
Measuring Climate–Labor Vulnerability in the Platform Economy Through a Climate-Informed Flexibility Vulnerability Index for Indonesia

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Abstract

This study develops the Climate-Informed Flexibility Vulnerability Index (CAFVI) to measure multidimensional climate–labor vulnerability among platform workers in Jakarta, Indonesia. The index integrates four dimensions: economic vulnerability, institutional vulnerability, demographic sensitivity, and environmental exposure. Using secondary data from Fairwork Indonesia, BPS Sakernas, and BMKG, the study applies variable normalization, equal weighting, and principal component analysis to produce comparable vulnerability scores across age groups and platform providers. The findings show a clear U-shaped pattern of vulnerability, with the highest scores observed among younger and older workers and the lowest among prime-age workers. At the platform level, vulnerability is shaped primarily by the interaction between institutional protection and income conditions, while environmental exposure functions as a shared structural baseline. Principal component analysis confirms the internal coherence of the index, with the first component explaining most of the total variance and all loadings remaining positive. The results indicate that climate stress does not operate independently but intensifies existing labor precarity where worker protection and income stability are weak. This study contributes by extending platform labor analysis beyond conventional fairness assessments and by offering a transparent, replicable framework for evaluating climate-sensitive labor vulnerability in data-constrained urban settings, especially in the Global South and comparable emerging economies.

Keywords: platform economy, digital labour, climate vulnerability, gig work, algorithmic management.

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1. Introduction

The fundamental transformation of global labor structures over the last decade has positioned digital technology at the heart of work reorganization a phenomenon particularly vivid across the burgeoning economic hubs of Southeast Asia (Nelson et al., 2024). Within Indonesia's metropolitan landscapes, this shift is most visibly manifested through the mass emergence of application-based services that instantaneously bridge consumer demand with service providers (Paithankar et al., 2026). Although these systems are frequently promoted as gateways to inclusivity, offering rapid income access and scheduling autonomy to those outside traditional formal sectors, the internal mechanisms governing these labor relations often transfer the burden of operational risk directly onto the individual (Demirel et al., 2021). The flexibility on offer is fundamentally asymmetrical; the ease of entry is traded for precarious earnings, a lack of comprehensive social protections, and a dependence on opaque algorithmic logic (Apriliawan, 2025). This arrangement fosters a new form of subordination determined not by conventional employment contracts, but by digital ratings, rigid platform protocols, and market fluctuations that remain entirely beyond the worker's control.

The characteristics of the Indonesian labor market provide a specific urgency to understanding these dynamics, as the expansion of the digital economy has grown alongside long-standing structural challenges, such as high informality and uneven legal protections (Shekhawat & Khare, 2025). The welfare of those reliant on these application-based systems is dictated by a convergence of technological infrastructure, labor market absorption, and the weak bargaining power of individuals in the face of service providers (Boyd et al., 2025). Current regulatory frameworks face a stalemate in classifying these labor relations, where partnership schemes often fail to address the reality of robust managerial control exerted by the platforms (Izzati & Kwang, 2025). This regulatory inability to reach data-mediated work dynamics leaves many trapped in vulnerability, facing economic instability without adequate safety nets, despite their critical role in sustaining modern urban service ecosystems.

However, the understanding of such economic and legal fragilities has yet to be fully integrated with an acknowledgement of the escalating environmental burden (Anwar & Graham, 2021). Major cities in Indonesia now confront intensifying extreme heat and erratic rainfall patterns that directly pressure those whose livelihoods demand a constant physical presence in public spaces. For mobile workers on the streets, adverse weather is not merely a physical hindrance; it is a direct disruption to productivity that reduces operational hours, elevates accident risks, and exacerbates physical exhaustion (Ellena et al., 2020). To ignore the environmental dimension in labor analysis produces a fragmented understanding, as if occupational and climate risks were separate entities, when in fact both are experienced simultaneously within every daily work process (Fieseler et al., 2019). This analytical separation obscures the reality that environmental hazards do not act as mere external shocks but serve as amplifiers of pre-existing economic fragility.

The intersection of digital governance and environmental pressure demands a shift in how we perceive labor autonomy (Kloppenborg et al., 2022). Application systems manage individuals through rating mechanisms and automated task allocations that create practical dependence beneath a rhetoric of temporal freedom. Conversely, exposure to extreme heat is socially discriminatory; the severity of the impact depends heavily on the interaction between physical condition, adaptive capacity, and social positioning (Mekonen & Berlie, 2021). For too long, inquiries into algorithmic management and climate adaptation have occupied separate spheres (N.M, 2022). A focus on technological efficiency often ignores the physical space where work occurs, while environmental impact analysis rarely touches upon how data-mediated labor relations restrict an individual’s ability to protect themselves from climate extremes (Opiyo et al., 2024). This gap renders the position of mobile street workers both pivotal and neglected within sustainable development discourse.

