The Potency of Coffee Plants in Agroforestry System in Baringin Village, Agam Regency, West Sumatra to Support Social Forestry Program and Its Contribution to Mitigate Climate Change

Dyah Ayu Kusumaningrum*, Atikah Risyad, Juliana Angelia Siagian, Katrina Melinda, Mentari Tisyadana
FAM Rural, Tanjuang Bonai, Lintau, West Sumatra 27293, Indonesia

*Corresponding email: dyakhkusumaningrum18@gmail.com

Abstract. This study investigates the viability of coffee agroforestry systems in supporting Indonesia's Social Forestry Program and contributing to climate change mitigation efforts. Conducted in the KUPS Kopi Data Baringin management area of West Sumatra, this research assesses the potential of coffee cultivation within an agroforestry system in Baringin Village, Agam District. Data collection encompassed a comprehensive census for social and economic aspects and purposive sampling for vegetation analysis. Findings revealed a diverse range of 29 tree species from 16 families, alongside eight types of agricultural crops from five families. Tree species exhibited lower diversity and abundance indices, while herbaceous and shrub categories demonstrated moderate diversity. Notably, *Coffea canephora*, the coffee species, exhibited a carbon content of 3.49 tons per hectare, contributing to climate change mitigation efforts and functioning as a valuable CO2 equivalent sink estimated at approximately 13 tons per hectare. Furthermore, the adoption of coffee agroforestry systems resulted in a notable increase in monthly income for KUPS members. These findings underscore the potential of coffee agroforestry systems as a sustainable land-use practice, supporting the Social Forestry Program objectives and making substantial contributions to climate change mitigation in Indonesia's forest and land management strategies.

1. Introduction
From 2013 to 2021, the highest deforestation rate in Indonesia occurred in 2014—2015, reaching over 1 million hectares. Subsequently, there was a significant decline in deforestation in 2019—2020, reducing to 115,459.8 ha, followed by a 4.5% increase to 120,705.8 ha in 2020—2021 (BPS, 2023). These figures represent Indonesia's lowest average deforestation rate from 2013 to 2021.
According to the Ministry of Environment and Forestry of Indonesia in the press release SP. 062/HUMAS/PP/HMS.3/3/2021, one of the successful government efforts in controlling and reducing deforestation is the Social Forestry Program. Social forestry is a sustainable forest management system implemented in state forest areas or customary or traditional forest areas, carried out by local communities or indigenous people as the main actors to improve their welfare, environmental balance, and socio-cultural dynamics in the form of Village Forests, Community Forests, People’s Plantation Forests, Customary Forests, and Forestry Partnerships (Ministry of Environment and Forestry, 2016).

The achievement of the social forestry area in 2018 was 2,470.34 ha (BPS, 2018) out of a total allocation of 12.7 million hectares. This social forestry program is a positive step taken by the government in responding to forest tenure issues and involving communities, especially in forest areas, to reduce the deforestation rate and mitigate climate change. This shared management is also expected to enhance the economic value of communities around the forest, empower people in forest institutions, and improve the ecological conditions of the forest (Maryudi et al., 2012). Data from the Ministry of Environment and Forestry in 2017 showed that 10.2 million people categorized as poor lived inside or around forest areas, which accounted for 36.73% of the total poor population in Indonesia.

Participation is one of the indicators of success or failure in community-based forest management (Bagherian et al., 2009). Therefore, the forest management system and the formation of forest farmer groups are key elements in the success of the social forestry program, with agroforestry being deemed as an aligned management system with the goals of social forestry. Agroforestry has been practiced by farmers for thousands of years, and researchers have recognized it since the 1970s. Today, agroforestry regains attention as a strategic model for land management to support climate change mitigation, biodiversity conservation, sustainable agriculture, and other objectives. Many organizations recommend agroforestry as a tool for ecosystem restoration in agriculture or forestry. The term "agroforestry" is used to describe the combination of trees with agricultural or livestock farming (or both) on the same land area (Gassner and Dobbie, 2022).

