Research Paper

Assessment of Environmental Carrying Capacity

Concepts and Implementation in Indonesia

Dema Amalia PUTRI[1], Joseph Pintor Kishore SIMAMORA[1], Aiko Perolihen BANCIN[2], Miftahul Jannah Jan RAMADHANI[1], Aisyah Sinta SUHARTA[1]

[1]Indonesian Association of Urban and Regional Planners, Indonesia
[2]Directorate of Environmental Impact Prevention and Regional and Sector Policy, Ministry of Environment and Forestry, Indonesia

Abstract

Population growth and climate change are exerting significant pressure on the availability of natural resources and environmental quality. The paradigm of sustainable development, characterized by principles of efficient resource management and reduced emissions, has increasingly been advocated as an alternative approach to address the constraints imposed by environmental limits. The concept of Environmental Carrying Capacity (ECC) is closely aligned with sustainable development as it aims to maintain a balance between environmental provision and utilization. ECC serves to depict the condition and capacity of the environment to support human activities. Therefore, this study examines the concept, measurement techniques, and implementation of ECC to evaluate support capacity potentials across diverse regions in Indonesia. The study utilized quantitative statistical and spatial methodologies to analyze ECC across multiple dimensions, including water, land, air, marine, and biodiversity, employing various data sources and conceptual frameworks. The finding of this study will disclose that characteristics in different regions exhibit distinct threshold capacities and challenges in sustaining their ECC. The study underscores the importance of continual development in ECC assessment to ensure the sustainability of natural resources in Indonesia. Furthermore, it advocates for strategies to enhance and standardize environmental carrying capacity through integrated, data-driven, and sustainable environmental policies.

Keywords

Environmental carrying capacity, environmental threshold, sustainable development

1. Introduction

Megatrends are driving significant changes that impact various aspects of human life (KLHK, 2023). Population growth and urbanization, key components of Megatrends, lead to socio-environmental problems due to the high demand for environmental resources (UNDP, 2014). It is estimated that global demand will increase by 40% for water, 50% for energy, and 35% for food from 2014 to 2030 (Retief et al, 2016). The Triple Planetary Crisis—climate change, biodiversity loss, and pollution—worsens these issues, stressing sustainability and creating resource scarcity (Stockholm Resilience Centre, 2023; Steffen et al., 2015). Approximately 70% of urban areas are projected to be at risk from climate change, with water scarcity predicted to be the top global risk in the future (UCCRN, 2018; PWC, 2015).

Indonesia is projected to reach a population of 324.06 million, with over 70% living in urban areas by 2045 (UN-DESA, 2022; Simarmata et al., 2023). However, Indonesia's environmental conditions are deteriorating, with a temperature rise of about 0.03°C per year (KLHK, 2020), a 17% loss in biodiversity (Setiawan, 2022), and air pollution reducing life expectancy by 2.5 years (Lee & Greenstone., 2021). Despite these challenges, Indonesia possesses abundant ecoregional characteristics that can support water resources, arable land, biodiversity, and mineral deposits. This makes Indonesia a global mega biodiversity hotspot with blue carbon potential representing at least 17% of the world's reserves (CIDES and WWF, 2021).

The environment provides the fundamental basis for development, necessitating planning within growth limits (von Weizsäcker & Wijkman, 2018). Therefore, development plans must integrate socio-economic challenges with a focus on environmental resilience (KLHK, 2023; Swiader et al., 2020). As consumption patterns continue to rise, they may eventually exceed the availability of natural resources, leading to conflicts between ecological space and human needs and threatening social crises such as population mortality (Yue & Wang, 2019). Ultimately, environmental destruction not only increases ecosystem vulnerability but also hinders sustainable development (Morshed et al., 2024; Ye et al., 2021).

Thus, emphasizing equity and sustainability is crucial for protecting natural resource use. The Environmental Carrying Capacity (ECC) approach supports these principles by estimating the environment's ability to fulfill human needs without degrading its functions (KLHK, 2023; Schroll et al., 2012). Qian et al. (2021) applied ECC to integrate social development with nature preservation, especially in vulnerable areas. Similarly, Zhang et al. (2019) reported that new urban development plans in China must follow ECC limits with monitoring mechanisms. ECC serves as a limit to growth; it can estimate natural resources needed for survival, including food, water, shelter, and energy (Lane et al., 2013; Edelman, 1997).

In Indonesia, ECC is normatively mandated by Law No. 32 of 2009 as an instrument for environmental and social safeguards. Thus, assessing ECC is fundamental because Indonesia is an archipelagic country with abundant natural resources but significant physical and social vulnerabilities due to its large population. Moreover, ECC aligns with the 1945 Constitution, which guarantees every Indonesian citizen the right to a healthy environment. In this paper, we aim to evaluate and identify the ECC assessment in Indonesia based on the condition of supply and demand for potentially renewable resources. We also discuss the challenges and limitations encountered during this assessment, including finding accurate methodologies to quantify and qualify physical conditions and data availability, as well as addressing gaps between ECC implementation and existing policies.

2. Literature Review

2.1. Environmental Carrying Capacity: A Strategic Pillar for Sustainable Development

Two interconnected factors create a domino effect in the development process. Humans continuously exploit natural resources to support their needs. However, they will also face ecological crises that threaten survival due to environmental pressures (Shi et al., 2019). These ecological crises are marked by risks to water and food availability, air purity, and the productivity of flora and fauna (Muta'ali, 2011). In conclusion, practical development now often paradoxically accelerates environmental degradation (Subekti & Suroso, 2018).