Efforts to measure labor decency have often focused on wage systems, contractual conditions, and representation. Yet, these assessments frequently stop at the level of institutional compliance without measuring how the accumulation of various risk burdens forms a lived reality of vulnerability. Meanwhile, environmental vulnerability indices are typically designed for communities or geographic territories, often failing to capture the specific dynamics of fragmented labor relations. What is required is a new framework capable of linking institutional aspects, economic fragility, and demographic sensitivity with environmental exposure through a single, unified lens. This approach does not merely treat the environment as a backdrop but as an active component determining the extent to which a worker can survive within a high-speed economy.

The development of the Climate-Informed Flexibility Vulnerability Index (CAFVI) aims to address this analytical void by reconceptualizing vulnerability as a multi-dimensional, interlocking condition. CAFVI distinguishes itself by moving beyond standard evaluations of platform rules, instead placing data-mediated work processes at the center of the environmental risk experience. Vulnerability in this framework is defined through the interaction of four primary pillars: economic uncertainty related to the life cycle, deficits in institutional protection from service providers, demographic sensitivity based on age-linked physical capacity, and the structural burden of heat and rainfall exposure in urban settings (van Doorn, 2017). This design is a direct response to the need for measurement tools that capture how environmental hazards aggravate already brittle labor relations, creating a more complete picture of the risks faced by the contemporary digital workforce (Venugopal et al., 2020).

Realities on the ground indicate that rising surface temperatures in metropolitan areas like Jakarta significantly erode the productivity of mobile-based workers by reducing weekly operational hours and monthly income (Andi Muh. Zulfadhil Zareka et al., 2025). These impacts are felt most heavily in areas with high building density and minimal green space. This group faces a higher level of vulnerability compared to other informal sectors due to their reliance on continuous outdoor movement and the weakness of their protection systems (Garcia Ferrari et

al., 2022). These conditions confirm that welfare in the digital economy cannot be understood through wages or technological sophistication alone; it must be viewed as an intersectional labor condition where climate threats amplify the uncertainty generated by the platform business model itself (Vu & Nguyen, 2024).

More broadly, prolonged heat exposure has long been known to diminish work performance, trigger extreme exhaustion, and adversely affect long-term health, particularly in sectors requiring physical presence in open spaces. This risk is not distributed evenly; it is mediated by the conditions of the built environment and access to protective infrastructure. For providers of application-based transport and delivery, thermal pressure on the streets meets the time pressure generated by task allocation systems (Wood et al., 2019). Unlike conventional manual laborers, every second spent resting from the heat can result in a lower performance score on the application, ultimately restricting future access to tasks (Cheung et al., 2016). In this position, the individual stands at the crossroads of an environmental crisis and digitally managed labor precarity.

Application systems are not neutral intermediaries; they possess the authority to reward or punish through algorithmic management mechanisms that often shift operational costs and time risks to the individual (Benlian et al., 2022). Different system designs across providers create varying levels of pressure, where bargaining positions and access to opportunities are heavily influenced by digital capital and social standing (Duggan et al., 2023). This indicates that vulnerability cannot be reduced to a mere weather problem but interacts closely with wage structures, management transparency, and the protection standards implemented by each firm. Therefore, the institutional dimension in this index is designed to view governance quality as a determining variable, allowing the risk experienced by workers to be interpreted as the result of accumulated structural conditions rather than mere personal unreadiness (Miao et al., 2023).

The conceptual foundation of this work rests on the integration of three primary perspectives. First, the understanding that physical hazards become a tangible threat only when they meet unequal social arrangements, meaning vulnerability is produced through access inequalities and institutional power asymmetries (Lajeunesse, 2025). Second, the recognition that the digital economy reorganizes labor markets through fragmented contracts and data-driven control while maintaining a pseudo-narrative of autonomy (Fast et al., 2023). Third, the evidence that extreme temperature is a crucial labor issue because it directly affects work intensity and human health (Kjellstrom et al., 2020). By unifying these elements into a single operational framework, the analysis shifts from sectoral abstractions toward a more concrete understanding of how digital governance and environmental risk meet in daily economic activities.

A persistent methodological challenge in studying labor markets in developing nations is the scarcity of specific, integrated micro-data. Many regions experiencing rapid digital growth lack official databases capable of linking income, age, social protection, and climate exposure (He et al., 2022). In the absence of such data, the use of transparent and replicable composite indices becomes highly relevant as a diagnostic instrument. By adapting established vulnerability

measurement logic to the digital labor context, CAFVI offers a practical tool for identifying risk patterns without waiting for perfect datasets. This contribution is both methodological and strategic, providing a scalable measurement architecture for various contexts where labor informality and climate pressure overlap.

