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Carbon-Embedded Pro-Poor Policies in Local Government: Evidence from Sleman Regency, Indonesia, Using a Regionalized EEIO Analysis

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Climate Vulnerability and Regional Development

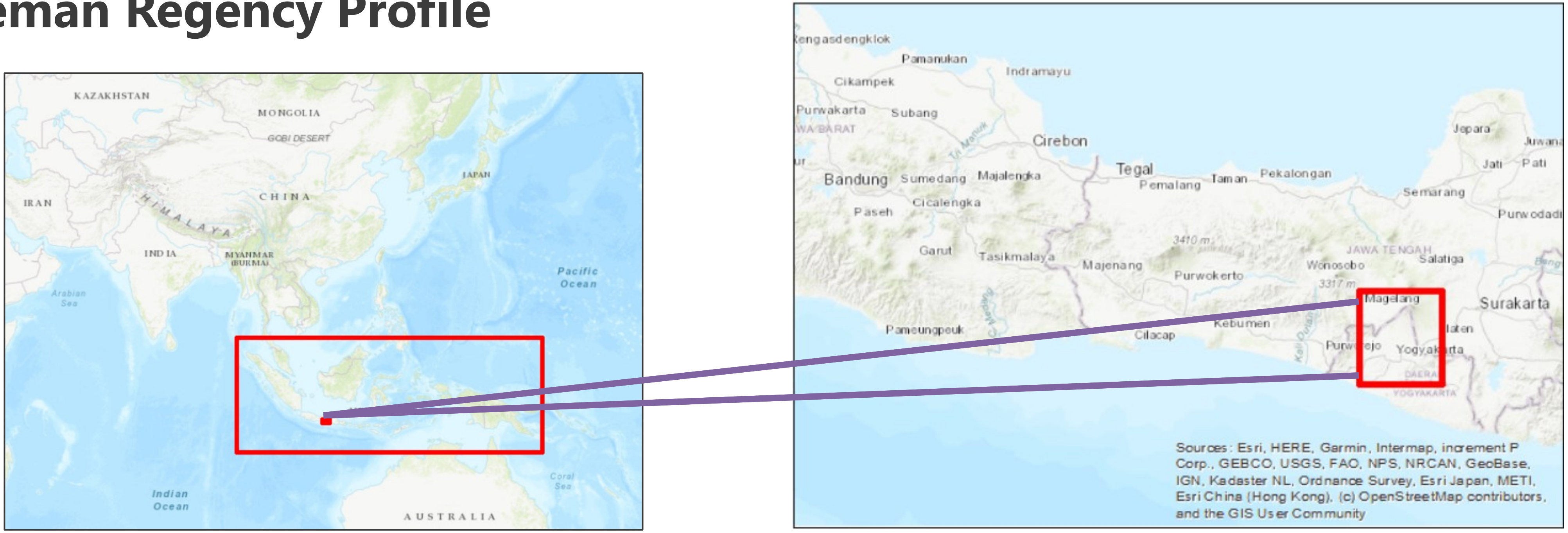
Global Climate Risk

- Climate vulnerability has become a major issue in development studies
- Carbon-intensive development increases socio-ecological risks
- 3.3–3.6 billion people live in highly vulnerable contexts
- (IPCC, 2022; UNEP, 2023)

Development Trade-off

- Local governments face challenges in balancing:
  - Economic growth
  - Poverty alleviation
  - Environmental sustainability
- Limited fiscal capacity intensifies policy trade-offs

