BIODIVERSITAS
Volume 26, Number 6, June 2025
Pages: 2832-2842

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260627

Assessing the potential of alternative energy from mangrove species in Segara Anakan, Central Java, Indonesia

ENDANG HILMI[1,♥], FITRI WINTARTI[2], MUKHTAR EFFENDI[3], MOH HUSEIN SASTRANEGARA[4], RAHAB[5], NORMAN ARIE PRAYOGO[1], TEUKU JUNAIDI[6], HENDRAYANA[7], TRI NUR CAHYO[7], ROSE DEWI[7]

[1]Program of Aquatic Resources Management and Graduate Program of Marine Science, Faculty of Fisheries and Marine Sciences, Universitas Jenderal Soedirman. Jl. Dr Soeparno, Karangwangkal, North Purwokerto, Banyumas 53122, Central Java, Indonesia. Tel./fax.: +62-281-6596700, ♥email: dr.endanghilmi@gmail.com
[2]Graduate Program of Environmental Science, Graduate School, Universitas Jenderal Soedirman. Jl. Dr Soeparno, Karangwangkal, North Purwokerto, Banyumas 53122, Central Java, Indonesia
[3]Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Jenderal Soedirman. Jl. Dr Soeparno, Karangwangkal, North Purwokerto, Banyumas 53122, Central Java, Indonesia
[4]Faculty of Biology, Universitas Jenderal Soedirman. Jl. Dr Soeparno, Karangwangkal, North Purwokerto, Banyumas 53122, Central Java, Indonesia
[5]Program of Management, Faculty of Economy and Bussiness, Universitas Jenderal Soedirman. Jl. Prof. DR. HR Boenyamin No.708, Dukuhbandong, Grendeng, North Purwokerto, Banyumas 53121, Central Java, Indonesia
[6]Program of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Universitas Jenderal Soedirman. Jl. Dr Soeparno, Karangwangkal, North Purwokerto, Banyumas 53122, Central Java, Indonesia
[7]Program Marine Science, Faculty of Fisheries and Marine Sciences, Universitas Jenderal Soedirman. Jl. Dr Soeparno, Karangwangkal, North Purwokerto, Banyumas 53122, Central Java, Indonesia

Manuscript received: 14 December 2024. Revision accepted: 31 May 2025.

Abstract. *Hilmi E, Wintarti F, Effendi M, Sastranegara MH, Rahab, Prayogo NA, Junaidi T, Hendrayana, Cahyo TN, Dewi R. 2025. Assessing the potential of alternative energy from mangrove species in Segara Anakan, Central Java, Indonesia. Biodiversitas 26: 2832-2842.* Mangroves have the potential to be developed for alternative energy to support the utilization of non-renewable energy because mangrove species have high carbon content, high caloric value, and high bulk density. This research aimed to analyze the potential of mangrove species as alternative energy resource to reduce non-renewable energy using the analysis of carbon percentage, caloric value, and fuel fumes. This research used destructive approach and laboratory analysis to analyze energy properties of mangrove species in Segara Anakan, Cilacap District, Central Java, Indonesia. The energy properties included percentage of fixed carbon (%), percentage of charcoal (%), wood density (gr/cm^3), fuel fumes (ppm), total Sulphur (%), caloric energy value (cal/gr) and class of energy using SNI (Indonesian National Standards) and American Society for Testing and Materials (ASTM) systems. This study also analyzed relationship between carbon percentage and energy properties. Mangroves in Segara Anakan contained biomass between 341.90-493.93 ton/ha with carbon percentage between 50.8-63.2% (average 59.1%), fuel fumes between 512.3-640.0 ppm (average 589.0 ppm) and caloric energy value between 6235-7230 cal/gr (average 6796.3 cal/gr). Lanscape scale analysis revealed that *Rhizophora apiculata, Rhizophora mucronata, Bruguiera gymnorrhiza,* and *Ceriops tagal* had the highest potential to produce alternative energy as a substitute for non-renewable energy. These species are recommended for mangrove rehabilitation and reforestation if aiming to generate renewable energy resource.

Keywords: Alternative energy, caloric value, fixed carbon, mangrove landscape

INTRODUCTION

Mangrove forest provides numerous ecosystem services, from serving as habitat of biodiversity to providing livelihoods to local communities, sequestering carbon to mitigate climate change (Hilmi et al. 2017, 2019; Dai et al. 2018; Azman et al. 2021; Selvaraj and Pérez 2023; Ariyanto and Pringgenies 2024) and especially supporting alternative energy to substitute non-renewable energy sources, such as fossil fuels (Valsan et al. 2024). The potential of mangroves as the substitute of non-renewable resources is based on the high caloric value contained in its wood biomass (Swangjang and Panishkan 2021) since mangrove wood has high carbon content (Hartoko et al. 2015; Hilmi et al. 2017; Swangjang and Panishkan 2021), which is influenced by its high wood density and high organic matters like as celluloses and others (Ray et al. 2011; Qaro and Akrawee 2020). Thu et al. (2023) revealed that charcoal produced from several wood species, such as *Leucaena*, *Acacia*, *Eucalyptus*, and bamboos, have high heating values, high fixed carbon content, and lower volatile compounds, but they are still lower than charcoal made from mangrove wood (Hilmi et al. 2019). Beside affected by species, the potential of alternative energy features also has related with the dimensional sizes (e.g., diameter) of wood charcoal (Ameen et al. 2016; Azman et al. 2021).

Despite the high potential of mangrove as renewable energy resources, Nascimento et al. (2023) warned that increasing mangrove utilization as energy alternative (as wood fuel or wood charcoal) might reduce the extent of mangrove forest in the world, including in Indonesia. The utilization and production of wood charcoal are considered among the main drivers of forest degradation, especially in developing countries (Owuor et al. 2019; Lulandala et al. 2023). Forest degradation will impact hydrological processes, accelerate climate change, and reduce water availability. On the other hand, heavily exploiting, producing, and using non-renewable energy resources, such as coal, are problematic since they might produce more negative impacts including high levels of air pollution and environmental degradation as the results of mining extraction (Lai et al. 2023; Zhang et al. 2023). There is increasing global concern regarding the energy utilization from coal which reaches 86.17 Exajoules (EJ), or equivalent to 53.8% of global energy consumption, and currently holds the major contributor in energy source. If the trend of very high exploitation of coal continues unabated, it will result in extensive destruction of ecosystems and environment due to coal mining activities (Zhang et al. 2023; Marrin et al. 2024).

Mangrove charcoal is produced as an alternative energy to support the demand and trade across the world, especially in the culinary sector (Oppong et al. 2024). The high utilization of mangrove charcoal as an energy alternative is caused by high calorific value, high fire suppression ability, cost-effectiveness and non-toxic fumes (Sitoe et al. 2014; Hilmi et al. 2017; Lai et al. 2023). The production of wood charcoal in a region is determined by education level of the community, household activities, ethnicity, available land for charcoal production and regulation. A study showed that the direct utilization of energy from wood charcoal by farmers reached 28.30 per 50 kg. Nevertheless, as a global trade commodity, the utilization of wood charcoal in a region has transnational impacts as in the case of high wood charcoal use in Europe which caused forest degradation and deforestation in Africa (Rocchi et al. 2023). At a local level, Lulandala et al. (2023) found that charcoal consumption by urban communities is a major driver of forest degradation in rural areas.

The problem of energy consumption must be solved to build efficiency in the use of non-renewable energy (Bogachov et al. 2022). One of which is by exploring alternative renewable energy resources including from mangrove charcoal. This study aims to analyze the energy potential of mangrove species occurring in Segara Anakan, Cilacap District, Central Java Province, Indonesia, by measuring carbon percentage analysis, caloric energy potential, and fuel fumes potential. Based on the value of caloric energy, wood density, fuels fumes, total Sulphur, self-heating, carbon percentage, total moisture, ash content and volatile matter (Santosa et al. 2021), it can be hypothesized that the mangrove species in Segara Anakan have the high potential to be developed as an alternative energy. The results of this study might be useful to inform strategies to reduce non-renewable energy utilization, especially from fossil fuels by sustainably utilizing renewable energy resources from mangrove charcoal.

