

International Journal of Human Capital in Urban Management
(IJHCUM)

Homepage: <http://www.ijhcum.net/>

ORIGINAL RESEARCH PAPER

Carbon footprint: A study of key components of pro-environmental

E. Gravitiani^{1*}, N. W. Mulia¹, A. Ratnadewati², D. T. Cahyaningsih³

¹Economic Development, Faculty of Economic and Business, Universitas Sebelas Maret, Surakarta, Indonesia

²Magister of Economic and Study Development, Faculty of Economic and Business, Universitas Sebelas Maret, Surakarta, Indonesia

³Faculty of Law, Universitas Sebelas Maret Surakarta, Indonesia

ARTICLE INFO

Article History:

Received 01 July 2025

Revised 12 December 2025

Accepted 19 May 2026

Keywords:

Carbon Footprint; Willingness to decrease; Principal Component Analysis (PCA); Environmental behavior

ABSTRACT

BACKGROUND AND OBJECTIVES: Carbon emissions from the daily activities of urban populations are a primary contributor to climate change. The city of Surakarta, characterized by high mobility and significant emissions, necessitates an approach that emphasizes individual participation in efforts to reduce carbon footprints. This research aims to assess the community's willingness to reduce their carbon footprint based on five key indicators: housing, food, waste and water management, energy use, and transportation. Additionally, an analysis is conducted to identify the dominant factors influencing the community's preferences for environmentally friendly behavior.

METHODS: This study was conducted across five sub-districts in Surakarta City: Mojosongo, Sumber, Jayengan, Serengan, and Sondakan, selected for their high levels of urban activity and environmental relevance. The analytical method employed was Principal Component Analysis, a multivariate statistical technique used to reduce the dimensions of data and identify latent structures within a set of correlated variables. Principal Component Analysis enabled the researchers to extract principal components that represent key behavioral dimensions related to the willingness to decrease carbon footprint. The analysis was performed using STATA-13 and Minitab software for statistical computation and data visualization.

FINDINGS: The research findings indicate that the primary factors influencing WDC are community preferences regarding energy efficiency, waste management, and food consumption, which collectively account for 49.7% of the variability. The preference for sustainable living spaces and environmentally friendly transportation emerges as the second major factor, explaining 21.7% of the variability. The overall willingness of the community to reduce its carbon footprint is categorized as moderate. Among the five sub-districts, Jayengan exhibits the highest WDC index at 1.30, followed by Sumber (1.19), Semanggi (1.14), and both Sondakan and Mojosongo, which have the lowest indices of 1.10 each.

CONCLUSION: Research shows that residents in Surakarta City's five sub-districts have a moderate desire to lower their carbon footprint. Although awareness and concern, particularly about housing and transportation, are increasing, this has not yet translated into strong actions across all behaviors.

DOI: 10.22034/IJHCUM.2026.04.01



NUMBER OF REFERENCES

33



NUMBER OF FIGURES

5



NUMBER OF TABLES

4

*Corresponding Author:

Email: evigravitiani_fe@staff.uns.ac.id

Phone: +6282225034455

ORCID: [0000-0003-2638-2476](https://orcid.org/0000-0003-2638-2476)

Discussion period for this manuscript open until January 1, 2027 on IJHCUM website at the "Show Article

INTRODUCTION

Climate change has emerged as one of the most significant global challenges today, driven by the rising concentrations of greenhouse gases in the atmosphere, including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), which result from human activities. The Intergovernmental Panel on Climate Change (IPCC) forecasts that the average global temperature will rise by more than 1.5°C in the coming decades (IPCC, 2022). The current increase in global temperatures has rendered the environment more susceptible to natural disaster risks, including flooding due to rising sea levels, wildfires caused by prolonged droughts, extreme weather events, and heatwaves, as well as the threat of extinction for various plant and animal species (Klingelhöfer et al., 2020). This climate change is expected to trigger widespread hunger, climate crises, massive economic losses (Callahan & Mankin, 2022), damage to human physical and mental health, and mortality rates (Yang et al., 2021). Although extensive research has explored the causes and consequences of global warming, a limited understanding remains of how urban communities, especially in developing countries, can effectively participate in mitigating climate change through household-level behavioral changes. Addressing these escalating threats requires a comprehensive approach that reconfigures energy, transportation, and resource flows to enhance resilience, particularly in developing countries (Rauf et al., 2023). However, existing studies tend to focus predominantly on macro-level or technological interventions, often overlooking micro-level behavioral determinants that shape household carbon emissions. This creates a knowledge gap regarding the socio-economic and cultural factors influencing individuals' willingness to engage in sustainable practices. Therefore, this study seeks to bridge this gap by examining behavioral dimensions of carbon footprint reduction in urban Indonesia. These growing risks underscore the urgent need for timely and coordinated responses at the urban level. Strengthening urban governance is particularly crucial for enhancing climate resilience in rapidly urbanizing contexts, such as Indonesia. In recent years, cities have increasingly adopted localized climate governance strategies that prioritize adaptability and foster cross-sectoral collaboration (Abdillah et al., 2023). Within this context, the Sustainable Development Goals (SDGs) provide a comprehensive

