Assessment of factors influencing natural rubber production among smallholder farmers in Liberia using Fuzzy AHP

Peter Davis Sumo (a,b) * Kollie Samuel Himbye (c) Alieu A. Sanoe (d) Mercy Gono (e)
Dorris Z. Sumo (f)

(a) Zhejiang Sci-Tech University, College of Textile Science & Engineering and International Institute of Silk Hangzhou, Zhejiang, China
(b) Organization of African Academic Doctors (OAAD) Off Kamiti Road, P. O. Box 2530500100, Nairobi, Kenya
(c) Zhejiang Gongshang University, School of Management Science and Engineering, China
(d) Zhejiang Sci-Tech University, School of Economics and Management, Hangzhou, Zhejiang, China
(f) Zhejiang Financial College, School of International Exchange, Hangzhou, Zhejiang, China

ABSTRACT
Natural Rubber (NR) is an important agricultural product utilized in various sectors. NR is one of the world's biggest industries and a critical component in many industries such as automotive, manufacturing, and medicine. Liberia is a top producer of NR with over 127 years of production history. However, since 2014, Liberia's NR net production has decreased by 0.7% year on year and has fallen behind Sri Lanka. NR production in Liberia has experienced scant performance due to many factors. In this project, we employ mixed-method research to examine the factors influencing the decline of the Liberian NR supply chain and propose solutions that will further stimulate the industry's growth. We conduct an MCDM study among 34 smallholder rubber farmers from Grand Bassa, Margibi and Bong counties. Their grading of ten policy objectives and recommendations are programmed using Fuzzy AHP.

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Introduction
Natural Rubber (NR) is an important agricultural product utilized in various sectors. NR is one of the world's biggest industries and a critical component in many industries such as technology, automotive, manufacturing, and medicine (Salvatore et al., 2021). Liberia is a top producer of NR with over 127 years of production history.

The Liberian economic system is based on free-market principles and is heavily dependent on natural resources, international assistance, and foreign direct investment (FDI) (ITA, 2021). Mineral exports, notably iron ore, gold, and natural rubber, are Liberia's principal sources of revenue (Sumo, 2019).

Liberia's NR exports account for about 12% of the country's overall exports. As of 2020, Liberia exported $115 million worth of NR to the world. According to sales figures released by Statista, Liberia ranked eleventh among nations exporting NR in 2020 (Tiseo, 2022). Among the top export destinations of Liberia's NR exports are the United States (49%), Canada (17%), Poland (4.0%), France (2.4%), Italy (1.7%), Spain (3.8%), Russia (1.5%), Germany (1.6%), Malaysia (9.5%), Brazil (1.9%). Other destinations include the United Kingdom, Mexico, the Czech Republic, Belarus, Finland, Singapore, and the People's Republic of China (OEC, 2017).
Since 2014, Liberia's NR net production has decreased by 0.7% year on year and has fallen so far behind Sri Lanka in the global ranking. NR production in Liberia has experienced disappointing performance due to many factors. These factors include high overhead costs associated with the concession agreements between large corporations such as Firestone and the Liberian government, low natural rubber production due to the prolonged civil wars, and the persistently low global NR prices. According to 2017 data, annual worldwide NR output increased from nine million tonnes to 13 million tonnes over three years, but demand has not kept pace, resulting in prices plunging from $5,000 per tonne in 2011 to barely $1,000 per tonne in 2018. Small and medium-sized farmers who produce and sell more than 15% of NR produce to the larger corporations in Liberia have hardly felt these events. Additionally, the sector's poor performance has led to more job layoffs and redundancies in big corporations such as Firestone.

Research on Liberia's NR sector is limited, and the few available works of literature draw analysis and conclusions using desk reviews and secondary data sources. Our study contributes to this knowledge gap by empirically assessing the significance of the NR value chain in Liberia. We employ mixed-method research to examine the factors influencing the decline of the Liberian NR supply chain and propose solutions that will further stimulate the industry's growth and boost its resilience. In this effort, our paper raises awareness among government and relevant authorities about the benefits of rubber production in Liberia while assessing the impact of socio-economic characteristics on rubber production in the country. We expand this scope by developing a policy framework that includes criteria for prioritizing Liberia's NR sector. We achieve this by conducting a multi-criteria decision-making (MCDM) study among 34 smallholder rubber farmers from Grand Bassa, Margibi and Bong counties. Their grading of policy objectives and recommendations are programmed using Fuzzy AHP.

We use the Analytical Hierarchical Process (AHP) developed by Saaty (Saaty, 1988) to compare multiple factors to assess their influences on the growth of NR production in Liberia. We further employ the use of fuzzy logic to reconcile the impressions that result from discrete decision-making. Due to slight differences in weights obtained from AHP and fuzzy AHP methods, the Ensemble technique, which determines the average of two weights, is used to combine the weights obtained from the two methods.

This paper is structured as follows: a review of literature is in section 2, the methodology is presented in section 3, the results are in section 4, and the conclusion and recommendation are presented in section 5.

**Literature Review**

**Natural Rubber**

Natural Rubber (NR) is an important agricultural product utilized in various sectors. Today, NR is one of the world's major industries and a critical component of contemporary technology, automotive, manufacturing, and medicine (Salvatore et al., 2021).

