Analysis of spatial utilization control in addressing the impact of land cover changes on the amount of carbon stock in Banyuasin Regency

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Abstract. Forest and land fires, along with rapid regional development, have led to significant land cover changes in Banyuasin Regency. These changes influence carbon stock levels, necessitating spatial utilization control strategies to mitigate carbon emissions. This study aims to analyze spatial patterns of land cover change, estimate current carbon stocks, and formulate effective land use control strategies in response to carbon stock shifts. A mixed-method approach was applied, combining GIS-based quantitative analysis and carbon estimation with qualitative assessment using the Analytic Network Process (ANP). Results show that between 2013 and 2023, land cover changes followed a random spatial distribution pattern, with increased areas of plantation and plantation forest, and reduced areas of water bodies, grassland, and secondary dryland forest. Overall carbon stocks rose by 11% during this period, indicating a sequestration trend. The main contributors to sequestration were the expansion of plantations and secondary swamp forest, while rice fields and open land contributed most to emissions. Priority spatial strategies for emission areas include strict technical regulation, ecosystem preservation, and green space development. For sequestration areas, priorities include conversion bans, conservation, ecosystem restoration, and forest protection. Notably, both conditions share the common strategy of adaptive protection measures.

1 Introduction

Law No. 32 of 2009 provides a clear definition of climate change, namely, changes in weather conditions over a long period. One of the main reasons for climate change is the presence of Greenhouse Gases (GHG), which can cause global temperatures to rise [1]. Carbon Monoxide (CO) is one of the major Green House Gases (GHG) since the increasing presence of CO could highly contribute to the greenhouse effect. CO gas, through natural processes in the atmosphere, could be oxidized to carbon dioxide (CO2). Fortunately, it is possible to

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reduce CO2 with the help of vegetation. Vegetation utilizes CO2 for photosynthesis and produces oxygen (O2). Within this process, vegetation is also able to store the carbon and transform it into biomass, which is referred to as carbon [2].

Banyuasin Regency has diverse topographic conditions, making this region experience varying disaster responses to the impacts of climate change. One of the main causes is the increasing concentration of greenhouse gases, which contribute to rising global temperatures. Greenhouse gas (GHG) emissions in the atmosphere are mostly produced from the combustion of fossil fuels and various other human activities, including changes and conversion of land use [3].

According to the Regional Disaster Management Agency (BPBD), Banyuasin Regency has the 3rd largest administrative area in South Sumatra Province and is currently under the attention of BNPB due to forest and land fires (karhutla/kebakaran hutan dan lahan) and extreme drought triggered by El Nino in 2023. Forest and land fires in Banyuasin Regency have caused significant changes in land cover, in addition to the development that has occurred in South Banyuasin Regency, which has also resulted in land conversion. Changes in land cover result in the loss of forests that have a large capacity to store carbon. These changes in land cover can reduce the ability of the ecosystem to absorb and store carbon, which has the potential to increase carbon concentrations in the atmosphere. Land cover elements can contribute to efforts to reduce GHG emissions, so calculating the carbon stock of the land cover is very important to do. By knowing changes in land cover and the amount of carbon, it is hoped that it can provide valuable information as a basis for consideration for the government when carrying out development, which is expressed through spatial planning strategies, especially spatial utilization control strategies.

The main objective of this strategy is to ensure that the planning and implementation of development in an area are guided by the previously established spatial plan, thus avoiding uncontrolled spatial utilization, further optimizing land use by maintaining and restoring forest areas, protecting peatlands, and developing sustainable agricultural models that can store carbon. In this case, it is important to identify areas with high carbon stocks and designate them as areas that must be protected or managed with conservation principles. Spatial utilization control strategies are useful in anticipating and adapting to climate change. This is especially related to the fact that land use in an area now and in the future has a major influence on the vulnerability of an area to the impacts of climate change.

The strategic approach in controlling spatial utilization is expected to function as a valid tool to reduce the level of exposure and sensitivity to the impacts of extreme climate events. Therefore, this study needs to be conducted to formulate a spatial utilization control strategy that begins with calculating carbon stock estimates and analyzing land cover changes on carbon emissions. With the existence of a spatial utilization control strategy based on data on carbon stocks and the impacts of land cover changes, it is hoped that Banyuasin Regency can face the challenges of land cover changes in a more structured and effective manner, and contribute to global efforts to reduce carbon emissions

2 Methodology

2.1 Research approach

The approach used is a mixed approach that combines qualitative research with quantitative research. The mixed research strategy used is sequential/gradual (sequential mixed methods), a strategy that combines data from one method with another method. Assessing from the type of problems observed, the type of research is a case study and descriptive research. In this study, the phenomenon or case of land cover changes in the amount of carbon stock reserves

in Banyuasin Regency will be studied, starting by providing a description of the condition of land cover over a period of 10 years divided into 5 years to obtain the characteristics or patterns of land cover in Banyuasin Regency. Furthermore, handling will be formulated through a strategy for controlling the use of space utilization through the use of data sources from questionnaires and interviews. The location for this study is Banyuasin Regency, which consists of 21 Districts.

2.2 Data collection

Data collection was conducted through primary surveys and secondary surveys. Primary data were collected through questionnaires and in-depth interviews with stakeholders. The information from respondents was collected using the purposive sampling technique. Secondary data were collected through a literature review of academic journals, government reports, planning documents, and other publications relevant to the research topic.

2.3 Data analysis

Data analysis consists of quantitative data analysis and qualitative data analysis as follows:

2.3.1 Quantitative data analysis

2.3.1.1 GIS Information System

Land cover change analysis will use secondary data in the form of land cover maps processed by overlaying using the ArcGIS software land cover maps in the time span of 2013, 2018, and 2023 to obtain changes in land cover area. The stages of land cover change analysis are illustrated in the following diagram.

