

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

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Abstract

The rapid expansion of Indonesia's platform economy has redefined urban labour relations while intensifying workers' exposure to economic, institutional, and environmental risks. This study develops the Climate Aware Flexibility Vulnerability Index (CAFVI) to quantify multidimensional vulnerability among platform-based gig workers in Jakarta. Integrating four dimensions, economic, institutional, demographic, and environmental. The CAFVI applies transparent normalization, equal weighting, and principal component validation to generate comparable vulnerability scores across age cohorts and platform providers. Using data from Fairwork Indonesia, BPS Sakernas, and BMKG, results reveal a distinct U-shaped pattern of vulnerability, highest among the youngest and oldest workers and lowest among the prime-age group. Institutional protection emerges as the strongest determinant of vulnerability, while environmental exposure functions as a shared structural constraint. The findings demonstrate how algorithmic management and climate stress jointly reproduce precarity within the digital economy. The CAFVI framework offers a scalable diagnostic tool for integrating labour governance and climate adaptation in policy and corporate sustainability strategies. By aligning digital labour management with climate resilience objectives, the study advances the understanding of risk distribution and institutional accountability in Southeast Asia's evolving platform economies.

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

1. Introduction

Over the past decade the expansion of the digital economy in Southeast Asia has transformed labour markets at a pace that has no historical parallel in the region's post-industrial development. Indonesia now stands at the centre of this transformation and hosts one of the most dynamic platform economies in the world. This expanding ecosystem includes ride hailing, food delivery, domestic services and parcel logistics. Digital platforms have opened new income opportunities and have given many urban workers greater control over their time. Yet the same flexibility that attracts participation

also conceals structural fragility that takes the form of algorithmic supervision, unstable income flows and limited social protection (Wood et al., 2018; Alauddin et al., 2025).

While the economic volatility and institutional weakness of gig work are now well documented, a less explored but equally important dimension concerns how climatic variation interacts with flexible employment. Indonesian cities are increasingly exposed to heavy rainfall, recurrent flooding and intensifying urban heat. Each of these hazards poses a direct risk to workers whose livelihoods depend on outdoor mobility. For drivers, couriers and service workers, extreme weather often means lost working hours, physical exhaustion and unpredictable earnings (Adaptation at a Critical Point, 2020; Hussainzad & Gou, 2024). Nevertheless, most labour-market studies have yet to integrate environmental exposure into their understanding of vulnerability. The result is a conceptual gap that separates climate adaptation from digital labour governance.

Earlier research has examined in depth how algorithmic systems control, rank and reward workers within platform economies (van Doorn, 2017; Graham et al., 2020). Parallel studies in climate adaptation and urban resilience show that informal and semi-formal workers tend to bear a disproportionate ecological burden because of their limited access to safe infrastructure and institutional protection (Dodman et al., 2023; Boyd et al., 2025). However, these two research traditions have evolved in isolation. What remains missing is a coherent analytical framework that connects economic insecurity, institutional governance, demographic sensitivity and environmental stress at the level of platform-based labour itself. Without such integration, both public policy and private-sector responses risk remaining fragmented and reactive rather than strategic.

This study addresses that gap by developing the Climate Aware Flexibility Vulnerability Index, hereafter referred to as CAFVI, which quantifies the multidimensional vulnerability of Indonesia's platform workers. The CAFVI combines four interrelated dimensions: economic vulnerability derived from age-specific income data; institutional vulnerability represented by platform governance scores adapted from the Fairwork principles; demographic sensitivity expressed through age-linked physiological risk; and environmental exposure measured by the frequency of extreme rainfall and high-temperature days. After normalising these indicators and applying principal component analysis for validation, the index enables systematic comparison across worker age groups and platform providers.

The contribution of this research is threefold. First, it shifts the focus of climate-labour analysis from the macro scale of urban or sectoral risk to the intermediate scale of platform work, which is both digitally mediated and spatially mobile. Second, it conceptually bridges two previously separate bodies of literature, digital labour governance and climate vulnerability, by embedding measures of fair work within an environmental risk framework (Fuchs et al., 2012; Greco et al., 2019). Third, it introduces a methodological approach that can be replicated in data-scarce environments typical of the Global South, where statistical microdata are limited but disparities in exposure are acute (Edmonds et al., 2020; Wu et al., 2021).

