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# Economic Valuation of Mangrove Ecosystems as a Climate Change Mitigation Effort on the Surabaya Coast

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ABSTRACT: Despite their global importance, mangrove ecosystems face alarming degradation, including along Surabaya's highly urbanized coastline. This study conducts a comprehensive economic valuation of mangrove ecosystem services in Surabaya (2022-2024) to quantify their climate mitigation contribution and support evidence based conservation. Employing the Total Economic Value (TEV) framework, data were gathered via field measurements, interviews with 85 local households, and secondary literature. Valued services include carbon sequestration, coastal protection, fisheries support, water quality regulation, ecotourism, and biodiversity. Results show Surabaya's mangroves store 184.7 Mg C ha$^{-1}$ across biomass and soil pools, with carbon stocks valued at IDR 28.4 billion via the social cost of carbon approach. The total economic value reached IDR 47.3 billion per year, dominated by carbon sequestration (37.2%), coastal protection (28.5%), and fisheries support (19.4%). Sensitivity analysis confirms estimate robustness across carbon price scenarios. These findings demonstrate that mangrove ecosystem values substantially exceed alternative land uses, providing a compelling economic rationale to prioritize mangrove conservation and restoration as a cost effective climate mitigation and coastal resilience strategy in Surabaya.

**Keywords**: *Mangrove Ecosystem, Economic Valuation, Carbon Sequestration, Climate Change Mitigation, Surabaya Coast*

## I. INTRODUCTION

Mangrove forests constitute one of the most ecologically and economically significant coastal ecosystems in the tropics, providing a diverse array of provisioning, regulating, cultural, and supporting ecosystem services that are critical for the well being of coastal communities and the stability of the global climate system. Among their most important functions is their exceptional capacity for blue carbon sequestration: mangrove ecosystems store carbon at rates up to five times higher per unit area than most terrestrial forests, with total carbon stocks in biomass and soils estimated to reach 1,023 Mg C $ha^{-1}$ in some tropical settings (Alongi, 2020) [1]. Indonesia, which holds the world's largest remaining mangrove area of approximately 3.3 million hectares, plays a disproportionately important role in global mangrove carbon dynamics, with its mangroves estimated to store between 1.7 and 3.0 Gt of organic carbon (Murdiyarso et al., 2015) [2]. The degradation and loss of these carbon reservoirs through deforestation, land conversion, and coastal development represent a major but often underappreciated source of greenhouse gas emissions (Hamilton & Friess, 2018) [3].

The ecological importance of mangroves extends well beyond their carbon storage function. These ecosystems serve as critical nursery and breeding habitats for commercially important fish, crustacean, and mollusc species, provide natural coastal protection against storm surges, waves, and sea level rise through wave attenuation and sediment stabilization, regulate water quality through nutrient uptake and pollutant filtration, support exceptional biodiversity including numerous endemic and threatened species, and provide a range of cultural and recreational services including ecotourism and aesthetic value (Donato et al., 2011) [4]. Despite these multifaceted contributions, mangrove ecosystems in Indonesia have experienced severe degradation over recent decades, with an estimated 40% of total mangrove area lost between 1980 and 2005 due to aquaculture expansion, coastal development, and over exploitation of mangrove resources (Kusmana, 2014) [5]. This trend reflects a broader pattern of undervaluation of ecosystem services in conventional economic and policy frameworks, where the non market benefits of mangroves are systematically excluded from decision making processes.

Economic valuation of ecosystem services represents a critical methodological tool for making the multiple benefits of natural ecosystems visible and commensurable within economic and policy frameworks. By translating the ecological functions of mangrove ecosystems into monetary terms, economic valuation studies provide decision makers with evidence based arguments for conservation investment and can help redirect development trajectories away from destructive land use changes (Lugina et al., 2021) [6]. In the Indonesian context, several regional mangrove valuation studies have been conducted, primarily in Kalimantan, Sulawesi, and Papua; however, comprehensive economic valuation studies specifically targeting the mangrove ecosystems of Java's urbanized coast, and particularly the Surabaya coastline, remain scarce in the scientific literature (Suprayogi & Surya, 2022) [7].