Sleman Regency Profile



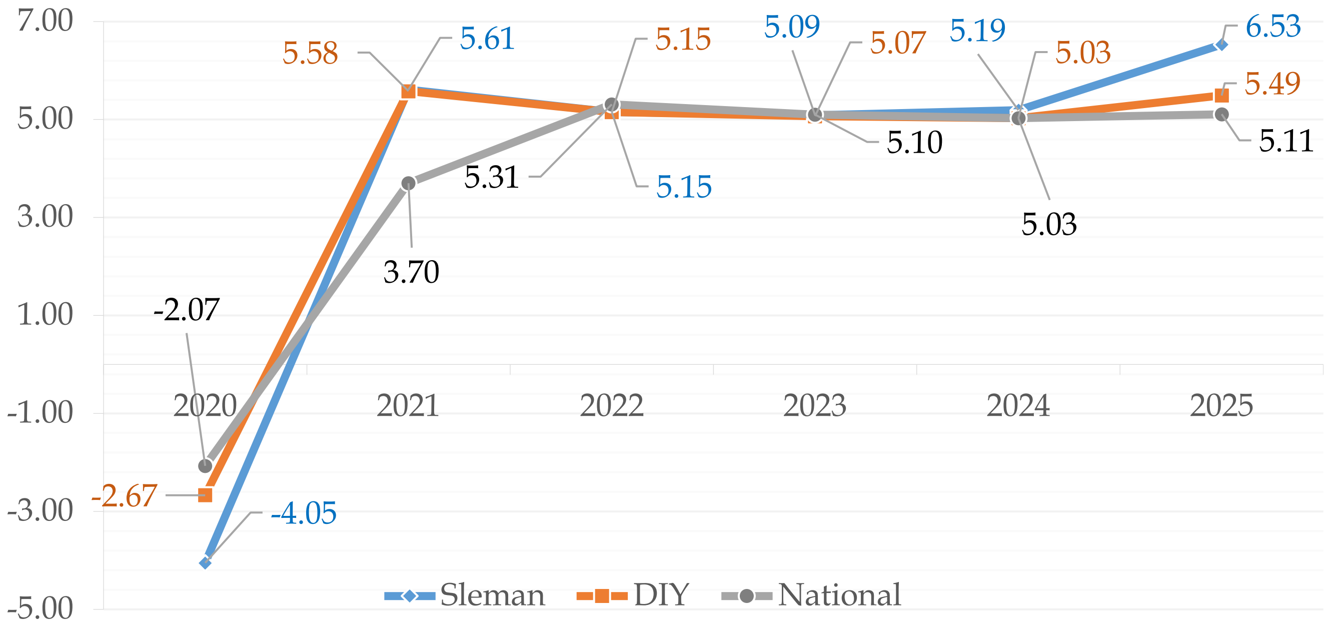
- **Area:** 574.82 km²; southern flat rice-field plains and northern upland volcanic slopes toward Mount Merapi.
- **Population (2025):** 1,129,730 people (+4,159; +0.37%).
- **Population Growth:** 1.16% in 2024 (down from 1.34% in 2023).

- **Area Characteristics:**
  - **Northern Region:** Merapi volcano slopes — water resources & eco-tourism.
  - **Eastern Region:** Cultural heritage (temples), dryland areas, white-stone quarries.
  - **Central Region:** Urban core — education, trade, and services.
  - **Western Region:** Irrigated wetlands — agriculture & traditional crafts (mendong, bamboo, pottery, roof tiles).

Background

- While Sleman's economy shows sectoral dynamism, the persistence of poverty levels suggests the need to examine how growth translates into inclusive welfare improvements.

Figure 1 Sleman Regency Economic Growth



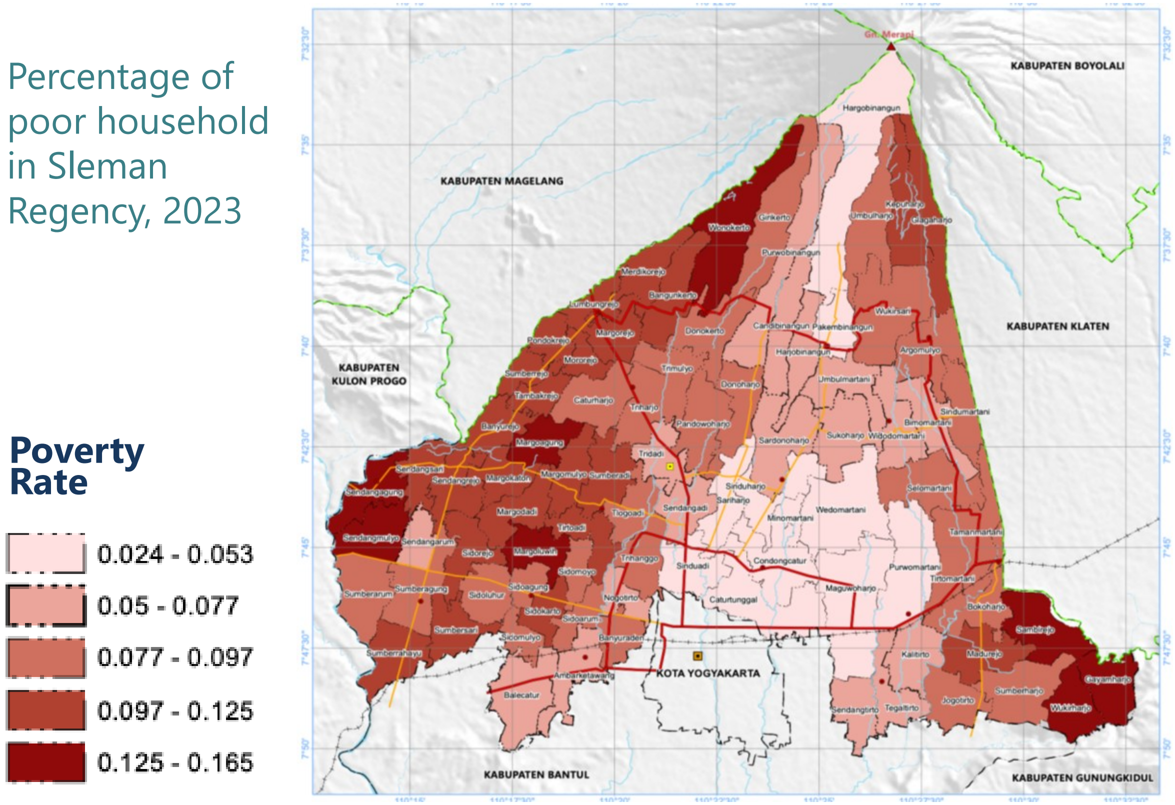
Source: Sleman Regency Government, 2026

- The economy of Sleman Regency in 2025 is dominated by the construction sector, contributing 13.21%,
- followed by the manufacturing sector at 12.18%,
- the accommodation and food service sector at 10.79%,
- and the information and communication sector at 9.7%.

