j^m(\{P_i^n\}, \{c_{ij}\}, \dots), m \in \{\text{retail}\} \quad (43)$$

$$T_{ij}^{mn} = T_{ij}^{mn}(P_i^n, H_i^k, \{E_j^*\}, \{c_{ij}^{mn}\}, \dots), m \in \{\text{retail}\} \quad (44)$$

$$S_{ij}^{mn} = S_{ij}^{mn}(P_i^n, \{W_j^m\}, \{c_{ij}^{mn}\}, \dots), m \in \{\text{retail}\} \quad (45)$$

We assume an upper-tier envelope that will handle, for example, migration (Rees and Wilson [25]) and the economy through an input-output model (see Zhang et al. [26]). We also need to recognise that further disaggregation may well be required. In relation to person types, for example, the superscript n may be a ‘vector’ of superscripts representing age, sex, education, skills, employment, income, and so on. For example, define P_{ij}^{dakmse} where i = residential location, j = workplace location (or a service location—probably not both needed at the same time), d = demographics, a = income, k = house type, m = employment sector, s = skill level, and e = education status.

Equation (37), along with Equation (44), when assembled into its various submodels, represents the population and associated activities, usually anchored in residence and work and with a strong interaction between these—the journey to work. It is also important to include those who don’t work away from home: those in regular employment but, post-pandemic, working from home; the retired; the unemployed; and those committed to domestic work. These latter categories will be an important element of the social inclusion challenge and are usually neglected in current models. It is then possible to enumerate the set of activities, usually modelled as spatial flows from home or work origin to a facility—such as retail, education, and health. We also seek to model the impact of these activities, such as the development of skills through education and in the treatment of disease, for example. As we noted earlier, many of these impacts are at future times, which implies in modelling a cross-section at each point in time. We need to take past histories into account, something that is not usually done, though the modelling of co-morbidities in health may be a pointer for future work on a broader basis. See Pagliara et al. [27] for a review of residential location models. Equation (38), along with Equation (43), works on a similar basis, but representing organisations in the economy, usually aggregated into sectors—though there is a challenge here in linking micro and meso/macro theory—see Pagliara et al. [28].

The interaction Equations (44) and (45) provide the basis for transport analysis and planning, which is a well-developed field of study in engineering. These models provide the key to providing generalised cost terms that figure throughout, handling congestion in networks, for example. See Boyce and Williams [14] for a brilliant review of the history of these models and an account of the current state of play.

The model system represented by Equations (36)–(45) is, essentially, handling time either through steady state or comparative static equilibrium assumptions. It is important to move towards explicit dynamics, particularly so that we can identify four-phase changes. The dynamic retail model of Harris and Wilson [7] provides a starting point. In formal terms, for a discrete time period, take the W-retail structure from Equation (43).

$$\Delta W_j^m = \Delta W_j^m (D_j^m - K W_j^m) W_j^m \quad (46)$$

where,

$$D_j^m = \sum_{in} S_{ij}^{mn} \quad (47)$$

Identification of phase changes is a particularly important task for the analytics of grand challenges—both to identify potential catastrophes and possible routes to ‘good’ outcomes. For a detailed account of progress in incorporating these dynamic concepts into a comprehensive model, see Dearden and Wilson [9].

There are submodels available for each element of the Equations (36)–(47) system—embracing demography, economics, residential and housing, basic industry, ‘retail’—people-driven services, employment, transport and telecoms. This formal system could be expanded to add the detail that these offers. It remains essential that these are combined into a general model, particularly in relation to grand challenges so as not to lose track of the interdependencies.

4.2. Analytics for grand challenges

We start with the initial assumption that the submodels listed in Section 4.1 are in place, along with comprehensive models that integrate these for tackling interdependence. This assumption will not typically be satisfied, of course: there are no organisations that are big enough to carry the full range. What is common to each case, as we can anticipate from the focus of the paper, is that responses will demand radical change in the organisation of our towns and cities, and the analytics base through modelling provides a means of assessing what is needed and what is possible. In each case, we need to calculate new kinds of indicators for sustainability analytics which can be used to guide us towards potentially effective plans. It is worth emphasising that analysis alone—modelling—will not solve problems and meet these grand challenges: inventiveness in creating plans and policies is essential.

The analysis above, taking insights from Lowry’s original comprehensive model, warns us that we will need to develop our current models to fill some gaps—notably to handle land more effectively (and associated questions of pricing and rent) and to understand the dynamics more deeply, particularly being able to identify phase changes that might be the basis of sustainability policies.

We proceed on the basis that an enhanced modelling system is in place, take each of the four grand challenge areas in turn, and note the state of play and the opportunities for further development of grand challenge analytics. We introduce the first three and then consider the social inclusion and associated housing challenges in more detail.

Climate change:

A starting point is to seek an indicator based on carbon production. This needs estimates that relate to activities in buildings and transport flows. When we have

estimates of carbon production at a fine scale, we can add these to our models to calculate carbon production for different kinds of towns and cities and then to pursue the questions: what is a reasonable and achievable target for carbon reduction, and how can this be done? We can conjecture that production will be a function of urban form—residential densities, housing, the organisation of workplaces, the ways in which services are accessed and used, and links strongly to transport and telecoms. At the present time, in relation to UK cities, for example, densities of new housing remain low, and its relation to workplaces and the availability of public transport means that car trips, on average, are lengthening. In other words, the intensity of carbon production is increasing and taking us further away from reduction targets. We can use our model systems, with enhanced indicators, to explore alternative forms and organisation and it will become very clear that radical policies are needed. This kind of work is well under way—for example, through Micael Wegener’s team in Germany—see for example, Huber et al. [15].

Demographic modelling and analysis will be important at both intra- and international scales, particularly in relation to migration flows. Modelling the economy through input-output models can be used to measure the effects of ‘greening’ policies and what this means for employment.

Pandemics:

COVID has shown that we need to be better prepared to handle future pandemics. In this case, urban models have been enhanced through integration with epidemiological modelling which facilitates the understanding of spread and the policies needed for control. This approach has been much extended by Spooner et al. [16]—this is essentially an ‘add-on’.

Security, geopolitics, and war:

Models are being developed that can generate probabilities of conflict, intra-nationally and particularly internationally [17,29,30]. These applications are based on a new use of the spatial interaction concept: as ‘threat’. The issues link to demographics, particularly migration, driven by climate-driven change—energy, food, and water shortages, for example. Effective and efficient international trade is important [31], again in relation to energy and food security, and this has generated models of other kinds of conflict, notably piracy [32]. This area provides a new challenge for modelers and new opportunities for analysis and planning in police and defense agencies.

Social inclusion:

This is an important area with huge potential, especially, as noted earlier, modelers lack of application to social exclusion. Our core models, as described in earlier sections, are well developed and potentially effective in their ability to represent the well-being of people (households) and organisations (the economy, private and public; mixed). Accessibility indicators are particularly important in relation to employment (and hence incomes), education, and health. We can work through this example in more detail using our illustrative interdependency chain and the associated formal model: education—skills—employment—income—housing. Although the stimulus for this is related to housing challenges, there are obviously wider implications for social inclusion.

If we assume that the core models are in place, we can extract from these to follow the chain through: education will be one of the sectors, m ; the population vector will be disaggregated to reflect skills levels and incomes (associated with age and gender); employment in all sectors will be disaggregated by skills needed and wage. The handling of time will be critical. For illustration, let us assume an annual cycle denoted by $t = 1, 2, 3, \dots$ and that the model system we are building will run through this time sequence. The shift from t to $t + \Delta t$ will be achieved through dynamic models such as Equations (46) and (47), with equivalent equations for housing. In terms of these structural variables, they will, at least in part, be specified exogenously through actions and plans. This might include investment in education provision to increase skills, and we would model the impacts of such investment through the skills element of the demographic model. Similarly, the developing employment distribution would be partly generated by the model (for the ‘retail’ sectors) and would be partly exogenous. This system would generate changes in income distribution over time, and these would become inputs into the housing model.

The key equations in the model for this case, in sequence, extracted from Equations (36)–(47) above and re-ordered as appropriate, follow. A brief commentary is added to show how this facilitates a walk along the chain.

$$E_j^m = E_j^m(W_j^m, \{P_i\}, \{c_{ij}^{mn}\}, \dots), m\epsilon\{\text{retail}\} \quad (48)$$

$$W_j^m = W_j^m(\{P_i^n\}, \{c_{ij}\}, \dots), m\epsilon\{\text{retail}\} \quad (49)$$

$$\Delta W_j^m = \Delta W_j^m(D_j^m - KW_j^m)W_j^m \quad (50)$$

to record investment in m = education through W_j^m and the take-up through D_j^m .

$$P_i^n = P_i^n(H_i^k, \{E_j^m\}, \{c_{ij}^{mn}\}, A_i^H, A_i^U, A_i^R, A_i^B) \quad (51)$$

$$S_{ij}^{mn} = S_{ij}^{mn}(P_i^n, \{W_j^m\}, \{c_{ij}^{mn}\}, \dots), m\epsilon\{\text{retail}\} \quad (52)$$

which will pick up access to education and training, the take-up, and the impact of increasing skill levels.

$$E_j^m = E_j^m(W_j^m, \{P_i\}, \{c_{ij}^{mn}\}, \dots), m\epsilon\{\text{retail}\} \quad (53)$$

$$D_j^m = \sum_{in} S_{ij}^{mn} \quad (54)$$

which will give us employment for all m , and then we can look at housing provision, which will feed back into Equation (55).

$$H_i^k = H_i^k(\{P_i^n\}, \{E_j^*\}, \{c_{ij}\}, \dots) \quad (55)$$

Equation (56) gives the journey to work.

$$T_{ij}^{mn} = T_{ij}^{mn}(P_i^n, H_i^k, \{E_j^*\}, \{c_{ij}^{mn}\}, \dots), m\epsilon\{\text{retail}\} \quad (56)$$

and the remaining equations check out the constraints:

$$A_i^H = A_i^H(\{P_i^n\}, \{E_j^m\}, A_i^U, A_i^R, A_i^B, \{c_{ij}^{mn}\}) \quad (57)$$

$$P_j^n \leq z^H A_j^H \quad (58)$$

$$E_j^m > z^m, m\epsilon\{\text{retail}\} \quad (59)$$

$$A_j^R \leq A_j - A_j^U - A_j^B \quad (60)$$

The hard work then begins in two respects: to develop the model system as indicated; and to integrate it into planning and policy development to respond to the social inclusion challenge, with appropriate creativity and invention to chart ways forward.

5. Concluding comments: The challenges of implementation

We can take for granted computing power, high levels of visualisation skills, and

abundant data. We have excellent account-based models of demographics and economics; we can model the functioning of most subsystems, though these skills are not universally applied; we have the beginnings of an understanding of dynamics with its implications of path dependence and phase changes. We could deal with the high-dimensionality challenge through the full integration of microsimulation.

To confront the grand challenges that we have used as examples, we have the modelling tool kit, which could be used at least for short-run analysis, but there is very little related modelling in practice. The modelers' agenda has been too narrow. So, what can be done? A central institute may be needed. This could lead to the development of best practices and the articulation of the research front line. However, government agencies would have to play their part with substantial in-house integrated units, connecting planning and policy development to analytics through inventive design. Britton Harris once remarked, "Policy, design, and analysis each involve different kinds of thinking. It is rare to find all three in the same room at the same time!" This highlights the organisational challenge. Universities would have to play their part with seriously large interdisciplinary centres, each substantially bigger than typical core departments—so a major restructuring is called for. There would be major battles as disciplines went into defensive mode.

Local government should have cross-council units that would construct an intelligent information system for a city or region, incorporating basic data through a GIS, policies and plans, and a model-based analysis and evaluation system. A best-practices system is needed to chart the way. The UK Department of Levelling Up, Communities, and Local Government should lead a cross-department 'joining-up' initiative. Universities should take interdisciplinary challenges more seriously, and some, at least, should use 'cities and regions' as a case study of what can be achieved. They would need to invest themselves, but they would also need partners among research councils, consultants, and government agencies. A new kind of cooperative structure is needed. There are significant implications for education: new courses will be needed for both young and mature students to generate an expanding skilled workforce in modelling and planning. The modelling community should break out of silos, extend horizons, and work in major public services (and the private sector), possibly re-invigorating operational research enroute. This is non-trivial and, with some notable exceptions, is not what we have now. The policy and planning communities should embrace intelligent analysis.

This all turns on a commitment to ambition in both the sciences and in policy and planning. The science needs to become 'big science'—exciting in its own terms but able to contribute to solving some of society's biggest problems. This is not essentially a funding problem; universities and government agencies could reorganise and commit to existing resources. It is a cultural problem with many dimensions. For example, academic researchers, in inefficient silos, have become accustomed to working on 'small' problems, often on 'toy' systems, because they are manageable; policymakers and planners typically have short-term perspectives and do not have the backgrounds to see that the science can help. They are also unambitious in that part of their own territory they should be good at: inventing and developing radical plans for problems that need radical solutions. These cultures are deep-seated, but perhaps dreaming the utopian dream could be the beginning of something new.

The paper aims to articulate for the urban modelling community how existing systems can be expanded to contribute to the analysis of grand challenges and the planning of responses. Although the argument is limited to one style of modelling, the conclusions can easily be translated to other approaches. This provides the basis for an important and urgent ongoing research programme.

Conflict of interest: The author declares no conflict of interest.

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Article

Assessment of benefits and challenges: Gender analysis of REDD⁺ pilot sites, Cross River State, Nigeria

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Abstract: Climate change impacts and its associated injustice have been identified as one of the major challenges to the actualization of gender livelihood and resilience, particularly among vulnerable groups in rural areas. This study assessed genders' benefits and challenges distribution measures in REDD⁺ (Reducing Emission from Deforestation and Forest Degradation⁺) pilot sites in Cross River State, Nigeria. The assessment adopted the sustainable livelihood approach of the REDD⁺ pilot sites (Afi Mbe, Ekuri, and Mangrove). Data were proportionately collected from selected 204 respondents at gender disaggregated levels using a questionnaire. Data were analyzed for descriptive and inferential statistics using SPSS Window (version 25). The Z-proportion test showed the existence of unequal benefit sharing that skewed in favour of men (livestock production (67%), livelihood enhancement (70%), distribution of seedlings to plants (100%), and distribution of REDD⁺ shirts (100%), among others. The challenges encountered, particularly for women, ranged from a lower percentage of accessibility (22%), participation (13%), benefits sharing (6%), no idea about the REDD⁺ (92%), no benefits from the REDD⁺ (90%), and no knowledge about the REDD⁺ (95%), among others, were statistically significant at $p = 0.005$. The benefit sharing of REDD⁺ projects, which formed the basis of fair distribution with few challenges, was statistically significant at the 95% level. Independent z-test ($p < 0.005$) showed that men benefited (livestock production, livelihood enhancement, distribution of seedlings to plant, and distribution of REDD⁺ shirts) more from the REDD⁺ project than women. This indicates that the project has been mundaned and considered as men's affairs, while gender mainstreaming during the designing and implementation of the programs has been neglected. Infrastructure, employment, and alternative livelihoods, among others, were promising institutional frameworks that indicated gender resilience in the study area. The study recommends adoption of strategies that would circumvent both existing and future challenges for successive initiatives programs such as REDD⁺, particularly for women.

Keywords: climate change; challenges; men; women; adaptation; livelihood; benefit sharing; decision making

1. Introduction

Whenever the issue of fairness is raised, it is always a fairness that exists between humans. Fairness has been characterised as a human's affair, therefore it involves human-human interactions and relationships. In the light of this, looking at it wholistically, it is better understood as a social concept. Fairness, specifically in the framework of environment and other interrelated issues, is frequently used concurrently with the concept of equity [1]. Since equity and fairness concepts are frequently knotted and projected in harmonized relationships, demands for equity are the same as demands for fairness. Equity, in its totality, means 'the quality of being fair or impartial' or 'something that is fair and just'. Different and numerous theories and approaches, among others, have addressed the issue of benefit sharing; they include [2–6]. For the sake of this study, two central themes—the distributive and procedural concepts of fairness in terms of benefits and challenges—were elaborated and discussed. The distributive concept in the context of climate change development programs deals with both equal and fair distribution of adverse effects of climate change among genders and the distribution of costs and benefits available to cope with and adapt to the changes [2]. Procedural, on the other hand, refers to equity in the policy process, i.e., recognition during decision-making and participation. Paavola and Adger [2] held the opinion that for a concept to fully realise its potential, the procedural aspect must have been progressed. Leach [6] in her own view, agitated for broadening of knowledge base in policy making process because single-minded evaluation can term a project a failure, assessing it through goals and outcome. Furtherance to her claim, she stated that this single-minded evaluation manifested because the actors that dominate the policy-making process consist of only scientists and conservationists of one type of knowledge. She elaborated more that the issue of nature and use of forest resources that involves other knowledge such as forest users, non-timber resource gatherers, and land use actors must be brought to the table for more discussion. Thereby, lack of proportion inherited from power and representation becomes an issue of equity and fairness. Just as climate benefits and challenges have been an instrument to balance power equity at the global level, they should be reciprocated to challenge power relations at the local level as well.

There is evidence of gender documentation on climate adaptation initiatives in Sub-Saharan Africa [7–10], but little or none is known about how benefits and challenges are being managed in Nigeria (REDD⁺) with much view from a gender lens. Consequently, the benefit sharing delivery system, which forms an integral part of gender effectiveness and function, has been eroded for different reasons that can be linked to neglected gender priorities; therefore, this study assessed gender and REDD⁺ benefits and challenges in Cross River State, Nigeria.

2. Materials and methods

2.1. Study area

This study was carried out in Cross River State (CRS) Nigeria, bound by latitudes 4°27' to 5°32' N and longitudes 7°50' to 9°28' E with an approximate

landmass area of 20,156 square kilometres respectively (**Figure 1**). For this study, three key sites (known as Reducing Emissions from Deforestation and Forest Degradation (REDD⁺ pilot sites) were selected. These sites include the Afi-Mbe, Ekuri, and Mangrove forest communities (**Figure 1**) [11].

The relief of Cross River State consists of the coastal creeks towards the southern border with the Atlantic Ocean, Cameroon Mountains, and part of Bamenda highland in the east, as well as the Cross River basin in the west. Altitude ranges from sea level, gently undulating basins to the volcanic hills of Oban and Ogoja that extend up to 1829 m [12]. There is an annual alternation of distinct wet and dry seasons, mostly determined by the movement of Inter Tropical Convergence Zone (ITCZ). Normally, annual rainfall starts in April and ends in October, with a peak usually in August in most parts of the country [13].