This methodological relevance is particularly vital given the transitional state of labor regulation in Indonesia. Debates regarding the legal status of application workers continue, while individuals on the ground continue to bear the costs of fuel, health risks, and the uncertainty of waiting times under erratic weather (Ramanya Gayathri M, 2025). The presence of a vulnerability index is not intended to resolve all legal complexities but to reveal where the greatest concentrations of risk lie and how these dimensions reinforce one another (Painter et al., 2024). By comparing profiles across age groups and platform providers, this approach can illuminate which combinations of factors are most likely to produce extreme vulnerability, thereby providing valuable input for urban adaptation planning and digital labor accountability.

Based on this line of reasoning, several logical expectations guide this analysis. First, vulnerability is expected to vary across age groups non-linearly, as economic instability and physiological susceptibility to heat do not affect individuals uniformly throughout the life cycle. Younger groups may face higher economic uncertainty, while older groups are more susceptible to physical exhaustion from extreme temperatures. Second, differences in governance standards among application providers will significantly determine the total vulnerability felt, where weak contract protections and opaque management will exacerbate risk even if income levels appear sufficient. Third, environmental exposure will act as a baseline structural burden for all mobile workers in Jakarta, given they face the same geographic realities in their daily routines.

Taken together, the objective of this study is to construct and apply the Climate-Informed Flexibility Vulnerability Index (CAFVI) as a tool for measuring labor vulnerability amidst Indonesia's digital economic dynamics. By integrating economic vulnerability, institutional protection, demographic sensitivity, and environmental exposure, this study contributes to broadening the scope of digital labor analysis, which has historically neglected ecological aspects. Furthermore, this approach extends climate adaptation research by highlighting how data-mediated labor relations affect how humans respond to environmental hazards. Through a replicable measurement strategy, this study argues that application-based work in Indonesia must be understood as a form of climate-exposed labor, where vulnerability is produced through the complex interaction between governance technology and escalating environmental pressures.

2. Research method

The framework of this analysis rests on a quantitative composite-index design, specifically developed to operationalize the Climate-Informed Flexibility Vulnerability Index (CAFVI). This methodological choice is a direct response to the multifaceted nature of the problem: vulnerability within the platform economy is not a monolithic state but an emergent property of

intersecting disadvantages (Sibilia et al., 2024). It arises from the friction between fluctuating income, a lack of institutional safeguards, the physiological realities of aging, and the structural burden of environmental stress. In a landscape where official statistics often fail to bridge the gap between company-level platform operations and individual worker experiences, a composite approach provides a necessary diagnostic bridge (Rowan et al., 2014). By assembling heterogeneous variables into a singular, interpretable scale, it becomes possible to map the cumulative weight of exposure and sensitivity that a single raw metric would inevitably obscure (Hinojos et al., 2026).

The architecture of CAFVI follows a rigorous computational sequence that prioritizes transparency and replicability. The index is built upon the premise that a worker's resilience is determined by more than just a daily wage; it is a function of the protective environment provided by the platform and the physical demands imposed by the urban climate (Hyder et al., 2012). Consequently, this study rejects the treatment of climate as a mere background variable, instead embedding it as a constitutive dimension of labor vulnerability itself. Structurally, CAFVI is conceived as an additive composite index. This design allows for a balanced integration of diverse indicators economic, institutional, demographic, and environmental ensuring that the final measure reflects the integrated research gap identified earlier (Lessy et al., 2025). To maintain analytical discipline, the development process moved through distinct stages of data assembly, normalization, and directional harmonization, followed by a validation process designed to test the internal coherence of the vulnerability signal (Smits & Huisman, 2024).

Jakarta serves as the primary laboratory for this index development, given its status as the epicenter of Indonesia's digital labor market and its acute susceptibility to seasonal environmental pressures (Izzati & Kwang, 2025). The city's dense metropolitan fabric, characterized by high-volume logistics and ride-hailing networks, creates a setting where digital management and climatic hazards are inseparable from the daily labor process (Apriliawan, 2025). To ensure temporal consistency, 2023 was selected as the reference year, aligning the institutional ratings of platforms with the most recent available labor force data and meteorological observations. This alignment is critical for the integrity of a composite measure, as it prevents the distortion that occurs when variables are drawn from disjointed economic or climatic periods (Wang et al., 2026).

The operational core of the index is divided into four primary dimensions. The institutional component is grounded in the governance quality of the platforms themselves, utilizing standardized evaluations of fair pay, conditions, contracts, management, and representation (Devi & Paul, 2026). These are transformed into a Platform Protection Score (PPS) by aggregating binary scores across these five principles and dividing by the maximum possible value. Because the index is designed so that higher values represent greater risk, this protection measure is inverted (Abdrabo et al., 2023). The resulting institutional vulnerability is expressed as:

$$PPS_p = \frac{Raw\ Fairwork\ Score_p}{5}$$

Through this inversion, a platform with minimal protections correctly yields a high vulnerability score, aligning it with the direction of the economic and demographic risk parameters (Sibilia et al., 2024). This ensures that when the dimensions are eventually aggregated, the signal remains consistent across all inputs.