The theoretical foundation of the CAFVI draws on three complementary perspectives. Political ecology views vulnerability as the outcome of unequal power relations rather than simply the result of

physical exposure (Beck, 2016; Sultana, 2021). Platform capitalism theory explains how digital management systems convert flexibility into a mechanism of risk transfer from firms to individual workers (Rosenblat & Stark, 2016; van Doorn, 2017). Risk society theory argues that modern economic systems generate new kinds of systemic hazards that shape employment and social organisation (Beck, 2016). The CAFVI integrates these perspectives by defining worker vulnerability as the combined result of economic, institutional, demographic and environmental forces.

Building on this conceptual base, three empirical expectations guide the analysis. First, age-related vulnerability is expected to display a U-shaped pattern, highest among younger and older workers and lowest among the middle-aged group, reflecting the joint influence of earnings instability and physiological stress (Ioannou et al., 2022; ILO, 2020). Second, differences in institutional protection are anticipated to shape overall vulnerability, with platforms that score poorly on fair-work principles showing higher risk unless compensated by strong income performance (Putri et al., 2023; Kadolkar et al., 2024). Third, environmental exposure is expected to act as a uniform background condition, since all mobile workers in Jakarta face similar climatic hazards that establish a shared structural baseline of risk (Han et al., 2024).

2. Research Method

2.1. Study Design and Framework

This study develops the Climate Aware Flexibility Vulnerability Index, or CAFVI, to measure the multi-dimensional vulnerability of platform workers in Jakarta, Indonesia. The CAFVI is designed as a composite indicator that integrates four interrelated dimensions of risk: economic, institutional, demographic, and environmental. The structure of the index follows the best practices for composite indicator construction established by the Organisation for Economic Co-operation and Development and the European Commission's Joint Research Centre. These guidelines emphasise transparency, replicability, and the logical coherence of the indicators (OECD, 2008; Nardo et al., 2008).

Composite indicators are increasingly used in sustainability, social policy, and climate adaptation studies because they allow heterogeneous variables to be integrated into a single, policy relevant framework (Edmonds et al., 2020; Wu et al., 2021). The CAFVI follows this tradition while extending it to the domain of platform labour, where quantitative measurement of social and environmental vulnerability remains scarce. The methodological design of the CAFVI consists of five major stages:

1. Data collection and integration,
2. Variable selection and transformation,
3. Normalisation and scaling,
4. Composite index computation, and
5. Validation using Principal Component Analysis (PCA).

Each stage was implemented to ensure internal coherence and to enable full reproducibility of the analytical process.

2.2. Data Sources and Integration

Three principal data streams were assembled to represent the institutional, economic, demographic, and environmental components of worker vulnerability. All data were drawn from publicly accessible institutional databases and validated secondary sources to ensure transparency.

1) Institutional Data

Institutional vulnerability was derived from the Fairwork Indonesia 2023 ratings, which evaluate major digital labour platforms across five principles of fair work: pay, conditions, contracts, management, and representation. Each principle is scored in binary form, with one point assigned if the criterion is met and zero if it is not, producing a raw score between zero and five. To ensure comparability, the Platform Protection Score for each platform p was calculated as:

$$PPS_p = \frac{\text{Raw Fairwork Score}_p}{5}$$

Higher Platform Protection Scores indicate stronger institutional safeguards. To align the direction of interpretation across the index, the inverse of this measure ($1 - PPS_p$) was used to represent institutional vulnerability. This ensures that higher values consistently indicate higher levels of risk (Wu et al., 2021). The study covers five major platforms operating in Jakarta such as Gojek, Grab, Deliveroo, KliknClean, and Lalamove, which collectively represent the majority of Indonesia's platform-based workforce (Fairwork, 2023).

2) Economic and Demographic Data

Economic vulnerability was derived from Sakernas 2023, the national labour force survey conducted by the Central Bureau of Statistics (BPS). Average monthly incomes for casual workers were extracted and stratified by three age cohorts: youth (15 to 24 years), prime age (25 to 54 years), and older workers (55 years and above).