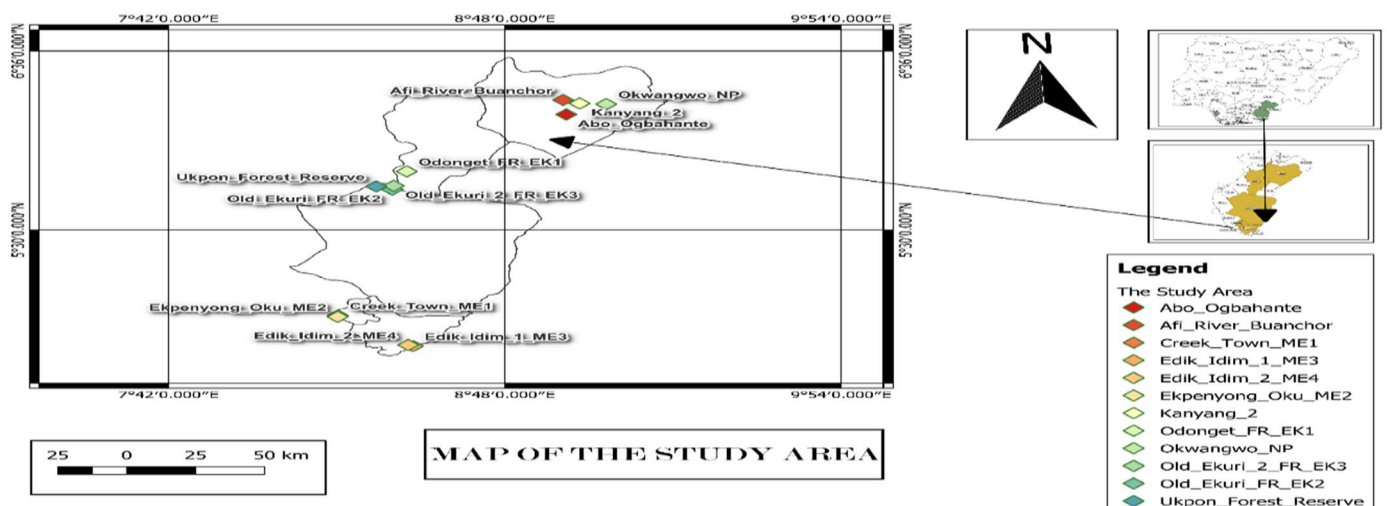


Figure 1. Map of Cross River State showing the three cluster sites and an insert map of Nigeria.

(Source: Author).

3. Methodology

3.1. Sampling procedure and methodology for questionnaire approach in data collection

The purposeful sampling method was used for the selection of Afi-Mbe, Ekuri-Iko, and Mangrove sites, as these are the approved Reducing Emissions from Deforestation and Forest Degradation⁺ (REDD⁺) pilot sites in Nigeria. The second stage as well adopted the purposive sampling method to select two communities each from Afi-Mbe (Olum and Buanchor), Ekuri-Iko (Old and New Ekuri), and Mangrove (Creek town and Edik Idim) sites. The number of households selected from each community was also based on the purposive sampling technique. Within each community selected, all the genders in the households were listed and stratified into men and women along age brackets (youth: 18–35 years, men/women: 36–59 years, and elderly: 60 years and above) [14], and then this disaggregated gender level was used to select the required number of men and women to constitute the sample units to whom the questionnaire was later administered. Peradventure: the actual respondents target is not available in a chosen household; the next household was

included, and this continued until the required respondents were captured. In all, 204 gendered-disaggregated respondents were interviewed proportionately: 102 men and 102 women (36 copies of questionnaires each for male youth, female youth, men, and women for both Afi Mbe (72) and Ekuri (72) study locations, while Mangrove shared eight copies of questionnaires each for male youth, female youth, men, women, and the elderly (60) [15,16] (**Table 1**). To complement the questionnaire in assessing gender benefits and challenges in the study location, both secondary literature (policy documents) and interview groups (REDD⁺ staff, Village Head, and Cross River State Forestry Commission principal officers) were conducted according to (a) respondents' perception of current benefits from trees, forests, and REDD⁺ for their livelihoods; (b) policy discourses on forest resource and REDD⁺ benefits sharing; (c) respondent's views and perceptions on REDD⁺ benefits; and (d) how respondents perceived and evaluated various actors and institutions in forest resource, REDD⁺ governance and structure, and their role in benefit sharing.

Table 1. Breakdown of the number of respondents sampled with age group per selected communities.

Gender with age bracket	Afi Mbe	Ekuri	Mangrove	Total
Youth (18–35 years)	Male = 12 Female = 12	Male = 12 Female = 12	Male = 12 Female = 12	72
Adult (36–59 years)	Men = 12 Women = 12	Men = 12 Women = 12	Men = 12 Women = 12	72
Elderly (60 and above)	Elderly men = 8 Elderly women = 8	Elderly men = 8 Elderly women = 8	Elderly men = 8 Elderly women = 8	60

3.2. Statistical analysis

Data were entered into MS Excel and then analyzed with SPSS (version 25) using descriptive and inferential statistics, and the results were presented in the form of tables.

This study adopted Z proportion to test for significant differences in the means of the both benefits and challenges major variables. The z-statistics are calculated using equation:

$$z = \frac{(\mu W - \mu M)}{\sqrt{\frac{\sigma_W^2}{N_W} + \frac{\sigma_M^2}{N_M}}} \quad (1)$$

where, μW and μM represent the means for the men and women categories, respectively, σ_W^2 and σ_M^2 stands for the standard deviations for the men and women, lastly, N_W and N_M stands for the sample size for the gender categories.

The null hypothesis (H_0) for the benefits and challenges is stated as:

H_0 : There is no significant difference in the means of the benefits and challenges distribution for men and women categories (μW and μM).

The alternate hypothesis (H_1) for benefits and challenges is stated as:

H_1 : There is a significant difference in the means of the benefits and challenges distribution for men and women categories ($\mu W \neq \mu M$).

4. Results and discussion

4.1. Gender Assessment of benefits associated with implementation REDD⁺ initiative in Cross River State, Nigeria

Table 2 showed gender-selective benefits derived from the REDD⁺ project since its inception in Cross River State, Nigeria. The table showed that men were more benefited in 14 out of the 17 benefits reported by gender categories in the study area.

Table 2. Gender assessment of benefits associated with implementation REDD⁺ initiative in Cross River State, Nigeria.

Benefits	Freq (n)	Freq (n)	% Men	% Women	Men vs. Women
	Men	Women			<i>p</i> -value
Project awareness	10	7	59	41	<0.001
Bridge/culvert construction	5	0	100	0	<0.001
Livelihood enhancement	7	3	70	30	<0.001
Livestocks production	8	4	67	33	<0.001
No REDD ⁺ benefits	11	13	46	54	-
Preservation of the forest	1	0	100	0	<0.001
Social trust and togetherness	1	1	50	50	-
Training on conservation and sustainable forest management	2	1	67	33	<0.001
REDD ⁺ shirts	1	0	100	0	<0.001
Mosquito nets	1	0	100	0	<0.001
Good forest management for sustainability	2	0	100	0	<0.001
Creation of knowledge of forest management	2	0	100	0	<0.001
Land use plan techniques	1	0	100	0	<0.001
The role of tree played in storing carbon	1	0	100	0	<0.001
Distribution of seedlings to plant on our farm	9	0	100	0	<0.001
Grading of roads	1	0	100	0	<0.001
Taken care of farm	1	0	100	0	<0.001

Independent *z*-test *p*-0.005.

The benefits derived include REDD⁺ project awareness (59%), bridge/culvert construction (100%), livelihood enhancement (70%), preservation of the forest (100%), training on conservation and sustainability (67%), distribution of REDD⁺ shirts (100%), mosquito nets (100%), good forest management for sustainability (100%), creation of knowledge of forest management (100%), land use plan techniques (100%), sensitization on the role of trees played in storing carbon (100%), distribution of seedlings to plant on our farm (100%), grading of roads (100%), and taking care of the farm (100%). Furthermore, the majority of women reported that they have not benefited from the REDD⁺ project since its inception (54%), while both categories agreed the REDD⁺ initiative has solidified their togetherness and social trust. As a result, there was a significant difference in the

mean of the selected variables between men and women ($p < 0.001$), indicating differences in productive, reproductive, and community engagement (Table 2).

4.2. Gender assessment of challenges associated with implementation REDD⁺ initiative in Cross River State, Nigeria

Twenty-two (22%) of the women agreed that they have not been having smooth accessibility to the REDD⁺ initiative in the community; 13% have not been actively participating in the initiative since inception, compared to men in terms of accessibility (78%), and participation (87%), respectively. This small percentage indicated that the project has been mundaned and considered as men's affairs (78%), as a result having a significant influence in decision-making, particularly in African settings. Proportion test results found this difference to be highly significant ($z = -15.245$, $p = 0.000$). Thus, it can be stated with nearly above 50% confidence that both men and women categories have vastly different views concerning who should have access to and participate in climate change action plans such as REDD⁺, and this has a great effect on the design and implementation of the REDD⁺ initiative. About 98% of the women category hold the opinion that attached benefits for the REDD⁺ initiatives have not been fairly distributed. They asserted that the benefits were skewed in favour of men (94%) compared to 30% of the women category. This indicates that gender mainstreaming during the designing and implementation of the programs has been neglected, and these differences between the two categories were statistically significant (Table 3).

Table 3 clearly shows the difference between gender, program integration, community organisation and REDD⁺ planning initiatives in the communities. 89% of men reported that members of the community were not carrying along, with 75% indicted poor community organisation and planning as the setbacks for the program compared to 11% and 25%, respectively, for the women response to the same investigation. Women had a higher percentage (92%) compared to (8%) men (that reported "no idea" about the REDD⁺ project), and the majority of men (78%) also agreed that the REDD⁺ project implementation has been a major challenge compared to women (22%). The results were significant in the difference at the z -test proportion results test ($z = 14.201$, $p = 0.000$; $z = 10.451$, $p = 0.000$). The low response from the women category both in project implementation and unawareness shows that both groups believe these two variables cannot be over-emphasized as far as climate change adaptation plans such as REDD⁺ success are concerned. On the other hand, about 4% of the women feel that the "logging activities" are challenges facing the REDD⁺ initiative. However, both gender categories agreed that the introduction of the REDD⁺ initiative in the visited communities has blocked several of their livelihood strategies (50% each). The z -value for the proportion test is 10.240, with a p -value of 0.0000. The women perceive that differences exist to a much greater degree with higher confidence.

Table 3. Gender Assessment of challenges associated with implementation REDD⁺ initiative in Cross River State, Nigeria.

Challenges	Men		Women		z proportion test indicator
	Freq	(%)	Freq	(%)	
Accessibility	30	78	8	22	***
Active participation	33	87	15	13	***
Benefit sharing	36	94	2	6	***
Community members were not carry along in decision making	34	89	4	11	***
Poor community organisation and planning	29	75	9	25	***
No idea	3	8	35	92	***
REDD ⁺ project implementation	30	78	8	22	***
REDD ⁺ project comes in phases	32	83	6	17	***
Logging	37	96	1	4	***
REDD ⁺ blocked several livelihoods of the community	19	50	19	50	-
No benefit derived from REDD ⁺ project since inception	4	10	34	90	***
No community empowerment since inception of REDD ⁺ project	34	90	4	10	***
No payment for community conservation since REDD ⁺ initiative inception	37	97	1	3	***
No knowledge of REDD ⁺ initiative	2	5	36	95	***
Inequality	2	6	36	94	***
No access to credit facilities for alternative livelihoods	3	9	35	91	***
No community development initiative	4	10	34	90	***
Source of revenue has been blocked	5	14	33	86	***
No youth empowerment	5	13	33	87	***
Only selected members of the community are involves in the REDD ⁺ programmes	3	7	35	93	***

Asterisks indicate where there was significant difference between the gender categories (z proportion test) at 95% (***) level of significance.

Nearly 100 percent (90% and 97%, respectively) of the men category have the impression that there has been no community empowerment and payment for ecosystem conservation since the inception of the project in the community, compared to 10% and 3% for women. Even among the women category, the majority (90%) reported that they have not benefited in whatever means from the REDD⁺ project since its inception compared to men (10%), and this has been a serious challenge as far as the project is concerned. This proportion produced a z value of 8.243 and it is statistically different at the 0.000 significance level. It can be stated with nearly 100% confidence that women are more likely than men to be the climate justice receiving end in terms of procedural and benefit sharing. The percentage of women who indicated that they do not have knowledge of REDD⁺ initiatives in the community was 95% compared to men 5%, respectively. The result suggests that in awareness and information dissemination related to the REDD⁺ project, women are still lagging behind. The percentage proportion among the women that reported no access to credit facilities for livelihood enhancement and no community development initiatives (91%:90%) compared to men (9%:10%), respectively, with *p*-value of 0.001, and it is significantly different between the gender groups. Both gender categories hold a very divergent view in terms of how

the introduction of REDD⁺ projects in the communities have blocked larger percentages of their source of revenue (86%) compared to men (14%), which is significant with a z score of 7.907, $p = 0.000$, providing 100% confidence that women and livelihood strategies in forms of revenue generation issues can never be over-emphasized as far as climate change and adaptation plans are concerned. Men and women categories were also differing regarding the introduction of the REDD⁺ project and youth empowerment. About 87% of women reported that REDD⁺ have not come with youth empowerment programs, while only 13% of men agreed with REDD⁺ and youth empowerment programs. Above 90% of women reported that “only selected members in the communities’ involves in the REDD⁺ projects/initiatives” compared to men (below 5%). Statistical testing revealed the difference between men’s and women’s responses ($z = 18.421$, $p = 0.000$). Overall, the shared responses from both women and men indicate that all the variables are fundamental factors that will determine the success and marred of the REDD⁺ project in the communities considering planning and implementation processes (Table 3).

According to Table 4, gender-supporting and promising frameworks were identified. These basically relied solely on the Sustainable Livelihood Approach (SLA), taking into consideration gender constructive roles and responsibilities in relation to REDD⁺ implementation.

Table 4. Promising institutional framework supporting gender sensitivity.

Men	Promising framework	Women	Promising framework
1)	Provision of succor materials in face of climate change effect or impact	1)	Provision of alternative livelihood strategies
2)	Provision of alternative livelihood support	2)	Creation of public awareness about climate change
3)	Creation of public awareness about climate change	3)	Conservation techniques on forest resources
4)	Capacity building on forest management and impact of climate change impact	4)	Creation of job and employment opportunities
5)	Community development and empowerment programmes	5)	Provision of infrastructural facilities
6)	Conservation techniques on forest resources	6)	Practicing incentive agriculture
7)	Creation of job and employment opportunities	7)	Capacity building on forest management and impact of climate change impact
8)	Educating people on alternative natural resources usage		
9)	Practicing incentive agriculture		
10)	Provision of infrastructural facilities		
11)	Training and skill acquisition programmes		

5. Discussion

Related to the subject of challenges and benefit-sharing arrangements. The 4 million USD take-off funding from the UN-REDD program that Cross River State received has already stirred controversy. The local communities feel excluded from the REDD⁺ monies, despite the REDD⁺ administrators’ claims that the funds are intended for capacity building. This led to increased mistrust and suspicion among the communities as a result of the contentious benefit sharing proposal created by the Cross River State Forestry Commission. According to this study, certain

communities in the study regions are not ready to participate in any benefit-sharing arrangement that does not provide them the largest share of the REDD⁺ benefits. According to Luttrell et al. [17], allocating benefits on the latter basis is advantageous for the local populations and is done thus in Brazil, Tanzania, and Peru. The issue with this strategy is that it undercuts the demand for additionality contained in the global REDD⁺ architecture. Given their different preferences for monetary payments or development projects in lieu, which have been clearly proven between men and women categories in the examined communities, further complications may still arise from intra-community benefit sharing. This supports the claim that different stakeholder preferences exist for direct or indirect payments in PES contexts, whether they take the form of cash rewards or infrastructure provision [18,19]. The inability to identify beneficiaries among REDD⁺ actors also led to the men's predominance of all small benefits (such as project awareness, bridge/culvert construction, livelihood improvement, livestock production, preservation of the forest, training on conservation and sustainable forest management, purchase of REDD⁺ shirts, collection of mosquito nets, good forest management for sustainability, creation of knowledge of forest management, for example). According to Luttrell et al.'s [17] recommendations, beneficiaries can be identified and selected based on who legally owns the forests, in accordance with any existing statutory or customary property rights. These criteria, however, are difficult to apply in the Nigerian setting because of the fierce conflict over forest tenure that exists between state governments and local communities, particularly in favor of men. Due to unclear criteria across gender divisions, the benefits sharing structure for REDD⁺ in Cross River State was met with a lot of skepticism and inequity. This study examines how gender concerns found in previous research have been taken into account by Nigeria's REDD⁺ pilot programs. The result of this study agrees with Griffiths [4] that the REDD policy process failed to accomplish equality aims since it does not take underlying power dynamics into consideration in the case of Nepal. The consideration of gender concerns in forest management by explicitly integrating women in the policy debates and payment criteria within REDD⁺ programs, including the REDD payment pilot project, is insufficient to address gender disparities in the absence of accounting for power.

Finally, the ability to benefit from things, as defined by Ribot and Peluso [20], depends on a "web of powers" that are exerted through social interactions and institutions, including markets, property, and informal, illegitimate, and coercive claims to resources. Gaining access to natural resources, whether legally or illegally, is essential for reaping their benefits. This includes access to other vital resources like capital, labor, market networks, technology, and knowledge. Access functions at higher organizational levels as well as at the level of interpersonal connections and skills.

6. Conclusion

This study fully specified the definition of equity as indispensable to just and effective policy, planning, and assessment of the social impacts of change in the value of ecosystem services. In contrast, much of the current policy discourse on

climate change seems to relegate equity to distribution alone. The study contends that the three interdependent dimensions of equity distribution, procedure, and the contextual disposition of capabilities in terms of access and power all contribute to the degree of (in) equity in the social condition. There are concerns over gender equity, which dominates current debates on gender participation and REDD⁺ implementation. Yet, despite the apprehension that these initiatives may bring lasting solutions, undermining gender equity in terms of benefits and challenges, distribution is generally left undefined (participation, decision-making, and social inclusion). Benefit sharing has come under scrutiny due to the marginalization of the entities that represent local forest communities in Nigeria's REDD⁺ program. This study comes to the conclusion that gender inequality exists in forest rights, benefits, and problems. Due to a lack of adherence to a gender-sensitive strategy, REDD⁺ proponents in REDD⁺ pilot communities have not defined the benefits and challenges of the program.

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Article

Challenges and way forward in the handling and disposal of battery waste: Towards sustainable practices

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Abstract: The management and disposal of battery waste, particularly lead-acid batteries, present numerous challenges that must be addressed to ensure environmental protection, public health, and sustainable resource management. This thesis examines the multifaceted nature of these challenges and explores potential solutions for sustainable battery management. Drawing on insights from prior research, field observations, stakeholder interviews, and literature reviews, the study synthesizes existing knowledge to inform strategies for mitigating the environmental, safety, and economic impacts associated with battery waste. The current scenario on battery waste management highlights significant challenges, including environmental pollution, health risks, safety hazards, recycling challenges, regulatory compliance issues, technological limitations, infrastructure constraints, and the need for public awareness and education. Countermeasures to address these challenges encompass regulatory interventions, technological innovations, infrastructure development, capacity building, and public engagement initiatives. By integrating findings from diverse sources, this thesis aims to contribute to the existing knowledge base on battery waste management and propel strategies for sustainable resource management.