framework for integrating climate adaptation into urban development, offering opportunities to align local initiatives with broader sustainability targets in a synergistic manner. Yet, while mitigation and adaptation are both central to achieving the SDGs, local actions to reduce emissions remain underexplored. Understanding how urban households perceive and act toward reducing carbon emissions is therefore crucial for effective urban sustainability policies. Moreover, recognizing the synergies and trade-offs between mitigation, adaptation, and the SDGs is essential. While mitigation strategies often generate co-benefits across multiple goals, adaptation measures, particularly those focused on urban resilience, remain comparatively underexplored, despite their crucial role in achieving balanced and inclusive progress toward the 2030 Agenda (Kuipers, 2024). The industrial sector, transportation, and human activities contribute to rising carbon emissions. This situation poses a threat to sustainable development, particularly for developing countries that often face greater challenges in mitigating and adapting to climate change (United Nations Environment Programme, 2020). Indonesia is among the countries that contribute significantly to global CO₂ emissions, primarily due to extensive use of fossil fuels, industrial activities, and transportation. The trend in carbon dioxide (CO₂) emissions in Indonesia has increased over the past decade. This rise may be triggered by rapid economic growth accompanied by a rising population. CO₂ emissions in Indonesia exhibit a fluctuating pattern, with notable spikes observed over the last five years. In 2013, Indonesia's emissions were recorded at 489.055 million tons, increasing to 594.101 million tons by 2018. After peaking in 2019 at 653.792 million tons, carbon emissions in Indonesia declined to 608.223 million tons in 2020 (Worldometers, 2025). This decrease may be attributed to the impacts of the COVID-19 pandemic, which led to restrictions on human activities and mobility. The COVID-19 pandemic, which began in late 2019, has had a widespread global impact on human activities, leading to a reduction in carbon emissions worldwide (Shamsi et al., 2022). This unanticipated reduction highlights the impact of behavioral change on climate mitigation efforts. Accordingly, the application of rigorous feasibility assessments is critical to evaluating the socio-political and technological preparedness of mitigation strategies, thereby

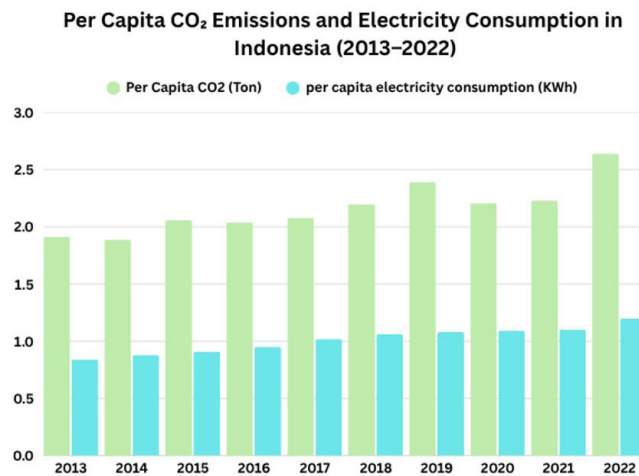


Fig. 1: Per capita CO₂ emissions and electricity consumption in Indonesia (2013–2022)

facilitating the integration of behavior-oriented approaches within broader climate policy frameworks (Nielsen et al., 2020). Recent evidence suggests that coal-based electricity generation and motorized transportation continue to be the primary sources of carbon emissions in Indonesia. Additionally, urban concentration and ongoing industrial expansion have been identified as key drivers of emission increases, particularly in densely populated regions (Zhang, 2019). The rapid growth of the transport sector, compounded by inadequate public infrastructure, further intensifies these emission challenges (Samad et al., 2022). Notably, during the COVID-19 pandemic, global CO₂ emissions temporarily declined by up to 17% due to widespread mobility restrictions and reduced economic activity, demonstrating the significant impact that behavioral and systemic shifts can have on emission trajectories (Le Quéré et al., 2020). Within this context, there is an increasing recognition of the value of incorporating behavioral strategies into climate mitigation efforts, particularly in low- and middle-income countries, where structural limitations often hinder the implementation of large-scale technological solutions (Nelms et al., 2022). Individual activities within households contribute directly and indirectly to 72% of greenhouse gas (Liu & Wang, 2024). On both individual and household levels, the accumulation of carbon emissions is referred to as the carbon footprint. The household carbon footprint is shaped by the lifestyle choices of each individual within the household, which generate emissions from

energy consumption, transportation, and dietary patterns (Huang et al., 2024). In densely populated areas, energy consumption is estimated to account for approximately 70% to 80% of CO₂ emissions (Lin & Li, 2020).