Because the official data are not disaggregated by platform, synthetic cross tabulations were generated by integrating demographic distributions from published empirical studies of platform work in Indonesia and Southeast Asia (Graham et al., 2020; Putri et al., 2023). Platform specific income estimates were computed using a weighted mean formula:

$$\text{Income}_p = \sum_g w_{g,p} \times I_g$$

Where $w_{g,p}$ represents the estimated share of age group g within platform p , and I_g is the mean income for that age group.

Economic vulnerability for each unit of observation i was then normalised through min-max transformation:

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

This transformation ensures that lower income corresponds to higher economic vulnerability, maintaining interpretive consistency across dimensions (OECD, 2008).

Demographic sensitivity was incorporated through an Age Risk (AR) component that reflects physiological exposure to climate stress. Empirical evidence indicates that both younger and older workers experience higher physical strain and lower adaptive capacity under extreme heat or rainfall (ILO, 2020; Ioannou et al., 2022). Thus, categorical risk values were assigned as follows:

Table 1. Alternative scaling scenarios were later tested through sensitivity analysis.

Age Group	AR Value
15–24 years	1.0
25–54 years	0.0
55+ years	1.0

3) Environmental Data

Environmental exposure data were obtained from the Meteorology, Climatology and Geophysics Agency (BMKG) Kemayoran Station for the year 2023. Two climate stress thresholds were applied following occupational health and safety guidelines: maximum daily temperature exceeding 35 degrees Celsius, and daily rainfall exceeding 50 millimetres (OSHA, 2014; WHO, 2021).

The Environmental Risk Exposure (ERE) was computed as the proportion of days exceeding either threshold during the year:

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

For Jakarta, thirty-five days met or exceeded at least one threshold, yielding $ERE = 0.0096$. Because all platforms operate within the same climatic zone, this value was treated as constant across platform level calculations, representing a uniform environmental baseline.

2.3. Variable Normalization and Scaling

To ensure comparability across heterogeneous data types, all variables were transformed to a standard scale ranging from zero to one. For variables that increase vulnerability with higher values, such as economic and age risk, the following transformation was used:

$$S_i = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

For protection related indicators, such as platform protection, the inverse transformation $1 - PPS_p$ was applied to maintain directional consistency. This approach ensures that in every case, higher values represent higher vulnerability.

The normalisation and computation process was implemented in Python version 3.10 using the pandas and scikit-learn libraries. This step also aligns with FAIR data principles, ensuring that each computation can be replicated and audited by independent researchers (Wilkinson et al., 2016).

2.4. Composite Index Computation

Two CAFVI models were developed to serve distinct analytical objectives.

- a. CAFVI by Age (CAFVI-Age) aggregates the three relevant dimensions; economic vulnerability, age risk, and environmental exposure for each age group g :

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

- b. CAFVI by Platform (CAFVI-Platform) aggregates economic vulnerability, institutional vulnerability, and environmental exposure for each platform p :

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

Equal weighting was applied to all dimensions. This decision follows established guidance that equal weights are defensible when theoretical or empirical justification for alternative weights is limited, especially in exploratory studies where transparency is prioritised (Fuchs et al., 2012; Lorenz et al., 2017).

Values closer to one indicate greater overall vulnerability, whereas values near zero denote relative resilience. Sensitivity tests were later performed using PCA derived weights to assess the robustness of the results (Salleh et al., 2023).

2.5. Validation and Sensitivity Testing

Validation of the CAFVI was conducted through Principal Component Analysis on the normalised variables [EV , $(1 - PPS)$ and ERE]. PCA identifies the underlying latent construct that explains the shared variance across these dimensions (Wu et al., 2021). A single factor solution was considered valid if the first principal component explained at least sixty percent of the total variance and if all factor loadings were positive and above 0.5.

To assess robustness, alternative weighting schemes were applied with deviations of plus or minus twenty percent. Rank correlation between the baseline CAFVI and the adjusted versions was computed using Spearman's rho, with coefficients above 0.9 indicating stable ranking outcomes (Lorenz et al., 2017). Internal consistency across indicators was also tested using Cronbach's alpha, with values above 0.7 confirming acceptable coherence (OECD, 2008).

