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Assessing the Sustainability of Palm Oil by Expert Interviews—An Application of the Analytic Hierarchy Process

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Abstract: Palm oil plays a crucial role in the food industry, industrial applications, and bioenergy, accounting for over one-third of global vegetable oil production. The production area has quadrupled, and the volume is about seven times higher today than in the early 1990s. This significant increase is attributed to several factors, including the oil palm's notably higher yield per hectare compared to other oilseeds, cost-effectiveness, versatility, and excellent manufacturing characteristics. Despite its economic benefits, industrial palm oil production raises substantial ecological and social concerns, such as deforestation, habitat loss, and labor issues. This study presents a comprehensive sustainability assessment that concurrently considers economic, environmental, and social aspects. Through qualitative expert interviews, various stakeholders in the supply chain evaluated the sustainability criteria of palm oil production and application using the Analytical Hierarchy Process (AHP), a decision support tool helping to analyze, structure, and solve complex decision problems. The results reveal that, on average, the experts consider environmental criteria to be of the highest importance, followed by social sustainability, while economic criteria are of lower significance. However, the approximations regarding the weighting of the criteria showed considerable variations among experts. The AHP priority index for RSPO-certified palm oil is nearly as high as the reference product "EU canola oil"; this observation is consistent with all expert judgments. This study provides an adequate approach to assessing the sustainability of agricultural supply chains, offering practical recommendations for the food industry and policymakers.

Keywords: palm oil; sustainability; sustainability assessment; decision support; analytical hierarchy process; AHP

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1. Introduction

Palm oil is a highly versatile oil, being used as an ingredient in processed foods, as biofuel, or in body care products (soaps, shampoos, etc.) [1]. At a price level, it competes favorably with alternatives such as soybean or canola rapeseed oil. Due to these factors, global palm oil production has experienced substantial growth over the last thirty years. From 11 million tons in 1990, it surged to approx. 76 million tons in 2020, reflecting a compound annual growth rate of 6.7% [2]. Over this time frame, the global cultivated area dedicated to palm oil more than quadrupled from 6.1 million hectares to 28.6 million hectares [2]. In some countries, such as Indonesia, palm oil is one of the most important contributors to the national GDP but also connected to immense ecological problems, in particular the loss of natural habitats due to deforestation and the loss of biodiversity [3]. This expansion can be attributed to three primary drivers: sustained population growth, increased demand for palm oil as an energy source, and a rising number of consumer products incorporating palm oil [4], not to forget the importance of palm oil for the production of biofuels [5]. Currently, palm oil production occupies 1.9% of the world's total agricultural land, ranking it as the fourth most cultivated oil crop, following soybean, rapeseed, and sunflowers in terms of acreage [2].

Indonesia and Malaysia dominate global palm oil production, accounting for 80% to 85% of global palm oil production [5,6]. Other countries, such as Thailand (4%) and Colombia (2%), trail far behind in production, with the remaining 7% divided among nations including Nigeria, Guatemala, Papua New Guinea, Cote d'Ivoire, Honduras, and Brazil [7].

Table 1 illustrates the distribution of palm oil consumption across different countries. These top seven consumers of palm oil consume 66% of the world's palm oil. Indonesia ranks as the largest consumer, accounting for 26% of global palm oil consumption, followed by India at 12%. China consumes 9%, and the European Union (EU) accounts for approximately 6% of the global total. Malaysia and Pakistan contribute to around 5% of worldwide consumption. The remaining 34% of palm oil is consumed by the rest of the world [8].

Table 1. Domestic consumption of palm oil by country (2023).

Country	Consumption in 1000 Metric Tons
Indonesia	20,100
India	9325
China	6950
EU-27	4600
Malaysia	3675
Pakistan	3495
Thailand	2740

Source: Index Mundi [8].

1.1. Sustainability of Palm Oil Production

There is an ongoing controversial debate about the sustainability of palm oil, especially in the European Union, which is the fourth biggest consumer of palm oil worldwide (see Table 1) [9,10]. Critics in this debate view it as an imposition of Western sustainability values onto the Asian countries involved in palm oil production [11]. But there is a growing scientific body of knowledge about the negative environmental impacts of palm oil production, such as the destruction of tropical rainforests, deforestation, and loss of biodiversity [12,13], an increase in greenhouse gas emissions (GHG) through forest clearings, wetland use and slash-and-burn techniques, soil erosion, water pollution, and the decline of air quality [14–16]. The critical view of many EU member states, classifying it as a high-risk biofuel for Indirect Land Use Change (ILUC) and as a product of "imported deforestation" [10], led to the EU ban on palm oil (and soybean oil as well) as biodiesel feedstock from 2023 on [17]. It can still be imported into the EU and used as oil-based biodiesel, but EU member states cannot use it to reach their targets for renewable energy, and it will not be eligible for corresponding subsidies [18]. An evaluation of eight agricultural commodities (palm oil, soybean, wood, cocoa, coffee, beef, rubber, and maize) showed that palm oil has the biggest share of "EU-embodied" deforestation, followed second by soybean and third by wood [19,20].

Palm oil production has both positive and negative impacts on social and economic sustainability. The negative impacts include conflicts, housing conditions, and land grabbing, while the positive impacts include income generation and employment. Both smallholders and the agri-food industry contribute to positive and negative impacts as well [21]. Overall, palm oil plays a vital role in enhancing the economies and well-being of local communities in numerous developing producer nations, significantly aiding in poverty alleviation and promoting food security. Nevertheless, the expansion of oil palm plantations has, in certain cases, worsened social disparities, and the economic growth stemming from the palm oil production chain is not consistently accompanied by fair working conditions [22]. The social aspect of sustainability has received less emphasis compared to the economic and environmental aspects [23].

The literature contains numerous assessments of palm oil production sustainability. The majority of these assessments are life cycle analyses that predominantly focus on the ecological dimension of sustainability. But there is a research gap in comprehensive palm oil assessments, including the social and economic dimensions of sustainability as well [24,25]. Morgans et al. [26] evaluated the effectiveness of the Roundtable on Sustainable Palm Oil (RSPO) in delivering sustainability objectives, highlighting the need for improved principles and criteria. This implies a potential gap in the development of user-friendly assessment methods that industry stakeholders can readily implement to enhance sustainability. On the one hand, palm oil is primarily considered in the context of being a renewable energy source rather than a food ingredient. Studies by Arvidsson et al. [27] and Schmidt [28,29] involve comparisons of the ecological impacts of palm oil with other plant-based oils. On the other hand, Choo et al. [30], Lam et al. [31], Gheewala et al. [5], and Yee et al. [32] assessed the ecological sustainability of palm oil as an energy source through life cycle assessments (LCAs). Notably, only a few sustainability evaluations incorporating LCA methodology also consider the social and economic aspects of palm oil as an energy source, such as Manik et al. [33].