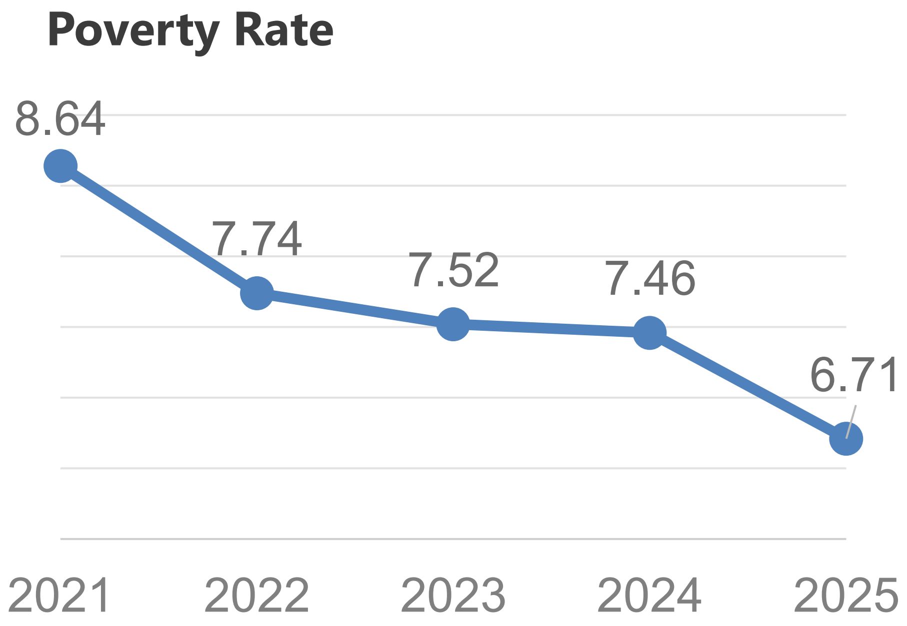
Background

- Therefore, poverty reduction policies must be evaluated to ensure inclusive growth aligns with Indonesia's climate commitments and long-term sustainability.

