Ecological footprint assessment of central java province: an input-output approach

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Abstract. The ecological footprint provides a vital measure of how human activities impact natural resources and the environment, highlighting the balance—or imbalance—between consumption and the Earth's capacity to regenerate resources. Understanding these dynamics is crucial for sustainable development, especially in regions facing resource constraints. This study assesses the ecological footprint of Central Java Province using an input-output approach to provide a comprehensive understanding of resource use and environmental impact across key sectors, including agriculture, forestry, fisheries, and built-up areas. By employing the 2016 input-output table and sector-specific land use data, this analysis calculates the direct and indirect land demands associated with final consumption and economic activities. The findings reveal that agriculture and fisheries exhibit the highest ecological footprints per capita, emphasizing their significant demand on land and water resources. The built-up sector, while more efficient in land use, contributes heavily to Central Java's export economy, indicating its vital economic role. Results also highlight Central Java's reliance on imported resources, particularly in forestry, to supplement local production, revealing the interconnectedness of regional and global resource flows. The study underscores the importance of adopting sustainable practices in high-impact sectors, such as agriculture, to reduce ecological strain and achieve a balanced resource footprint. This ecological footprint assessment offers insights into sector-specific sustainability challenges and guides policy recommendations for sustainable resource management in Central Java.

1 Introduction

Since its first publication in the early 1990s, the ecological footprint has become the most popular ecological indicator [1,2]. The ecological footprint (EF) is an essential indicator for understanding the pressure that human activities exert on the Earth's ecosystems. It quantifies the biologically productive land and water area required to supply the resources a population consumes and to assimilate the waste it generates. Expressed in global hectares (gha), this measure provides a comprehensive view of sustainability by comparing human demand with

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the planet's capacity to regenerate these resources. The EF is used at multiple scales, from individuals to nations, to inform sustainable development policies [3].

Assessing ecological footprints at the subnational level, such as provinces, is crucial for gaining a more localized understanding of resource use and environmental impact. This granularity is particularly valuable for identifying areas where resource consumption surpasses sustainable limits and can guide region-specific policy interventions [4,5]. In regions like Central Java, such assessments can reveal ecological deficits where resource demand exceeds the local biocapacity. This urgent concern requires targeted strategies to mitigate potential long-term environmental degradation [6,7].

The ecological footprint approach has been employed successfully to evaluate sustainability across various sectors, including urban development, agriculture, and industry [8]. Its application helps policymakers integrate ecological considerations into economic planning, promoting sustainable resource management. In Indonesia, where rapid economic growth is often accompanied by significant environmental challenges, such as deforestation and land degradation, understanding the ecological footprint at a regional level is essential for balancing development with sustainability [9,10].

While several methodologies are available for assessing the ecological footprint, the input-output approach is particularly advantageous for this analysis. This approach integrates economic and environmental data, allowing for a detailed examination of the relationships between various economic sectors and their respective resource demands. By leveraging input-output table, researchers can quantify the indirect effects of consumption and production patterns, providing a more holistic view of a region's ecological impact [11,12].

The objective of this paper is to measure the ecological footprint of Central Java Province using the input-output approach. Central Java Province is an ideal case study for employing this approach due to its diverse economic structure, which includes significant contributions from agriculture, manufacturing, and services. Analyzing the ecological footprint using this method will offer valuable insights into the province's sustainability challenges and inform strategies for reducing ecological deficits. Furthermore, the input-output approach facilitates the identification of key sectors where policy interventions can most effectively reduce environmental impacts and promote sustainable practices [13].

2 Methods

To estimate the ecological footprint (EF), this study utilized an input–output approach, consistent with the methodology proposed by [14] and refined by [15]. This approach is particularly suited for capturing both direct and indirect land use impacts associated with economic activities and final consumption.

2.1 Input-Output analysis framework

This study employed the standard input–output table for Central Java Province, Indonesia, for the year 2016 to assess the ecological footprint. The input–output table outlines the economic transactions between different sectors of the economy, facilitating the calculation of both direct and indirect environmental impacts. The primary focus was on calculating the land use associated with the production of goods and services that support final consumption, following the method used by [14]. This involves deriving sector-specific land input coefficients, which are then applied to the Leontief inverse matrix to determine the land use requirements.