Therefore, as time progresses, sustainable development principles become increasingly recommended to address these environmental issues. The World Commission on Environment and Development defines sustainable development as the process of fulfilling present needs without compromising the ability of future generations to fulfill their own needs. The emphasis on sustainable development increased following the publication of *The Limits to Growth*, which concluded that finite natural resources would severely constrain economic growth. Sustainable development can also help manage the conflict between social and economic development with the ability to protect the environment.

Here, ECC plays a fundamental role as a key approach to illustrating the importance of sustainable development. Manafi et al. (2009) found that the sustainability of natural resources relies on not exceeding their carrying capacity. ECC often serves as a threshold for supporting human needs; exceeding this limit can lead to environmental damage (Santoso et al., 2014; Kozlowski, 1990). It is expected that population consumption patterns significantly contribute to climate change. For example, agricultural and plantation expansion in Indonesia accounts for 96% of deforestation drivers (Austin et al., 2019). These sectors are used for population needs and economic growth. If unchecked, they will lower the ECC threshold, rendering the environment unusable (Nurikah & Cahyani, 2019). However, with an estimated 125 million hectares of forest, Indonesia could harness ECC to become a carbon offset superpower and effectively mitigate climate change impacts.

Simarmata et al. (2023) link ECC at the urban scale with climate change, noting that water crises often emerge as a primary issue. This has led cities to adopt the Sponge City concept, ensuring water availability as a key ECC factor. Consequently, water-sensitive urban design promotes long-term carbon emission reductions in urban development. Meanwhile, Isman et al. (2017) use carbon footprint as a component of ECC to determine land capacity for carbon absorption. Thus, ECC indirectly provides a framework for formulating climate change policies as part of sustainable development.

2.2. Challenges in Implementing Environmental Carrying Capacity for Effective Environmental Management

In Indonesia, the concept of ECC has been integrated into spatial planning legislation, particularly concerning environmental issues (Schroll et al., 2012). It is mandated in Law No. 32 of 2009 as the legal foundation for Indonesia's environmental management and protection. This law defines ECC as the environment's capacity to support human life, other living beings, and the balance between them. ECC serves as a limiting factor in the utilization of natural resources across forestry, tourism, marine, agriculture, and mining sectors (KLHK, 2023). Thus, this has led us to understand that ECC is a fundamental element in ensuring environmental sustainability to support the livelihoods of Indonesia's population.

The Indonesian government faces challenges in assessing ECC, including discrepancies between scientific advancements and the accuracy of data availability. This has led to frequent revisions of ECC's operational definition to align with current methodologies. Conceptually, ECC assessment in Indonesia emphasizes balancing supply and demand, influenced by ecosystem services by the regulations. Firmansyah et al. (2020) stated that ECC based on ecosystem services effectively represents environmental conditions both quantitatively and spatially, including the environment's ability to support human needs. The Millennium Ecosystem Assessment (2003) categorizes ecosystem services into provisioning, regulating, supporting, and cultural, which Burkhard and Maes (2017) further differentiated by natural resource types.

Ecosystem services are inherently influenced by ecoregions, which define the natural characteristics of the environment in providing natural resources. Therefore, Indonesia tailors its ECC assessments to match the region's physical conditions and its capacity to recover from environmental depletion. Indonesia began assessing ECC based on water resources as a critical resource to support basic human needs. This ECC approach estimates water availability, population thresholds, and potential water-deficit areas based on the capacity of water provisioning and regulating services. However, Indonesia has only calculated river water availability without considering its quality, leading to a generalized assumption that all river water is usable.

Meanwhile, Hamakonda et al. (2019) stated that most rivers in Indonesia have faced significant pollution in recent years. In 2022, only 8% of 111 identified rivers met quality standards (BPS, 2023). This has led Indonesia to refocus ECC assessments on land resources, which are indirectly influenced by water availability and biodiversity. The revised approach uses biocapacity and ecological footprint methods, as per Ministerial Regulation No. 17 of 2009, in which land use is impacts overall environmental sustainability and most suitable for evaluating ECC (Subekti & Suroso, 2018). The reassessment also encounters challenges due to limitations in analytical tools, resulting in less accurate spatial connections and standardized land needs across islands despite varying consumption patterns.

Therefore, it is evident that the assessment of Environmental Carrying Capacity (ECC) in Indonesia remains constrained by several limitations. These limitations prompt the Indonesian government to persist in refining its calculations by reinforcing methodologies and improving data availability. These efforts have led Indonesia to reassess ECC by incorporating additional potentially renewable resources. According to Miller (1990), these resources encompass freshwater, prime land, air, biodiversity, and marine ecosystems. The interdependence of these five resources enables their sustainable utilization.

3. Methodology

This study, conducted by the Indonesian government, follows up on the principles and methods for calculating ECC established in 2015. The ECC assessment in Indonesia used an island-based scale, but for this initial research, Bali Province was chosen as a study case due to its significance as a global tourism hub, which poses environmental sustainability challenges. The ECC assessment focuses on balancing the supply and demand of five potentially renewable natural resources: freshwater, arable land, air, ocean, and biodiversity. The analysis calculates the ECC for each resource, integrating them through Multiple Criteria Analysis (MCA). MCA, which evaluates different units using decision-maker scores (Hajkowicz & Collins, 2006), is widely used in environmental decision-making (Balasubramaniam & Voulvoulis, 2005). In this study, MCA determines the relative weights of the five resources based on their impact within the ECC context.