Keywords: lead-acid batteries; battery waste management; environmental pollution; health risks; recycling challenges

1. Introduction

The history of lead-acid batteries dates back to their inception in the mid-19th century, marking a pivotal milestone in the annals of energy storage [1,2]. Over the decades, these batteries have entrenched themselves as indispensable components across a plethora of industries, spanning automotive, telecommunications, and renewable energy sectors [3–5].

Despite their ubiquity and reliability, the pervasive utilization of lead-acid batteries has unfurled a tapestry of challenges, necessitating a concerted effort to navigate the labyrinth of environmental, safety, and recycling concerns [6,7]. An extensive body of research has illuminated the multifaceted nature of these challenges, drawing attention to the intricate nexus between battery waste management and sustainable practices [8,9].

A compendium of scholarly works has meticulously dissected the environmental repercussions engendered by lead-acid battery waste, shedding light on the release of toxic substances such as lead and sulfuric acid into the ecosystem, thus imperiling soil, water, and air quality [10,11]. Furthermore, the specter of health hazards stemming from exposure to lead and acid in battery waste has been underscored, accentuating

the deleterious effects on human health, particularly among workers in battery-related industries [12,13].

Safety hazards intrinsic to lead-acid batteries, encompassing fire and explosion risks, have garnered significant attention, prompting the implementation of stringent safety protocols to mitigate potential accidents [14,15]. Moreover, the challenges surrounding the recycling of lead-acid batteries have been thoroughly examined, with studies elucidating economic constraints, technological limitations, and regulatory frameworks influencing recycling rates and practices [16,17].

Synthesizing insights from previous thesis works and scholarly articles, this study endeavors to plunge deeper into the multifaceted challenges of handling and disposing of lead-acid batteries while exploring potential solutions and pathways for sustainable battery management [18,19]. By amalgamating findings from prior research endeavors, field observations, stakeholder interviews, and literature reviews, this thesis aspires to contribute to the existing corpus of knowledge and propel strategies for alleviating the environmental, safety, and economic impacts associated with lead-acid battery waste [20,21].

A plethora of recent research efforts have underscored the urgency of addressing these challenges and have provided valuable insights into potential solutions. For instance, Zhang et al. emphasized the importance of adopting environmentally friendly battery chemistries and materials to minimize the release of toxic substances during battery production and disposal [22]. Similarly, Sharma et al. highlighted the need for stringent safety protocols and specialized packaging to mitigate the risk of accidents during battery handling and transportation [23]. Furthermore, Wang et al. proposed the development and adoption of advanced recycling technologies to improve the efficiency and sustainability of battery recycling operations [24].

2. Materials and method

The study is conducted based on field observations, interviews with stakeholders engaged in battery waste management across various states of India, as well as a review of existing literature on battery waste management.

2.1. Current scenario on management and handling of battery waste

The current scenario on the management and handling of battery waste highlights several significant challenges that must be addressed to ensure environmental protection, public health, and sustainable resource management. These challenges encompass various aspects:

Environmental pollution: Battery waste, particularly from lead-acid batteries, poses a threat of environmental pollution due to the release of toxic substances like lead, sulfuric acid, and heavy metals into soil, water, and air. Improper disposal practices can result in ecosystem contamination, wildlife harm, and adverse effects on human health.

Health risks: Exposure to hazardous materials present in battery waste, such as lead and acid, presents serious health risks to workers involved in handling, recycling, and disposal, as well as nearby communities. Inhalation or ingestion of lead particles can lead to neurological damage, developmental disorders, and other adverse health

effects.

Safety hazards: Batteries, especially lead-acid batteries, are susceptible to safety hazards such as fire and explosion risks, particularly under conditions like overcharging, short circuits, or physical damage. Implementing proper handling, storage, and transportation protocols is essential to mitigate these risks and prevent accidents.

Recycling challenges: Despite the recyclability of many battery types, recycling rates remain inadequate due to economic factors, insufficient infrastructure, and lack of awareness. Traditional recycling methods may also face limitations regarding efficiency, scalability, and environmental impact, necessitating the development of innovative recycling technologies.

Regulatory compliance: Adhering to regulatory frameworks governing the handling, transportation, and disposal of battery waste is crucial to minimize environmental pollution and safeguard human health. However, challenges in enforcement, loopholes, and inconsistencies in regulations can undermine their effectiveness, emphasizing the need for strengthened regulatory frameworks and enforcement mechanisms.

Technological limitations: Existing recycling technologies may encounter limitations in terms of efficiency, environmental sustainability, and scalability. Investing in research and development of innovative recycling technologies, such as hydrometallurgical processes and electrochemical methods, is critical to overcome these limitations and improve recycling rates.

Infrastructure and capacity: Inadequate infrastructure and limited recycling capacity pose challenges to effective battery waste management. Enhancing recycling capabilities and addressing the growing volume of battery waste require building and scaling up recycling infrastructure, as well as investing in workforce training and capacity building.

Public awareness and education: Insufficient awareness among consumers, businesses, and policymakers about the importance of proper battery waste management can impede efforts to improve recycling rates and reduce environmental pollution. Initiatives such as public awareness campaigns and educational programs are necessary to promote responsible battery disposal practices and encourage recycling.

2.2. Countermeasures to address the challenges of handling and disposing of battery waste

Environmental pollution is a significant concern associated with battery waste, particularly from lead-acid batteries. To address this issue, it is essential to implement strict regulations and enforcement mechanisms governing the proper handling, transportation, and disposal of battery waste. These measures should include strategies to prevent leakage and contamination, thereby minimizing the release of toxic substances into the environment. Additionally, promoting the use of environmentally friendly battery chemistries and materials can help minimize the release of hazardous substances during both the production and disposal stages. Moreover, the development and adoption of advanced recycling technologies offer promising solutions for

efficiently recovering and neutralizing hazardous materials from battery waste, thereby reducing environmental pollution.

Health risks are another critical consideration in battery waste management. Workers involved in battery handling, recycling, and disposal are particularly vulnerable to exposure to hazardous materials. To mitigate these risks, it is essential to provide adequate training and protective equipment to ensure their safety. Regular health monitoring and screening programs can help detect and prevent health issues associated with exposure to toxic substances, thereby safeguarding the well-being of workers in battery-related industries. Furthermore, educating the public about the health risks associated with battery waste is crucial for promoting safe disposal practices and minimizing exposure to harmful chemicals.

Safety hazards present additional challenges in battery waste management. Batteries, especially lead-acid batteries, are prone to safety risks such as fires, explosions, and other accidents. Implementing stringent safety protocols for the handling, storage, and transportation of batteries is essential to minimize these risks and prevent accidents. Utilizing specialized packaging and containment systems can further mitigate the impact of accidents during battery transportation and storage. Regular safety inspections and audits of battery storage facilities, recycling plants, and transportation routes are essential to identify and address potential hazards promptly.

Recycling challenges also pose significant obstacles in battery waste management. Investing in the development and deployment of advanced recycling technologies is crucial for improving the efficiency, sustainability, and scalability of battery recycling operations. Providing financial incentives, grants, and subsidies can support the expansion of recycling infrastructure and the adoption of innovative recycling processes. Collaboration with industry stakeholders, research institutions, and government agencies is essential for identifying and overcoming barriers to battery recycling, such as economic viability, technology limitations, and regulatory compliance.

Regulatory compliance plays a pivotal role in ensuring effective battery waste management. Strengthening regulatory frameworks governing the handling, transportation, and disposal of battery waste is necessary to minimize environmental pollution and protect human health. Establishing monitoring and reporting systems can track compliance with regulatory requirements and identify areas for improvement in battery waste management practices. Encouraging international cooperation and harmonization of regulatory standards is crucial to ensure consistent and effective management of battery waste across borders.

Technological limitations also need to be addressed to enhance battery waste management practices. Fostering innovation and research in battery recycling technologies through public-private partnerships, government grants, and research funding initiatives can drive progress in this area. Providing incentives and support for the commercialization and deployment of emerging recycling technologies is essential for improving the efficiency and sustainability of battery recycling operations. Promoting knowledge sharing and collaboration among industry stakeholders, research institutions, and technology developers can accelerate the development and adoption of innovative recycling solutions.

Infrastructure and capacity are fundamental aspects of effective battery waste

management. Investing in the expansion and modernization of battery recycling infrastructure, including recycling plants, collection centers, and transportation networks, is critical to meet the growing demand for battery waste management services. Providing technical assistance, training programs, and capacity-building initiatives can enhance the skills and capabilities of workers in the battery recycling industry. Fostering partnerships between the public and private sectors can leverage resources, expertise, and infrastructure to improve battery waste management practices and increase recycling rates.

Public awareness and education are essential for promoting responsible battery waste management practices. Launching public awareness campaigns and educational initiatives can raise awareness about the importance of proper battery waste management and encourage responsible disposal practices. Providing educational materials, training programs, and outreach activities targeting consumers, businesses, schools, and community organizations can inform them about the environmental and health risks associated with battery waste. Engaging with media outlets, social influencers, and community leaders can amplify messaging about the benefits of recycling batteries and the role of individuals in reducing waste and protecting the environment.

3. Observations and discussion

The introduction sets the stage for understanding the historical significance and contemporary challenges associated with lead-acid batteries, highlighting their pervasive use across various industries. It effectively synthesizes previous research to underscore environmental safety and recycling concerns surrounding battery waste management.

The paper effectively delineates the multifaceted challenges posed by lead-acid battery waste, including environmental pollution, health risks, safety hazards, and recycling challenges. It acknowledges the intricate interplay between these challenges and emphasizes the urgency of addressing them to ensure sustainable battery management.

By integrating insights from prior research endeavors, field observations, stakeholder interviews, and literature reviews, the study aims to contribute to the existing knowledge base on battery waste management. It underscores the importance of amalgamating findings from diverse sources to inform strategies for mitigating the environmental, safety, and economic impacts of battery waste.

Moreover, the paper identifies countermeasures to address the challenges of handling and disposing of battery waste, ranging from regulatory compliance and technological innovations to infrastructure development and public awareness campaigns. These countermeasures encompass a comprehensive approach to addressing the complex challenges associated with battery waste management.

Overall, the introduction lays a solid foundation for the subsequent discussion by providing a comprehensive overview of the current state of battery waste management and outlining the key challenges and potential solutions. It effectively contextualizes the study within the broader discourse on sustainable resource management and underscores the importance of interdisciplinary approaches to address the multifaceted

challenges of battery waste management.

4. Conclusion

The management and handling of battery waste, particularly lead-acid batteries, pose significant challenges that require immediate attention and concerted efforts from various stakeholders. The pervasive utilization of lead-acid batteries across industries has led to environmental pollution, health risks, safety hazards, and recycling challenges. Regulatory compliance, technological innovations, infrastructure development, capacity building, and public awareness initiatives are essential components of comprehensive strategies for addressing these challenges. By synthesizing insights from prior research and empirical observations, this thesis underscores the urgency of adopting sustainable practices in battery waste management to safeguard environmental and public health while promoting resource efficiency. Moving forward, interdisciplinary collaboration, stakeholder engagement, and concerted action are imperative to achieve sustainable battery management and mitigate the adverse impacts of battery waste on the environment and society. Future research should focus on addressing key knowledge gaps and advancing solutions for sustainable battery management. Areas for further investigation include the development of novel recycling technologies, lifecycle assessment of alternative battery technologies, policy analysis for promoting sustainable battery management, and socio-economic research on the impacts and opportunities of the transition towards green energy storage solutions.

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Article

Variation analysis in historical demographic distribution within urban agglomeration: Experimental evidence from the Wuhan “1+8” City Circle

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Abstract: Understanding the spatial distribution of population is crucial in regional research, as it informs the development of effective population policies, long-term regional planning, and the balanced growth of the economy, resources, and environment. This study employs a quantitative approach to construct a research framework using demographic data to elucidate the historical population dynamics within the Wuhan “1+8” City Circle (WCC). The study examines whether the central city and its peripheral cities have experienced coordinated growth or if a town has dominated. The findings reveal several key findings and insights: Wuhan, as the core city of the WCC and the capital of Hubei Province, shows population growth driven not only by natural increases but also by a significant population siphoning effect, with Hongshan of Wuhan experiencing the most pronounced impact; from 2010 to 2020, the WCC’s overall population distribution displayed a dispersal trend, while population density continued to concentrate, particularly around Wuhan and its vicinity, thereby establishing Wuhan as a central population hub. Gender distribution within the WCC generally reflects a higher proportion of males than females, with exceptions in Jiang’an of Wuhan and Huangshigang of Huangshi, where females outnumber males. This pattern may result from attracting male labor to industrial parks and female labor to service sectors. In summary, the WCC needs to refine its regional development strategies, especially for crucial siphoning areas such as Hongshan of Wuhan and Wuchang of Wuhan, to foster balanced regional growth. Additionally, policies to encourage childbirth, enhance elderly care services, and implement a comprehensive population data monitoring and forecasting system are crucial for addressing demographic shifts and achieving sustainable development.

Keywords: demography; historical dynamical; spatial characteristics; structural trends; county-level scale; Wuhan “1+8” City Circle (WCC)

1. Introduction

Nowadays, the multiple pressures of demographic, social, economic, and environmental issues have led to a gradual shift in the development dynamics of Chinese cities from industrial industries to service industries and diversified emerging digital industries [1]. Cities with better economic and industrial structures are better positioned to dominate the allocation of resources and attract talent [2]. These effects are most pronounced in more developed cities, providing residents with more competitive social service policies [3]. With China’s working-age population having peaked in 2015, the competition for talent among towns is expected to intensify [4]. Population research not only focuses on characteristics such as total population, density, growth rate, and composition in different regions but also on population

movements, migration, and the relationship between population, economy, society, resources, and the environment [5]. As the most dynamic element in urbanization, the population's demographic characteristics, overall scale, and spatial distribution are crucial for sustainable city development [6]. In recent years, as urbanization continues to advance, large numbers of migrants have flocked to cities. While this rapid urban population growth has stimulated economic development, it has also caused significant social and environmental issues, including regional environmental degradation, traffic congestion, insufficient public facilities, and the lagging development of service facilities in densely populated areas, along with the coexistence of over-utilization and inefficient use of land [6,7]. Generally, city development is accompanied by changes in population distribution, with regional overpopulation and underpopulation resulting from the imbalance of natural endowments and socio-economic development, as well as the progress of regional socio-economic development to certain stages [8]. Overpopulation leads to competition for resources and environmental carrying capacity, while underpopulation results in labor shortages and decreased domestic demand [9,10]. Thus, the spatial distribution of the population, which examines the distribution, dispersion, and combination of regional populations at a certain point in time, is the most fundamental manifestation of the man-land relationship, an essential aspect of regional spatial structure, and a key prerequisite for the coordinated allocation of industrial resources [4,11–15].

As a core focus of regional research, the spatial distribution of the population has received unprecedented and widespread attention from the academic and policy communities. Understanding the patterns and dynamics of demographic information is crucial for formulating rational population policies, long-term regional development planning, and the coordinated development of the economy, resources, and environment [4,5,7,8,16,17]. (1) In terms of regional scope, scholars have explored the spatial distribution of populations in different historical periods at the national administrative scale in countries such as Spain [18,19], China [20], Jordan [21], and Tanzania [22] using demographic grids, censuses, or area statistics. Additionally, some researchers have monitored and analyzed designated town areas [23], specific demarcation lines [24], and metropolitan areas [25] by employing numerical tools and multiple sources of demographic data to understand demographic dynamics in specific regions. (2) Regarding data characteristics, scholars have identified spatial distribution patterns of populations during specific historical periods by categorizing basic population attributes, including the female population [26], the elderly population [27], the rural population [28], and different ethnic groups [29–31]. Other researchers have revealed the spatial distribution characteristics of specific populations by dividing various population attributes, such as employed populations [32], higher education levels [33], mobile populations [34], border populations [35], and potential populations [36]. (3) In the realm of population prediction and simulation, scholars have based their analyses on data reflecting population locations, such as remote sensing image data [37], nighttime lighting information [38,39], cell phone positioning information [40], and traffic dynamics data [41]. Predictive modeling methods, including spatial statistical measurement [42,43], geospatial modeling [44], localized spatial three-dimensional modeling [45], and machine learning algorithms [46–49],

have been employed to simulate and estimate the spatial distribution of urban populations.

In addition, some scholars use the spatial distribution of the population as an essential variable indicator for research: (1) to comprehensively explore the relationship between the spatial distribution of the population and various vital elements of cities and towns, such as spatial structure [50], population mobility [51,52], economic structure [53,54], transportation system [55,56], terrain conditions [57,58], and land use [59]; (2) to examine its relationship with the distribution of various service facilities [60], such as medical institutions [61], housing space [62], commercial facilities [63], and shelters [64]; and (3) to investigate its relationship with potential risk prevention, such as climate change [65,66], epidemic or disease transmission [67], and crime risk [68,69]. Therefore, the population's spatial distribution is a critical factor affecting regional socio-economic vitality, infrastructure construction, public service allocation, urban transportation, housing, and ecological issues. Acquiring and understanding information on the urban population's spatial distribution provides an essential scientific basis for formulating regional long-term development policies and urban management measures.

After a comprehensive literature review of existing studies on the spatial distribution of the population, it is found that, as a focal issue of regional research, there has been abundant progress and various approaches in the academic community. Among them, Chinese academics have conducted the most extensive research, but there remains a gap, specifically in studies related to population distribution patterns from the perspective of urban agglomerations. China's urbanization is advancing rapidly and on a large scale, yet existing studies on the population distribution of urban agglomerations typically focus on coastal regions such as the Yangtze River Delta, the Pearl River Delta, and Beijing-Tianjin-Hebei, with fewer studies on inland urban agglomerations [70,71]. Uneven population distribution at the macro level not only leads to social problems such as widening regional development gaps but also exacerbates imbalances in the development of education, healthcare, and elderly care, resulting in the wastage of social resources [10,72]. Therefore, this study takes the Wuhan "1+8" City Circle (WCC) as the case study area, using 2010 and 2020 as historical reference points. The study focuses on the population distribution pattern within the urban agglomerations, exploring the general and structural characteristics of population distribution in inland urban agglomerations, and explains the internal patterns of population in the process of urban agglomeration development. The study results show that analyzing the changes in the population distribution pattern of the WCC helps to determine the population's spatial development trend, thereby providing insights into historical demographic problems and their logical relationships within the region. This has empirical value and significance for regional coordinated development and the rational allocation of resources.