2.2 Land use classification

For this analysis, lands were classified into four main categories: agricultural land, forest land, fisheries, both inland and offshore fisheries, and degraded land which covering manufacture, commercial, and services sectors, as described by [14]. Each sector's land use was multiplied by the sector's output to estimate the total land requirement. The methodology also considered imported goods by estimating the foreign production land required to produce imports, and similarly for exports.

2.3 Ecological footprint estimation

The EF was calculated as the total productive land required to support the final consumption of the population. The land use multiplier for each sector was obtained by dividing the total sectoral land input by the sector's monetary value of output, which was then applied to the domestic final demand. Following the approach of [15], this study also adopted the composition of land multipliers when presenting results by land categories to correct for the conceptual errors found in previous studies. The detailed steps employed in the calculation of EF, are as follows:

1. In the transaction matrix ($\mathbf{Z}$), the indirect input coefficients ($\mathbf{A}$), also known as the matrix of technical coefficient, can be obtained by
$$\mathbf{A} = \mathbf{Z}\left(\hat{\mathbf{X}}\right)^{-1} \quad (1)$$
where $\left(\hat{\mathbf{X}}\right)^{-1}$ is the inverse of diagonalised a vector of sectoral total output, $\mathbf{x}$.
2. In the input-output framework, interdependence among different sectors of the economy is expressed by
$$\mathbf{X} = \mathbf{AX} + \mathbf{F} \quad (2)$$
where $\mathbf{F}$ is final demand. Given final demand, the solution for total output of the economy is given by
$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{F} = \mathbf{LF} \quad (3)$$
where $(\mathbf{I} - \mathbf{A})^{-1}$ or $\mathbf{L}$ is called the inverse Leontief matrix or matrix of interdependence coefficients or multiplier matrix. This matrix measures the direct and indirect output levels from each sector of the economy that are needed to meet a specified level of final demand.
3. Based on total output $\mathbf{X}$, the sectoral land coefficients, $\mathbf{c}$, can be obtained by dividing sectoral land input (elements in $\mathbf{M}$) by total input (elements in $\mathbf{X}$) as in (4).
$$\mathbf{c} = \mathbf{M}\left(\hat{\mathbf{X}}\right)^{-1} \quad (4)$$
Next, the total land requirement is determined based on the domestic provincial economic sector ($\mathbf{S}$) is as outlined in equation (5),
$$\mathbf{S} = \mathrm{diag}(\mathbf{c})(\mathbf{I} - \mathbf{A})^{-1}\mathbf{F} \quad (5)$$

In an open economy, trade allows consumers to access goods that are not produced domestically. To compute the total environmental footprint (EF), it is important to consider both exported and imported commodities. This involves deducting the land embodied in exports and adding the land embodied in imports to the domestic sectoral land requirements, represented by the vector $\mathbf{S}$. Following [14], it is assumed that the direct and indirect land requirements for domestically produced goods are similar to those for exported and imported commodities. Consequently, the sectoral land requirements for exports and imports are considered to be equivalent. As such, sectoral land requirements for export and import are
$$\mathbf{S_x} = \mathrm{diag}(\mathbf{c})(\mathbf{I} - \mathbf{A})^{-1}\mathbf{F_x} \quad (6)$$

$$\mathbf{S_m} = \mathrm{diag}(\mathbf{c})(\mathbf{I} - \mathbf{A})^{-1}\mathbf{F_m}$$

2.4 Data source and assumptions

The primary data sources used in this study are secondary data related to Central Java Province, Indonesia. This includes the 2016 input-output table, land use data, and population statistics from the Central Bureau of Statistics [16]. Additionally, data on land sectoral inputs were obtained from the Central Java provincial statistics, which cover agriculture, forestry, fisheries, and built-up land use, as detailed by the Regional Development Planning Agency [17,18].