Lim et al. [24] conducted an analysis of existing methodologies for assessing the sustainability of palm oil production and voluntary production standards. Their research highlighted the absence of a comprehensive approach that addresses all three dimensions of sustainability. Frequently, the relevant indicators are omitted from the assessment methodologies, and the indicators that are included often lack precision and pose challenges in terms of measurement. To address these limitations, Lim and Biswas [25,34] developed the POSA (Palm Oil Sustainability Assessment) model, primarily based on palm oil production in Malaysia. The subsequent section briefly outlines the POSA model as it forms the fundamental framework for the empirical AHP model utilized in our study.

POSA is a multi-criteria model based on indicators and structured hierarchically, following a similar approach to the AHP. In the POSA model, the primary aim of sustainability is represented by three overarching "headline performance indicators" (HPIs). These HPIs serve as the highest level of indicator aggregation and encapsulate fundamental sustainability principles. Within each HPI, there are one or more "key performance indicators" (KPIs) that delineate the primary areas of impact related to that HPI. These KPIs can either facilitate or impede the achievement of specific sustainability objectives. At the most granular level, each KPI is further broken down into "performance measures" (PMs). These performance measures are quantifiable values that are subsequently converted into a 5-point scale. In this scale, a rating of 1 signifies the least desirable scenario, 3 represents a threshold value, and 5 signifies the optimal scenario.

Lim and Biswas [34] derived their indicators through a combination of sources, including existing literature and insights gathered from stakeholder and expert interviews. These indicators from the POSA model have been adopted for use in the AHP model in this study, and a more detailed explanation of them will be provided in the subsequent chapter. In 2019, Lim & Biswas published an assessment of a representative palm oil supply chain in Malaysia [35]. Their findings indicate that POSA serves as an "evidence-informed decision-making tool for site-specific sustainability assessment". The specific supply chain they evaluated received a score of 3.47 out of 5 points, indicating that it falls short of being considered sustainable. Deficiencies were identified in various aspects, including "smallholder equity", "average annual income of workers", "local employment opportunities", "greenhouse gas emissions", "biomass waste recycling and recovery at the mill", and "plantation practices". To enhance the sustainability of this particular supply chain, recommended measures include increasing the annual income for plantation workers, improving employment opportunities for the local population, reducing greenhouse gas emissions, increasing the proportion of recycled organic waste at the mill, and enhancing working conditions at the plantations.

Sustainability assessments play a crucial role in promoting the development of a more sustainable palm oil industry. These assessments are widely employed within the agricultural and food sectors to pinpoint areas where sustainability may be lacking [36–39]. With the constant growth in demand for palm oil and its increasing impact on ecosystems, various methods have been developed to evaluate the sustainability of palm oil production. However, it is noteworthy that many of these methods predominantly focus on the ecological aspect of sustainability, often overlooking the social and economic dimensions. Several existing studies aim to evaluate the sustainability of palm oil with a primarily technical focus, mainly focusing on ecological aspects [5]. An exception to this trend can be found in the comprehensive study conducted by Lim and Biswas [34], which took into account the ecological, social, and economic aspects of sustainability when evaluating palm oil production in Malaysia.

Bartzas et al. [40] highlight the complexity involved in assessing sustainability, which often necessitates a comprehensive set of indicators derived from dependable data. Collecting such reliable data can be both time-consuming and costly. A possible solution could be using expert opinion and multi-criteria assessment [41]. Moreover, the adoption of intricate evaluation methods can face challenges regarding acceptance, as these tools may not be readily embraced at the value chain level [42]. One key reason for this hesitance lies in the limited applicability of these tools as direct decision-making aids for leading stakeholders. A stakeholder-oriented approach may offer a solution to address these limitations [43].

To promote sustainable palm oil production, the Roundtable on Sustainable Palm Oil (RSPO) has introduced a voluntary standard serving as a guideline [44]. However, despite the widespread utilization of this standard, doubts persist regarding its effectiveness due to several limitations associated with it [35,45–47].

1.2. Aims of This Study and Research Questions

A deficiency exists in comprehensive sustainability assessment methods that are user-friendly and permit stakeholder involvement. This study aims to bridge this gap by illustrating the integration of multiple supply chain stakeholders in the evaluation of palm oil production. This will be achieved through the utilization of an evaluation method based on the Analytic Hierarchy Process (AHP). The AHP methodology is commonly employed in natural resources management, including group decision-making processes. For instance, it is utilized in areas such as land management [48], water management [49,50], and bioenergy, as demonstrated in Buchholz et al. [51].

This approach will unveil the stakeholders' perceptions of the relative significance of various sustainability criteria and determine the favored palm oil production alternative. The principal research inquiries are as follows:

Q1: What is the assessment of the significance of specific sustainability criteria by various stakeholders within the palm oil supply chain?
Q2: How do stakeholders from various parts of the palm oil supply chain assess the sustainability of non-certified palm oil, RSPO-certified palm oil, and European canola oil?

In the subsequent Section 2, we will describe the methodology, the Analytic Hierarchy Process (AHP). We will outline the criteria and alternatives integrated into the AHP assessment model, present the expert interviews and AHP assessment, and subsequently describe and discuss the obtained results. Finally, we will deduce conclusions for science and the agri-food sector.

2. Materials and Methods

2.1. The Analytic Hierarchy Process

The AHP, initially introduced by Saaty [52], forms the foundation of our decision support system. The central approach of the AHP is to (1) structure intricate decision scenarios using a hierarchical format. In our case, the hierarchy included an overarching goal (in this context: assessing the sustainability of palm oil), criteria (encompassing the holistic evaluation of sustainability, spanning ecological, economic, and social criteria), and sub-criteria (within the ecological domain, such as climate change and biodiversity). (2) In the next step, we identified alternatives aligned with the overall goal, encompassing various palm oil variants and canola oil. When quantitative data were unavailable, we approximated priorities for criteria, sub-criteria, and alternatives by asking industry experts to conduct pairwise comparisons for each item, which is a common feature of the AHP. For pairwise comparisons of criteria and sub-criteria, we used Saaty's 9-point scale as a reference. Saaty's scale is a semantic scale where 1 denotes equal importance, 5 signifies higher importance, and 9 indicates absolute dominance of one element over another, with intermediate values conveying their respective meanings [52]. (3) From this hierarchical set of information, the AHP method estimated priorities for each criterion and alternative. In line with Saaty's recommendations, we employed the Eigenvector method (principal right eigenvector), although it is worth noting that there are alternative approximation methods that may yield slightly different results. (4) We aggregated the individual expert evaluations by following the approach advocated by Forman and Peniwati [53].

