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Review

Potential of Beekeeping to Support the Livelihood, Economy, Society, and Environment of Indonesia

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Abstract: The management of natural resources based on socio-economic and ecology development has led to a focus on the bioeconomy in the policy discourse of non-timber forest products (NTFPs). Honey is an important NTFP with high socio-economic value, and its production involves millions of Indonesians. This article reviews the current status of honey-producing bee management, cultivation and harvesting system, marketing and socio-economic values, and the industry's environmental function in Indonesia. This research utilized a meta-narrative review method to collect data and information from Google Scholar, Scopus, Science Direct, ResearchGate, *Sinta*, and *Garuda*. The study showed that the four bee species, namely *Apis mellifera*, *Apis cerana*, *Apis dorsata*, and stingless bee, are the most common species in honey production in Indonesia. The four species have specific characteristics based on habitat, production capacity, derivative products, management intervention to meet honey product standards, and sustainable livelihoods. The value chain of bees' major products, such as honey, propolis, pollen, royal jelly, wax, and other derivative products, involves the distribution of honey to all involved communities, including beekeepers, honey gatherers/hunters, intermediate traders, and the processing industry. This study also found a significant association between environmental sustainability statutes that affects functional sustainability and economic function. The finding parallels the global trends that put forward a forest-based bioeconomy approach to forest resource management. The policy must be strengthened in managing relationships among supporting actors for sustainable honey production.

Keywords: beekeeping; bioeconomy; forest-based bioeconomy; honey; non-timber forest products

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Citation: Harianja, A.H.; Adalina, Y.; Pasaribu, G.; Winarni, I.; Maharani, R.; Fernandes, A.; Saragih, G.S.; Fauzi, R.; Tampubolon, A.P.; Njurumana, G.N.; et al. Potential of Beekeeping to Support the Livelihood, Economy, Society, and Environment of Indonesia. *Forests* **2023**, *14*, 321. https://doi.org/10.3390/f14020321

Academic Editors: Emin Z. Başkent, José G. Borges, Davide M. Pettenella and Yu Wei

Received: 30 December 2022
Revised: 1 February 2023
Accepted: 2 February 2023
Published: 6 February 2023

1. Introduction

The biodiversity of tropical forests in Indonesia, including those of non-timber forest products (NTFPs) and under-valued, neglected, or minor forest commodities, plays a vital role in the livelihood of the forest communities [1,2]. Honey is an NTFP that can be grown and developed in the suitable natural conditions of tropical Indonesia due to various ecological and climatic conditions. The community has traditionally harvested honey directly from the forest. Apiculture and meliponiculture have been developed in almost all regions of Indonesia, producing various honey products and mainly supported by the government as a part of a forest preservation program [3].

Most of the honey products on the market are pure since the process is straightforward, fast, and inexpensive. For honey-derived products, the major primary products harvested from beekeeping are honey, beeswax, pollen, and propolis [4]. However, some of these primary products have a limited market until they are added to the more commonly used products. Imported honey dominates the supply of high-quality and innovative honey products, such as honey enriched with active ingredients [5]. Post-harvest handling and processing need to be improved to maintain honey quality. It is imperative to increase the innovation of honey-derived products to fill the domestic market, which is dominated by imported honey products. Government support for beekeepers is needed for better productivity and quality of honey products [6].

Indonesian forest covers an area of 95.56 million hectares, constituting 50.90 percent of the country's total land area [7]. The forests are foraging habitats for bees that contain various nectar and pollen sources plants. Although beekeeping has been widely practiced across this archipelago, honey production has not reached its full potential. Indonesian Statistical Bureau [8] data recorded that Indonesia's honey production reached 189,780.00 L/year in 2021. This production has not met the national demand. The population of Indonesia reached 269.61 million people in 2020 [9]. If the consumption of honey per capita is 30 g/year [10], the demand for honey is 8080 tons per year. The increasing domestic demand for honey that the Indonesian beekeeping industry has not fulfilled has created a wide-open market opportunity for the honey business.

The direct economic contribution of NTFPs has become an essential element in the forest conservation system, such as for the household economy of forest farmers and other stakeholders involved in their process and trade [11–13]. In addition, indirect economic contributions are essential, including supporting other sectors such as agriculture and the environment [1,14]. Research in the United Kingdom (UK) suggests that honeybee support in pollinating plants was worth millions of pounds in 2017 [15]. A review stated that soybean farming supported by pollinators such as honeybees is evidenced by the decline in the productivity of soybean plants due to land fragmentation and increasing distance from the forest, leading to the decreasing occurrence of forest honeybees [16]. As studied in Europe and the United States (US), the increasing area of corn and soybean farmlands had a similar impact on the declining number of colonies and bee products [17].

The linkage of beekeeping systems to the traditional economy and the agricultural and environmental sectors is crucial and has the potential to bring the development of the bioeconomy and forest-based bioeconomy to the mainstream. The bioeconomic perspective developed in the last two decades, especially in developed countries [18,19], can encourage an economic transition towards using forest resources, including bees. Forests and forestry-based bioeconomy can play an essential role in the latest sustainability transition [20], bridging the interests of economic growth and sustainability [21], although, at present, this is still in the discourse level [22]. The broad definition of the forest-based bioeconomy by the OECD [23–26] as all economic activities related to renewable resources, the use of natural products and processes to produce food, feed, and bioenergy led to the idea that beekeeping can be one of the critical sectors in forest-based bioeconomy.

This paper presents the current condition of Indonesian beekeeping products, including farming, production, product diversification, the sociocultural dimension of honey in Indonesia, marketing and economic value, environmental value, governance, and prospects.

The present study determined various problems and alternative solutions to Indonesian beekeeping problems through a review of related literature, including the stages of exposure, identification of problems, and future potential. We also analyzed the future challenges to designing the governance of beekeeping honey in Indonesia to maximize the benefits for all related actors.

2. Methods

This study adopted the review method promoted by Wong et al., 2013 and Schouten, 2020 [27,28]. The references were collected using international and national databases, namely Scopus, Science Direct, Google Scholar, ResearchGate, Sinta, and Garuda. Search terms employed were in English and Bahasa Indonesia, as follows "bee farming", "beekeeping", "honey", "honey bee", "stingless bee", "honey bee product", "economic value of bee farming", "bioeconomy", "forest-based bioeconomy", "governance", "environment value", "lebah", "lebah madu", "kelulut", "madu hutan", "madu peternakan", "perhutanan sosial", "nilai ekonomi perlebahan", "nilai sosial perlebahan" and "nilai lingkungan perlebahan". The studies retrieved were published between 2013 and 2022. Results in English and Bahasa Indonesia were included, and then the title was screened to ensure that the study area was in Indonesia. The next step was to sort the results based on the publication types. Book chapters, and website articles were excluded. Only journal articles, conference papers, thesis, dissertation and statistical reports are included in this review. The results were input to the Mendeley group and checked for duplication. This research then examined and grouped relevant references according to the subject matter, which was then used for synthesizing and projecting honey beekeeping potential as a prospective sector of the forest-based bioeconomy. The results are presented in Table 1.

Table 1. Reviewed publications.

Theme	Number of Literature	References
Farming, feed, diversity	57	[3,29–84]
Production and product diversification, health benefits	89	[4–6,17,77,85–165]
Sociocultural dimension, regulation	23	[28,164,166–186]
Marketing and economic value	30	[18–20,22–26,187–208]
Environmental value, conservation, and threat	29	[15,16,73,156,209–233]

The official reports by the Statistical Bureau of Indonesia were purposively included since these are the only official source of honey production data in Indonesia. Codex Standard for Honey and the Indonesian National Standard for Honey were also cited in this study. Studies on the same themes mentioned in Table 1 from other countries were included as a comparison.

3. Results

3.1. Beekeeping and Bee Diversity

Meliponiculture and apiculture involve several steps, including collecting beehives in the forest, transferring the hive, transporting the hive to the beekeeping location, beehive maintenance, and product harvesting [29]. Bees can be transferred to the hive box for beekeeping in the farmer's house, yard, or garden. At least once a week, the farmers visit and check the hive boxes to protect them from pests such as lizards, spiders, ants, frogs, and birds [29].

Indonesia is a country with significant biodiversity, including bees. Seven out of nine species of the *Apis* genus are found in Indonesia, along with more than forty species of stingless bees [40]. Honeybees include *Apis cerana* Fabricius, *Apis nuluensis* Tingek, *Apis* *nigrocincta* Smith, *Apis koschevnikovi* Enderlein, *Apis dorsata* Fabricius, *Apis florea* Fabricius, and *Apis andreniformis* Smith. *Apis nigrocincta* Smith is an endemic Sulawesi species native to Indonesia [3]. Honeybee species found in Indonesia are *Apis nigrocincta* [234,235], *Apis koschevnikovi* [236] *A. Cerana* [30], *A. Dorsata* [28,32], and *A. Andreniformis* [237].