Percentage of poor household in Sleman Regency, 2023



Source: Sleman Regency Government, 2026

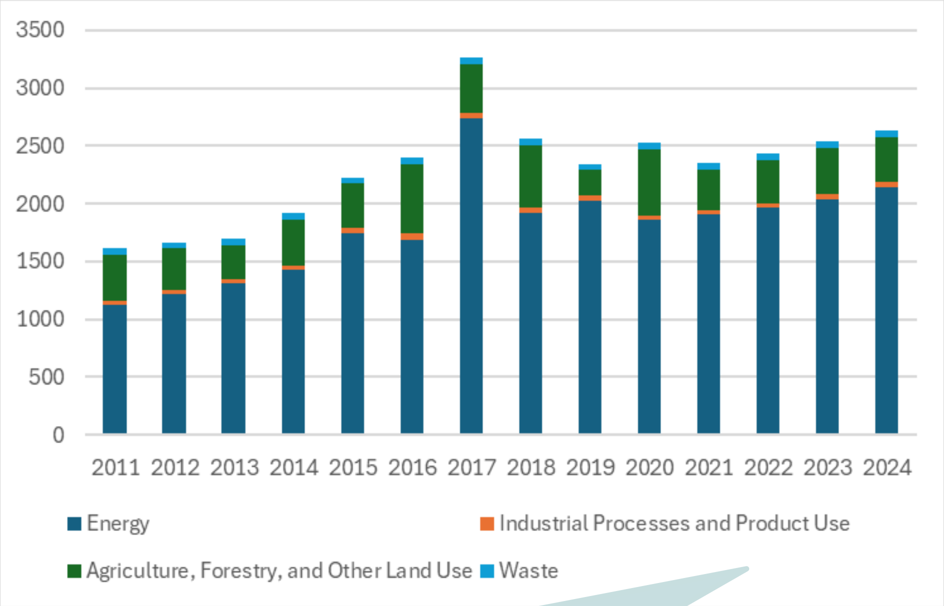


Source: Statistics Indonesia, 2026

Background

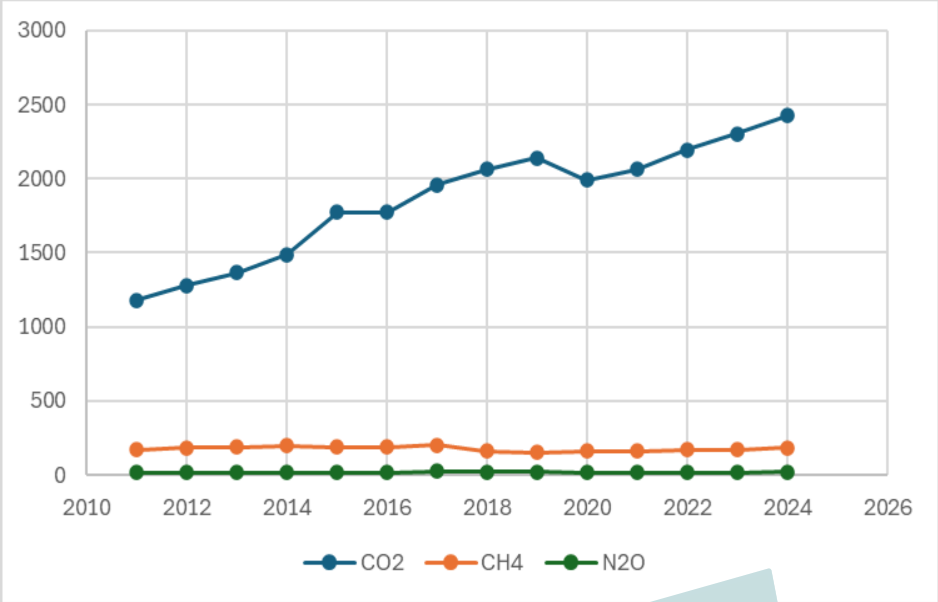
- At the same time, rising GHG emissions—dominated by the energy sector—create a development–environment trade-off.

Aggregate Greenhouse Gas (GHG) Emission Trends in Sleman Regency, 2011–2024



- Energy sector emissions rose from **1126.5** Gg in 2011 to **2135.9** Gg in 2024.
- 2017 recorded the highest total emissions, mainly driven by energy."

Greenhouse Gas (GHG) Trends by Gas Type in Sleman Regency from 2011 to 2024



- CO2 increased from **1181.9** Gg in 2011 to **2426** Gg in 2024.
- CH4 and N2O remained relatively stable throughout the period.

Source: Sleman Environmental Agency, 2025

Research Objectives

To assess the carbon footprint of economic sectors by estimating direct and indirect emissions through an EEIO framework.

To determine priority sectors for policy intervention that support both emission reduction and poverty alleviation goals.

Literature Review

Poverty reduction depends on which sectors grow are most poverty-reducing. (Chukwu, 2025)

"Regulatory inconsistency and lack of coordinated implementation undermine CE initiatives." (Gallego-Schmid et al., 2026)

EEIO captures direct + indirect emissions across sectors, ideal for evaluating APBD impacts on carbon footprints. (Putra & Anita, 2024)

Government spending impacts sectors unevenly, so sector-level analysis is essential. (Maitra & Hossain, 2025)

"Weak governmental commitments and lack of stakeholder-collaboration mechanisms hinder sustainability transitions." (Pathak, Mondal & Hajoary, 2025)

Data and Methodology

EEIO Analysis

$$\mathbf{C} = \mathbf{K}(\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{F}}$$

Where:

- **C** = Embodied environmental burden of the regency (including intersectoral and supply chain effects)
- **I** = Identity matrix
- **A** = Technical coefficient matrix
- $\hat{\mathbf{F}}$ = Final demand vector
- **K** = Direct environmental burden coefficient

This model identifies sectors with the highest carbon intensity and emission contributions.

Nakamura, S. (2023)

K was derived from 2023 BPS GHG emission intensity data, converted to match GRDP units, and aligned with the regional IO sectors for EEIO analysis.

"This method quantifies sectoral carbon footprints by capturing both direct and indirect emissions across economic sectors using an EEIO framework, while identifying carbon-intensive sectors through emission intensity and their contribution to total regional emissions."

Methods

2DLQ for Estimating Regional Coefficients

$$\tilde{a}_{ij}^{R} = \left[\frac{1}{2}\tanh(SLQ_i - 1) + \frac{1}{2}\right]^{\alpha} a_{ij}^{N}\left(wx_j^{R}\right)^{\beta}$$

Adjust national input–output coefficients using **two dimensions**:
α for production specialization (rows), **β** for purchasing sector size (columns).

$$\tilde{a}_{ij}^{R} = r_i(\alpha) a_{ij}^{N} s_j(\beta)$$

- a_{ij}^{N} = national input coefficient
- SLQ_i = specialization of producing sector (row adjustment)
- w_j^{R} = size of purchasing sector (column adjustment)
- α = parameter correcting production specialization
- β = parameter correcting purchasing sector size

The tanh function appears in a **modified version of 2DLQ** — specifically when the **specialization index SLQ_i** exceeds 1.

This smooths the correction factor for sectors that are **highly specialized**, avoiding abrupt jumps in coefficient values. It's a form of **nonlinear dampening**

Pereira-López, X., et al. (2020)

"This method is used to regionalize the provincial input–output (IO) table down to the regency level, enabling sectoral carbon footprint analysis in regions where no survey-based IO tables exist at the regency scale."