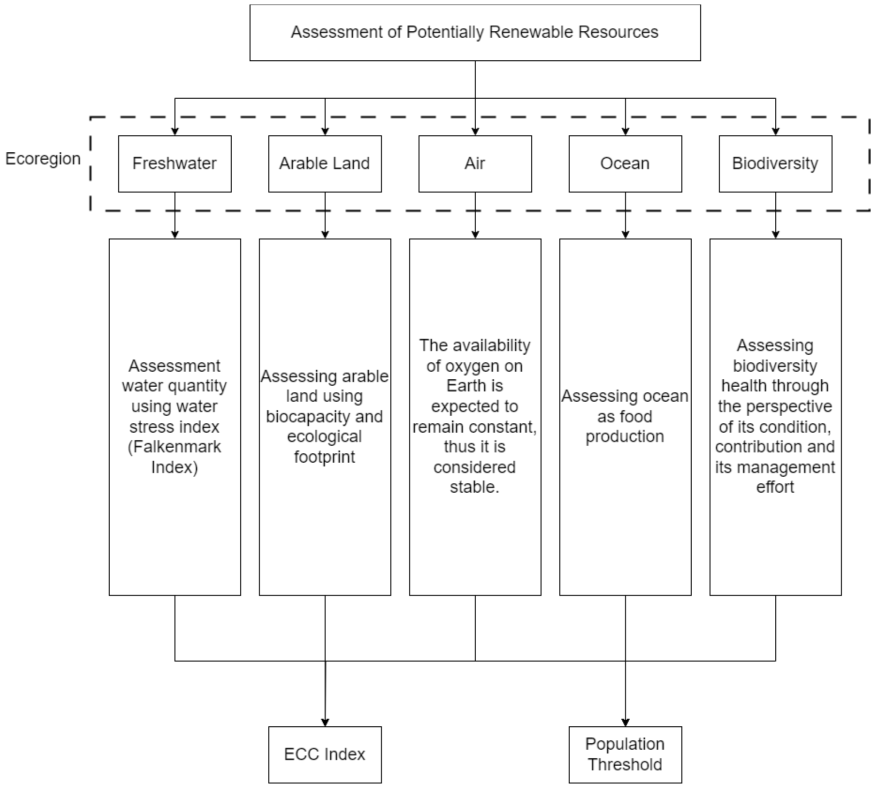

Figure 1 The Concept of ECC Assessment in Indonesia
Source: Authors, 2024

3.1. Data Collection

In this study, relevant data per each potentially renewable resource is used as follows.

Table 1 Data Collection in ECC Assessment

Potentially Renewable Resources	Parameter	Variable
Freshwater	Ecosystem Services	Ecosystem Services for Water Provision
	Natural Water Supply	Water Supply Debit
	Polluted Water	Total Suspended Solids
		Dissolved Oxygen (DO)
		Biochemical Oxygen Demand (BOD)
		Chemical Oxygen Demand (COD)
		Total Fosfat
		Fecal Coliform
		Total Coliform
		Other pollutants that can be found in the monitoring point
	Water demand per capita	Water demand standard per capita for domestic, agriculture, and industry using Falkenmark Index
	Population	Total population
Arable Land	Biocapacity	Arable Land Cover

Potentially Renewable Resources	Parameter	Variable
		Ecoregions
	Ecological Footprint	Land Demand for Food
		Land Demand for Clothes
		Land Demand for Shelter
Ocean	Food Production	Temperature
		Chlorophyll
		Oxygen
		Plankton
Biodiversity	Biodiversity Condition	RTE Species
		Habitat Types
		Forest Connectivity
		Essential Ecosystem
	Biodiversity Contribution	Ecosystem Services for Biodiversity & Habitat Supports
	Biodiversity Management	Conservation Area

Source: Authors, 2024

3.2. Data Analysis

Freshwater Carrying Capacity

Freshwater Carrying Capacity refers to an area's ability to provide a certain amount of freshwater to fulfill human needs. It is defined based on the supply-demand relation to support human beings. It is acquired from the ratio of freshwater supply (surface water and groundwater) with water demand per capita, which the Falkenmark Index represents. The assimilative capacity of freshwater will be a deduction factor in determining its carrying capacity. This calculation will produce a Water Stress Index ranging from 1 to 5, where 1 indicates water scarcity, and 5 indicates no water stress.

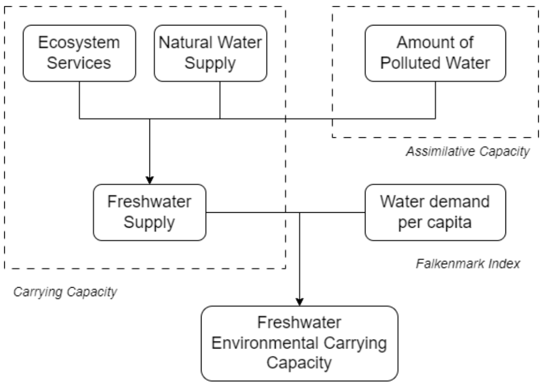

Figure 2. The Concept of Freshwater Environmental Carrying Capacity
Source: Authors, 2024

Arable Land Carrying Capacity

Arable Land Environmental Carrying Capacity refers to an area's ability to provide a certain amount of arable land to support the needs of food, clothing, and shelter. It is acquired based on the supply-demand relation, in which biocapacity represents the supply side and ecological footprint represents the demand side. Biocapacity is based on land outside conservation areas and high ecosystem services for water regulation, biodiversity support, and carbon sink.