MATERIALS AND METHODS

Study area and period

This study was conducted in Segara Anakan Lagoon (SAL), Cilacap District, Central Java Province, Indonesia (Figure 1 and Table 1). Data were collected from 29 stations divided into two mangrove regions, namely (i) East Segara Anakan, consisted of the Donan River, Donan-Kalipanas River, Donan Pertamina, Kembang Kuning River 1, Kembang Kuning River 2, the estuary of East Pelawangan 1, the estuary of East Pelawangan 2, Sapuregel River 1, Sapuregel River 2, Sleko and Tritih), and (ii) West Segara Anakan, consisted of: Ujung Gagak area, Lorogan, Majingklak Village, Mauara Cawitali, Kebuyutan, Batu Macan, Jongor, Muara Legok, Kayu Mati, Langkap, Karang Braja, Klaces, Inti Ujung Gagak, Muara Bagian, Muara Masigitsela, Pertigaan Ujung Alang, Ujung Alang, the domestic port of Ujung Alang, Kali Semak, and Pertigaan Sudiro (Hilmi et al. 2021b). The mangrove ecosystem in West Segara Anakan and East Segara Anakan were dominated by *Rhizophora* spp., *Bruguiera* spp., *Avicennia* spp., *Sonneratia* spp., *Ceriops* spp. and *Nypa fruticans* (Hilmi et al. 2021a, 2023).

Table 1. The geographical location of study station in Segara Anakan Lagoon, Cilacap District, Central Java Province, Indonesia

Stations		Coordinates	
		Latitude (S)	Longitude (E)
1	Batu Macan	108°47'46"	07°41'38"
2	Dermaga Ujung Alang	108°51'53"	07°42'60"
3	Inti Ujung Gagak	108°49'47"	07°40'34"
4	Jongor	108°48'20"	07°40'23"
5	Karang Braja	108°48'47"	07°40'59"
6	Kayu Mati	108°48'27"	07°39'50"
7	Kebuyutan	108°47'45"	07°41'13"
8	Klaces	108°49'47"	07°41'50"
9	Langkap	108°48'44"	07°38'48"
10	Lorogan	108°48'30"	07°40'44"
11	Majingklak	108°48'1"	07°40'32"
12	Estuary of Ciawitali	108°47'41"	07°41'46"
13	Estuary of Bagian	108°51'42"	07°40'58"
14	Estuary of Legok	108°48'13"	07°39'48"
15	Estuary of Masigitsela	108°50'46"	07°41'24"
16	Pertigaan Ujung Alang	108°51'39"	07°41'44"
17	Ujung Alang	108°51'42"	07°42'01"
18	Ujung Gagak	108°48'43"	07°40'13"
19	Donan	108°59'57"	07°40'34"
20	Donan Kalipanas	108°59'24"	07°42'10"
21	Donan Pertamina	108°59'43"	07°41'15"
22	Kembang Kuning 1	108°55'42"	07°43'13"
23	Kembang Kuning 2	108°54'53"	07°42'25"
24	Estuary of East Pelawangan 1	108°59'11"	07°43'48"
25	Estuary of East Pelawangan 2	108°58'07"	07°43'21"
26	Sapuregel 1	108°57'42"	07°42'54"
27	Sapuregel 2	108°57'38"	07°41'53"
28	Sleko	108°59'29"	07°42'46"
29	Tritih	109°00'34"	07°40'22"

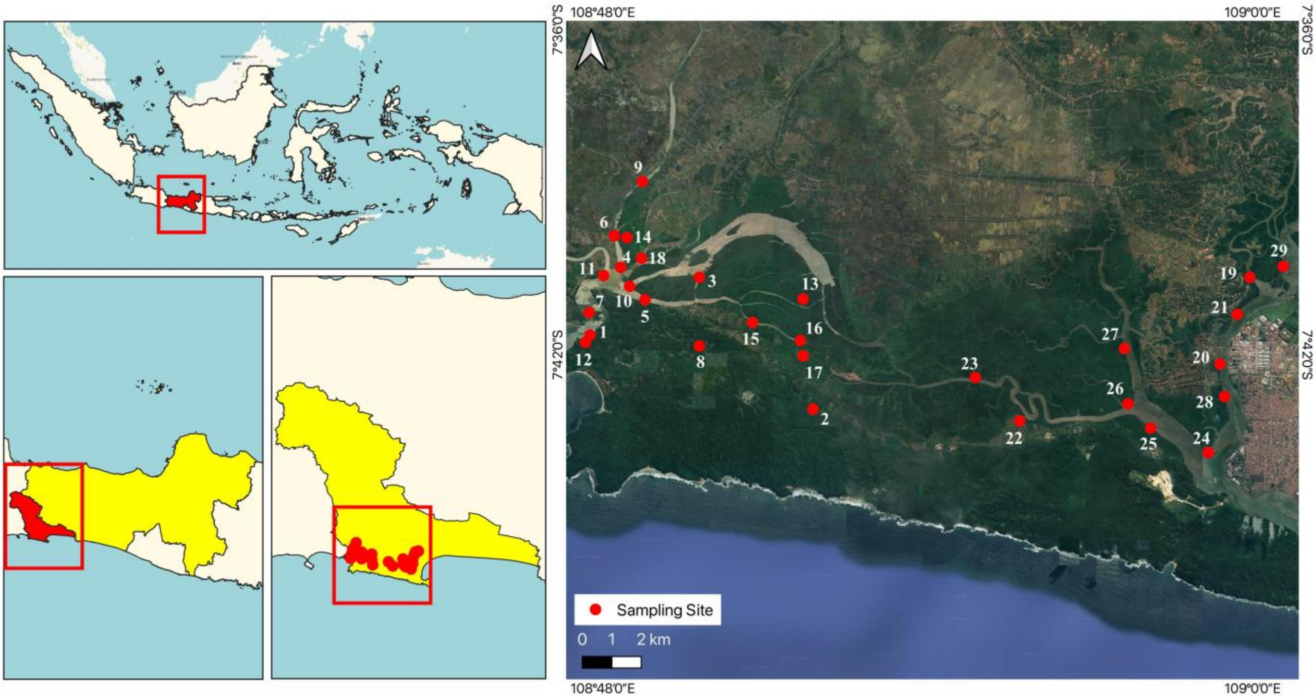

Figure 1. Map of geographic location of the study area in Segara Anakan Lagoon, Cilacap District, Central Java Province, Indonesia. 1: Batu Macan; 2: Dermaga Ujung Alang; 3: Inti Ujung Gagak; 4: Jongor; 5: Karang Braja; 6: Kayu Mati; 7: Kebuyutan; 8: Klaces; 9: Langkap; 10: Lorogan; 11: Majingklak; 12: Estuary of Ciawitali; 13: Estuary of Bagian; 14: Estuary of Legok; 15: Estuary of Masigitsela; 16: Pertigaan Ujung Alang; 17: Ujung Alang; 18: Ujung Gagak; 19: Donan; 20: Donan Kalipanas; 21: Donan Pertamina; 22: Kembang Kuning 1; 23: Kembang Kuning 2; 24: Estuary of East Pelawangan 1; 25: Estuary of East Pelawangan 2; 26: Sapuregel 1; 27: Sapuregel 2; 28: Sleko; 29: Tritih

Study procedures

Destructive analysis

This study used destructive method to collect wood, root, and leaf samples (Chabi et al. 2016). The destructive method was carried out by cutting parts of the tree sample and then collecting them using plastic bag (Hartoko et al. 2015; Chabi et al. 2016). The samples were then brough to laboratory to analyze carbon percentage, caloric energy value, wood density, and fuel fumes (Chabi et al. 2016; Amiruddin and Saismana 2020; Thu et al. 2023; Zhang et al. 2023).

