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Research Paper

Urbanization and Consequent Carbon Footprints from Transportation and Construction Sector in Malaysia after Industrial Revolution 4.0

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Abstract

Malaysia has experienced rapid urbanization since Industrial Revolution (IR) 4.0, which has resulted in significant changes in energy consumption and CO_2 emissions. Its urban areas are characterized by high population densities, which has led to increased demand for transportation and construction activities, thereby enhancing the carbon footprint of Malaysia. Yet, the country has also set ambitious targets for reducing its carbon footprint and has committed itself to the Paris Agreement on climate change. The government has set a target to reduce the intensity of greenhouse gas emissions by 45%, compared to the level in 2005, by 2030. Therefore, this study aimed to identify the domains from the transportation and construction sectors that are most responsible for Malaysia's CO_2 emissions along with exploring the government's initiatives to mitigate these emissions. In order to recommend sustainable techniques that are currently most suitable for the Malaysian context, a survey was conducted. The results showed that sustainable building materials and green building certifications should be the two top priorities of the government in order to control emissions from selected domains. The research also provides practical suggestions to help the country achieve its sustainability targets.

Keywords: *carbon footprint; CO_2 emissions; construction; Malaysia; urbanization.*

Introduction

Malaysia has seen rapid urbanization in the IR 4.0 era, with the urban population increasing from 33.5% in 1980 to 78.5% in 2020 [1]. On the one hand, these changes have contributed to the country's economic growth; on the other hand, they have also led to a significant increase of the country's carbon footprint. It is a reality that urbanization knows no limit, especially after IR 4.0. This has resulted in increased energy consumption and transportation activities, which have in turn led to a rise in CO_2 emissions. It is worrying that the global warming potential of CO_2 is the highest among all gases that can cause global warming [2]. The transportation and construction sectors are the major contributors to this phenomenon in the country. According to the Department of Environment (DOE) in Malaysia, the country's energy consumption has increased by 2.7% annually over the past decade and transportation and industrial activities are its major sources. This increased consumption has caused an average increase of 2.6% in CO_2 emissions annually over the same period. The situation is alarming, as global warming leads to climate change with harmful effects on air quality and health. This creates a pressing need for the government to address the impact of CO_2 emissions and take necessary actions accordingly that are feasible to be adopted by Malaysia. First, considering the transportation sector, the increasing number of vehicles on the road coupled with a lack of efficient public transportation systems, has resulted in a significant increase in CO_2 emissions. Privately owned vehicles are on the rise too [3]. Official statistics reveal that the number of vehicles on the roads has increased by 6.8% annually over the past decade,

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with a significant portion of these vehicles being privately owned cars. This rise in ownership of personal vehicles has resulted in excessive use of fossil fuels, leading to a rise in CO_2 emissions. According to *Loganathan et al.* [4], urbanization in Malaysia has led to an increase in energy consumption and carbon dioxide emissions, where a noteworthy share comes from the transportation sector. This study highlights the importance of implementing sustainable transportation policies to reduce CO_2 emissions and mitigate the effects of urbanization on the environment. Another significant contributor to CO_2 emissions in Malaysia is the industrial sector. According to a study by the Malaysian Industrial Development Authority (MIDA), the industrial sector accounted for 34.7% of the country's total CO_2 emissions over the past decade. To make matters worse, the practices adopted by the construction industry are also the least environmentally friendly. The building sector accounts for 30-40% of the total energy consumption and 20-30% of CO2 emissions globally [5]. Most of the buildings are designed and constructed without considering energy-efficiency measures, leading to high energy consumption and carbon emissions [6].