Economic and demographic variables require a more nuanced synthesis to overcome the limitations of aggregate labor statistics (Smits & Huisman, 2024). While national surveys provide clear age-disaggregated income data, they lack the granularity of company-specific earnings (Shiozaki et al., 2024). To address this, the study employs a weighted estimation procedure that combines observed income averages for three distinct cohorts youth (15–24), prime age (25–54), and older workers (55 and above) with the estimated distribution of these groups within specific platforms. The platform-specific mean income is calculated as:

$$Income_p = \sum_g w_{g,p} \times I_g$$

In this formula, $w_{g,p}$ represents the estimated proportion of age group g on platform p , while I_g denotes the average income for that group. Once these values are established, the economic dimension is scaled using a min-max transformation to ensure it occupies a bounded 0–1 interval:

$$EV_i = 1 - \frac{I_i - I_{min}}{I_{max} - I_{min}}$$

This scaling ensures that lower earnings are mathematically translated into higher vulnerability scores, preserving the rank order of economic precarity while allowing it to be combined with non-monetary indicators (Lessy et al., 2025).

The demographic dimension introduces the Age Risk (AR) parameter, which acknowledges that physiological sensitivity to environmental stress is not distributed linearly across a worker's life (Ellena et al., 2020). Younger workers often face higher entry-level economic instability, while older workers experience significantly higher physical strain and slower recovery from heat exposure (Rahmawati et al., 2025). To capture this U-shaped risk profile, a categorical coding is applied where both the youngest and oldest cohorts are assigned a risk value of 1.0, while the prime-age group is set at 0.0. This is not a biomedical measure but a comparative diagnostic tool intended to highlight the periods of the life course where work-capacity is most sensitive to external shocks (Devi & Paul, 2026).

Environmental exposure (ERE) is treated as a shared structural baseline for all mobile workers within the Jakarta metropolitan area. Utilizing daily observations from the primary meteorological station, the study applies two critical thresholds: days with a maximum temperature exceeding 35°C and days with rainfall surpassing 50 mm. These benchmarks are selected for their operational significance; they represent conditions that actively disrupt navigation, increase the risk of physical exhaustion, and threaten the safety of outdoor labor (Song et al., 2025). The environmental risk is calculated as the proportion of days in the year that meet or exceed at least one of these thresholds:

$$ERE = \frac{Days_{>threshold}}{365}$$

For the 2023 observation period in Jakarta, thirty-five days met these criteria. By applying this as a common baseline, the index reflects the reality that while platform governance varies, the atmospheric pressure of the city is a collective burden borne by all who labor in its streets.

The final computation of CAFVI is split into two models to allow for granular comparison. The first, CAFVI-Age, aggregates the dimensions relevant to each age cohort to identify which life stages are most exposed:

$$CAFVI_{Age.g} = \frac{EV_g + AR_g + ERE}{3}$$

The second, CAFVI-Platform, identifies how the specific governance and pay structures of different companies contribute to worker risk:

$$CAFVI_{Platform.p} = \frac{EV_p + (1 - PPS_p) + ERE}{3}$$

In both instances, the arithmetic mean is utilized for aggregation. This choice prioritizes transparency and ensures that the resulting score ranging from 0 (resilience) to 1 (extreme vulnerability) is directly interpretable for policy interventions. While the baseline model assumes equal weighting across dimensions to reflect their conceptual parity, the robustness of these rankings is subjected to rigorous testing.

Validation of the index focuses on the shared variance among the normalized variables to ensure they are indeed measuring a coherent underlying construct. Principal Component Analysis (PCA) is employed as a diagnostic device; if the first principal component captures a dominant share of the variance (typically above 60%) and the loadings are positive across all dimensions, the additive index is considered statistically defensible (Abdrabo et al., 2023). This is supplemented by sensitivity testing, where the baseline weights are perturbed by $\pm 20\%$ and the resulting changes in platform rankings are measured using Spearman's rho (Okoye & Hosseini, 2024). High correlation in these tests confirms that the substantive conclusions of the study are not mere artifacts of the weighting scheme but are rooted in the structural data (Thein et al., 2025).

By documenting every transformation and scaling rule, this method ensures that the research remains an open and auditable process. It acknowledges the boundaries of the data notably the use of synthetic income estimates and a shared climate baseline yet it positions these as necessary methodological bridges in the pursuit of immediate, evidence-based policy (Nelson et al., 2024). The result is a replicable architecture that can be scaled to other urban centers, providing a consistent lens through which to view the intersection of digital labor and the escalating challenges of the urban environment.