Africa has cultivated NR since the 19th century (Umar et al., 2011) and currently holds a 7.4% share of the 13.86 million tons of global NR production (ANRPC, 2021). Most of Africa's total NR production (1.1 million tons) is concentrated in West Africa; a figure shared between Ivory Coast 82.4%, Liberia 9.1%, Nigeria 4.6%, and Cameroon 3.9% (SIPH, 2021). NR is a crucial role player in these developing countries (Manivong & Cramb, 2008). It is a critical cash crop fueling the economy of many developing nations through job creation, improved livelihoods, revenues generations, and increased food and nutrition security (Achterbosch, 2014; Mulbah et al., 2021). In Liberia, rubber has a long and contentious history—the cultivation of the crop began more than 127 years ago during the tenure of President Hilary R.W. Johnson in 1890. In 1926, the Liberian government granted Firestone one million acres of land at six cents per acre in a 99-year lease agreement. Due to interruption in NR production in the late 1940s, the Liberian government quickly ushered in seven additional concessions to booster production. These included the Cocopa Rubber Plantation, which signed a 40-year agreement in 1949. The Sinoe Rubber Corporation concluded its concession agreement for 80 years in 1953. The Guthrie Rubber Plantation was established in 1954 and commenced production in 1963. The Liberia Agriculture Corporation (LAC), a multi-national company, signed a 70-year lease agreement on 125,000 hectares in 1959. The Salala Rubber Corporation was established in 1959, with 40,000 hectares and the Cavalla Rubber Plantation (Kraaij, 2015; Mulbah et al., 2021). NR is Liberia's most important agricultural export product and a source of income for many rural residents (Seward, 2021). In addition, the sector is a provider of a much-needed source of government revenue and a corridor for formal employment for many in a nation with a mostly subsistence agricultural economy (Outram, 2016). For example, between 2003 and 2010, NR accounted for over 85% of Liberia's total export earnings. The industry is dominated by small and medium-sized farms, which account for more than 5% of agricultural land (Mulbah et al., 2021). Continent-wise, Liberia is currently the second biggest NR producer in Africa, behind the Ivory Coast and 14th highest producer globally, with 70101 metric tons, according to a 2019 report (NationMaster, 2019).

Despite the establishment of the above multi-national corporations (MNCs) and the enormous contributions of natural rubber to export earnings and livelihoods of Liberia, there are still low income and high poverty rates among the farmers. Additionally, there has been no attempt to erect a processing plant to fabricate necessities such as rubber sandals, inner tubes, slappers, tires, or rubber dishes for local consumption purposes.

**Fuzzy Logic and AHP**

As an MCDM tool, Thomas L. Saaty created the Analytic Hierarchy Process (AHP) in the 1970s. MCDM involves making decisions based on criteria or goals in a hierarchical manner. They are generally based on some criterion or sub-criteria that significantly impact the decision-making process. In an MCDM situation, utilizing an AHP technique, psychological qualities are transformed into...
mathematical reasoning with relative priority using hierarchal structures. It creates a quantitative framework based on pairwise comparisons to lead the criteria and options towards the needed aim. Each criterion's relative importance or weightage is assessed and scored for comparison (Lin et al., 2019; Penadés-Plà et al., 2016).

AHP is a powerful MCDM technique with extensive acceptance and application in numerous research domains due to its methodological simplicity and flexibility in gathering input data in a hierarchical structure (Kaya et al., 2019). The AHP method, on the other hand, is unable to account for the uncertainty in the preference ratings used to score the criterion. Fuzzy logic developed by (Zadeh, 1965) is paired with AHP to form fuzzy AHP. Combining fuzzy logic with AHP solves the imprecision complexity by enabling decision-makers to express their opinions using a range of values on a fuzzy scale rather than the AHP scale. This integrated technique maintains AHP's advantages and has been extensively used (Chan et al., 2007; Mardani et al., 2015).

A detailed review of Fuzzy logic and AHP and some of their applications can be found in the following citations: (Baumann et al., 2019; Guersola et al., 2018; Kaymaz et al., 2021; Kramar & Topolšek, 2018; Liu et al., 2020; Navarro et al., 2020; Pelissari et al., 2021; Ruiz Bargueño et al., 2021; Sarjono et al., 2020; Sitorus et al., 2019; Yap et al., 2019).

Methodology

Data Sourcing and Study Point

Interviews and data collected for this study were taken from three (3) rubber producing areas of Liberia—Grand Bassa, Margibi and Bong counties. Attempts were made to reach farmers in other parts of the country, including Maryland, Grand Gedeh and Lofa counties. However, due to limited resources, poor network coverage, and these counties' remoteness for our interviewer, data from them could not be sourced. In addition, interviews were conducted for selected farmers in Nimba county, but the accompanied FAHP forms were not returned, amounting to exclusion for Nimba county.

The three regions surveyed harbor some of the largest farms and together form the most significant rubber-producing points in Liberia. For instance, Margibi county hosts the largest plantation and processing center, Firestone, which covers an area of 1 million acres. Our surveyed regions also host essential plantations in the country, such as the Liberia Agriculture Corporation (LAC), a multinational company with a 70-year lease agreement on 125,000 hectares, the Salala Rubber Corporation with 40,000 hectares, etc. The presence of these plantations has fueled the growth of smallholder farmers who sell their latex to these large plantations at a low cost.