2. Materials and methods

2.1. Description of the study area

Urban agglomeration refers to a vast urbanized area comprising several regions that are spatially adjacent and functionally interconnected [73]. The WCC, also known

as the Wuhan Urban Agglomeration (WUA) [74]. Located in Hubei Province, China (**Figure 1**), the WCC includes the prefecture-level administrative units of Wuhan, Huangshi, Ezhou, Xiaogan, Huanggang, Xianning, and the special county-level administrative units of Xiantao, Tianmen, and Qianjiang, with Wuhan at its center [75]. According to China's Compendium of Administrative Divisions, the administrative hierarchy below the prefecture-level units is county-level units, which generally encompass city districts, county-level cities, and counties [76].

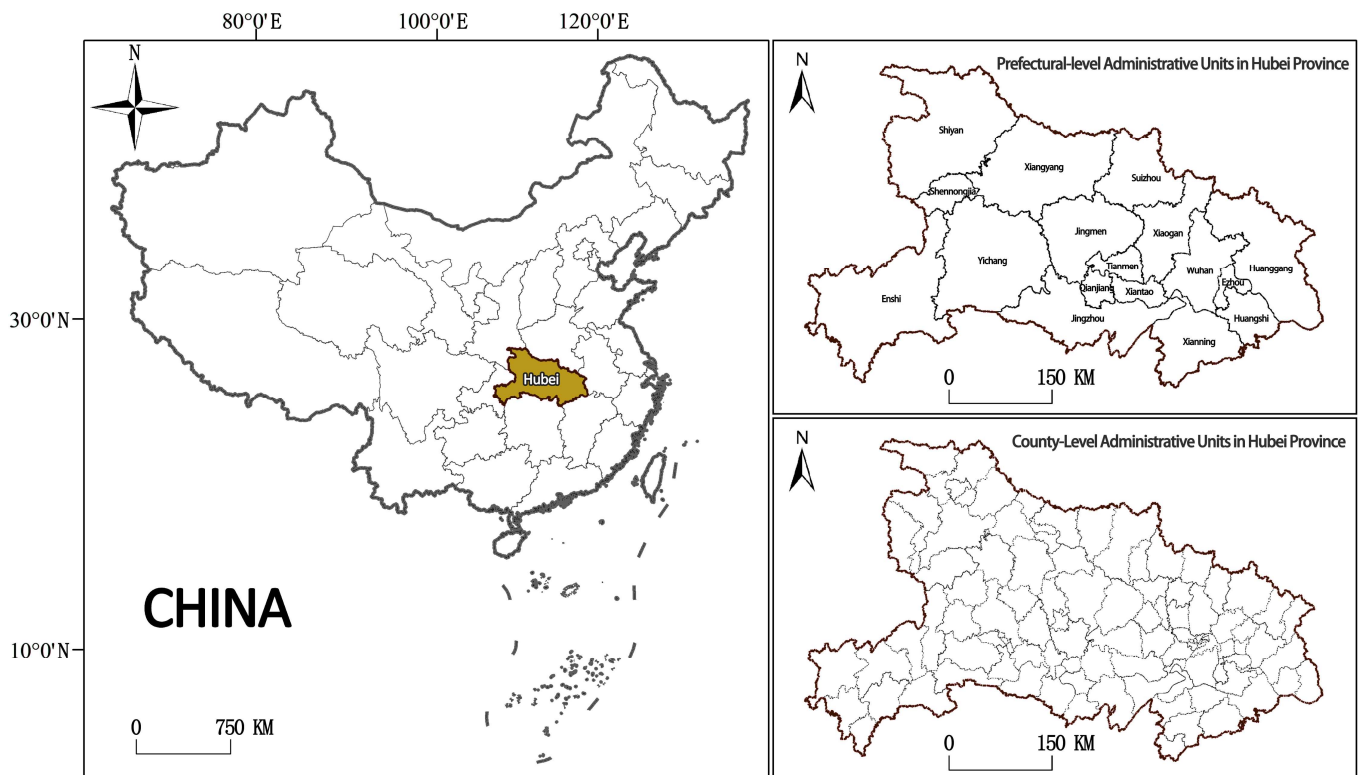


Figure 1. Geographical location and distribution range of administrative units in Hubei Province, China.

[Note: The base map is based on the Chinese standard map with the approval number GS (2020) 4619].

2.2. Data collection

Population census data from the Hubei Provincial Statistics Bureau's website (<http://tjj.hubei.gov.cn/>) was utilized. The data includes the 2010 census (sixth nationwide population census) and the 2020 census (seventh nationwide population census) for the county-level administrative units within the WCC. The research focuses on the county-level administrative units under the jurisdiction of the prefecture-level units within the WCC. Consequently, 48 county-level units within the nine prefecture-level units of the WCC were selected for the study (**Figure 2**). These data were collected and organized by national and regional census leading groups collaborating with local authorities over nearly three years, ensuring comprehensive coverage without missing values in the county-level administrative units.

$$\sigma_x = \sqrt{2} \sqrt{\frac{\sum_{i=1}^n (\tilde{x}_i \cos \theta - \tilde{y}_i \sin \theta)^2}{n}}, \sigma_y = \sqrt{2} \sqrt{\frac{\sum_{i=1}^n (\tilde{x}_i \sin \theta + \tilde{y}_i \cos \theta)^2}{n}} \quad (4)$$

where, SDE_x and SDE_y denote the form of the standard deviation ellipse; $\tan \theta$ denotes the direction angle when the ellipse is rotated, with the x -axis as the base and the noon direction as 0 degrees, clockwise rotation; σ_x and σ_y denote the standard deviation of the x -axis and y -axis; n is the total number of the feature i ; x_i and y_i are the coordinates of the feature i ; $\tilde{x}_i$ and $\tilde{y}_i$ are the deviations of the x_i and y_i from the weighted mean center.

The study then examined the spatial correlation of the population spatiotemporal data through the Moran's I index. The results were used to identify the relationship between the overall distribution of the population within the WCC in 2010 and 2020. The Moran's I used to provide feedback on the overall correlation between the data elements and determined each spatial element's dependence [79,80]. Moran's I greater than 0 indicated that the spatial elements were positively correlated, with larger values representing more significant overall spatial clustering dynamics; Moran's I less than 0 indicated that the spatial elements were negatively correlated, with smaller values representing more significant overall spatial dispersion dynamics; Moran's I equal to 0 meant that the spatial elements were randomly distributed [81]. The Moran's I is calculated as the following formulation [78].

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^n \sum_{j=1}^n w_{i,j} z_i z_j}{\sum_{i=1}^n z_i^2} \quad (5)$$

$$S_0 = \sum_{i=1}^n \sum_{j=1}^n w_{i,j} \quad (6)$$

where, $w_{i,j}$ is the spatial weight between element i and j ; z_i is the deviation of an attribute for element i from its mean $x_i - \bar{X}$; z_j is the deviation of an attribute for element j from its mean $x_j - \bar{X}$; n is equal to the total number of elements; S_0 is the aggregate of all the spatial weights.

3. Results and discussion

3.1. Dynamic variation of population number characteristics

3.1.1. Spatiotemporal trends in the distribution of the population number

Through data collation and statistical analysis, this study revealed that the population of Wuhan increased by 2,541,100 between 2010 and 2020, whereas the population of the WCC only increased by 1,623,400 during the same period. This indicates that the eight prefecture-level units other than Wuhan lost 917,700 people. This loss accounted for 36.11% of Wuhan's new population and 56.53% of the new population in the WCC. These variations suggest that Wuhan's population growth was driven not only by the natural population growth rate but also by the advantages brought by its regional development level, which had a significant siphoning effect on the surrounding population.

Analyzing the spatial distribution of population numbers in 2010 and 2020, an overall east-west oval deviation was observed in both years, indicating that population numbers were more significant in the east-west direction than in the north-south direction. The weighted average center of population was in Hongshan, Wuhan

(**Figure 3**). The fastest growth in total population numbers occurred in Hongshan, where the population was 1,390,300 in 2010 and increased by 1,394,900 between 2010 and 2020, more than doubling over the ten years (**Figure 4**). This rapid growth suggests a pronounced population siphoning effect in Hongshan [82]. Conversely, one of the fastest decline units in total population was observed in Xishui of Huanggang, known on the internet as “a large working county [83].”

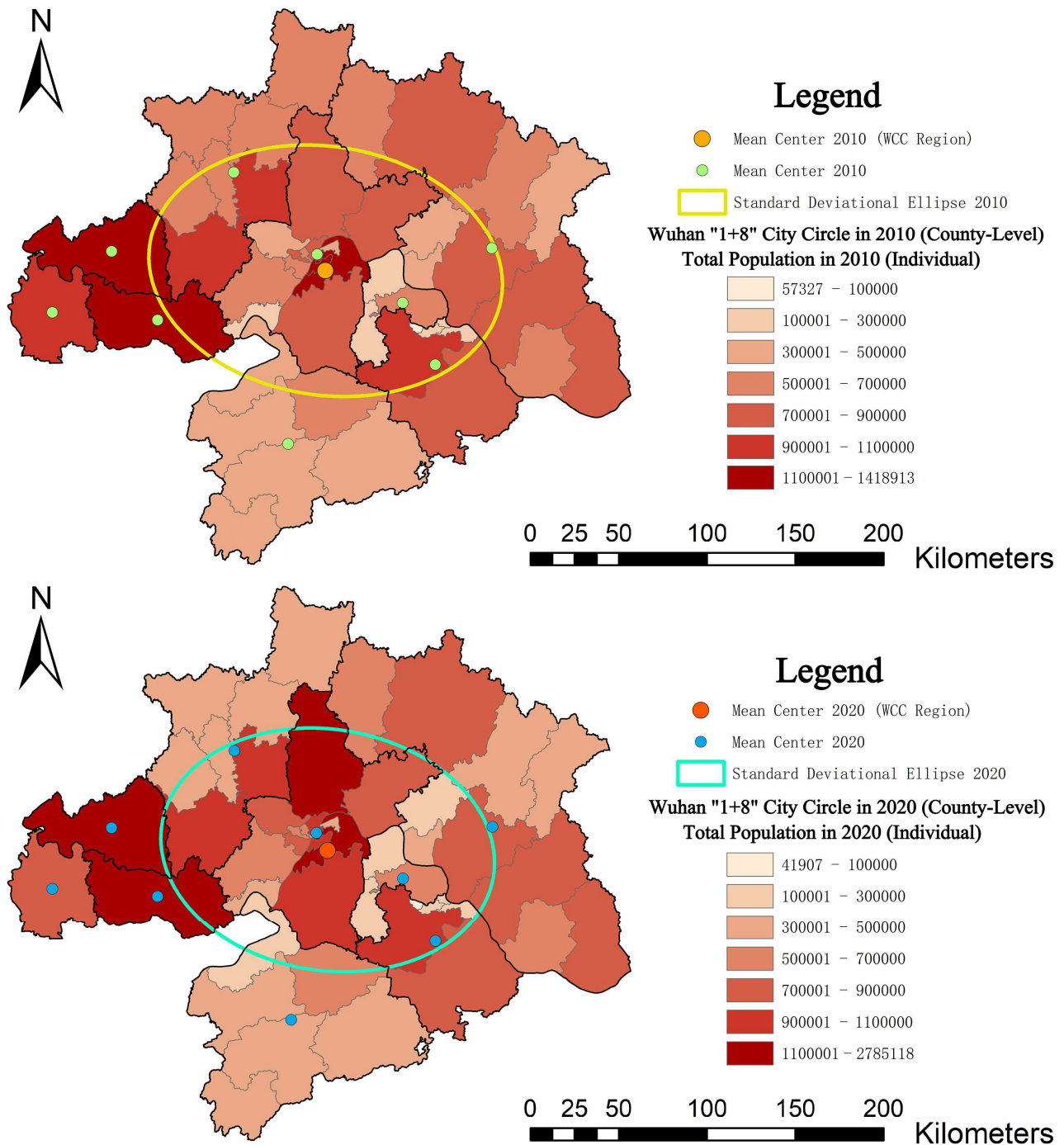


Figure 3. Population number distribution of the Wuhan “1+8” City Circle in 2010 and 2020.

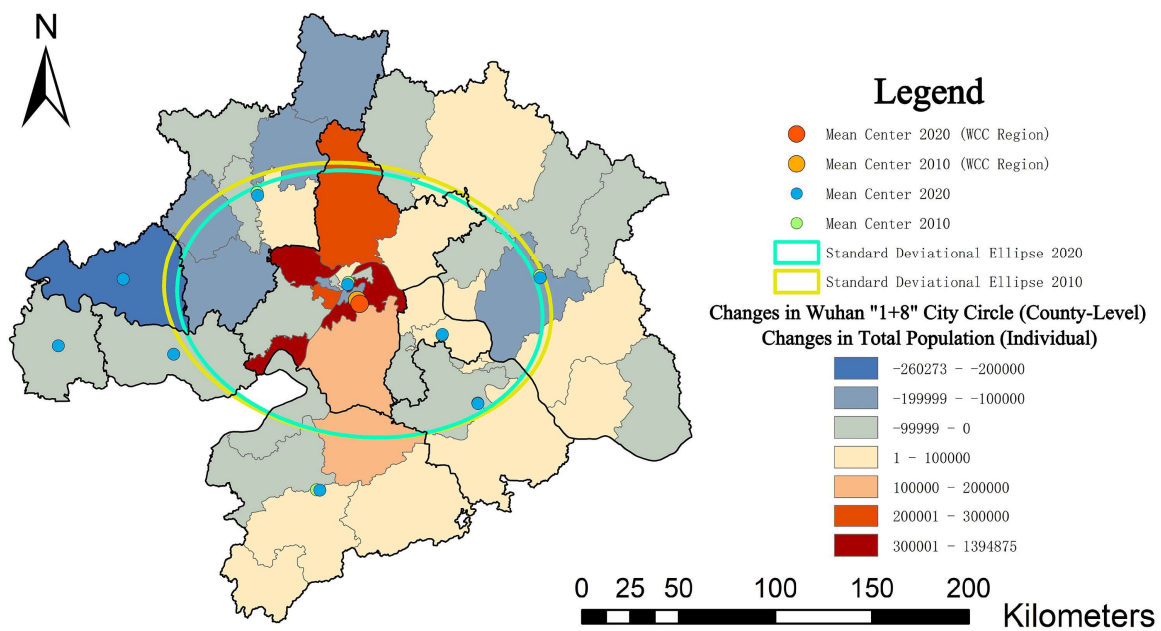


Figure 4. Population number variation of the Wuhan “1+8” City Circle from 2010 to 2020.

3.1.2. Spatial relations of population number in the county units of regions

The spatial autocorrelation results based on geospatial analysis yielded the following conclusions. The Moran’s I value decreased from 0.349 to 0.187, with the p -value and z -value remaining within the 95% confidence interval of the statistical test (**Table 1**). This suggests that the overall regional distribution of the total population in 2010 and 2020 exhibited a clustering pattern, although the significance of this clustering has diminished over time. This significant decrease indicates an expanding dispersion of population numbers in the WCC over the past ten years.

Table 1. Moran’s I result for the population number of the Wuhan “1+8” City Circle.

Year	Moran’s I	E -Value	Variance	Z -Value	P -Value	Spatial relation
2010	0.349049	-0.021277	0.011145	3.507840	0.000452	
2020	0.187402	-0.021277	0.008330	2.286385	0.022232	

3.2. Dynamic variation of population density characteristics

3.2.1. Spatiotemporal trends in the distribution of the population density

The spatial distribution of population density in 2010 and 2020 showed an overall east-west elliptical deviation in both years (**Figure 5**), indicating that population density was more significant in the east-west direction than in the north-south direction. Population density changes revealed that Hongshan of Wuhan and Hanyang of Wuhan experienced the fastest growth in population density (**Figure 6**). These areas reflected rapid changes due to the siphoning effect of population migration in addition to natural population growth. Conversely, Jiangnan of Wuhan, Qiaokou of Wuhan, and Wuchang of Wuhan were regions with the fastest decreasing population density. Additionally, some areas in the western and eastern parts of the WCC experienced varying degrees of population density reduction, while certain northern and southern regions showed increases in population density.

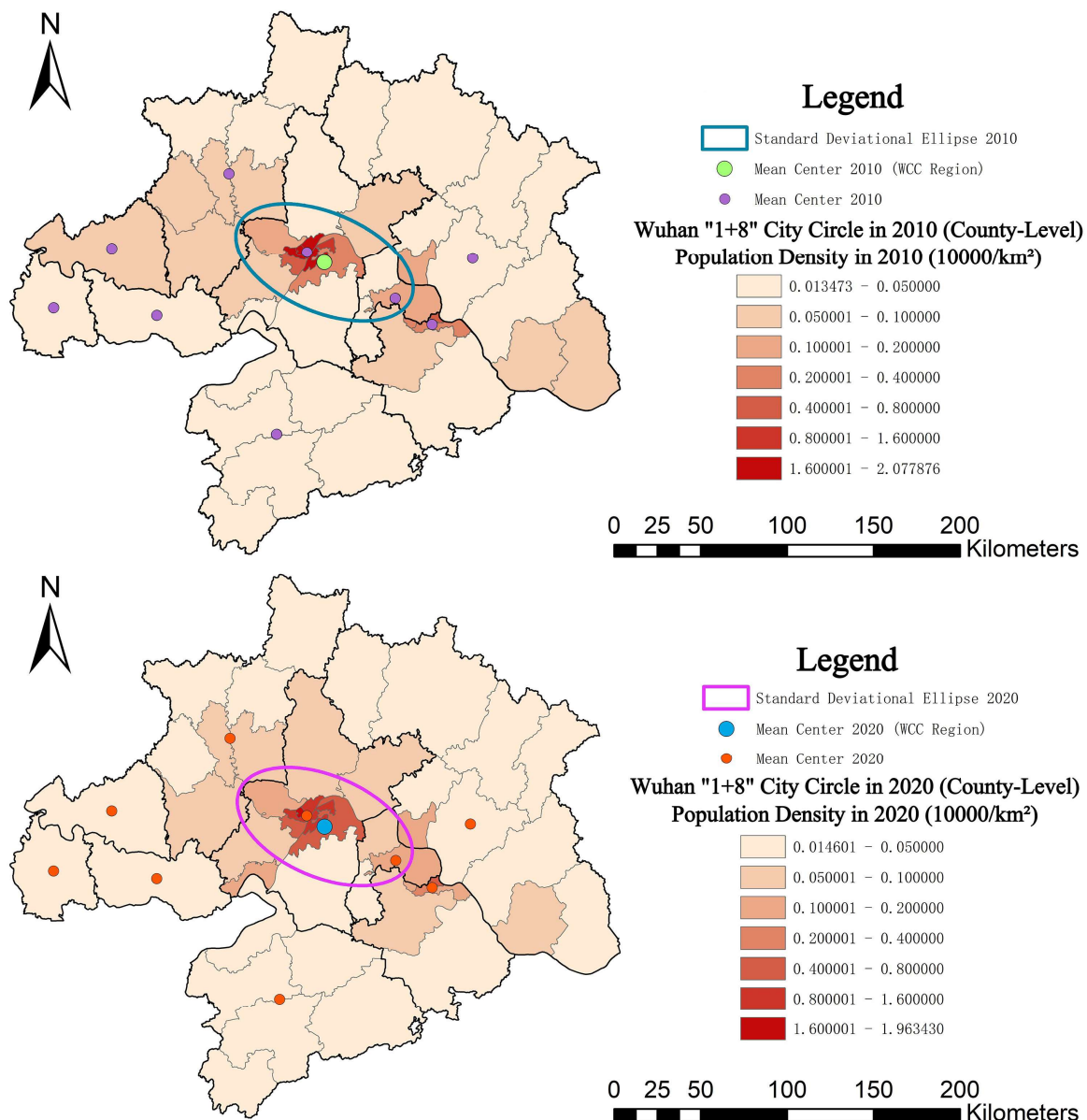


Figure 5. Population density distribution of the Wuhan "1+8" City Circle in 2010 and 2020.

