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Projection of further expansion of oil palm plantation in Jambi Province

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Abstract. *The expansion of oil palm plantations has become of global concern. Jambi Province in Indonesia is one of the regions experiencing a rapid shift in land use, and oil palm plantation, settlement, and agriculture have emerged as the primary force behind this shift. This study aims to project scenarios of future land-use change and expansion of oil palm plantations in Jambi Province in 2030, 2060, and 2100. This study uses land-use map Jambi Province and driving factor data, including elevation, slope, river, road, and forest. Projections of land-use change scenarios are conducted using the Land Change Modeler (LCM), in which Cellular Automata Markov (CA-Markov) is the model base. The validation of the model against historical land-use changes showed an overall kappa value of 0.97. In the no-conservation scenario, assuming a continuation of the trends from 1990 to 2011, the forest area continues to decrease. Oil palm will replace forest as the dominant land-use cover in Jambi Province in 2100. Driving factors explaining the spatial distribution of oil palm plantation expansion include distance from forest, distance from road, and elevation. Our study shows the importance of government regulations' importance in slowing or stopping deforestation, especially for forests near plantations.*

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INTRODUCTION

Palm oil contributes significantly to the Indonesian economy. The export value of palm oil in 2020 is US$22.9 billion, rising by 52% in 2021 at US$35 billion (GAPKI 2022). Oil palm has the potential to enhance economic development through employment opportunities. Over five million local farmers work in oil palm plantations, and another 16 million are employed in the processing sector (Nurfatriani et al. 2018). The rising global need for food, energy, and other manufacturing products drives up demand for palm oil, triggering the expansion of oil palm plantations over the globe.

The expansion of oil palm plantations become of global concern because it causes massive deforestation, biodiversity loss, and disruption in other ecosystem services (Vijay et al. 2016). In Indonesia, oil palm plantations and timber plantations accounted for more than two-fifths of national deforestation during 2001–2016 (Austin et al. 2018). Oil palm plantation in Indonesia is concentrated in Sumatra and Kalimantan Island. Jambi Province in Sumatra is one region experiencing a rapid shift in land use, and plantation has emerged as the primary force behind this shift (Melati 2017). Plantations in Jambi Province are dominated by oil palm and rubber (Clough et al. 2016; Drescher et al. 2016; Merten et al. 2020). Rubber plantations have been established since the Dutch colonial era, and oil palm cultivation began in the province in the middle of the 1980s (Merten et al. 2020). However, the area of rubber plantations is declining continuously and being replaced by oil palm plantations as oil palm has a more positive impact on local farmer likelihood. Farm households can increase their consumption as a result of economic gains. According to some previous studies, oil palm has lower labor demand than other crops like rubber and, thus high gross margin per unit of labor (Drescher et al. 2016; Kubitza et al. 2018). Because of their higher economic value, rubber plantations have been replaced by oil palm plantations as the primary source of worker subsistence (Azzahra et al. 2017).

Expansion of oil palm and other crops from 2000 to 2015 in Jambi Province caused the land surface temperature to increase by about 1.05 ºC (Sabajo et al. 2017). Conversion of forests to plantations in Jambi Province also causes drier and hotter microclimatic conditions (Meijide et al. 2018). Besides, this conversion impacts soil densities, decreasing soil infiltration and leading to higher surface runoff (Tarigan 2016; Merten et al. 2020). According to Merten et al. (2020), plantation development can increase the magnitude and frequency of flooding. In summary, the conversion of forest to plantation has several negative impacts on ecosystems, but at the same time, it has positive impacts on the likelihood of local communities. Because oil palm plantation is profitable, it will continue to expand in the future. Regional planning to minimize the impact of land-use change is important to do. Therefore, the objectives of our study are (a) to project scenarios of future land use change and expansion of oil palm plantations in Jambi Province and (b) to identify drivers for the spatial patterns of expansion.