Carbon percentage

The carbon percentage was calculated based on volatile value and ash value using Eq. 1 (Piponiot et al. 2016; Hilmi et al. 2017):

$$\text{Carbon percentage (\%)} = 100\% - (A+B) \qquad [1]$$

Where,

A is volatile value, (%) = $\frac{(a1-a2)}{a2} x\ 100$

B is ash value, (%) = $\frac{b1}{b2} x\ 100$

a_1 is the initial sample weight, gram

a_2 is the sample weight after heating, gram

b_1 is residual ash, gram

b_2 is the sample weight, gram

Caloric value

Caloric value of mangrove wood was measured using calorimeter and calculated using Eq. 2 (SNI 01-6235, 2000; SNI 06-3730, 1995; SNI 8021, 2020):

$$\text{Caloric value (Cal/g)} = \frac{\Delta Tw - I1 - I2 - I3}{W1} \qquad [2]$$

Where,

ΔT is the temperature rise using a thermometer

w is 2426 cal/°C

I1 is mL Na_2CO_3 used for titration

I2 is 13.7x1.02xsample weight

I3 is 2.3xlength of burnt fuse wire

m is the sample weight, gram

Wood density

Wood density of mangrove wood (gram per centimeter cubic (g/cm^3)) was also calculated using Eq. 3 (SNI 01-6235, 2000; SNI 06-3730, 1995; SNI 8021, 2020):

$$\text{Wood density} = \frac{\text{the sampe weight (gram)}}{\text{volume sample } (cm^3)} \qquad [3]$$

Fuels fumes

Fumes are gas formed from incomplete combustion reactions because burning firewood can produce toxic gases such as CO as a result of a negative oxygen imbalance. In this study, fumes is measured through the potential amount of carbon monoxide (CO) and carbon dioxide (CO_2) (Amiruddin and Saismana 2020; Tjan et al.

2021). Smoke analysis was conducted through oxygen balance analysis at a laboratory scale (SNI 01-6235, 2000; SNI 06-3730, 1995; SNI 8021, 2020).

Data analysis

Classification of coal energy

The classification of coal energy used two systems, namely American Society for Testing and Materials (ASTM) and Indonesian National Standard (SNI). The ASTM classified coal energy into four categories: a) Low calorific coal is a type of coal with the lowest rank, soft-hard, easy to press, contains high water content (10-70%), shows a woody structure, calorific value <5100 calories per gram (Cal/g) in air-dried basis (AD); b) Medium calorific coal is a type of coal with a higher rank, harder in nature, easy to squeeze-cannot be squeezed, relatively lower water content, generally the wood structure is still visible, calorific value is 5100-6100 Cal/g (AD); c) High calorific coal is a type of coal with a higher rank, harder in nature, is not malleable, relatively lower water content, generally, the wood structure is not visible, and the calorific value is 6100-7100 Cal/g (AD); d) Very high calorific coal is the highest ranking type of coal, generally influenced by intrusions or other structures, very low moisture content, and calorific value >7100 Cal/g (AD). This grade was created to limit high calorific coal.

The SNI system was based on energy level according to SNI 13-6011-1999 where coal energy is grouped into two categories, namely a) Low energy coal (brown coal) is a type of coal with the lowest rank, easily brittle, soft, has a high water content (10-70%), consists of soft low energy coal (soft brown coal) and lignite coal that shows a woody structure with a calorific value <7000 calories per gram (in dry form-ASTM); b) High energy coal (hard coal) is all types of coal that rank higher than brown coal, compact, difficult to brittle, harder in nature, has a relatively low moisture content, generally the wood structure is no longer visible when handling (coal handling) is relatively resistant to physical damage, calorific value >7000 calories per gram (in dry form-ASTM).

Correlation analysis

The data was tabulated to produce the average value and standard deviation. Correlation analysis was conducted using trendline in Excel to investigate the relationship between carbon content and fuel fumes, and carbon content and caloric value (Nascimento et al. 2023; Sangsuk et al. 2023).

RESULTS AND DISCUSSION

The potential of biomass and carbon percentage of mangrove species

The mangrove ecosystem in Segara Anakan had a potential biomass between 341.90-493.93 tons/ha. *Rhizophora apiculata* had the biggest biomass with a potential of 170.45±16.14 tons/ha, *Rhizophora mucronata* 136.71±25.90 tons/ha, while *Xylocarpus granatum, Xylocarpus mollucensis* and *Aegiceras floridum* had the lowest biomass between 0.47-1.82 tons/ha (Figure 2). The potential biomass in Segara Anakan is lower potential than that in Rangsang Island and Merbau Island (Hilmi et al. 2017) with dominant species of *R. apiculata, Sonneratia alba, Lumnitzera racemosa* and *Metroxylon sagu* (Hilmi et al. 2017).

The percentage of carbon in mangrove species ranged between 50.8-63.20% (Table 2). *Bruguiera gymnorrhiza, Bruguiera sexangula, R. apiculata,* and *R. mucronata* were the mangrove species with high percentage of carbon. Species with the lowest carbon percentage was *N. fruticans* (50.80-51.84%). A study in Indragiri Hilir and Meranti Island found that species with the highest of carbon percentage were *R. apiculata, R. mucronata, B. gymnorrhiza and Aegiceras corniculatum* with 51.10-55.55%, while the lowest were *N. fruticans, M. sagu, Terminalia catappa,* and *Heritiera littoralis* with carbon percentage between 43.5-49.9% (Hilmi et al. 2017).

The potential of energy resource from the mangrove ecosystem is influenced by potential stand-level growth, tree diameter (Obeyed et al. 2020) and rate of tree growth as a response to climate change, environmental factors (such as salinity, soil, and sea tide), and climate change (Boongaling and Azcuna 2022). These factors have an impact on mangrove diversity, above-ground biomass, and below-ground biomass (Ahmed et al. 2021, 2023). The potential of biomass correlates with the potential of carbon storage both in stem, leaves, and roots (Adame et al. 2017) and mangrove are productive forest which has a large capacity of carbon sequestration (Adame et al. 2017). Potential carbon sequestration of mangroves is estimated up to 1.71±0.17 megagram carbon per hectare per year (MgC/ha/y) (Kandasamy et al. 2021). Mangrove has a higher carbon per-unit area than terrestrial forests because mangroves have an ecosystem that is highly productive and stores large carbon (Kandasamy et al. 2021). Such figures suggest the potential of mangroves as an energy alternative to reduce coal energy utilization.

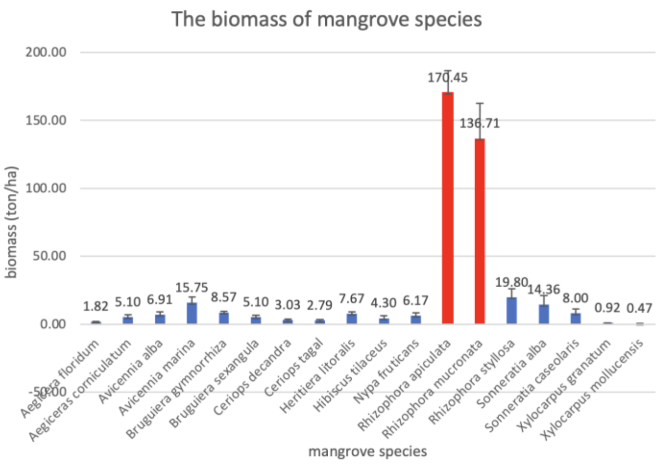

Figure 2. The potential biomass of mangrove ecosystem (ton/ha) in Segara Anakan, Cilacap District, Central Java, Indonesia

Table 2. The carbon percentage of mangrove species in Segara Anakan, Cilacap District, Central Java, Indonesia

Mangrove species	Carbon potential			
	Total moisture (%)	Ash content (%)	Volatile matter (%)	Carbon percentage (%)
Aegiceras floridum	3.70-3.80	7.67-7.81	28.67-28.81	59.58-59.96
Aegiceras corniculatum	3.40-3.52	7.81-8.91	27.33-29.15	58.42-61.46
Avicennia alba	3.91-4.01	10.25-10.40	26.83-28.20	57.39-59.01
Avicennia marina	3.60-3.75	8.43-9.77	27.19-27.70	58.78-60.78
Bruguiera gymnorrhiza	3.21-3.56	7.25-8.62	27.20-29.08	58.74-62.34
Bruguiera sexangula	3.63-3.66	7.55-7.56	27.74-28.90	59.88-61.08
Ceriops decandra	3.59-3.77	9.31-10.40	29.20-31.28	54.73-57.72
Ceriops tagal	3.11-4.33	6.26-9.44	28.70-32.27	56.32-60.71
Heritiera littoralis	3.87-4.09	7.66-8.25	29.33-29.76	58.49-58.55
Hibiscus tilaceus	3.46-4.10	6.33-7.08	27.78-29.30	59.52-61.43
Nypa fruticans	5.63-5.73	10.91-11.73	30.81-32.56	50.80-51.84
Rhizophora apiculata	4.11-4.24	7.47-9.03	25.78-27.16	58.13-62.64
Rhizophora mucronata	3.26-3.83	7.82-8.40	25.72-29.13	59.22-63.20
Rhizophora styllosa	4.30-4.68	8.50-9.94	26.65-31.90	59.78-60.55
Sonneratia alba	4.37-5.01	6.76-8.23	27.16-28.21	59.55-60.71
Sonneratia caseolaris	3.88-4.00	7.13-7.23	28.39-29.21	59.56-60.60
Xylocarpus granatum	3.90-4.20	7.87-9.59	26.50-28.60	58.91-60.43
Xylocarpus mollucensis	4.21-4.50	8.56-8.94	29.38-31.77	54.79-57.85