Similar to conventional agriculture, agroforestry usually has a flagship species. For example, in coffee agroforestry, coffee is the main species, accompanied by shade trees or additional agricultural plants such as bananas or tubers. DaMatta 2004 states that coffee cultivation with shade is relatively more
stable compared to coffee cultivation without or with minimal shade. In Indonesia, the area of coffee plantations in 2022 is dominated by smallholder coffee plantations, accounting for 1.26 million ha, which is 98% higher than the large-scale coffee plantations managed by the state or private sector.

Agroforestry coffee gained attention since the Kyoto Protocol in 1997 as a strategy to sequester carbon in agricultural landscapes and reduce the impacts of climate change (Jose and Bardan, 2012). Therefore, coffee systems grown under shade are recognized as a viable greening and reforestation strategy to enhance carbon sequestration and climate change mitigation (Niguse et al., 2022).

One of the coffee-producing regions in Indonesia is Agam Regency, West Sumatra. The area of coffee plantations in Agam Regency is approximately 1,710 ha, with a production capacity of 1,584.22 tons. Furthermore, until 2022, the West Sumatra Province has distributed forest management through social forestry covering up to 275,000 ha out of a total allocation of 522,000 ha. Therefore, this study aims to explore the potential of coffee in agroforestry systems to support social forestry and climate change mitigation, with a case study in the Agroforestry Community Forest Enterprises (KUPS) of Baringin Data, Agam Regency, West Sumatra.

2. Research Methodology
Data was collected from September 2022 to June 2023 in Baringin Village, Agam Regency, West Sumatra. Baringin Village is situated on the slopes of Lake Maninjau's hills at an altitude ranging from 900 to 1,100 meters above sea level.

Social and economic data were collected through a census. Interviews were conducted with 13 members of the Community Forest Enterprises (KUPS) Agroforestry Kopi Data Baringin and village government officials using a guided questionnaire. Meanwhile, vegetation data were obtained through purposive sampling, creating 20m x 20m plots on land owned by KUPS members to record information about tree species, height, diameter, and types of agricultural plants found in those areas.

2.1 Species Diversity Index
The Shannon-Wiener species diversity index (H') was calculated using the following formula (Ludwig and Reynold 1988):

$$H' = -\sum_{i=1}^{s} \left( \frac{n_i}{N} \ln \frac{n_i}{N} \right)$$

H': Shannon-Wiener species diversity index
ni: the number of individuals of species i
N: the total number of individuals of all species
s: the total number of species found

The criteria for the Shannon-Wiener index values are as follows: $H' < 2$ (low diversity), $2 < H < 3$ (moderate diversity), and $H' \geq 3$ (high diversity).

2.2 Species Abundance Index
The calculation of the species abundance index (e) is determined using the following formula (Odum 1993):

$$e = \frac{H'}{\log S}$$

e: species abundance index
H': Shannon-Wiener species diversity index
S: the total number of species found
The Odum species abundance index is classified as low if $e \leq 0.3$, moderate if $0.3 < e < 0.6$, and high if $e > 0.6$.

### 2.3 Carbon Storage and CO2 Sequestration

The biomass of *Coffea canephora* was measured using the allometric equation for trees with a diameter > 5 cm, as follows:

Above Ground Biomass (AGBST) of coffee trees (Arifin 2001)

\[
AGBST = 0.281 \times H \times D^{2.06}
\]

**AGBST** : Above Ground Biomass  
**H** : height  
**D** : diameter

Below Ground Biomass (BGBST), which is 20% of the above-ground biomass, was calculated using the following formula (MacDiken 1997):

\[
BGBST = AGBST \times 0.20
\]

The estimated equivalent CO2 sequestration in the coffee agroforestry system was calculated using the following formula (Niguse et al. 2022):

\[
CO2e = 3.67 \times TC\ CO2
\]