2.2. Criteria for the AHP Model

We incorporated the criteria from the POSA model, as outlined in the works of Lim and Biswas [25,34], into the AHP model presented in this study. The indicators within the POSA model are firmly grounded in both theoretical principles and empirical evidence, and the hierarchical framework of the model aligns seamlessly with the AHP methodology. The two hierarchical levels of the AHP model are depicted in Table 2.

Table 2. Criteria of the AHP model.

Criteria [25,34]	Measure	Sources
1 Ecological sustainability		
1.1 Climate change	THG-emissions t CO_2e/t palm oil	[28,54]
1.2 Quality of air, water, and soil	Acidification SO_2/t palm oil	[28,55]
	Eutrophication NO_3/t palm oil	[28,55,56]
1.3 Volume of waste	Recycling biomass (a)	[56,57]
1.4 Biodiversity	Loss of species (b)	[28,54]
1.5 Use of resources (fossil fuels)	Fossil fuels MJ/ha	[55,58]
2 Economic sustainability		
2.1 Productivity	t palm oil/ha	[26,55]
2.2 Profitability	Price/ton (US$)	[59,60]
2.3 Relative poverty	Average income per month (US$)	[34,61]
2.4 Inclusion of the local population and wealth distribution	Possibility of employment etc. (c)	[58,61]
3 Social sustainability		
3.1 Fulfillment of basic needs	Access to water, food, housing, etc. (c)	[35,61]
3.2 Empowerment of local people	Access to information, knowledge, etc. (c)	[58,61]

(a) qualitative valuation, open dumping (increase in CH_4) vs. mulching in the plantations. (b) qualitative valuation, different measurements. (c) qualitative valuation.

At the first level of the hierarchy, the model encompasses the three foundational aspects of sustainability, in alignment with the principles outlined in the Brundtland Report from the World Commission on Environment and Development [WCED] in 1987 [39]. Consistent with the findings of Lim and Biswas [25,34], this top-level structure includes the three core criteria: ecological, economic, and social sustainability. Criterion 1, denoted as "Environmental sustainability", further breaks down into several sub-criteria: 1.1 Climate change; 1.2 Quality of soil, water, and air; 1.3 Volume of waste; 1.4 Impact on biodiversity; and 1.5 Use of resources, which gauges the extent of fossil fuel consumption during production and processing. Within the "climate change" sub-criterion, the focus is on quantifying the greenhouse gas emissions associated with palm oil production. Meanwhile, the quality of soil, water, and air is assessed by measuring the degree of eutrophication and acidification resulting from palm oil production activities.

The "volume of waste" criterion assesses the proportion of recycled organic residues derived from palm oil fruit. Biodiversity encompasses considerations related to plantation methods, land utilization, and the impact on species preservation.

We operationalized economic sustainability through four sub-criteria and measured criterion 2.1, "Productivity", by the oil yield per hectare and criterion 2.2, "Profitability", by the palm oil price per ton. Sub-criterion 2.3, "Relative poverty", is quantified based on the average monthly income, and 2.4, "Inclusion of the local population and wealth distribution", reflects the potential for employing the local population and promoting equitable wealth distribution.

Within the domain of social sustainability, we considered two sub-criteria in accordance with findings from the literature [34,35]. Firstly, 3.1, "Fulfillment of basic needs", evaluates the accessibility of clean water, food, housing, and sanitation for plantation workers. The broad criterion "basic needs" comprises several aspects of basic requirements for a better human life. Employment opportunity for the local population and workers' accessibility to water supply, healthcare, sanitation, and housing facilities [34]. Secondly, 3.2, "Empowerment of local people", assesses the local population's access to information and knowledge, involvement in decision-making processes, the establishment of fair partnerships, and the degree of acceptance within the community regarding plantation and processing activities. Altogether, these aspects of social sustainability contribute to sharing economic benefits with local workers and their families. This goes beyond merely providing employment and housing to meet their basic needs; it also involves enhancing the empowerment of local communities, which have "the attributes of confidence, inclusiveness, organizational ability, cooperation, and ability to influence" [34]. Measuring this criterion accurately poses a challenge. Lim and Biswas [34] developed key performance indicators for social equality. In particular, we divided "local community empowerment and engagement" into "access to information and knowledge", "community involvement in decision-making", and "community acceptance of plantation and mill activities".

To our knowledge, social sustainability (basic needs and empowerment in our AHP model) is the most challenging aspect in the comprehensive assessment of the sustainability of agri-food products compared to environmental and economic criteria [23], as no reliable data are available. In accordance with Lim and Biswas [34,35], this study therefore employs a qualitative method, too, by simply rating alternatives from one (worst) to three (best).

2.3. Alternatives Included in the AHP Model

The AHP model encompasses two alternative methods of palm oil production. The first alternative, A1, corresponds to conventional, non-certified palm oil, which represents the predominant share of global palm oil production. The second alternative, A2, pertains to RSPO-certified palm oil, which accounts for approximately 19% of palm oil produced worldwide. The third alternative (European canola oil), A3, serves as a reference. Rapeseed, a major oil crop in Europe, achieved an annual production volume of 20 million tons in 2019. The significance of rapeseed cultivation varies significantly on a national level, such as in Austria, where it ranks as the second most produced oil crop after soybean, with a harvest volume of 121,000 tons in 2019 [61]. Canola oil exhibits the technical potential to replace palm oil in various food products, boasting an average yield per hectare of 1.5 tons in Europe, surpassing the global average of 0.7 tons [62].

Margarine, a key end product for palm oil, is amenable to substitution with nearly any other oil. Similar straightforward technical replacements can be employed in products like ice cream, bread, and pastries [62]. Table 2 consolidates all the relevant sources utilized to assess alternatives A1 to A3 in the context of the AHP hierarchy's sub-criteria.

Figure 1 depicts the comprehensive AHP model, featuring criteria and alternatives sourced from existing literature. To gauge the sustainability of alternatives A1 to A3, a panel of eight experts drawn from various sectors, including the food industry, food trade, palm oil production, and non-governmental organizations, assessed the significance of the criteria and sub-criteria within the AHP hierarchy. We subsequently aggregated the estimated priorities with factual metrics associated with the alternatives concerning all the sub-criteria within the AHP hierarchy, as outlined in Table 2.