A. dorsata is a giant bee that only lives in tropical and subtropical Asian countries, including Indonesia [125,238]. This species is a wild honey producer and cannot be bred [40]. The honey produced by *A. dorsata* colony is the target of traditional honey hunters [239]. This honeybee is the most productive honey producer compared to other species. Each colony constructs a single vertical comb that hangs on the branches of trees, open ceilings, cliff rocks, roofs, rock caves, and other similar areas [125].

The eastern honeybee, *A. cerana*, is a honeybee cultivated for pollinating food crops with enormous ecological and economic value [240]. Historically, *A. cerana* was geographically isolated in Asia [240]. This species spread throughout the Asian continent and has been used for pollination and beekeeping for thousands of years [241]. *A. cerana* colonies have specific behavior. The worker accumulates nectars from scattered flower resources and forages under cloudy conditions at a temperature of 7 °C [241]. This honeybee can be cultivated in highland and lowland areas [62]. During unfavorable environmental conditions, such as the lack of feed, *A. cerana* tends to escape [238]. This species is resistant to disease, especially parasitic mites, but is more sensitive to the Thai sac brood virus [229].

A. mellifera is a western honeybee from Europe and Africa that was introduced in Asia with the advancement of the beekeeping industry [240]. *A. mellifera* is the primary pollinator of several crops, such as strawberries and sunflowers [228]. They also used propolis to seal their hive holes to protect against pathogens and were dormant at 7 °C [241].

Unlike the honeybee, the stingless bee (Apidae: Meliponinae) has no sting or a hexagonal nest [136]. Stingless bees are eusocial bees found in sub-tropical and tropical regions [147]. Stingless bees are found in different countries and are adapted to the local ecosystem [158]. Stingless bees can adapt to environmental changes (temperature, humidity, and rainfall) and changes in food sources within a few weeks to 3 months to form perfect colonies (Hrncir et al., 2019). Stingless bees also produce bee products, namely honey [165], propolis, bee wax, and bee pollen. In Indonesia, *Tetragonula laeviceps* Smith, *Tetragonula biroi* Friese, *Geniotrigona thoracica* Smith, and *Heterotrigona itama* Cockerell are cultivated due to their high productivity. The native Indonesian stingless bee is *Tetragonula* sp. [242]. *T. laeviceps* is the most commonly distributed stingless bee and known for its productivity [136]. Compared to the honeybee, *T. laeviceps* produces less honey, but it produces six times more propolis than the honeybee [85]. Stingless bees have a crucial role in the small-scale economy, especially for villagers, by providing honey, propolis, and bee pollen [83,230]. Stingless beehives can mostly be found on rock crevices, soil or underground cavities, and tree trunks or branches [208]. Every species of stingless bee has preferences for food resources, so they have different behavior in foraging. For example, *Tetragonula biroi* Friese and *H. itama* preferred to forage at locations closer to their colonies [83].

Indonesia's honey-producing bee species are *Apis* sp. (*A. dorsata*, *A. mellifera*, and *A. cerana*) and stingless bees (*Trigona* sp.). The indicated distribution of the bees is presented in Figure 1. Honey derived from stingless bees is produced in the Hulu Sungai Selatan, Tanah Bumbu, Tanah Laut, and Banjar areas [84]. *Apis dorsata* honey is mainly produced in North Sumatra, Lampung, Ujung Kulon, Bali, Central Java, West Kalimantan, North Sulawesi, East Nusa Tenggara, and South Kalimantan [28]. Meanwhile, honey originating from *A. cerana* is harvested in Aceh, North Sumatra, Riau, Banten, West Java, Yogyakarta, East Java, and Sumbawa [30].

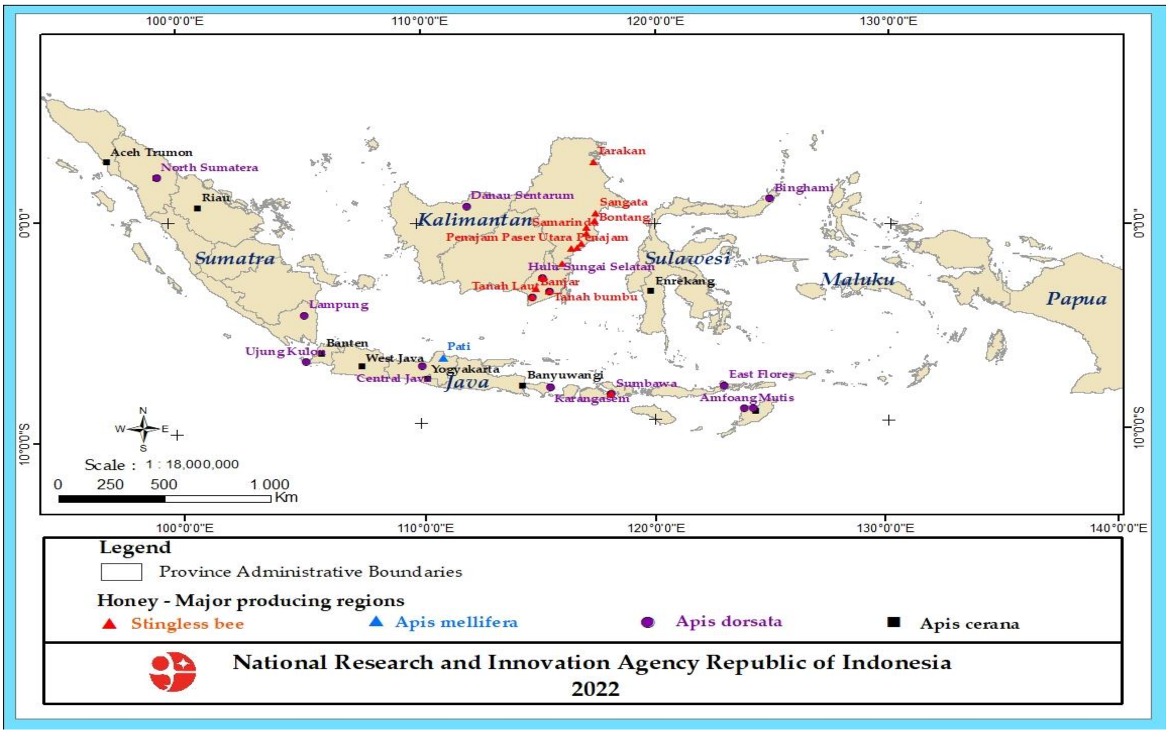

Figure 1. The distribution of major honey producing bees in Indonesia (Source: [3,28,29,31–33,40,84,86,237,243–245]).

The primary product of beekeeping in Indonesia is honey. On average, the predicted national production is 3.7 million L/year [3,246]. Citing previous studies, the indicated location and predicted production of honey are presented in Table 2; *A. dorsata* has the highest productivity [98], so the region cultivated this species is the highest contributor to the national production [61]. *A. mellifera* contributes approximately 25% of national production [246].

Table 2. Predicted annual honey production by region.

No	Type of Bees	Honey Production (L/Year)	Regional Indication
1	*A. dorsata*	218.3	Protected forest in Bukit Gatan, South Sumatra. Located in the northern and southern areas of the equator [247]
2	*A. dorsata*	166.7–250	The buffer zone of Ujung Kulon National Park, in Banten Province, covers 22.875 Ha of forested area [248]
3	*A. dorsata*	333.3	Protected and production forest in Lampung Province [249]
4	*A. dorsata*	1666.7–3333.4	Mangrove forest in Kubu Raya Regency West Kalimantan [250]
5	*A. dorsata*	50	Rantau Forest Area with Special Purpose, Ministry of Environment and Forestry, South Kalimantan [103]
6	*A. dorsata*	3106	Mutis forest, Timor Island [176]
7	*A. dorsata*	500–1215	Sisimeni Sanam Forest Area with Special Purpose, Timor Island [93]
8	Stingless bee	15–30	Community forest in Mempawah Regency, West Kalimantan [251]
9	Stingless bee	625	Agroforestry in Community forest in Kubu Raya Regency, West Kalimantan Province [252]
10	*A. mellifera*	19,016.7	Production forest managed by Forest Business Enterprise (Perhutani) in Java Island.

Generally, Indonesian honey has a high moisture content, around 22% for *Apis* and 27.5% for stingless bee honey [250]. It is higher than that required by Indonesian National Standard. The high moisture content is caused by the region's high air moisture, ranging from 60 to 90%. The availability of food sources is crucial for bees. Bees need nectar, pollen, resin, and water to survive, construct hives, and develop colonies [34,231,253]. Bees collect nectar from flowers or other plant parts, store it in a particular organ called the honey stomach, and then carry it to the hive [232]. During foraging, the nectar mixes with natural enzymes produced by bees. Inside the hive, it is kept in wax cells and dehydrated to a moisture content of about 18%–23% [87]. Honey produced from nectars of various plant species is called multi-flora honey. Bees need various nutrients (carbohydrates, lipids, proteins, amino acids) and obtain them from nectar and pollen. Oligolectic bees have a specific preference for plants. Polylectic or generalist bees feed on many plant species [254]. Bees feed on plants available within their foraging range [255]. Morphology differences between honeybees and stingless bees affect their ability to collect pollen and nectar, so their feed preferences also differ [256]. Bees prefer one source over another, for example, *A. mellifera* prefers *Cocos nucifera*, which has high sucrose concentration [257].