Second, the construction sector has played a significant role in shaping the urbanization process and has contributed significantly to CO_2 emissions in the IR 4.0 era. Tran *et al.* [7] suggest that while urbanization in Malaysia has had a positive impact on economic growth, it has also contributed to environmental degradation, including the increase of Malaysia's carbon footprint. They highlight the need for a balanced approach to urban development that considers the social, economic, and environmental dimensions. The building sector is responsible for a significant portion of energy consumption and carbon emissions. One of the major factors contributing to CO_2 emissions in the construction industry is the energy consumption during the building operation phase. Buildings require heating, cooling, lighting, and ventilation systems that consume energy and contribute to carbon emissions. The energy consumption of buildings is affected by several factors, such as the design, construction materials, and building operation and maintenance practices. In Malaysia, most buildings are designed and constructed without considering energy efficiency measures, resulting in high energy consumption and CO_2 emissions [6]. Another factor contributing to CO_2 emissions in the construction industry is that the manufacture of building materials such as cement, steel, and glass requires a significant amount of energy and contributes to CO_2 emissions. Cement production is one of the major contributors to carbon emissions in the construction industry, accounting for around 8% of global CO_2 emissions. Malaysia is the third-largest cement producer in Southeast Asia, with a total production capacity of 29 million metric tons per year. The high demand for cement and other construction materials in Malaysia has led to an increase in energy consumption and CO_2 emissions in the building production phase [8]. Hamzah *et al.* [9] revealed that the process of urbanization in Malaysia has led to changes in construction activities, whereby altered land-use patterns amplifyied carbon footprints. Hamzah *et al.* [9] emphasize the need for integrated land-use planning to mitigate the environmental impact of urbanization and promote sustainable development.

The construction industry in Malaysia is aware of its environmental impact and has taken initiatives to reduce carbon emissions. The government of Malaysia has launched several initiatives to promote green buildings and sustainable construction practices. The Green Building Index (GBI) is a rating tool that evaluates the environmental performance of buildings based on their design, construction, and operation. The GBI has been widely adopted in Malaysia, with over 300 buildings certified as green buildings. The government also launched several policies to promote energy-efficient building designs and construction materials [10].

In conclusion, the rapid urbanization process in Malaysia has led to an increase in the construction of buildings and infrastructure projects, resulting in an increase in energy consumption and CO_2 emissions. The energy consumption during the operational phase of buildings, the manufacture of construction materials, and the transportation of construction materials and equipment are the major factors contributing to CO_2 emissions. The government of Malaysia has taken initiatives to promote green buildings and sustainable construction practices.

In view of the above discussion, this study explored the relevant literature on two broad categories, namely transportation and construction, to find domains that emit CO_2 and to explore the government's initiatives to help reduce these emissions. The identified domains and government initiatives are listed in Table 1.

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Table 1 Identified domains from the transportation and construction sectors that increase CO2 emissions.

Identified domains that have increased CO_2 emissions in Malaysia after IR 4.0	Government initiatives to combat emissions from identified domains	References
	Transportation	
Diesel and gasoline vehicles emit greenhouse gases, which increases CO2 levels	Promotion of EVs and HEVs, adoption of cleaner fuels	[11, 12]
Increased number of personal vehicles due to urbanization, leading increased CO2 emissions	Tax incentives and subsidies	[13]
Railway transportation	Mass transit projects as alternatives to road traffic	[14, 15]
Transportation and distribution of natural gas through pipelines	Natural Gas Vehicle (NGV) program	[16, 17]
	Construction Industry	
Concrete and cement production	Promoting usage of alternative fuels, reducing water usage, recycling waste materials, regulations, and policies	[18, 19]
Production of reinforcing steel	Suggesting the usage of alternative materials	[20, 21]
Electricity generation	Usage of renewable energy resources, net energy metering, tax incentives	[22, 23]
Building in its operational phase	Passive designs, few government offices being made energy efficient	[24-26]

A number of studies have investigated the relationship between urbanization and carbon dioxide emissions in Malaysia [11, 27]. However, few studies specifically focused on summarizing the domains that cause emissions and in which the government has shown a certain level of stewardship. Despite the efforts made by the government to reduce carbon footprints, the problem persists due to a lack of mechanisms that prioritize effective policies and strategies most suitable for Malaysia. As a result, Malaysia's pledge to reduce its carbon emissions by 45% by 2030 as part of its commitment to the Paris Agreement seems difficult to achieve.

The present study aimed to fill the above-mentioned gap present in the body of literature by identifying domains from the transportation and construction sectors that result in increased CO_2 emissions, along with identifying initiatives taken by the government so far to combat emissions from the identified domains. The importance of this research lies in the fact that it contributes to the literature by highlighting the lag in part of the governmental actions. The identification of the level of response when compared to the scale of the problem triggers the need for swift and sustainable action. Without problem identification, the course cannot be set in the right direction. The study highlights three priority areas that require attention on an urgent basis. These are: sustainable building materials, green building certification, and circular economy principles.