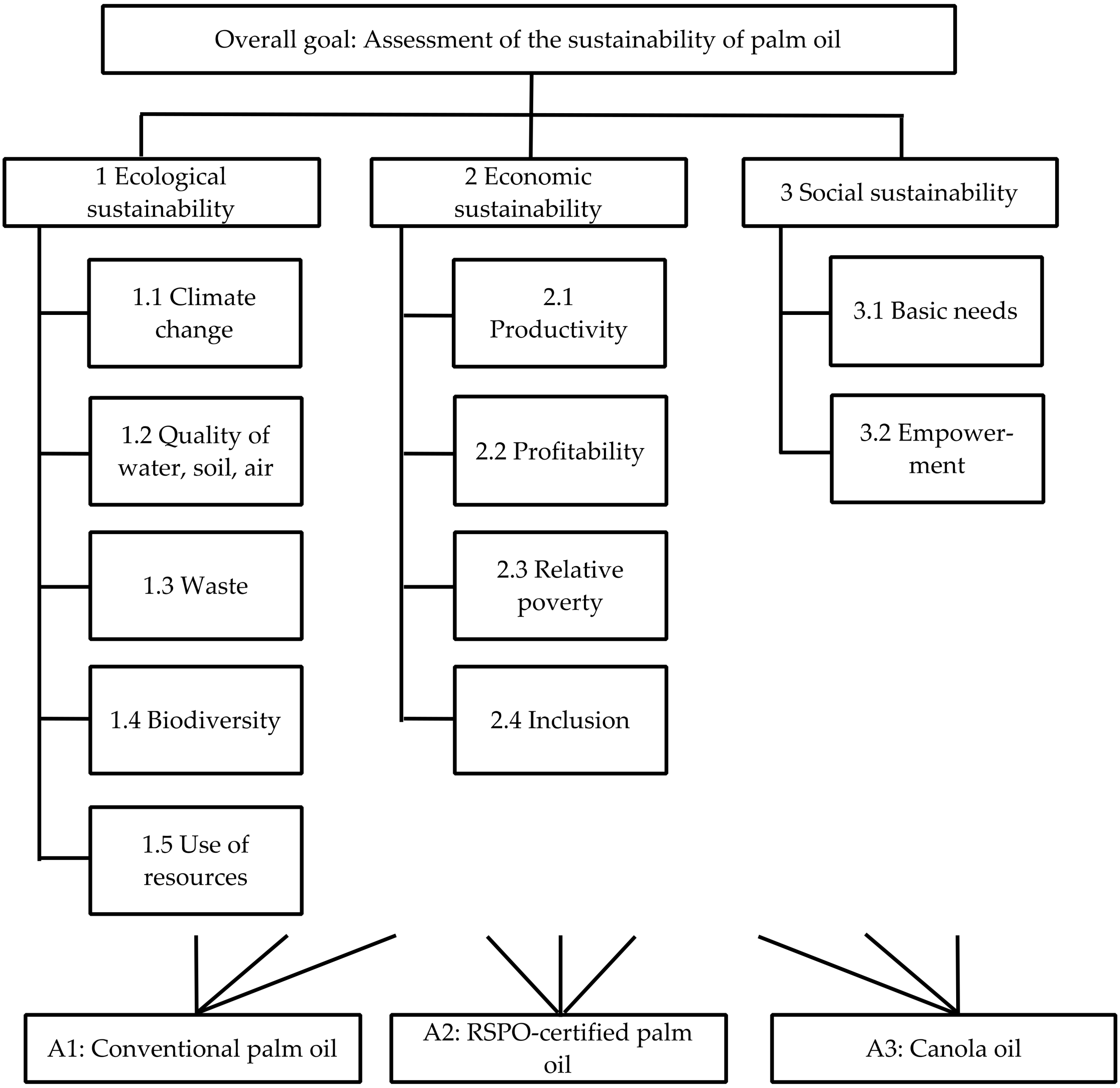

Figure 1. AHP model to approximate the sustainability of palm oil. Source: In accordance with Lim & Biswas [25,34].

2.4. AHP Assessment: Expert Interviews

In total, we conducted eight interviews with experts from the food sector and NGOs, aiming to gather essential data for approximating the significance of the evaluation criteria in the AHP hierarchy illustrated in Figure 1. We selected experts based on their professional experience within the palm oil industry. These experts, as outlined in Table 3, are stakeholders and influential decision-makers in the food supply chain, regularly grappling with the utilization of palm oil within their respective companies or organizations. Given the diverse perspectives stemming from the distinct nature of each company or organization, the assessment of the importance of sustainability criteria through the AHP yielded varied results. This diversity will be comprehensively addressed in the following section.

Table 3. Participants in expert interviews.

Expert	Organization/Company	Function	Field of Activity
E1	Organic food company	Head of product management and sales	Food processing
E2	Fair trade organization	Intelligence department and public relations	Food processing
E3	Consumer protection organization	Executive board member	Food consumption
E4	International NGO	CEO	Sustainability
E5	International food retailing company	Senior manager sustainability department	Food retail
E6	International NGO	Program management	Animal welfare, sustainability
E7	International food retailing company	Head of sustainability department	Food retail
E8	Global palm oil producing company	Assistant manager, production department	Palm oil production

3. Results

3.1. Assessment of the Importance of the AHP Hierarchy Elements

To assess the importance of the elements of the AHP hierarchy illustrated in Figure 1 (and, consequently, to assess the priorities of the palm oil alternatives applying quantitative data), each hierarchy level was evaluated by each expert applying pairwise comparisons a_{ij} where all the elements i are compared with all other elements j. As the pairwise comparison matrices $\boldsymbol{A}_{\mathbf{ij}}$ are reciprocal matrices where $a_{ji} = 1/a_{ij}$, the individual pairwise comparison matrices are aggregated by building the geometric mean of a_{ij}. For instance, the aggregated pairwise comparisons for the sub-elements of the criterion "ecological sustainability" 1.1 to 1.5 (including minimum and maximum a_{ij}) can be taken from Table 4. As suggested in the literature, we also evaluated the consistency of the pairwise comparisons of all experts by means of the consistency ratio (CR) proposed by Saaty [52], confirming Formulas (1) and (2), where λ_{max} is the maximum eigenvalue of the pairwise comparison matrix $\boldsymbol{A}_{\mathbf{ij}}$ with n elements and R represents the consistency of a random matrix. Confirming Saaty [52], R = 0.52, 0.89, and 1.11 for a pairwise comparison matrix, with the number of elements being n = 3, 4, and 5, respectively.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

$$CR = \frac{\mathrm{CI}}{R} \tag{2}$$

Table 4. Pairwise comparison matrix $\boldsymbol{A}_{\mathbf{ij}}$ of sub-elements 1.1 to 1.5 of ecological sustainability.