The energy properties of mangrove species

Mangrove wood charcoal is a potential alternative energy source to substitute non-renewable energy resources because the high-quality energy characteristics it has (Riungu et al. 2022; Samson et al. 2023; Li et al. 2024), and has the economic potential to support energy consumption (Siregar et al. 2024). For example, mangrove wood has a high bulk density, high carbon percentage, and potential carbon stock between 166.97-370.58 tonC/ha, medium-high calorific value (like brown coal and hard coal), and low Sulphur but high fumes (Larekeng et al. 2024).

The result of our study showed that the mangrove a had high carbon percentage (between 50.80-63.20%), high wood density (between 0.70-0.99), and moderate to high caloric value (between 6235-7230 Cal/g) as presented in Tables 2 and 3. For comparison, according Istomo and Tristiasti (2019), the caloric value of coal is between 5836-7192 Cal/g while another study by Afin and Kiono (2021) found that the potential caloric energy of coal is lower than 6100 Cal/g. Table 3 shows that *B. gymnorrhiza, Ceriops tagal, R. apiculata* and *R. mucronata* are the mangrove species with very high caloric energy. Based on the SNI system these species are classified as hard coal. Mangrove charcoal has the characteristic of brown coal-hard coal (high to very high caloric value). Mangrove species in this study had total Sulphur between negative values to 0.03%, fuel fumes of CO between 23.40-33.25 ppm and CO_2 between 512.3-640.4 ppm.

The consumption of wood charcoal in the European Union (EU) reaches one million tons per year. Rocchi et al. (2023) state that many developing countries use wood charcoal to supply the energy needs of consumption. Another rationale for the utilization of charcoal is that this energy resource can support industry and urban activities (Amiruddin and Saismana 2020). Based on data of Geology Department of the Ministry of Energy and Mineral Resources (ESDM), Indonesia has potential coal reserves of 186 billion tons which could be exhausted within 83 years. Most of the coal reserves are young coal with low quality with potential caloric content of only 6,100 Cal/g. For this reason, efforts need to be made to reduce the use of coal as an energy source by prospecting alternative energy resources including charcoal (Istomo and Tristiasti 2019; Afin and Kiono 2021).

One negative impact of the utilization of coal and charcoal as energy resources is the fumes, they produced which can harm the environment. However, the fumes produced by charcoal are generally lower than those from coal which might reduce the negative impacts to the environment (Amiruddin and Saismana 2020). Fumes are a toxic gas that is very dangerous because it is formed from incomplete combustion reactions (Tjan et al. 2021; Lai et al. 2023). Based on the result of this study, coal produced from mangrove species produced fumes between 20.40-34.29 ppm of CO and 530.7-640.5 ppm of CO_2. One of the gases formed due to incomplete combustion is carbon monoxide (CO) gas, which is very dangerous because it is flammable, odorless, tasteless, and colorless, so it is very difficult to detect (Tjan et al. 2021; Lai et al. 2023). Nonetheless, wood burning generally has carbon-emitting properties with non-toxic characteristics, cost-effectiveness, and high fire extinguishing ability (Lai et al. 2023).

The energy potential of mangrove species

The potential of mangrove species to be developed as alternative energy is shown in Table 4. The data shows that the mangrove species had fuel fumes between 405,270.0-119,508,062.0 ppm/ha, caloric value between 5,280,445,945-1,349,013,721,182 Cal/g/ha, and carbon potential between 0.17-116.88 ton/ha. The result of our study suggests that *R. apiculata, R. mucronata, B. gymnorrhiza,* and *C. tagal* have the greatest potential to be developed as energy alternative to substitute coal energy.

Table 3. Energy properties of mangrove species in Segara Anakan, Cilacap District, Central Java, Indonesia

Mangrove species	Percentage of charcoal (%)	Wood density (g/cm^3)	Fuel fumes (ppm)		Total Sulphur (%)	Self-heating	Caloric energy value (cal/g)	Energy classification	
			CO	CO_2				SNI	SNI
Aegiceras floridum	17.20-19.73	0.76-0.79	25.21-26.31	580.5-588.4	Negative	Negative	6567-6735	Brown coal	High caloric energy
Aegiceras corniculatum	18.20-20.39	0.72-0.77	26.30-27.82	613.5-628.0	Negative	Negative	6753-6835	Brown coal	High caloric
Avicennia alba	16.20-17.15	0.76-0.82	28.01-30.11	588.1-590.5	0.01-0.02	Negative	6680-6745	Brown coal	High caloric
Avicennia marina	18.67-19.21	0.80-0.84	30.10-33.78	574.3-588.5	0.01-0.02	Negative	6635-6830	Brown coal	High caloric
Bruguiera gymnorrhiza	20.21-23.21	0.72-0.81	28.33-30.21	578.9-603.2	Negative	Negative	6898-7109	Brown-Hard coal	High-very high caloric
Bruguiera sexangula	20.12-22.91	0.77-0.81	27.91-29.22	563.2-580.1	Negative	Negative	6882-6982	Brown coal	High caloric
Ceriops decandra	19.44-19.51	0.74-0.76	28.63-29.33	547.7-567.0	Negative	Negative	6793-6840	Brown coal	High caloric
Ceriops tagal	21.19-23.05	0.77-0.87	20.40-22.90	605.7-620.7	0.01-0.02	Negative	6829-7215	Brown coal	High-very high caloric
Heritiera littoralis	19.86-20.20	0.70-0.77	31.29-33.25	590.5-607.8	Negative	Negative	69030- 6978	Brown-Hard coal	High caloric
Hibiscus tiliaceus	20.88-22.09	0.80-0.83	23.40-25.69	512.3-589.3	0.02-0.03	Negative	6554-6580	Brown coal	High caloric
Nypa fruticans	17.26-17.40	0.73-0.78	33.20-34.03	632.8-640.4	0.02-0.03	Negative	6380-6455	Brown coal	High caloric
Rhizophora apiculata	20.59-23.60	0.85-0.99	29.03- 34.29	622.7-640.5	0.02-0.03	Negative	6852-7230	Brown-Hard coal	High-very high caloric
Rhizophora mucronata	18.90-21.82	0.94-0.99	28.70-31.73	620.1-633.2	0.02-0.04	Negative	6775-7030	Brown-Hard coal	High caloric
Rhizophora styllosa	19.60-20.25	0.83-0.87	23.56-25.35	617.4-625.7	0.02-0.03	Negative	6780-6929	Brown coal	High caloric
Sonneratia alba	18.89-20.83	0.72-0.82	25.61-26.17	550.8-560.7	0.01-0.02	Negative	6655-6770	Brown coal	High caloric
Sonneratia caseolaris	19.01-21.27	0.70-0.76	26.33-28.19	530.7-556.7	0.01-0.03	Negative	6652-6829	Brown coal	High caloric
Xylocarpus granatum	18.92-19.65	0.70-0.73	27.11-29.08	533.1-567.4	Negative	Negative	6909-6946	Brown coal	High caloric
Xylocarpus mollucensis	24.05-24.78	0.72-0.80	23.40-26.35	550.3-602.4	Negative	Negative	6235-6670	Brown coal	High caloric

Table 4. Energy potential of mangrove species in Segara Anakan, Cilacap District, Central Java, Indonesia