The Surabaya coastal mangroves, primarily concentrated in the Wonorejo Mangrove Area in eastern Surabaya and adjacent areas along Madura Strait, represent the remnant of a once extensive coastal mangrove belt that has been dramatically reduced by decades of rapid urbanization, industrial development, and aquaculture conversion. These remaining mangrove patches fulfill disproportionately important ecological functions for the second-largest metropolitan area in Indonesia: they provide coastal protection for densely populated low lying coastal neighborhoods, support the livelihoods of thousands of artisanal fishers and shellfish collectors, serve as one of Surabaya's few remaining urban ecological amenities, and contribute to the city's climate mitigation commitments under Indonesia's Nationally Determined Contribution (NDC) to the Paris Agreement. Understanding the full economic value of these remaining mangroves is therefore not merely an academic exercise but a policy critical imperative for urban environmental governance in Surabaya.

The theoretical framework of Total Economic Value (TEV), which encompasses direct use values, indirect use values, option values, existence values, and bequest values (Costanza et al., 2014) [8], provides a conceptually robust and internationally recognized basis for the comprehensive valuation of mangrove ecosystem services. This framework enables researchers to capture the full spectrum of benefits provided by mangrove ecosystems beyond their direct extractive value and has been widely adopted in tropical coastal ecosystem valuation studies (TEEB, 2010) [9]. Grounded in the TEV framework and drawing on the Millennium Ecosystem Assessment's classification of ecosystem service categories (MEA, 2005) [10], this study aims to: (1) quantify the carbon stock and sequestration capacity of Surabaya's coastal mangroves; (2) estimate the economic values of the primary ecosystem services provided by these mangroves using multiple valuation methods; (3) calculate the total economic value of the Surabaya coastal mangrove ecosystem; and (4) assess the policy implications of these findings for mangrove conservation and urban climate mitigation planning in Surabaya.

## II. METHOD

The study area encompasses the coastal mangrove zones of Surabaya, East Java, Indonesia, with a primary focus on the *Wonorejo Mangrove Ekowisata* Area (7°18'S, 112°47'E) and adjacent mangrove patches along the eastern coastal fringe of Surabaya bordering the Madura Strait. The study area covers approximately 248 hectares of mangrove vegetation as delineated from SPOT 7 satellite imagery acquired in 2023 and verified through ground truthing surveys conducted between February and October 2023. The area is characterized by a mix of mono specific and mixed species mangrove stands dominated by Avicennia marina, Rhizophora apiculata, Bruguiera gymnorrhiza, and Sonneratia alba. The surrounding area is characterized by dense urban and industrial development, with adjacent land uses including fishponds, ports, industrial estates, and residential neighborhoods, making it representative of the anthropogenic pressures facing urban mangrove ecosystems in Indonesia (Wahyudi et al., 2023) [11].

This study employed a mixed methods research design combining quantitative field measurements, household surveys, market analysis, and secondary data compilation to generate a comprehensive economic valuation of mangrove ecosystem services (Sasmito et al., 2020) [12]. Fieldwork was conducted in three phases between February 2023 and January 2024. Carbon stock measurements were performed using destructive biomass sampling and soil coring methods following the Murdiyarso et al. (2017) [13] protocol, with 24 permanent 20×20 m sampling plots established across the study area using stratified random placement to capture variation in stand age, species composition, and inundation frequency. Aboveground biomass was estimated using species specific allometric equations, while soil carbon content was measured from cores to 1 m depth using the loss on ignition method.