	1.1 Climate Change	1.2 Air, Water, and Soil Quality	1.3 Waste	1.4 Biodiversity	1.5 Use of Resources
1.1 Climate change	1 (1; 1)	1.82 (1; 5)	2.83 (1; 7)	0.92 (1/3; 3)	1.89 (1; 3)
1.2 Air, water, and soil quality	0.55 (1/5; 1)	1 (1; 1)	1.97 (1; 5)	0.65 (1/5; 1)	1.19 (1; 4)
1.3 Waste	0.35 (1/7; 1)	0.51 (1/5; 1)	1 (1; 1)	0.45 (1/7; 1)	0.58 (1/5; 1)
1.4 Biodiversity	1.09 (1/3; 3)	1.53 (1; 5)	2.24 (1; 7)	1 (1; 1)	1.25 (1; 3)
1.5 Use of resources	0.53 (1/3; 1)	0.84 (1/4; 1)	1.72 (1; 5)	0.80 (1/3; 1)	1 (1; 1)

a_{ij} = geometric mean (min, max); CR = 0.007.

In general, CR should lie below 0.1 [52]. This condition was fulfilled throughout the whole evaluation process; consistency amounts to a max of CR = 0.099 for E7 (pairwise comparison 2.1 to 2.4), and on average, over all pariwise comparisons of E1 to E8, it amounts to $\overline{CR}$ = 0.036.

By means of pairwise comparison matrices $\boldsymbol{A}_{\mathbf{ij}}$ as compared to Table 4, the significance of all sustainability criteria was approximated. This qualitative methodology is essential due to the absence of reliable quantitative data regarding the importance of these criteria. The approximation of priorities was conducted by the usual approach of the principal right eigenvector. The prioritization is contingent on the specific company objectives and the organization's position within the food supply chain. Consequently, the overall outcome, approximated from the aggregation of individual expert judgments, lacks homogeneity. Individual approximations necessitate careful interpretation.

As depicted in Table 5, the overall significance assigned to ecological ($\overline{w}_\mathrm{i}$ = 0.459) and social ($\overline{w}_\mathrm{i}$ = 0.376) sustainability criteria is notably higher when contrasted with economic sustainability criteria ($\overline{w}_\mathrm{i}$ = 0.165). The bandwidth of individual priorities for ecological sustainability lied between 0.22 (E8) and 0.69 (E7); for social sustainability, between 0.22 (E7) and 0.47 (E1); and for economic sustainability, between 0.05 (E1) and 0.46 (E8). Therefore, this estimation might depend on the relevant strategic goals of the expert's organization and/or the individual preferences, values, and attitudes of the experts themselves. For instance, in the case of E3 (consumer protection), all elements are deemed equally important and must be equally fulfilled. A comparable approximation can be found with E2 (fair trade organization)—even though ecology is slightly more important for E2 compared to economy and social sustainability. These viewpoints may signify evaluations based on organizations prioritizing objectives beyond economic benefits, such as those centered on consumer protection and fair trade conditions. Expert E8 places high importance on economic sustainability (w_i = 0.46). This outcome aligns with expectations, considering the assessment was tailored to validate the strategic standing of the sole palm oil production company in our sample. Another noteworthy outcome arises with E7, a food retailer, where environmental sustainability overwhelmingly takes precedence within the AHP hierarchy (w_i = 0.69).

Table 5. Approximation of priorities for sustainability criteria.

Criteria	E1		E2		E3		E4		E5		E6		E7		E8		Total		
	w_i	$w_\mathrm{i.j}$	w_i	$w_\mathrm{i.j}$	w_i	$w_\mathrm{i.j}$	w_i	$w_\mathrm{i.j}$	w_i	$w_\mathrm{i.j}$	w_i	$w_\mathrm{i.j}$	w_i	$w_\mathrm{i.j}$	w_i	$w_\mathrm{i.j}$	$\overline{w}_\mathrm{i}$	$\overline{w}_\mathrm{i.j}$	***rel.*** $\overline{w}_\mathrm{i.j}$
1 Ecological sustainability	0.47		0.41		0.33		0.59		0.43		0.43		0.69		0.22		0.459		
1.1 Climate change		0.20		0.41		0.20		0.25		0.33		0.32		0.46		0.16		0.291	0.134
1.2 Quality of water, soil, and air		0.20		0.12		0.20		0.14		0.12		0.23		0.21		0.19		0.181	0.083
1.3 Waste		0.20		0.07		0.20		0.14		0.04		0.04		0.06		0.19		0.101	0.047
1.4 Biodiversity		0.20		0.26		0.20		0.33		0.38		0.23		0.15		0.26		0.257	0.118
1.5 Use of resources		0.20		0.14		0.20		0.14		0.13		0.19		0.12		0.19		0.170	0.078
2 Economic sustainability	0.05		0.26		0.33		0.08		0.14		0.14		0.09		0.46		0.165		
2.1 Productivity		0.07		0.07		0.30		0.08		0.17		0.09		0.15		0.24		0.135	0.022
2.2 Profitability		0.04		0.07		0.10		0.04		0.17		0.10		0.09		0.33		0.100	0.016
2.3 Relative poverty		0.44		0.44		0.30		0.44		0.50		0.43		0.35		0.24		0.414	0.068
2.4 Inclusion		0.44		0.42		0.30		0.44		0.17		0.38		0.41		0.19		0.351	0.058
3 Social sustainability	0.47		0.33		0.33		0.33		0.43		0.43		0.22		0.32		0.376		
3.1 Basic needs		0.80		0.75		0.75		0.50		0.88		0.50		0.75		0.50		0.696	0.262
3.2 Empowerment		0.20		0.25		0.25		0.50		0.13		0.50		0.25		0.50		0.304	0.114

w_i ... local weight (priority) for criterion *i*; $w_\mathrm{i.j}$ ... weight (priority) for sub-criterion *j*; $\overline{w}_\mathrm{i,\,i.j}$ ... aggregated weights; approximation by geometric mean aggregated matrices; *rel.* $\overline{w}_\mathrm{i.j}$ ... relative (global) weight for sub-criterion *i.j*; *rel.* $\overline{w}_\mathrm{i.j} = \overline{w}_\mathrm{i} \times \overline{w}_\mathrm{i.j}$.

The range in these outcomes clearly underscores the limited generalizability of aggregated approximations, particularly in the context of intangible and subjective elements where evaluations may be significantly influenced by the overarching company goals and strategies or individual preferences, values, and attitudes. For instance, it was not surprising at all that the expert E8 from the one palm oil-producing company in the sample has a differing position compared to all other judgments and assumes economic sustainability to be of the highest priority (w_i = 0.46). Therefore, we further grouped the experts' assessments into three clusters: Experts E2 and E3, both food-related NGOs, evaluated all elements of the main criteria level to be more or less of equal importance (Table 6). Experts E1 and E4 to E7 have a clear preference for ecological sustainability, followed by social aspects. E8 (the sole palm oil-producing company) rated economic sustainability as of the utmost importance.