Fig. 1 presents a comparative trend of per capita CO₂ emissions and electricity consumption in Indonesia between 2013 and 2022. Both variables exhibit a generally increasing trend, with CO₂ emissions peaking at 2.64 tons per capita in 2022 (International Energy Agency, 2022). This increase occurred gradually, although there were years, such as 2020–2021, when the growth slowed before sharply rising again in 2022. The rise was from 2.23 tons in 2021 to 2.64 tons in 2022. This increase is largely attributed to economic activities and energy consumption following the pandemic. The rise in per capita carbon emissions correlates with the increase in per capita electricity consumption, which also experienced a notable uptick during the same period, particularly from 2017 to 2019. The increase in electricity consumption has the potential to elevate CO₂ emissions, as a significant portion of Indonesia's electricity is still generated from the combustion of fossil fuels, such as coal and natural gas (Ministry of Energy and Mineral Resources, 2023). Nevertheless, promoting sustainable behavior in urban areas continues to face significant challenges (Rauf et al., 2023). It is emphasized that advancing urban sustainability requires a strong focus on resource efficiency, inclusive governance, and transformative behavioral changes as essential

components for achieving long-term resilience and meeting climate goals. In line with these global challenges and priorities, the Indonesian government is actively engaged in efforts to reduce carbon emissions as part of its climate change mitigation strategy. This is outlined in Law Number 16 of 2016 regarding the Ratification of the Paris Agreement to the United Nations Framework Convention on Climate Change. Through the Nationally Determined Contribution (NDC), Indonesia has committed to reducing Greenhouse Gas (GHG) emissions by 31.9% by 2030 through its efforts and by 43.2% with international support ([Institute for Essential Services Reform, 2023](#)). Achieving these targets requires coordinated action not only at the national level but also within local governments. Assessing local carbon reduction initiatives within the framework of the SDGs enables policymakers to monitor progress more efficiently. Research has shown that incorporating carbon neutrality indicators into local SDGs tracking systems can strengthen policy alignment and improve accountability at the municipal scale ([Bilsky, E., Moreno, A. C., & Fernández Tortosa, 2021](#); [Ciambra & Stamos, 2023](#)). One of the measures implemented by the Indonesian government to decrease carbon emissions is the establishment of a carbon tax. The carbon tax is a fee imposed on taxpayers, whether individuals or entities, who purchase goods containing carbon or engage in activities that produce carbon emissions. The primary objective of this tax is to fulfil commitments under the Paris Agreement and to accelerate the development and utilization of new renewable energy sources. The tax rate is regulated in Article 13, paragraphs 8 and 9 of the Tax Regulation Harmonization Law, with a minimum carbon tax rate set at Rp 30 per kilogram of CO₂e or an equivalent unit. Reducing carbon emissions can begin with minimizing the carbon footprint generated by individual activities. Although the changes made may be small, their impact can be significant when implemented gradually. Daily lifestyle choices play a crucial role in determining the success of these efforts. Key factors include the type of housing, energy consumption patterns, dietary habits, waste management, and transportation choices. Additionally, urban life transformation, household consumption patterns, and social practices are also key elements that support sustainable efforts to reduce carbon footprints ([Lombardi et al., 2017](#)). Specifically, this study aims to identify the factors that

drive urban residents' willingness to engage in pro-environmental actions and to determine the most influential behavioral domains that can effectively reduce carbon emissions. These findings are expected to enhance understanding of the role of individual and collective behaviors in supporting sustainable urban systems and to provide insights that can inform policy strategies for behavior-based mitigation. To achieve these objectives, this paper employs an empirical approach that combines socio-economic analysis and behavioral assessment. The study was conducted in Surakarta, a rapidly growing Indonesian city characterized by high energy consumption and mobility levels. The analysis focuses on five behavioral domains: housing, food consumption, waste and water management, energy use, and transportation, to explore how daily lifestyles affect the overall household carbon footprint. This methodological approach enables a contextual understanding of the interrelationship between individual choices and emission outcomes in developing urban areas.