Honeybees spend most of their time collecting nectar and pollen, while stingless bees collect more resin to build the hive's defenses [34]. Considering their smaller body size, the sources of nectar that stingless bees collect are more diverse and cover a wide range of flower sizes [38]. Stingless bees also prefer specific flower species [39]. *Tetragonula laeviceps* prefers flowers from Poaceae family (76.49%), *Lepidotrigona terminate* prefers Euphorbiaceae (80.46%), and *Heterotrigona itama* prefers Solanaceae (83.33%).

3.2. Food Sources

Bees can forage in forests [41,88], plantations [42], agriculture [89], and agroforestry area [233]. Considering the high diversity of tropical forest ecosystems and their constituent species, several regions in Indonesia also have diverse food sources as presented in Figure 2. In Sumatra, food sources of honeybees include the families of Leguminosae, Melastomataceae, Myrtaceae, Sapotaceae, Anacardiaceae, Moraceae, Rutaceae, Musaceae, Solanaceae, Euphorbiaceae, Arecaceae, Sapindaceae, Myrtaceae, Sapindaceae, Polygonaceae, Compositae, Rutaceae, and Passifloraceae [31]. Families of Leguminosae and Arecaceae cover significant areas of Sumatra, particularly in Riau, Jambi, and North Sumatra. In addition, there are other families, such as Solanaceae, Muntingiaceae, Malvaceae, Combretaceae, and Acanthaceae [44].

In West Java, particularly in Bogor, bees' feed sources are plants belonging to Arecaceae, Combretaceae, Leguminosae, Meliaceae, Lamiaceae, Myrtaceae, Malvaceae, Poaceae, Rubiaceae, Anacardiaceae, Caricaceae, Lauraceae, Oxalidaceae, and Poaceae. [45]. The most common families of bees' feed In Kairatu District, West Seram Regency, are Arecaceae, Myristicaceae, Malvaceae, Sapindaceae, Myrtaceae, Anacardiaceae, Meliaceae, and Musaceae [46]. In East Nusa Tenggara, particularly in Mutis, *A. dorstata* feed sources are the families of Myrtaceae, Myristicaceae, Malvaceae, Moraceae, Leguminosae, Meliaceae, Anacardiaceae, and Arecaceae [32].

The availability of nectar produced by flowering plants differs depending on the species, location, and season. For some plants that flower seasonally, mixed-species planting is a better strategy for providing feed throughout the year, such as the coffee-agroforestry system in the Lake Toba region, North Sumatra [176]. In Padang Pariaman, West Sumatra, coconut and areca nut plantations flower year-round and provide a sustainable source of nectar and pollen, while maize only provides feed for bees during the flowering season [258]. Sugarcane plantation is a source of nectar extrafloral available throughout the year. After sugarcane was harvested, *A. cerana* and *A. mellifera* collected nectar dripping from sugarcane stalks. Alternatively, sugarcane nectar also can be obtained by rod milling process. Nectar sugarcane can be a substitute or supplement of sugar, which beekeepers commonly use to avoid feed scarcity during the rainy season. The use of pure sugar cane water is advised due to its macro- or micro-nutrients content [259]. Oil palm plantations also provide abundant pollen, so apiculture around oil palm and acacia plantations in Riau and Jambi support honey production throughout the year. The benzoin tree (*Styrax* spp.) simultaneously produces resin, nectar, and pollen in North Sumatra.

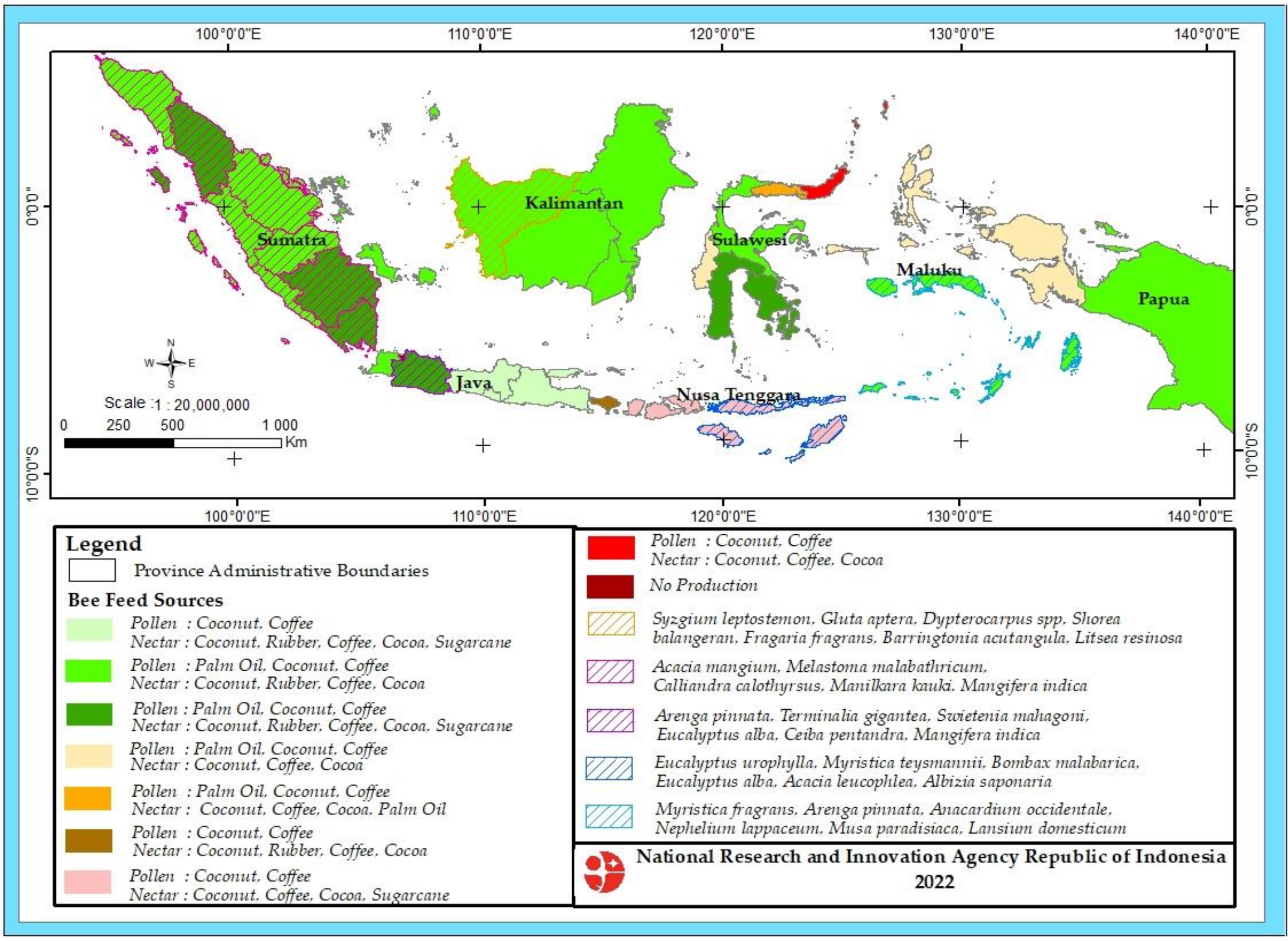

Figure 2. The distribution of bee feed sources in Indonesia [31,32,44–46,94].

The nectar and pollen yield per flower depend on the plant species and climatic conditions. The average nectar production is 0.046 kg per plant per year [207]. The carrying capacity of an area is defined as the number of bee colonies that can be sustained in the area. The carrying capacity is calculated based on the total nectar production per hectare per day, divided by the average need of one colony per day. Some examples are as follows: A cayenne pepper plantation produces 17.77 L/day/ha of nectar with a carrying capacity of 122 hives/ha; tomatoes produce 22.2 L/day/ha of nectar with a carrying capacity of 153 hives/ha in the flowering season [89]. During the three months of the flowering season, a coffee (*Coffea arabica* L.) plantation occupied by 70 bee colonies produces 190 L of honey [94]. Another fast-growing plant, calliandra (*Calliandra calothyrsus)* produces more than 100 liters of nectar per hectare per day. Calliandra produces 250 L of honey in the flowering season from 70 colonies for two months [94].