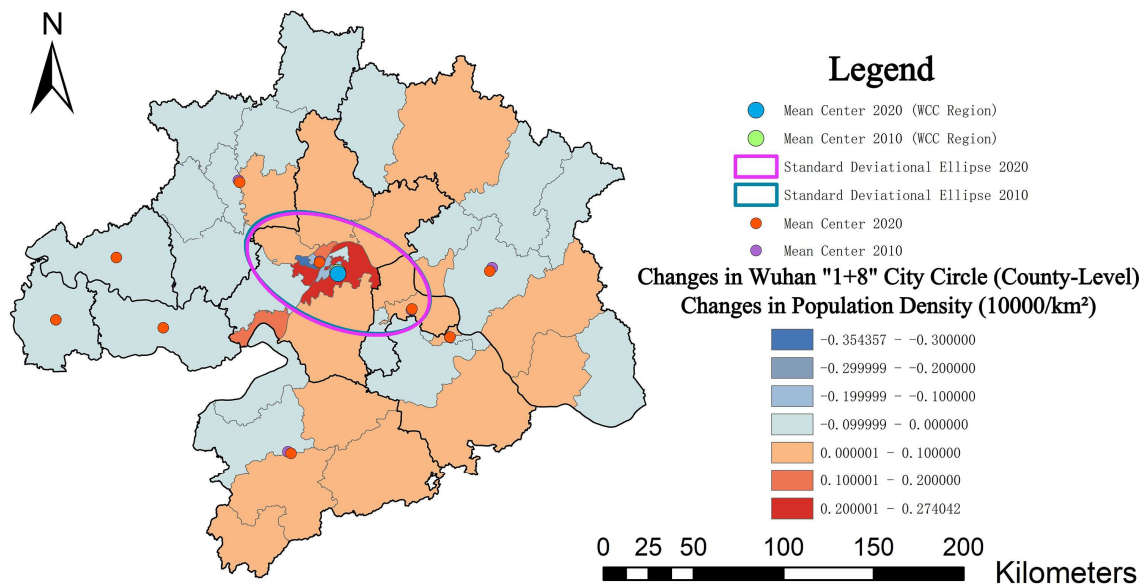


Figure 6. Population density variation of the Wuhan “1+8” City Circle from 2010 to 2020.

3.2.2. Spatial relations of population density in the county units of regions

The spatial autocorrelation results for population density revealed continuous changes over the past decade. Moran’s I increased from 0.502 to 0.569, with the *p*-value and *z*-value within the 99% confidence interval of the statistical test (Table 2). This indicates that the overall regional distribution of population density in 2010 and 2020 showed a general clustering trend, with the significance of this clustering increasing over time. This suggests that Wuhan has developed a more regular and centered high-value density cluster, attracting populations from other nearby regions within the WCC.

Table 2. Moran’s I result for the population density of the Wuhan “1+8” City Circle.

Year	Moran’s I	E-value	Variance	Z-value	P-value	Spatial relation
2010	0.502251	−0.021277	0.009699	5.315880	0.000000	
2020	0.568892	−0.021277	0.009961	5.913225	0.000000	

3.3. Dynamics variation of population structure characteristics

3.3.1. Spatiotemporal trends in the distribution of the gender structure

The spatial distribution of the population gender structure in 2010 and 2020 showed that all regions within the WCC had a higher proportion of males than females, except for Jiang'an of Wuhan and Huangshigang of Huangshi, where the proportion of females was higher (**Figure 7**). The overall change in population gender structure from 2010 to 2020 exhibited a north-south elliptical deviation (**Figure 8**), indicating that changes were more significant in the north-south direction than in the east-west direction.

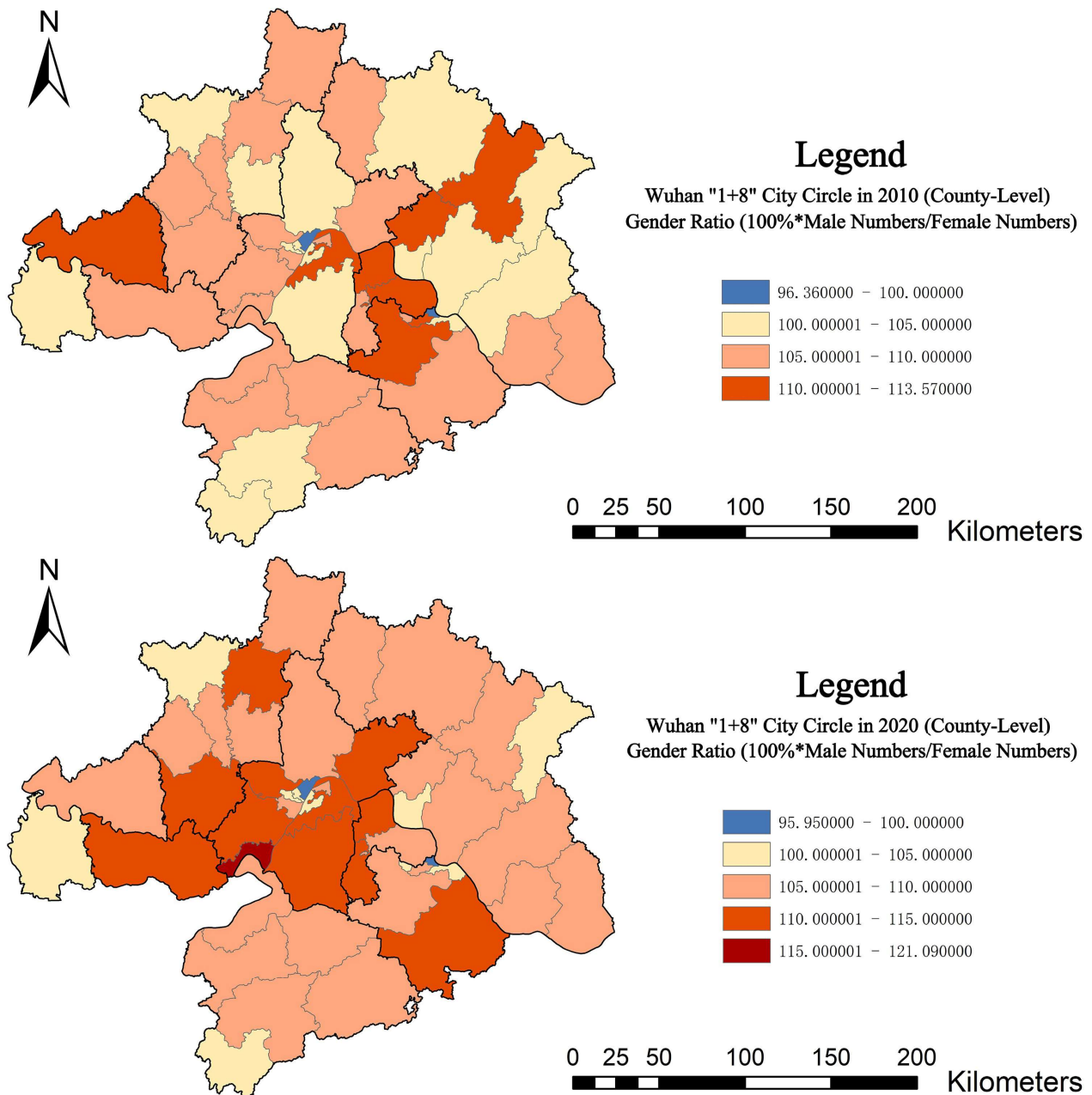


Figure 7. Gender structure distribution of the Wuhan “1+8” City Circle in 2010 and 2020.

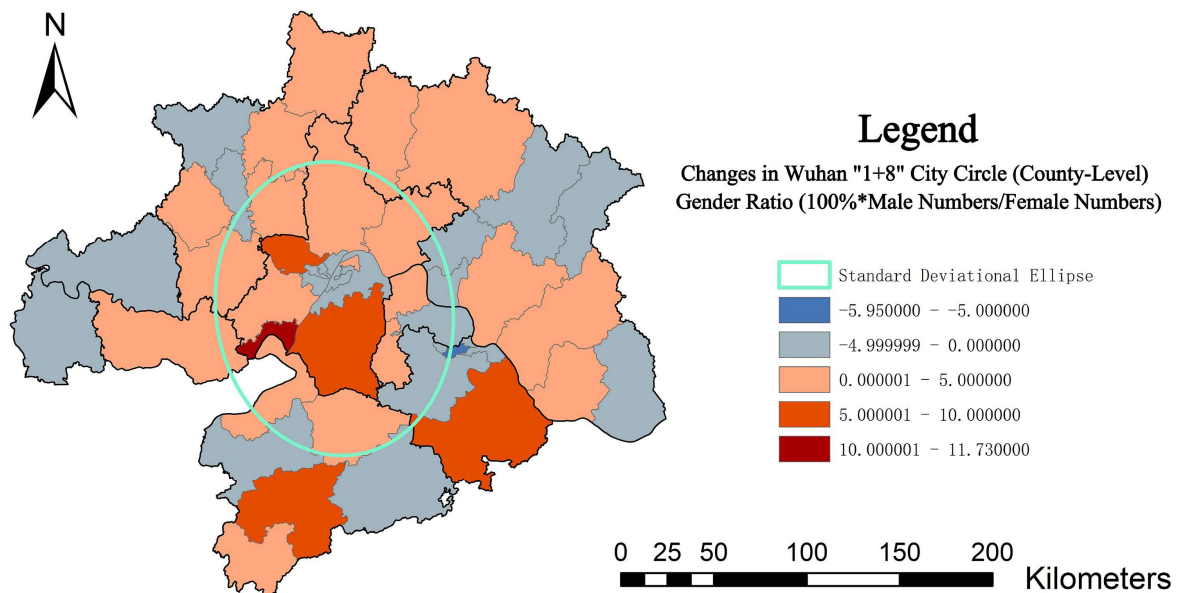


Figure 8. Gender structure variation of the Wuhan “1+8” City Circle from 2010 to 2020.

The regions of Dongxihu of Wuhan, Hannan of Wuhan, Jiangxia of Wuhan, Chongyang of Xianning, and Yangxin of Huangshi experienced an overall increase in the proportion of males from 2010 to 2020. This rise in Dongxihu, Hannan, and Jiangxia is likely influenced not by differences in the birth sex ratio but by population movement and migration affecting the gender structure. The presence of many industrial parks in Dongxihu, Hannan, and Jiangxia may have attracted more male laborers from surrounding regions due to labor shortages in these areas. Conversely, Echeng of Ezhou and Luotian of Huanggang showed an increase in the proportion of females. This change is less likely due to natural population growth differences and more likely a result of the loss of the male population due to the siphoning effect of Wuhan. This aligns with the social phenomenon in rural China, where “men would leave their homes to work outside while women remained behind to take care of the household in the past.” Therefore, the characteristic changes in the population structure of the WCC were likely to be affected by the regional migration of the labor force caused by the Wuhan siphon effect.

3.3.2. Spatiotemporal trends in the distribution of the age structure

The spatial distribution of the population age structure in 2010 and 2020 indicates that the age weights of the 0–14 and 65+ age groups are increasing, while the age weight of the 14–65 age group is decreasing (**Figure 9**). This suggests a decline in the labor force age group in 2020 compared to 2010. Most regions within the WCC experienced an increase in the 0–14 age group, ranging from 0 to 5 percent, and an increase in the 65+ age group by 5 percent or more from 2010 to 2020. These results highlight a significant aging trend in the WCC population over the decade [84]. The reduction in the proportion of the 65+ age group in Hannan of Wuhan may be attributed to the influx of a large labor force in the area, as it is home to numerous factories and industrial parks that require a substantial number of young and middle-aged workers (**Figure 9i**).

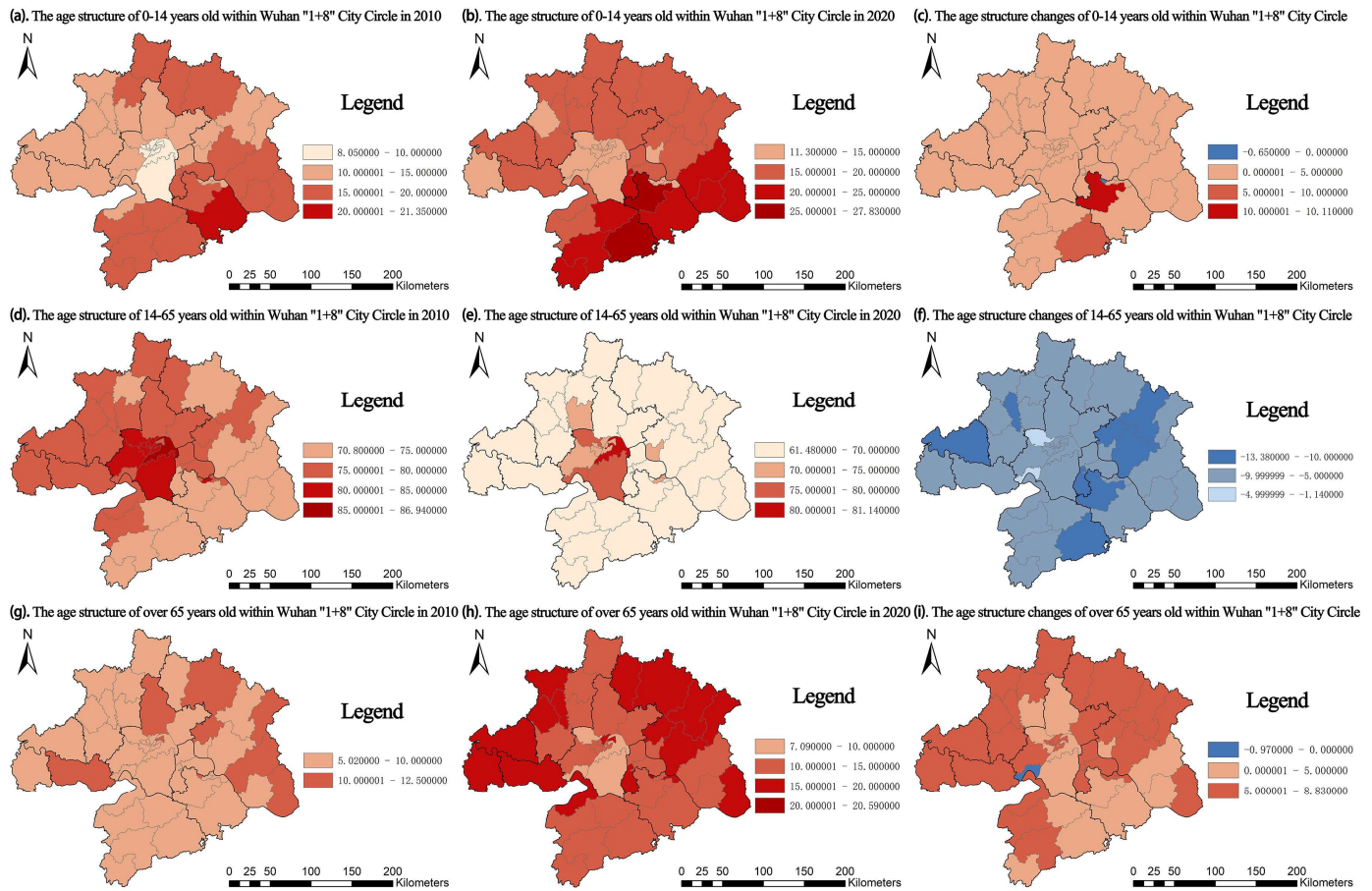


Figure 9. Age structure distribution and changes of the Wuhan "1+8" City Circle in 2010 and 2020.

4. Conclusion

As the core city of the WCC and the capital of Hubei Province, some units of Wuhan have seen significant population growth driven by natural increases and a pronounced population siphoning effect. Among the WCC's administrative units, Hongshan has experienced the most noticeable siphoning effect. This effect is further supported by the rapid development of the Donghu High-tech Zone in Hongshan, which continues to attract talent. The success of policies such as talent recruitment, the establishment of high-tech industrial parks, and initiatives to retain college graduates have contributed to this trend, enhancing the ability of Hongshan to attract population migration.

The analysis of population and population density from 2010 to 2020 reveals distinct trends. While the total population across the WCC shows a dispersal pattern, the population density has continued to cluster, with this clustering becoming more pronounced over the decade. This indicates that the WCC has evolved into a population magnet centered around Wuhan, with Wuchang and Hongshan emerging as crucial areas influencing this population siphoning effect. Regarding gender distribution, the WCC's overall structure reflects national trends, with a higher proportion of men compared to women. However, Jiang'an and Huangshigang are exceptions, where the proportion of females surpasses that of males. This disparity suggests that industrial parks in more remote areas of Wuhan may attract more male laborers, while the service-oriented industries in Hongshan may draw more female

workers.

Looking ahead, the WCC should continue refining and implementing policies to address the challenges posed by the population siphoning effect and ensure sustainable development. To better manage and adapt to evolving demographic trends, the WCC must focus on regional coordinated development, improving the population age structure, and enhancing data monitoring. Specifically, local authorities should optimize development strategies for regions experiencing significant population siphoning, such as Hongshan and Wuchang, and promote balanced regional growth. Policies encouraging childbirth and supporting family-friendly environments are essential to address the declining working-age population. Investment and construction in elderly care services and facilities should be increased to meet the aging population's needs. Finally, establishing a robust system for monitoring and forecasting population trends will enable timely policy adjustments and effective responses to demographic changes.