Table 6. Approximation of priorities for sustainability criteria of identified clusters.

Criteria	Cluster 1: E2-3			Cluster 2: E1,4-7			E8		
	$\overline{w}_i$	$\overline{w}_{i.j}$	$rel.\ \overline{w}_{i.j}$	$\overline{w}_i$	$\overline{w}_{i.j}$	$rel.\ \overline{w}_{i.j}$	w_i	$w_{i.j}$	$rel.\ w_{i.j}$
1 Ecological sustainability	0.37			0.53			0.22		
1.1 Climate change		0.30	0.11		0.32	0.17		0.16	0.04
1.2 Quality of water, soil, and air		0.16	0.06		0.18	0.10		0.19	0.04
1.3 Waste		0.13	0.05		0.08	0.04		0.19	0.04
1.4 Biodiversity		0.24	0.09		0.26	0.14		0.26	0.06
1.5 Use of resources		0.17	0.06		0.16	0.09		0.19	0.04
2 Economic sustainability	0.30			0.10			0.46		
2.1 Productivity		0.15	0.04		0.11	0.01		0.24	0.11
2.2 Profitability		0.09	0.03		0.08	0.01		0.33	0.15
2.3 Relative poverty		0.38	0.11		0.45	0.04		0.24	0.11
2.4 Inclusion		0.38	0.11		0.36	0.04		0.19	0.09
3 Social sustainability	0.33			0.37			0.32		
3.1 Basic needs		0.75	0.25		0.71	0.26		0.50	0.16
3.2 Empowerment		0.25	0.08		0.29	0.11		0.50	0.16

w_i ... local weight (priority) for criterion *i*; $w_{i.j}$ ... weight (priority) for sub-criterion *i.j*; $\overline{w}_{i,\ i.j}$ ... aggregated weights; aggregated by geometric mean; $rel.\ \overline{w}_{i.j}$ ... relative (global) weight for sub-criterion *i.j*; $rel.\ \overline{w}_{i.j} = \overline{w}_i \times \overline{w}_{i.j}$.

The sub-criteria, along with their corresponding relative weights, $rel.\ w_{i.j}$ highlight distinct priorities across the clusters. It is important to note that the relative weights $rel.\ w_{i.j}$ in Table 6 are influenced by the number of sub-criteria, making comparisons of metric weights advisable with caution. For instance, climate change emerges as the most crucial sub-criterion in the ecological sustainability sections of Clusters 1 and 2 ($\overline{w}_{i.j}$ = 0.30 and 0.32, respectively), while biodiversity is evaluated to be slightly more important for E8 ($w_{i.j}$ = 0.26). In Cluster 2, climate change overwhelmingly dominates among ecological sub-criteria ($\overline{w}_{i.j}$ = 0.32), while in Cluster 1, the importance of the sustainability criteria is by far more balanced. Overall, relative weights $rel.\ w_{i.j}$ of social sustainability elements are, compared to other sub-elements, partly higher because this hierarchy level only consists of two sub-elements (basic needs and empowerment). All weights can be taken from Table 6.

3.2. Assessment of the Importance of Alternatives A1 to A3

Considering the disparities in evaluations among individual experts, especially between the identified clusters, one would expect that further analysis of approximating priorities for alternatives would yield a wide range of priority weights as well. To achieve this, the quantitative data for the three alternatives—A1: conventional palm oil, A2: RSPO-certified palm oil, and A3: the reference product canola oil (Table 7)—is combined with the previously established prioritization of the elements within the decision hierarchy.

The quantitative data in Table 7 are transformed into AHP priorities, $w_{A1,2,3}$ by building the sum of each row and dividing individual values through this sum—if higher values represent a higher benefit (e.g., productivity in t / ha). In the case of cost attributes (e.g., climate change: THG-emissions t CO_2e), inverse and reciprocal values are applied (*r* in Table 7). Consequently, $w_{A1,2,3}$ is then multiplied with $rel.\ \overline{w}_{i.j}$. The overall priorities index for A1 to A3 is approximated by $\overline{p}_{A1,2,3} = \sum rel.\ \overline{w}_{i.j} \times w_{A1,2,3}$. The index $\overline{p}_{A1,2,3}$ in Table 8 represents the level of sustainability between conventional palm oil (A1), RSPO-certified palm oil (A2), and canola oil (A3).

Table 7. Quantitative data and approximation of priorities for alternatives A1: conventional palm oil; A2: RSPO-certified palm oil; and A3: canola oil.

Sub-Criterion	Measure				Values for Utility Approximation			Sum	Priorities		
	A1	A2	A3		A1	A2	A3		w_{A1}	w_{A2}	w_{A3}
1.1 Climate change (THG-emissions t CO_2e/t palm oil)	5.34	3.41	2.22	*r*	0.187	0.293	0.450	0.931	0.201	0.315	0.484
1.2 Air, water, and soil quality											
(Acidification SO_2/t palm oil)	14.8	10.3	20.2	*r*	0.068	0.097	0.050	0.214	0.316	0.453	0.231
(Eutrophication NO_3/t palm oil)	124	86	140	*r*	0.008	0.012	0.007	0.027	0.301	0.433	0.266
1.3 Waste (recycling biomass) [a]	1	3	3		1	3	3	7	0.143	0.429	0.429
1.4 Biodiversity (loss of species) [b]	1	2	3		1	2	3	6	0.167	0.333	0.500
1.5 Use of resources (Fossil fuels, MJ/ha)	2.11	2.11	4.116	*r*	0.474	0.474	0.243	1.191	0.398	0.398	0.204
2.1 Productivity (t/ha)	3.75	5	1.5		3.75	5	1.5	10.25	0.366	0.488	0.146
2.2 Profitability (Price/ton in US$)	700	800	900		700	800	900	2400	0.292	0.333	0.375
2.3 Relative poorness (Average income per month in US$)	15	40	7		15	40	7	62	0.242	0.645	0.113
2.4 Inclusion (Possibility of employment, etc.) [c]	1	2	3		1	2	3	6	0.167	0.333	0.500
3.1 Basic needs (Access to water, food, housing, etc.) [c]	1	2	3		1	2	3	6	0.167	0.333	0.500
3.2 Empowerment (Access to information, knowledge, etc.) [c]	1	1	3		1	1	3	6	0.2	0.2	0.6

[a] qualitative, open dumping (increase in CH_4) vs. mulching in the plantations. [b] different approximation methods: PDF/m^2/year/kg RBD oil and standard wS100. [c] qualitative, ranking. *r* ... reciprocal values ($1/a_i$; less = higher utility).