Mangrove species	Potency fuel (ppm/ha)		Caloric value (Cal/g/ha)		Carbon (ton/ha)	
	min	max	min	max	main	max
Aegicera floridum	1,029,829.09	1,097,932.01	11,650,107,935	12,567,253,671	1.06	1.12
Aegiceras corniculatum	1,966,724.24	4,391,136.46	21,648,392,508	47,792,066,444	1.87	4.30
Avicennia alba	2,756,827.38	5,390,270.18	31,313,733,843	61,570,486,651	2.69	5.39
Avicennia marina	6,585,376.64	11,792,781.71	76,082,141,766	136,864,399,474	6.74	12.18
Bruguiera gymnorrhiza	4,538,562.66	5,608,768.56	54,080,161,077	66,102,015,451	4.61	5.80
Bruguiera sexangula	2,097,568.68	3,759,603.23	25,631,157,053	45,250,042,660	2.23	3.96
Ceriops decandra	1,332,504.25	2,055,426.61	16,526,750,725	24,795,622,553	1.33	2.09
Ceriops tagal	1,430,680.86	1,993,670.51	16,130,294,843	23,174,372,031	1.33	1.95
Heritiera littoralis	3,641,949.89	5,578,649.96	43,037,301,107	64,524,365,270	3.61	5.37
Hibiscus tilaceus	1,179,580.76	3,705,801.54	15,090,713,047	41,378,201,445	1.37	3.86
Nypa fruticans	2,449,310.79	5,429,892.51	24,694,378,677	54,731,349,403	1.97	4.40
Rhizophora apiculata	96,089,100.45	119,508,062.02	1,057,335,018,897	1,349,013,721,182	91.38	116.88
Rhizophora mucronata	68,715,938.05	102,967,185.33	750,766,780,048	1,143,176,425,880	66.24	102.77
Rhizophora styllosa	8,393,380.33	16,265,246.49	92,172,203,830	180,121,292,841	8.10	15.74
Sonneratia alba	4,131,518.08	11,896,405.21	49,918,759,672	143,639,492,160	4.47	13.09
Sonneratia caseolaris	2,528,844.77	6,252,606.66	31,697,522,896	76,700,289,004	2.84	6.81
Xylocarpus granatum	405,270.05	610,401.02	5,280,445,945	7,540,184,577	0.45	0.66
Xylocarpus mollucensis	174,135.01	378,044.25	1,972,981,628	4,185,848,491	0.17	0.36

The utilization of mangrove wood as an alternative energy to substitute non-renewable energy can reduce the utilization of coal to minimize the negative impacts of mining on environment and air pollution (Nascimento et al. 2023; Thu et al. 2023; Zhang et al. 2023). Since mangrove charcoal has similar characteristics to coal energy (Ahmad et al. 2023; Lai et al. 2023), the utilization of mangroves can reduce the consumption of coal energy as happening in China, Europe, and America (Rocchi et al. 2023; Zhang et al. 2023)· The utilization of mangrove wood to support charcoal demmand and trade requires marketing strategies to support global energy needs, because charcoal is a solid residue made primarily of wood, which is renewable resource (Oppong et al. 2024).

Nevertheless, the utilization of charcoal might drive forest degradation (Kantharajan et al. 2018; Lapolo et al. 2018; Lulandala et al. 2023). The production and utilization of charcoal must be done sustainably with low negative impact on the environment to achieve forest management sustainability (Rocchi et al. 2023). There is difference of the utilization of charcoal, including those from mangrove, between developing and developed countries. In developing countries, charcoal is used for households and small industries while in developed countries, charcoal is generally used during leisure time. More than 90% of Africans use either firewood or charcoal to support the energy sector in cooking and heating purposes (Oppong et al. 2024). Charcoal consumption from urban activities uses tree species with high calorific value and suitable dimensions (Wolswijk et al. 2020; Lai et al. 2023).

The potential of mangrove ecosystem in Segara Anakan for alternative energy resource

Table 5 and Figure 3 show the potential of mangrove ecosystem in Segara Anakan if utilized for alternative energy resources through the production and utilization of mangrove charcoal. The data shows that the alternative energy potential was between 883.155,70 and 21.858.650,00 Cal/g/ha assuming that the mangrove density between 533 and 3300 trees/ha. The potential of alternative energy in mangrove ecosystems provides high benefits to support the substitution of energy utilization. Using the variable of caloric value suggests the high potential of mangrove ecosystem to substitute coal energy because mangrove vegetations have high wood density, high carbon percentage, high cellulose, high hemicellulose, and high extractive matter (Hilmi et al. 2017, 2019; Azman et al. 2021; Chen et al. 2021).

Mangrove density significantly affected the potential utilization of mangrove ecosystem to be developed as alternative energy to substitute coal energy as indicated by mangrove ecosystems in Ujung Alang, Batu Macan, Sapuregel and Donan which have higher density compared to the other stations. Figure 3 shows that mangrove ecosystem in East Segara Anakan has higher potential compared to West Segara Anakan since the mangrove density is higher in East Segara Anakan (Hilmi et al. 2017, 2019a; Azman et al. 2021; Chen et al. 2021).

The relationship between energy properties

The relationship between energy properties is presented in Figure 4. Figure 4.A show the relationship between carbon percentage and fuel fumes while Figure 4.B shows the relationship between carbon percentage and caloric value (cal/g). There is weak relationship between carbon percentage and fuel fumes (Figure 4.A) while Figure 4.B shows that carbon percentage has positive linear relationship with caloric value. This finding suggests that increasing carbon percentage will increase the caloric value of mangrove charcoal. This is because carbon percentage is influenced by cellulose, hemicellulose, and extractive compounds (Hilmi et al. 2017, 2019). The higher cellulose and hemicellulose will increase the potential caloric value of charcoal (Hilmi et al. 2019; Cooray et al. 2021).

Table 5. The potential of mangrove ecosystem in Segara Anakan to be developed as alternative energy resource

Location	Mangrove density (trees/ha)		Potential as alternative energy measured as caloric value (Cal/g/ha)		
	Average	St.dev	Average	St.dev	Grade /class
Batu Macan	2399	1328	15,892,762	1,380,882	class 3
Dermaga Ujung Alang	3300	917	21,858,650	953,571	class 4
Inti Ujung Gagak	533	235	3,530,503	244,825	class 1
Jongor	1233	118.09	8,167,187	122,780	class 2
Karang Braja	1400	305.02	9,271,181	317,138	class 2
Kayu Mati	133	47.14	883,156	49,017	class 1
Kebuyutan	600	57.74	3,974,366	60,030	class 1
Klaces	400	120.33	2,647,347	125,108	class 1
Langkap	2133	785.52	14,130,889	816,737	class 3
Lorogan	833	77.17	5,515,467	80,242	class 1
Majingklak	400	90.14	2,647,347	93,727	class 1
Estuary of Ciawitali	500	145.29	3,311,917	151,068	class 1
Estuary of Bagian	366	95.71	2,422,137	99,518	class 1
Estuary of Legok	600	329.75	3,972,114	342,851	class 1
Estuary of Masigitsela	2000	468.94	13,249,919	487,578	class 3
Pertigaan Ujung Alang	333	50.92	2,207,989	52,942	class 1
Ujung Alang	500	212.13	3,311,917	220,563	class 1
Ujung Gagak	767	23.57	5,078,294	24,505	class 1
Donan	2617	549.30	17,332,364	571,137	class 4
Donan Kalipanas	1733	541.94	11,481,311	563,484	class 3
Donan Pertamina	2633	639.18	17,442,761	664,588	class 4
Kembang Kuning 1	1489	311.86	9,862,152	324,252	class 2
Kembang Kuning 2	2467	487.65	16,338,789	507,035	class 3
Estuary of East Pelawangan 1	1700	321.46	11,260,517	334,232	class 2
Estuary of East Pelawangan 2	1967	717.18	13,026,872	745,688	class 3
Sapuregel 1	1780	206.85	11,790,423	215,071	class 3
Sapuregel 2	2588	472.23	17,139,169	491,002	class 4
Sleko	1633	346.73	10,818,928	360,512	class 2
Tritih	1850	575.10	12,253,356	597,954	class 3