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Article

Heat adaptation and health in the informal housing—An exploratory research in Ahmedabad, India

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Abstract: As the global temperature rises, Urban Heat Island (UHI) impacts are slated to enhance in the cities due to temperature increase. The informal settlement dwellings, constructed of heat-absorbing materials, having poor ventilation, and located in neighborhoods with a lack of green and open spaces, are more vulnerable to heat than the formal housing settlements. Rising temperatures are expected to adversely impact the health of the population in general and of the dwellers of the informal settlements in particular. While replacing the entire informal housing stock with formal housing requires stupendous costs, modifying this housing through introducing cool roofs is an interim physical adaptation solution to mitigate the heat impacts. The objective of this exploratory study is to assess whether built environment characteristics, with emphasis on cool roofs introduced in dwelling units in the informal settlements in Ahmedabad City in India, have improved thermal comfort within these dwelling units and, if so, whether this intervention has translated into mitigating health impacts of heat. The study reveals that the cool roofs have reduced temperatures within the dwelling unit by 1 °C to 1.5 °C during peak summer days. But other built environment characteristics such as cross ventilation, ceiling height, trees adjoining the dwelling unit, and open space in the neighborhood too have contributed toward reducing indoor temperatures. Adaptation to high temperatures in the informal settlements requires localized, doable solutions in the immediate term.

Keywords: climate change & heat; informal housing adaptation; health

1. Introduction

The increase in average global temperatures is expected to have adverse consequences for health. The Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6 (AR6) states three facts: (i) the globe has experienced an average increase of 0.99 °C in the first two decades of the 21st century; (ii) the temperature increase recorded in the last decade (2011–2020) is higher by 1.09 °C over the 1850–1900 levels [1]; and (iii) there is a 50% likelihood of global warming reaching or exceeding 1.5 °C in the near term (i.e., 2021–2040) for the low greenhouse emissions scenario.

A long-term warming trend in annual mean surface temperature has been observed across Asia during 1960–2015, and the warming accelerated after the 1970s [2–5]. Furthermore, in South Asia, the projected warming is of 5 °C or less in the RCP8.5 [2]/SSP5-8.5 [3] scenarios and limited to 2 °C under the SSP1-2.6 [4]. The number of days experiencing excess heat stress 41 °C and above is expected to increase by 50–150 days for SSP5-8.5 at the end of the century and up to 30 days for SSP1-2.6 and above 35 °C by 10–50 days by the mid-century under SSP5-8.5 [5,6]. India could experience heat waves beyond human survival limits, states a World Bank Report [7]. In a business-as-usual scenario of global emissions, India's average temperature will

rise by 4.4 °C (39.9 °F) by 2100, while heatwaves will multiply by a factor of two or three and their duration will double compared to the 1976–2005 period [8,9].

The year 2024 is said to be globally the hottest year so far [10]. The year 2023 has experienced unprecedented high temperatures; up to 2nd October, around 86 days in the year have been over 1.5 °C warmer than the pre-industrial average [10]. In India too, a recent study points to unprecedented heat waves across Indian cities [11]. Heat waves in cities translate into Urban Heat Island (UHI) effects, which have worsened the local effects of rising temperatures [11]. UHI is an outcome of multiple factors at the city level, which is discussed later in this section. The heat stress or thermal discomfort thus created is not just a function of rising temperatures but a combination of air temperature, land surface temperature, and relative humidity [11].

The rising temperatures, along with humidity factors, are expected to have health implications. The IPCC's Reports of the Sixth Assessment Cycle have indicated that the heat-related risks have increased. Certain groups are vulnerable to heat-related health risks, such as infants, the elderly, people with physical disabilities, the underprivileged, outdoor laborers, slum dwellers, and others [12,13]. High temperatures present a hazard, but risk related to heat is a function of social, economic, demographic, infrastructural, and physical environmental variables in particular [14,15]. In the cities of the global south, the poor tend to work in the informal economy and live in crowded housing, experiencing high heat stress [16]. They also have limited capacity to cope and hence are more vulnerable to heat conditions due to, in general, poor nutrition and health that reduces their immunity to heat, and poor access to water are more vulnerable to heat conditions [16,17].

Recognized direct effects of weather and climate on physical health include heat stress; respiratory conditions linked to heat combined with air pollution and aeroallergens; injury from floods, landslides, and windstorms; plus illnesses from vector-borne and infectious disease, as well as water- and food-related pathogens [18,19]. There is also growing evidence of “unseen” impacts of extreme weather events on mental health, such as post-traumatic stress disorder, anxiety, depression, complicated grief, survivor guilt, recovery fatigue, substance abuse, and even suicide [20,21]. The physiological responses to excessive heat exposure are well-known—ranging from heat rash, oedema, dizziness, dehydration, and cramps to heat exhaustion, heatstroke, and death [22]. Existing pulmonary, cardiac, kidney, and psychiatric illnesses also may be aggravated by heat. Heat-related mortality and morbidity are expected to rise in Asia over the coming decades, driven by a combination of climate change, rapid population and urban growth, and demographic change [23].

In the recent heat waves in India, more than 100,000 people have died [24,25]. Azhar et al. [24] have speculated that the increase in mortality in Ahmedabad during periods of high temperatures is heat-related mortality. High temperatures lead to heat-related mortality and morbidity, such as dizziness, unconsciousness, blood pressure increase, abdominal pains, chest pains, and vomiting [26]. In summer 2017, of the 10,135 heat-related emergencies handled in Ahmedabad by the emergency ambulance service during April–May 2017, abdominal pain constituted 25 percent, followed by unconsciousness (22 percent), victim falling (15.2 percent), and chest pain (11.9 percent) [27]. In May of 2022, based on the data from an emergency ambulance

service, 5055 cases of heat-related emergencies needed patients to be transported to hospitals in the city, i.e., 163 patients per day [28]. Dehydration and salt loss lead to low blood pressure, further causing dizziness and then body ache. It also leads to fever. The ultimate effect is loss of working days. The heat-related morbidity and mortality were not reported in the summer months of 2020 and 2021 due to the health systems being overrun by COVID-19 cases [29]. The heat-related illnesses are an outcome of a combination of pre-existing medical conditions, exposure, age, and access to health information and resources [30], which does not take away the fact that heat has been the trigger of the health effects mentioned above. This paper focuses on heat stress experienced within Dwelling Units (DUs) in a city in India, namely Ahmedabad.

1.1. Built-form and indoor thermal stress

The indoor heat experience is influenced by the immediate outdoor ambient temperature and housing characteristics. The immediate outdoor ambient temperatures are influenced by different factors at different levels in a city (**Table 1**), besides the changes in average temperatures at the city level [31]. The built-form factors such as land use, density, transport systems, housing type, building materials, and Dwelling Unit (DU) built characteristics influence temperatures experienced within individual Dwelling Unit (DU). This implies that adaptation to rising temperatures requires actions at all these levels. In this paper, we focus on actions at the individual DU and immediate neighborhood level, where households and communities have control. The actions at other levels are in the remit of the city government, which is outside the scope of this research.

Table 1. Factors influencing heat experience at the dwelling unit level.

Level	Factors	References
1 City-level	• Density of the city	Schatz and Kucharik [32]; Wang et al. [33]; Zander et al. [34]; ADB [16]
	• Spatial structure: land uses and built form	Xu et al. [35]; Soltani and Sharifi [36]
	• % Green and Blue spaces	Schatz and Kucharik [32]; Gunawardena et al. [37]; Emmanuel and Loconsole [38]; AbotElata and AbdElfattah [39]; Yu et al. [40]; Rahul et al. [41]; Borthakur et al. [42]
	• Local weather such as cloud cover, wind speed, relative humidity, etc.	Schatz and Kucharik [32]
	• Availability of Public Transport / Traffic congestion	Lee et al. [43]
2 City's Sub-region level	• Density	Pramanik et al. [44]; Stone et al. [45]; Zander et al. [34]
	• Spatial structure: land use and built form	Xu et al. [35]; Elmarakby et al. [46]
	• % Green and Blue Cover	Schatz and Kucharik [32]; Gunawardena et al. [37]; Emmanuel and Loconsole [38]; AbotElata and AbdElfattah [39]; Yu et al. [40]; Rahul et al. [41]; Borthakur et al. [42]
	• Income of neighborhood	Jacobs et al. [47]
	• Air pollution level	ADB [16]

Table 1. (Continued).

Level	Factors	References
3 Immediate Neighbourhood level	• Density	Pramanik et al. [44]; Stone et al. [45]; Zander et al. [34]
	• Spatial structure and Built form including building materials	Xu et al. [35]; Lee et al. [43]; Elmarakby et al. [46]
	• % Green and Blue Cover	Schatz and Kucharik [32]; Gunawardena et al. [37]; Emmanuel and Loconsole [38]; AbotElata and AbdElfattah [39]; Yu et al. [40]
	• Proximity to open space	Xu et al. [35]
	• Use of air-conditioning	Lee et al. [43]
	• Income of neighbourhood	Jacobs et al. [47]
	• Street canyon direction and materials	Xu et al. [35]
4 Individual DU level	• DU roof and wall materials	Alexandri and Jones [48]; Doick and Hutchings [49]; Zhao et al. [50]
	• Storey on which DU is located	Tomilson et al. [51]
	• Number of walls exposed to direct sun	Alexandri and Jones [52]; Doick and Hutchings [49]; Zhao et al. [50]
	• Cross Ventilation	Satterthwaite et al. [52]; Head et al. [53]
	• DU layout	Lomas and Giridharan [54]
	• Treatment of roof for increasing albedo and reducing heat transfusion or vice versa (i.e. use of heat absorbing materials such as tar)	ADB [16]
	• Use of cooling devices	Jay et al. [55]

Source: By the author.

At the city level, the temperatures are, first of all, impacted by overall weather and the formation of heat waves [31]. Thereafter, density is considered to be the primary driver of temperature patterns; the higher the density, the higher is the temperature [33,34]. Density at the sub-city level and neighborhood level too matter. There is a strong positive relationship between the density index and heat index, which then translates into heat-related health impacts [44]. While climate change mitigation promotes high density, this also has the possibility of creating local heat islands [45,56], which is indeed an issue that requires further attention. Urban morphology, that is, the built-up density, building heights, street pattern, land use, surface cover, etc. also determine Urban Heat Island Impact (UHI) effects [46].

The secondary drivers of the temperatures are wind speed, cloud cover, relative humidity, etc. Wind circulation can have two different types of impacts; if there are water bodies nearby, then when hot air rises, cool air from the surrounding areas with either higher tree cover or a water body moves in and reduces the temperatures.

Both blue and green spaces and their proportion in the city influence the average temperatures at the city level as well as smaller than city spatial levels [37–39]. Green areas have high albedo. The canopy of trees prevents heat from reaching the street canyon. Air temperature in spaces with green cover is lower than in spaces without green cover at the same time of the day [39]. Research shows that the blue-green spaces have cooling effects not only in the area where these are but also in the surrounding areas [40]. More built spaces and fewer green spaces lead to intense UHI [36].

Evidence is growing that rapid urban expansion and loss of green space are contributing to more intense heat waves in tropical cities. Conversely, the protection of green areas and water bodies can create a cool “oasis effect,” especially for cities in arid and semiarid climate zones [41,42]. Unfortunately, people residing in high-density, informal neighborhoods are more exposed to higher ambient temperatures than those residing in affluent neighborhoods [46].

At the sub-regional and neighborhood level, open spaces provide a possibility of reducing air temperatures. Open spaces help in heat diffusion [35]. Mahadevia et al. [57] also find that more open space and green cover assist in reducing indoor temperatures; however, open space has a greater impact than tree cover.

At the sub-city and neighborhood level, the UHI effect is enhanced by the materials used in building façade; glazing and concrete used in façade and asphalt roads enhance UHI effects [43]. The use of air conditioners, which are prominent in dense urban areas as well as commercial areas, also leads to an increase in the UHI effect [43]. In dense areas, there is high traffic and hence congestion, which also leads to an increase in local temperatures [43]. Narrow streets, low urban permeabilities, and tall buildings that create road canyons where the wind does not flow can also lead to a high UHI effect [46].

Building design and layout, occupancy level (crowdedness), ventilation [52,53], and building materials in particular the roofing materials [48] (discussion on roofs follows) influence indoor temperatures at individual building levels. Indoor fans are beneficial up to 45 °C [55].

In cities of the global south, low-income housing such as squatters, slums, and other informal housing is more vulnerable to heat stress than formally built housing [52,58] due to crowded living conditions, low-quality housing [58] with inadequate ventilation, and limited access to cooling in the former [16]. The DUs in informal housing are generally made of heat-trapping materials such as tin, asbestos, cement sheet, plastic, cardboard, plywood scraps, polyvinyl chloride or PVC tarps, etc., especially for roofing [16], which transfer heat indoors, which cumulatively reduces the ability to cool down [59]. The prevalence of cooking stoves inside ill-ventilated DUs and economic activities within these exacerbate the indoor heat experience [60]. The absence of greenery and tree shade around the houses also adds to indoor heat stress [60]. Many households lack reliable water and electricity supplies [16], two essential items for cooling during heat waves. These housing do not meet mandated building or planning standards and are often poorly located, such as near industrial states, in settlements with no or little open spaces and narrow roads preventing air circulation [52].

In the cities in India and South Asia, where a large proportion of households are living in the informal housing described above, immediate interventions to cope with rising heat stress are required. One option for heat adaptation in the informal settlements is transiting the households living in these settlements to formal housing, with planned neighborhoods, basic services such as water supply and electricity, and well-ventilated DUs. This is an expensive option, as proved by Mahadevia et al. [57], taking the example of Ahmedabad. Thus, modifying housing is an important immediate local-level adaptation intervention to heat and building short-term resilience to climate change [16,57,61].

1.2. Adaptation measures in informal housing

Housing-related adaptation measures include solutions at individual DU levels that deal with roofs, wall materials, building form, ventilation, etc., as well as neighborhood level, such as treating pavements (cool pavements) [16], if any, and greenery around. In low-income housing, the individual DU-level interventions have to be simple and cost-effective. If informal housing has to be made heat-proof, investments are required, which would require policy measures and fiscal support for upgrading, which, however, Satterthwaite et al. [52] argue is hard to come by. Nonetheless, actions are recommended to deal with increasing heat stress in informal housing.

One of the widely used measures to reduce heat transfer within DUs is to modify roofs. These measures include roof insulation, cool roofs, and radiant barriers. Although roof insulation is quite commonly used, cool roofs and radiant barriers are relatively new solutions. Cool or high-albedo roofs refer to the outer layer or exterior roof surface that acts as the key reflective surface. Radiant barriers are a way of increasing the thermal performance of a roof by introducing a new layer with low emissivity below the roof surface [62]. Based on the literature, cool roofs appear to offer the most viable solution for the urban poor: they are more cost-effective than insulation and feasible for new buildings as well as retrofitted ones.

There are three types of cool roofs: naturally cool roofs (use of white vinyl or white surface materials), coated roofs, and insulated roofs (using a thermal barrier) [16]. Studies [59,63] have categorized cool roof techniques in the context of lower-income communities into three categories: Tiled or painted cool roofs, membrane cool roofs such as a sheet covering existing roofs, and special cool roof materials such as Mod Roof. Tiled/painted cool roofs, which includes the application of white paint, or in the case of Ahmedabad (the focus of this paper), the application of white lime paint. Ultra-white vinyl paints can achieve more than 98 percent sunlight reflection [64]. Membrane cool roofs, that is, adding a membrane or sheeting to cover the roof, as used in the Hyderabad Cool Roofs Programmer, which uses a high-density polyethylene (HDPE) cool roof membrane [65]. Special cool roof materials such as Mod Roof, which is made of coconut husk and paper waste, have been installed in households around Gujarat and Delhi and can serve as an alternative to reinforced cement concrete (RCC) roofs. The introduction of a thermal barrier (thermocool, cardboard, etc.) as a membrane also insulates roofs [64]. Made of packaging waste and coconut fiber held together by a natural binder and covered in waterproofing material, the Mod Roof panels are made to be strong, waterproof, fireproof, and long-lasting, which improves safety and decreases maintenance.

We have limited research available on housing, heat experience, and health in Indian cities and whether physical adaptive measures at the DU level positively impact both. There can be many local-level physical adaptive measures, such as increasing blue and green cover and shifting from hard to soft surfaces in the immediate neighborhood level and changing the building materials to ones that have high albedo, such as brick walls instead of concrete or glass walls, and replacing GI or asbestos sheet roofs with concrete or covering GI or asbestos sheet roofs with less heat-absorbing materials, as discussed above. In this study, we focus on these physical

adaptive measures, starting with the cool roofs and then including other physical variables such as open and green spaces in the neighborhood and micro conditions such as the height of the ceiling, availability of cross ventilation, and shades over openings.

This study is different from available studies on heat impacts in India as well as in Ahmedabad. There are general studies on changing temperatures and factors influencing experienced heat stress in selected cities in India. A few studies have analyzed temperature trends and linked these with the reported mortality rates at the city level. One such study is by Azhar et al. [24], which links excess in reported mortality rates to periods of high temperatures. We find fewer empirical studies of the health impacts of cool roofs on the residents of informal housing. The ones available measure the impact of roof treatment on heat stress within informal housing. For example, a study in South Africa found that cool roof paints can improve the performance of uninsulated, low thermal mass homes in informal settlements by lowering heat stress conditions by 42%–63% [66]. A study in Ahmedabad [67] showed Mod Roof was found to be 4.5 °C cooler than conventional roof types. Both these studies stopped short of assessing health impacts. Studies related to adaptation efforts are restricted to specific work groups such as police, construction workers, etc. But adaptations at the house level are a few. Furthermore, we do not have studies that analyze the combined effect of cool roofs, other local housing conditions such as open and green spaces in the neighborhood, and micro conditions such as the height of the ceiling, availability of cross ventilation, shades over openings, etc. The Cool Roofs programme is recommended as a solution to heat adaptation in Indian cities. Thus, such micro-level analysis of what works at the individual DU level offers a grounded solution to heat adaptation. Hence, learnings from this research will contribute towards a swifter adaptation of informal housing to increasing temperatures due to climate change. These are the low-hanging solutions that can be easily implemented at the local community and household level.

This is an exploratory study, with 120 sample households living in the informal sector in the city. This paper assesses the impact of cool-roof intervention as a mechanism to adapt to extreme heat in the informal housing in Ahmedabad City (population of about 8 million), India, and its consequent health impacts. The city has been selected because of the implementation of the Cool Roofs programmer in the city by Mahila Housing Trust, first on a pilot basis in 2017, and then 15,000 DUs in the slums in 2020 [68]. The city introduced the first Heat Action Plan (HAP) in 2010 [69], which is reviewed every year. But this HAP is an early warning system. In recent years, after the first pilot Cool Roof implementation, the Cool Roofs programme has also been included in the city's HAP. About 22 cities in India have HAPs, of which a quarter have proposed Cool Roofs and one in five have proposed increasing green cover as solutions (This data is based on sifting through climate adaptation measures announced by 133 cities in India).

The objectives of this study are (i) to assess the impact of the built environment characteristics with an emphasis on cool roofs on temperatures experienced within the dwellings in the informal settlements, and (ii) if the temperatures experienced indoors have reduced due to built environment characteristics, then to assess whether it has impacted the health status of the residents of these dwellings.