3. Results and Discussion

3.1. Results

The calculation of the CAFVI confirms that vulnerability is not a static condition but a dynamic outcome of overlapping disadvantages. In the platform-level model, the integration of

economic and institutional variables alongside a shared environmental baseline allows for a clear comparison of service providers (Rosli et al., 2025). Simultaneously, the age-group model illuminates how life-stage sensitivities dictate the severity of risk. All indicators were directionally harmonized, ensuring that higher values consistently represent greater vulnerability (Mekonen & Berlie, 2021). This standardization is particularly critical for the institutional dimension, which was derived from Fairwork Indonesia ratings. In the 2023 assessment, Gojek and Grab each secured only two points out of a possible ten, while Deliveroo, KliknClean, and Lalamove received one point. These low scores translate into a pervasive environment of weak governance across the observed ecosystem, where protections for pay, conditions, and representation remain largely unfulfilled (Dobbs & Levitt, 2017).

The descriptive profile of the CAFVI components reveals a cumulative risk structure where institutional deficits and income insecurity are the primary drivers of differentiation (Woodside et al., 2021). Table 1 summarizes these components, showing that institutional vulnerability recorded the highest mean (0.80), reflecting a systemic lack of platform-based safeguards. Economic vulnerability follows with a mean of 0.30, while environmental exposure remains constant as a shared climatic baseline (0.10). The resulting composite CAFVI mean of 0.45 suggests a moderate yet significant level of risk. This indicates that the vulnerability of Jakarta’s platform workers is not driven by catastrophic climatic values in isolation, but by the fact that even moderate environmental stress is layered onto deep-seated institutional and economic fragility. This pattern aligns with evidence that heat-induced productivity loss among gig riders is mediated through lower working hours and diminished income rather than a purely meteorological trigger.

Table 1. Descriptive summary of CAFVI components, Jakarta, 2023

Variable	Mean	Std. Dev.	Min	Max	Description
Economic vulnerability (EV)	0.30	0.05	0.20	0.42	Captures income-related fragility after normalization
Institutional vulnerability (1 – PPS)	0.80	0.05	0.69	0.93	Captures platform-governance deficits from Fairwork scores
Environmental risk exposure (ERE)	0.10	0.00	0.10	0.10	Shared climatic baseline across Jakarta platforms
Composite CAFVI (platform model)	0.45	0.12	0.30	0.63	Overall multidimensional vulnerability

Source: Authors’ computation from BPS/Sakernas 2023, Fairwork Indonesia Ratings 2023, and BMKG 2023.

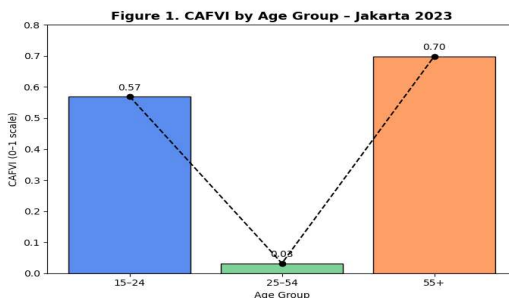
The assessment of demographic sensitivity highlights a non-linear relationship between age and risk, forming a distinct U-shaped curve in Figure 1. As shown in Table 2, vulnerability is concentrated at the opposite ends of the age spectrum. The youngest cohort (15–24 years) recorded a CAFVI score of 0.57, while the oldest group (55+ years) reached the highest level of 0.70. Conversely, prime-age workers (25–54 years) exhibited the lowest vulnerability at 0.03. These results suggest that while younger workers struggle with income instability and initial

occupational positioning, older workers face the most severe burden due to the combination of high normalized economic vulnerability and physiological sensitivity to heat (Odonkor & Adams, 2022). The constant environmental term across all groups reinforces the conclusion that age-linked differences are driven by the intersection of income fragility and bodily capacity rather than varied weather exposure.

Table 2. CAFVI by Age Group, Jakarta 2023

Age group	EV	AR	ERE	CAFVI	Interpretation
15-24	0.61	1.00	0.10	0.57	High vulnerability driven by income instability and age risk
25-54	0.00	0.00	0.10	0.03	Lowest vulnerability among the three cohorts
55+	1.00	1.00	0.10	0.70	Highest vulnerability driven by economic and demographic sensitivity

Note: $CAFVI = \frac{(EV + AR + ERE)}{3}$



Source: Authors' computation from BPS/Sakernas 2023 and BMKG 2023.

The comparison of specific platforms provides the clearest evidence of how economic and institutional dimensions converge. The ranking in Table 3 must be read in descending order of risk, with KliknClean recording the highest vulnerability (0.63) and Deliveree the lowest (0.30). This ordering illustrates that higher income can partially mitigate, but not entirely erase, the risks posed by weak governance. Deliveree serves as a case in point: despite possessing a weak protection score, its relatively stronger income position lowers its total vulnerability score. In contrast, KliknClean exhibits the most severe risk profile by compounding the weakest economic profile with significant institutional deficits. These findings underscore that while all platforms operate under the same climatic baseline, the internal structures of pay and protection are what determine the actual degree of worker precarity.