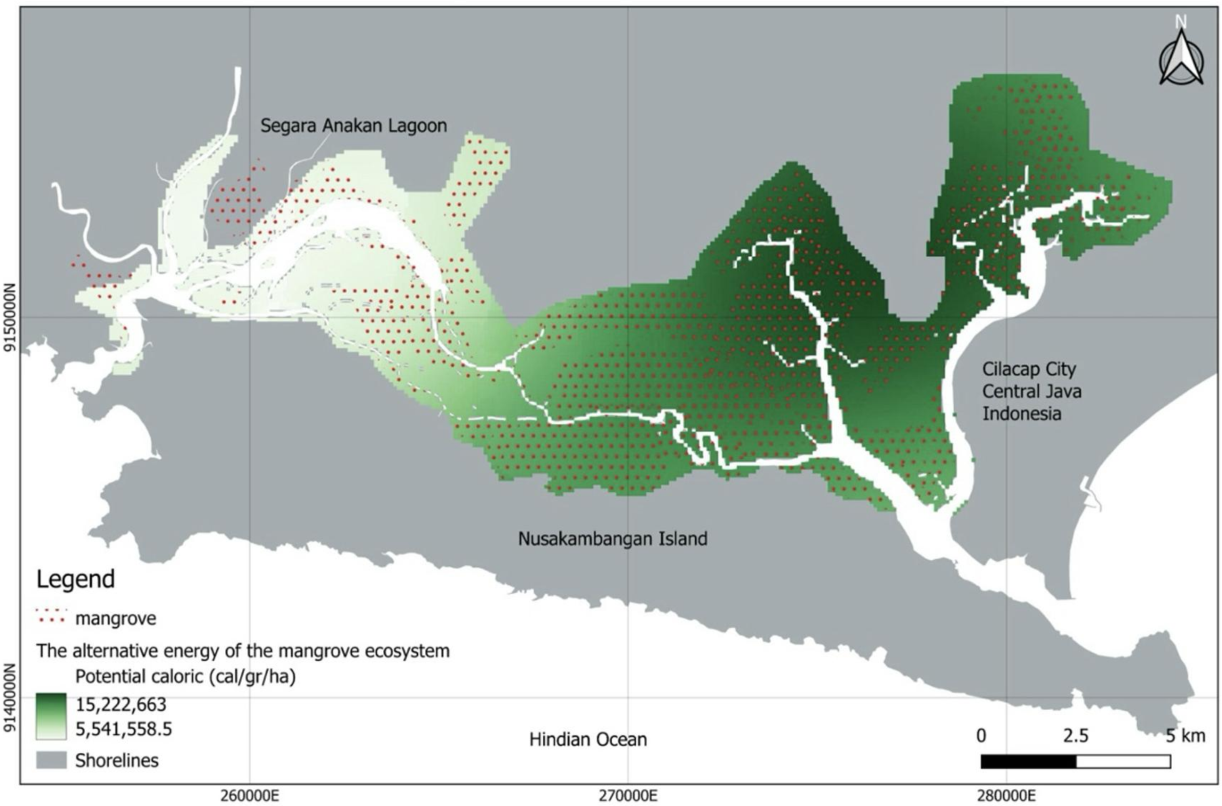

Figure 3. Spatial distribution of alternative energy potential in mangrove ecosystem in Segara Anakan, Cilacap District, Central Java, Indonesia

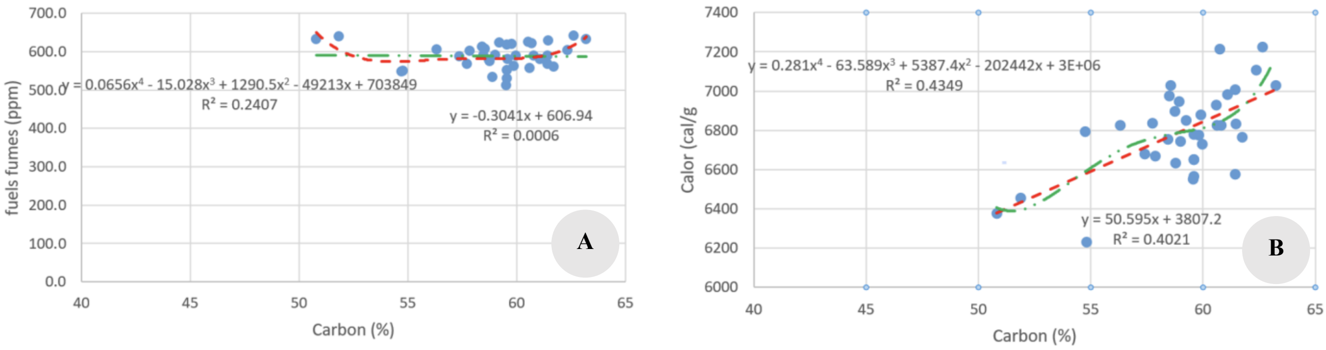

Figure 4. The relationship between carbon percentage and: A. Fuel fumes; B. Caloric value

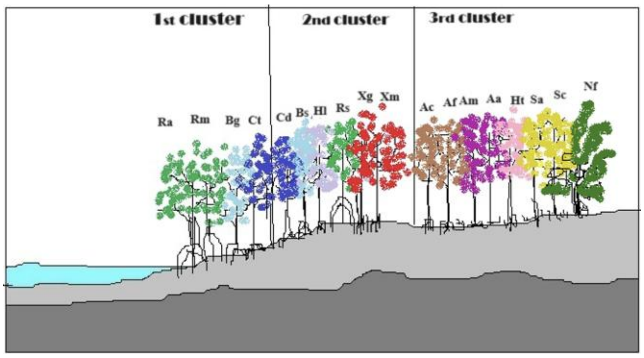

Figure 5. Clustering of mangrove landscape in Segara Anakan, Cilacap District, Central Java, Indonesia, based on potential energy. Notes: Aa: *Avicennia alba*; Am: *Avicennia marina*; Ac: *Aegiceras corniculatum*; Af: *Aegiceras floridum*; Bg: *Bruguiera gymnorrhiza*; Bs: *Bruguiera sexangula*; Cd: *Ceriops decandra*; Ct: *Ceriops tagal*; Hl: *Heritiera littoralis*; Ht: *Hibiscus tiliaceus*; Nf: *Nypa fruticans*; Ra: *Rhizophora apiculata*; Rm: *Rhizophora mucronata*; Rs: *Rhizophora styllosa*; Sa: *Sonneratia alba*; Sc: *Sonneratia caseolaris*; Xg: *Xylocarpus granatum*; Xm: *Xylocarpus mollucensis*

Based on the results above, mangrove landscape in Segara Anakan can be clustered based on the potential of mangrove species for alternative energy resources using the parameters of caloric value, bulk density, and fixed carbon percentage (Figure 5). The first cluster consists of *R. apiculata, R. mucronata, C. tagal,* and *B. gymnorrhiza* which produce the highest energy potential. The second cluster consists of *B. sexangula, Ceriops decandra, H. littoralis, Rhizophora styllosa, X. granatum* and *X. mollucensis*. The last cluster consists of *A. floridum, A. corniculatum, Avicennia alba, Avicennia marina, Hibiscus tiliaceus, S. alba* and *Sonneratia caseolaris.* Nevertheless, the potential of mangrove landscape for alternative energy resource is determined by mangrove regeneration (Das et al. 2019), mangrove biomass (Jakovac et al. 2020; Swangjang and Panishkan 2021), and mangrove ability to absorb, sequestrate and store carbon (Hilmi et al. 2019; Azman et al. 2021; Chen et al. 2021).

In conclusion, mangroves have the great potential to be developed as renewable energy sources as an alternative for non-renewable resources such as coal. This is because mangrove species have high carbon percentage (50.80-63.20%), high wood density (0.70-0.99), and moderate to high caloric value (6235-7230 cal/g) with species having with the highest values are *B. gymnorrhiza, B. sexangula, R. apiculata,* and *R. mucronata*. Compared with coal, mangrove charcoal is classified as brown coal-hard coal (high to very high caloric value). Mangroves in Segara Anakan have fuel fumes between 405,270.0-119,508,062.0 ppm/ha, caloric value between 5,280,445,945-1,349,013,721,182 Cal/g/ha, and carbon storage of 0.17-116.88 ton/ha. This study revealed that *R. apiculata, R. mucronata, B. gymnorrhiza,* and *C. tagal* are the mangrove species with the highest potential to be developed as alternative energy to substitute coal. Such species are recommended for mangrove rehabilitation in Indonesia if aiming to produce energy resources.