This research provides insight to help identify the major contributing domains of CO_2 emissions from the transportation and construction sectors, to help identify the initiatives for the government as a response to these agents to adopt sustainable urban development practices in Malaysia to mitigate the negative impact of urbanization on the environment, and lastly to provide a basis for future research for other developing countries. Success will be achieved only when this problem is addressed in a coordinated effort from the government, the private sector, and the public sector.

Research Methodology

Step 1: In the first step of the research, wide-ranging research papers belonging to the fields of civil and architectural engineering were explored that center around mitigating the harmful effects of urbanization and carbon emissions. By studying these papers, a gap in the body of literature was identified and the objectives of the study under discussion were formulated. The objectives included identifying domains from the transportation and construction sectors that cause CO_2 emissions, identifying initiatives taken by the Malaysian government against the identified domains and proposing ranked sustainable techniques to the government to be used in the future as per their feasibility for the country.

Step 2: In the second step, a literature review was conducted, as it is an essential part of any research [28]. Research papers were searched from different online libraries and digital databases like ASCE, Taylor & Francis Online, ScienceDirect, Emerald Insight, and Google Scholar. The search terms used included: 'urbanization in Malaysia', 'carbon footprint', 'CO_2 emissions', 'construction', 'transportation', 'sustainable techniques opted by the Malaysian government', etc. The scope of the research included papers from 2000-2023 that discuss the effects of urbanization and consequent carbon footprints, particularly after IR 4.0, in Malaysia only. Similarly, only initiatives taken by the Malaysian government were taken into account.

In terms of the limitations of this study, firstly, the research relied on statistical data analysis techniques, which may not encompass the complex socio-economic and environmental dynamics of urbanization and CO_2 emissions in Malaysia. Secondly, the study focused on the period from 2000 to 2023, which may not provide a comprehensive understanding of the long-term trends and patterns of urbanization and CO_2 emissions in Malaysia. Lastly, the study focused on the impact of urbanization on CO_2 emissions in Malaysia without considering other factors, such as economic growth, population dynamics, and natural resource management.

The data collection process involved both primary and secondary data sources. Primary data was obtained from the literature while secondary data included data collected from a questionnaire survey. The objectives of identification of carbon emission domains from the transportation and construction sectors and related government initiatives were achieved in this phase of the study. Also, the sustainable techniques to be ranked via a survey were extracted from the literature review. The techniques along with their explanation are given in Table 2 below.

Table 2 Identified techniques from the literature along with their explanation.

Techniques	Explanation
Indoor air quality improvements	The adoption of ventilation systems and building materials that enhance indoor air quality reduces the need for energy-intensive HVAC systems, contributing to the reduction of CO_2 emissions.
Adoption of digital technologies	The construction industry has embraced digital technologies, including Building Information Modeling (BIM), robotics, and automation, which optimize construction processes and reduce energy consumption, leading to lower CO_2 emissions.
Renewable energy integration	The construction industry has increased the integration of renewable energy sources like solar power, wind turbines, and geothermal energy, reducing reliance on fossil fuels and mitigating CO_2 emissions.
Life cycle assessment (LCA)	Life cycle assessment tools are used to evaluate the environmental impact of construction projects, helping stakeholders make informed decisions to minimize CO_2 emissions throughout the project's lifecycle.
Collaboration and knowledge sharing	Stakeholders in the construction industry collaborate and share knowledge to promote sustainable construction practices, fostering innovation, and reduction OF CO_2 emissions.
Public awareness and education	Increased public awareness about the environmental impact of construction activities, including CO_2 emissions, drives demand for sustainable construction practices and encourages industry-wide adoption.
Prefabrication and modular construction	Off-site construction methods, such as prefabrication and modular construction, minimize waste, optimize resource utilization, and decrease CO_2 emissions during the construction process.
Smart construction equipment	Advanced construction equipment with improved fuel efficiency and reduced emissions is employed, minimizing CO_2 emissions during construction activities.
Carbon offset initiatives	Construction companies may engage in carbon offset initiatives, such as investing in renewable energy projects or supporting reforestation efforts, to offset their CO_2 emissions.
Efficient transportation and logistics	Advanced logistics and supply chain management systems reduce transportation distances, optimize routes, and minimize CO_2 emissions associated with the delivery of construction materials and equipment.
Green roofs and vertical gardens	Integration of green roofs, vertical gardens, and living walls in building designs improves insulation, reduces energy consumption, and sequesters carbon, leading to lower CO_2 emissions.
Waste management and recycling	Effective waste management practices, including recycling and reuse of construction waste, help reduce CO_2 emissions associated with waste disposal.
Research and development	Ongoing research and development efforts focusing on developing innovative construction materials, techniques, and technologies to further reduce CO_2 emissions and improve sustainability in the industry.
Water conservation	Implementation of water-efficient technologies and practices in construction projects reduces energy consumption associated with water supply and treatment, indirectly reducing CO_2 emissions.
Energy-efficient building designs	Advanced design techniques, such as parametric design and energy modeling, are used to create energy-efficient buildings that minimize energy consumption and CO_2 emissions.
Energy-efficient lighting systems	The use of energy-efficient lighting systems, such as LED lighting and daylight harvesting techniques, reduces energy consumption and CO_2 emissions in constructed buildings.
Government regulations and incentives	Governments enact regulations and provide incentives to encourage sustainable construction practices and emissions reduction, influencing the industry to prioritize CO_2 mitigation.
Circular economy principles	The construction industry increasingly embraces circular economy principles, aiming to reduce waste, promote resource efficiency, and minimize CO_2 emissions through strategies like material reuse and recycling.
Green building certification	Certifications like GreenRE and GBI promote sustainable construction practices and energy efficiency, resulting in lower CO_2 emissions in the built environment.
Sustainable building materials	The use of sustainable building materials, such as recycled materials, low-carbon concrete, and environmentally friendly alternatives, helps reduce CO_2 emissions associated with material production.