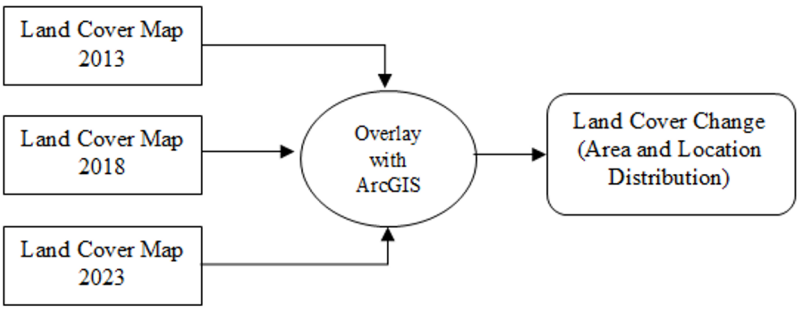

Fig. 1. Land cover change analysis (Author, 2025)

2.3.1.2 Mathematical Calculation

Mathematical calculations are used to answer the 2nd objective, namely calculating and analyzing the Carbon Stock in Banyuasin Regency. To calculate the carbon stock in this study, the following equation is used [5]:

GHG Emissions or Absorption = Δ *Land Use* * FE.....(1)

Information :

Δ Land Use: activity data shown by changes in the area of each type of land cover change from two time periods (hectares)

FE: emission factor for each type of land use change based on KLHK provisions, (ton CO2eq/ha).

GHG emissions/absorption: emission values from each land cover change from two time periods.

For the terms used as follows (ton CO2eq):

1. Emission value more than (>) 0 means emissions, namely the release of carbon into the air due to changes in land cover,
2. the emission value is equal to (=) 0, meaning no emission or no change in the emission value,
3. Emission values less than (<) 0 mean sequestration, namely the presence of carbon reserves formed due to changes in land cover.

As for the value of emission factors for each type of land use change are as follows:

Table 1. Carbon stock (emission factor) based on land cover type

No	Land Cover Class	Code	Carbon Stock Constant (TonC/Ha)
1.	Primary dry land forest	Hp / 2001	195.4
2.	Secondary/former developed dry land forest	Hs / 2002	169.7
3.	Primary Swamp Forest	Hrp / 2005	196
4.	Secondary Swamp Forest / Formerly Built Up	Hrs / 20051	155
5.	Primary Mangrove Forest	Hmp / 2004	170
6.	Secondary Mangrove Forest / Formerly Built	Hms / 20041	120
7.	Plantation Forest	Ht / 2006	64
8.	Plantation / Garden	Pk / 2010	63
9.	Shrubs	B / 2007	30
10.	Swamp scrub	Br / 20071	30
11.	Savanna / Grassland	S/3000	4.5
12.	Dry land farming	Pt / 20091	10
13.	Mixed shrubs / mixed gardens	Pc / 20092	30
14.	Rice field	Sw / 20093	2
15.	Pond	Tm / 20094	0
16.	Built up land	Pm / 2012	5
17.	Transmigration	Tr / 20122	10
18.	Open land	T / 2014	2.5
19.	Mining	Tb / 20141	0
20.	Body of water	A/5001	0
21.	Swamp	Rw / 50011	0
22.	Cloud	Aw / 2500	0
23.	Airport / Port	Bdr/Plb / 20121	0

Source: Kurniawan *et al.* 2023

Next, to calculate the change in carbon stocks in biomass caused by changes in land cover, it will be calculated using the stock difference approach (change in carbon stocks). Analysis of changes in carbon stocks is carried out by mathematical calculations through the following equation [6]:

$\Delta C = (Ct2 - Ct1)/(t2 - t1)$ ..... (2)

Information :

ΔC = annual carbon stock change in each carbon reservoir (tC/year)
Ct1 = carbon stock of each carbon reservoir at the beginning (tC)
Ct2 = carbon stock of each carbon reservoir at the end (tC)
t1 = initial year of carbon storage
t2 = end year of carbon storage

The calculation of carbon stock changes is measured using a backward looking scenario to measure Business as Usual (BAU) carbon stocks based on land use trends

2.3.2 Qualitative data analysis

In this study, qualitative data analysis was carried out to achieve the objective of spatial utilization control strategies based on climate change adaptation options for the amount of carbon stock, starting with creating a questionnaire containing strategic choices resulting from a comparison or synthesis of various related theories and then conducting an analysis, *Analytical Network Process*(ANP). In ANP, it begins with creating a network structure, then the next step is to create a questionnaire containing multiple choice questions to provide an assessment with a paired comparison between Criteria Against Alternatives, between Alternatives against Criteria, and between Objectives Against Criteria. This is done for each condition, namely emission conditions and sequestration conditions. Then a value is given in a paired comparison or Comparative Judgment where the preference scale is one for the lowest level (equal importance) to a scale of nine for the highest level (extreme importance).

The next stage determines the influence of each element on each criterion and priority weight, followed by an assessment given whether it is consistent or not, conducting an assessment of the influence and calculating the component value using the ANP model created previously. The alternative given the highest priority is the most appropriate. The questionnaire containing the recommended strategy choices resulting from the ANP analysis will be reconfirmed for the answers filled in the previous questionnaire through in-depth interviews with stakeholders or experts who are experienced in the fields of spatial planning, environment, and disasters in order to better explore the answers from respondents

3 Results and discussion

3.1 Spatial patterns of change land cover of Banyuasin regency in 2013, 2018 and 2023

During 2013 to 2018, the percentage change with the largest increase was in plantation land cover. In 2013, the area of plantation land cover in Banyuasin Regency was 106,132.33 Ha to 278,354.24 Ha in 2018, or an increase of 172,221.91 Ha. Next is the secondary mangrove forest 2013 from 18,783.17 Ha to 64,272.12 Ha in 2018, or an increase of 45,488.95 Ha. While for the changes that experienced a decrease in the area of land cover in the period 2013 to 2018, namely in the savanna/grassland land cover. In 2013, the area of savanna/grassland was 96,492.76 Ha to 6,679.34 Ha in 2018 or decrease of -89,813.42 Ha. Then, swamp shrubs with an area of 325,189.93 Ha in 2013 to 247,685.96 Ha in 2018 or a decrease of -77,503.96 Ha.