2. Approach, materials & methods

Generally, epidemiological studies of heat-related health effects use outdoor weather conditions as the primary indicator to estimate indoor heat stress [70,71], and policymakers too use heat-health warnings based on outdoor temperatures [72], as in the case of Ahmedabad's Heat Action Plan (HAP) [73]. This reliance on outdoor conditions can mislead the interpretation of health effects and associated solutions since most people who stay indoors are assumed to be protected from outdoor thermal conditions [74].

The study is located in Ahmedabad, which has had the Ahmedabad Cool Roofs Programme [63] since 2017. We adopted the granular approach of looking at the housing conditions in great detail, such as roof materials, type, treatment, and height; wall materials, walls exposed to sun, and overhang on walls; and openings and their locations. We also looked at the characteristics of the immediate neighborhood, such as street conditions, tree cover, and neighborhood-level land use. The granular analysis at the immediate neighborhood level and the house levels gives adaptation solutions at the housing as well as neighborhood level, which local communities and NGOs can assist in implementing.

Ahmedabad, located in Gujarat state (**Figure 1**), has been selected for the research site because of the ease of conducting fieldwork—the research team being located in the city, high and increasing average temperatures in the city (see **Figure 2**), a non-governmental organization (NGO) (Mahila Housing Trust (MHT)) working with the slum dwellers to increase their resilience to increasing temperatures, and a heat action plan (HAP) at the city level. The MHT has been assisting individual households to treat their roofs; for example, replace their roof with a Mod Roof [70], and paint their roofs white (with lime-mixture or paint) to reduce internal temperatures. The municipal area, which covers an area of 466 sq. km, is under the jurisdiction of the Ahmedabad Municipal Corporation (AMC).

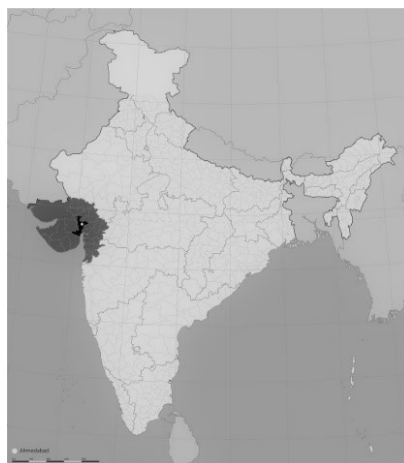


Figure 1. Location of Ahmedabad.

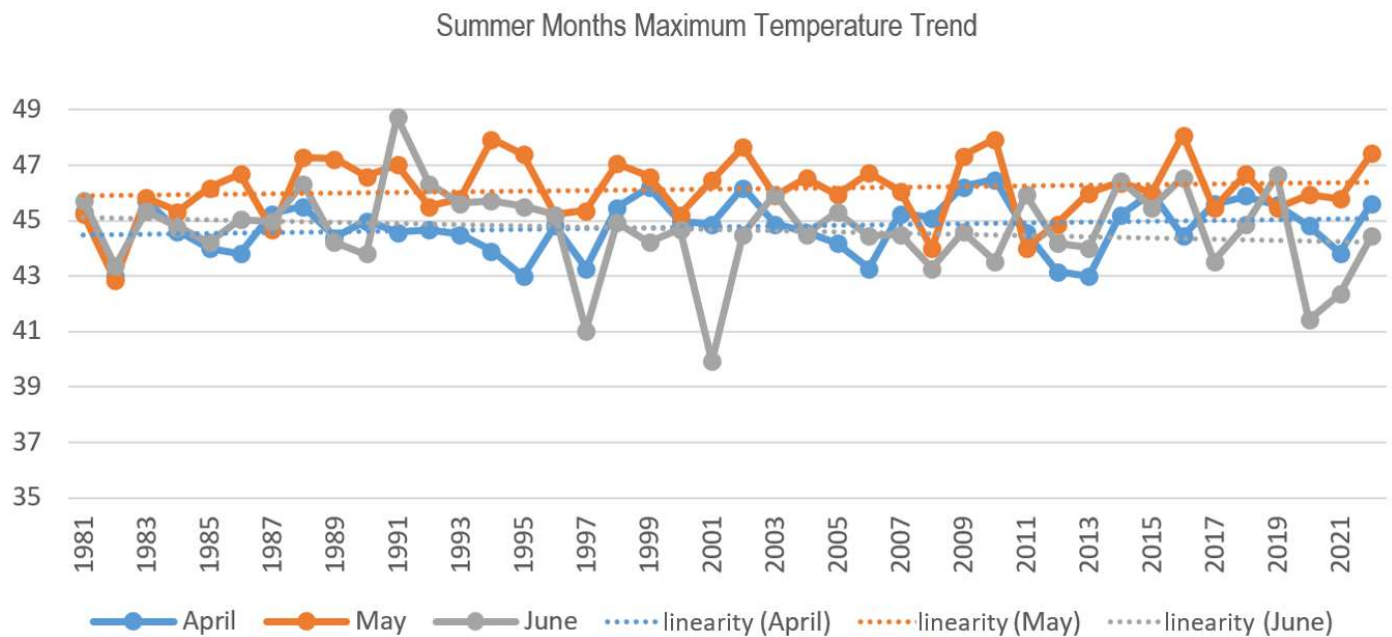


Figure 2. Summer maximum temperature trend, Ahmedabad [75].

Ahmedabad faces a major climate risk, i.e., the increase in observed ambient temperature and frequency of heat waves [76]. The city's warm, dry conditions are conducive to heat waves. The Ahmedabad HAP defines a heat wave as daily maximum temperatures in excess of 40 °C (104 °F) as measured at the Ahmedabad Meteorological (Met) Centre [68]. It issues a yellow alert when the temperature is between 41.1 °C and 43 °C, an orange alert for 43.1 °C–44.9 °C and a red alert when temperature exceeds 45 °C.

Morphologically, Ahmedabad is broadly divided into two segments, the east and the west. Eastern Ahmedabad, to the east of the river Sabarmati, consists of the 600-year-old walled city and the industrial areas around it on the north, east, and south, all the way to the eastern boundary of the city. The low-income households live close to the industrial areas in eastern Ahmedabad. The western parts of the city are occupied by higher income groups and locate new high-end gated community developments. The western parts of the city have more green and open spaces than the eastern parts. On the whole, only 2% of the AMC's land area is under green cover, which is very low by the norms mentioned in the city's Development Plan [77].

We decided to conduct a household-level survey in collaboration with the MHT, whose settlement-level contact person identified sample DUs with cool roofs. We then decided to select other DUs close by without a cool roof to assess the benefit of the intervention. In no way is the purpose of this research to assess MHT's efficacious intervention but to assess what types of interventions have helped in reducing temperatures experienced within a DU. Being knowledgeable about the diversity of DUs in informal housing and weary of the reductionist approach of bunching all of these under one broad brush of 'informal housing', we decided to explore the differences within such DUs. The sample DUs in the nine selected informal settlements varied in their floor layouts, materials used for roofs in particular, treatment of roofs, roof heights, openings in the walls, number of storeys, green coverage nearby, and road conditions. The household survey solicited information

related to the physical characteristics of the surveyed DU, including the location of the kitchen, availability of water supply and electricity, neighborhood characteristics such as street features, green cover, and open space nearby, and land use of the city's sub-region, the socio-economic profile of the household, reported illness in the 15 days before the survey, and measures taken to address illness.

We measured temperatures immediately outside the DU and within the DU with the fan on and fan off using a hand-held Wet Bulb Global Temperature (WBGT) device. The city's average temperature was the one measured by the Indian Meteorological Department and displayed on smartphones. We recorded the city's average temperature in the survey form at the time of indoor and outdoor temperature measurement in the selected households. Household surveys were carried out from 2 June to 17 June 2022, in the daytime. We did not measure nighttime temperatures. It is important to mention that we could have installed temperature-measuring devices within the DU and could have asked the residents to record night temperatures as well. However, we were not confident of the response rates from among those surveyed.

We have created a measure called Local Heat Island (LHI) that gives the difference between the city's average temperature at the time of the survey and the outdoor temperature measured using WBGT. We have refrained from using the concept of UHI, which is commonly used in research, as it is hard to obtain temperatures around the city's periphery to assess the UHI.

The survey was conducted in 121 households spread over nine settlements, three in West Ahmedabad, one near the walled city of Ahmedabad, and the rest five in East Ahmedabad (**Figure 3**). The valid answers received were 117. Two peripheral settlements in East Ahmedabad were located in the industrial area (**Table 2**). Although we started to identify our sample around cool roofs, only 17.9 percent of sample households had cool roofs, and in three settlements none had any treatment of roofs to deal with heat. The survey covered 553 individuals.

Table 2. Housing characteristics by settlement.

Settlement	Location	Number of sample HHs	% HHs with cool-roofs	% HHs living in single-storey DUs	% HHs with ceiling height <10ft	% HHs having open ground nearby	% HHs having a tree adjoining DU	% DUs having cross-ventilation
Bhagwatinagar (E-1)	East Ahmedabad-periphery	6	50.0	100	100	0	33	0
Mahavirnagar (E-2)	East Ahmedabad	10	60.0	100	80	10	0	40
Sarapur (E-3)	East Ahmedabad	21	28.6	100	95	38	29	71
Patannagar (E-4)	East Ahmedabad	17	11.8	100	76	6	6	29
Vishwasnagar (E-5)	East Ahmedabad-periphery	11	18.2	100	45	18	0	100
Prem darwaza (C-1)	Walled City	10	10.0	100	90	0	20	20
Jadibanagar (W-1)	West Ahmedabad	16	0.0	94	87	25	6	88

Table 2. (Continued).

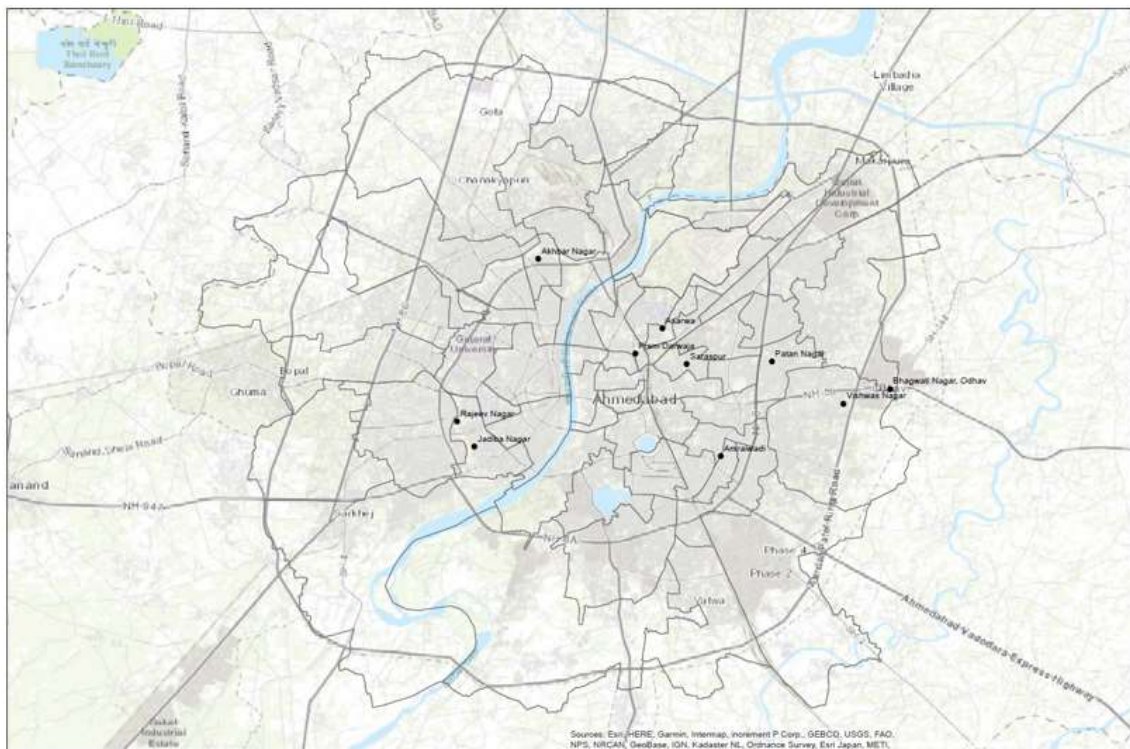
Settlement	Location	Number of sample HHs	% HHs with cool-roofs	% HHs living in single-storey DUs	% HHs with ceiling height <10ft	% HHs having open ground nearby	% HHs having a tree adjoining DU	% DUs having cross-ventilation
Akhbarnagar (W-2)	West Ahmedabad	11	0.0	100	93	53	33	60
Rajeevnagar (W-3)	West Ahmedabad	15	0.0	73	82	18	18	82
Total		117	17.1	97	84	22	16	59

Source: Primary survey.

3. Results

3.1. Sample profile

In the sample of 553 persons, 36 percent, or 207 were, children and 12 senior citizens. The average household size of the surveyed is 4.8. The average monthly income of the households covered was INR 15,881 (USD 203 (At the exchange rate of 1USD = INR 78 in June 2022)). All households, therefore, belong to the low-income category.

**Figure 3.** Surveyed settlements on Ahmedabad map.

Source: Prepared by the author.

Table 2 gives housing conditions for the surveyed households in each of the settlements. All but four Dwelling Units (DUs) in the sample were single-storey or ground floor. The implication is that all of these DUs would have been exposed to direct heat from the roof. Twenty DUs used mechanisms to cool the roofs (**Table 2**). However, in two settlements, E-1 and E-2, more than half the surveyed DUs had used some method of cooling roofs. Seven DUs had modified roofs, such as adding a

bamboo layer at the top, putting thermacol sheets or cardboard below the roof, and putting porcelain tiles or wood planks on the roof. Thirteen households had painted the roof with white paint. All DUs had brick walls. Half the DUs were with GI or asbestos sheet roofs, another 42 (36 percent) used cement sheet roofs, and 11 DUs had concrete roofs. Five DUs had *katcha* roofs using bamboo, thatch, plastic, etc., as roof materials. Most DUs were in good condition. Eighty-four percent of DUs had a ceiling below 10 feet, and the remaining ones had a ceiling higher than 10 feet. All surveyed DUs had electricity access; all surveyed households reported access to toilets; 97 percent of them had an individual toilet. All households except three reported access to tap water. Thus, all the surveyed DUs had basic services.

About 60 percent of the DUs had cross-ventilation, but none in E-1 and less than 30 percent of the DUs in in C-1 and E-4 had cross-ventilation. Most of the DUs had two walls shared with adjoining DUs and thus had only two walls exposed to direct heat. Lastly, 65 percent of the surveyed DUs were located on streets that were shaded. These settlements are crowded and lack open grounds. Only 16 percent of DUs reported having a tree in proximity. The plans and photos of the surveyed settlements and DUs in them are presented in **Figures 4 and 5**.



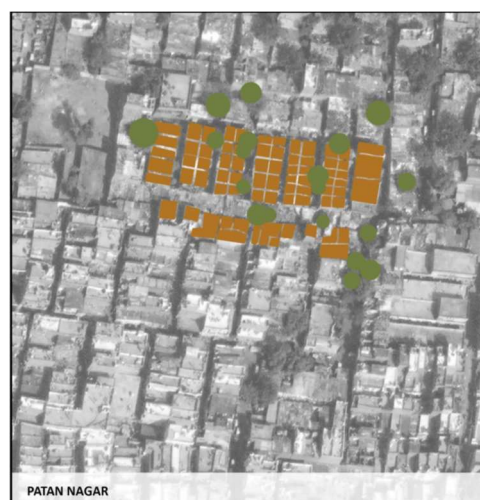
E-1



E-3



E-2



E-4

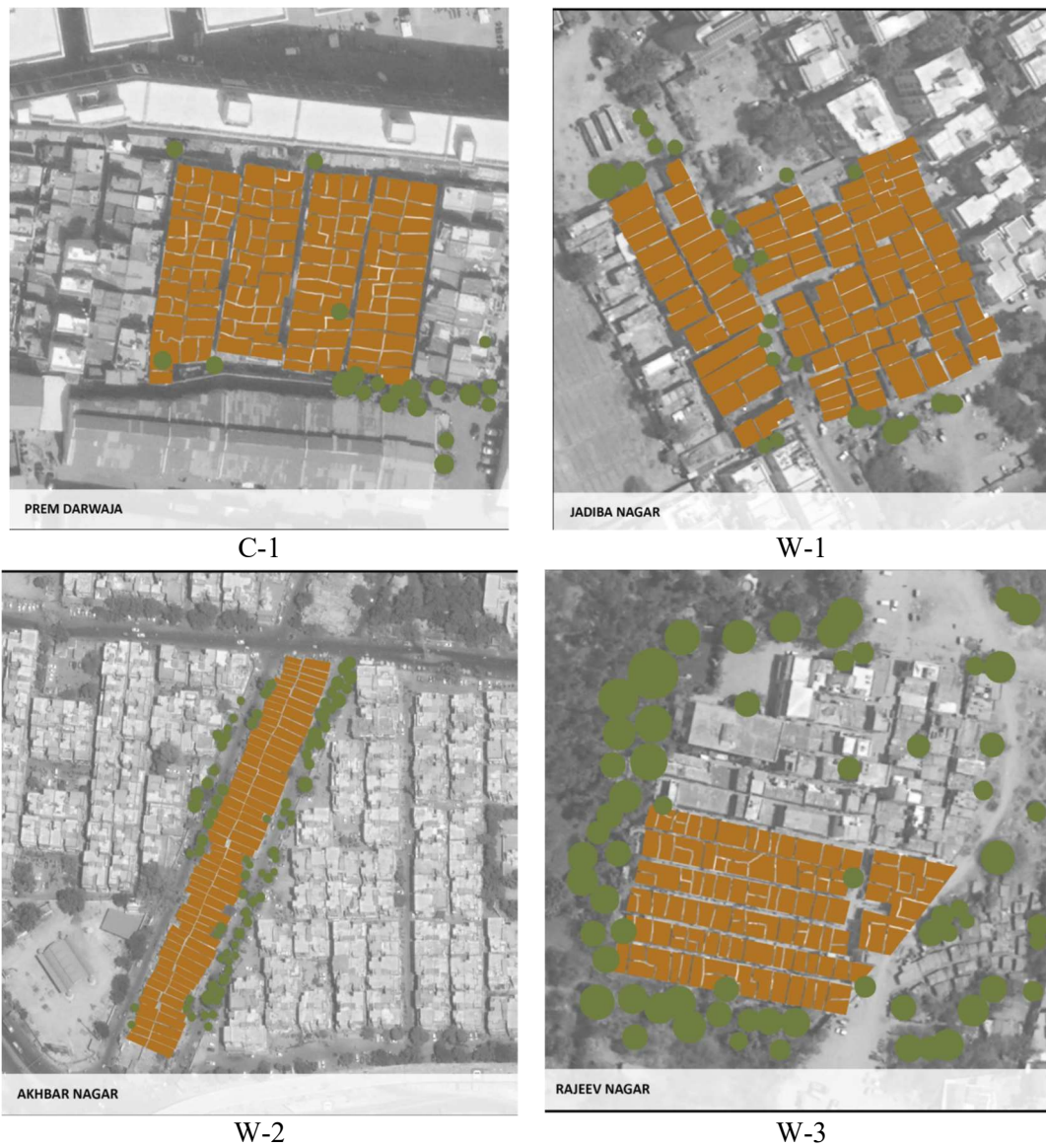


Figure 4. Settlement layouts and photos.