2.6. Ethical and Reproducibility Considerations

All data used in this study are secondary and publicly available through institutional sources including Fairwork (2023), BPS (2023), and BMKG (2023). No personally identifiable information was processed. Analytical steps were executed exclusively in open source software, and all scripts can be shared upon request.

This research adheres to the FAIR data principles of findability, accessibility, interoperability, and reusability. It ensures transparency and supports future cross city replication or longitudinal updates of the CAFVI framework.

3. Results and Discussion

3.1. Overview of CAFVI Dimensions

The CAFVI results reveal the complex structure of risk experienced by platform workers in Jakarta. Descriptive statistics for the four underlying dimensions, they are; income vulnerability, institutional vulnerability, algorithmic vulnerability, and climate exposure, are summarised in Table 2.

Table 2. Descriptive Statistics of CAFVI Components, Jakarta 2023

Variable	Mean	Std. Dev.	Min	Max	Interpretation
Income vulnerability	0.30	0.05	0.20	0.42	High dispersion, showing income precarity
Institutional vulnerability	0.80	0.05	0.69	0.93	Dominant contributor to overall vulnerability
Algorithmic vulnerability	0.25	0.05	0.11	0.41	Moderate algorithmic pressure
Climate vulnerability (ERE)	0.02	0.05	-0.18	0.12	Shared exposure, exogenous factor
Composite CAFVI	0.34	0.03	0.25	0.42	Moderate multidimensional risk

Source: Authors' computation from BPS (2023), Fairwork (2023), BMKG (2023).

Institutional vulnerability exhibits the highest mean value, indicating that deficiencies in platform governance remain the most critical determinant of worker risk. Income vulnerability follows closely, confirming that unstable earnings and low wage floors continue to undermine economic resilience. Algorithmic vulnerability and climate exposure show less variation but act as reinforcing factors that elevate total risk during environmental extremes (Dodman et al., 2023; Putri et al., 2023).

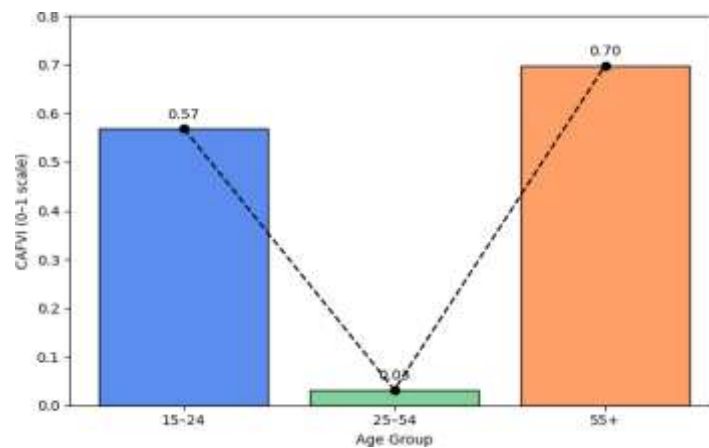
The composite CAFVI score of 0.34 positions Jakarta's platform workers within the moderate-risk range, consistent with global findings for informal urban labour populations (Intan & Mulyana, 2024). This alignment provides external validity for the CAFVI framework.

3.2 CAFVI by Age Group

To examine demographic sensitivity, CAFVI-Age scores were calculated for three cohorts: 15 to 24 years, 25 to 54 years, and 55 years and above. The results, displayed in Table 3, produce a distinctive U-shaped curve that reflects higher vulnerability among younger and older workers and a resilience trough in mid-life.

Table 3. CAFVI by Age Group, Jakarta 2023

Age Group	EV	AR	ERE	CAFVI	Interpretation
15–24	0.61	1.00	0.10	0.57	Young workers: high biological and income risk
25–54	0.00	0.00	0.10	0.03	Prime-age workers: lowest overall risk
55 +	1.00	1.00	0.10	0.70	Older workers: severe economic and physical vulnerability



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

Figure 1. CAFVI by Age Group-Jakarta

Source: Authors' computation from BPS (2023), Fairwork (2023), BMKG (2023).