For changes in land cover from 2018 to 2023, the largest increase also occurred in plantation land cover with an area in 2018 of 278,354.24 Ha to 372,008.31 Ha in 2023 or an increase of 93,654.07 Ha. Meanwhile, the changes in land cover that experienced the largest decrease were in open land cover with an area in 2018 of 37,491.49 Ha to 4,982.13 Ha or a decrease of -32,509.36 Ha and shrubs with an area in 2018 of 31,032. 08 Ha to 8,892.21 Ha in 2023 or a decrease of -22,139.87 Ha. The results of processing the Banyuasin Regency Land Cover Map for 2013, 2018 and 2023 produced the following land cover area results:

Table 2. Land cover area based on map interpretation results for 2013, 2018 and 2023

No	Land Cover	Year 2013	Year 2018	Year 2023	Percentage Change 2013 – 2023 (%)	Information
1	Water Body	42,669.48	37,928.71	36,843.98	-15.81	Reduce
2	Primary mangrove forest	131,136.25	75,358.28	91,302.99	-43.63	Reduce
3	Secondary Mangrove Forest	18,783.17	64,272.12	44,680.43	57.96	Increase
4	Secondary Swamp Forest	62,587.70	39,459.50	32,695.63	-91.43	Reduce
5	Secondary Dry land Forest	685.43	0.02	0.00	-100.00	Reduce
6	Plantation Forest	604.05	28,547.72	30,502.02	98.02	Increase
7	Settlement	48,742.16	48,122.48	45,109.97	-8.05	Reduce
8	Plantation	106,132.33	278,354.24	372,008.31	71.47	Increase
9	Mining	1,782.39	1,140.17	1,067.25	-67.01	Reduce
10	Dry Land Farming	29,759.68	24,558.73	16,011.32	-85.87	Reduce
11	Mixed Shrub Dry Land Farming	105.107,03	99,987.35	98,053.93	-7.19	Reduce
12	Swamp	37,020.20	10,452.60	9,009.99	-310.88	Reduce
13	Savanna/ Grassland	96,492.76	6,679.34	0.00	-100.00	Reduce
14	Rice field	164,564.09	180,808.15	180,443.77	8.80	Increase
15	Shrubs	26,661.96	31,032.08	8,892.21	-199.84	Reduce
16	Swamp Bush	325,189.93	247,685.96	250,144.33	-30.00	Reduce
17	Pond	7,618.24	17,850.55	7,981.22	4.55	Increase
18	Open Land	24,192.65	37,491.49	4,982.13	-385.59	Reduce

Source: Analysis results (2025)

Based on the table above, it can be explained that during the period of 2013 and 2018 there were 7 (seven) types of land cover that increased, namely secondary mangrove forests, plantations, plantations, rice fields, bushes, open land and ponds. The remaining 12 (twelve) types of land cover experienced a reduction in area. For the increase that occurred in rice field land cover, this is because Banyuasin Regency is a food barn spread to 4 (four) in Indonesia and is the number 1 (one) the largest food barn in South Sumatra Province which continues to strive to increase food agricultural output, one of which is the addition of rice field area through optimizing idle land into productive land [4]. Meanwhile, from 2018 to 2023, there are 4 (four) types of land cover that have experienced additional areas, namely primary mangrove forests, plantation forests, plantations and swamp shrubs.

Overall, during the period 2013 to 2023, the plantation land cover continues to increase in area with an increase percentage of 71.47% and the plantation forest land cover increases by 98% from 2013. Meanwhile, the land cover of water bodies, savanna/grasslands and secondary dry land forests continues to decline. Specifically for the forest area which is the largest contributor of carbon reserves in 2023, the area decreased, namely in primary mangrove forests decreased by -39,833.26 Ha or 43.63% from 2013 and secondary swamp forests decreased by -36,990.15 Ha or 144.51% from 2013.

An overview of changes in land cover in Banyuasin Regency as a whole from 2013, 2018 and 2023 can be seen in the following figure:

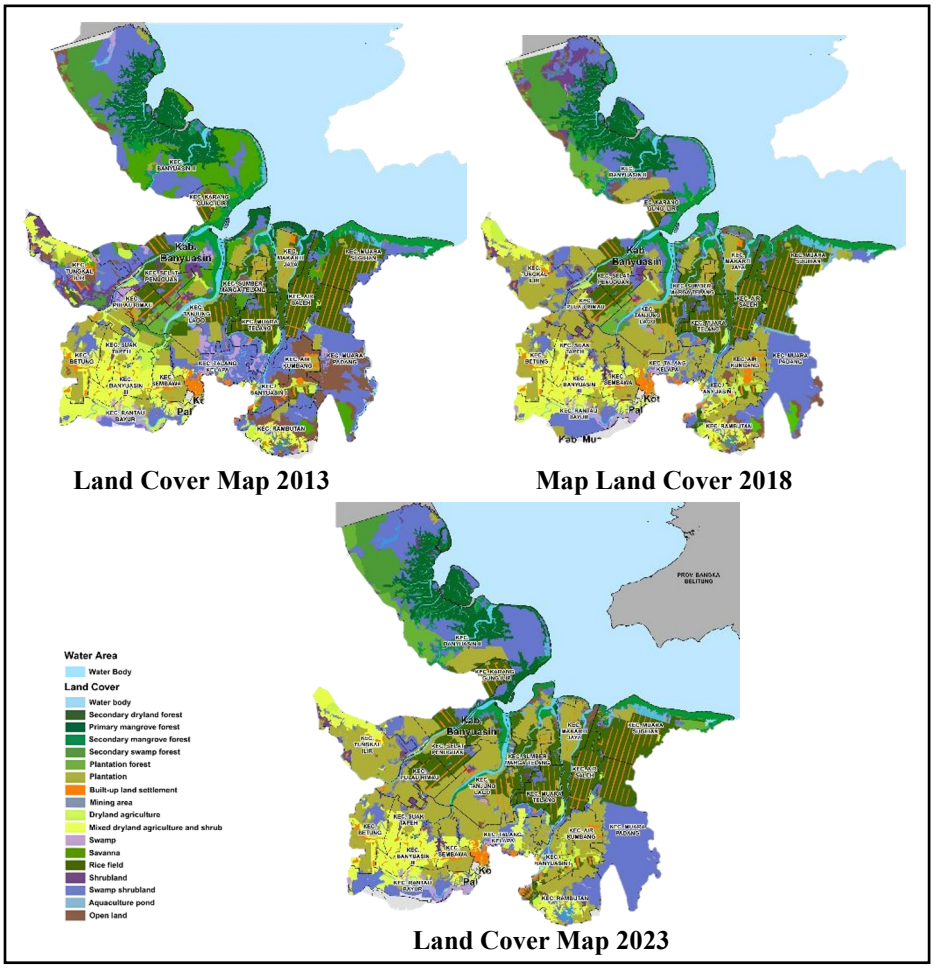

Fig. 2. Land cover map of Banyuasin regency in 2013, 2018 and 2023

For further clarity, the following will present changes in land cover types from one type of land cover to another type of land cover or those that do not experience changes, as can be seen in the following Table 3.

Spatial distribution patterns are generally divided into three, namely: a. Clustered, namely some points are concentrated close to each other, while there is a large area with a few points that appear to have an insignificant distance b. Dispersed, namely each point is spread with a relatively even distance and is not meaningfully close c. Random, namely points arise randomly without a certain pattern, and the position of one point is not related to other points [7]. When associated with this pattern, the spatial pattern shown from changes in land cover in Banyuasin Regency in the period 2013, 2018 and 2023 has formed a spatial pattern of land cover distribution randomly because the land cover that occurs experiences changes in area and location that are different for each time period. A detailed discussion of changes in the type of land cover will be used as a basis for calculating carbon stock estimates in the next section.

Table 3. Matrix of land cover type changes in Banyuasin regency 2013-2023 (ha)

LAND COVER		Year 2023																
		Water Body	Primary Mangrove Forest	Socondary Mangrove Forest	Primary Swamp Forest	Socondary Swamp Forest	Plantation Forest	Open Land	Plantation	Settlement	Mining	Dry Land Farming	Mixed Shrub Dry Land Farming	Swarp	Ricefield	Shrubs	Swamp Bush	Pond	Grand Total
Year 2013	Water Body	36140,17	51,65	2597,69	-	-	31,68	4,62	37,73	8,41	-	0,01	0,03	0,09	103,44	0,24	3683,52	10,22	42669,48
	Primary Mangrove Forest	408,4	85100,41	25966,93	-	0,001	0,51	3479,89	6185,2	9,09	-	89,51	-	-	4082,79	6,88	3773,93	2032,72	131136,25
	Socondary Mangrove Forest	199,75	5074,37	7449,42	-	52,02	1293,1	108,47	1263,09	38,26	-	143,85	-	-	-	16,16	2879,16	265,51	18783,17
	Secondary Swamp Forest	5,1	-	920,36	7054,77	20195,05	8911,43	321,39	14478,44	7,27	-	-	63,49	-	242,75	724,1	9625,73	37,82	62587,7
	Secondary Forest	-	-	-	-	-	-	-	397,86	-	-	-	216,76	-	-	45,57	25,24	-	685,43
	Plantation Forest	-	-	-	-	-	-	-	353,51	-	-	-	250,54	-	-	-	-	-	604,05
	Open Land	-	-	-	-	-	206,68		2074,33	26,76	-	840,42	601,12	-	-	-	2917,78	-	6667,08
	Settlement	0,04	-	54,66	-	-	-	0,95	5275,9	41214,35	-	5,14	1196,85	0,44	457,54	2,02	418,5	115,75	48742,16
	Plantation	0,22	-	4,38	-	-	-		102997,99	731,63	-	0	544,06		352,01	15,19	1477,96	8,89	106132,33
	Mining	0	-	49,81	-	-	-	34,99	620,29		910,6	-	-	-	46,82		119,87	-	1782,39
	Dry Land Farming	1,55	-	-	-	-	-	75,37	15298,65	452,04	0	9174,34	542,55	1333,81	847,81	444,72	1588,83	-	29759,68
	Mixed Shrub Dry Land Farming	5	-	11,78	-	-	-	17,88	8726,66	645,25	114,37	0,49	82913,14	1409,9	1045,24	1756,23	8461,08	-	105107,03
	Swarp	0,54	60,06	292,37	-	-	-	20,61	18035,97	13,3			729,78	4808,88	1215,91	520,62	11292,3	29,85	37020,2
	Savanna/ Grassland	0,89	102,06	1909,77	-	-	9007,96	73,37	14859,93	352,09	0,07	5,69	1366,48	-	17561,91	165,33	50927,33	159,88	96492,76
	Ricefield	1,57	8,4	3,11	-	-	-	78,76	38865,31	430,01				-	123958,01		224,3	994,63	164564,09
	Shrubs	3,24	-	-	-	-	-	11,12	16765,71	39,09	42,21	991,92	2415,53	-	1365,23	3509,59	1518,33	-	26661,96
	Swamp Bush	67,81	833,6	4853,32	43,31	5350,47	11050,67	470,96	115291,77	1028,77	-	4333,83	6878,17	1369	25323,82	1330,99	145633,1	1330,34	325189,93
	Pond	9,7	32,79	563,69	-	-	-	3,21	2315,45	7,44	-				289,47		1434,65	2961,85	7618,24
	Open Land	0,01	39,66	3,14	-	-	-	280,53	8164,54	106,21	-	426,12	335,44	87,87	3551,01	354,58	4142,72	33,76	17525,58
	Grand Total	36843,98	91302,99	44680,43	7098,08	25597,55	30502,02	4982,13	372008,31	45109,97	1067,25	16011,32	98053,93	9009,99	180443,77	8892,21	250144,33	7981,22	1229729,48