METHODS

Study Area

Jambi Province is located in the eastern part of Central Sumatra Island's east coast with an area of 50,160 km^2. The topography of Jambi Province varies from 0 meters above sea level in the East. i.e., the lowlands, to an altitude above 1,000 meters above sea level in the Barisan mountains in the West. Jambi Province is characterized by moderate and high rainfall, with an average annual rainfall of 2,300 mm (Drescher et al. 2016). The average air temperature reaches 27.11 °C, while for the highlands in the West, air temperature reaches 22.0 °C (Rustiadi et al. 2018).

Data

The data used in this study consists of land-use maps and driving factors (Table 1). Land-use maps from Melati (2017) in 1990 and 2011 are utilized for developing and training the model, while the land-use map in 2013 is used as the validation model. The land-use map used originally has 22 land-use classes. However, in this study, the land-use map is reclassified into six land-use classes, as shown in Table 2. Reclassification is used to merge several land covers that have similarities. This land-use projection used five driving factors: elevation, slope, rivers, and roads from the Geospatial Information Agency (*https://tanahair .indonesia.go.id/portal-web*) and forests from Melati (2017).

Table 1 The data that were used for this study

No	Data	Year	Source
1	Land-use map	1990	Melati (2017)
2	Land-use map	2011	Melati (2017)
3	Land-use map	2013	Melati (2017)
4	Elevation	2018	Geospatial Information Agency
6	River	2017	Geospatial Information Agency
7	Road	2017	Geospatial Information Agency
8	Forest	2011	Melati (2017)

Table 2 Reclassification of land-use classes

Land use (Melati 2017)	Reclassification
Primary dryland forest, plantation forest, primary mangrove forest, primary swamp forest, secondary dryland forest, secondary mangrove forest, secondary swamp forest, and jungle Rubber	Forest
Oil palm	Oil palm
Rubber	Rubber
Dryland agriculture, mixed dryland agriculture, paddy field,	Cropland
Shrub, swamp bush, bare land, mining,	Shrub
Settlement, transmigration, airport, water body, and fishpond	Settlement

Land-Use Change Modelling

Land-use change projection was conducted using the Land Change Modeler (LCM), and the general procedure is shown in Figure 1. In LCM, the projection of land-use change used a Cellular Automata Markov (CA-Markov) approach. The CA-Markov model is a combination of cellular automata and the Markov chain, and it is used to predict trends and characteristics of land-use change over time (Hua 2017). Markov chain analysis is based on the physical assumption that the probability of a system in a given state at a given time can be defined if the previous state is known (Gharaibeh et al. 2020). This method created a land-use change transition probability matrix among two different time steps. This matrix will estimate the chances that each pixel in a particular land-use class will either be converted to a different class or remain in the same class. Each cell's condition is contingent upon its neighbors' spatial and temporal conditions. Markov chain can be represented mathematically as follows (Mathanraj et al. 2021):

$$L\ (t, t + 1) = Pij \times S(t)$$

Where L(t) is land use at time t, L(t + 1) is land use at time t + 1, and Pij is the transition probability matrix for an individual land state.

The Multi-Layer Perceptron-Neural Network (MLP-NN) algorithm is used to identify land change transition probability in LCM. Before processing MLP, similar land-use change transitions are grouped into a single sub-model. This study defined the sub-models based on land-use transition between 1990 and 2011. In each sub-model, there are driving factors that will affect the occurrence of land change. This study used five driving factors: elevation, slope, distance from rivers, distance from roads, and distance from forests. Before the drivers of change are incorporated into the model, they must be tested using Cramer's V test. The Cramer's V coefficient describes the association relationship between land use and the drivers of land change (Gibson et al. 2018). High Cramer's V value indicates a good factor used in the model. The land-use change projections are made with two scenarios: assuming a future policy toward forest conservation and without. In the conservation scenario, the forest does not change into another land cover, and the forest area remains the same.