MATERIALS AND METHODS

Survey design and data collection

This study employed a quantitative survey design to systematically capture behavioral, socio-demographic, and attitudinal factors influencing individuals' willingness to decrease their carbon footprint (WDCF) in Surakarta City. This research was conducted in five sub-districts of Surakarta City, namely Semanggi, Jayengan, Sondakan, Sumber, and Mojosongo. The purposive selection of these areas was guided by two key considerations. First, these five sub-districts are sites where passive sampler devices have been installed by the Environmental Agency of Surakarta City, which are utilized to monitor the concentration of carbon emissions, particularly the pollutants SO₂ and NO₂. Second, these areas are situated along the transit routes of the Batik Solo Trans public transportation system and exhibit a high level of mobility. These criteria ensure that the selected sites represent diverse urban characteristics, combining both environmental monitoring zones and high-activity corridors. Thus, the five areas are considered representative of the broader urban structure across 54 sub-districts in Surakarta City. A total of 204 respondents were surveyed across the five sub-districts. The sample size was determined to achieve statistical adequacy and reflect the demographic diversity of Surakarta's urban population,

including variations in age, income, education, and occupation. Respondents were selected using a stratified random sampling approach to ensure balanced representation across gender and neighborhood categories. Data were collected using a structured questionnaire divided into two main sections. The first section collected socio-demographic information, including gender, age, education, occupation, monthly household income, and residential location. The second section measured behavioral and psychological dimensions associated with carbon reduction. The questionnaire instrument was adapted from Khanam et al. (2022) with modifications to align with Indonesia's urban context. The instrument was designed to develop the Willingness to Decrease Carbon Footprint Index (WDCFI), which captures pro-environmental behavior across five key domains: housing, food consumption, waste and water management, energy use, and transportation. Each domain included 2 to 3 statements measuring behavioral tendencies, rated on a 5-point Likert scale (Strongly Agree = 2 to Strongly Disagree = 0). Certain items, such as renewable energy use or vehicle ownership, were measured dichotomously (Yes = 2; No = 0). The total scores were normalized to form the WDCF index values, allowing cross-domain comparisons of behavioral readiness. The design of the WDCF is theoretically grounded in environmental behavior research, which emphasizes attitudes, values, and awareness as predictors of sustainable behavior (Batalla-bejerano et al., 2020). Therefore, this instrument not only measures stated preferences but also reflects the psychological and contextual determinants of behavioral change.

Analytical framework

The analytical framework of this study integrates multivariate statistical techniques to identify latent behavioral dimensions and the factors influencing WDCF. Data from 204 participants were analyzed using Stata 13. The main analytical tool employed is Principal Component Analysis (PCA), a method suitable for reducing complex behavioral data while preserving essential variance. PCA was selected because it enables the extraction of key behavioral dimensions (principal components) that explain the largest proportion of variance in WDCF indicators, while minimizing multicollinearity among correlated variables. This methodological choice aligns with recent studies for that have applied multivariate analysis to urban

SDG monitoring and behavior-based sustainability assessments (Jia et al., 2024; Yin et al., 2023). PCA is a statistical technique utilized to transform a set of correlated original variables into a new set of uncorrelated variables (principal components), aiming to reduce data dimensions without losing significant information. This technique enables researchers to identify latent structures within the data and to avoid multicollinearity issues among independent variables in subsequent analysis models (Abdi, H., and Williams, 2010; Ongbali et al., 2024). The justification for employing PCA lies in its ability to identify underlying structures in behavioral data and reveal how different socio-economic and psychological factors cluster together to influence carbon-reducing behavior. All extracted principal components (PC1–PC5) were continuous variables that cumulatively explained 100% of the data variation, with the first few components contributing the majority of the explanatory power. These components were subsequently interpreted as distinct behavioral constructs reduce the carbon footprint in Surakarta City. Fig. 2 illustrates the conceptual framework of the study, highlighting five key components that represent dimensions of environmentally friendly behavior: housing, food consumption, waste and water management, energy use, and transportation. The steps for implementing PCA in this study include: (1) standardizing the data for each WDCF indicator to ensure comparable variance, (2) calculating the correlation matrix among variables, (3) extracting principal components based on eigenvalues, and (4) interpreting factor loadings to ascertain the contribution of each indicator to the components. Principal components with eigenvalues greater than one ($\lambda > 1$) are utilized for further analysis. The PCA results are then used to construct the total WDCI, which reflects the community's collective willingness to reduce carbon emissions in the study area.