Regionalizing the IO Table using 2DLQ

Step 1. Regionalization

- The national IO table was regionalized to the provincial level using the 2DLQ method.
- Various parameter combinations were tested:
  - α = 0.2 – 2.0
  - β = 0.05 – 0.4
- The optimal parameters were selected based on the lowest estimation error.

Step 2. Validation

The regionalized IO table was compared with the survey-based provincial IO table using:

$$WAPE = 100 \sum_{i=1}^{n} \sum_{j=1}^{n} |\tilde{a}_{ij}^{R} - a_{ij}^{R}| / \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}^{R}$$

(Weighted Absolute Percentage Error)

$$U = 100 \sum_{i=1}^{n} \sum_{j=1}^{n} |\tilde{a}_{ij}^{R} - a_{ij}^{R}| / n^2$$

(Average Absolute Deviation per Cell)

$$U^{*} = 100 \sum_{i=1}^{n} \sum_{j=1}^{n} |\tilde{a}_{ij}^{R} - a_{ij}^{R}| (n^2 - z)$$

(Average Absolute Deviation for Non-Zero Cells)

Selected Parameters

•α = 0.6

•β = 0.03

Validation Results

•WAPE = 17.9%

•U = 0.26

•U* = 0.26

RESULTS

Regional Technical Coefficient Matrix of Sleman Regency

	A	B	C	D	E	F	G	H	I	J	K	L	M, N	O	P	Q	R, S, T, U
A	0.018	0	0.127	0.00003	0.00015	0.00010	0.002	0.001	0.066	0.00000002	0.000039	0	0.001	0.003	0.002	0.001	0.005
B	0.00000008	0.023	0.004	0.00008	0.0011	0.018	0.0000003	0.0000003	0.00006	0.00000029	0.0000006	0.000001	0.000002	0.0000030	0.0000005	0.000	0.00000015
C	0.030	0.003	0.087	0.0008	0.012	0.057	0.003	0.016	0.145	0.004	0.010	0.002	0.010	0.019	0.017	0.024	0.034
D	0.0002	0.0004	0.002	0.231	0.025	0.003	0.010	0.002	0.005	0.010	0.001	0.009	0.003	0.007	0.003	0.003	0.005
E	0.00005	0.0007	0.00013	0.00007	0.001	0.0001	0.00038	0.00027	0.00021	0.000	0.000037	0.00012	0.00013	0.001	0.000	0.00026	0.001
F	0.000003	0.000006	0.00008	0.00003	0.016	0.052	0.000014	0.00044	0.00018	0.001	0.010	0.056	0.00008	0.027	0.008	0.003	0.003
G	0.012	0.010	0.038	0.002	0.016	0.048	0.008	0.025	0.028	0.004	0.007	0.003	0.010	0.025	0.010	0.025	0.020
H	0.006	0.036	0.020	0.010	0.016	0.016	0.032	0.072	0.009	0.005	0.007	0.008	0.089	0.082	0.015	0.030	0.011
I	0.0002	0.0006	0.008	0.003	0.002	0.019	0.001	0.037	0.001	0.001	0.002	0.001	0.003	0.099	0.012	0.036	0.023
J	0.0008	0.005	0.005	0.010	0.004	0.005	0.024	0.029	0.005	0.151	0.023	0.015	0.013	0.018	0.011	0.011	0.016
K	0.013	0.022	0.018	0.009	0.007	0.007	0.024	0.003	0.004	0.002	0.009	0.009	0.018	0.007	0.004	0.007	0.009
L	0	0.042	0.008	0	0.021	0.007	0.030	0.010	0.002	0.017	0.007	0.002	0.010	0.009	0.013	0.007	0.018
M, N	0.003	0.004	0.003	0.004	0.015	0.005	0.011	0.010	0.001	0.010	0.020	0.024	0.057	0.056	0.015	0.014	0.005
O	0.00008	0	0	0.002	0.00020	0.00000009	0	0.005	0.000004	0.014	0.003	0.001	0.004	0.005	0.011	0.005	0.005
P	0.00003	0.0001	0.00012	0.00014	0.00046	0.00016	0.00037	0.001	0.00013	0.00015	0.005	0.00014	0.001	0.005	0.021	0.003	0.002
Q	0.0007	0.00008	0.0007	0.000016	0.00041	0.0006	0.00007	0.007	0.002	0.00004	0.002	0.00014	0.00033	0.00033	0.003	0.010	0.003
R, S, T, U	0.0005	0.001	0.0029	0.00013	0.006	0.0012	0.004	0.004	0.005	0.002	0.002	0.009	0.011	0.006	0.009	0.026	0.020

A. Agriculture, Forestry and Fishing
B. Mining and Quarrying
C. Manufacturing
D. Electricity and Gas
E. Water Supply, Sewerage, Waste Management and Remediation Activities
F. Construction
G. Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles
H. Transportation and Storage