Bee product harvesting is one of the activities that support the livelihoods of the community around the forest. Bee products harvested from forests include honey, beeswax, and pollen [209]. Riau, North Sumatra, Central Java, Lampung, Bali, East Java, Lombok, Ujung Kulon National Park and the surrounding Lake Sentarum are some well-known *Apis* sp. honey producer regions [28]. There are differences in harvesting wild honey of *A. dorsata* and the farmed honey of *A. cerana* and *A. mellifera*. *A. dorsata* is the primary producer of wild honey and has not been cultivated. This species usually nests in tall trees and do not require a hive for nesting *A. dorsata* hives are often found on large trees in forest areas; in one tree, there can be more than one hive [98]. Some food source trees are also nesting trees of the bee. The kapok tree (*Ceiba pentandra*) is a common wild honeybee nesting site. *A. dorsata* in Kalimantan nests in *Terminalia catappa* and *Alstonia scholaris* [52]). In East Nusa Tenggara *A. dorsata* hives are found in *Albizia chinensis* (Osbeck) Merr), *Gyrocarpus americanus* Jacq., *Wenlandia buberkilli* var. *timorensis*, *Dalbergia latifolia* Roxb., and *Eucalyptus urophylla* S.T. Blake trees [32]). *Gluta renghas* Linn and *Artocarpus maingayi* King are nest trees for *A. dorsata* in Sumatra [53].

Stingless bee honey from Kalimantan is produced by *Heterotrigona itama*, *Geniotrigona thoracica*, and *Tetragonula laeviceps* [29]. Stingless bees build hives in sugar palm stalks, bamboo, wood, tree trunks, and underground [99]. Most *Tetragonula* bees are found nesting in public areas, and few are found nesting in the forest. Due to its size, *Tetragonula* can nest in small places such as wooden frames, house foundations, electrical boxes, and small holes in buildings. *Tetragonula sapiens* in Halmahera nests in the trunk of *Vitex coffasus* Reinw. and *Cocos nucifera* L. root [82].

Most honey hunters consider harvesting honey a sacred activity involving traditional and religious rituals that must be obeyed according to their traditions [209]. Harvesting honey from the forest is part of local wisdom, which also aims to conserve bees [183,260]. In Mutis, East Nusa Tenggara province, communities are prohibited from cutting nectar-source trees [184]. Wild honey hunting is generally carried out in groups consisting of 5–7 males with a travel distance of 5–20 km. They stay in the forest for 5–10 days, depending on the amount of honey obtained [183,209]. Usually, harvesting begins by reciting mantras and then climbing the nest trees using ropes [40,185]. Indigenous people in Sumatra, Sumbawa, Kalimantan, and East Nusa Tenggara use mantras in honey harvesting [28,184,186]. Harvesting wild honey includes preparing tools and materials, making smoke by burning coconut husks or dry leaves, climbing trees, smoking the tree while cutting hives, and post-harvest handling processes [192].

There are traditional destructive harvesting methods, but there is also a sustainable technique. The sustainable harvesting technique only involves cutting off the beehive's top and leaving the bee eggs behind. The hive and honey are separated by sieving [166]. This method separates honey and honeycomb by letting honey drop from the honeycomb without squeezing [52,166,193]. Wild honey can be harvested during the day and at night. In Java and Sumatra, honey is harvested during the day, while in Kalimantan, honey is harvested at night and during the dark moon [167] because bees are less aggressive. Honey of *Apis* sp. usually can only be harvested once in each nesting location.

The bee migration route depends on the flowering season [167,168]. The harvesting frequency is determined by the availability of feed plants and bee migration [55]. In West Kalimantan *Apis* sp. honey is harvested from September to December [169]; November–December in Central Kalimantan [167]; April, May, July, November, and December in Sumbawa, West Nusa Tenggara; April, May, and October in Moyo island [55]; January, March, May, June, October, and November in Mutis, East Nusa Tenggara [168]; September-October and January-February in Sulawesi [102], and January to March in Nusa Penida, Bali [28]. In South Sumatra, honey harvesting can be performed 2–3 times a year due to the continuous flowering seasons, and bees do not have to migrate [170]. Intentionally, beekeepers in Central Java herd *A. mellifera* bees to migrate following flowering season of crops to be able to harvest honey all year round [40].

On some bee farms, honey harvesting is conducted semi-mechanically. *Apis* sp. honey from the farm in Deli Serdang, North Sumatera, is harvested using an extractor [33] by cutting the hive. *A. cerana* honey in South Kalimantan is also harvested using an extractor, and the harvesting is carried out in daylight when the worker bees leave the hive for foraging. However, the harvesting method of cutting honeycomb produces a lot of beeswax waste, and honey is not fully extracted [56]. Modern harvesting techniques use extractors and beehive frames, so honey harvesting can be done more quickly and efficiently [33]. *Apis mellifera* honey can be harvested if there are at least 25,000 bees in one colony. The characteristic of a ready-to-harvest hive is that a layer of wax has covered the combs. First, the combs are cleaned from the attached bees, then the wax is peeled off.

Trigona sp honey harvesting does not require special skills and does not depend on the flowering season. In stingless beekeeping, understanding stingless bee foraging behavior is vital to maintaining the colonies' health and maximizing honey production. Beekeepers usually harvest the honey half year after the colonies settle in the hive box [29]. *H. itama* honey in Tanah Laut, South Kalimantan, is harvested in March, May, July, and September [194].

Deforestation and the increasing number of high-temperature days cause bee migration and affect the harvesting process, quality, and frequency [167]. The decrease in nectar-producing plants, the use of pesticides, and the lack of knowledge in beekeeping also lowered honey production [40,170]. The correct technique for harvesting wild and farmed honey will positively impact the honey quality and lower bee mortality. So, honey production and bee productivity can increase. Moreover, to maintain the sustainability of the beehives, only the part that contains honey should be cut. If the entire hive is removed, it can interfere with the development of the honeybee colony population [192] and the sustainability of honey harvesting [171]. The sustainability of the bee's natural habitat is the main factor of wild honey production. Even in conventional honey harvesting management, customary laws regulate bee food resources' sustainability [168].

3.3. Products, Processing, and Utilization

Honey bees produce honey, propolis, beeswax, pollen, and royal jelly [4]. The average *A. cerana* product yields are 17.20% of honey, 13.97% propolis, and 60.05% beeswax [102]. Traditional bee farmers in the Himalayas harvested 3–5 kg *A. cerana* honey per colony/year [105]. It is similar to honey production from *A. cerana* hives in Nusa Penida, which varies from 0.5 to 5 kg per hive every three months [30]. In the Enrekang district, *A. cerana* produces 1137.5 g/hive of honey each harvesting season. On average, the production consists of 250.58 g/hive of honey, 169.17 g/hive of bee bread, 250.58 g/hive of beeswax, and 105.42 g/hive of bee brood (pupae, hatchlings, and eggs) [102]. A single colony of *A. dorsata* produces an average of 13 kg of honey, ranging from 0.8 to 30 kg [28]. One nest can yield up to 40 kg of honey each season [170]. One family in Gunung Mutis commonly harvested honey from 5 to 15 nested trees, producing around 50 to 250 L of honey [168]. In Lake Sentarum, West Kalimantan, one hive of *A. dorsata* in *Barringtonia actutangula* (L.) Gaertn tree produces 1–20 kg of honey [166]. It is estimated that Sumbawa, West Nusa Tenggara provides 40 tons of honey annually, worth approximately USD 229.586 [28]. *A. cerana* provides income to 20 beekeepers who produce honey worth IDR 216,00,000 IDR (USD 14,590) yearly in Bandung, West Java [210]. The average *A. mellifera* beekeeper produces 23.5 kg/hive/year of honey in Daang Valey, Nepal [195]. In comparison, the total annual *A. dorsata* honey yield is 16–25 kg or 12–18 L per colony in Southern Thailand [57].

Stingless bee products consist of 15.4% honey, 63.7% propolis, and 20.9% bee pollen [104]. *Trigona* sp. produces 63.7% propolis, 20.9% bee bread, and 15.4% honey [103]. Stingless bee produces one to two kg or an average of 2 L honey per colony per year [106]. *Tetragonula laeviceps* produces much less honey than *A. dorsata*, ranging from 60 to 263 g per colony [99]. Stingless bee honey harvested during the rainy season averaged 0.17 L/month/colony, compared to 0.24 L/month/colony in the dry season [58]. *Trigona* sp. produces 18.20–30.80 g propolis each harvest time in Gangga district, West Nusa Tenggara province [107]. Honey production of stingless bees in Kapuas Hulu is 1.98–27.15 L each colony [29] or 2.37 kg each colony per year [59].

The difference in the source of nectar and the enzymes involved in collecting nectar causes the taste and aroma of stingless bee honey to be different and distinctive, more sour and bitter than the honeybees' [49]. Besides affecting the taste and aroma of honey, the food sources also affect the color. In Mutis, East Nusa Tenggara Province, the honey produced in October-November is greenish and tastes slightly bitter because of the nectar from *Wenlandia buberkilli* var. timorensis [32]. The farmers prefer honey produced after *Eucalyptus alba* and *E. urophylla* flowering season, which is sweeter.