Validation

Output from the model is validated against existing land use data for a certain year. In this study, land-use maps from 2013 are utilized as model validation. The accuracy of the output model is determined by the kappa value as below (Wang et al. 2012).

$$\text{Kappa Accuracy} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i}*x_{+1})}{N^2 - \sum_{i=1}^{r} x_{i+}*x_{+1}}$$

Where N is the total number of land-use points that are verified, r is the number of land-use types, x_{ii} is the number of model outputs in row and column i that corresponds to the actual land use, x_{+1} is number of interpretation points on land use types in column i, and x_{1+} is number of reference points on land use types in column i.

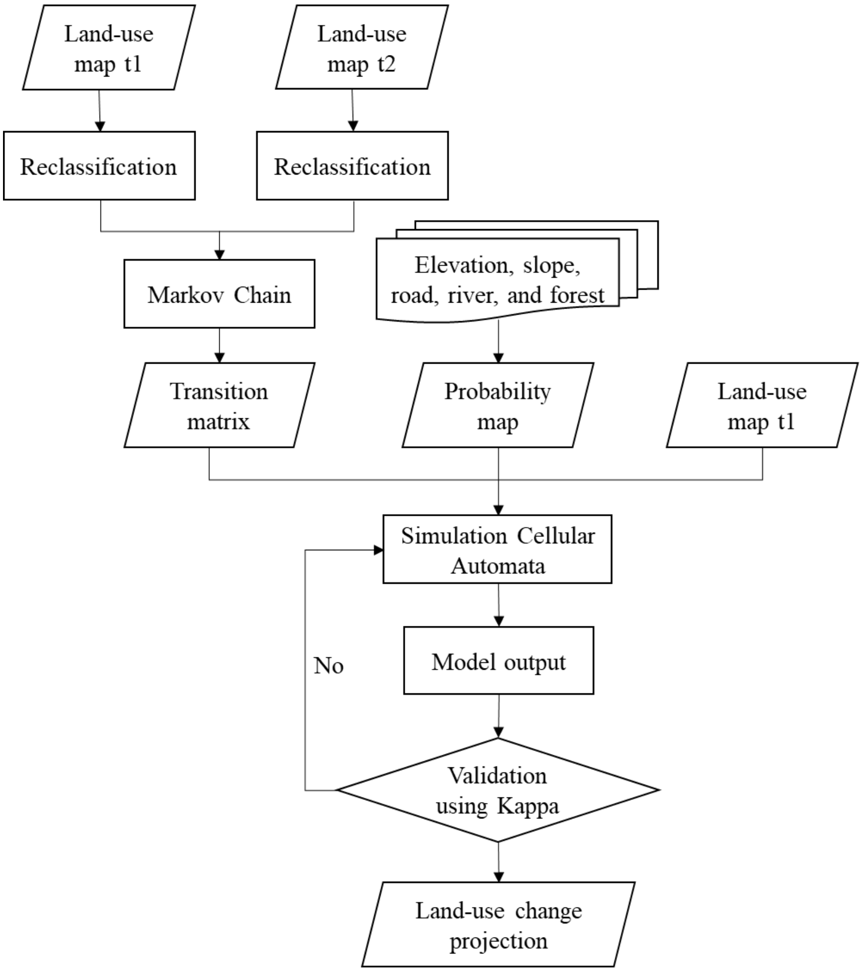

Figure 1 Flow diagram of study

RESULT AND DISCUSSION

Land-Use Change between 1990 and 2011 in Jambi Province

Land-use in Jambi Province is very dynamic following human development. Figure 2 shows land-use cover in Jambi Province in 1990 and 2011. These land-use maps serve as a baseline for studying land-use projection. Land use in 1990 was dominated by forest in which 52% of total area in Jambi Province is covered by forest (Table 3). Rubber is the second dominant land use covering about 17% of the total area. In 2011, the forest lost 16% of its total area due to the expansion of rubber, oil palm, shrub, cropland, and settlement. From 1990 to 2011, the area of rubber had a net increase even though some rubber plantations were converted to oil palm plantation and cropland.