**e** : estimated equivalent CO2 sequestration  
**TC** : total carbon

### 3. Result

This study examined the potential of Robusta coffee (*C. canephora*) in the KUPS Agroforestry Kopi Data Baringin management area from ecological, economic, and socio-cultural aspects, including its carbon sequestration potential and its suitability in supporting social forestry programs and climate change mitigation. The results are as follows:

#### 3.1 Ecological Potential

In the KUPS management area (Table 1), there are 29 plant species belonging to 16 different families, comprising various growth stages, including saplings, poles, and trees. Meanwhile, in the category of herbs and shrubs considered agricultural plants (Table 2), there are 8 plant species belonging to 5 different families.

<table>
<thead>
<tr>
<th>No.</th>
<th>Species (Scientific Name)</th>
<th>Local Name</th>
<th>Families</th>
<th>No.</th>
<th>Species (Scientific Name)</th>
<th>Local Name</th>
<th>Families</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Coffee canephora</em></td>
<td>Kopi robusta</td>
<td>Rubiaceae</td>
<td>6</td>
<td><em>Theobroma cacao</em></td>
<td>Kakao</td>
<td>Malvaceae</td>
</tr>
<tr>
<td>2</td>
<td><em>Persea americana</em></td>
<td>Alpukat</td>
<td>Lauraceae</td>
<td>7</td>
<td><em>Artocarpus heterophyllus</em></td>
<td>Nangka</td>
<td>Moraceae</td>
</tr>
<tr>
<td>3</td>
<td><em>Cinnamomum sp.</em></td>
<td>Kayu manis</td>
<td>Lauraceae</td>
<td>8</td>
<td><em>Toona sp.</em></td>
<td>Suren</td>
<td>Meliaceae</td>
</tr>
<tr>
<td>4</td>
<td><em>Syzygium polyanthum</em></td>
<td>Salam</td>
<td>Myrtaceae</td>
<td>9</td>
<td><em>Murraya koenigii</em></td>
<td>Sicerek</td>
<td>Rutaceae</td>
</tr>
<tr>
<td>5</td>
<td><em>Claoxyylon sp.</em></td>
<td>Sitepu</td>
<td>Euphorbiaceae</td>
<td>10</td>
<td><em>Areca catechu</em></td>
<td>Pinang</td>
<td>Arecaceae</td>
</tr>
</tbody>
</table>
Table 2. Agricultural Plants (Herbs and Shrubs)

<table>
<thead>
<tr>
<th>No.</th>
<th>Species (Scientific Name)</th>
<th>Local Name</th>
<th>Families</th>
<th>No.</th>
<th>Species (Scientific Name)</th>
<th>Local Name</th>
<th>Families</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Saccharum officinarum</em></td>
<td>Tebu</td>
<td>Poaceae</td>
<td>5</td>
<td><em>Musa sp.</em></td>
<td>Pisang</td>
<td>Musaceae</td>
</tr>
<tr>
<td>2</td>
<td><em>Curcuma longa</em></td>
<td>Kunyit</td>
<td>Zingiberaceae</td>
<td>6</td>
<td><em>Carica papaya</em></td>
<td>Pepaya</td>
<td>Caricaceae</td>
</tr>
<tr>
<td>3</td>
<td><em>Cymbopogon nardus</em></td>
<td>Sereh</td>
<td>Poaceae</td>
<td>7</td>
<td><em>Capsicum frutescens</em></td>
<td>Cabai rawit</td>
<td>Solanaceae</td>
</tr>
<tr>
<td>4</td>
<td><em>Zingiber officinale</em></td>
<td>Jahe</td>
<td>Zingiberaceae</td>
<td>8</td>
<td><em>Amomum compactum</em></td>
<td>Kapulaga</td>
<td>Zingiberaceae</td>
</tr>
</tbody>
</table>

Results of the Shannon-Wiener species diversity analysis indicate that the diversity level in the KUPS area for saplings, poles, and trees falls under the low category with $H' = 1$, while for herbs and shrubs, it falls under the moderate category with $H' = 1.4$. The Shannon-Wiener diversity index is a metric used to measure species richness and diversity within an ecosystem.