3.2 Calculation of carbon reserves in banyuasin regency in 2013, 2018 and 2023

The calculation will be carried out based on a backward looking approach which is an estimated calculation by looking at changes in existing land cover without any intervention, assuming that regional growth and development tend to follow the current pattern. The first stage will be calculated as an overall estimate of carbon stocks in Banyuasin Regency in 2013, 2018 and 2023. Next, the estimated changes in carbon stocks for each land cover class will be discussed using the mathematical equation of differential stocks that compare carbon stocks due to changes in land cover in 2013-2018, 2018-2023 and 2013-2018. By using the mathematical equation, namely multiplying the area of land cover in the analysis year by emission factors for each type of land cover [4], then the results of the calculation of carbon reserves for Banyuasin Regency in 2013, 2018 and 2023 can be seen in Table 4.

From the results of the calculation of overall carbon reserves in Banyuasin Regency in 2013, 2018 and 2023, we can see a comparison of changes in carbon reserves as an impact of changes in land cover that occurred in Banyuasin Regency in Fig 3.

Table 4. Calculation of carbon reserve estimation in Banyuasin Regency

No	Land Cover	Carbon Reserves (TonC) 2013	Carbon Reserves (TonC) 2018	Carbon Reserves (TonC) 2023
1	Water Body	0	0	0,00
2	Primary mangrove forest	22.293.162,50	3,39	15.521.508,30
3	Secondary Mangrove Forest	2.253.980,28	12.810.907,60	5.361.651,60
4	Secondary Swamp Forest	9.701.093,50	7.712.654,40	5.067.822,65
5	Secondary Dryland Forest	116.317,47	6.116.222,50	0,00
6	Plantation Forest	38.659,20	1.827.054,08	1.952.129,28
7	Settlement	243.710,78	240.612,40	225.549,85
8	Plantation	6.686.336,79	17.536.317,12	23.436.523,53
9	Mining	0	0	0,00
10	Dry Land Farming	297.596,82	245.587,30	160.113,20
11	Mixed Shrub Dry Land Farming	3.153.210,90	2.999.620,50	2.941.617,90
12	Swamp	0	0	0,00
13	Savanna/ Grassland	434.217,42	30.057,03	0,00
14	Ricefield	329.128,18	361.616,30	360.887,54
15	Shrubs	799.858,80	930.962,40	266.766,30
16	Swamp Bush	9.755.697,90	7.430.578,80	7.504.329,90
17	Pond	0	0	0
	Open Land	60.481,62	93.728,73	12.455,33
	Total	56163452,16	58335922,55	62811355,38

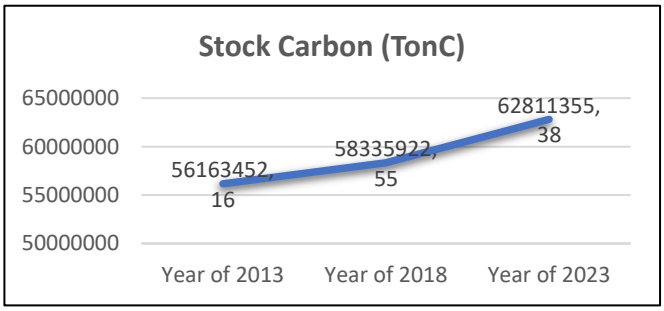

Fig. 3. Carbon reserve graph of Banyuasin Regency

From the graphic image above, it can be explained that in the period from 2013 to 2023, carbon reserves in Banyuasin Regency continued to increase by 11%. This is greatly influenced by changes in land cover in Banyuasin Regency, although most of the land cover has decreased, there is land cover that has experienced a significant increase in area, especially changes in land cover that contribute to absorbing carbon. One of them that has increased significantly is plantation land cover, and also primary mangrove forests. Plantation land cover contributes to carbon reserves in Banyuasin Regency by 37% in 2023, while primary mangrove forests contribute 24% in 2023.

The increase in the area of plantation land cover in Banyuasin Regency occurred due to the physical conditions in the Banyuasin Regency area which has the potential for plantation development, especially oil palm plantations. Data from BPS states that the total area of oil palm plantations in Banyuasin Regency in 2017 was 170,175 Ha when compared to the data on land cover area in Banyuasin Regency in 2018, this area is almost 50% of the total area of plantation land cover in Banyuasin Regency. Based on research that has been conducted, it is stated that oil palm has the capacity to absorb and store carbon dioxide as a carbon reserve. As the age of the plant increases, the carbon reserves stored tend to increase [8]. In

addition to oil palm plantations, Banyuasin Regency also has quite large potential for rubber plantations, which is almost 37% of the total plantation area. Rubber plants are similar to forest plants, able to absorb CO_2 and use it as a carbon source in the photosynthesis process, especially if cultivated with inter cropping pattern [9].