To simplify the calculations without losing generality, several assumptions underpin the input-output analysis. The assumptions are as follows:

1. The input–output coefficients are fixed and do not account for economies of scale [14].
2. All imported products are assumed to have the same land intensity as domestic products due to a lack of detailed international data on land use [15].
3. The analysis does not account for unsustainable practices such as soil degradation or fossil fuel depletion, as these are complex to quantify in land use terms [14]..

3 Results and Discussion

According to the 2016 input-output table for Central Java Province (Table 1), the built-up sector—encompassing manufacturing, construction, mining, transportation, commercial, and service industries—plays a pivotal role in the provincial economy, contributing approximately IDR 1.9 trillion in total output. Its interconnectedness with other sectors, such as agriculture, forestry, and fisheries, underscores its significant economic influence.

Table 1. Transaction table (**Z**) of Central Java Province, 2016 (million IDR)

Sectors	Agriculture	Forestry	Fisheries	Built-up	Final demand	Export	Total output
Agriculture	10,855,131.35	145.70	16,019.76	79,293,383.42	43,503,199.15	37,764,413.35	171,432,292.73
Forestry	3,410.86	56,836.30	911.43	6,000,354.90	28,159.98	288,706.57	6,378,380.03
Fisheries	0	0	235,953	6,504,301	6,403,843	81,060	13,225,156
Built-up	25,635,597.21	796,009.58	1,227,905.24	582,822,709.74	880,848,280.75	410,272,445.64	1,901,602,948.16
Imports	9,286,676.75	260,389.68	546,737.75	320,181,521.76			
Gross Value Added	125,651,476.56	5,264,998.77	11,197,628.99	906,800,677.64			
Total input	171,432,292.72	6,378,380.03	13,225,156.13	1,901,602,948.07			
Land input (ha)	1,729,418.00	670,453.00	1,771,497.24	733,563.00			

The built-up sector demonstrates substantial demand for products from other sectors. For example, it absorbs IDR 79 billion from agriculture, IDR 6 billion from forestry, and IDR 6.5 billion from fisheries. This cross-sector demand reveals how industrial and service-based growth in Central Java is closely tied to primary industries, emphasizing the importance of these sectors in supporting the built-up sector's needs. Furthermore, the built-up sector is not merely a consumer; it also plays a crucial role in Central Java's export economy, with about IDR 880 billion directed toward exports, highlighting its impact on the province's trade.

When examining sector inputs, the built-up sector exhibits the highest gross value added, with over IDR 906 billion, reflecting its substantial contribution to the provincial Gross Domestic Product (GDP). This high value-added stems from the sector's diverse economic

activities, particularly in manufacturing and services, which often yield higher economic value than primary sectors like agriculture or forestry.

In terms of land use, the built-up sector occupies a relatively modest area (733,563 hectares) compared to agriculture and forestry. However, it achieves remarkable economic output per hectare, a typical feature of industrial and service sectors that generate high outputs within limited physical space, unlike agriculture and forestry, which rely on extensive land use. This difference in land input versus output underscores the built-up sector's efficiency and its potential for economic intensification without requiring additional land, which is especially relevant in densely populated regions.

In summary, the built-up sector's substantial output, strong export contribution, high gross value added, and efficient land use position it as a critical driver of economic growth in Central Java. This analysis highlights the potential for further developing the built-up sector while fostering sustainable interactions with primary sectors, particularly given the limitations on land resources.

The ecological footprint assessment for Central Java Province further illuminates the region's resource demands and environmental impacts. This assessment examines four primary sectors—agriculture, forestry, fisheries, and built-up—and considers the ecological footprint stemming from domestic production, imports, and exports. The following discussion explores these findings in detail based on the provided tables.

3.1 Overview of total land requirements

In Central Java, the total land requirements for each sector are assessed by analyzing the land needed to meet the demand generated by the province's economy. Table 2 shows that forestry and fisheries require the most land per unit of economic output, with forestry needing 0.106 hectares and fisheries requiring 0.137 hectares per 1 million IDR increase in final demand. In contrast, the agriculture sector has a smaller land requirement of 0.011 hectares per million IDR, highlighting the relatively low land intensity of agriculture compared to the resource-heavy forestry and fisheries sectors. Built-up land, while essential for urban and infrastructural development, has the lowest land requirement of 0.002 hectares, emphasizing its concentrated nature and limited direct resource demand.