The analysis of the Odum species abundance index for trees also showed low results, with $e=1.3$. This species abundance index is used to measure the evenness and diversity of the number of individuals of each species within a population area. The low values of species diversity and abundance are attributed to robusta coffee being the flagship species present in the KUPS Coffee Data Baringin management area, with other trees mostly being fruit trees consumed by the community.

The selection of tree species in the managed area owned by KUPS members is based on their needs. This aligns with what was stated by Gassner in 2022, that the selection of tree species planted by farmers in agroforestry systems is motivated by their need to meet food and income requirements, as well as to
To protect soil fertility and land productivity. Additionally, trees are usually planted as boundary markers or to establish household rights to the land.

To achieve ecological objectives such as biodiversity conservation, water management, climate change mitigation, or land restoration, the needs of farmers, as mentioned earlier, cannot be disregarded. Thus, both of these needs must be met to optimize the ecological and economic functions of agroforestry. Therefore, coffee has the potential to be developed within social forestry programs because it can serve as a productive tree species utilized by farmers and ecologically, it can thrive well under the shade of taller trees.

3.2 The Potency of Carbon Storage and CO2 Sequestration
The carbon storage calculation in *C. canephora* found in the KUPS management area is 3.49 tons/ha. This carbon storage calculation specifically focuses on coffee and does not include other tree species, litter, soil, or understory plants. When compared to the findings of Lestari’s research in 2023, the carbon storage value in robusta coffee plants in Baringin is still higher than the carbon storage of robusta coffee in simple agroforestry in Jember, which is 0.52 tons/ha. However, it is lower when compared to the carbon storage of robusta coffee in complex agroforestry in Jember, which is 12.70 tons/ha. The differences in carbon storage potential are influenced by the vegetation phase and the diameter of coffee trees, as they are directly proportional to their carbon storage potential. Larger diameters lead to higher carbon storage (Rawana et al., 2021).

![Figure 2. Carbon storage in robusta coffee](image)

The diameter of coffee trees is influenced by environmental factors such as sunlight intensity, water content, temperature, and soil fertility, which in turn affect the process of photosynthesis (Sugirahayu and Rusdiana, 2011). Optimal coffee growth occurs at a sunlight intensity level of 34% during the vegetative phase and 50-60% during the generative phase (Thoriq et al., 2020). Coffee cultivated in agroforestry systems exhibits higher carbon storage compared to coffee grown under direct sunlight (Dossa et al., 2005). Based on Niguse et al.’s research in 2022, on average, coffee contributes to 12.8% of the carbon storage in coffee agroforestry systems. Moreover, there is a positive correlation between high carbon storage and biodiversity conservation (Venter, 2014).

Robusta coffee (*C. canephora*) found in the working area of KUPS has the potential to sequester 13 tons/ha of CO2. CO2 is one of the greenhouse gases (GHGs) responsible for a temperature increase of 4.25°F (Jauhari et al., 2021). CO2 concentration contributes approximately 75% of the composition of greenhouse gases in the atmosphere (Rawung, 2015). Therefore, woody plant cultivation is one of the
solutions to mitigate the increase of greenhouse gases that cause climate change. According to Hung et al. in 2021, tree stands and agricultural crops in agroforestry systems represent potential ecosystems for sequestering greenhouse gases, especially CO2. Based on data from Nair et al. in 2010, globally, coffee in agroforestry systems is estimated to have a carbon sequestration potential of 44.8–4.66 Pg C/year in biomass and soil.