Cool Roofs



Cool Roof

Figure 5. Settlements' visuals.

3.2. Temperatures experienced

During the period of our survey, which spanned from 2 June to 17 June 2022 but was carried out only for nine days during the period, the city's average temperature was 37.06 °C, with a maximum being 40.16 °C and a minimum of 32.72 °C (see **Figure 6**). On all the days of the survey, the temperatures recorded outside the DU were higher than the city's average at the time of the survey, indicating the formation of a Local Heat Island (LHI) (**Figure 6**). The average indoor temperatures recorded

with or without a fan on, as well as outdoor temperatures on all days of the survey, were higher than the average temperature of the city at the time of the survey (**Figure 6**). Thus, we can observe the LHI that has kept indoor temperatures high in the surveyed DUs.

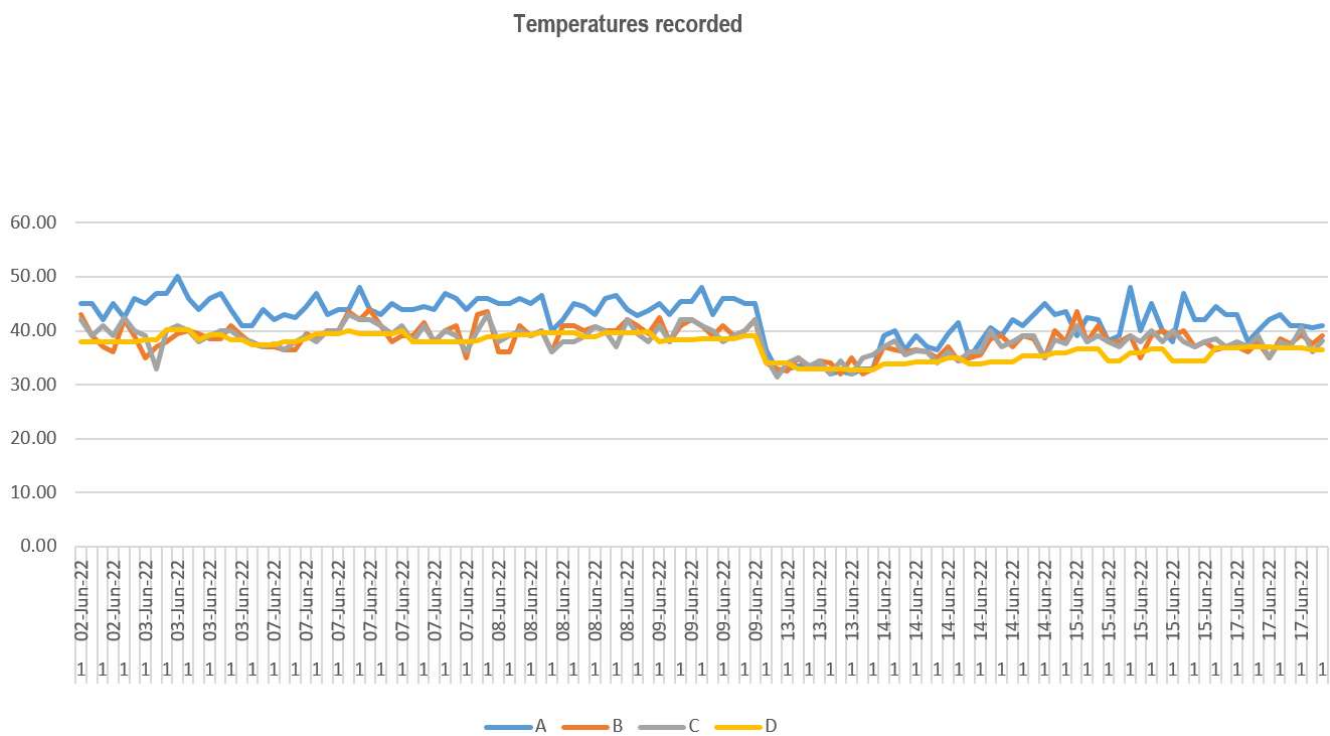


Figure 6. Temperatures observed during survey period.

A = Temperature Recorded Outside DU; B = Temperature Recorded Inside House with Fan On; C = Temperature Recorded Inside House with Fan Off; D = City's Temperature at the Time of Survey (displayed on smart phone).

Geographically, the settlements in East Ahmedabad, except E-5, experienced much higher LHI, which is the difference between the city's average temperature at the time of survey and the on-site temperature as compared to the three settlements in West Ahmedabad. The exception is W-2, where the LHI impact is 6.34 °C on the day of the survey, but the average temperature outside DU in the settlement is lower than in East Ahmedabad settlements. Average temperatures recorded in the settlements in East Ahmedabad, i.e., outside DU, and temperatures experienced within the DUs are higher than in settlements in West Ahmedabad (**Table 3**). On the day the survey was canvassed in E-5, the highest temperature of the day was 35 °C [78] as it was a cloudy day. We have thus excluded E-5 from further analysis. The LHI impact was observed in all the settlements. It has led to an increase in temperature in the settlements studied, represented by the temperature measured outside the DU (**Table 3**). On average, over the whole sample, the temperature increase due to LHI impact is 5.20 °C, indicating that most settlements selected for the study have experienced higher local temperatures as compared to that of the city at the time of the survey (**Table 3**).

Table 3. Temperatures recorded on survey days by settlements (in °C).

Settlement	Temperature outside DU	Temperature inside DU with fan	Temperature inside DU without fan	City's average temperature	LHI Impact measured in °C (A-D)
	A	B	C	D	
E-1	44.25	39.33	40.58	37.98	6.27
E-2	45.70	38.60	38.85	39.05	6.65
E-3	44.21	39.26	39.26	38.57	5.64
E-4	44.54	39.99	39.24	39.35	5.19
E-5*	33.22	33.46	33.86	33.15	0.07
C-1	45.20	40.55	40.30	38.49	6.71
W-1	39.53	36.63	36.72	34.37	5.16
W-2	41.95	38.90	38.47	35.62	6.34
W-3	41.55	37.39	37.65	36.81	4.74

* Vishwasnagar data has been excluded from further analysis due its data captured on low temperature day.

Source: Primary survey.

3.3. Effect of cool-roofs on IN-DU temperatures

Seventeen percent of surveyed households had made efforts to cool their roofs with the purpose that the temperature experienced inside is lower than that of the outside. In this paper we have used the adaptive thermal comfort band as 24 °C–35 °C based on Mahadevia et al. [57]. Faheem et al. [79] give this range as 26.1 °C–32.8 °C. Rawal et al. [80], taking samples from different climatic zones, estimate 80 percent of the Indian residential occupants experienced a neutral thermal sensation in the indoor operative range of 16.3 °C–35 °C. In all settlements (excluding E-5) the temperatures experienced within the DU with the fan on are above 35 °C (**Table 3** and **Figure 7**). The first part of the chart are the DUs with cool-roof interventions. In these DUs as well, the inside temperatures recorded are above 35 °C, but are lower than the inside temperatures recorded within DUs without cool-roofs.

**Figure 7.** Temperatures outside and within DUs, city average and cool roof impact.

A = Outside Temperature; B = Inside Temperature with Fan; C = City's Average at the Time of Survey; A-B = Difference between Outside and Inside Temperatures.

Source: Primary survey.

We also analyzed the combined impact of other built environment characteristics on temperatures and cool roofs (**Table 4**). The combination of a cool roof with each of the three other built environment characteristics, such as a tree nearby, open ground in the neighborhood, and cross ventilation, reduces indoor temperatures further. Thus, the difference between the outside and inside temperatures too increases.

Table 4. Temperature comparison of houses with cool roofs and other housing characteristics.

Built environment characteristics	Average Temperature Inside DU* (°C)	Difference between Outside and Inside Temperatures (°C)
Cool roof + tree nearby	37.33	5.67
Cool roof + cross ventilation	37.65	3.90
Cool roof + open ground in neighborhood	35.50	4.75
Cool roof + no direct sun	38.06	5.44

* Measured with fan on.

We decided to run regressions to check which of the built environment factors influenced the temperatures within the sampled dwelling units (**Table 5**). The built environment characteristic of cross ventilation is statistically significant ($p < 0.05$) and significantly impacts the temperature inside the house. Other predictors, cool roofs, a tree adjoining the house, and open ground in the neighborhood did not display any significant impact on the temperatures inside the house.

Table 5. Regression results.

Built Environment Characteristics	Chi-Square	df: 26	p-value
Cool Roof	29.579	26	0.285
Cross Ventilation	56.908	26	0.000
Tree Adjoining	26.433	26	0.440
Open Ground in Neighborhood	32.991	26	0.162

Sample disaggregated by settlements does not give a clear advantage to the DUs with cool-roof the difference between outside DU and inside DU temperatures in all settlements except E-4 and C-1. The three settlements in west Ahmedabad did not have cool-roofs, and hence these have been excluded from **Table 6**. We do not see cool roofs alone having an advantage in reducing in-DU temperatures because other factors too have played a role in lowering temperatures within the DUs. These factors are availability of a storey above (where we have measured temperatures only on the ground floors), availability of cross ventilation, high roof (more than 10 feet), tree adjoining the DU, no direct sunlight on the walls, and shaded streets.

On average, the difference between the outside and inside temperatures in DUs with cool roofs is 5.39 °C (**Table 7**). This difference in the case of DUs without cool-roofs is lesser, 4.20 °C. If the DUs had a storey above, cross-ventilation, a tree adjoining, a roof higher than 10 feet, and shaded street and DU-walls, these led to reducing temperature inside the DU compared to only ground-floor DUs, DUs without cross-ventilation, no adjoining tree, a roof lower than 10 feet, and direct sunlight hitting the streets and walls of the DU.

Table 6. Temperature (°C) difference with and without cool roofs.

Settlement	With Cool-roof			Without Cool-roof		
	Outside DU	Inside DU	Difference	Outside DU	Inside DU	Difference
	A	B	A–B	A	B	A–B
E-1	43.50	39.33	4.17	45.00	39.33	5.67
E-2	45.00	38.08	6.92	46.75	39.38	7.38
E-3	43.08	38.50	4.58	44.67	39.57	5.10
E-4	45.25	40.00	5.25	44.44	39.99	4.45
C-1	43.00	38.00	5.00	45.44	40.83	4.61

Source: Primary survey.

Table 7. Impact of housing related elements on average temperature inside DU, temperature reduction within DU as compared to outside DU and incidence of illness.

Housing Related Parameters	Temperature inside DU with fan on (°C)	Difference of temperature outside DU to temperature inside DU (°C)	Incidence of illness (%)
	Average	Average	
With cool-roof interventions	38.64	5.39	36.0
Without cool-roof interventions	38.83	4.20	40.0
Single storey DUs (Only ground floor)	38.89	4.38	35.5
Two-storey DUs (Ground + one) (only 4 DUs in sample) *	36.38	5.00	75.0
DUs with cross ventilation	37.89	4.43	34.8
DUs without cross ventilation	39.90	4.36	39.6
Roof 10ft or low	38.85	4.45	41.2
Roof above 10 ft	38.40	4.24	10.0
Roof GI/Asbestos/Cement Sheets	39.09	4.15	39.6
Roof Concrete	36.72	4.92	18.2
Open ground nearby	39.10	3.76	38.5
No open ground nearby	38.71	4.59	39.6
Tree adjoining DU	38.71	4.91	26.3
No tree adjoining DU	38.82	4.29	38.8
Direct sunlight on DU	38.93	4.12	32.1
No direct sunlight on DU	38.52	5.00	38.6
Shaded street adjoining DU	38.48	4.20	33.8
No shaded street adjoining DU	39.29	4.71	45.0

Source: Primary survey.

Notes: * Temperatures were measured only on the ground floor in two-storey DUs.

3.4. Health impacts

The reported heat-related illnesses are: stomach ache (1 person), blood pressure (1 person), chest pain (3 person), blood from the ear and nose (3 person), dizziness (16 person), dehydration (13 persons), vomiting (7 persons), and any other (3 persons). Two people did not state which illness they suffered. 43 of the 49 who reported illness stated that they fell ill due to heat.

Of those who reported illness, 6 percent were children below age 15 years, 26

percent were in age 15–30 years, the largest 61 percent were in age 30 to 60 years (the working age), and 6 percent were elderly above 60 years. Of the seven senior citizens in the survey, three have fallen ill. Of 207 children, only three reported illness. 65 percent of those who reported illness were women.

Mainly, the illness is among the adults expected to go out of the house. 23 of those who reported illness were employed in work that required them to go outside the house, such as labor work, street vending, manufacturing, etc. 16 of those who reported illness either did not work as they were elderly or children or did not report their work. Among 10 who reported they fell ill were either home-based workers (5 of them) or were housewives or worked indoors. Sixteen of those who reported illness had co-morbidity such as diabetes (3 people), kidney ailment (1 person), heart-related issues such as high or low blood pressure, and others (12). Those with heart-related ailments also reported diabetes.

Table 8. Reported morbidity and mortality incidence by settlements.

	Incidence of illness (per 1000 pop)	Incidence of death (per 1000 pop)	% age women among ill
E-1	200.0		33.3
E-2	73.2		66.7
E-3	74.1		50.0
E-4	39.2		75.0
C-1	114.3		100.0
W-1	125.0		80.0
W-2	84.5		83.3
W-3	166.7	23.8*	57.1
Overall	88.6	1.8	65.3

Source: Primary survey.

* Should be mindful of small sample size in interpreting this data.

The incidence of illnesses reported is a combined effect of employment conditions (as seen above), co-morbidities, and housing conditions, which we analyze next. Of the 49 who reported illness, only eight reported using any method to cool the roof to reduce the effect inside the house. Of these eight, five had painted their roofs with a white coat. Except for three, all those who reported illness stayed in a house with GI/Asbestos/Cement sheets, i.e., houses that had reported higher internal temperatures. Further, 40 percent of the DUs with GI/Asbestos/Cement sheets reported someone ill. This number for those staying in DUs with concrete roofs was 18 percent. While 84 percent of DUs had ceilings below 10 feet (**Table 8**), 95 percent of those reporting illness stayed in such houses. These DUs had registered slightly higher internal average temperatures at the time of the survey than the DUs with higher ceilings. DUs having cross ventilation did report relatively lower internal temperatures at the time of the survey and hence reduced the incidence of illness among their residents. The same with regards to the shaded adjoining street, which reduced internal temperature (**Table 5**) and hence reduced the incidence of illness. A tree adjoining the DU did reduce internal temperature (**Table 5**), and hence also had an impact on reducing the incidence of illness among the residents; 26 percent of DUs with a tree adjoining reported illness, while this number for DUs not having any tree adjacent is

39 percent. Shaded streets too made a difference; the incidence of illness among the residents of DU on shaded streets was 33.8 percent, and for those living in DUs that did not have a shaded street, it was 45.0 percent. The inside DU temperatures in the latter were higher than in the former. Thus, we find that micro-level factors discussed above not only influenced the temperature experienced within the DU but also influenced the incidence of morbidity. Hence, the incidence of illness is an outcome of compounded factors: employment conditions, the presence of co-morbidities, housing conditions, including the presence of cool roofs, and street characteristics.

4. Discussion

This exploratory research started by assuming that cool roofs lower indoor temperatures, leading to an increase in thermal comfort and fewer illnesses. While on the field, we realized that other local built environments (physical dimensions of a DU) work to reduce indoor temperatures. Our research was conducted during the peak summer period when none of the DUs surveyed reported inside temperatures within the thermal comfort band. However, other built environment characteristics made a difference of a few degrees within the DU. The internal temperatures experienced also impacted the incidence of illness.

The research broadly finds that the cool roof reduced internal temperatures. The DUs with cool roofs experienced 1.19 °C less inside than the ones without cool roofs. This is reflected in the incidence of illness reported as well; in the DUs with cool roofs, the proportion of residents reporting illness was 36 percent, whereas in DUs without cool roofs, this number was 40 percent. The DUs with a storey above recorded lower internal temperatures and also a lower incidence of illness than only single-storey DUs. However, two-storey DUs in our sample were only four in number, and hence we cannot draw any significant conclusions from the data. The DUs with cross ventilation recorded lower inside DU temperatures, a higher difference between the outside and inside DU temperatures, and a lower incidence of illness. DUs with low ceiling height (10 ft or low) recorded higher inside temperatures than the DUs with higher ceiling height (above 10 ft), and the former also registered a higher incidence of illness compared to the latter. Roofs of GI/Asbestos/Cement sheets reported higher inside DU temperatures and also a higher incidence of illness compared to the DUs with concrete roofs. In this study, open ground nearby a DU did not influence the internal temperatures as well as the incidence of illness. A tree adjoining the DU reduced internal experience of temperature and also larger difference between the outside DU and inside DU temperatures as compared to a DU not having a tree abutting it. The former DUs also reported a lower incidence of illness compared to the latter. Shaded streets matter. The presence of shaded streets in a built form that is predominantly low-rise, single- or two-storey, has the potential to reduce temperatures experienced inside the DUs and thus also reduce the incidence of illness. However, the regression analysis does not establish any of these characteristics as significant predictors of temperatures experienced inside the dwelling units in the informal settlements.

For physical adaptive actions, a combination of micro-level built environment characteristics, including the roof material, influence temperatures experienced within

a DU in informal housing. The heat-adaptation efforts within the informal housing in the cities of the global south, which may not be able to transit to formal housing in the short and medium term, will need to tackle local-level built environment characteristics, which include immediate neighborhood-level interventions as well as individual DU-level interventions to adapt to increasing temperatures and urban heat island impacts. The emphasis on cool roofs alone may not lead to effective adaptive interventions.

Urban Heat Island (UHI) has become a reality in Ahmedabad and cities in India. Adaptation to it requires small interventions at the individual house and local neighborhood levels, which in turn has the potential to reduce heat-induced morbidity and mortality. These efforts would be predominantly at the individual household level, however, with the assistance of the communities, non-governmental organizations, and local governments. This study is of housing in the informal settlements, which as an urban form is expected to persist and even expand in rapidly urbanizing India as well as the cities of the global South. Thus, the efforts to build resilience to heat will have to pay attention to the informal housing units. We cannot wait till the residents of all the informal settlements transit to the formal housing, which is a long way ahead. At the same time, longitudinal and large-scale surveys or participatory research on a long-term basis is required to establish housing upgrading efforts in the informal settlements to ensure adaptation to increasing heat on account of climate change.

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