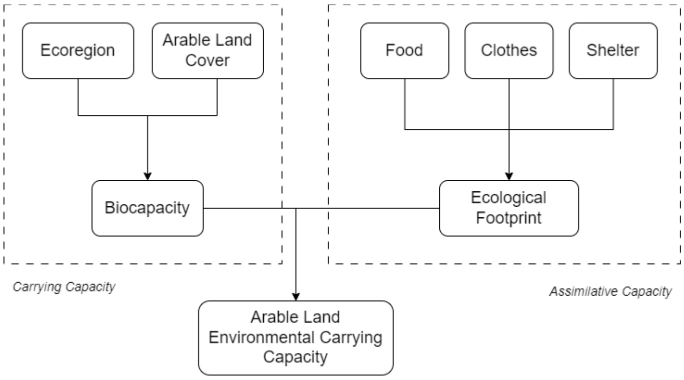

Figure 3 The Concept of Arable Land Carrying Capacity
Source: Authors, 2024

Ocean Carrying Capacity

Ocean Carrying Capacity refers to the ocean's ability to support fish food sources. The method is a modification of IKLI (Indonesia Ocean Health Index), which was adopted from OHI (Ocean Health Index). Ocean Carrying Capacity uses four indicators that influence each other with weighted overlay analysis based on expert judgment: 20% for temperature, 20% for chlorophyll, 30% for oxygen, and 30% for plankton.

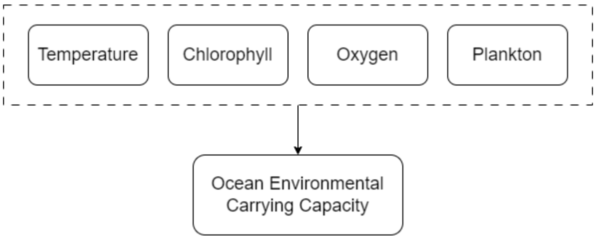

Figure 4 The Concept of Ocean Carrying Capacity
Source: Authors, 2024

Biodiversity Carrying Capacity

Biodiversity Carrying Capacity refers to the health (condition and contribution) of biodiversity in the area and its management effort. Biodiversity Carrying Capacity uses indicators such as habitat types, endangered species, and forest connectivity to show its condition and ecosystem services for its contribution to human needs. The analysis used in the calculation is weighted overlay, which is based on expert judgment: 30% of biodiversity condition, 30% of biodiversity contribution, and 40% of biodiversity management.

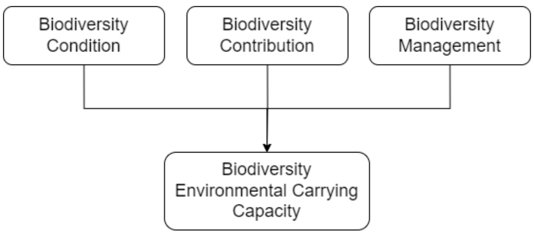

Figure 5 The Concept of Biodiversity Carrying Capacity
Source: Authors, 2024

ECC Threshold

The threshold indicates the maximum capacity of the environment to support human needs without damaging ecosystems. This research focuses on two thresholds related to the index and population quantity as follows:

- **Index Threshold**

  The index threshold aims to determine whether the aggregate value of the index is in an ideal condition or remains sufficient. We identify the index threshold by linking the dominating index with its constraints. This identification process employs the Analytical Hierarchy Process (AHP), a decision-making tool widely used for selecting the most relevant criteria (Vaidya & Kumar, 2006). The index score reflects the dominant index in Bali, with weights derived from expert judgment assessing the impact of natural resources on Ecosystem Carrying Capacity (ECC): freshwater (0.44), prime land (0.26), air (0.076), sea (0.093), and biodiversity (0.128). For the Index Threshold, we utilize an index of 3 on a scale of 1-5, representing a midpoint with the assumption that the quantity and quality of natural resources remain adequate. The following formula is employed:

$$Index\ Value = (Index\ Score\ x\ Index\ Weight)$$

- **Population Threshold**

  The population threshold aims to determine the number of populations that the environment can support, defined as the ability to fulfill basic living needs independently from environmental services. However, this research has limitations, as not all renewable natural resources can produce this population threshold. This is because it is derived solely from natural resources that can be quantitatively measured, including:

  <u>Freshwater Carrying Capacity</u>

$$Population\ Threshold\ in\ Freshwater = \frac{Availability\ of\ Usable\ Water\ (m^3/year)}{Standard\ Water\ Demand\ (m^3/cap/year)}$$

  <u>Arable Land Carrying Capacity</u>

$$Population\ Threshold\ in\ Arable\ Land = \frac{Availability\ of\ Land\ (ha/year)}{Ecological\ Footprint\ (ha/cap/year)}$$

  In this research, the determination of the population threshold is based on a conservative approach and minimal risk management, focusing on a minimum quantity. Additionally, selecting this minimum quantity assumes the potential to reduce pressure on natural resources and prevent overcapacity.

4. Findings and Discussion

This study identifies the ECC conditions for potentially renewable resources at the ecoregion and island levels using spatial analysis based on supply and demand concepts. A key finding in the ECC assessment is the condition of each potentially renewable resource represented as an index, which serves as a reference for determining thresholds regarding both resource availability and the capacity of the supported population.