Another well-known bee product is propolis, called "bee glue", because of its stickiness, comprises leaves, twigs, and buds mixed with wax and salivary catalysts excreted by the bees gathered from various plants [85,108]. It is also a part of the hive structure because worker bees use propolis to close gaps in the hive [109]. Propolis is a herbal product with many active compounds: alkaloids, flavonoids, saponins, tannins, triterpenes, anthraquinones, fatty acids, glycosides, and volatile oils [110]. The chemical content of propolis from stingless bees (*Tetrigona apicalis* (Smith, 1857), *Tetrigona binghami* (Schwarz, 1937), and *Homotrigona fimbriata* (Smith, 1857)) consists of carboxylic acid (17.1%), sugar (31.4%), sugar alcohol (11.4%), terpenoids (14.3%), aldehydes (5.7%), hydrocarbons (5.7%), miscellaneous components (11.4%), and amino acids (2.9%) [111]. The active compounds of propolis depend on the plant source [112]. Propolis has various pharmacological activities, including antioxidant, antibacterial, antimycotic, antiprotozoal, antifungal, antitumor, antiviral, anticancer, hepatoprotective properties, and antiulcer properties [113]. Moreover, propolis has been reported to have different medical advantages for gastrointestinal, gynecological, oral, and dermatological issues [114].

Royal jelly is exuded by the worker bee's mandibular and hypopharyngeal organs, which have thick, white, and jelly-like characteristics. It is called a "superfood" that the worker bees provide for larvae and adult queen bees [114]. Royal jelly contained 185 organic compounds, carbohydrates (15%), water (50%–60%), lipids (3%–6%), protein (18%), vitamins, and mineral salts (1.5%) [5]. Bee pollen is a granular composite of pollen and nectar gathered by bees and then compacted with a gluey substance [115]. Bee pollen contains vitamins, proteins, lipids, amino acids, carbohydrates, and minerals [116] that have potential medicinal, apitherapeutic, and nutritional applications [117].

Over the last decade, increasing demand for bee products required more efficient and effective processing techniques on a larger scale. Various food processing techniques, both conventional and modern, have been applied to maintain the quality of bee products. These techniques include drying, storage, extraction, isolation, and identification of the nutritional content [118–121]. The techniques applied are different according to the bee products. Products with high moisture and easily contaminated by microbes, such as bee pollen and bee bread, should be kept in the dark, low-temperature storage [118,122,123]. Propolis also should be stored at low temperatures, while honey can be stored at temperatures of 4 to 20 °C [122,123].

Processing techniques affect the composition of the active compounds, physical properties, flavors, and functions of the bee products [121]. The drying technique is essential to control the moisture of the bee products [119–121]. Traditional drying methods include sun drying, freeze-drying, and hot air chamber [120,121]. A hot air chamber requires a shorter drying time, but it affects the product's organoleptic quality and characteristics, physicochemical properties, and morphological structure [120,121]. Therefore, freeze-drying is the most suitable method, with a rapid rehydration rate and high rehydration capacity [124].

Furthermore, innovative and a01dvanced drying methods such as infrared radiation (IR), thin layers, microwaves [118], microwave-assisted vacuum drying (MW-VD), low-temperature high velocity (LTHV)-assisted fluidized bed drying have been applied in drying bee products that have high humidity, especially bee pollen [120,126,127]. Innovations such as ultrasonic temperature distinction, ultrasonication high shear (US-HS) method, and supercritical carbon dioxide (CO_2) have been applied to prevent yeast and hydrolysis of compounds.

Propolis, honey, beeswax, bee pollen, and royal jelly are common ingredients in traditional medicine. Advanced research has reported bee products as raw materials for medicines. Honey from various parts of the world, including Indonesia, contains nutrients for human health. Consumer demand for honey has increased dramatically during the COVID-19 pandemic period. Honey is thought to have the potential to boost immunity [196]. The health benefits of honey are related to antioxidant, anti-inflammatory effects, wound healing, and anticancer effects [128,129]. Honey also prevents health problems due to its antioxidant properties [130,139]. Honey is an effective antioxidant because it contains phenolic compounds, flavonoids [261], and vitamin C [262]. At the same time, quercetin in honey reduces the effects of pesticides on the bees' food sources [263]. Honey also contains water-soluble vitamins, proteins, and unsaturated organic molecules [132].

Indonesian *A. cerana* honey gathered from Bali, Banten, Papua, and Banyuwangi has antioxidant and anticancer properties [133,134,140–142]. The bioactive content and antioxidant activity of *A. dorsata* Binghami from North Sulawesi also demonstrated high free radical reduction activity compared to vitamin C [143]. *Trigona* sp honey products contain polyphenols, alkaloids, and flavonoids [264,265], including calcium, magnesium, iron, phosphorus, potassium, and sodium [265,266]. The stingless bee honey's antioxidant and biological activity is higher than that of *A. mellifera* honey [267]. *Heterotrigona itama* honey collected from bee farms in East Kalimantan, Indonesia, has antioxidant activity. The antioxidant activity (IC_{50}) ranged from 43.54 to 71.27 ppm [86]. Indonesian honey protein isolated from *Tetragonula* sp. has antibacterial activity against *E. coli* [268]. *Propionibacterium acnes* can also be inhibited and killed by Indonesian honey [134].

The flavonoid content of propolis and honey is produced in a modular *Tetragonula* hive [136]. It has potential for the food, pharmacy, and cosmetic industries [269]. The stingless bee propolis was mostly made up of lipids (45.60%–47.86%) with very little protein (0.18%–1.18%) and carbohydrate (0.17%–0.48%). Propolis is a good source of minerals due to its high content of mineral elements while containing low concentrations of heavy metals [158]. Propolis ethanol extract also demonstrated antimicrobial activity against four bacterial strains (*E. coli*, *S. aureus*, *P. aeruginosa*, and *B. subtilis* [158]. Propolis is also scientifically proven to treat gastric disorders [270]. Propolis has been used in dentistry as an antimicrobial [271]. Bee pollen is a therapeutic product that is very useful as a natural medicine due to its nutraceutical applications [272]. The active components in bee pollen are beneficial for health. The bioactive compounds in bee pollen are carbohydrates, polyphenols, amino acids, proteins, vitamins, lipids, and minerals [273].

Royal jelly has different pharmacological properties and contains proteins, sugars, nutrients, lipids, minerals, polyphenols, flavonoids, and a few organic active compounds [274]. Bees secrete wax to build a hive. Beeswax is used in the food industry and cosmetics and has very effective therapeutic properties for healing bruises, inflammation, and burns [275]. Beeswax is an emulsifier in cosmetics that gives elasticity and plasticity and improves skin adhesion [276]. Beeswax for industrial purposes has begun to be widely developed as a material quality-enhancing agent to improve margarine's texture [277]. Beeswax is an alternative to plastic packaging, and during storage, without changing the texture and taste [278], beeswax is also used for enhancing antimicrobial activity [279].

Bee products, especially honey, have a good effect on the skin and hair [276]. The anti-inflammatory, antibacterial, and antioxidant activity can repair and reduce scar tissue effectively. Honey application is encouraged in treating acne [280,281]. Honey is also a skin moisturizer [276,281]. The content of fructose, glucose, amino acids, minerals, vitamins, and high enzymes has been proven to provide a moisturizing effect on the skin [276,280,282]. The hydration effect helps moisturize the skin and improve its function. In hair care, honey increases hair abundance, maintaining waves and lubricating hair, making it easier to comb. Honey can penetrate deep into the hair shaft and improve flexibility and elasticity [276].

3.4. Sociocultural Dimension

Traditional honey harvesting has been performed for a long time in Indonesia [28], and honey is considered one of the ancient products [125]. Honey is one of the ancient 'staples food' for people on Timor Island as the most farmers in West Timor cope with the food crop deficit with honeybee products, and protecting the forest is a customary obligation [283]. In many places in Indonesia, mainly marginal areas, NTFPs are essential for food safety and livelihood.

Although bees are found across Indonesia, written documents regarding the early trade of the bees' products and the "political ownership" and occupations seem to be available only from the Eastern part of Indonesia, particularly in the dryland or dominated semi-arid areas. The marginality of the Eastern region seems limited European colonial interest only for indigenous forest products of sandalwood (*Santalum album* L.) and beeswax. As for the local people, increased economic value of the product and being an important "food" of honey has brought ownership claims of the natural resources, while European colonial interest in forest trade in some degrees has shaped their claims over the semi-arid regions of Nusa Tenggara. To some degree, European colonial interest in forest products trade has also shaped their claims over the semi-arid regions of Nusa Tenggara [12,283].