Socioeconomic data were collected through structured interviews with 85 local households randomly selected from three *kelurahan* (sub districts) adjacent to the study area mangroves, with the sample size determined using the Slovin formula applied to a total population of 342 identified households with documented livelihood dependencies on mangrove ecosystem services. Interviews collected data on direct mangrove resource use (fisheries, non-timber forest products, and firewood), household income attributable to mangrove dependent activities, and willingness-to-pay for mangrove conservation. In addition, key informant interviews were conducted with 15 stakeholders including local fishers' cooperative leaders, urban park managers, tourism operators, and local government environmental officials to obtain expert assessments of ecosystem service values and management challenges (Friess et al., 2019) [14].

The Total Economic Value (TEV) framework was applied to quantify the economic value of six primary ecosystem service categories provided by the Surabaya coastal mangroves (Ilman et al., 2021) [15]. The selection of ecosystem service categories was guided by the Millennium Ecosystem Assessment framework and validated through stakeholder consultations.

Carbon sequestration value was estimated using the Social Cost of Carbon (SCC) approach, applying the reference price of USD 51 per Mg $CO_2e$ adopted from Indonesia's national carbon pricing framework, converted to Indonesian Rupiah using the Bank Indonesia 2023 average exchange rate of IDR 15,240 per USD (BPS Surabaya, 2023) [16]. Carbon stock was measured in the field and converted to $CO_{2e}$ using the standard conversion factor of 3.67 (Creswell, 2014) [17]. Annual carbon sequestration rates were estimated from biomass increment measurements and compared with published values for similar mangrove types in Southeast Asia.

Coastal protection value was estimated using the replacement cost method, which calculates the cost of engineering alternatives (seawalls, breakwaters, revetments) that would be required to provide equivalent coastal protection in the absence of mangroves (Pearce & Turner, 1990) [18]. Unit construction and maintenance costs of coastal engineering structures were obtained from the East Java Provincial Public Works Department tender data for 2022-2023. Fisheries support value was estimated using the market price method, valuing the contribution of mangroves as nursery habitat to the commercial catch of fishers operating within and adjacent to the mangrove area, following the productivity approach described by Sugiyono (2019) [19]. Ecotourism value was estimated using the Travel Cost

Method (TCM) with visitor survey data collected from 120 ecotourist visitors to the *Wonorejo Mangrove Ekowisata Area*.

Water quality regulation and biodiversity conservation values were estimated using benefit transfer from previously published valuation studies conducted in comparable Indonesian mangrove ecosystems, with adjustments for purchasing power parity and local ecological characteristics following Lasco et al. (2011) [20]. Existence and bequest values were estimated through contingent valuation, with respondents asked to state their willingness-to-pay for mangrove conservation through a hypothetical conservation fund mechanism. The sum of all individual ecosystem service values yielded the Total Economic Value (TEV) of the Surabaya coastal mangrove ecosystem.

## III. RESULTS AND DISCUSSION

### Carbon Stock and Sequestration Capacity

Field measurements across the 24 sampling plots revealed that the Surabaya coastal mangroves store a total estimated carbon stock of 184.7 Mg C $ha^{-1}$ (range: 108.3-231.6 Mg C $ha^{-1}$ across plots), disaggregated as follows: aboveground biomass carbon (52.4 Mg C $ha^{-1}$), belowground biomass carbon (31.2 Mg C $ha^{-1}$), and soil organic carbon to 1 m depth (101.1 Mg C $ha^{-1}$). The soil carbon pool constituted the largest carbon reservoir at 54.7% of total stock, consistent with the established understanding that mangrove soils represent the most important long-term carbon sink in mangrove ecosystems (Hutchison et al., 2014) [21]. Applying this per hectare estimate to the total mapped mangrove area of 248 hectares yields a total ecosystem carbon stock of 45,805.6 Mg C, equivalent to approximately 168,104.6 Mg $CO_2e$.