Table 3. CAFVI by platform provider, Jakarta, 2023

Platform	EV	PPS	1-PPS	ERE	CAFVI	Vulnerability rank	Dominant risk pattern
KliknClean	1.00	0.20	0.80	0.10	0.63	1	Economic and institutional vulnerability compound

Lalamove	0.66	0.20	0.80	0.10	0.52	2	Institutional weakness with moderate income fragility
Gojek	0.66	0.40	0.60	0.10	0.45	3	Income vulnerability remains substantial despite stronger protection
Grab	0.33	0.40	0.60	0.10	0.34	4	Lower economic vulnerability reduces total risk
Deliverree	0.00	0.20	0.80	0.10	0.30	5	High institutional vulnerability partly offset by stronger income position

Note: $CAFVI = \frac{(EV + (1-PPS) + ERE)}{3}$; higher values indicate greater vulnerability

Source: Authors' computation from BPS/Sakernas 2023, Fairwork Indonesia Ratings 2023, and BMKG 2023

The internal validity of these findings was tested through Principal Component Analysis (PCA) to ensure the selected variables represent a coherent latent construct. The results in Table 4 show that the first principal component (PC1) explains 67.4% of the total variance, with an eigenvalue of 2.02. All loadings on this component were positive and significant, ranging from 0.62 for environmental exposure to 0.79 for economic vulnerability. This indicates that the indicators move together in a meaningful direction, supporting the interpretation of the CAFVI as a unified measure of vulnerability. Furthermore, a Cronbach's alpha of 0.81 confirms high internal consistency. Sensitivity testing, involving weight perturbations of $\pm 20\%$, showed that the relative ranking of platforms remained stable, with a Spearman rank correlation above 0.90. This stability confirms that the observed patterns are not mere artifacts of the weighting scheme but are rooted in the underlying structural data (Fast et al., 2023).

Table 4. PCA loadings and explained variance

Component	Eigenvalue	Variance explained (%)	EV loading	(1 – PPS) loading	ERE loading
PC1	2.02	67.4	0.79	0.74	0.62
PC2	0.65	21.6	—	—	—
PC3	0.33	11.0	—	—	—

Source: Authors' computation

The empirical regularities identified through this process confirm three central truths. First, age-related vulnerability is non-linear, placing the greatest burden on those at the beginning and end of their working lives (Anwar & Graham, 2021). Second, institutional vulnerability is the most pervasive and consistently elevated dimension, signifying that the absence of platform-level protections is the most critical source of worker risk (Navajas-Romero et al., 2026). Third, environmental exposure acts as a structural baseline that elevates the vulnerability of all mobile workers, yet it is the variation in pay and protection that primarily drives the differences in risk between platforms (Shaheen et al., 2026). These results highlight the intersectional nature of precarity, where climate hazards amplify the fragile employment relations already present in the digital economy.

3.2. Discussion

The findings presented here delineate a fundamental shift in how we interpret the precariousness of modern work, suggesting that vulnerability within the platform economy cannot be viewed as a purely institutional failure or an isolated environmental hazard (Kashif et al., 2026). Instead, the Climate-Informed Flexibility Vulnerability Index (CAFVI) reveals an interlocking state where governance deficits, income instability, and physical sensitivity converge under the shared pressure of a changing urban climate. This integrated approach moves beyond existing frameworks that often evaluate labor standards in a vacuum or treat climate adaptation as a broad community issue (Odonkor & Adams, 2022). By embedding labor governance within a climate-sensitive architecture, this analysis demonstrates that the first principal component of worker risk is driven simultaneously by economic, institutional, and environmental indicators (Lessy et al., 2025).

The most significant structural pattern identified is the pervasive elevation of institutional vulnerability (Bolitho & Miller, 2017). Across the platforms observed, protection deficits remain consistently high, suggesting that these digital entities function as governing labor institutions rather than neutral facilitators of exchange (Aleksynska & Cazes, 2016). The current regulatory environment in Indonesia appears to struggle with the asymmetrical nature of this work, leaving individuals in a legal gray area between formal employment and nominal partnership (Dwiputrianti et al., 2025). As indicated by the Fairwork Indonesia scores, consistent deficits in fair management, contractual transparency, and representation are not mere side effects but defining characteristics of the sector. The CAFVI makes this quantifiable, proving that weak governance is the most systematically elevated dimension in the risk profile of Jakarta's mobile workforce.

This evidence clarifies a long-standing ambiguity in debates surrounding the gig economy (Izzati & Kwang, 2025). While platform work is often marketed as a vehicle for flexibility, the results here suggest that such flexibility is frequently a mechanism for risk externalization (Fieseler et al., 2019). In a system where institutional support is minimal, the worker alone absorbs the costs of idle time, traffic congestion, demand volatility, and adverse weather (Apriliawan, 2025). Flexibility does not reduce vulnerability; rather, it often dictates that the worker must bear the brunt of environmental and operational shocks. This is consistent with the broader understanding of algorithmic control, where the appearance of autonomy masks a practical dependence that diminishes individual agency (Navajas-Romero et al., 2026).