This is indicated by the results of the calculation of carbon reserves that have been presented above, that carbon reserves in Banyuasin Regency have increased along with the increase in the area of plantation cover. Almost the same thing happened to the primary mangrove forest land cover, which also provided quite a large carbon reserve in 2023 in Banyuasin Regency. The physical condition of the Banyuasin Regency area, which is 80% tidal, has caused the growth of mangrove vegetation that can absorb carbon, especially in the Sembilang National Park area, Banyuasin II District. Furthermore, to find out the estimated change in carbon reserves due to changes in land cover in Banyuasin Regency in 2013 - 2018 and 2018 - 2023, it will be calculated through the following mathematical equation:

Table 5. Estimated changes in carbon stocks in Banyuasin regency

Period Year	Calculation
2013-2018	ΔC = (58,335,922.55 - 56,163,452.15)/(2018-2013) = 434,494.08 TonC/Year
2018-2023	ΔC = (62,811,355.38- 58,335,922.55)/(2023-2018) = 895,086.57 TonC/Year
2013-2023	ΔC = (62,811,355.38- 56,163,452.15)/(2013-2023) = 664,790.34 TonC/Year

From the calculation above, the estimated carbon reserves due to changes in land cover in Banyuasin Regency within five years, namely 2013-2018, the results shown are 434,494.08 TonC/year, while the five years 2018-2023 obtained results of 895,086.57 TonC/year and overall for the period 2013-2023, carbon reserves amounted to 664,790.34 TonC/year. Estimation of land cover carbon reserves. This shows that carbon absorption or carbon sequestration has occurred during this period. This increase is due to land cover in 2023, which has a larger total carbon stock compared to 2013. Furthermore, an analysis of carbon stock calculations will be carried out for each change in land cover class in Banyuasin Regency from 2013 to 2023. In this discussion, a more in-depth identification will be carried out on changes in each land cover class, which can absorb carbon (sequestration) and which can release carbon (emissions).

For the terms used as follows, (ton CO2eq)Emission value more than (>) 0 means there is emission, Emission value equal to (=) 0 means there is no emission or change in emission value and Emission value less than (<) 0 means there is sequestration, which is the formation of carbon reserves that occurs due to changes in land cover. The results of the calculation of changes in carbon reserves for each land cover are explained in the following Table 6.

Table 6 presents the results of the carbon stock calculations for each land cover class. The results are obtained from the results of multiplying the area of change in each land cover by subtracting the value of the previous carbon constant and the current constant. Cumulatively in the 10-year period, namely 2013 - 2023, the results of changes in land cover that cause emissions are changes in land cover to rice fields of 1,571,607.13 TonC and changes in land cover that cause sequestration, namely changes in land cover to plantations of -8,837,210.51 TonC. These results show that the area of plantation land cover and also the area of rice fields that continue to increase is also followed by an increase in emissions and carbon absorption produced.

Table 6. Calculation of carbon reserves for the period 2013 – 2023

LAND COVER		2023															
		Water Body	Primary Mangrove Forest	Socondary Mangrove Forest	Socondary Swamp Forest	Plantation Forest	Open Land	Plantation	Settlement	Mining	Dry Land Farming	Mixed Shrub Dry Land Farming	Swarp	Ricefield	Shrubs	Swamp Bush	Pond	Grand Total
2013	Water Body	0	-8779,74	-311722,21	-	-2027,25	-11,55	-2376,74	-42,06	-	-0,13	-0,78	0	-206,87	-7,15	-110505,54	0	-435680
	Primary Mangrove Forest	69427,4	0	1298346,47	0,02	54,54	582881,07	661815,91	1500,48	-	89,51	-	-	685909,4	963,37	528350,06	345561,77	4174900,02
	Socondary Mangrove Forest	23969,73	-253718,5	0	-1820,85	72413,71	12745,54	71995,95	4399,49	-	143,85	-	-	-	1454,14	259124,53	31861,62	222569,23
	Secondary Swamp Forest	790,95	-	32212,6	0	810939,89	49011,94	1332016,1	1089,9	-	-	7936,31	-	37140,7	90512,41	1203216,2	5862,55	3570729,69
	Secondary Forest	-	-	-	-	-	-	42451,3	-	-	-	30281,14	-	-	6366,35	3526,34	-	82625,13
	Plantation Forest	-	-	-	-	0	-	353,51	-	-	-	8518,39	-	-	-	-	-	8871,9
	Settlement	0,18	-	-6286,45	-	-	2,39	-306002,21	0	-	5,14	-29921,24	2,21	1372,62	-50,57	-10462,59	578,74	-350761,79
	Plantation	13,91	-	-249,46	-	-	-	0	42434,78	-	0	17953,95	-	21472,73	501,15	48772,65	560,27	131459,98
	Mining	0	-	-5977,08	-	-	-87,47	-39078,43	-	0	-	-	-	-93,65	-	-3596,04	-	-48832,67
	Dry Land Farming	15,5	-	-	-	-	-188,43	-810828,69	2260,2	0,03	0	-10851,02	13338,09	6782,49	-8894,4	-31776,65	-	-840142,9
	Mixed Shrub Dry Land Farming	149,88	-	-1059,9	-	-	491,79	-287979,91	16131,16	3431,16	0,49	0	42296,94	29266,75	0	0	-	-197271,62
	Swarp	0	-10210,82	-35084,68	-	-	-51,54	-1136265,8	-66,5	-	-	-21893,46	0	-2431,81	-15618,57	-338768,92	0	-1560392,19
	Savanna/ Grassland	4,02	-16891,06	-220578,93	-	-535973,53	146,73	-869306,02	-176,05	0,31	5,69	-34845,23	-	43904,78	-4215,81	-1298646,8	719,45	-2935852,49
	Ricefield	3,14	-1410,46	-366,46	-	-	-39,38	-2370783,6	-1290,02	-	-	-	-	0	-	-6280,46	1989,26	-2378178,02
	Shrubs	97,27	-	-	-	-	305,7	-553268,32	977,27	1266,15	991,92	0	-	38226,46	0	0	-	-511403,55
	Swamp Bush	2034,16	-116704,4	-436798,99	-674222,22	-375722,77	12951,53	-3804628,4	25719,22	-	4333,83	0	41069,92	709066,96	0	0	39910,1	-4572991,09
	Pond	0	-5574,46	-67643,14	-	-	-8,03	-145873,22	-37,2	-	-	-	-	-578,94	-	-43039,51	0	-262754,49
	Open Land	0,03	-6642,54	-368,78	-	-12710,53	0	-619451,86	-331,2	-	1266,54	-25755,29	219,68	1775,51	-9751	-194163,61	84,39	-865828,68
	Grand Total	96506,17	-419931,97	244423	-676043,05	-43025,93	658150,3	-8837210,5	92569,47	4697,66	6836,85	-58577,23	96926,84	1571607,1	61259,92	5749,66	427128,17	