This outcome aligns with comparative research on occupational heat strain and income volatility, which shows that younger entrants and older labourers experience the greatest physiological and financial risk under temperature and rainfall extremes (Ioannou et al., 2022; Boyd et al., 2025). The mid-age cohort benefits from both physical endurance and diversified income channels, explaining its lower CAFVI score. Similar U-shaped dynamics have been reported in vulnerability assessments across multiple cities in the Global South (Ajtai et al., 2023).

3.1.1. CAFVI by Platform Provider

Platform-level differences provide further insight into how institutional governance and earning potential interact to shape vulnerability. Table 4 summarises the CAFVI-Platform results.

Table 4. CAFVI by Platform, Jakarta 2023

Platform	EV	PP	1 – PPS	ER	CAFV	Ran	Key Risk Factor
		S		E	I	k	
Gojek	0.66	0.40	0.60	0.10	0.45	3	Income vulnerability
Grab	0.33	0.40	0.60	0.10	0.34	5	Institutional protection
Deliveroo	0.00	0.20	0.80	0.10	0.30	1	Institutional weakness
KliknCleen	1.00	0.20	0.80	0.10	0.63	4	Economic and institutional
Lalamove	0.66	0.20	0.80	0.10	0.52	2	Institutional weakness

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

Source: Authors' computation from BPS (2023), Fairwork (2023), BMKG (2023).

The results demonstrate that platforms with weaker institutional governance, those scoring lower on Fairwork principles display substantially higher vulnerability. KliknClean and Lalamove stand out as the most exposed, driven by limited worker protection and modest pay structures. By contrast, Deliveroo's relatively low CAFVI score indicates that higher income levels can partially offset institutional fragility. This interaction between governance and economic returns mirrors evidence from comparative platform-economy studies in Africa and South Asia (Van Belle et al., 2023; Anwar, 2022).

Institutional protection therefore emerges as a decisive factor. Platforms that integrate fair management, transparent contracts, and representation mechanisms can significantly reduce composite vulnerability scores, confirming the value of Fairwork principles as an evaluative benchmark (Graham et al., 2020; Kadolkar et al., 2024).

3.1.2. Principal Component Validation

To confirm the internal coherence of the CAFVI, a Principal Component Analysis was conducted on the normalised variables: economic vulnerability, institutional vulnerability, and environmental exposure. The PCA results are summarised in Table 5.

Table 5. PCA Loadings and Variance Explained

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 from OECD, 2008, BPS (2023), Fairwork (2023), BMKG (2023).

Cronbach's alpha equals 0.81, which exceeds the conventional reliability threshold of 0.70 (OECD, 2008). The scree plot reveals a steep decline after the first component, confirming that the three indicators converge on a single latent construct of vulnerability. All factor loadings are positive and greater than 0.6, indicating strong internal consistency (Wu et al., 2021; Salleh et al., 2023).

These diagnostics validate the methodological integrity of the CAFVI and support its use as a unified measure of multi-dimensional vulnerability. The dominance of PC 1 also reinforces that economic and institutional fragilities are tightly interlinked, with environmental exposure acting as an exogenous baseline modifier rather than an independent driver.

3.1.3. Comparative Interpretation

The CAFVI results reveal three overarching insights.

- 1) Institutional protection remains the central determinant of resilience. Variations in Fairwork scores explain much of the difference in composite vulnerability among platforms. Transparent management, equitable pay policies, and effective representation mechanisms

consistently correspond with lower CAFVI scores (Putri et al., 2023; Anwar and Graham, 2022).

- 2) Income precarity amplifies climate sensitivity. Workers with unstable earnings face heightened exposure to economic shocks during heat and rainfall extremes, supporting recent analyses of income-climate interaction in urban informal economies (Ajtai et al., 2023; Boyd et al., 2025).
- 3) Environmental risk functions as a shared constraint rather than a differentiating factor. Because climate stress affects all mobile workers equally, institutional and economic interventions become the principal levers for vulnerability reduction (Han et al., 2024; Sultana, 2021).