Defining the NR Factors

Interviews conducted among the 34 smallholder rubber farmers highlighted many factors or challenges impeding the NR production sector. However, some factors were more personal and did not reflect the feeling of others. In addition, owing to the limitation of AHP and to keep the analysis as concise as possible, we summarized factors into ten critical points that were then fed to the AHP model. Table 1 contains the list of summarized factors.

Table 1: The NR criteria considered for this project

| Factors                  | Description                                                                 |
|--------------------------|-----------------------------------------------------------------------------|
| C1                       | Reliance on low-yielding seedlings—this is due to lack of know-how in the production of clonal rubber, lack of farmers' self-initiative, government's reluctance to make interventions |
| C2                       | Difficulties getting rubber to the market due to deplorable roads and defective vehicles |
| C3                       | Lack of technical know-how in the growing of clonal rubber                   |
| C4                       | Limited or no access to credit finance                                       |
| C5                       | Obscurity of land ownership in communal towns is a source of land conflict   |
| C6                       | Falling rubber prices compounded by the rising cost of farm inputs           |
| C7                       | The practice of slash-and-burn farming, which is frowned upon by environmentalists and, environmental protectionists, buyers of rubber and rubber-related products. The vast majority of farmers do not have the means to procure or hire machines to clear their farms. |
| C8                       | Unavailability of buyers in or near parts of the country—e.g., Grand Gedeh, River Gee, Maryland, Grand Kru and Sinoe Counties |
| C9                       | Lack of technical ability and know-how in value addition                    |
| C10                      | Illicit tapping and theft of rubber crops from farmers                      |
Table 2: Demographic data of respondents

| Measure   | Items          | Margibi County | Bong County | Grand Bassa County |
|-----------|----------------|----------------|-------------|--------------------|
|           | Freq | %   | Freq | %   | Freq | %   |
| Gender    |       |      |      |      |      |      |
| Male      | 11   | 91.7 | 11  | 100 | 9    | 81.8 |
| Female    | 1    | 8.3  | 0   | 0   | 2    | 18.2 |
| Age       |       |      |      |      |      |      |
| 10-19     | -    | -    | -   | -   | -    | -    |
| 20-29     | -    | -    | -   | -   | -    | -    |
| 30-39     | 2    | 16.7 | 1   | 9.1 | 1    | 9.1  |
| 40-49     | 3    | 25.0 | 3   | 27.3| 3    | 27.3 |
| 50-59     | 3    | 25.0 | 4   | 36.4| 3    | 27.3 |
| 60 & above| 4    | 33.3 | 3   | 27.3| 4    | 36.4 |
| Total     | 12   | 100 | 11  | 100 | 11   | 100  |

Model Formulation

AHP

To extract essential choices relevant to the improvement of the NR supply chain, we begin with a set of criteria, which we fed to the AHP model. As a result, we developed pairwise comparisons based on the judgments of 34 farmers as follows:

Step 1: Our study obtained criteria weights through pairwise comparisons of factors collected from each respondent and calculated the average of each response for each criterion from all respondents. Using Saaty’s scale (table 3) to compare criteria, we determined the significance of each factor $n^{th}$ based on the weight denoted as $a_n$. The graded value is considered when the grade attached to the decision criterion appears in column 2 of Table 3; otherwise, the inverse value is considered. Accordingly, we can compute a pairwise comparison of matrix $A$.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \text{ where } i,j = 1, \ldots, n$$

Table 3: Five-point fuzzy preference scale, numbers and inverse values

| Preference Value         | Numerical Value | Fuzzy Numbers | Inverse Values |
|--------------------------|-----------------|---------------|----------------|
| Equally Preferred        | 1               | 1.000         | 1.000          | 1.000          | 1.000          |
| Moderately Preferred     | 3               | 2.000         | 3.000          | 4.000          | 0.250          | 0.333          | 0.500          |
| Strongly Preferred       | 5               | 4.000         | 5.000          | 6.000          | 0.167          | 0.200          | 0.250          |
| Very Strongly Preferred  | 7               | 6.000         | 7.000          | 8.000          | 0.125          | 0.143          | 0.167          |
| Extremely Preferred      | 9               | 9.000         | 9.000          | 9.000          | 0.111          | 0.111          | 0.111          |

Step 2: To normalize the pairwise comparison matrix, we divide each column total by its element in the pairwise comparison matrix using equations 2 and 3.

$$X_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{ij}} \text{ for all } j = 1, 2, \ldots, n$$

$$X = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & X_{nn} \end{bmatrix}$$

Step 3: To obtain the weighted matrix (equation 4), we take the average of the rows of the normalized matrix.