I. Accommodation and Food Service Activities
J. Information and Communication
K. Financial and Insurance Activities
L. Real Estate Activities
M,N. Business Activities
O. Public Administration and Defense, Compulsory Social Security
P. Education
Q. Human Health and Social Work Activities
R,S,T,U. Other Services Activities

RESULTS

High-intensive Carbon Footprint Sectors

Key Characteristics

- Highly energy-intensive sectors
- Strong dependence on fossil fuels
- Generate substantial direct and indirect emissions
- Utility sectors provide essential inputs for regional economy

Need for

- energy transition,
- cleaner technology,
- and better utility management

Table Emission Multipliers estimated in this study by descending order

Sector	carbon footprint intensity [$kgCO_2e$/million IDR]
D. Electricity and Gas	3.7951
E. Water Supply, Sewerage, Waste Management and Remediation Activities	3.0514
C. Manufacturing	2.4635
I. Accommodation and Food Service Activities	0.3894
H. Transportation and Storage	0.2340
F. Construction	0.1903
B. Mining and Quarrying	0.1746
O. Public Administration and Defense, Compulsory Social Security	0.1485
R,S,T,U. Other Services Activities	0.1276
A. Agriculture, Forestry and Fishing	0.1256
Q. Human Health and Social Work Activities	0.1032
P. Education	0.0745
M,N. Business Activities	0.0672
J. Information and Communication	0.0662
L. Real Estate Activities	0.0601
G. Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	0.0600
K. Financial and Insurance Activities	0.0377

RESULTS

Medium-intensity Carbon Footprint Sectors

Characteristics
- Emissions generated from:
  - fuel consumption,
  - transportation,
  - production & distribution activities
- Tourism-related activities contribute significantly to regional emissions

Implication
- Although intensity is lower than utility sectors, total emissions remain substantial due to large-scale economic activity.

Table Emission Multipliers estimated in this study by descending order

Sector	carbon footprint intensity [kgCO_2e/million IDR]
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RESULTS

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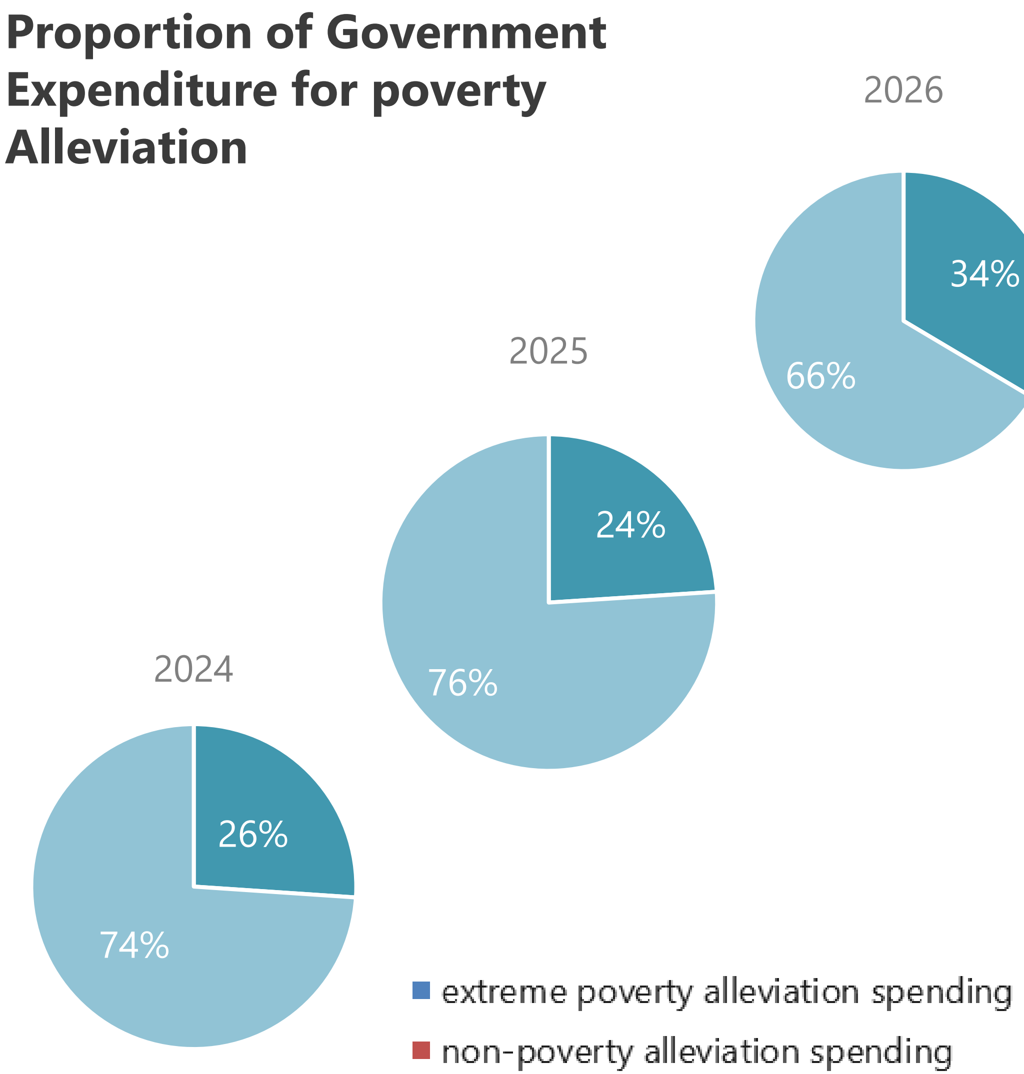
J. Information and Communication	0.0662
L. Real Estate Activities	0.0601
G. Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	0.0600
K. Financial and Insurance Activities	0.0377