4.1 Mapping the ECC Value of Potentially Renewable Resources

The ECC assessment of the five potentially renewable resources is based on the analysis of each indicator, which is assumed to represent the supply and demand of resources in Indonesia. The results of the ECC reflect the quantity of these resources available to fulfill basic human needs. The analysis and mapping results of the ECC assessment, particularly for Bali Province, are as follows.

<u>Freshwater Carrying Capacity</u>

Ecosystem services for water provision are essential for understanding natural water availability in Bali Province. According to the analysis, surface water from river basins is estimated at 1,645,890,623.61 m^3/year, and groundwater from aquifers at 1,389,000,000 m^3/year. This indicated that ecosystem service through precipitation and evaporation can naturally provide 3,034,890,623.60 m^3/year of water in Bali Province. However, not all of this water is usable due to river pollution. It is estimated that contaminated water in Bali totals 333,837,968.59 m^3/year. Consequently, the total usable water to fulfill the population's basic needs is 2,701,052,655.01 m^3/year. This usable water is the basis for estimating the Freshwater Carrying Capacity Index by dividing it by the existing population. The map shows that 52% of Bali Province's area has low Freshwater Carrying Capacity, failing to fulfill the required standards. With the current population, the average water supply is 613.28 m³ per capita per year, indicating overall water scarcity.

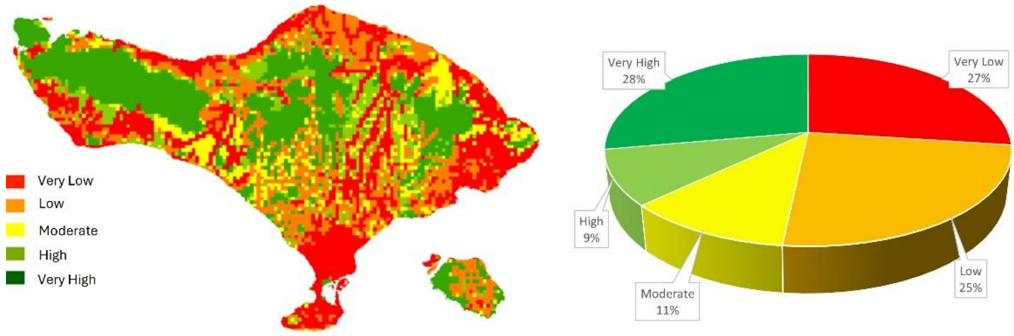

Figure 6 Map of Arable Land Carrying Capacity
Source: Analysis, 2024

Arable Land Carrying Capacity

The availability of arable land in Bali is determined by subtracting areas designated as protected forests, high-value ecosystem services for food, and highly critical land from the province's total area. This results in 385,378 hectares/year of usable arable land, or about 68% of Bali's total area. From the demand side, the ecological footprint is estimated based on basic needs: 0.05 ha/cap/year for food, 0.41 ha/cap/year for clothing, and 0.00029 ha/cap/year for shelter. Compared to the existing population, it indicates that each resident in Bali requires approximately 0.07 ha/cap/year or about 321,769.46 ha/year from the total area. These indicators serve as the basis for estimating the Arable Land Carrying Capacity Index by dividing them. The map shows that 64% of Bali Province's area has low Arable Land Carrying Capacity, which indicates two conditions: (1) Some areas are restricted from human activities to fulfill their needs, and (2) The unprotected areas are insufficient to fulfill the population's requirements optimally.

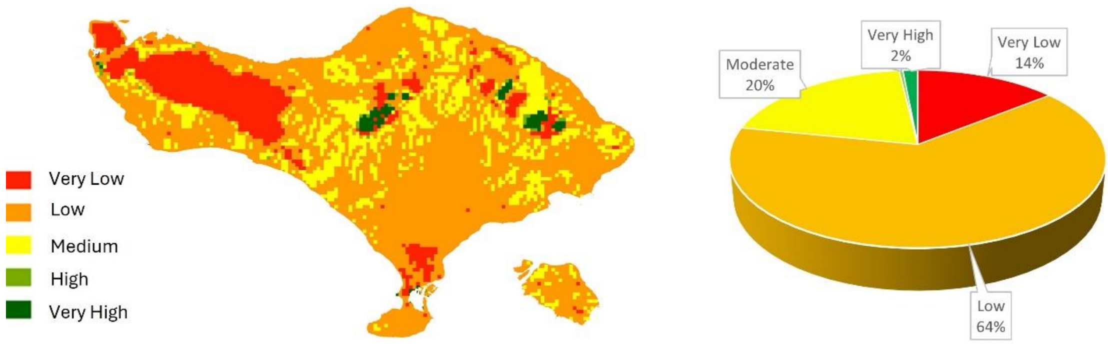

Figure 7 Map of Arable Land Carrying Capacity
Source: Analysis, 2024

Ocean Carrying Capacity

The assessment of Marine Carrying Capacity differs from other renewable resources by focusing on the marine ecoregion, which includes coastal waters with a relatively homogeneous species composition relevant to fisheries management. This assessment aggregates areas within the same marine ecoregion rather than relying on administrative boundaries. The analysis identifies key indicators supporting fish food sources: (1) moderate sea surface temperatures, which indicates optimal plankton production; (2) high chlorophyll availability, which indicates a healthy marine ecosystem; (3) sufficient oxygen levels for sustainable food sources; and (4) moderate phytoplankton availability which indicates supporting primary production for fish. These four indicators serve as the basis for estimating the Ocean Carrying Capacity Index through weighted overlay. The map shows that Bali Province is located in the marine ecoregion of Bali and Nusa Tenggara and predominantly at Level 3. This indicates moderate marine conditions that adequately supply fish resources, though improvements are needed to address pollution issues.