Tabel 2. Total land requirement (**R**) of the Central Java Province four-sector economy.

Sectors	Agriculture	Forestry	Fisheries	Built-up
Agriculture	0.011	0.000	0.000	0.001
Forestry	0.000	0.106	0.000	0.000
Fisheries	0.000	0.000	0.136	0.001
Built-up	0.000	0.000	0.000	0.001
Total[a]	0.011	0.106	0.137	0.002

[a]Total land required (ha) per 1million IDR increase in final demand.

3.2 Domestic ecological footprint analysis

Table 3 details the domestic ecological footprint by sector for Central Java Province in 2016. The fisheries sector has the highest per capita ecological footprint (0.043 hectares), reflecting substantial resource use to support local fisheries activities. The agriculture sector follows, with a footprint of 0.031 hectares per capita, indicating its significant contribution to local ecological demands. Forestry and built-up sectors show lower footprints per capita, at 0.013 and 0.015 hectares, respectively, although their combined ecological impact remains

considerable. The total domestic ecological footprint across all sectors reaches 3,463,621 hectares, with an overall per capita footprint of 0.102 hectares.

Tabel 3. Domestic ecological footprint for the Central Java Province four-sector economy (2016)

Sectors	Final demand domestic (**F**)	Total land requirement (**S**)(ha)	Ecological footprint (**S**/population)
Agriculture	43,503,199.15	1,050,157	0.031
Forestry	28,159.98	436,604	0.013
Fisheries	6,403,842.95	1,477,378	0.043
Built-up	880,848,280.75	499,483	0.015
Total		3,463,621	0.102

These findings highlight the intense demand on local resources for agriculture and fisheries, both crucial to Central Java's economy. The fisheries sector's high footprint suggests that sustaining local consumption requires extensive water and land resources, which could strain regional ecosystems. Agriculture, though slightly lower in per capita footprint, is similarly impactful, underscoring the need for sustainable practices in this sector. Built-up areas, while less demanding per capita, represent continuous urban growth that may further stress natural land resources over time.

3.3 Imported ecological footprint

Table 4 presents the ecological footprint attributable to imports in Central Java. The total imported ecological footprint for 2016 stands at 3,877,918 hectares, surpassing the domestic footprint. Agriculture and fisheries lead in imported footprint per capita, with values of 0.037 and 0.034 hectares, respectively, followed closely by forestry at 0.022 hectares. Built-up land has an imported footprint of 0.021 hectares per capita, showing that even urban infrastructure relies partially on external resources.

Tabel 4. Imported ecological footprint for the Central Java Province four-sector economy (2016)

Sectors	Final demand imported ($\mathbf{F_m}$)	Total land requirement ($\mathbf{S_m}$)(ha)	Ecological footprint ($\mathbf{S_m}$/population)
Agriculture	9,286,676.75	1,242,556	0.037
Forestry	260,389.68	738,519	0.022
Fisheries	546,737.75	1,173,262	0.034
Built-up	320,181,521.76	723,581	0.021
Total		3,877,918	0.114

The reliance on imports reveals Central Java's dependency on resources beyond its borders, especially for sectors that may exceed local production capacity, such as forestry. Importing resources helps satisfy local demand and mitigates domestic environmental strain, but it also reflects an ecological impact on other regions. This trend emphasizes the interconnectedness of global supply chains and highlights the potential benefits of strengthening local sustainable practices to reduce dependency on imported resources.

3.4 Exported ecological footprint

The exported ecological footprint, detailed in Table 5, reflects Central Java's contribution to external markets and its ecological "outflow." In 2016, the province's total export footprint reached 5,765,239 hectares, the highest among the categories analyzed. Agriculture is the most significant contributor, with an exported footprint of 0.080 hectares per capita. Fisheries, forestry, and built-up land also contribute, with export footprints of 0.035, 0.027, and 0.028 hectares per capita, respectively. These figures indicate that a substantial share of Central Java's ecological resources, particularly from agriculture, is directed toward meeting external demand.