ACKNOWLEDGEMENTS

The authors gratitude and appreciation go to Dean of the Faculty of Fisheries and Marine Sciences, Universitas Jenderal Soedirman, the Leader of LPPM Universitas Jenderal Soedirman, Kemendiktas DIKTI, Indonesia who has supported the Grand Fundamental Research DIKTI with master contract number of 054/E5/PG.02.00.PL/2024 and derivative contract number [20.10/UN23.35.5/PT.01.00/VI/2024]. The authors also thank to the scientific partners who support the present study.

REFERENCES

Adame MF, Cherian S, Reef R, Stewart-koster B. 2017. Mangrove root biomass and the uncertainty of belowground carbon estimations. For Ecol Manag 403: 52-60. DOI: 10.1016/j.foreco.2017.08.016.

Afin AP, Kiono BFT. 2021. Potensi energi batubara serta pemanfaatan dan teknologinya di Indonesia tahun 2020-2050: Gasifikasi batubara. Jurnal Energi Baru Terbarukan 2: 144-122. DOI: 10.14710/jebt.2021.11429. [Indonesian]

Ahmad N, Suryani F, Royani I, Lesbani A. 2023. Results in chemistry charcoal activated as template Mg/Al layered double hydroxide for selective adsorption of direct yellow on anionic dyes. Results Chem 5: 100766. DOI: 10.1016/j.rechem.2023.100766.

Ahmed S, Kamruzzaman M, Azad MS, Khan MNI. 2021. Fine root biomass and its contribution to the mangrove communities in three saline zones of Sundarbans, Bangladesh. Rhizosphere 17: 100294. DOI: 10.1016/j.rhisph.2020.100294.

Ahmed S, Kumar S, Friess DA, Sullibie C, Naabeh S, Pretzsch H, Jacobs M. 2023. Mangrove tree growth is size-dependent across a large-scale salinity gradient. For Ecol Manag 537: 12095. DOI: 10.1016/j.foreco.2023.120954.

Ameen F, Moslem M, Hadi S, Al-Sabri AE. 2016. Biodegradation of diesel fuel hydrocarbons by mangrove fungi from Red Sea Coast of Saudi Arabia. Saudi J Biol Sci 23: 211-218. DOI: 10.1016/j.sjbs.2015.04.005.

Amiruddin MF, Saismana U. 2020. Analisis kegiatan produktivitas terhadap fuel ratio alat angkut dan alat gali muat pada PIT 2 di PT Pro Sarana Cipta. Jurnal Himasapta 5: 41-46. DOI: 10.20527/jhs.v5i2.2341. [Indonesian]

Ariyanto D, Pringgenies D. 2024. Carbon sequestration rate in sediment mangroves from natural and rehabilitated mangroves. Glob J Environ Sci Manag 10: 1951-1960. DOI: 10.22034/gjesm.2024.04.27.

Azman MS, Sharma S, Shaharudin MAM, Hamzah ML, Adibah SN, Zakaria RM, MacKenzie RA. 2021. Stand structure, biomass and dynamics of naturally regenerated and restored mangroves in Malaysia. For Ecol Manag 482: 118852. DOI: 10.1016/j.foreco.2020.118852.

Bogachov S, Kirizleyeva A, Mandroshchenko O, Shahoian S, Vlasenko Y. 2022. Economic policy of Eastern European countries in the field of energy in the context of global challenges. Glob J Environ Sci Manag 8: 1-16. DOI: 10.22034/gjesm.2022.01.01.

Boongaling C, Azcuna A. 2022. Now or later? Optimal timing of mangrove rehabilitation under climate change uncertainty. For Ecol Manag 503: 119739. DOI: 10.1016/j.foreco.2021.119739.

Chabi A, Lautenbach S, Orekan VOA, Kyei-Baffour N. 2016. Allometric models and aboveground biomass stocks of a West African Sudan Savannah watershed in Benin. Carbon Balance Manag 11: 16. DOI: 10.1186/s13021-016-0058-5.

Chen S, Chen B, Guangcheng C, Ji J, Yu W, Liao J, Ganlin C. 2021. Higher soil organic carbon sequestration potential at a rehabilitated mangrove comprised of *Aegiceras corniculatum* compared to *Kandelia obovata*. Sci Total Environ 752: 142279. DOI: 10.1016/j.scitotenv.2020.142279.

Cooray PLIGM, Kodikara ASK, Kumara MP, Jayasinghe UI, Madarasinghe SK, Dahdouh-Guebas F, Gorman D, Huxham M, Jayatissa LP. 2021. Climate and intertidal zonation drive variability in the carbon stocks of Sri Lankan mangrove forests. Geoderma 389: 114929. DOI: 10.1016/j.geoderma.2021.114929.

Dai Z, Trettin CC, Frolking S, Birdsey RA. 2018. Mangrove carbon assessment tool: Model development and sensitivity analysis. Estuar Coast Shelf Sci 208: 23-35. DOI: 10.1016/j.ecss.2018.04.035.

Das L, Patel R, Salvi H, Kamboj RD. 2019. Assessment of natural regeneration of mangrove with reference to edaphic factors and water in Southern Gulf of Kachchh, Gujarat, India. Heliyon 5: e02250. DOI: 10.1016/j.heliyon.2019.e02250.

Hartoko A, Chayaningrum S, Febrianti DA, Ariyanto D, Suryanti. 2015. Carbon biomass algorithms development for mangrove vegetation in Kemujan, Parang Island Karimunjawa National Park and Demak Coastal Area-Indonesia. Proc Environ Sci 23: 39-47. DOI: 10.1016/j.proenv.2015.01.007.

Hilmi E, Amron A, Sari LK, Cahyo TN, Siregar AS. 2021a. The mangrove landscape and zonation following soil properties and water inundation distribution in Segara Anakan Cilacap. Jurnal Manajemen Hutan Tropka 27: 152-164. DOI: 10.7226/jtfm.27.3.152.

Hilmi E, Pareng R, Vikaliana R, Kusmana C, Iskandar I, Sari LK, Setijanto. 2017. The carbon conservation of mangrove ecosystem applied REDD program. Reg Stud Mar Sci 16: 152-161. DOI: 10.1016/j.rsma.2017.08.005.

Hilmi E, Prayogo NA, Junaidi T, Mahdiana A, Fikriyya N. 2023. Adaptive pattern of mangrove species and the mangrove landscaping in the heavy metal polluted area of Eastern Segara Anakan Lagoon, Indonesia. Biodiversitas 24 (5): 2927-2937. DOI: 10.13057/biodiv/d240548.

Hilmi E, Sari LK, Cahyo TN, Kusmana C, Suhendang E. 2019. Carbon sequestration of mangrove eosystem in Segara Anakan Lagoon, Indonesia. Biotropia 26: 181-190. DOI: 10.11598/btb.2019.26.3.1099.

Hilmi E, Sari LK, Cahyo TN, Mahdiana A, Samudra SR. 2021b. The affinity of mangrove species using association and cluster index in North Coast of Jakarta and Segara Anakan of Cilacap, Indonesia. Biodiversitas 22 (7): 2907-2918. DOI: 10.13057/biodiv/d220743.

Istomo FP, Tristiasti A, 2019. Penetapan nilai kalori dalam batubara dengan kalorimeter Parr 6200. Jurnal Sains Natural 7 (2): 83. DOI: 10.31938/jsn.v7i2.257. [Indonesian]

Jakovac CC, Latawiec AE, Lacerda E, Leite LI, Korys KA, Iribarrem A, Malaguti GA, Turner RK, Luisetti T, Strassburg BNB. 2020. Costs and carbon benefits of mangrove conservation and restoration: A global analysis. Ecol Econ 176: 106758. DOI: 10.1016/j.ecolecon.2020.106758.

Kandasamy K, Rajendran N, Balakrishnan B, Thiruganasambandam R, Narayanasamy R. 2021. Carbon sequestration and storage in planted mangrove stands of *Avicennia marina*. Reg Stud Mar Sci 43: 101701. DOI: 10.1016/j.rsma.2021.101701.

Kantharajan G, Pandey PK, Krishnan P, Ragavan P, Jeevamani JJJ, Purvaja R, Ramesh R. 2018. Vegetative structure and species composition of mangroves along the Mumbai coast, Maharashtra, India. Reg Stud Mar Sci 19: 1-8. DOI: 10.1016/j.rsma.2018.02.011.