Table 8. Approximation of priorities for alternatives A1 to A3.

	All			Cluster 1: E2-3			Cluster 2: E1, E4-7			E8		
	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3
1 Ecological sustainability												
1.1 Climate change	0.027	0.042	0.065	0.023	0.035	0.054	0.034	0.053	0.081	0.007	0.011	0.017
1.2 Air. water. soil quality	0.026	0.037	0.021	0.019	0.027	0.015	0.030	0.043	0.024	0.013	0.019	0.011
1.3 Waste	0.007	0.020	0.020	0.007	0.020	0.020	0.006	0.018	0.018	0.006	0.018	0.018
1.4 Biodiversity	0.020	0.039	0.059	0.015	0.030	0.044	0.023	0.046	0.069	0.009	0.019	0.028
1.5 Use of resources	0.031	0.031	0.016	0.025	0.025	0.013	0.034	0.034	0.017	0.017	0.017	0.009
2 Economic sustainability												
2.1 Productivity	0.008	0.011	0.003	0.016	0.021	0.006	0.004	0.005	0.002	0.041	0.054	0.016
2.2 Profitability	0.005	0.005	0.006	0.008	0.009	0.010	0.002	0.002	0.003	0.044	0.051	0.057
2.3 Relative poorness	0.016	0.044	0.008	0.028	0.073	0.013	0.011	0.028	0.005	0.027	0.071	0.012
2.4 Inclusion	0.010	0.019	0.029	0.019	0.037	0.056	0.006	0.012	0.018	0.014	0.029	0.043
3 Social sustainability												
3.1 Basic needs	0.044	0.087	0.131	0.041	0.083	0.124	0.044	0.088	0.132	0.027	0.053	0.080
3.2 Empowerment	0.023	0.023	0.069	0.017	0.017	0.050	0.022	0.022	0.066	0.032	0.032	0.096
Sustainability index $\overline{p}_{A1,2,3}$	0.215	0.359	0.426	0.216	0.378	0.406	0.215	0.351	0.434	0.238	0.375	0.388

$\overline{p}_{A1,2,3}\overline{p}_{A1,2,3}$ ... average priority index for alternatives A1 to A3.

Although there was considerable heterogeneity in individual assessments of the importance of sustainability criteria, the final results among different experts (Figure 2) and expert groups (Figure 3) are remarkably similar. On average, conventional palm oil (A1) stands out as the least sustainable alternative (average sustainability index $\overline{p}_{A1} = 0.215$), followed by RSPO-certified palm oil (A2) ($\overline{p}_{A2} = 0.359$), and canola oil (A3) ($\overline{p}_{A3} = 0.426$). A2 and A3 exhibit less distinct separation compared to A1. Changes in the importance of specific sustainability criteria could impact the rankings of A2 and A3 (which is not the case when considering the clusters). A sensitivity analysis revealed that significant changes are only likely if economic criteria gain substantial importance, reaching around 0.4 at the expense of environmental criteria. In the context of sustainability, such a shift is considered unrealistic.

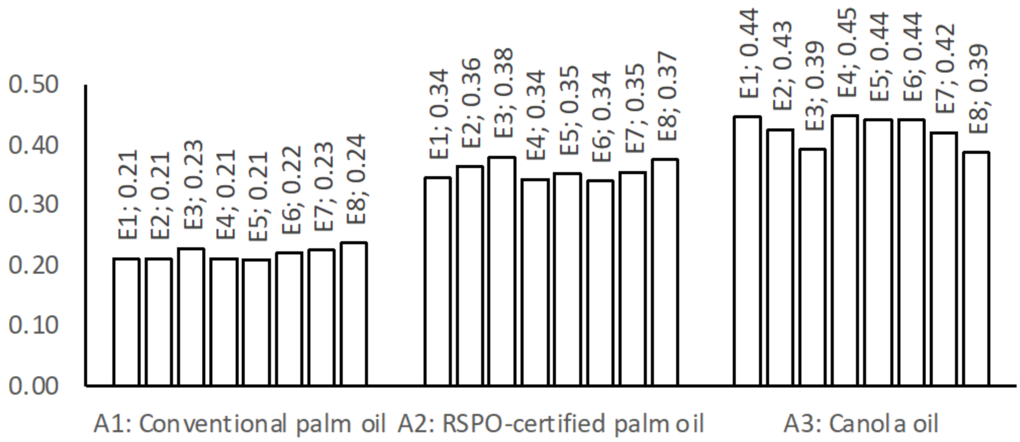

Figure 2. Sustainability index: $p_{A1,2,3}$ for alternatives A1 to A3; individual judgments of E1 to E8.

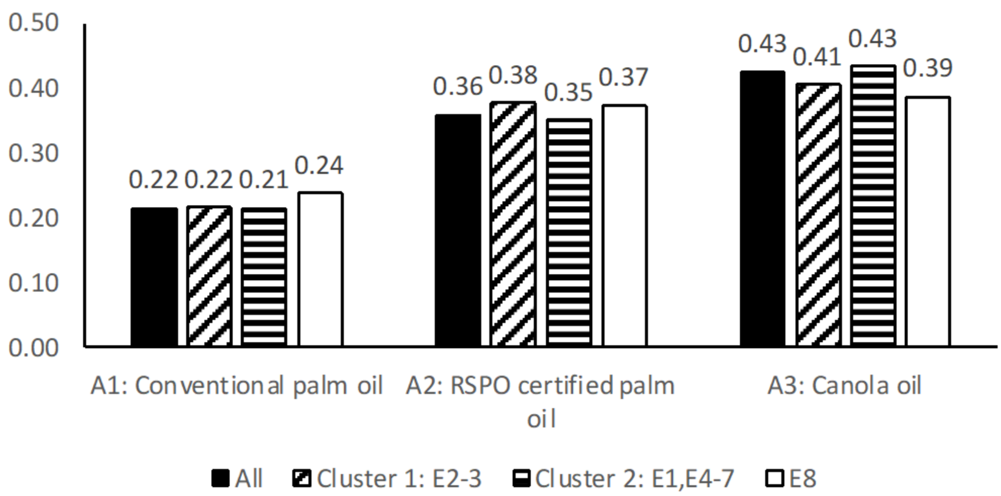

Figure 3. Sustainability index: $\overline{p}_{A1,2,3}$ for alternatives A1 to A3; total result; and clusters (experts E1–E8).