Tabel 5. Exported ecological footprint for the Central Java Province four-sector economy (2016)

Sectors	Final demand exported ($\mathbf{F_x}$)	Total land requirement ($\mathbf{S_x}$)(ha)	Ecological footprint ($\mathbf{S_x}$/population)
Agriculture	37,764,413.35	2,717,043	0.080
Forestry	288,706.57	935,398	0.027
Fisheries	81,059.62	1,176,478	0.035
Built-up	410,272,445.64	936,320	0.028
Total		5,765,239	0.169

The high export footprint in agriculture suggests that Central Java is a key supplier of agricultural products to other regions or countries, which places additional pressure on its land and water resources. While exports contribute to economic growth, they also increase the ecological burden on local ecosystems. Sustainable agriculture practices, such as crop rotation, organic farming, and water-efficient methods, could help mitigate this impact by reducing the land and water needed per unit of agricultural output.

3.5 Aggregated ecological footprint and net analysis

Table 6 summarizes the ecological footprint across domestic, imported, and exported categories, presenting a net footprint estimate for each sector. Notably, agriculture exhibits a negative net footprint (-0.012 hectares per capita), indicating that Central Java exports more ecological value in agriculture than it imports or uses domestically. This negative net footprint could imply an unsustainable level of resource outflow, as local agricultural resources are heavily directed toward external markets. Conversely, fisheries show a stable and positive net footprint (0.043 hectares per capita), highlighting ongoing pressure on local water and land resources for both domestic and external needs.

Table 6. Ecological footprint for Central Java Province four-sector economy (2016)

Sectors	Domestic (ha)	Imports (ha)	Exports (ha)	Estimated EF (ha)
Agriculture	0.031	0.037	0.080	-0.012
Forestry	0.013	0.022	0.027	0.007
Fisheries	0.043	0.034	0.035	0.043
Built-up	0.015	0.021	0.028	0.008
Total	0.102	0.114	0.169	0.046

The forestry and built-up sectors maintain modest positive net footprints of 0.007 and 0.008 hectares per capita, respectively, suggesting that while they rely on external resources, their ecological demands are less intensive. The overall net ecological footprint for Central

Java stands at 0.046 hectares per capita, underscoring a balance between resource imports and exports across sectors, albeit with a notable ecological burden placed on the agriculture and fisheries sectors.

3.6 Comparative insights and policy implications

When comparing Central Java's ecological footprint with findings from other regions, a common pattern emerges: agrarian economies like Central Java often exhibit high ecological footprints in agriculture and fisheries due to the intensive land and water requirements of these sectors. Regions with similar profiles, such as parts of Vietnam and Thailand, show a reliance on local ecosystems for agricultural exports, placing strain on local biodiversity and water resources [19]. This comparison suggests that Central Java could benefit from adopting sustainable practices observed in these regions, such as organic agriculture or integrated water resource management.

European countries, on the other hand, have implemented various policies aimed at reducing their ecological footprint through efficient resource use and sustainable farming methods [20]. Denmark, for instance, has embraced organic agriculture and nutrient recycling, which reduces environmental impacts and enhances soil health [21,22]. Adopting similar practices could enable Central Java to maintain its agricultural productivity while minimizing ecological strain, especially in response to growing export demands.

4 Conclusion

The ecological footprint assessment for Central Java highlights the complex dynamics between domestic consumption, imported resources, and exported products. The region's high ecological footprint in agriculture and fisheries underscores the critical role these sectors play in local resource use. Meanwhile, its reliance on imports in forestry and the substantial ecological outflow in agriculture suggest that sustainable resource management is essential for long-term ecological balance. By incorporating sustainable practices in agriculture and fostering local production for imported resources, Central Java can work towards a more balanced ecological footprint that supports both economic growth and environmental resilience.

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