The U-shaped demographic pattern provides a crucial nuance to our understanding of labor sensitivity. In this model, younger and older cohorts exhibit higher vulnerability than prime-age workers, yet the drivers of their risk are distinct. The youngest workers are primarily burdened by income instability and a fragile position within the labor market, whereas the oldest workers face a compounding crisis of high economic vulnerability and peak demographic sensitivity to heat and physical strain (Shekhawat & Khare, 2025). This distinction prevents age from being treated as a linear gradient and highlights that rising temperatures are not just a health issue but

a productivity hazard that intersects with unstable earnings and weak protection. The physiological strain of outdoor labor becomes an economic penalty when it is not mitigated by institutional standards or work-rest protocols (Venugopal et al., 2020).

Environmental exposure, while constant across the platforms analyzed in Jakarta, serves as a shared structural baseline that magnifies existing inequalities. Treating this dimension as a collective pressure clarifies that the levers of resilience are found primarily in the economic and institutional domains (Preña & Labayo, 2026). Climate stress is not background noise; it is a persistent labor hazard that reduces operational hours and monthly income. In a metropolitan context, this environmental pressure does not just add a new risk but intensifies the pre-existing fragility of those working without wage guarantees or insurance (Rowan et al., 2014). This realization necessitates a policy shift where climate adaptation and labor regulation are no longer treated as separate silos.

The findings further reveal that platform precarity and climate stress are mutually reinforcing. A worker might manage the physical demands of extreme heat or heavy rain if earnings were stable and protections were in place, but those same climatic events become damaging when layered over uncertain pay and weak contracts (Sibilia et al., 2024). This is exemplified by the case of Deliveroo, where a stronger income position offsets institutional weakness to yield the lowest overall vulnerability score. Conversely, where weak safeguards and unfavorable economic conditions coincide, as seen in KliknClean and Lalamove, the vulnerability effect of climate is at its most severe. This proves that the impact of the environment on labor is filtered through the quality of the institutions governing that labor (Nelson et al., 2024).

From a methodological standpoint, the validation results provide the necessary evidence for this integrated logic. With the first principal component explaining 67.4% of the total variance and all loadings exceeding 0.60, the data confirms that economic, institutional, and environmental indicators converge on a single latent construct. A Cronbach's alpha of 0.81 further reinforces this internal consistency, while rank stability remains high even under alternative weighting schemes. These diagnostics ensure that the CAFVI is not an artifact of arbitrary assumptions but a robust reflection of a coherent vulnerability signal. The additive structure of the index is thus supported by the data, justifying its use as a comparative diagnostic tool (Oncioiu et al., 2026).

The implications for society and policy suggest a need for layered interventions. Reducing vulnerability at the platform level requires more than just productivity incentives; it demands transparent management, fair contracts, and genuine representation (Gebauer, 2023). At the city level, labor-sensitive climate adaptation must include cooling infrastructure, accessible shade, and weather-responsive mobility planning (Razavi, 2022). Nationally, labor regulations and adaptive social protection must explicitly account for platform workers, recognizing that climate action and social protection are inextricably linked (Aleksynska & Cazes, 2016). Providing universal social protection is a vital component of a just transition for a workforce that is increasingly exposed to environmental extremes.

Ultimately, this analysis contributes a measurable framework for understanding the platform economy in Indonesia as a site of climate-exposed labor. By making this vulnerability visible, the study offers a replicable strategy for other regions where rapid digital expansion and environmental stress overlap under conditions of limited data. While the model can be refined in the future to include air quality or route-specific exposure, its current form establishes that resilience in the digital age depends as much on the design of labor institutions as it does on the stability of the climate (Hope & Martelli, 2019).

4. Conclusion and Recommendations

The Climate-Informed Flexibility Vulnerability Index (CAFVI) was developed to provide an integrated analytical lens for measuring the multidimensional nature of risk within Indonesia's platform economy. The central problem addressed by this work is the inherent limitation of viewing worker vulnerability through isolated metrics, whether purely economic, institutional, or environmental. Conventional indicators often fail to capture the synergy between these forces, yet the lived reality of a mobile worker in Jakarta is defined by their simultaneous impact. This synthesis confirms that an integrated composite approach is not merely a methodological alternative but a substantive necessity for understanding the precariousness of modern labor. The index successfully demonstrates that the vulnerability experienced by this workforce is a cumulative, structural condition produced through the friction between governance deficits, income instability, and the physical demands of laboring in a changing urban climate.

The findings clarify that vulnerability in this sector cannot be reduced to a single source of disadvantage. Instead, it emerges from a layered structure of risk in which institutional vulnerability stands as the most consistently elevated component. The systematic failure of platforms to provide robust protections in management, contractual transparency, and representation remains the most decisive factor in shaping comparative risk profiles. While income fragility acts as a significant contributor—particularly where earnings volatility meets a lack of social safeguards—the shared environmental baseline of Jakarta ensures that all workers operate under a common climatic pressure. In this framework, climate does not act as a separate, external shock; rather, it functions as an amplifier that intensifies the consequences of already fragile institutional and economic arrangements.