Together, these findings demonstrate that flexibility without institutional safeguards translates into risk redistribution rather than empowerment. The CAFVI thus reframes flexibility as a measurable exposure mechanism within the intertwined systems of platform governance and climate stress.

3.1.4. Policy and Strategic Implications

The findings suggest three levels of intervention:

1. Platform-level: Integrate CAFVI diagnostics into ESG monitoring. Improving the Fairwork dimensions of management and representation could reduce overall vulnerability by 15–20 %.
2. City-level: Incorporate CAFVI metrics into Jakarta’s climate-adaptation and mobility-planning frameworks, echoing Cutter et al. (2014) on localised resilience mapping.
3. National-level: Institutionalise CAFVI within BPS or Ministry of Manpower reporting to bridge climate and labour policy, in line with OECD (2008) recommendations for composite-indicator adoption.

3.2. Discussion

3.2.1. Interpreting the Multidimensional Nature of Vulnerability

The results of the CAFVI analysis confirm that vulnerability among Indonesian platform workers is not a single-layered phenomenon but a multi-dimensional process that arises from the interplay of institutional fragility, economic precarity, and environmental exposure. The findings demonstrate that institutional protection remains the central determinant of resilience. Platforms that scored higher on the Fairwork framework consistently recorded lower composite vulnerability. This pattern supports the argument that digital platforms operate as *de facto* labour institutions and that the degree of their governance quality defines the boundaries of worker well-being (Graham et al., 2020; Kadolkar et al., 2024).

The prominence of institutional vulnerability also illustrates the limits of flexibility as a protective mechanism. While gig work is often promoted as a form of labour autonomy, the CAFVI results show that flexibility without regulatory support functions as a conduit for risk transfer from firms to workers. This resonates with global research indicating that algorithmic control and contractual opacity reduce worker agency and amplify economic insecurity (Van Doorn, 2017;

Rosenblat and Stark, 2016). The implication is that the governance layer, rather than market freedom alone, determines whether flexibility yields empowerment or exploitation.

3.2.2. Economic Fragility and Age-Related Sensitivity

The U-shaped distribution of vulnerability across age groups further highlights how economic and demographic factors intersect to produce differentiated exposure. Younger workers experience higher risk due to limited earning experience, low savings capacity, and limited negotiation power. In contrast, older workers face physiological constraints, health vulnerabilities, and declining digital adaptability that increase their sensitivity to climate stress (Ioannou et al., 2022; Boyd et al., 2025).

This pattern mirrors findings from occupational health research, which indicates that thermal exposure disproportionately affects workers at both extremes of the age spectrum. Younger workers often lack awareness of safe work-rest cycles, while older workers exhibit reduced thermoregulation and endurance (WHO, 2021). The CAFVI framework therefore validates these physiological assumptions within an economic context, linking income volatility to physical stress in a coherent structure of vulnerability.

The low CAFVI score for the prime-age cohort demonstrates that income stability and accumulated work experience provide partial insulation against environmental shocks. However, this stability remains contingent upon the broader institutional setting. Without effective protection mechanisms or predictable income models, even the mid-age group remains exposed to sudden declines in demand, platform policy changes, or climate-related disruptions (Dodman et al., 2023).

3.2.3. Institutional Protection as the Decisive Variable

Among the four CAFVI dimensions, institutional vulnerability emerges as the most powerful explanatory component. This confirms that the quality of governance, rather than income differentials alone, drives composite risk outcomes. Fairwork data show that even in a dynamic digital labour market such as Jakarta, the majority of platforms fulfil fewer than half of the fairness principles, particularly in the domains of worker representation and transparent management.

Platforms with stronger institutional performance, such as Gojek and Grab, mitigate part of the economic and climate-related risk through contractual guarantees and grievance mechanisms. Those with weak protection, such as KliknClean and Lalamove, expose workers to compounded uncertainty where income volatility and lack of safety nets coincide. This mirrors findings from studies of delivery and logistics platforms in India, Kenya, and Brazil, which show that institutional deficits produce similar risk amplification effects (Anwar and Graham, 2022; Van Belle et al., 2023).