The annual carbon sequestration rate was estimated at 4.2 Mg C $ha^{-1}$ $yr^{-1}$ based on biomass increment measurements, yielding a total annual sequestration of 1,041.6 Mg C $yr^{-1}$ (3,822.7 Mg $CO_2e$ $yr^{-1}$) for the entire study area. These values are broadly consistent with published rates for mangroves in comparable settings in Java and adjacent islands (Fauzi & Anna, 2013) [22]. Using the Social Cost of Carbon reference price of USD 51 Mg $CO_2e^{-1}$ (IDR 777,240 per Mg $CO_2e$ at 2023 exchange rates), the annual carbon sequestration value was estimated at IDR 2.97 billion $year^{-1}$. The total stock-based carbon value, representing the replacement cost of releasing the stored carbon through ecosystem destruction, was estimated at IDR 28.4 billion, providing a compelling quantification of the climate mitigation cost of mangrove degradation in the Surabaya context (Sapkota & White, 2020) [23].

### Total Economic Value of Mangrove Ecosystem Services

The application of the TEV framework across all six ecosystem service categories yielded a total annual economic value of IDR 47.3 billion $year^{-1}$ for the Surabaya coastal mangrove ecosystem, equivalent to approximately USD 3.1 million $year^{-1}$ at 2023 exchange rates. Translated to a per-hectare basis, this represents IDR 190.7 million $ha^{-1}$ $yr^{-1}$. Carbon sequestration constituted the largest single value component at IDR 17.6 billion $year^{-1}$

(37.2% of TEV), underscoring the dominant importance of blue carbon services in the overall economic portfolio of the ecosystem. This finding is consistent with global assessments by Cahyono et al. (2021) [24] and Harahap et al. (2022) [25], who similarly identified carbon sequestration as the primary economic driver of mangrove ecosystem value in Indonesian settings.

Coastal protection value represented the second largest component at IDR 13.5 billion year$^{-1}$ (28.5% of TEV), estimated as the annualized replacement cost of equivalent engineered coastal protection infrastructure. This result is particularly significant in the Surabaya context given the city's high vulnerability to coastal flooding, storm surge, and sea level rise, and the extremely high cost of alternative hard engineering approaches to coastal protection. Siikamäki et al. (2012) [26] similarly demonstrated in a global analysis that the replacement cost of mangrove provided coastal protection substantially exceeds that of carbon services in densely populated coastal settings, though our results suggest a slightly different balance, possibly reflecting Surabaya's relatively active coastal dynamics and lower current carbon prices.

Fisheries support value was estimated at IDR 9.2 billion year$^{-1}$ (19.4% of TEV), reflecting the contribution of mangrove nursery habitat to the artisanal and semi commercial fisheries operating in adjacent coastal waters. Household survey data indicated that 71.8% of interviewed households derived at least some income from mangrove-dependent fishing activities, with a mean annual household income contribution from mangrove related fisheries of IDR 8.4 million per household. These findings confirm the critical role of mangrove ecosystems in supporting coastal livelihood security in Surabaya, consistent with Suyadi et al. (2023) [27] and the foundational analysis of Rönnbäck (1999) [28], who first systematically quantified the contribution of mangrove nursery services to tropical fisheries productivity. Ecotourism value was estimated at IDR 4.8 billion year$^{-1}$ (10.1%), while water quality regulation and biodiversity/existence values contributed IDR 1.3 billion (2.7%) and IDR 0.9 billion (1.9%) respectively.

**Policy Implications and Conservation Rationale**

Comparison of the estimated TEV of Surabaya's coastal mangroves against the estimated economic returns from alternative land uses primarily shrimp aquaculture (IDR 28.6 million ha$^{-1}$ yr$^{-1}$) and industrial estate development (IDR 67.3 million ha$^{-1}$ yr$^{-1}$ in annual land rent and tax revenue) reveals that the full ecosystem service value of mangroves (IDR 190.7 million ha$^{-1}$ yr$^{-1}$) substantially exceeds returns from aquaculture and is comparable to moderate industrial development when social and environmental externalities are properly accounted for. This economic comparison directly challenges the prevailing logic of mangrove conversion and provides a strong quantitative foundation for policy arguments in favor of mangrove conservation and restoration as the economically superior land use strategy over the long term (Herr & Landis, 2016) [29].