Wild honey management has been developed for a long time in Indonesia and is a part of the socio-cultural tradition of the local community. It takes place in various ethnic communities, including the Dayak communities [166,167,284], Sumatra [285], and Timor [168]. This tradition marks a strong relationship between humans and the forest through the utilization of wild honey. This relationship affects the knowledge and recognition of bees, including nest trees, the value of bee benefits, habitat management, and community participation in honeybee protection [286].

Indonesia's multi-cultural and archipelagic characteristic impacts the variations in bee habitat management models. The indigenous people of the Mutis forest on Timor Island carry out forest landscape management based on traditional management areas called "Suf" [287], including home gardens and traditional agroforestry "Mamar" [168,288]. The honey harvesting tradition is a cultural feast started by a traditional ritual procession involving community leaders, religious leaders, and family members with traditional territorial management rights [168]. Local wisdom of honey management outside the forest area can be found in the agroforestry system. Maintaining bee food sources has sociocultural, economic, and ecological benefits, thereby strengthening the sustainable management in the community [289] and protecting bee habitat that supports pollination and farm production [290,291].

Most wild honey hunting and cultivation practices have been passed across generations, such as in Bali [292] and Timor island [168]. This traditional practice raises public awareness that the presence of bees and honey production indicates the forest ecosystem's and the surrounding environment's health.

Beekeeping provided a new chance to enhance household revenue, especially for rural communities [83,293] in Indonesia and other countries. In Ethiopia, honey bee farming encouraged rural people to improve their livelihoods through honey and other bee products [230]. In Zambia, beekeeping and honey hunting are crucial sources of income for 20,000 villagers [209]. Beekeeping is a source of income, even the primary source, through the intensive cultivation of a large number of colonies [294]. Market demand affects the cultivation of honey-producing bees. Research showed that stingless beekeeping is very profitable and has become the household's primary source of income [28]. The contribution of income from honey production varies widely, ranging from 4.8% for the cultivation of *A. mellifera* in South Sumatra [295] to 14.72% for the income of *A. dorsata* honey in South Sulawesi [296].

The price of bee products, especially honey, in the world market indicated that bee products could play essential roles in improving human welfare. The honey produced by *A. mellifera* dominates the world honey market. However, the honey produced by native Asian bees may achieve better market prices [297]. *A. cerana* and *A. dorsata* are crucial native species that significantly contribute to the honey market, especially in Southeast Asia [297].

Beekeeping is an attractive business because it has low risk, does not require high education and creates jobs [205]. As mentioned above, beekeeping can improve people's welfare, but several aspects must be considered. The beekeepers should have access to a modern beekeeping system, upgrade the traditional bee farm to a large-scale business [40], improve knowledge and skill, organize bee product marketing, involve equipment suppliers, and promote beekeepers' network alongside collaboration with the private sector and research institutions [204]. In Indonesia, a group leader still plays a vital role in the development of beekeeping [80].

3.5. Marketing and Economic Value

Honey and other bee-derived products are harvested from wild and farmed bees throughout Indonesia. However, the most prominent supplier is Nusa Tenggara Barat Province, which accounted for 80% of the national supply, according to the Forestry Office of West Nusa Tenggara Province. A study stated that the province's honey production reached 40 tons annually [28]. However, honey adulteration by mixing honey with liquid sugar is commonly found. The producers do not fulfil the standard of pure honey [52], although most buyers pursue honey's health benefits.

Honey has been known for its benefit in maintaining human health, thus increasing its market value [203]. Some benefits of consuming honey are increasing pregnant women's health, boosting children's appetite, providing additional vitamins and nutrients, restoring body condition after illness, and relieving coughing, influenza, thrush, stomach ache, tonsillitis, and pain in the throat. In addition, honey is used to treat stomach acid diseases, diabetes, ulcers, hyper cholesterol, anaemia, heart disease, cancer, and skin and facial treatment such as removing dark spots and acne [52]. Some countries use bee's colony to assist in pollinating agricultural plants such as seasonal crops and fruit plants [14,15,164], contributing to increasing crop productivity. The pollinating assisting contract schemes provide a stable income for beekeepers [17,161–163]. The high domestic and international demand for Indonesian honey cannot be fulfilled by domestic honey production. Indonesia imported 6216 tons and exported 214 tons of honey in 2022 [298]. The difference between the imports and exports reached 6002 tons, making Indonesia the net importer of honey [40].

Regions producing a surplus of honey sell it for the national market or export them. However, Indonesia's honey exports are still relatively small. Furthermore, the honey exported from Indonesia has low quality due to its moisture content, sugar content, the quality of feed sources, and the contamination of pesticides sourced from the feed plants [40]. Nevertheless, beekeepers' jobs could provide additional household income, as high as 68% in Sumbawa communities [28]. This phenomenon is also experienced by other forest dwellers' communities, although the job was available seasonally [170,202]. Unfortunately, the forest conversion into agricultural fields and plantations also threatens the wild honey harvesting, a livelihood of some villagers in the area. An example was the expansion of oil palm plantations in Bengkayang, West Kalimantan, Indonesia [52]. The forest area was a significant producer of wild honey.

The Central Bureau Statistics Agency (BPS) 2021 noted that honey production in Indonesia fluctuated drastically from 2017 to 2021 (Figure 3). The graph showed that the lowest production of the last five years was in 2020 due to limited honey-collecting activities and the difficulties in marketing following the national restriction policy on citizen movement and transportation services to mitigate the COVID-19 pandemic. However, it increased after the government loosened the restrictions in 2021 [168]. According to the Statistics Agency, honey production in 2021 was 189,780 liters, far below a study that reported 3.7 million liters [3]. The data on actual Indonesian honey production has not been properly recorded.

Java Island was the largest honey producer in 2021, which reaches 180,508 L or 95.11% of the national production. Sumatra is the second largest producer, with honey production reaching 7534 L or 3.97% of the total national production. Bali-Nusa Tenggara and Kalimantan contributed 1111 L and 627 L, respectively. The fluctuations in honey production are partly caused by insufficient feed sources for bees, especially in Java. An effort to revive the community's success in producing honey is through beekeeping [52]. Optimizing the flowering period of monoculture plants can increase honey production [179].

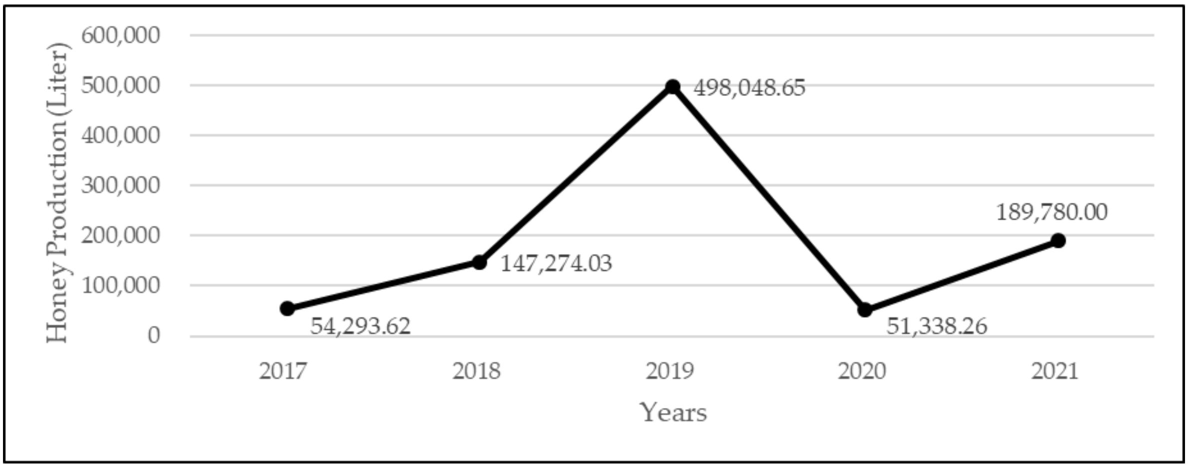

Figure 3. Production of honey in Indonesia 2017–2021 [8].

The most common problem related to the economic aspect of beekeeping in developing countries is the farm's distance from the potential market [28]. The beekeepers are located near the forest area, which barely has sufficient road infrastructure, thus making the selling price low. The decline in honey quality (high moisture content and fermentation) was also due to poor product packaging and the lack of knowledge of post-harvest honey processing [28].

Problems related to honey production can be summarized as follows, (1) honey extraction from honeycombs is done manually, which is time-consuming and ineffective for extracting all honey; (2) the hygiene of honey products since the equipment used in the post-harvest up to package processing is not sterilized; (3) honey is stored in plastic jerry cans, reused glass or plastic bottles which unlabelled and unsafe; (4) the marketing is still done traditionally (honey is sold to the nearest retailers or beekeepers themselves sold honey in a stall on the village's main road). Some irresponsible retailers mix pure honey with liquid sugar, thus reducing the quality of the honey; and (5) The lack of an organization of beekeepers to improve the quality, production, and marketing of honey.