The area of oil palm plantations increased by 5% between 1990 and 2011 (Table 3). Conversion from forests was the highest contributor to the expansion of oil palm plantations, with more than 1600 km^2 area of forest converted to oil palm plantations (Figure 3). Conversion from rubber plantations was the second largest contributor to the expansion of oil palm plantations, with about 650 km^2. The contribution from cropland and shrub to the expansion of oil palm plantations was lower than 400 km^2.

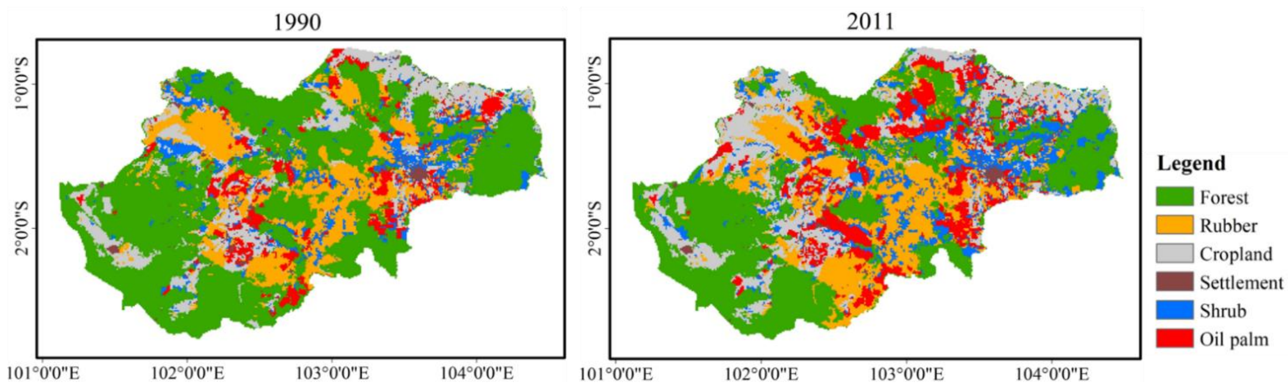

Figure 2 Land-use cover of Jambi Province in 1990 and 2011

Table 3 Percentage of Land Cover in Jambi Province in 1990 and 2011

Land	Percentage of land-use cover (%)	
	1990	2011
Forest	52	36
Rubber	17	20
Cropland	14	19
Settlement	2	2
Oil Palm	7	12
Shrub	8	11

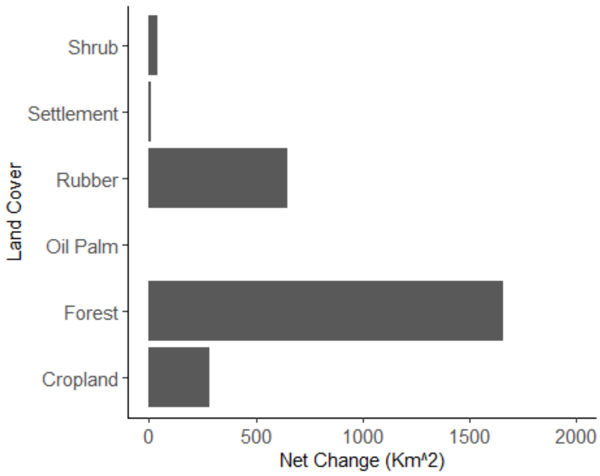

Figure 3 Contribution to net increase in oil palm plantation area

The Driver of Land-Use Change

The driving factors of expansion of oil palm plantations in our study consist of elevation, slope, distance from forests, distance from rivers, and distance from roads (Figure 4). Elevation is expected to impact land-use changes as oil palms are typically cultivated in the lowlands, which will lead to a higher potential for land-use change in the lowlands compared to the mountains. High elevations are located in the Western part of Jambi province, while the lowlands are in the Center and Eastern parts. Slope conditions also affect land use. Areas with a low slope will be used more by the community so that the rate of land change is high. Areas with high slopes are also located in the Western part of Jambi Province because of the Barisian mountains in this region. The distance from forests can impact land-use change as oil palm plantations near forests have a high potential to expand. Rivers greatly affect land-use changes as areas close to rivers have high availability of water resources and a high accessibility which typically fosters the area's development. Road is also one of the infrastructures needed for accessing an area. Easy access typically results in rapid regional development causing high land demand and triggering land conversion.