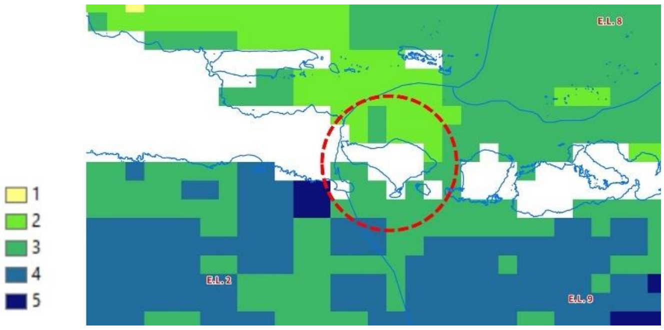

Figure 8 Map of Ocean Carrying Capacity
Source: Analysis, 2024

Biodiversity Carrying Capacity

The assessment of Biodiversity Carrying Capacity focuses solely on terrestrial availability, excluding marine biodiversity. The analysis identifies key indicators affecting biodiversity sustainability: (1) Sub-Index of Habitat Contribution, which is predominantly low in providing breeding habitats; and (2) Sub-Index of Habitat Condition, which indicates high habitat diversity but significant fragmentation, low peat distribution, and reduced karst coverage, suggesting a loss of ecological function, low forest connectivity implies that remaining forest areas are poorly linked, and the presence of Rare, Threatened, and Endangered (RTE) species is moderate, indicating a considerable proportion of threatened species. These two indicators serve as the basis for estimating the Biodiversity Carrying Capacity Index through weighted overlay. The map shows that 43% of Bali Province's area has low Biodiversity Carrying Capacity, which indicates high ecosystem pressure from intensive human activities, particularly land conversion, resulting in the loss of natural habitats.

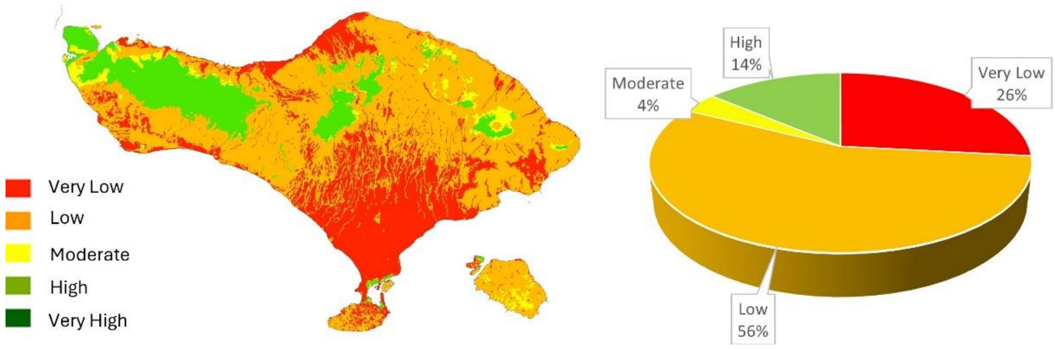

Figure 9 Map of Biodversity Carrying Capacity
Source: Analysis, 2024

4.2 ECC Threshold

After assessing each ECC's potentially renewable resources, the next analysis estimates the ECC threshold based on index values and population. The threshold determines whether the aggregate index value is ideal or sufficient. If the index value is below the threshold, the ECC is considered less optimal for fulfilling human needs. The threshold is set by comparing the aggregate index (dominance) with the median classification value for each resource, with an index value of 3 as a midpoint based on a Likert Scale of 1 to 5, with higher values indicating better ECC conditions. The threshold is also influenced by weighting from the AHP analysis, which prioritizes the impact of each resource on ECC sustainability. The most influential resources are freshwater, prime land, biodiversity, ocean, and air.

Table 2 Index Value and Index Threshold in the ECC Assessment of Bali Province

ECC	Freshwater	Arable Land	Air	Ocean	Biodiversity
Index Value	0.44	0.52	0.38	0.28	0,26
Index Threshold	1.32	0.78	0,23	0.28	0,38

Source: Analysis, 2024

The table shows that the aggregate index values for freshwater, prime land, and biodiversity are below their respective thresholds. This indicates that these resources in Bali Province are not in optimal condition to fulfill basic human needs. Consequently, policy interventions are necessary for the sustainable utilization, management, and protection of these resources. It is recommended to enforce stricter regulations and monitoring of permits related to extraction and exploitation activities within terrestrial ecoregions. Regarding air, the Air Carrying Capacity was excluded from the analysis, as the literature suggests that oxygen availability on Earth remains constant and consistently above the threshold. The marine resource index aligns with its threshold, indicating that the condition of Bali Province's marine ecosystems is currently adequate but requires careful management to ensure sustainability.

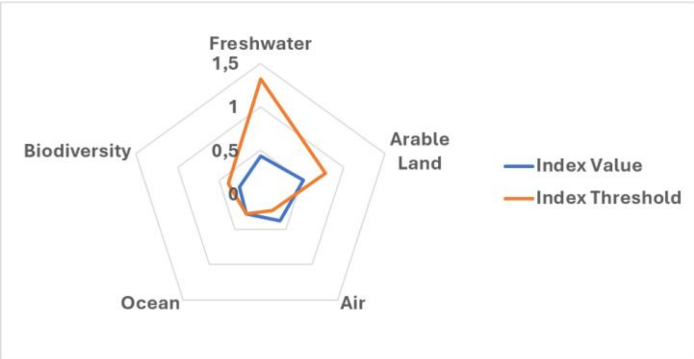

Figure 10 The Relationship Between Index Values and Threshold Index Using a Spider-Web Chart. Source: Analysis, 2024.