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Step 3: In the third step, data collection took place. For this, a questionnaire was developed on Google Forms to be circulated online. Construction professionals were asked to rank the techniques identified in the literature review. First, a pilot survey was conducted to check if the form needed any amendments. Once it was approved by professionals, the questionnaire was circulated [29]. It was split into two sections: the first section sought to learn about the respondent's profile, and the second section, which consisted of Likert-scale questions, aimed to determine the importance of the techniques that must be adopted by the government on a priority basis. The targeted audience consisted of construction professionals, either working in site engineering, surveying, or architecture branches of the field.

The identified techniques from the literature were ranked via the relative importance index upon analysis of the survey data. The relative importance index (RII) is a qualitative measure of the relative importance of different aspects in a decision. It is calculated as the sum of weighted factors, where each factor has a weight that reflects its relative importance.

Moreover, a correlation test was used to examine whether any two variables were correlated with one another or not. It is a statistical technique that measures the strength and direction of association between two ranked variables. It is non-parametric in nature, so it doesn't require any assumption about the distribution of the data. To perform the test, each variable is independently ranked, and the difference between the ranks of corresponding values from the two variables is calculated.

Step 4: In the last phase of the study, the results were compiled as the final stage of the research methodology, which involved drawing conclusions based on the analysis of the data. Hence, this study recommends several policy interventions to promote sustainable urban development in Malaysia based on the findings of the analysis. Therefore, this study aimed to fill the gap present in the literature by identifying the domains from the transportation and construction sectors that play a part in enhancing CO_2 emissions, the steps taken by the government so far to reduce emissions from these sources, and finally recommending ranked sustainable techniques that must be given priority to achieve success in mitigating negative effects of urbanization from the subject domains.

Results and Discussion

Through a Google Form survey, data was collected from engineers, site engineers, site supervisors, and other professionals in the construction field. The survey was distributed from May to July 2023, and a total of 42 respondents participated; details are provided in Table 3. The survey had three sections: general information, awareness of carbon emissions in Malaysia, and how urbanization has impacted the emission of carbon after IR 4.0. The results were used to organize a framework of digitalization in the construction industry.

This section discusses the survey results and their implications for the role of urbanization in the emission of CO_2 in Malaysia. First, the general information section provides insight into the demographic profiles of the respondents. Next, the awareness of carbon emissions was examined, exploring how familiar respondents are with carbon emissions and the related dangers. Following this, barriers to implementing digital technologies in construction were analyzed, identifying the challenges that companies face when trying to adopt these technologies. Finally, the opportunities for digital transformation in IR 4.0 are explored, looking at how digitalization can help companies improve their processes and increase their competitiveness in the market. Overall, this section provides a comprehensive overview of the challenges and opportunities that digitalization presents for the construction industry in Malaysia.