RESULTS AND DISCUSSION

Descriptive statistics and factor analysis for variables entering the analysis

This research involved 204 individuals residing in five sub-districts of Surakarta City, namely Semanggi, Jayengan, Sondakan, Sumber, and Mojosongo. These locations were purposively selected due to their high levels of residential carbon emissions, primarily nitrogen dioxide (NO₂) and sulfur dioxide (SO₂), which are major air pollutants in urban areas. Individuals were

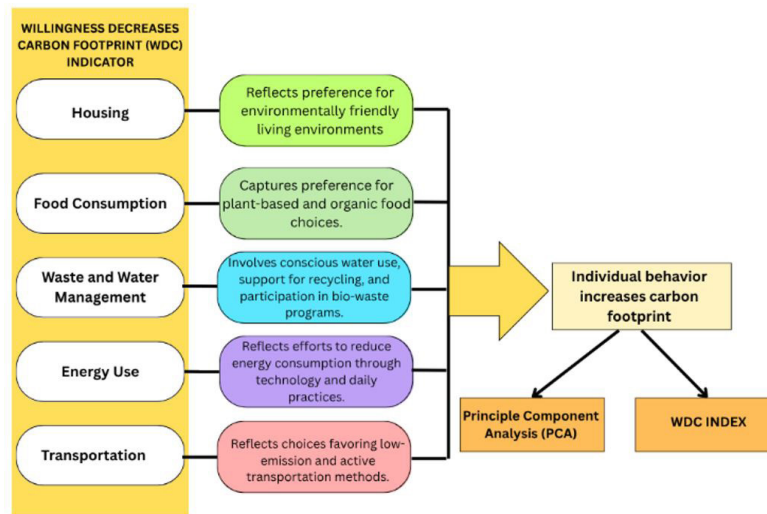


Fig. 2: Research concept

chosen as the unit of analysis because their daily activities, such as energy use, mobility, and consumption patterns, directly contribute to household-level carbon emissions. The research instrument consisted of 13 items representing five key behavioral indicators: housing (WDCF-H), food (WDCF-F), waste management (WDCF-W), energy (WDCF-E), and transportation (WDCF-T). Data collected from the 204 respondents were analyzed using Principal Component Analysis (PCA) to identify the dominant behavioral factors influencing the willingness to decrease carbon footprint (WDCF) among Surakarta residents. To evaluate the suitability of the data for factor analysis, the Kaiser-Meyer-Olkin (KMO) test was applied, yielding a KMO value of 0.727, which exceeds the minimum threshold of 0.50 (Verdian, 2019). This indicates that the data are appropriate for factor analysis.

Table 1 indicates that the KMO value obtained is 0.727, which exceeds the threshold of 0.05. There-

fore, it can be concluded that the variables utilized in this study are suitable for further analysis through factor analysis. In addition to the KMO test, the anti-image matrix analysis is also employed to assess the partial correlations among the variables and to evaluate the appropriateness of each variable in the factor analysis process. This matrix produces the Measure of Sampling Adequacy (MSA) values for each variable, serving as an indicator of their suitability. According to Fatati and Puspitasari (2015), variables with MSA values above 0.05 are considered eligible for inclusion in the factor analysis, as they indicate that these variables possess adequate partial correlation levels with other variables in the model.

Table 2 presents the MSA values for each variable, specifically, the WDCF-H variable at 0.7748, WDCF-F at 0.6183, WDCF-W at 0.4626, WDCF-E at 0.3903, and WDCF-T at 0.9260. From these results, it is evident that the MSA values for all variables exceed 0.05. Con-

Table 1: KMO test

Variables	KMO
WDCF-H	0,749
WDCF-F	0,786
WDCF-W	0,739
WDCF-E	0,685
WDCF-T	0,652
Total	0,727

Table 2: Result of anti-image covariance

Variabel	WDCF-H	WDCF-F	WDCF-W	WDCF-E	WDCF-T
WDCF-H	0,7748				
WDCF-F	-0.0520	0,6183			
WDCF-W	0.1002	-0.0796	0,4626		
WDCF-E	0.1334	-0.1925	-0.2234	0,3903	
WDCF-T	-0.1532	-0.0618	-0.0648	-0.0334	0,9260

Table 3: Result of PCA

Variable	PC1	PC2	PC3	PC4	PC5
Eigenvalue	2,4844	1,0851	0,6767	0,4421	0,3117
Proportion of Variance	0,497	0,217	0,135	0,088	0,062
Cumulative Proportion	0,497	0,714	0,849	0,938	1,000

sequently, it can be concluded that all variables are suitable for further analysis. The eigenvalue measures the amount of data variance that can be explained by each principal component. A higher eigenvalue indicates that the component explains a greater variance in the data.