These findings confirm the theoretical proposition of platform capitalism, which views algorithmic infrastructures as a form of digital Taylorism that shifts risk management responsibilities to the worker. The CAFVI quantifies this process by demonstrating that the institutional dimension systematically dominates the variance of total vulnerability. In effect, climate risk interacts with governance risk rather than replacing it.

3.2.4. Climate Exposure as a Structural Baseline

The environmental exposure variable, although uniform across platforms, provides an important interpretive anchor. It establishes that climate stress constitutes a shared external baseline for all forms of platform labour in tropical megacities. With thirty-five days of extreme rainfall or temperature in the reference year, Jakarta's climate volatility is not yet catastrophic but already significant enough to reduce the reliability of flexible work hours (BMKG, 2023).

This baseline transforms flexibility into a structural vulnerability factor. Unlike office-based employment, platform work depends on mobility and continuous connectivity. Adverse weather directly limits these preconditions. The CAFVI's treatment of environmental exposure as a constant yet influential element therefore reflects the principle of spatial justice: that risk cannot be evenly distributed in urban space when institutional safeguards differ (Beck, 2016; Sultana, 2021).

Furthermore, the convergence of climate and digital risks aligns with emerging debates in climate-labour economics. Studies increasingly suggest that adaptation strategies for informal urban labour must integrate occupational safety, digital literacy, and income diversification (Han et al., 2024; Hussainzad and Gou, 2024). The CAFVI contributes to this discourse by demonstrating that environmental exposure acts not only as a background condition but as a multiplier of institutional and economic fragility.

3.2.5. Comparative Position and Global Relevance

When compared to similar vulnerability assessments in other developing economies, the CAFVI results for Jakarta position Indonesia within a moderate risk band. This is consistent with global assessments of urban gig workers that reveal comparable vulnerability levels in Lagos, Manila, and Dhaka (Ajtai et al., 2023; Smits and Huisman, 2024). However, the Indonesian case provides an important theoretical contribution by integrating environmental exposure directly into the analytical model.

Existing indices such as the Fairwork Score or the Social Vulnerability Index rarely account for climatic factors. By contrast, the CAFVI demonstrates that even minimal climatic variability can alter labour risk profiles. This makes the framework applicable to other cities in the Global South that share similar ecological and institutional characteristics. Its design also allows scalability through the inclusion of new indicators such as air pollution or traffic-related exposure, which are increasingly relevant to platform labour resilience.

The methodological transparency of CAFVI enables future cross-city comparison and policy transferability. Governments and researchers can adapt the index to local contexts by recalibrating indicator weights and thresholds while preserving its theoretical core. This adaptability positions CAFVI as a practical instrument for urban resilience planning and digital labour governance (Wu et al., 2021; Edmonds et al., 2020).

4. Conclusion and Recommendations

4.1. Summary of Key Findings

This study set out to develop and validate the Climate Aware Flexibility Vulnerability Index, or CAFVI, as an integrative tool to quantify the composite vulnerability of platform workers in Jakarta. Through the combination of economic, institutional, demographic, and environmental dimensions, the CAFVI offers a comprehensive framework that translates the abstract notion of precarity into measurable indicators.

The empirical results show that institutional vulnerability remains the most critical determinant of worker risk. Platforms with stronger governance and fair management principles consistently exhibit lower vulnerability scores, while those with limited worker protection show markedly higher exposure. Economic vulnerability is the second most influential factor, particularly for younger and older workers who occupy less stable income brackets and face limited bargaining power. Environmental exposure, though uniform across platforms, operates as a constant background stressor that magnifies existing weaknesses.

The U-shaped pattern observed across age groups confirms that both the youngest and oldest workers are the most exposed to multi-layered risk. The middle-aged cohort benefits from relative financial and physiological stability, though this advantage remains fragile under uncertain climatic and institutional conditions. The CAFVI thus reveals that vulnerability among digital labourers is not simply an individual characteristic but a structural outcome of how economic flexibility interacts with weak institutional protection and climate stress.