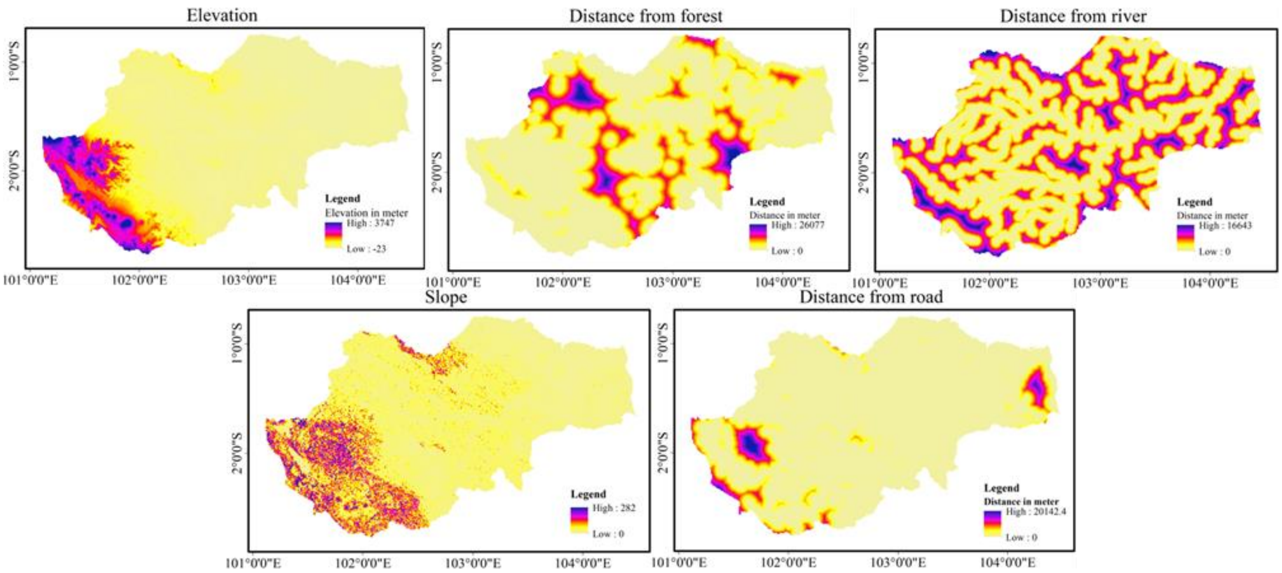

Figure 4 Driving factor of land-use projection (the distance is in meter)

Table 4 Cramer’s V test.

Driving factor	Cramer’s V
Elevation	0.217
Slope	0.186
Distance from forest	0.405
Distance from road	0.218
Distance from river	0.124

In this study, Cramer's V test used to understand the association between land use and drivers of land-use change. All driving factors have a Cramer’s V of more than 0.1, indicating that all are driving factors are associated with land-use cover change in Jambi Province (Table 4). Distance from forest, distance from road, and elevation have a Cramer’s V value higher than 0.2 and higher than the other driving factors. From these three driving factors, distance from the forest has the most significant weight, which means that this driving factor has the highest influence on land-use change in Jambi Province.

Projection of Land-Use Change in Jambi Province

Forest degradation in Indonesia is controlled by forest moratorium through Presidential Instruction (INPRES 2011). This moratorium aims to protect primary forest and peatland from conversion for oil palm, pulpwood, and timber, which account for about half of the forest cover lost in the country (Busch et al. 2015). From 2011 to 2015, forest loss decreased with the moratorium, although the number is still low (Busch et al. 2015). Two scenarios were considered for land-use projection in this study to evaluate the expansion of oil palm in the future with a forest moratorium. First a "base" scenario in which oil palm and other land covers could develop from any land-use cover, and a "conservation" scenario in which such expansion would be prohibited in forested areas.