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\[ W_i = \frac{\sum_{j=1}^{n} X_{ij}}{n} \]

\[ W = \begin{bmatrix}
W_1 \\
W_2 \\
\vdots \\
W_n
\end{bmatrix} \]

for all \( i = 1, 2, ..., n \)

**Step 4:** Using the pairwise comparison of the matrix \( C \), we summed the column elements multiplied by the corresponding weight \( W_i \) to derive the consistency vector.

\[ C_{V_i} = [C_{1i} + C_{2i} ... C_{ni}] \times W_i \]

where \( i = 1, 2, ... n \)

**Step 5:** Using equation 8, we calculated the principal eigenvalue \( \lambda_{max} \) by summing the elements of the consistency vector \( (C V) \).

\[ \lambda_{max} = \sum_{i=1}^{n} C_{V_i} \]

**Step 6:** The Consistency Index \( (CI) \) is a metric for determining how consistent respondents' views are. The CI, calculated as the difference between the smallest eigenvalues and the dimension of the comparison matrix \( n \), quantifies how much respondents' views vary.

\[ CI = \left( \frac{\lambda_{max} - n}{n-1} \right) \]

**Table 4:** Random index values

| Matrix | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Random (RI) | 0   | 0   | 0.58| 0.9 | 1.12| 1.24| 1.32| 1.41| 1.45| 1.49| 1.51| 1.58|

The Random Consistency Index \( (RI) \), dependent on the number of criteria, is calculated by comparing the computed \( CI \) with values of the random index developed by Saaty (see table 4).

**Step 7:** Using the following equation, we calculate the consistency ratio between \( CI \) and \( RI \).
\[ CR = \frac{CI}{RI} \]

**Fuzzy AHP**

**Step 8:** TFN is defined by \( \tilde{M} = (l, m, u) \) with \( l \) and \( u \) as lower and upper bounds, respectively. \( u \) defines the point at which \( \mu_{\tilde{M}}(x): U \subseteq R \to [0,1] \), with membership function as in equation 11, where \( \mu_{\tilde{M}}(x) = 1 \):

\[
\mu_{\tilde{M}}(x) = \begin{cases} 
\frac{x}{m-l} & x \in [l, m] \\
\frac{m-x}{m-u} & x \in [m, u] \\
0 & \text{otherwise}
\end{cases}
\]

**Step 9:** If \( \tilde{M}_1 = l_1, m_1, u_1 \) and \( \tilde{M}_2 = l_2, m_2, u_2 \) then the operational laws of addition, multiplication, reciprocal, and division for these two TFN can be presented as follows:

\[
\begin{align*}
\tilde{M}_1 \oplus \tilde{M}_2 &= (l_1 + l_2, m_1 + m_2, u_1 + u_2) \\
\tilde{M}_1 \otimes \tilde{M}_2 &= (l_1 + u_2, m_1 - m_2, u_1 + l_2) \\
\tilde{M}_1 \oplus \tilde{M}_2 &= (l_1, m_1 + m_2, u_1 + u_2) \\
\tilde{M}_1 \otimes \tilde{M}_2 &= \left( \frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2} \right) \\
\tilde{M}_1 \tilde{M}_1^{-1} &= \left( \frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1} \right) \text{ for } l, m, u > 0
\end{align*}
\]

The decision maker’s judgment about the relative importance of factor \( i \) relative to factor \( j \) at the same hierarchical level is expressed in the matrix \( \tilde{A} \) of fuzzy estimates with fuzzy comparison values \( \tilde{a}_{ij} \), which expresses the decision maker’s judgment about the scale level for each indicator and the weighting of the criteria.

\[
\tilde{A} = \begin{bmatrix}
\tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\
\tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn}
\end{bmatrix}
\]

**Step 10:** The fuzzy priority is then estimated using the geometric mean approach described by (Buckley, 1985)
\[ \bar{r}_i = \left( \frac{1}{n} \prod_{j=1}^{n} \bar{r}_{ij} \right)^{1/n} \]

and

\[ \bar{w}_i = \bar{r}_i \otimes \left( \sum_{i=1}^{n} \bar{r}_i \right)^{-1}, i = 1, 2, ..., n \]

Where \( \bar{r}_i \) is the geometric mean of fuzzy priority, \( n \) denotes the number of criteria or alternatives, while \( \bar{w}_i \) denotes the fuzzy number. Lastly, we defuzzify \( \bar{w}_i \) as described in the following equation (20).

\[ \bar{w}_i = \left( \frac{l + m + u}{3} \right) \]

**Ensemble of AHP and Fuzzy Weights**

**Step 11:** Due to slight differences in weights obtained from AHP and fuzzy AHP methods, the Ensemble technique, which determines the average of two weights, is used to combine the weights obtained from the two methods (Das & Pal, 2020; Sahani, 2021).

\[ Ensemble \text{ weight} = \frac{AHP_{gw(n)} + FAHP_{gw(n)}}{2} \]

Where \( gw(n) \) is the global weight value of the same alternative or criterion derived by AHP and Fuzzy AHP at the same hierarchical level.

**Results and Discussion**

In this project, we employ a mixed-method research to examine the factors influencing the decline of the Liberian NR supply chain and propose solutions that will further stimulate the industry’s growth and boost its resilience. We applied fuzzy logic and AHP to develop matrices from pairwise comparisons of factors affecting natural rubber production in Liberia using a 5-point comparison scale proposed by (Saaty, 1988). We determined the weights of factors (criteria) by first computing the AHP, which tested the consistency of the comparison data and subsequently applied fuzzy logic to phase out the imprecision in respondents’ judgements. Lastly, due to the variations in weights from the AHP and fuzzy logic calculations, we employed the Ensemble method, which averages the results of the two methods. The results of our computations are presented in Tables 5 to 7.