The results indicate that most of the respondents in the study had a Doctor of Philosophy (PhD) degree (47.6%) as their highest education level. The high representation of PhD graduates suggests that there is considerable interest and expertise in the topic of CO_2 emissions within the academic community. PhD graduates are likely well-versed in the scientific and technical aspects of climate change and greenhouse gas emissions. They have received rigorous training and research in their respective fields, which often involves staying up to date with the latest developments and research. Their participation in the survey implies that the study attracted individuals with significant knowledge and interest in the subject matter. The second most common education level reported was a master's degree (31%), followed by a bachelor's degree (14.3%), and lastly, others at 7.5%.

While having educated and knowledgeable respondents can be beneficial, it may also introduce a bias in the survey results. The perspectives and concerns of PhD students might differ from the general population or other specific groups that the survey intended to represent. Thus, the findings may not be fully representative of the broader public's views on CO_2 emissions. Thus, the survey's methodology and outreach strategy may have caused an overrepresentation of PhD students. For example, if a survey is conducted primarily within academic institutions or research circles, it may lead to a higher response rate from this group. The results of such a survey could be valuable for academia and policymakers, as it provides insight into the views and attitudes of individuals with a deep understanding of climate-related issues. However, when interpreting and applying the findings, it is essential to acknowledge the potential bias and consider ways to generalize the results more broadly.

Moreover, the results in Table 3 show that most of the respondents resided in urban areas (over 90.5%). The remaining 9.5% of the respondents resided in rural areas. This indicates that most of the respondents were aware of the climatic change and increase in the level of greenhouse gas emissions.

Table 3 Background of respondents

General Information	Number	Percentage (%)
Education Level		
Bachelor's Degree	6	14.3%
Master's Degree	13	31%
PhD	20	47.6%
Other	3	7.1%
Residence		
Urban	38	90.5%
Rural	4	9.5%
Organization Type		
Construction sector	13	31%
Education sector	21	50%
Other	8	19%
Work experience (Years)		
Less than 10	38	90.2%
Less than 20	4	9.8%
Less than 30	0	0%
More than 30	0	0%

In terms of organization type, the data indicate that workers in the education sector had the highest representation, with 50% of the respondents affiliated with this type of organization. The next most common type was the construction sector, which accounted for 31% of the respondents, and other respondents from different fields had the smallest portion of the response percentage (19%). These results show that this study's topic raised more interest in the education sector.

In terms of work experience, the respondents had less than 10 years of experience, accounting for 90.2%, and the rest had experience of less than 20 years, at only 9.8%. Unfortunately, there were no responses from respondents with more than 20 years of experience. Most respondents with less than 10 years of experience likely represent a younger and less experienced cohort. They may include recent graduates, early-career professionals, or individuals who have entered the workforce in the last decade. The views and attitudes of individuals with less experience might differ from those with more extended professional histories. Younger professionals may have a fresh perspective on environmental issues, including CO_2 emissions, and may be more attuned to the importance of sustainability and climate change mitigation. Younger professionals are often more open to adopting new practices and technologies. Their engagement in a survey about CO_2 emissions may indicate a willingness to address environmental challenges and explore innovative solutions. While younger respondents can bring enthusiasm and openness to a survey, they may have limited experience and expertise in the field of CO_2 emissions. This factor could impact the depth of insight provided in the survey responses. The predominance of respondents with less than 10 years of experience could introduce a bias in the survey results. Thus, it may not fully capture the perspectives of more experienced professionals who have encountered different challenges and witnessed the evolution of environmental practices over time. Respondents with less experience are likely to have more recently completed their education, including formal training on environmental topics. This could influence their awareness and understanding of CO_2 emissions and climate-related issues.

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Reliability Analysis

Based on the result of the reliability test used by the SPSS software, Cronbach's alpha value was 0.934, which is a good result (0.7 to 0.9 is reliable, 0.5 to 0.7 is somewhat reliable and 0.5 below is very poor). The result obtained was very good with N = 20.

Correlation Analysis

The correlation between the residence of respondents to their level of education was -0.355, which indicates a negative correlation. The correlation between the level of education and the field of work was 0.011, which indicates a positive correlation, meaning that an increase in the level of education leads to an increase in the field of work and vice versa. The correlation between field of work and experience was -0.164, indicating a negative correlation. The details can be seen in Table 4.

Table 4 Data validity and correlation.