Land use projections in Jambi were made for 2030, 2060, and 2100 assuming that the same driving factors continue to act as between 1990 and 2011. In the first step, the model was validated using the land-use map of 2013. The validation showed an overall kappa value of 0.97, indicating that the predictions are very close to reality or high level of accuracy (Figure 5).

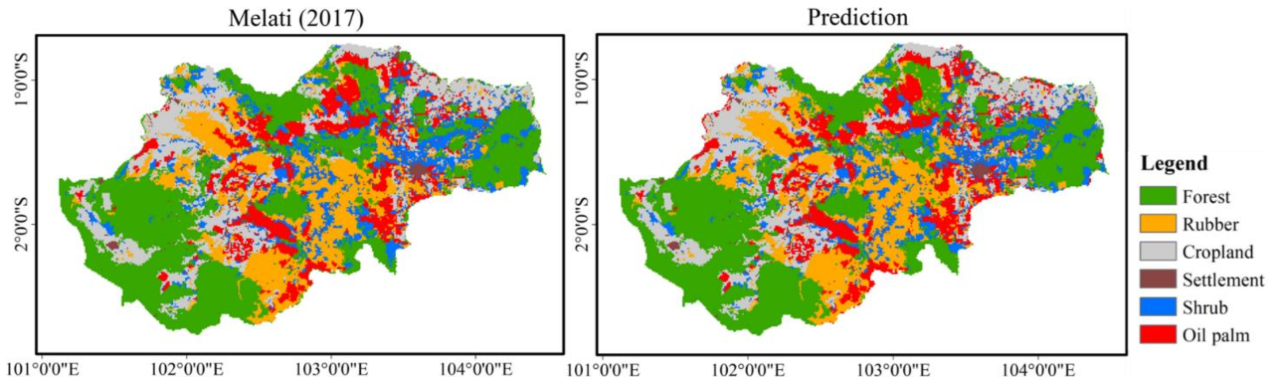

Figure 5 Land-use map of Jambi Province in 2013 from Melati (2017) vs prediction

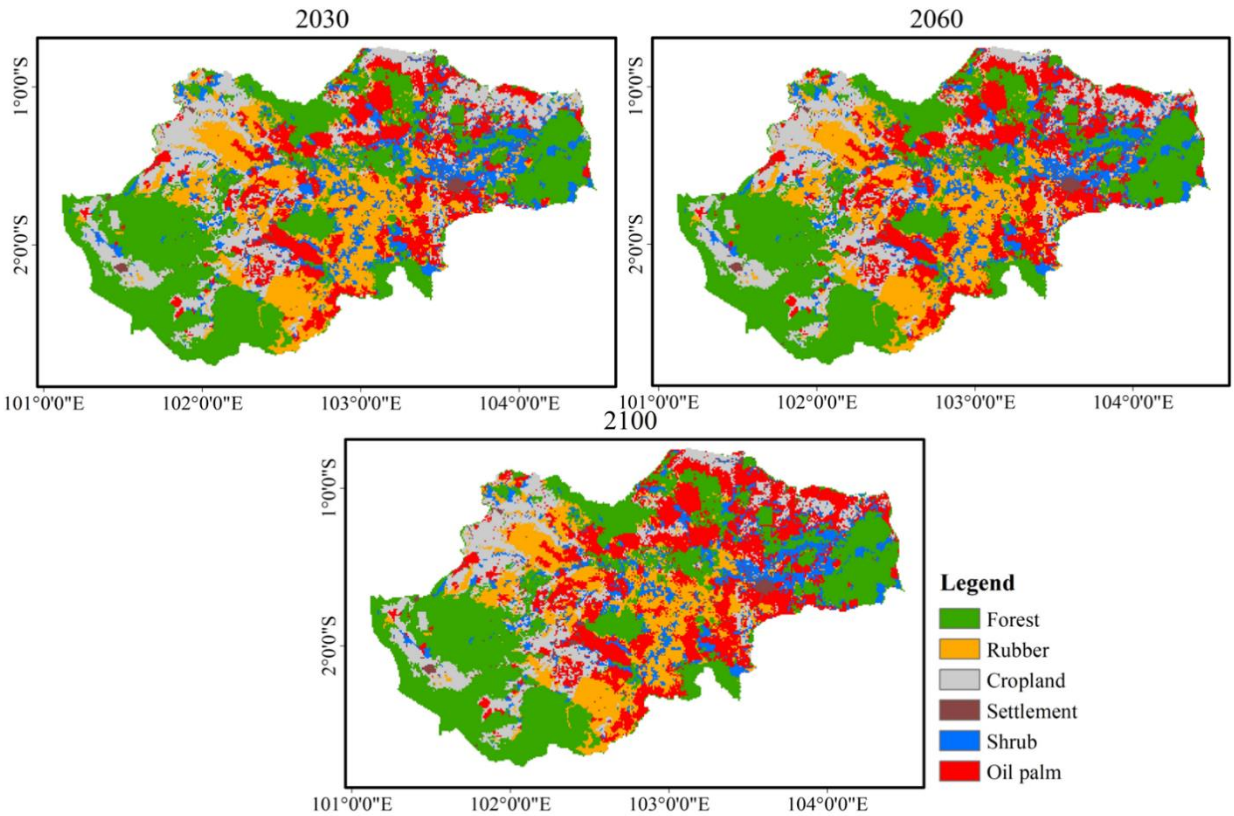

Figure 6 Projected land-use cover change in 2030, 2060, and 2100 with forest conservation scenario

In the conservation scenario, forest areas are unlikely to be converted to another land-use cover in the future. This resulted in a low expansion of oil palm plantations of 3%, 7%, and 10% in 2030, 2060, and 2100 respectively, from the baseline in 2013 (Figure 6). In contrast, oil palm expansion rapidly increases in the non-conservation scenario. In 2030, 2060, and 2100 the area of oil palm plantations will increase by 6%, 12%, and 18%, respectively, from the baseline in 2013 (Figure 7). Spatially, the expansion of oil palm plantations is centered in low-slope and lowland areas suitable for oil palm plantations. In addition, oil palm plantation was also expanding in areas close to forests and in areas with high accessibility. Maulidya et al. (2021) applied land-use change projection with non-conservation scenario in East Kalimantan. The result shows that oil palm plantation expansion in Penajam, East Kalimantan, in 2031 is about 7%. Oil palm expansion also dominated in the lowlands and near roads with high accessibility.

Forest is the highest contributor to oil palm expansion, even though expansion of oil palm plantations generally does not occur in conservation areas such as Taman Nasional Berbak, Taman Nasional Bukit Tiga Puluh, Taman Nasional Bukit 12, and Taman Nasional Kerinci. Based on data from Statistics Indonesia or BPS, conservation areas in Jambi Province are not decreasing. Conservation areas increased in areal extent from 676,120 ha in 2000 to 685,471 ha in 2019 (Badan Pusat Statistik 2022). At the same time, the production of forest decreased from 1,312,190 ha in 2000 to 1,222,077 ha in 2019 (Badan Pusat Statistik 2022). The conversion into oil palm plantations and other land use probably causes the reduction of production forest area.