Ensemble values in table 7 show that C4—limited or no access to credit finance experienced principally by nearly 90% of Liberia’s smallholder NR farmers is the most significant concern among farmers in Liberia. The limited or no access to credit finance is particularly severe for farmers who farm on customary (communal) lands which are not statutorily deeded to individual members of the communities and, hence, unfit for collateral. Falling rubber prices compounded by the rising cost of farm inputs (C6) was ranked as the second most significant factor affecting farmers’ efficiency in NR production in Liberia. This is evident in Liberia as, since 2014, NR net production has decreased by 0.7% year on year and has fallen behind Sri Lanka in terms of the global ranking. The high overhead costs associated with concession agreements between Firestone, the leading buyer, and the persistently low global natural rubber prices greatly influence the falling rubber prices.

Other priorities as expressed by farmers include C2—difficulties getting rubber to the market due to deplorable roads and defective vehicles. This concern of farmers is reflected in Iimi & Rao’s (2018) work on the spatial analysis of Liberia’s transport connectivity and potential growth. The authors highlight that the road network has deteriorated drastically due to a lack of maintenance caused by the prolonged civil war. Over 60% of unpaved roads are in poor or very poor condition. Secondary and tertiary road networks, which provide last-mile connections in rural regions, are in deplorable conditions. About 40% of major roads, 50% of secondary roads, and 60% of tertiary roads are in appalling conditions (Iimi & Rao, 2018). Farmers’ lack of technical ability and know-how in their value addition processes (C9) was ranked as the fourth point of concern. Illicit tapping and theft of rubber crops from farmers (C10) has been reported on many farms and plantations. These atrocities are mainly perpetrated by gangs of mostly young men, who illegally tap the latex rubber trees and sell them to merchants for profit.

C3—the lack of technical know-how in the growing of clonal rubber—and C8—the unavailability of buyers in or near parts of the country—e.g., Grand Gedeh, River Gee, Maryland, Grand Kru and Sinoe Counties were ranked 6th and 7th, respectively. Buyers’ inability to access smallholder farmers in these areas is highly influenced by the lack of road infrastructure in the country. procurement or hire machines to clear their farms. Lastly, C5—obscurity of land ownership in communal towns, a source of land conflict, was ranked 10.
Table 5: AHP comparison matrix obtained from all responses

|   | C1    | C2    | C3    | C4    | C5    | C6    | C7    | C8    | C9    | C10   |
|---|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| C1| 1     | 1/5   | 1     | 1/5   | 3     | 1/5   | 1     | 1/3   | 1/5   | 1/3   |
| C2| 5     | 1     | 3     | 1     | 5     | 1     | 3     | 1     | 5     | 1     |
| C3| 1     | 1/3   | 1     | 1/3   | 1     | 1/5   | 1     | 3     | 1     | 3     |
| C4| 5     | 1     | 3     | 1     | 7     | 3     | 9     | 5     | 5     | 5     |
| C5| 1/3   | 1/5   | 1     | 1/7   | 1     | 1/7   | 1     | 1/3   | 1/3   | 1/3   |
| C6| 5     | 1     | 5     | 1/3   | 7     | 1     | 9     | 5     | 3     | 3     |
| C7| 1     | 1/3   | 1     | 1/9   | 1     | 1/9   | 1     | 1/3   | 1/3   | 1/3   |
| C8| 3     | 1/3   | 1/3   | 1/5   | 1     | 1/5   | 1     | 1/3   | 1/3   | 1/3   |
| C9| 1     | 1/5   | 1/5   | 1/3   | 3     | 1/3   | 3     | 3     | 1     | 1     |
| C10| 5    | 1     | 3     | 1     | 3     | 1/3   | 3     | 3     | 1     | 1     |

Table 6: Fuzzy AHP comparison matrix obtained from all responses

|   | C1    | C2    | C3    | C4    | C5    | C6    | C7    | C8    | C9    | C10   |
|---|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| C1| (1,1,1)| (1/6,1/5,1/4)| (1,1,1)| (1/6,1/5,1/4)| (2,3,4)| (1/6,1/5,1/4)| (1,1,1)| (1/4,1/3,1/5)| (1/6,1/5,1/4)| (1/4,1/3,1/5)|
| C2| (4,5,6)| (1,1,1)| (2,3,4)| (1,1,1)| (4,5,6)| (1,1,1)| (2,3,4)| (2,3,4)| (1,1,1)| (4,5,6)|
| C3| (1,1,1)| (1/4,1/3,1/5)| (1,1,1)| (1/4,1/3,1/5)| (1,1,1)| (1/6,1/5,1/4)| (1,1,1)| (2,3,4)| (1,1,1)| (2,3,4)|
| C4| (4,5,6)| (1,1,1)| (2,3,4)| (1,1,1)| (6,7,8)| (2,3,4)| (9,9,9)| (4,5,6)| (4,5,6)| (4,5,6)|
| C5| (1/4,1/3,1/5)| (1/6,1/5,1/4)| (1,1,1)| (1/8,1/7,1/6)| (1,1,1)| (1/8,1/7,1/6)| (1,1,1)| (1/4,1/3,1/5)| (1/4,1/3,1/5)|
| C6| (4,5,6)| (1,1,1)| (4,5,6)| (1/4,1/3,1/5)| (6,7,8)| (1,1,1)| (9,9,9)| (4,5,6)| (2,3,4)| (2,3,4)|
| C7| (1,1,1)| (1/4,1/3,1/5)| (1,1,1)| (1/9,1/9,1/9)| (1,1,1)| (1/9,1/9,1/9)| (1,1,1)| (1/4,1/3,1/5)| (1/4,1/3,1/5)|
| C8| (2,3,4)| (1/4,1/3,1/5)| (1/4,1/3,1/5)| (1/6,1/5,1/4)| (1,1,1)| (1/6,1/5,1/4)| (1,1,1)| (1/4,1/3,1/5)| (1/4,1/3,1/5)|
| C9| (4,5,6)| (1,1,1)| (1,1,1)| (1/6,1/5,1/4)| (2,3,4)| (1/4,1/3,1/5)| (2,3,4)| (2,3,4)| (1,1,1)| (1,1,1)|
| C10| (2,3,4)| (1/6,1/5,1/4)| (1/4,1/3,1/5)| (1/6,1/5,1/4)| (2,3,4)| (1/4,1/3,1/5)| (2,3,4)| (2,3,4)| (1,1,1)| (1,1,1)|