4. Discussion

In summary, the findings underscore the challenges associated with evaluating intangible, qualitative attributes such as sustainability. Our aim was to adopt a more comprehensive perspective on the concept of "sustainability", moving beyond a singular emphasis on the ecological dimension, a common focus in many studies involving life cycle analyses—Arvidsson et al. [27]; Schmidt [28,29]; Yee et al. [32]—to name just a few. Nonetheless, individual preferences, goals, visions, and strategies, along with comparable factors as well as personal perceptions, attitudes, and values, could significantly impact the overall outcome of qualitative judgments, leading to varying degrees of heterogeneity. Given this, we have an answer for Q1, but there is no consensus among stakeholders regarding the assessment of sustainability. Instead, they tend to evaluate the importance of selected sustainability criteria differently. This issue should be addressed in future research.

We integrated all dimensions of sustainability that were missing, confirming Lim et al. [24]—based on their analysis of existing voluntary production standards—the absence of a holistic method encompassing all three dimensions of sustainability. This was a broader approach compared to Lim and Biswas [35], who only evaluated a typical supply chain of palm oil in Malaysia. However, it is evident that the priorities are influenced by the factors mentioned above. Despite the divergent importance assigned to sustainability criteria, the assessment of the sustainability of the alternatives paints a rather clear picture (Q2): European canola oil is considered the most sustainable alternative, closely followed by RSPO-certified palm oil. The gap to the least sustainable alternative, conventional, non-certified palm oil, is substantial. Stakeholders, closely connected to the food supply chain or even integral parts of it, may not entirely encapsulate the viewpoints of their customers (consumers and/or other partners within the food supply chain). Nevertheless, the results provide a clear and, based on the expertise of the interviewed individuals, trustworthy depiction of the sustainability of palm oil. This finding contradicts the doubts raised about the effectiveness of the RSPO standard and the associated sustainability improvements [35,45–47]: RSPO-certified palm oil was deemed nearly as sustainable as canola oil, a finding that may surprise the scientific community and warrant further investigation in future studies. It is essential to note that our results represent hypotheses, as we used a qualitative study design with only a limited number of expert interviews. This approach is, however, an important widening of existing approaches based on life cycle inventories such as Gheewala et al. [5], where also the stakeholder of the whole supply chain can be part of the evaluation procedure. In addition, we could demonstrate that the combination of qualitative evaluations based on expert knowledge in combination with quantitative data might provide significant insights beyond a more tech-oriented sustainability assessment. Future studies should aim for a comprehensive application of the AHP, involving a larger number of experts. This could be achieved by incorporating new findings for the quantitative assessment of alternatives and by broadening the methodological approach to enhance our understanding of heterogeneity in group decision-making. Pashaei Kamali et al. [41] demonstrated that expert opinions, when incorporated into multi-criteria decision support systems, yield cost-effective and robust results in comparison to data-rich quantitative methods. We followed Saaty [52] when applying the AHP. Actual developments in the AHP methodology might be useful in order to cover heterogeneity in group decision processes (e.g., Meixner and Haas [63]). In general, literature shows that the application of the AHP is very useful in natural resource management, such as land [48] or water management [49,50]. Expanding the application of the AHP for sustainability assessments appears promising, in particular to aggregate complex data by means of the AHP framework, irrespective of which crops or products the sustainability assessment is intended for. Future research could use our methodological approach as a solid foundation.

It is important to note that approximating sustainability through the AHP has its limitations. The overall outcome depends on two pre-conditions: (1) the validity of the elaborated AHP model, and (2) the availability of sufficient expert knowledge among the decision-makers tasked with evaluating the AHP model. This becomes even more crucial when reliable quantitative data are lacking. Notably, measuring social sustainability proves to be the most challenging aspect within our decision hierarchy. Due to the absence of reliable data, we followed the suggestions of Lim and Biswas [34,35] and evaluated the alternatives in view of only two streamlined criteria (basic needs and empowerment) using a simplified rating method. While this approach may be somewhat limiting, future research might address this important issue in particular in view of social responsibility; measurability should be much more elaborated and comparable to existing approaches for economic and environmental attributes.

5. Conclusions

A common limitation of sustainability assessments is the predominant focus on the environmental aspect, often neglecting the economic and social dimensions of sustainability [37,39]. In our study, we evaluated the sustainability of different palm oil supply chains by applying the three pillars of sustainability: the economic, ecological, and social dimensions. Out of the eight experts interviewed, seven ranked the ecological dimension as the highest priority, followed by the social dimension, with the economic dimension ranking third.

The application of the Analytical Hierarchy Process (AHP), a qualitative multi-criteria decision support system based on expert opinions, facilitated the assessment of global agricultural supply chains without the need for costly quantitative data collection. The experts' evaluations yielded a robust and comprehensible assessment, ranking the reference product "EU canola oil" as the most sustainable alternative, followed by RSPO-certified palm oil, and non-certified palm oil as the least sustainable alternative. Therefore, it can be concluded that the AHP methodology supports the transparency and traceability of food supply chains. By doing so, it promotes the adoption of sustainable farming practices by providing reliable information based on expert knowledge from various stakeholders for a wide variety of food supply chains.

In sustainability assessments, it is generally recommended to adopt a multi-stakeholder approach [41,42] to incorporate diverse and sometimes conflicting perspectives on sustainability. This approach often results in heterogeneous expert judgments on individual sustainability criteria, reflecting the diversity of opinions inherent in multi-stakeholder assessments. Diversity of opinions is a welcomed, one could say democratic, aspect of multi-stakeholder assessments. Sustainability is a widely contested notion; therefore, dissonance or differences between expert opinions should be anticipated or even actively sought. The existing strength of the AHP lies in its ability to maintain transparency in group decision-making, allowing for a thorough discussion of assessment outcomes. Clustering expert opinions based on judgment patterns also facilitates the illustration of different positions. Highlighting the diversity of expert opinions is crucial, as it prevents the misleading perception of unanimous expert judgments. Therefore, we highly recommend approaches that quantify the heterogeneity of collected expert judgments in sustainability assessments, irrespective of whether the AHP or another multi-criteria method is employed.

The demonstrated approach/methodology in our paper would be well-suited for assessing the sustainability of other agricultural supply chains that face public scrutiny, such as the soybean, dairy, cacao, or cotton supply chains. It delivers valuable information for all stakeholders in the food supply chain (policy makers, producers, retailers, consumers, and the scientific community) to assess the overall sustainability of agricultural commodities. For instance, it would be possible for policymakers to adapt regulations and certification schemes accordingly. Consumers might be able to modify their purchasing behavior toward more sustainable food choices. The retail sector and producers could use the data within their supply chain management systems. These are only exemplary suggestions; the presented AHP model likely has much broader applicability. It would have to be adjusted to meet the specific requirements of the corresponding commodity or to align with local conditions. The method's user-friendly nature and the transparency of the approximated priorities indicate its potential for commercial application beyond academia.

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