3.6. Environmental Contribution

Bees are sub-components of natural ecosystems, directly or indirectly influencing the dynamics of forest ecosystems. Bees' direct influence on forests derives from their ecological function in pollination [78], assisting the regeneration of woody vegetation species in forest ecosystems, including nesting trees [57,219]. Bees are the most dominant pollinators of flowering plant species [79], including food crops [159,160,273]. Therefore it is one of the reasons for conserving bees and their habitat [77,78]. Bees' pollination service in the agricultural sector has increased significantly in the last 50 years which has implications for the food production [299]. The ecological relationship of biotic and abiotic components of the natural vegetation community supports pollination functions, including influencing variations in the nutritional content of the honey produced [150]. This variation is caused by the type of vegetation, including the nature of wild bees in forest areas that prefer flowering trees. It differs from agricultural land, which uses bee colonies for pollination. Under these conditions, the characteristics and diversity of agroecosystem vegetation have implications for the habitat's carrying capacity and wild bee population in agricultural ecosystem units [48].

Changes in forest ecosystems, such as habitat degradation, reduce the habitat's carrying capacity for bee colonies [300]. The bee population may decrease or even become extinct in forest ecosystems. The overexploitation of forests and smoke from deadly forest fires reduce bee colonies. The decrease in forest cover with dense vegetation and the conversion of forest into agricultural land resulted in declining biodiversity and wild honey production [168]. It indicates that the abundance of bee populations and honey production in an ecosystem unit is a unitary function; thus, the stability of environmental factors influences them [149]. These environmental factors affect bee productivity and regeneration.

On the other hand, bees also play a role as bio-indicators of environmental damage, including the emergence of viruses that attack humans [218,222]. It proves that environmental factors and the diversity of vegetation types determine the sustainability of bees and their role in ecosystem services. Forest honey bees, as pollinators, preserve the plants and the forest environment. Various landscapes provide habitats that are usually linked to the vegetation structure and composition impacting the wild bee population [67,68]. In commercial cultivation, bee productivity decrease when the heterogeneity of plant species is less than in natural condition [69], thus impacting pollination services.

Habitat sustainability determines the sustainability of honey production in natural forests. Moreover, community dependence on forests for various purposes is still high, such as the need for firewood and free-range livestock systems [216,301]. Deforestation can eliminate bee habitat, reducing the income of rural communities [302]. Moreover, 75% of Indonesia's honey is produced by wild bees. Using herbicides and pesticides causes soil pollution and affects soil pH and fertility. This problem disrupts the balance of the forest ecosystem, ultimately hindering bee conservation. Pesticides and herbicides contaminated bees' food sources. As a result, bees' nectar and pollen are contaminated with pesticides, which can cause poisoning, decrease the bee's natural immunity and ultimately lead to the colony's death [66]

The role of wild bees as pollinators on peat land also contributes to reforestation so that the soil moisture level is maintained and forest fires on peatlands are prevented. The development of NTFP commodities fulfils the requirements for sustainable forest management, e.g., socially and equitably accepted, environmentally friendly, and has a positive impact on the community's livelihood with a 10%–60% increase in household income [200,217]. The urgency of sustainable forest management has also accelerated paradigm shifts on a national and global scale [217].

Bees have contributed to increased human welfare, health, and the bioeconomy and supported various SDG targets. Human awareness and a positive attitude toward the important ecological role of insects provide opportunities to save bee habitats and form initiatives in the sustainable management of crop production and forest lands. Most cultivated plants are pollinated by honeybees and they significantly improve the quantity and quality of the products on average by 65% [303]. Wild bees contribute USD 3251 per hectare on average to insect-pollinated crop production, similar to that provided by farmed honeybees [156]. A small number of the most common wild bee species provide the majority of bee-related crop pollination services [156]. Other insects, such as flies, wasps, beetles, and butterflies, also have an essential role in plant pollination [155].

The general contribution of bees and their environmental valuations should be assessed comprehensively. Discussions on bees' environmental valuation should consider the contribution of all bee species, including wild and cultivated populations. There was evidence of competition for food and nesting resources in forests, disruption of native plant-pollinator tissues, and the potential for viral disease transmission between species, as the IUCN assessed 483 bee species in 2019 [79].

Bees and their products provide vital opportunities to build a bioeconomy and sustainable development targets for forest communities in Indonesia (Figure 4) [79,177]. The culture of conserving wild bees while protecting the forest and beekeeping provides a reference for community forest development in the present and the future. Bees' multidimensional role includes increased quantity and quality of food production, including vegetables, fruits, non-timber forest products, and biofuels. Moreover, it increases community empowerment, which impacts forest health, ecosystem diversity, forest conservation, and cultivation of forest plants with high economic value. For example, on the island of Bangka Belitung, Indonesia, *Tristaniopsis obovata*, *T. merguensis*, and *T. whiteana* (Myrtaceae) are bees' nesting trees. They also produce edible ectomycorrhizal *Hemioporus retisporus* mushrooms in the rainy season, which have high economic value [220]. It is a good example of how trees can improve people's nutrition through honey and generate income. NTFP commodities can be used to prevent forest conversion and environmental damage, which is currently being exploited for tin mining.

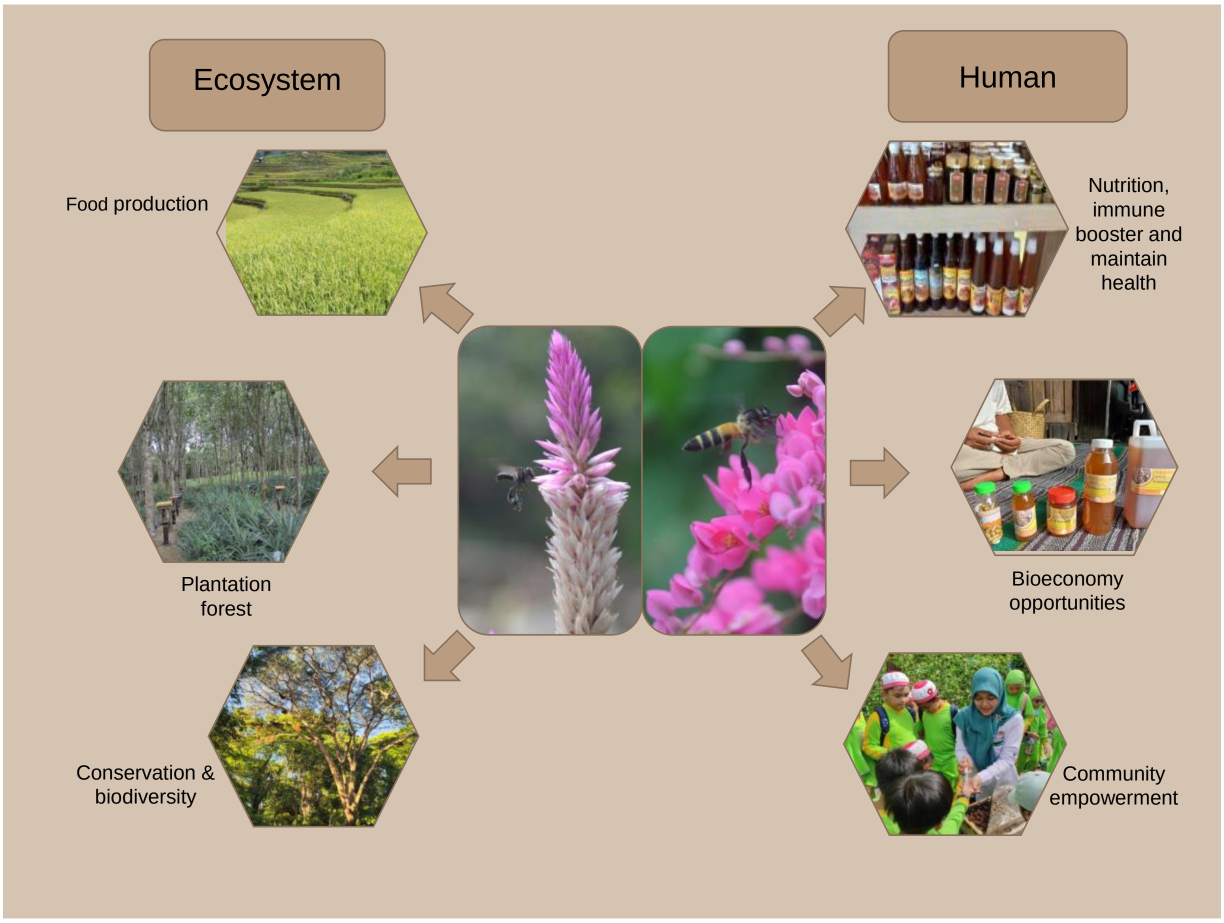

Figure 4. The role of bees' contribution to bioeconomy and sustainable development targets (modified from [79]).