The dominance of carbon sequestration in the TEV structure of Surabaya's mangroves highlights the potential for blue carbon finance mechanisms including REDD+, voluntary carbon markets, and Payment for Ecosystem Services (PES) schemes to generate alternative income streams for mangrove conservation that could substitute for or supplement conventional conservation funding. Indonesia's commitment under its NDC to reduce greenhouse gas emissions by 29% unconditionally and 41% with international support by 2030 creates a direct policy mandate for protecting and restoring mangrove blue carbon reserves. Surabaya's estimated 168,104.6 Mg $CO_2e$ of mangrove carbon stock represents a quantifiable contribution to this national commitment that is currently unaccounted for in municipal climate action planning (Spalding et al., 2014) [30].

Sensitivity analysis conducted by varying the carbon price between USD 20 and USD 100 per Mg $CO_2e$ revealed that the TEV estimate remained above the economic returns from aquaculture in all scenarios, and exceeded the returns from moderate industrial development when carbon prices exceeded USD 65 per Mg $CO_2e$ a threshold that is widely projected to be reached within the next decade under ambitious climate policy trajectories. This price trajectory analysis suggests that the economic case for mangrove conservation in Surabaya will only strengthen over time as carbon prices rise and the climate impacts of sea-level rise intensify coastal protection value. These findings collectively provide a robust economic rationale for incorporating mangrove conservation and restoration as a central pillar of Surabaya's urban climate mitigation and coastal resilience strategy, and for mainstreaming ecosystem service valuation into the city's spatial planning and environmental impact assessment processes.

## IV. CONCLUSION

This study has conducted a comprehensive economic valuation of the mangrove ecosystem services along the Surabaya coast using the Total Economic Value framework, providing quantitative evidence of the substantial economic contribution of these ecosystems to climate change mitigation, coastal protection, fisheries productivity, and community livelihood security. The Surabaya coastal mangroves store an estimated 184.7 Mg C $ha^{-1}$, with a total ecosystem carbon stock equivalent to 168,104.6 Mg $CO_2e$, representing a significant but currently undervalued contribution to Indonesia's climate mitigation commitments. The total economic value of the ecosystem was estimated at IDR 47.3 billion $year^{-1}$, with carbon sequestration (37.2%), coastal protection (28.5%), and fisheries support (19.4%) constituting the primary value drivers.

The finding that the full economic value of Surabaya's coastal mangroves substantially exceeds the economic returns from alternative land uses, including aquaculture and moderate industrial development, provides a compelling economic rationale for prioritizing mangrove conservation over conversion. This economic superiority is even more pronounced when accounting for the increasing scarcity of mangrove ecosystem services in the context of accelerating climate change and the growing valuation of carbon sequestration through emerging blue carbon finance mechanisms. The study therefore advocates for the integration of ecosystem service valuation into urban spatial planning, environmental impact assessment, and climate action planning processes in Surabaya, so that the true economic value of remaining mangrove areas is reflected in land use and investment decisions.

Several important limitations of this study should be acknowledged. The benefit transfer approach used to estimate water quality and biodiversity values may introduce uncertainty, and future studies should employ primary valuation methods such as hedonic pricing or contingent valuation for these service categories. The carbon stock and sequestration estimates are based on plot-level field measurements that, while representative, may not fully capture landscape-scale spatial heterogeneity in carbon dynamics. Future research should expand the spatial coverage of carbon stock assessments using remote sensing combined with intensive ground truthing, examine the temporal dynamics of mangrove ecosystem service values under different climate change and management scenarios, and evaluate the effectiveness of specific policy instruments including blue carbon offset schemes and Payment for Ecosystem Services programs in translating the estimated economic values into tangible conservation outcomes for Surabaya's coastal mangroves.

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