Code	Factor	Correlation coefficient	P-value
F1	Adoption of digital technologies: The construction industry has embraced digital technologies, including Building Information Modeling (BIM), robotics, and automation, which optimize construction processes and reduce energy consumption, leading to lower CO_2 emissions.	0.850	<0.001
F2	Energy-efficient building designs: Advanced design techniques, such as parametric design and energy modeling, are used to create energy-efficient buildings that minimize energy consumption and CO_2 emissions.	0.931	<0.001
F3	Renewable energy integration: The construction industry has increased the integration of renewable energy sources like solar power, wind turbines, and geothermal energy, reducing reliance on fossil fuels, and mitigating CO_2 emissions.	0.487	<0.001
F4	Sustainable building materials: The use of sustainable building materials, such as recycled materials, low-carbon concrete, and environmentally-friendly alternatives, helps reduce CO_2 emissions associated with material production.	0.549	<0.001
F5	Prefabrication and modular construction: Off-site construction methods, such as prefabrication and modular construction, minimize waste, optimize resource utilization, and decrease CO_2 emissions during the construction process.	0.667	<0.001
F6	Efficient transportation and logistics: Advanced logistics and supply chain management systems reduce transportation distances, optimize routes, and minimize CO_2 emissions associated with the delivery of construction materials and equipment.	0.900	<0.001
F7	Waste management and recycling: Effective waste management practices, including recycling and reuse of construction waste, help reduce CO_2 emissions associated with waste disposal.	0.422	<0.001
F8	Green building certification: Certificates like GreenRE and GBI promote sustainable construction practices and energy efficiency, resulting in lower CO_2 emissions in the built environment.	0.324	<0.001
F9	Life cycle assessment (LCA): Life cycle assessment tools are used to evaluate the environmental impact of construction projects, helping stakeholders make informed decisions to minimize CO_2 emissions throughout the project's lifecycle.	0.497	<0.001
F10	Energy-efficient lighting systems: The use of energy-efficient lighting systems, such as LED lighting and daylight harvesting techniques, reduces energy consumption and CO_2 emissions in constructed buildings.	0.523	<0.001
F11	Smart construction equipment: Advanced construction equipment with improved fuel efficiency and reduced emissions is employed, minimizing CO_2 emissions during construction activities.	0.463	<0.001
F12	Green roofs and vertical gardens: Integration of green roofs, vertical gardens, and living walls in building designs improves insulation, reduces energy consumption, and sequesters carbon, leading to lower CO_2 emissions.	0.409	<0.001
F13	Collaboration and knowledge sharing: Stakeholders in the construction industry collaborate and share knowledge to promote sustainable construction practices, fostering innovation and reduction of CO_2 emissions.	0.454	<0.001
F14	Government regulations and incentives: Governments enact regulations and provide incentives to encourage sustainable construction practices and emissions reduction, influencing the industry to prioritize CO_2 mitigation.	0.433	<0.001
F15	Carbon offset initiatives: Construction companies may engage in carbon offset initiatives, such as investing in renewable energy projects or supporting reforestation efforts, to offset their CO_2 emissions.	0.255	<0.001

Code	Factor	Correlation coefficient	P-value
F16	Circular economy principles: The construction industry increasingly embraces circular economy principles, aiming to reduce waste, promote resource efficiency, and minimize CO_2 emissions through strategies like material reuse and recycling.	0.259	<0.001
F17	Water conservation: The implementation of water-efficient technologies and practices in construction projects reduces energy consumption associated with water supply and treatment, indirectly reducing CO_2 emissions.	0.401	<0.001
F18	Indoor air quality improvements: The adoption of ventilation systems and building materials that enhance indoor air quality reduces the need for energy-intensive HVAC systems, contributing to the reduction of CO_2 emissions.	0.521	<0.001
F19	Public awareness and education: Increased public awareness about the environmental impact of construction activities, including CO_2 emissions, drives demand for sustainable construction practices and encourages industry-wide adoption.	0.729	<0.001
F20	Research and development: Ongoing research and development efforts focus on developing innovative construction materials, techniques, and technologies to further reduce CO_2 emissions and improve sustainability in the industry.	0.750	<0.001