Table 3 displays the factors that have eigenvalues greater than one, highlighting two main components: PC1 with a value of 2.4844 and PC2 with a value of 1.0851. Collectively, these components explain 71.4% of the data's variation. The first principal component (PC1), accounting for 49.7% of total variance, is dominated by variables related to energy efficiency (WDCF-E), waste management (WDCF-W), and food consumption (WDCF-F). This dimension reflects internal household management and daily resource-use behavior, suggesting that residents' awareness of energy use, food choices, and waste practices collectively shape their pro-environmental attitudes. The second principal component (PC2), explaining 21.7% of the variance, is primarily influenced by housing (WDCF-H) and transportation (WDCF-T). This component represents external lifestyle choices that are more structural and infrastructural in nature, such as the design of housing units, proximity to transportation access, and reliance on private vehicles.

Fig. 3 illustrates the scree plot resulting from the PCA analysis, which displays the distribution of eigenvalues for each principal component. The X-axis shows the eigenvalues, or the variance explained by each component. The graph to PC5. It can be concluded

that PC1 and PC2 sufficiently capture the primary information in the data's variation. The loading plot provides a visual interpretation of the two principal components, namely component 1 (PC1) and component 2 (PC2). The loading plot is utilized to depict the variables that exert the most influence on each component. In this study, the loading plot reveals the contribution of each variable in the principal component analysis related to Willingness to Decrease Carbon Footprint (WDCF). The identified variables include housing (WDCF-H), food (WDCF-F), waste management (WDCF-W), energy (WDCF-E), and transportation (WDCF-T).

Fig. 4 illustrates the spatial distribution of variables in the principal component analysis (PCA). The variables WDCF-H and WDCF-T are located far on the negative side of the X-axis (PC1) and have positive values on the Y-axis (PC2), suggesting that these behaviors are distinct from the others and may contribute more strongly to the second component. In contrast, WDCF-E, WDCF-W, and WDCF-F are clustered closer along the PC1 axis, indicating a stronger influence on the first principal component and highlighting their shared underlying patterns in environmentally conscious behavior. Figures 3 and 4 (Scree and Loading Plots) visualize the differentiation between the two components. Variables WDCF-H and WDCF-T cluster along PC2, while WDCF-E, WDCF-W, and WDCF-F cluster along PC1, confirming that internal consumption and external mobility are two distinct yet interconnected behavioral domains influencing WDCF.

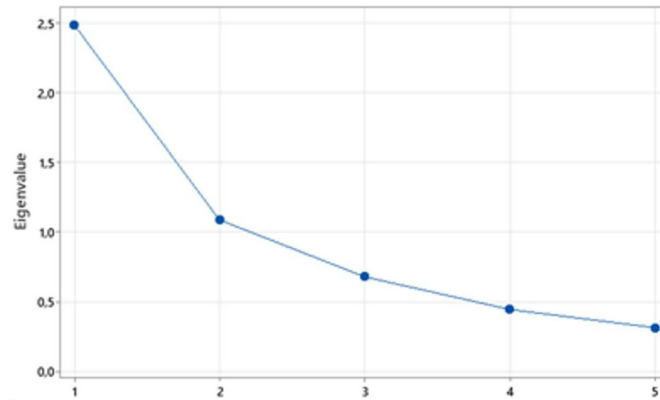


Fig. 3: Scree plot PCA

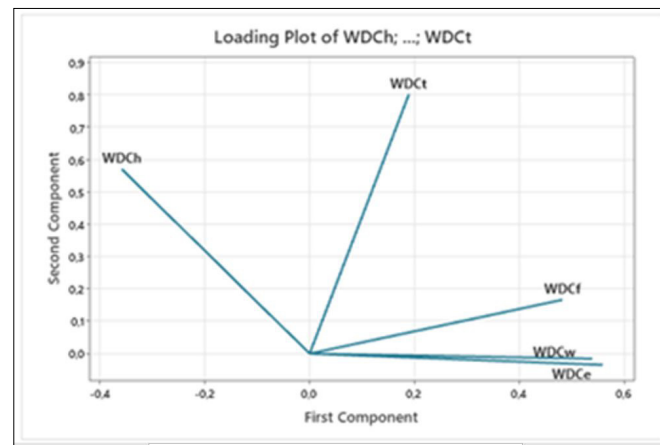


Fig. 4: Loading plot

Table 4 presents the results of the eigenvector values, which elucidate the relative contributions of each variable to the principal components. The eigenvector value for WDCf-H indicates a negative contribution to PC1, quantified at -0.358, while it shows a significantly large positive contribution to PC2, measured at 0.571. WDCf-T, positioned far on the positive side of the Y-axis, exhibits a dominant eigenvector value of 0.803 on PC2, signifying that this variable plays a substantial role in the second dimension. The variables WDCf-F, WDCf-W, and WDCf-E have eigenvector values of 0.482, 0.539, and 0.559, respectively, indicating high weights on PC1 and lower weights on PC2. From the principal component analysis with the loading plot, it can be concluded that the second principal component (PC2) is more influenced by the preferences of Surakarta City residents in reducing their carbon footprint through