3.3 Economical Potential
Community-based forest management or community forestry, particularly in Asia and the Pacific, emerged due to the failure of public forestry organizations to sustainably manage forests (FAO, 2000). Additionally, the forestry industry also failed to develop socio-economic development and meet the needs of the community (FAO, 2016). Meanwhile, the community requires adequate income to fulfill their livelihood needs. Therefore, one of the objectives of social forestry is to help improve the economic well-being of the community in a lasting manner. One approach is through Community Forest Enterprises (CFEs), where social forestry classifies CFEs as Social Forestry Enterprise Groups or KUPS (Kusumawardhani, 2019). CFEs easily adapt to the local community, increase their economic income, encourage investments, and create further job opportunities (Chow, 2015).

In 2017, Baringin Village through the Nagari Forest Management Agency (LPHN) obtained the right to manage a ~484 ha village forest area under the social forestry scheme in the protected forest area of Baringin Village. Then, in 2022, the KUPS Coffee Agroforestry Data Baringin was formed, consisting of robusta coffee farmers in Baringin Village (Nagari). Currently, the land ownership status of KUPS Coffee Agroforestry Data Baringin is the private land of its members. However, KUPS Coffee Agroforestry Data Baringin, which is an organization under the auspices of LPHN Baringin, is projected to acquire management rights over part of the social forestry area. This will expand the management area of KUPS Coffee Agroforestry Data Baringin and potentially contribute to their economic improvement.

The establishment of KUPS helps the community obtain higher selling prices for their coffee harvest. This is because KUPS categorizes the coffee harvest based on grades by conducting sorting for coffee cherries and beans after they have been peeled and dried. As a result, high-quality coffee fetches a higher price, and vice versa. KUPS also adheres to certain standards, such as selling only red coffee cherries, preventing farmers from selling unripe cherries (green and red harvested together). Red coffee cherries indicate mature coffee, while green ones indicate unripe coffee. Harvesting and processing both cherries together can affect the flavor of the coffee. Members of KUPS involved in this activity receive a share of the profits from the final coffee products sold. In line with Kusumawardhani’s statement in 2019 that collective actions can work well if individuals have incentives to collaborate and the capacity to do so.

The income of KUPS members experienced an increase with the sales model developed by KUPS. As depicted in Figure 3, the income range of members showed an increase from the previous range. The average income of members was Rp1,784,000 before the establishment of KUPS. After the establishment of KUPS, their average income increased by 56.82% to Rp2,797,662. Sales of coffee, including the revenue-sharing scheme of KUPS, contributed 55.42% to this increase. This demonstrates that the institutional model within the coffee farmer community has a positive impact on the economic improvement of coffee farmers in Baringin Village.
3.4 Social and Cultural Potential

The involvement and participation of local communities as forest users have been analyzed as an integral part of community-based forest management to promote collective action (Lund, 2015). Collective action within local institutions has been recognized as crucial for effective natural resource management (Shrestha and McManus, 2006). Based on empirical studies, several factors influence community participation in collective action programs, including demographic and socioeconomic variables, social behavior, cost-benefit analysis, community expectations, and satisfaction (Bagherian et al., 2009).

Membership participation in KUPS Agroforestry Coffee Data Baringin is influenced by various factors, including kinship relationships based on ethnicity. The membership of KUPS Agroforestry Coffee Data Baringin consists of three main ethnic groups, namely Sikumbang, Koto, and Tanjung, with Sikumbang being the dominant group. While the recruitment process is open, individuals are more likely to join KUPS if they receive invitations from fellow members of the same ethnic group. Nonetheless, KUPS also accepts coffee contributions from non-members, reflecting the spirit of inclusivity and collaboration in the development of the coffee sector within community-based forest management.

Figure 4. The percentage of kinship based on tribe
KUPS Agroforestry Coffee Data Baringin, established in August 2022, comprises 13 members, with 84.62% being male and 15.38% female. Although males outnumber females, gender differences do not affect their roles and activities. Gender here denotes the roles of males and females resulting from cultural and societal norms, laws, values, and ideologies rather than biological distinctions (Suharjito et al. 2003).