In addition to the index threshold, this study estimates the population threshold, defined as the maximum number of individuals supportable by five renewable natural resources. Expert discussions reveal that this threshold can only be reliably established for resources with quantifiable assessments, specifically freshwater and arable land. The Freshwater Carrying Capacity is calculated by dividing the total usable water by the Falkenmark Index standard of 1,700 m^3 per capita per year, which allows for the support of approximately 1,588,855 people. For Prime Land Carrying Capacity, the available prime land is divided by the total ecological footprint per person, which allows for the support of around 5,526,750 people. These thresholds are aggregated based on the lower capacity resource, concluding that the overall ECC condition in Bali Province can support a population of up to 1,588,855 people.

4.3 Research Limitations

We have assessed ECC in Indonesia since 2015, initially utilizing an ecosystem services approach, followed by calculations based on water and land resources. Nevertheless, during the assessment process, we encountered several challenges, as the available data did not fully align with the commonly accepted methodologies. Despite these challenges, we remain committed to reassessing ECC by incorporating potentially renewable resources, such as freshwater, arable land, air, ocean, and biodiversity, which are interdependent to ensure environmental sustainability. Consequently, this research constitutes an initial study or pilot project, using Bali Province as a case study for ECC assessment, although limitations in the calculations persist, similar to previous ECC evaluations. These limitations are rooted in the specific characteristics of each potentially renewable resource, as outlined in the following table.

Table 3 The Limitations of ECC Assessment on Potentially Renewable Resources

Potentially Renewable Resources	Limitations of ECC Assessment
Freshwater	• The availability of usable water is static, based on the average calculations of rainfall and evaporation, along with the percentage of pollution index for one year. • Water quality is generalized from monitoring points that are not evenly distributed. • Water demand is estimated using general standards from previous studies to meet domestic, agricultural, and industrial needs per capita.
Arable Land	• Land availability is static, determined based on land cover identification within one year, without accounting for potential changes in land cover. • The availability of data for calculating food, clothing, and housing needs varies by year. • The conversion of food, clothing, and housing needs into ecological footprint (in hectares) is assumed to be uniform for every individual within administrative boundaries.
Air	The Air Carrying Capacity cannot be calculated, as the Earth's oxygen levels are estimated to remain constant; therefore, only the Air Assimilative Capacity can be measured.
Ocean	Calculations based on indicators and weighting are based on expert judgment in relevant fields, which requires field validation.
Biodiversity	

Source: Analysis, 2024

5. Conclusion

5.1 Broader Project Impact

ECC assessment in Indonesia can be an instrument to guide policy and decision-making towards sustainable development that can balance human needs and environmental preservation. The balance resulting from the implementation of ECC in policy and decision-making can be an optimal point that must be maintained as the economy and population grow. The concept of ECC integrated with spatial planning and long-term development planning can be a new perspective in determining optimal boundaries.

5.2 Next Development

The ongoing ECC assessment in Indonesia is an initial study focusing on five potentially renewable natural resources. This study recognizes that there are still gaps in assessing ECC, so going forward, the following is needed.

- Improving the ECC approach will require refining the methodology and updating the data. ECC assessment is evolving with nationally and internationally recognized science.
- Early research still produced separate ECC values for the five potentially renewable resources. Therefore, future efforts will be made to combine these ECCs into one holistic value.
- Mainstreaming the integration of ECC into existing and future policies is crucial. This is important to ensure that if an area exceeds its carrying capacity, all planning and activities within it must be done with caution.

Acknowledgment

This research is part of a collaboration project between the Indonesian Association of Urban and Regional Planners and the Ministry of Environment and Forestry in Indonesia, titled 'Establishment of the National Index for Environmental Carrying and Assimilative Capacity.'