housing choices (WDCf-H) and transportation (WDCf-T). In contrast, the first principal component (PC1) is predominantly influenced by the community's preferences for energy efficiency (WDCf-E), waste management (WDCf-W), and food consumption (WDCf-F). These findings are consistent with [Tajpour & Razavi 2023](#)), who emphasized that collective team performance and entrepreneurial mediation enhance adaptability and innovation capacity within organizational systems, a mechanism that mirrors how household-level behavioral cooperation and collective awareness can foster greater climate resilience. Similarly, [Arabiun et al., \(2024\)](#) found that digital leadership strengthens organizational performance through the mediating role of entrepreneurship, reflecting how leadership and initiative at the community level can drive the diffusion of sustainable practices in urban environments.

Table 4: Eigenvector value

Variables	PC1	PC2	PC3	PC4	PC5
WDCF-H	-0,358	0,571	-0,610	0,403	0,104
WDCF-F	0,482	0,167	-0,564	-0,589	-0,273
WDCF-W	0,539	-0,016	0,017	0,661	-0,521
WDCF-E	0,559	-0,035	-0,107	0,178	0,802
WDCF-T	0,189	0,803	0,546	-0,144	0,008

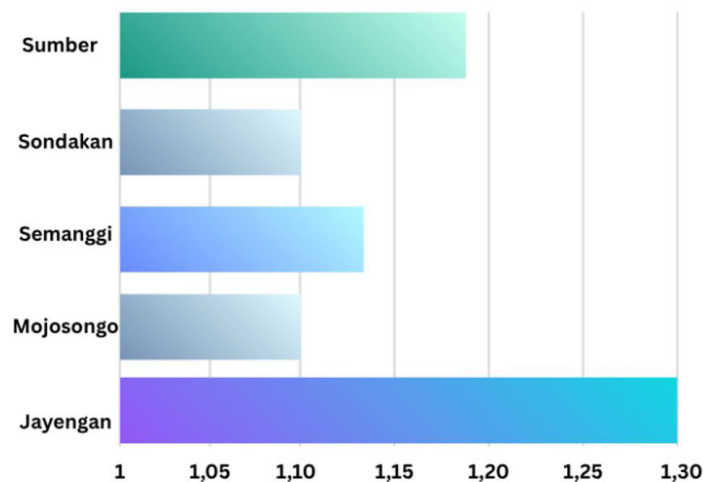


Fig. 5: Results of the WDC index by region

Estimation of the willingness to decrease the carbon footprint index

The index value reflecting the community's willingness to reduce its carbon footprint is based on five primary indicators: housing (WDCF-H), food (WDCF-F), waste management (WDCF-W), energy (WDCF-E), and transportation (WDCF-T). These five indicators are derived by summing the response codes for each section, dividing the sum by the number of questions in that section, and then dividing the result by the number of questions in that section. The resulting index is categorized as follows: 0–0.50 Low Willingness, 0.51–1.00 Moderate Willingness, 1.01–1.50 High Willingness, and 1.51–2.00 Highly Willingness. The results of these calculations are presented in Fig. 5.

Fig. 5 presents the results of the WDCI disaggregated by region. The figure highlights regional variations in community willingness to reduce carbon emissions across the five sub-districts studied. The willingness to decrease the carbon footprint index across the

five sub-districts in Surakarta exhibits values within the same category, specifically indicating a moderate willingness. The sub-district of Jayengan records the highest index value at 1.30. The second-highest index is for the sub-district of Sumber, with a value of 1.19. Meanwhile, the fourth-highest index is held by the sub-district of Semanggi, with a value of 1.14. The sub-districts of Sondakan and Mojosongo show lower index values, both at 1.10. These results reveal that Surakarta residents demonstrate moderate but relatively consistent readiness to adopt low-carbon behaviors. Several contextual factors may explain this outcome: (1) Limited environmental literacy regarding the long-term benefits of individual behavioral change; (2) Economic constraints that prioritize affordability over ecological consideration; (3) Infrastructure limitations, such as inadequate public transport and access to renewable energy. This pattern aligns with [Khanam et al., 2022](#), who note that even when awareness is present, habitual and financial barriers often limit be-

havioral transformation. Similarly, Ivanova et al. (2020) highlight that although households are responsible for over 70% of global emissions, willingness to change behavior does not always translate into action due to lifestyle lock-ins, infrastructure limitations, and the lack of strong behavioral incentives. By connecting household-level behaviors with broader sustainability strategies, this study contributes to the growing literature on urban human capital development and climate-responsive governance consistent with the integrative frameworks proposed by Tajpour and Razavi (2023) and Arabiun et al., (2024), who highlight the importance of entrepreneurial capability and leadership transformation in enhancing sustainable urban performance.