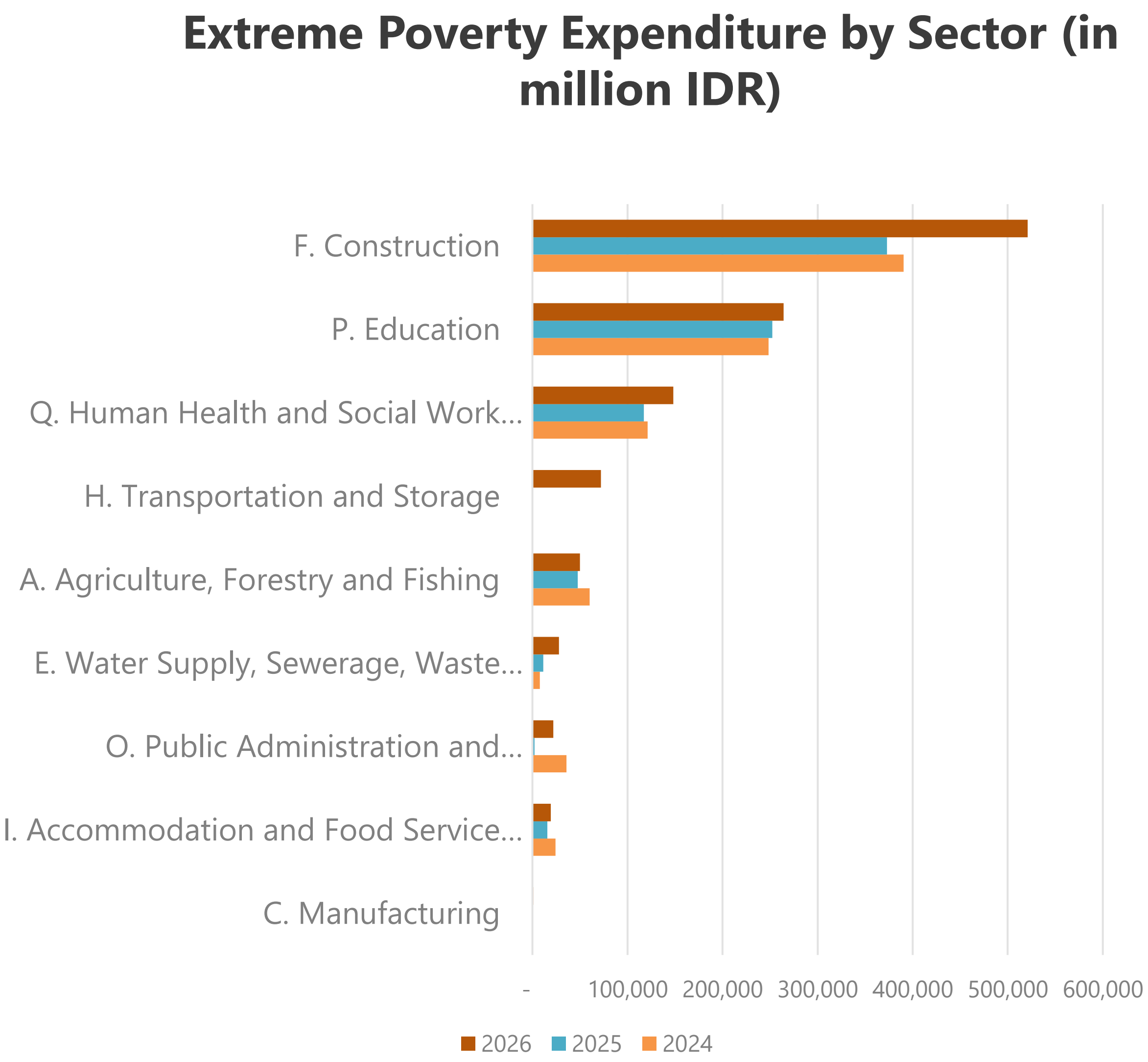
Low-intensity Carbon Footprint Sectors

Characteristics
- Less dependent on energy-intensive production
- Lower material and fuel consumption
- More compatible with low-carbon development

Implication
- Potential sectors for:
  - sustainable development,
  - human capital improvement,