Ranking of the Factors

Table 5 presents the RII and ranking of various factors that can be applied in Malaysia to reduce the emission of CO2. The results indicate that sustainable building materials with code F4 received the highest rank, with an RII of 0.885714. Building materials such as cement/concrete largely produce CO_2 during manufacture and replacing them with sustainable materials would reduce CO_2 emissions. Green building certification followed in the second place, with an RII of 0.866667, while circular economy principles ranked third, with an RII of 0.861905. These factors are very crucial in balancing sustainable development with environmental conservation. Energy-efficient lighting systems and government regulations and incentives followed in fourth place, with an RII of 0.857142, while energy-efficient building designs came in fifth place with an RII of 0.852381. Three factors, i.e., waste management and recycling, water conservation, and research and development, came in sixth place, with an RII of 0.842857. Efficient transport and logistics, and carbon offset initiatives came in seventh place, with an RII of 0.838095, while smart construction equipment came in eighth place, with an RII of 0.833333. If these factors can be achieved in Malaysia, then there would be great improvement in the control of CO_2 emissions. The middle factors prefabrication and modular construction, collaboration and knowledge sharing, and renewable energy regulation were considered less important in the reduction of CO2 emissions in Malaysia. The last two factors of the adoption of digital technologies and indoor air quality improvements do not seem to contribute much to the emissions of CO_2 in Malaysia.

Table 5 RII ranking of the factors.

Code	Factor	RII	Rank
F1	Adoption of digital technologies	0.804762	12
F2	Energy-efficient building designs	0.852381	5
F3	Renewable energy integration	0.809524	11
F4	Sustainable building materials	0.885714	1
F5	Prefabrication and modular construction	0.828571	9
F6	Efficient transportation and logistics	0.838095	7
F7	Waste management and recycling	0.842857	6
F8	Green building certifications	0.866667	2
F9	Life cycle assessment (LCA)	0.823811	10
F10	Energy-efficient lighting systems	0.857142	4
F11	Smart construction equipment	0.833333	8
F12	Green roofs and vertical gardens	0.838095	7
F13	Collaboration and knowledge sharing	0.823811	10
F14	Government regulations and incentives	0.857142	4
F15	Carbon offset initiatives	0.838095	7
F16	Circular economy principles	0.861905	3
F17	Water conservation	0.842857	6
F18	Indoor air quality improvements	0.795238	13
F19	Public awareness and education	0.823811	10
F20	Research and development	0.842857	6

Conclusion

In conclusion, the impact of urbanization on carbon dioxide emissions in Malaysia in the IR 4.0 era is a critical environmental issue that requires urgent attention. The rapid urbanization and industrialization in the country

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have led to a significant increase in carbon dioxide emissions, contributing to climate change and environmental degradation. The incorporation of IR 4.0 technologies in urban development and transportation systems has further exacerbated the problem by increasing energy consumption and CO_2 emissions. The findings from this study consistently highlight the strong relationship between urbanization and carbon dioxide emissions in Malaysia. This study underscores the urgent need for sustainable urban planning and transportation policies to address the challenges posed by increasing carbon dioxide emissions. The rise in the number of vehicles on the road and the lack of efficient public transportation infrastructure emerged as major contributors to carbon dioxide emissions. To combat this, integrated land-use planning, and strategies to promote cleaner and energy-efficient transportation options are crucial. The study recommends that factors F4 (sustainable building materials), F8 (green building certification), and F16 (circular economy principles) must be given priority by the Malaysian government to fulfil the lag that it currently faces in tackling the environmental challenge.

Future research should focus on identifying and implementing sustainable building materials that are environmentally friendly through empirical model analysis. This will involve conducting detailed studies on the impact of specific IR 4.0 materials on carbon dioxide emissions. Additionally, research should explore the potential of renewable energy sources and green technologies to mitigate carbon dioxide emissions in urban areas. Moreover, public awareness and education campaigns should be conducted to promote sustainable lifestyles and behaviors that reduce carbon dioxide emissions. Encouraging the use of public transportation, promoting energy-efficient practices in households and industries, and incentivizing the adoption of green technologies are crucial steps in this direction.

In conclusion, the impact of urbanization on carbon dioxide emissions in Malaysia is a complex and pressing issue. The combined efforts of the government, industries, urban planners, and the public are essential to mitigate the negative impacts of urbanization and achieve sustainable development goals. By adopting a holistic approach and incorporating innovative solutions, Malaysia can pave the way towards a low-carbon future and contribute to global efforts in combating climate change.

Compliance with ethics guidelines

The authors declare that they have no conflict of interest or financial conflicts to disclose.

This article does not contain any studies with human or animal subjects performed by any of the authors.

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