CONCLUSION

This research indicates that the level of community willingness in five sub-districts of Surakarta City to reduce carbon footprints is generally categorized as Moderate, based on calculations of the Willingness to Decrease Carbon Footprint index (WDCFI). This index value is derived from five behavioral indicators: housing (WDCF-H), food consumption (WDCF-F), waste and water management (WDCF-W), energy use (WDCF-E), and transportation (WDCF-T). The average index value across all sub-districts reflects a sufficient level of community participation, although it has not yet reached the high willingness category. The highest index value was recorded in Jayengan Sub-district (1.30), followed by Sumber (1.19) and Semanggi (1.14). Meanwhile, Sondakan and Mojosongo both had the lowest value of 1.10. All these values remain within the Moderate Willing classification, indicating that the community is beginning to show concern for the issue of carbon footprint reduction, yet has not been fully mobilized towards more concrete and comprehensive actions. The eigenvector values from the PCA illustrate the relative contributions of each indicator to the two main components. The WDCF-H variable exhibits a negative contribution to PC1 (-0.358) and a significantly positive contribution to PC2 (0.571), whereas WDCF-T has a dominant contribution to PC2 (0.803), indicating that the second dimension is heavily influenced by community preferences regarding environmentally friendly housing and transportation choices. Conversely, the variables WDCF-F (0.482), WDCF-W (0.539), and WDCF-E (0.559) exhibit high weights concerning PC1, indicating that the first dimension is pre-

dominantly influenced by energy efficiency behaviors, waste management, and sustainable food consumption. Therefore, it can be concluded that PC1 represents a dimension of household behavior oriented towards efficiency and consumption, while PC2 more accurately reflects environmental preferences in the context of spatiality and mobility. These findings can serve as a foundation for formulating more targeted intervention strategies, taking into account the behavioral aspects that most significantly affect the community's willingness to reduce its carbon footprint.

AUTHOR CONTRIBUTIONS

E. Gravitiani conducted a literature review, designed the experiments, prepared the manuscript, and performed the final editing. N. W. Mulia conducted the experiments, performed the literature review, analyzed the data, and contributed to the preparation of the manuscript. A. Ratnadewati collaborated in developing the research idea and provided critical proofreading and feedback on the manuscript. D. T. Cahyaningsih translated the manuscript and conducted final editing

ACKNOWLEDGEMENT

The author expresses gratitude to the Environmental Agency (DLH) of Surakarta City for their support in providing data and information regarding the research location. Appreciation is also extended to the respondents and all individuals who have contributed to the research process.

CONFLICT OF INTEREST

The author asserts that there are no conflicts of interest in this research, whether financial, personal, or professional, that could influence the results or interpretations of the conducted study.

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ABBREVIATIONS (NOMENCLATURE)

CH ₄	Methane
CO ₂	Carbon dioxide
GHG	Greenhouse Gas
KMO	Kaiser-Meyer-Olkin
N ₂ O	Nitrous oxide
NDC	Nationally Determined Contribution
NO ₂	Nitrogen dioxide
PC1	Principal Component 1
PC2	Principal Component 2
PC3	Principal Component 3
PC4	Principal Component 4
PC5	Principal Component 5
PCA	Principal Component Analysis
SDGs	Sustainable Development Goals
SO ₂	Sulfur dioxide
WDCF-E	Willingness to Decrease Carbon Footprint for Energy
WDCF-F	Willingness to Decrease Carbon Footprint for Food
WDCF-H	Willingness to Decrease Carbon Footprint for Housing

WDCFI	Willingness to Decrease Carbon Footprint Index
WDCF-T	Willingness to Decrease Carbon Footprint for Transportation
WDCF-W	Willingness to Decrease Carbon Footprint for Waste

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HOW TO CITE THIS ARTICLE

Gravitiani, E.; Mulia, N. W.; Ratnadewati, A.; Cahyaningsih, D.T., (2026). Carbon Footprint: A study of key components of pro-environmental. *Int. J. Hum. Capital. Urban Manage.*, 11(4): 645–656

DOI: 10.22034/IJHCUM.2026.04.01

URL: https://www.ijhcum.net/article_735866.html