The changes in land cover classes that provide the largest emission and sequestration conditions in the 10-year period (2013 - 2023) are presented in Table 7. In the 10 years of land cover change in Banyuasin Regency, namely 2013-2023, it can be seen that the change of swamp bushes into rice fields and primary mangrove forests into open land has caused emissions in Banyuasin Regency. In the change of land cover into rice fields, according to data from Low Carbon Development Indonesia, the agricultural sector contributes around 13% of the total carbon emissions in Indonesia. One of the main components in the agricultural sector that produces significant emissions is rice production through two main sources, namely methane (CH_4) and nitrous oxide (N_2O) emissions. Rice production has an environmental impact. The latest research provides an overview that the agricultural sector, especially rice production, plays a major role in climate change. This is very contradictory when associated with Banyuasin Regency, as the largest food barn in South Sumatra Province, which will continue to increase the area of productive rice fields.

Table 7. Estimated value of the largest carbon emissions due to changes in land cover class in banyuasin regency 2013-2023

Period	Initial Land Cover	Final Land Cover	GHG Emission Value	Information
2013-2023	Swamp Bush	Rice field	709,066.96	Emission
	Primary mangrove forest	Open Land	582,881.07	Emission
	Swamp Bush	Secondary Swamp Forest	-674,222.22	Sequestration
	Swamp Bush	Plantation	-3,804,628.43	Sequestration

The change of mangrove forests into open land, which also contributes to emissions in Banyuasin Regency, must be controlled immediately to maintain the existence of mangrove forests in good condition. Banyuasin Regency is one of 3 regencies in South Sumatra Province that has the largest mangrove forest potential. The sustainability status of mangrove ecosystem

management, especially in Sembilang National Park, Banyuasin Regency, is in a less sustainable condition [10] and one of the causes is the change into open land (deforestation). Meanwhile, changes in land cover that provide carbon absorption are changes in swamp shrubs into secondary swamp forests and changes in swamp shrub land cover into plantations. Secondary swamp forests are wetland forests that have been cut down or have degraded. Secondary swamp forests in Banyuasin Regency are identified as being in a peat ecosystem, which is one of the potential lands that must be protected [11]. Banyuasin Regency is one of 4 regencies in South Sumatra Province that have peat protected forest areas [12]. Peat is considered a wetland habitat that has a high capacity to absorb (sequester) and store (sink) large amounts of carbon. This ability plays an important role in preventing the release of greenhouse gases, especially CO_2, into the atmosphere, thereby helping to reduce the impact of climate change [13].

In the plantation area in Banyuasin Regency, it is very large and can contribute to carbon absorption, especially in oil palm plantations, with the ability to store large amounts of carbon both in vegetation and in the soil. According to Henson's research (1999), oil palm plants are able to absorbs up to 64.5 tons of carbon per hectare per year [14]. This value is greater than that of tropical forests is able to absorb carbon of around 25 tons of carbon per hectare per year from palm oil research [15]. This ability makes oil palm plants one of the most efficient plants in mitigating carbon dioxide emissions. In addition, carbon storage in biomass is also important in the context of climate change.

Considering the above results, the next discussion that will be input in the process of formulating a strategy for controlling spatial utilization will focus on land cover that provides the largest emission value, namely changes in land cover to Rice Fields and changes in land cover to Open Land. While in sequestration conditions, the formulation of the strategy will focus on changes in land cover to plantations and secondary swamp forests.

3.3 Space utilization control strategy

The spatial utilization control strategy is intended to ensure that the spatial utilization of each land cover class can be controlled. In this case, the spatial utilization control strategy will be applied to land cover that contributes to emissions, namely rice fields and open land, so that it can minimize emissions and to land cover that provides carbon absorption (sequestration), namely plantations and secondary swamp forests so that they continue to optimally store carbon. The formulation of the spatial utilization control strategy is generated from the ANP analysis, as determining what strategy should be chosen in determining the control of space utilization for two conditions, namely carbon loss conditions (emissions) and carbon capture conditions (sequestration). In data processing and analysis, data obtained from 8 experts in different fields and with the same level of expertise will be used in data processing using the ANP method. The data processing process in this study uses SuperDecisions Version.2.10 software. There are several stages carried out in the ANP process, including interpreting the problem, determining criteria and alternatives, ensuring component weighting from an expert's perspective, creating a Pairwise Comparison Matrix, Consistency Test, Super matrix Calculation, Priority Calculation, and Alternatives Ranking.

From the results of the ANP analysis, three alternatives were obtained that had the highest priority value for emission conditions, namely strict technical requirements, followed by land ecosystem sustainability and green open space or reforestation. The selected criteria resulted in a choice of protection adaptation options. The formulation of the spatial utilization control strategy for land cover that provides emission conditions is as follows:

Table 8. Space utilization control strategy emission conditions

No	Land Cover	Selected adaptations	Space Utilization Control Strategy
1.	Rice field	Protection	1. Rice field development is carried out by providing strict technical requirements, in the form of: - Implementation of intermittent rice field irrigation system - Selection of low emission rice varieties - Use of low emission herbicides - utilization of fuel in agricultural equipment with low carbon technology 2. Developing rice fields while maintaining the sustainability of land ecosystems by minimizing the exploitation of natural agricultural resources. 3. The development of rice fields is followed by reforestation by planting trees around the rice fields.
2.	Open Land	Protection	1. Open land development is carried out by providing strict technical requirements, in the form of an obligation to have environmental documents and environmental approval. 2. Open land development is carried out while maintaining the sustainability of the land ecosystem through: - It is not permitted to use open land which could result in environmental damage. - Open land development must be followed by soil and water conservation - Carrying out land restoration that has experienced a decline in the ecological function of the soil 3. The use of open land is permitted for reforestation with carbon-absorbing plants and use as green open space.