Table 7: AHP, FAHP and Ensemble weights of all factors

| Criteria | Weights | Ensemble Weights | Rank |
|----------|---------|-----------------|------|
| AHP      | 0.038   | 0.036           | 0.037| 8    |
| FAHP     | 0.165   | 0.166           | 0.166| 3    |
|          | 0.069   | 0.064           | 0.067| 6    |
|          | 0.259   | 0.264           | 0.262| 1    |
|          | 0.031   | 0.031           | 0.031| 10   |
|          | 0.197   | 0.203           | 0.200| 2    |
|          | 0.034   | 0.035           | 0.035| 9    |
|          | 0.041   | 0.040           | 0.041| 7    |
|          | 0.095   | 0.093           | 0.094| 4    |
|          | 0.070   | 0.069           | 0.070| 5    |
| CR=0.09  | 0.070   | 0.069           | 0.070| 5    |

Reliance on low-yielding seedlings (C1) was ranked 8th. This is due to a lack of know-how in the production of clonal rubber, a lack of farmers' self-initiative, and the government's reluctance to make interventions. It was followed by (C7) the practice of slash-and-burn farming, which is frowned upon by environmentalists and environmental protectionists, buyers of rubber and rubber-related products. The vast majority of farmers do not have the means to
Conclusion

Rubber is the most significant agricultural product in Liberia. In recent years, foreign investment in this sector has risen due to the reemergence of substantial commercial agricultural concessions. Smallholder subsistence agriculture is the most important source of income for the vast majority of the Liberian people. Despite considerable progress in Liberia’s agricultural industry, the country still faces several obstacles. A series of concerns have been raised for the rubber sector to remain viable. They call for the industry to take an integrated approach to resource management that incorporates new farming methods and prioritizes vital agricultural systems for local farmers.

Contracting methods and protections and crop production and processing criteria for latex have received little attention in the Liberian agricultural policies. This has led to a policy vacuum, which has ramifications for current enterprise initiatives and smallholders in the short and medium term. Smallholder rubber farmers are becoming increasingly sensitive to these challenges. They are thus converting to other crops due to policy uncertainty, market changes in latex prices, and price variations in NR and other agricultural commodities. To address this challenge, the government should design an effective, sustainable, long-term, and locally beneficial rubber industry by adapting appropriate policies in collaboration with the private sector. Rubber concessions and contracts review should be hastened to provide clear steps for investors and the government to address lingering difficulties.

Government and relevant authorities can address reliance on low-yielding seedlings due to lack of know-how in the production of clonal rubber, lack of farmers’ self-initiative, and their reluctance to intervene by providing knowledge and skill development training in the production of budded rubber stumps. This training should encompass planting and managing seeds nursery and budwood garden, bud-grafting of rubber seedlings, and planting budded plants. In addition, significant rubber concessions such as Firestone, Liberia Agricultural Company (LAC) can collaborate with the Rubber Development Fund (RDF) to provide high-yielding clones to farming communities that can be used to plant budwood gardens for farmers of those communities.

Farmers pay four cents on every dollar of rubber sold as turnover tax to the government. It is thus paramount for the government to reinvest a quarter to a third of this money in the rehabilitation of farm-to-market roads to ease the difficulties of getting rubber to the market due to deplorable roads and defective vehicles. It is also paramount for large rubber concessions and local companies buying rubber to help rehabilitate at least 25 km of farm-to-market roads each year. These initiatives can help buttress farmers’ efforts to share the cost of road rehabilitation through companies through MOUs that provide some form of cost-sharing.

Large rubber concessions can emphasize full extension (farm advisory) services that include the deployment of technicians across the country to help ease the lack of technical know-how in the growing of clonal rubber. With these efforts, farmers can take advantage of vocational training or college education in agriculture. Training workshops/seminars on cultivating clonal rubber either by government or development partners is also a welcomed approach.