The formation of KUPS not only enhances the community’s income from robusta coffee but also fosters closer social bonds. This is evident in weekly activities, such as joint trips to members’ coffee gardens every Monday and communal work every Friday for coffee cultivation, green bean sorting, or other KUPS activities. These activities also enhance the members’ cooperative abilities, assessed through point systems that can be converted into monetary rewards as an appreciation for active participation.

Furthermore, the establishment of KUPS can also foster a Community of Practice (CoP) among coffee farmers in Baringin. CoP refers to a group of individuals who share a common interest, set of issues, or passion for a particular topic and continuously deepen their knowledge and expertise in this field through ongoing interactions (Wenger et al., 2002). The coffee farming skills in Baringin have been passed down through generations, with coffee trees managed by KUPS being around 100 years old. However, knowledge and skills related to post-harvest coffee processing are limited. KUPS can serve as a platform for farmers to enhance their knowledge and skills, particularly in post-harvest coffee practices.

### 3.5 Coffee Agroforestry System for Social Forestry Program

Ecologically, the coffee agroforestry system in the management area of KUPS Agroforestry Kopi Data Baringin combines robusta coffee trees, fruit trees, and agricultural crops. If applied in social forestry in the protected forest area of Baringin Village, the coffee agroforestry model can still be implemented by integrating the existing tree species in the protected forest area. Economically, the implementation of the coffee agroforestry system, supported by the establishment of the community institution in the form of the Community Forest Enterprises (KUPS) at the farmer level, has proven to have a positive impact on the economic enhancement of KUPS members. Additionally, this institutional model also helps farmers strengthen social bonds and improve their knowledge and skills in coffee cultivation and processing. The cultivation of coffee in the forest area directly contributes to forest protection and deforestation prevention, as the existing forest trees positively influence the productivity of their coffee plants. Consistent with the findings of Neguse (2022), coffee-based forests receive more attention compared to forests without coffee plants. Hence, the coffee agroforestry model and the establishment of KUPS in Baringin Village, Agam Regency, West Sumatra, have the potential to support the implementation of Social Forestry Programs in Indonesia.
3.6 The Implication of Coffee Agroforestry System in Climate Change Mitigation

In this study, the potential carbon storage and CO2 sequestration were calculated only for coffee plants, excluding the entire scope of soil, litter, undergrowth, or other trees. If assessed comprehensively, the potential carbon storage and CO2 sequestration would undoubtedly be greater. Therefore, besides its economic potential, coffee agroforestry also demonstrates promising capabilities in carbon sequestration and CO2 absorption, which would have implications for climate change mitigation.

4. Conclusion

Coffee cultivation using agroforestry models holds the potential to support the objectives of social forestry programs. The institutional model in the form of Community Forest Enterprises (KUPS) within coffee agroforestry has proven effective in enhancing coffee farmers' income and facilitating their knowledge and skills development in coffee cultivation and post-harvest processes. Coffee plants in agroforestry systems also contribute to carbon sequestration, which aids in climate change mitigation.

References

[3] Central Bureau of Statistics 2019 Achievement of Social Forestry Area per Scheme (1,000 Ha) 2017-2018
[4] Central Bureau of Statistics 2023 Deforestation Figures (Net) in Indonesia within and outside Forest Areas from 2013 to 2021 (Ha/Year)
Index (NDVI) Value. Konversi. 10(1) 13–17


[16] Lestari K W 2023 Carbon Storage Potential in Various Agroforestry Types Based on Robusta Coffee (Coffea Canephora) in Rowosari Village, Sumberjambe Subdistrict, Jember Regency Undergraduate thesis (Jember: Jember State University)


[27] Rawung F C 2015 The Effectiveness of Green Open Space (Ruang Terbuka Hijau - RTH) in Reducing Greenhouse Gas Emissions (GRK) in the Urban Area of Boroko Media Matrasain. 12(2) 17-32