Meanwhile, for alternative sequestration conditions that have the highest priority value, namely prohibiting conversion, then conservation, preservation and restoration and preventing forest encroachment. For the selected criteria, it produces a choice of protection adaptation options. The formulation of the strategy for controlling the use of space for land cover that provides sequestration conditions is as follows:

Table 9. Space utilization control strategy for sequestration conditions

No	Land Cover	Selected adaptations	Space Utilization Control Strategy
1.	Plantation	Protection	1. Plantation development must be followed by efforts to manage plantations sustainably through conservation, preservation and restoration, in the form of: - Implementation of High Conservation Value (HCV) management - implementation of the round table on Sustainable Palm Oil (RSPO) - optimizing the use of low carbon fertilizers - plantation management can be carried out with an inter cropping pattern. 2. Conversion of plantation land is carried out in a hasty manner with the following requirements: - Implemented in accordance with the provisions stipulated in laws and regulations - Every plantation business and/or activity must have environmental documents and environmental approval.
2.	Secondary Swamp Forest	Protection	1. Conducting forest conservation and protection, forest rehabilitation and preserving the function of the area as a carbon sink. 2. Prohibiting the conversion of secondary swamp forests which can cause ecosystem damage. 3. Prohibiting encroachment on secondary swamp forests which can damage protective functions and threaten environmental sustainability.

4 Conclusion

Land cover changes in Banyuasin Regency between 2013 and 2023 occurred in a spatially random pattern, with significant increases in plantation (71.47%) and forest plantation (98%) areas, while water bodies, savanna/grasslands, and secondary dry land forests declined. Over this period, the region experienced a net carbon sequestration of -6,647,903.23 TonC, with carbon absorption outweighing emissions. Major emission sources were conversions to rice fields and open land, while the greatest carbon absorption resulted from converting swamp shrubs to plantations and secondary swamp forests. Based on ANP analysis, emission-priority areas like rice fields and open land require strict technical regulations, ecosystem sustainability, and reforestation. In contrast, for high-sequestration areas like plantations and secondary swamp forests, priority strategies include prohibiting land conversion, conservation, restoration, and forest protection, with adaptation-based protection identified as the top strategy for both emission and sequestration contexts.

References

1. K.D. Novanto, Perencanaan teknis reduksi emisi Gas Rumah Kaca (GRK) sektor domestik rumah tangga di Kota Tegal. Dep. Tek. Lingkung. Fak. Tek. Univ. Diponegoro, Semarang, 2023.

2. F.A. Nuzir, A. Kurniawan, S.D. Chandra, Jamaludin, A.S. Munawaroh, Study on the potential of historical Mahogany Trees in improving urban air quality. International Journal of Building, Urban, Interior and Landscape. 63–72 (2022).
3. Intergovernmental Panel on Climate Change, IPCC Guidelines for National Greenhouse Gas Inventories, Institute for Global Environmental Strategies (IGES), Hayama, Japan (2006).
4. Pemerintah Kabupaten Banyuasin, Materi teknis RTRW Kabupaten Banyuasin Tahun 2024-2044. Pemerintah Kabupaten Banyuasin, Banyuasin (2023).
5. P.B. Iredo, Mewujudkan perencanaan tata ruang yang ramah lingkungan melalui analisis emisi berbasis lahan. Reka Racana Jurnal Online Institute Teknologi Nasional. **3**, 1–9 (2017).
6. E.F. Suebu, Kajian strategi implementasi mitigasi penurunan emisi GRK sektor berbasis lahan di Provinsi Papua. Institut Teknologi Sepuluh November, Surabaya, 2017.
7. D.A. Novitasar, Spatial Pattern Analysis dan Spatial Autocorrelation Produk Domestik Regional Bruto (PDRB) sektor industri untuk menggambarkan perekonomian penduduk di Jawa Timur. Ekbis. **13**, 629-637 (2015).
8. A.R. Lubis, Pendugaan cadangan karbon kelapa sawit berdasarkan persamaan allometrik di lahan gambut kebun meranti paham PT Perkebunan Nusantara IV Kabupaten Labuhan Batu Sumatera Utara (2018). [Online]. Available: https://doi.org/10.29244/medkon.2.
9. Sahuri, Potensi penyerapan karbon pada karet pola tumpangsari tanaman hutan. Jurnal Hutan Tropis. 4, 3 (2016).
10. T. Theresia, M. Boer, N.T.M. Pratiwi, Status keberlanjutan pengelolaan ekosistem mangrove di Taman Nasional Sembilang Kabupaten Banyuasin Provinsi Sumatera Selatan. Ilmu dan Teknologi Kelautan Tropis. 703–714 (2015).
11. Pokja PTGL-EHKB, Strategi pelaksanaan tata guna lahan untuk mendukung pembangunan rendah emisi di Kabupaten Musi Banyuasin, Pokja Ekonomi Hijau Kab. Musi Banyuasin. Pokja Ekonomi Hijau Kab. Musi Banyuasin, Sekayu, Indonesia, Musi Banyuasin (2016).
12. Pemerintah Provinsi Sumatera Selatan, Peraturan Daerah Provinsi Sumatera Selatan Nomor 6 Tahun 2024 tentang Rencana Tata Ruang Wilayah Provinsi Sumatera Selatan Tahun 2024–2044. Pemerintah Provinsi Sumatera Selatan, Sumatera Selatan (2024).
13. F. Agus, M. Noor, R. Boedionom, Potensi penyerapan karbon pertanian di Lahan Gambut. Pojok Iklim (2018).
14. I.E. Henson, The comparative ecophysiology of oil palm and tropical rainforest, Oil Palm Environ. Perspect. 9-39 (1999).
15. "PASPI," 2023. [Online]. Available: https://palmoilina.asia/berita-sawit/sawit-sebagai-carbon-sink/