There is a need for the extension of soft or uncollateralized loans with the provision that, in case the borrower (farmer) defaults, the lender can take over and manage farm(s) until the loan is fully liquidated. Such a move is a suggested solution to ease the problem of limited or no access to credit finance which is experienced principally by nearly 90% of Liberian farmers who farm on customary (communal). Organizing farmers into cooperatives, seen as formal organizations, will also attract some financing.

Obscurity of land ownership in communal towns is a source of land conflict. The government needs to enact strong legislation that spells out how communal land should be distributed. In addition, farmers can follow best practices and institute measures to control cost, reduce wastage, and maximize their production to address the falling prices of rubber.

Slash-and-burn farming is frowned upon by environmentalists, protectionists, and buyers of rubber and rubber-related products. The vast majority of farmers do not have the resources to procure or hire machines to clear their farms. Thus, it is recommended to develop country-specific rules that make slash and burn acceptable in third-world countries where most people are poor and underprivileged. This approach is restricted to secondary jungle or land that has been left fallow for the growth of annual or biennial crops.

The government’s intervention in improving road connectivity to remote parts of the country will help ease the unavailability of buyers in or near parts of the country. Farmers’ initiatives could also form cooperatives to pool crops, share costs, and manage resources.

Illicit tapping and theft of rubber crops is a severe challenge for farmers. Rubber processors can improve this challenge by discontinuing rubber broker activities with illicit tappers and dealing directly with rubber farmers. They could also assess farms and buy only the amount of rubber that each farmer or group can bring. On the other hand, Rubber farmers could build consensus to report anybody found with tuber and is trying to sell, or pass it through, another farmer. The government’s intervention could prohibit the export of unprocessed natural rubber in order to support the technical ability and know-how in the NR value addition. Lastly, authorities should prosecute and harshly punish culprits found in illicit tapping in accordance with the law.

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References

Achterbosch, T. (2014). Cash crops and food security: Contributions to income, livelihood risk and agricultural innovation. 59. ANRPC. (2021). The Association of Natural Rubber Producing Countries (ANRPC). http://www.anrpc.org/

Baumann, M., Weil, M., Peters, J. F., Chibeles-Martins, N., & Moniz, A. B. (2019). A review of multi-criteria decision making approaches for evaluating energy storage systems for grid applications. Renewable and Sustainable Energy Reviews, 107, 516–534. https://doi.org/10.1016/j.rser.2019.02.016

Buckley, J. J. (1985). Fuzzy hierarchical analysis. Fuzzy Sets and Systems, 17(3), 233–247. https://doi.org/10.1016/0165-0114(85)90090-9

Chan, F. T. S., Chan, H. K., Ip, R. W. L., & Lau, H. C. W. (2007). A decision support system for supplier selection in the airline industry. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 221(4), 741–758. https://doi.org/10.1243/09544054JEM629

Das, B., & Pal, S. C. (2020). Assessment of groundwater vulnerability to over-exploitation using MCDA, AHP, fuzzy logic and novel ensemble models: a case study of Goghat-I and II blocks of West Bengal, India. Environmental Earth Sciences, 79(5), 104. https://doi.org/10.1007/s12665-020-8843-6

Guer sola, M., De Lima, E. P., & Steiner, M. T. A. (2018). Supply chain performance measurement: a systematic literature review. International Journal of Logistics Systems and Management, 31(1), 109–131. https://doi.org/10.1504/IJLSM.2018.094193

Ilim, A., & Rao, K. (Eds.). (2018). Spatial Analysis of Liberia's Transport Connectivity and Potential Growth. The World Bank. https://doi.org/10.1596/978-1-4648-1286-6

ita. (2021). Liberia - Market Overview. https://www.trade.gov/country-commercial-guides/liberia-market-overview

Kaya, I., Çolak, M., & Terzi, F. (2019). A comprehensive review of fuzzy multi criteria decision making methodologies for energy policy making. Energy Strategy Reviews, 24, 207–228. https://doi.org/10.1016/j.esr.2019.03.003

Kaymaz, Ç. K., Birinci, S., & Kızılkan, Y. (2021). Sustainable development goals assessment of Erzurum province with SWOT-AHP analysis. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-021-01584-w

Kraaij, F. P. M. van der. (2015). Liberia: from the love of liberty to paradise lost (Issue 21). African Studies Centre.

Kramar, U., & Topolšek, D. (2018). Applications of Fuzzy Analytic Hierarchy Process in Urban Mobility System. Tehnicki Vjesnik - Technical Gazette, 25(5). https://doi.org/10.17559/TV-20160927163837

Lin, R., Liu, Y., Man, Y., & Ren, J. (2019). Towards a sustainable distributed energy system in China: decision-making for strategies and policy implications. Energy, Sustainability and Society, 9(1), 51. https://doi.org/10.1186/s13705-019-0237-9

Liu, Y., Eckert, C. M., & Earl, C. (2020). A review of fuzzy AHP methods for decision-making with subjective judgements. Expert Systems with Applications, 161, 113738. https://doi.org/10.1016/j.eswa.2020.113738

Manivong, V., & Cramb, R. A. (2008). The Adoption of Smallholder Rubber Production by Shifting Cultivators in Northern Laos: A Village Case Study. In P. K. R. Nair, D. J. Snedler, & R. D. Lasco (Eds.), Smallholder Tree Growing for Rural Development and Environmental Services (Vol. 5, pp. 117–137). Springer Netherlands. https://doi.org/10.1007/978-1-4020-8261-0_5