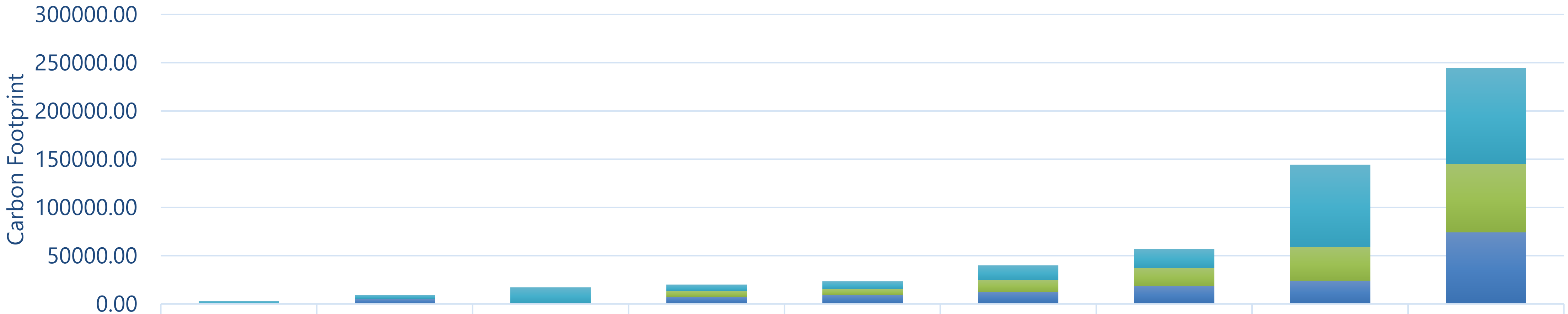
DISCUSSION


Proportion of Government Expenditure for poverty Alleviation
2026
34%
66%
2025
24%
76%
2024
26%
74%
extreme poverty alleviation spending
non-poverty alleviation spending


Extreme Poverty Expenditure by Sector (in million IDR)
F. Construction
P. Education
Q. Human Health and Social Work...
H. Transportation and Storage
A. Agriculture, Forestry and Fishing
E. Water Supply, Sewerage, Waste...
O. Public Administration and...
I. Accommodation and Food Service...
C. Manufacturing
-
100,000
200,000
300,000
400,000
500,000
600,000
2026
2025
2024

DISCUSSION

Carbon Footprint of Pro-Poor Policy Based on Government Expenditure in Sleman Regency (kgCO2e)



	C. Manufacturing	O. Public Administration and Defence, Compulsory Social Security	H. Transportation and Storage	A. Agriculture, Forestry and Fishing	I. Accommodation and Food Service Activities	Q. Human Health and Social Work Activities	P. Education	E. Water Supply, Sewerage, Waste Management and Remediation Activities	F. Construction
2026	2539.79	3246.93	16835.06	6258.97	7493.61	15302.78	19679.48	85418.24	99114.13
2025	0.00	332.52	157.78	5990.99	6159.53	12100.15	18793.13	34761.09	70950.28
2024	0.00	5322.21	59.22	7560.99	9400.75	12515.17	18511.16	24161.39	74286.15

Policy Implication

Decarbonizing Infrastructure

Sector F (Construction) is the primary driver of total emissions.

As the largest absolute emitter in **99.1 Tons CO2e**, green procurement is essential to align physical development with regional emission targets.

High-Intensity Utility Risk

Sector E (Water/Waste) represents a systemic risk.

Despite receiving only **5.3%** of the construction budget, its extreme intensity **(3.05 kgCO2e)** drives massive emissions in **85.4 tonsCO2e**.

Low-Carbon Pathway for Human Capital:

Investing in **Education and Health (Sectors P & Q)** is the most sustainable strategy.

This is the **optimal** pathway: absorbing **IDR 412.4 Billion** in funding while generating only 35 tonsCO2e combined.

Conclusions

Most Important Finding

- Poverty-alleviation efforts remain concentrated in infrastructure that relatively high-intensive sector, requiring stronger energy-use and waste-management interventions to balance Sleman's carbon footprint.
- Low-emission, high-resilience sectors (Education, Health) offer greater protection for vulnerable communities

The tourism sector requires greater attention to ensure sustainable development, including improving transport systems that strongly support tourism.

Limitation

- Regionalization from provincial IO introduces structural assumptions and may not fully capture Sleman's informal and micro-sector dynamics.
- When provincial IO coefficients are downscaled to the district level using 2DLQ, sectors with weak local specialization or limited local intermediate linkages tend to receive smaller adjusted coefficients. This dampens their indirect emission pathways and results in a lower estimated multiplier.

Future Outlook

- Integrate EEIO metrics into routine planning, budgeting, and monitoring.
- Co-develop low-carbon, inclusive policy options with local communities to strengthen resilience and reduce vulnerability.

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TERIMA KASIH

"Rahayuning bawana kapurba waskitaning manungsa"

The well-being of the world begins with the wisdom of humankind.