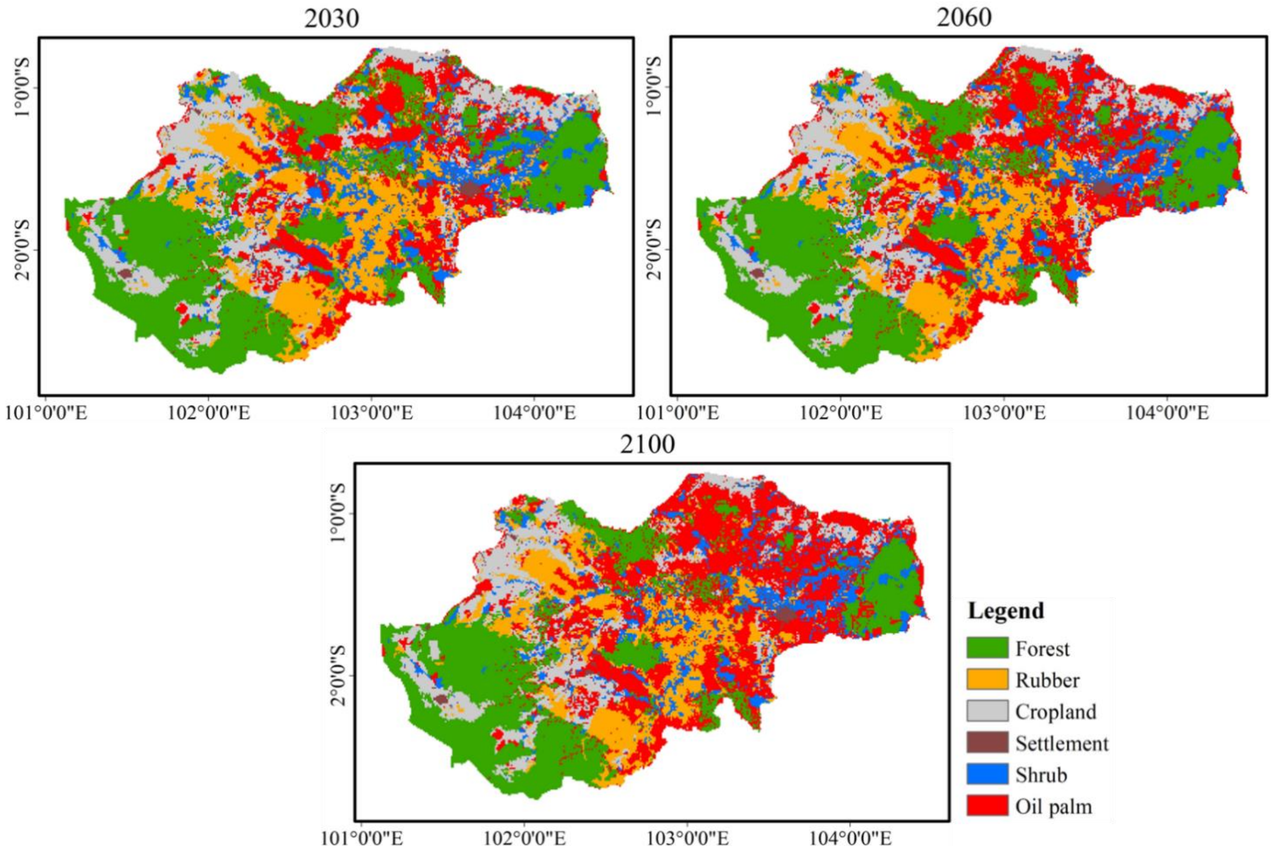

Figure 7 Projected land-use cover change in 2030, 2060, and 2100 without forest conservation scenario.

CONCLUSION

Oil palm in Jambi Province is expected to increase. 1990 the forest was still the dominant land-use cover, but its area decreased along with an increase in oil palm and rubber plantations in 2013. If assuming a continuation of this trend and without conservation measures, oil palm plantations are projected to replace forest as the dominant land-use cover in Jambi Province in 2100, covering about 30% of the area. The dominant driving factors explaining the spatial pattern of land-use change in Jambi Province are distance from forests, distance from roads, and elevation. The true land-use change in the coming decades will depend on changes in the local and international socio-economic conditions as well as on government regulations reducing deforestation and promoting conservation areas such as national parks and other conservation areas, including the program implemented by *Hutan Harapan*. Our study does not represent a projection of future development but rather indicates a scenario of what would have happened if the trends from 1990 to 2011 had continued into the future without any changes in socio-economic conditions and governmental regulations.

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