Mardani, A., Jusoh, A., Zainab, N., & Valipour, A. (2015). Multiple criteria decision-making techniques and their applications – a review of the literature from 2000 to 2014. Economic Research-Ekonomiska Istraživanja, 28(1), 516–571. https://doi.org/10.2478/ire-2015-0317

Mubah, F. B. B., Ritho, C., & Mburu, J. (2021). Do transaction costs influence smallholder rubber farmers' choice of selling outlets? Evidence from Liberia. Development in Agriculture, 18(1), 69–80. https://doi.org/10.1080/09614524.2020.1789068

NationMaster. (2019). Natural Rubber Production in Liberia. In NationMaster. https://www.nationmaster.com/mnx/timeseries/liberia-natural-rubber-production

Navarro, I. J., Penadés-Pià, V., Martínez-Muñoz, D., Rempling, R., & Yepes, V. (2020). Life Cycle Sustainability Assessment For Multi-Criteria Decision Making In Bridge Design: A Review. Journal Of Civil Engineering And Management, 26(7), 690–704. https://doi.org/10.3846/jcem.2020.13599

OEC. (2017). OEC - Liberia (LBR) Exports, Imports, and Trade Partners. https://legacy.oec.world/en/profile/country/lbr/

Outram, Q. (2016). Africa south of the sahara 2017: Liberia: Economy. Taylor & Francis.

Pelissari, R., Khan, S. A., & Ben-Amor, S. (2021). Application of Multi-Criteria Decision-Making Methods in Sustainable Manufacturing Management: A Systematic Literature Review and Analysis of the Prospects. International Journal of Information Technology & Decision Making, 1–23. https://doi.org/10.1142/S0219622021300020
Penadés-Plà, V., García-Segura, T., Martí, J., & Yepes, V. (2016). A Review of Multi-Criteria Decision-Making Methods Applied to the Sustainable Bridge Design. **Sustainability**, 8(12), 1295. https://doi.org/10.3390/su8121295

Ruiz Barquèno, D., Salomon, V. A. P., Marinis, F. A. S., Palominos, P., & Marrone, L. A. (2021). State of the Art Review on the Analytic Hierarchy Process and Urban Mobility. **Mathematics**, 9(24), 3179. https://doi.org/10.3390/math9243179

Saaty, T. L. (1988). What is the Analytic Hierarchy Process? In **Mathematical Models for Decision Support** (pp. 109–121). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-83555-1_5

Sahani, N. (2021). Application of hybrid SWOT-AHP-FuzzyAHP model for formulation and prioritization of ecotourism strategies in Western Himalaya, India. **International Journal of Geotechnology and Parks**, 9(3), 349–362. https://doi.org/10.1016/j.ijgeop.2021.08.001

Salvatore, A., A., A., V., J., S.-B., L., N., E., G., E., P., & A., M. (2021). **Natural rubber systems and climate change: Proceedings and extended abstracts from the online workshop, 23–25 June 2020**. Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/008029

Sarjono, H., Seik, O., Defan, J., & Simamora, B. H. (2020). Analytical hierarchy process (Ahp) in manufacturing and non-manufacturing industries: A systematic literature review. **Systematic Reviews in Pharmacy**, 11(11), 158–170. https://doi.org/10.31838/srp.2020.11.23

Seward, D. M. (2021). Case Study on Value Chain Analysis of Natural Resource Exports in Liberia. **Journal of Service Science and Management**, 14(06), 597–626. https://doi.org/10.4236/jssm.2021.146038

SIPH. (2021). **Production**. https://siph.groupesifca.com/en/natural-rubber-production

Sitoriis, F., Cilliers, J. J., & Brito-Parada, P. R. (2019). Multi-criteria decision making for the choice problem in mining and mineral processing: Applications and trends. **Expert Systems with Applications**, 121, 393–417. https://doi.org/10.1016/j.eswa.2018.12.001

Sumo, P. D. (2019). Impacts of Ebola on Supply Chains in MRB Countries. **International Journal of Research in Business and Social Science** (2147-4478), 8(3), 122–139. https://doi.org/10.20525/ijrbs.v8i3.264

Tiseo, I. (2022). Liberia natural rubber exports value 2020. In **Statista**. https://www.statista.com/statistics/1184220/natural-rubber-exports-value-from-liberia/

Umar, H. Y., Giroh, D. Y., Agbonkpolor, N. B., & Mesike, C. S. (2011). An Overview of World Natural Rubber Production and Consumption: An Implication for Economic Empowerment and Poverty Alleviation in Nigeria. **Journal of Human Ecology**, 33(1), 53–59. https://doi.org/10.1080/09709274.2011.11906350

Yap, J. Y. L., Ho, C. C., & Ting, C.-Y. (2019). A systematic review of the applications of multi-criteria decision-making methods in site selection problems. **Built Environment Project and Asset Management**, 9(4), 548–563. https://doi.org/10.1108/BEPAM-05-2018-0078

Zadeh, L. A. (1965). Fuzzy sets. **Information and Control**, 8(3), 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

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