6. References

1. Kementerian Lingkungan Hidup dan Kehutanan. (2023). Materi Teknis Daya Dukung dan Daya Tampung Lingkungan Hidup (D3TLH) Nasional. Jakarta: Kementerian Lingkungan Hidup dan Kehutanan.
2. Retief, F., Bond, A., Pope, J., Morrison-Saunders, A., & King, N. (2016). Global megatrends and their implications for environmental assessment practice. *Environmental Impact Assessment Review*, 61, 52-60.
3. Stockholm Resilience Centre. (2023). *Planetary Boundaries*. *E-book library* [online]. Available at: https://www.stockholmresilience.org./research/planetary-boundaries.html.
4. Steffen *et al*. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, 347 [online]. Available at: 10.1126/science.1259855. (Accessed: 5 August 2024).
5. Urban Climate Change Research Network. (2018). The Future We Don’t Want: How Climate Change Could Impact the World’s Greatest Cities. Colombia University: UCCRN Technical Report.
6. Simarmata *et al*. (2023) Metropolitan Indonesia: Status Terkini dan Tantangan ke Depan. Jakarta: IAP Press.
7. Kementerian Lingkungan Hidup dan Kehutanan. (202). *Roadmap Nationally Determined Contribution (NDC) Adaptasi Perubahan Iklim.* Jakarta: Kementerian Lingkungan Hidup dan Kehutanan.
8. Setiawan, A. (2022). Keanekaragaman Hayati Indonesia: Masalah dan Upaya Konservasi. *Indonesian Journal of Conservation, 11(1), pp 13-21*.
9. Greenstone, M., & Lee, K. (2021). Air Quality Life Index Annual Report. Chicago: Energy Policy Institute at the University of Chicago
10. Ekaptiningrum, K. (2021). *Blue Carbon Indonesia Simpan 17 Persen Cadangan Karbon Global*. Avalibale at: https://ugm.ac.id/id/berita/22090-blue-carbon-indonesia-simpan-c17-persen-cadangan-karbon-global/
11. Von Weizsäcker, E., & Wijkman, A. (2018). *Come On! Capitalism, Short-Termism, Population, and the Destruction of the Planet*. Berlin: Springer.
12. Świąder M. Szewrański S and Kazak JK (2020) Environmental Carrying Capacity Assessment—the Policy Instrument and Tool for Sustainable Spatial Management. *Front. Environ. Sci. 8:579838*.
13. Ye, S., Wei, C., Wang, Z., Wang, H., Chai, J. (2021). Resources and Environment Carrying Capacity, Social Development and Their Decoupling Relationship: A Case Study of Hubei Province, China. Int. J. Environ. Res. Public Health 2021, 18, 12312.
14. Morshed, S. R., Esraz-Ul-Zannat, Md., Fattah, Md. A., & Saroar, M. (2024). Assessment of the future environmental carrying capacity using machine learning algorithms. *Ecological Indicators, 158, 111444*.
15. Schroll, H., Andersen, J., & Kjaergard, B. (2012). Carrying Capacity: An Approach to Local Spatial Planning in Indonesia. *The Journal of Transdisciplinary Environmental Studies*.
16. Qian, X., We, S., Yili, Z., & Fengyum, M. (2021). Research Progress in Ecological Carrying Capacity: Implications, Assessment Methods, and Current Focus. *Journal of Resources and Ecology, 8(5).*
17. Lane et al. (2013). The essential parameters of a resource-based carrying capacity assessment model: An Australian case study. *Ecological Modelling. 272: 220– 231*.
18. Edelman. D. (1997). Carrying capacity-based regional planning by the National Institute of Urban Affairs. New Delhi. *Project Paper Institute for Housing and Urban Development Studies. 11. Rotterdam*.
19. Shi, Y., Shi, Shouzheng., & Wang, H. (2019). Reconsideration of the methodology for estimation of land population carrying capacity in Shanghai metropolis. *Science of the Total Environment, 652, 367-381*.

20. Muta'ali, L. (2011). Environmental Carrying Capacity Based on Spatial Planning. *Indonesian Journal of Geography, 43(1), 142-155*.
21. Subekti, R. M., & Suroso D.A. (2018). Ecological Footprint and Ecosystem Services Models: A Comparative Analysis of Environmental Carrying Capacity Calculation Approach in Indonesia. *IOP Conference Series: Earth and Environmental Science, 158*.
22. Manafi et al. (2009). Aplikasi Konsep Daya Dukung Untuk Pembangunan Berkelanjutan Di Pulau Kecil (Studi Kasus Gugus Pulau Kaledupa. Kabupaten Wakatobi). *Jurnal Ilmu ilmu Perairan dan Perikanan Indonesia 16(1), 63.*
23.
24. Santoso, E. B., Erli, K. D., Aulia, B. U., & Ghozali, A. (2014). Concept of Carrying Capacity: Challenges in Spatial Planning (Case Study of East Java Province. Indonesia). *Procedia–Social and Behavioral Sciences, 135:130-135*.
25. Kozlowski. J.M. .1990. Sustainable Development in Professional Planning: A Potential Contribution of the EIA and UET Concepts. *Landscape and Urban Planning. 19(4): 307-332*.
26. Hakim, A. M., Baja, S., Rampisela, D. A., & Arif, S. Quantifying future environmental carrying capacity based on land use/land cover data and ecosystem services valuation: a case study in Makassar City, Indonesia. *International Journal of Environmental Studies*.
27. Austin, K. G., Schwantes, A., Gu, Y., & Kasibhatla, P. S. (2019). What causes deforestation in Indonesia?. *Environmental Research Letters, 14, 024007.*
28. Nurikah & Cahyani, F. A. (2019). Forest Utilization Policy in Indonesia in Improving Environmental Carrying Capacity. *Advances in Social Science, Education and Humanities Research, Vol 367*.
29. Firmansah, F., Umilia, E., Yusuf, M., & Pratomoatmojo, N. A. (2020). Carrying capacity and environmental capacity analysis based on ecosystem services in Surabaya. *IOP Conf. Series: Earth and Environmental Science, 562, 012027*.
30. Burkhard, B. & Maes, J. (2017). *Mapping Ecosystem Services*. Advanced Books. Sofia: Pensoft Publishers.
31. Balasubramaniam, A., & Voulvoulis, N. (2005). The Appropriateness of Multicriteria Analysis in Environmental Decision-Making Problems. *Environmental Technology, 26*(9), 951-962.
32. Hamakonda, U.A., Suharto, B., & Susanawati, L.D. (2019). Analisis kualitas air dan beban pencemaran air pada sub DAS Boentuka Kabupaten Timor Tengah Selatan. *Jurnal Teknologi Pertanian Andalas, 23(1), 56-67*.