A critical nuance revealed by this work is the non-linear relationship between age and vulnerability, manifesting as a distinct U-shaped pattern across the life course. Both younger and older workers exhibit significantly higher vulnerability than the prime-age cohort, though the underlying drivers differ for each. For the youngest participants, risk is primarily rooted in labor-market insecurity and the instability of early-career earnings. For older workers, however, high economic vulnerability is compounded by peak demographic sensitivity to heat and physical strain. This pattern clarifies that age is far more than a marginal control variable; it is a fundamental dimension of sensitivity that dictates how bodily resilience interacts with

occupational demands. It reinforces the argument that even when exposed to identical weather hazards, the actual burden of vulnerability is unevenly distributed based on the worker's position in their life cycle.

The comparative analysis of platform providers further illustrates how governance and earnings structures jointly determine outcomes. The results show that platforms with weak institutional performance consistently record higher vulnerability scores unless exceptional income conditions exist to partially offset those deficits. This provides a clear distinction between the CAFVI and traditional fairness assessments. While existing ratings are invaluable for auditing labor standards, they are not designed to measure how governance gaps interact with environmental stress to shape the total burden borne by the individual. By embedding platform protection within a broader vulnerability architecture, this method provides a more holistic understanding of labor in metropolitan settings where outdoor mobility and informality are the norm.

Conceptually, this work strengthens the argument that the flexibility inherent in platform work should not be conflated with genuine labor autonomy. Under a regime of weak institutional protection, flexibility frequently serves as a mechanism for the externalization of risk, allowing firms to shift the costs of idle time, traffic, and adverse weather directly onto the worker. This transfer of uncertainty is not merely economic or contractual; it is also physical and climatic. A worker who must remain mobile during extreme heat or heavy rainfall to maintain a performance rating, while lacking wage guarantees or grievance channels, faces a structurally intensified form of precarity. The CAFVI makes this interaction measurable, moving the discourse beyond separate silos of fair work and climate adaptation toward a unified understanding of climate-exposed labor.

From a methodological standpoint, the study validates the utility of a transparent composite-index approach in data-constrained environments. The coherence of the index is supported by the normalization and aggregation rules, with Principal Component Analysis confirming that the selected indicators converge on a meaningful latent construct. This statistical alignment justifies the use of the baseline model and demonstrates that methodological simplicity does not equate to analytical weakness. In contexts like Indonesia, where granular microdata are often inaccessible, a replicable and transparent framework is far more effective for policy diagnosis than over-specified models that cannot be updated or reproduced by local stakeholders.

The policy implications of these findings are profound and suggest a need for a fundamental shift in labor governance. If institutional deficits are the primary drivers of risk, then strengthening governance standards becomes the most direct mechanism for building resilience. Fair contracts, transparent management, and worker representation are not secondary issues; they are the front lines of risk mitigation. Furthermore, the findings demand that climate adaptation and labor policy be integrated. For those whose workplace is the street, heat and rainfall are occupational hazards that require cooling infrastructure, shade, and weather-

responsive urban planning. The CAFVI thus serves as a practical diagnostic instrument that can help government agencies and worker organizations identify where these gaps are most acute.

However, these conclusions must be interpreted within specific boundaries. The reliance on synthetic income estimates and a shared metropolitan climate baseline reflects the limits of current secondary data sources. While these choices were necessary to build a comparative model, they may overlook micro-spatial variations in environmental exposure or localized differences in platform pay. Additionally, the index does not yet account for other relevant stressors such as air quality, road safety, or household care burdens. As such, the CAFVI should be viewed as a platform-level diagnostic tool rather than a comprehensive causal map of every possible dimension of worker precarity.

These limitations provide a clear roadmap for future inquiry. There is a meaningful opportunity to test this framework in other metropolitan centers across Southeast Asia to examine its generalizability under different regulatory and climatic regimes. Future iterations would benefit from the integration of more granular data, such as GPS-linked exposure records or worker-level financial diaries. Such refinements would allow the index to evolve from a structural comparison into a spatially sensitive, dynamic measurement model. Long-term research will be particularly valuable in determining whether improvements in platform governance can effectively buffer workers against the rising intensity of climate stress over time.

In conclusion, the vulnerability of Jakarta's platform workers is neither incidental nor temporary; it is a systemic outcome of the interaction between digital labor management and environmental pressure. The CAFVI provides the necessary framework to translate this complex condition into a measurable reality. The central message remains that resilience in the platform economy cannot be achieved through flexibility alone. It requires a policy architecture that recognizes climate as a labor issue and institutional protection as a primary pillar of adaptation. For Indonesia and similar economies, the challenge is to move the platform model toward a future that is not only efficient but also just, adaptive, and structurally resilient against the gathering storms of the 21st century.

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