Lai Y, Liu X, Fisk C, Davies M, Wang Y, Yang J, Cotton L, Zhang Y, Willmott J. 2023. Combustion inhibition of biomass charcoal using slaked lime and dolime slurries. Fire Saf J 140: 103841. DOI: 10.1016/j.firesaf.2023.103841.

Lapolo N, Utina R, Baderan DWK. 2018. Diversity and density of crabs in degraded mangrove area at Tanjung Panjang Nature Reserve in Gorontalo, Indonesia. Biodiversitas 19 (3): 1154-1159. DOI: 10.13057/biodiv/d190351.

Larekeng SH, Nursaputra M, Mappiasse MF, Ishak S, Basyuni M, Sumarga E, Arifanti VB, Aznawi AA, Rahmila YI, Yulianti M, Rahmania R, Mubaraq A, Salmo GS, Ali HM, Yeny I. 2024. Estimation of mangrove carbon stocks using unmanned aerial vehicle over coastal vegetation. Glob J Environ Sci Manag 10: 1133-1150. DOI: 10.22034/gjesm.2024.03.13.

Li S, Zhu Z, Deng W, Zhu Q, Xu Z, Peng B, Guo F, Zhang Y, Yang Z. 2024. Estimation of aboveground biomass of different vegetation types in mangrove forests based on UAV remote sensing. Sustain Horizons 11: 100100. DOI: 10.1016/j.horiz.2024.100100.

Lulandala L, Bargu A, Masao CA, Nyberg G, Ilstedt U. 2023. The size of clearings for charcoal production in miombo woodlands affects soil hydrological properties and soil organic carbon. For Ecol Manag 529: 120701. DOI: 10.1016/j.foreco.2022.120701.

Marrin P, Bhomia RK, Murdiyarso D. 2024. Assessment of coastal vulnerability to support mangrove restoration in the northern coast of Java, Indonesia. Reg Stud Mar Sci 70: 103383. DOI: 10.1016/j.rsma.2024.103383.

Nascimento MN, Beltran J, Bressers C, Van DJ, Vermeulen J, Ron SD, Bruijn A, Raczka MF, Maezumi SY, Gosling WD, Bush MB, Mcmichael CNH. 2023. Charcoal abundance measurements are affected by freeze-drying. Palaeogeogr Palaeoclimatol Palaeoecol 629: 111790. DOI: 10.1016/j.palaeo.2023.111790.

Obeyed MH, Akrawee ZM, Mustafa YT. 2020. Estimating aboveground biomass and carbon sequestration for natural stands of *Quercus aegilops*. in Duhok Province. Iraqi J Agric Sci 51: 366-375. DOI: 10.36103/ijas.v51i1.936.

Oppong N, Addo S, Dickson S, Osei-gyabaah P, Nakuja T, Afotey S. 2024. Determinants of charcoal production and marketing in the Mankranso Forest District in the Ashanti region of Ghana. Heliyon 10: e23800. DOI: 10.1016/j.heliyon.2023.e23800.

Owuor MA, Mulwa R, Otieno P, Icely J, Newton A. 2019. Valuing mangrove biodiversity and ecosystem services: A deliberative choice experiment in Mida Creek, Kenya. Ecosyst Serv 40: 101040. DOI: 10.1016/j.ecoser.2019.101040.

Piponiot C, Cabon A, Descroix L, Dourdain A, Mazzei L, Ouliac B, Rutishauser E, Sist P, Hérault B. 2016. A methodological framework to assess the carbon balance of tropical managed forests. Carbon Balance Manag 11: 15. DOI: 10.1186/s13021-016-0056-7.

Qaro SAM, Akrawee ZM. 2020. Assessment of carbon storage and sequestration by using I-Tree program for Atrush Forest/North of Iraq. Iraqi J Agric Sci 51: 75-85. DOI: 10.36103/IJAS.V51ISPECIAL.884.

Ray R, Ganguly D, Chowdhury C, Dey M, Das S, Dutta MK, Mandal SK, Majumder N, De TK, Mukhopadhyay SK, Jana TK. 2011. Carbon sequestration and annual increase of carbon stock in a mangrove forest. Atmos Environ 45: 5016-5024. DOI: 10.1016/j.atmosenv.2011.04.074.

Riungu PM, Nyaga JM, Githaiga MN, Kairo JG. 2022. Value chain and sustainability of mangrove wood harvesting in Lamu, Kenya. Trees For People 9: 100322. DOI: 10.1016/j.tfp.2022.100322.

Rocchi L, Campioni R, Brunori A, Mariano E. 2023. Forest policy and economics environmental certification of woody charcoal: A choice experiments application. For Policy Econ 154: 103042. DOI: 10.1016/j.forpol.2023.103042.

Samson DO, Shukri A, Hashikin NAA, Zuber SH, Buba AAD, Aziz AMZ, Hashim R, Yusof MF, Gemanam SJ, Samson PA. 2023. Performance of natural product-based materials as adhesives in the fabrication of mangrove wood composites. Heliyon 9: e13032. DOI: 10.1016/j.heliyon.2023.e13032.

Sangsuk S, Buathong C, Suebsiri S. 2023. Modified Iwate kiln for production of good quality charcoal and high volume of wood vinegar. Fuel Commun 17: 100095. DOI: 10.1016/j.jfueco.2023.100095.

Santosa I, Hilmi E, Susanto H. 2021. Farming handling with pro conservation: Lesson learned from farmers at marginal land in the District of Karangkobar, Banjarnegara Regency, Central Java. Intl J Soc Sci Perspect 8: 1-7. DOI: 10.33094/7.2017.2021.81.1.7.

Selvaraj JJ, Gallego PBE. 2023. Estimating mangrove aboveground biomass in the Colombian Pacific coast: A multisensor and machine learning approach. Heliyon 9: e20745. DOI: 10.1016/j.heliyon.2023.e20745.

Siregar ES, Sentosa SU, Satrianto A. 2024. An analysis on the economic development and deforestation. Glob J Environ Sci Manag 10: 355-368. DOI: 10.22034/gjesm.2024.01.22.

Sitoe AA, Mandlate LJC, Guedes BS. 2014. Biomass and carbon stocks of Sofala Bay mangrove forests. Forests 5: 1967-1981. DOI: 10.3390/f5081967.

SNI 01-6235. 2000. Briket Arang Kayu. [Indonesian]

SNI 06-3730. 1995. Arang Aktif Teknis. [Indonesian]

SNI 8021. 2020. Pelet Kayu. [Indonesian]

Swangjang K, Panishkan K. 2021. Assessment of factors that influence carbon storage: An important ecosystem service provided by mangrove forests. Heliyon 7: e08620. DOI: 10.1016/j.heliyon.2021.e08620.

Thu T, Huynh H, Tongkhao K, Hengniran P, Vangnai K. 2023. Assessment of High-temperature refined charcoal to improve the safety of grilled meat through the reduction of carcinogenic PAHs. J Food Prot 86: 100179. DOI: 10.1016/j.jfp.2023.100179.

Tjan KS, Hartami PN, Purwiyono TT. 2021. Analisis pengaruh kelembapan lubang ledak terhadap fumes hasil peledakan tambang batubara. Indones Min Energy J 3 (1): 29-35. [Indonesian]

Valsan G, Kumar A, Anusree S, Tamrakar A, Khaleel R, Rangel-Buitrago N. 2024. Seasonal variation of microplastics in tropical mangrove waters of South-western India. Reg Stud Mar Sci 69: 103323. DOI: 10.1016/j.rsma.2023.103323.

Wolswijk G, Satyanarayana B, Dung LQ, Siau YF, Ali BAN, Saliu IS, Fisol BMA, Gonnelli C, Dahdouh-Guebas F, 2020. Distribution of mercury in sediments, plant and animal tissues in Matang Mangrove Forest Reserve, Malaysia. J Hazard Mater 387: 121665. DOI: 10.1016/j.jhazmat.2019.121665.

Zhang P, Gong F, Luo S, Si X, Xu L. 2023. Damage constitutive model of uniaxially compressed coal material considering energy dissipation. J Mater Res Technol 27: 920-931. DOI: 10.1016/j.jmrt.2023.09.281.