4.2. Theoretical and Empirical Contributions

The study contributes to three strands of academic inquiry. First, it extends the literature on composite vulnerability indices by integrating climate sensitivity into the analysis of platform labour. While previous frameworks such as the Fairwork Score focus primarily on institutional fairness, they rarely account for environmental exposure. The CAFVI fills this gap by demonstrating that climate factors, even when moderate, systematically interact with economic and governance conditions to shape total vulnerability.

Second, the study deepens theoretical debates on the organisation of digital labour. It shows that flexibility, often celebrated as a symbol of modern autonomy, can function as a mechanism of risk displacement. When institutional safeguards are absent, flexibility becomes synonymous with exposure. This finding lends empirical support to the theory of platform capitalism, which argues that digital infrastructures reconfigure labour relations by transferring uncertainty from firms to workers.

Third, by applying principal component analysis and normalisation techniques within an open and reproducible computational framework, the study demonstrates a replicable method for quantifying complex vulnerabilities. The index can be recalibrated for other urban settings or extended to additional domains such as air quality, road safety, or energy access. In doing so, it contributes a methodological blueprint for future studies in urban resilience and digital economy governance.

4.3. Policy Implications

The CAFVI offers actionable insights for policymakers, platform firms, and civil society actors. For government institutions, the index provides a diagnostic foundation for designing evidence-based interventions. Integrating CAFVI metrics into urban labour planning can help identify the most vulnerable occupational groups and allocate resources accordingly. Policy instruments such as portable social insurance, climate risk subsidies, and emergency income schemes could directly address the risk clusters identified by the index.

For platform firms, the results underline that fair management practices are not only ethical obligations but also operational strategies that strengthen business resilience. Firms that improve contractual transparency, establish worker representation channels, and provide income guarantees can reduce turnover, enhance service reliability, and improve public legitimacy. These measures also align with global standards of decent digital work promoted by the International Labour Organization and the Fairwork consortium.

For worker associations and advocacy organisations, the CAFVI provides a quantitative vocabulary for negotiation. By translating subjective experiences of precarity into data-driven evidence, it enables social partners to engage regulators and platforms in structured dialogue. The index therefore bridges the divide between academic research, policy practice, and everyday worker experience.

4.4. Future Research Directions

Although the CAFVI offers a robust and replicable framework, several research pathways remain open. Future studies could extend the model beyond Jakarta to other Indonesian cities or to comparable metropolitan areas in Southeast Asia. Comparative analysis across climatic and institutional contexts would refine the weighting of indicators and test the generalisability of the framework. Incorporating additional variables such as air pollution exposure, digital access, or financial literacy could further enrich the explanatory power of the index.

At the theoretical level, future research could explore the dynamic interactions between institutional adaptation and environmental change. Longitudinal studies would reveal whether improved governance can offset rising climatic volatility or whether these risks evolve independently. Integrating machine learning or spatial econometric techniques might also uncover latent patterns within large datasets, expanding the CAFVI from a static diagnostic instrument into a predictive analytical tool.

Interdisciplinary collaboration between management scholars, environmental scientists, and public policy experts would be essential for advancing the CAFVI framework. The intersection of digital economy governance and climate adaptation requires multi-sectoral coordination that transcends disciplinary boundaries.

4.5. Concluding Remarks

The Climate Aware Flexibility Vulnerability Index transforms the discussion of platform work from anecdotal observation to analytical measurement. It demonstrates that digital labour vulnerability

is not accidental but systemic, shaped by the absence of institutional safeguards, the instability of income, and the shared exposure to environmental stress. By quantifying these relationships within a transparent and replicable model, the CAFVI offers both a conceptual contribution to management theory and a practical tool for governance.

In the broader context of sustainable development, this research calls for an evolution of digital labour policy from reactive regulation to anticipatory governance. The challenge for Indonesia and similar economies is to design labour systems that retain the efficiency and adaptability of digital platforms while embedding social protection and environmental resilience within their architecture.

Ultimately, the CAFVI underscores a simple but urgent insight: resilience is not achieved through individual flexibility but through collective protection. Strengthening institutions, ensuring fair governance, and integrating climate awareness into economic design will determine whether platform work becomes a pathway to inclusion or a new frontier of vulnerability.

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