There are many places in Indonesia where the community's economy is based on bee products, either wild or farmed bees [168]. People in honey production sites also know honey's social, environmental, and economic value. The communities realize the importance of preserving the environment for bees, which also positively impacts their livelihoods. Social values are formed not only because of public awareness but also the potential threat of damage to the bee habitat, such as forest fires, theft, or human environmental destruction. Local wisdom is essential and contributes to efforts to save forest resources. There are many examples of local wisdom in Indonesia related to the role or contribution of forest honeybees in the value of the surrounding social environment. This is usually the case in forest bee-based honey production centers [167,168]. The local wisdom is typically long-lasting because the communities believe that losing their local wisdom leads to the risk of losing their identity, a reduction in their quality of life, and a threat to the natural resources that support livelihoods [167].

Local wisdom is not only in the form of tools or methods but also customary agreements, local regulations, and related to harvest and post-harvest processes. The basic principle of the regulation is to protect the quality of the bee habitat to maintain the stability of honey productivity, harvest frequency, the bee population, and the maintenance of honey quality. An example of local wisdom called "*Tikung*" protects the habitat and population of wild bees in the honey production center area at Danau Sentarum in the village of Nanga Tuan, West Kalimantan [167]. The local wisdom begins with a collective agreement in choosing trees for *Tikung* installation, division of management areas around the lake, sanctions for tree loggers and *Tikung* thieves, requirements for harvesting natural honey, and post-harvest treatment [175]. Similar local wisdom is also found in the people of Muara Ripung village, South Barito District, Central Kalimantan Province. Local wisdom is reflected in the materials and harvesting equipment used and rituals carried out at harvest time.

Maintaining social and environmental values by complying with local regulations related to bee management is also found in West Timor. There is a prohibition or taboo called "*Banu*". It is a prohibition regulated by traditional leaders (Ama Rao) and local indigenous peoples (Manobe) related to preserving the forest environment or bee habitat and determining harvest time. This local regulation regulates the distribution of honey products evenly and in rotation to members of the local community, both those who have bee-nesting trees and those who do not. This local wisdom can be found in Polen Village, Loli Sub-district, South Central Timor District, East Nusa Tenggara Province. Harvesting season is in July and October, with the largest harvest in October. Bees' food sources in the area are *Ficus* sp., *Eucalyptus alba*, *Gliricidia sepium,* and *Chromolaena odorata*. In this village, half of the community member has honeybee nest trees, and up to 80 hives are found in a tree with a productivity of 5 to 7 L/hives. However, due to COVID-19 pandemic, the harvesting rituals were simplified [168].

Local wisdom is an effort to regulate the environmental balance and maintain sustainability so that the forest bee population is maintained. A local community views bee as an inseparable part of their economic system. The actions and views of this local wisdom are motivated by the long-term benefits of forest bees in their environment. Local wisdom has also incorporated an innovation from outside, such as the example of the Sentarum lake community, which introduces the "*Panen Lestari*" method, the harvest method originating from Vietnam. This method has increased the production and frequency of harvesting wild honey from once a year to two to three times a year. The community's adherence to local knowledge is the key to ensuring the preservation of forest ecosystems.

3.7. Governance

Regulations in wild bee management are needed to guarantee the quality, benefit for humans, and economic value [148] so that the presence of bees can be maintained and honey production improves the economy of forest communities [199]. Developing beekeeping includes business scale upgrading, standardization, routinization, and specialization of labor to increase yields and profits. For example, the USA obtained the first honeycomb design patent in 1852, which is considered the beginning of modern beekeeping in which the farmers could inspect bee colonies and arrange more productive harvesting [161]. The development of bee farming also relies on the dynamic of bee habitats and connects to the socio-cultural development of the farmers. Scientific assistance in the development and modernization of beekeeping governance is also essential, providing course materials related to honeybee governance in universities and disseminating through agricultural activities [161].

The growing understanding of bees as part of forest and agricultural ecosystems has characterized the governance of bees in several countries, including the UK, France, and the Netherlands, although it has not prevailed regionally or internationally. Other countries have also tried to develop best practices to assist the development of beekeeping. Vietnam has included the management of beekeeping in the certified biosphere system. This country registers the honey beekeepers based on two criteria: An environmentally friendly, safe, and healthy bee farm and a bee farm that improves local communities' livelihood and protects the traditional culture. The main aim is to control the overexploitation of natural resources and unsustainable development [214]. The Netherlands believes that urban gardens could be managed to attract bees so that the space could be used as a habitat for beekeeping [213]. Brazil has designed integrative management of beekeeping in community-based management of the Xingu River basin, considering that beekeeping is a significant livelihood of the households in that area [212].

The role of bees as wild pollinators has not been widely considered and protected by the policy. The increasingly intensive use of agricultural inputs, including pesticides and insecticides, land use, and climate change, threatens bee survival [211]. Organic farming more or less contributes positively to the protection of bees as pollinators. The main factors identified in the case of declining honey production and bee colonies in the U.S. are changes in the land function triggered by regulations and market forces that reduce conservation lands and the intensification of corn and soybean farming. The policies that help farmers access capital in the form of agricultural insurance utilized to convert bushland that beekeepers previously used have also negatively impacted the honey production and colonies of bees [17]. Research suggested that the protection arrangement of pollinators based on the number of hives in a particular area requires a review since the attractiveness of plants to the pollinators is not the same. The preference of pollinators is influenced by the plant diversity and habitats that attract pollinators, such as bees [173].

Increasing environmental awareness on a global scale contributes to the conservation of pollinators, including bees [14]. However, the understanding that only cultivated bees play an essential role in pollination marginalizes wild bees' contribution [304]. In addition, there has been no international consensus on the protection of pollinators, including bees. Generally, conservation strategies are still available at the national, state, or lower government levels. For example, the U.S. designed and implemented several measures that included raising public awareness, pathogen management, establishing a task force for pesticide control, improving pollinator habitats, and funding research and monitoring of bees and natural pollinators [304]. Some of the key points that characterize the success of the participatory governance that engages the collaboration of beekeepers, policymakers, and community participation include the consideration of (1) Equal treatment of professional scientists with beekeepers' views and fairness of respect for beekeepers, (2) policies made based on future changes, and (3) The conflict of interest between pollinator conservation and pro-productivity agricultural development strategies. Another study suggested that bee management planning should consider economic and environmental factors. The potential norms of habitual social norms and human motivation also have the potential to play a crucial role in understanding the development of more attractive and effective bee governance [172].

Bees have provided ecosystem services that maintain balance and support life on this planet [226]. Bees have a bioeconomic foundation and are attached to sustainable development targets. Research proves bees' function in pollination, biological pest control, natural life cycle regulation, seed dispersal, and bio-inspiration. The contribution of bees is key to achieving SDGs and can be specifically identified and synthesized (Table 3).

Table 3. Contribution of tropical honey bees on bioeconomy and sustainable development goals (SDGs).

No.	The Role of the Honey Bee as Part of the Bioeconomy and Sustainability	Contributions of the Tropical Honey Bee to SDG Targets	Specification of the Contribution of Tropical Honey Bees to SDG Targets	References
1.	Forest communities have crops, food from forests, and essential nutrients for life	SDG #2 Zero Hunger	Bees contribute to pollination and flowering, increasing seed, vegetable, and fruit production.	[227,273]
2.	Various types of honey from different nectar sources have the medicinal potential for health	SDG #3 Good Health and Well Being	Forest bee products are a source of traditional and modern medicines to treat various diseases and increase the human body's immunity. The contribution of bees to pollination builds good forests and clean air quality	[225]

Table 3. *Cont.*

No.	The Role of the Honey Bee as Part of the Bioeconomy and Sustainability	Contributions of the Tropical Honey Bee to SDG Targets	Specification of the Contribution of Tropical Honey Bees to SDG Targets	References
3.	Successful reforestation and improving the quality of healthy forests and good bee pollination processes are the keys to the sustainable production of clean drinking water and the necessities of daily life	SDG #6 Clean Water and Sanitation	The contribution of bees in the pollination process in tropical forests increases the population of tree species that grow and bear fruit to become an evergreen area so that the forest provides clean water and sanitation for communities around the forest.	[71,273]
4.	Management, cooperation habits, and characteristics of bees, along with the architecture of their hives, are the inspiration for humans to innovate and build knowledge-based infrastructure from bees	SDG #9 Industry Innovation and Infrastructure	Innovation by imitating the character of bees for building design, aircraft design, computers and bee cooperation methods to streamline production	[153,154]
5.	Bee pollination has a role in the sustainability of flowers in gardens and urban forests, shows air quality improvement in urban areas	SDG #11 Sustainable Cities and Communities	The Tilia tree species (Malvaceae) can pollinate in the studied urban forest. This species contributes to ecosystem services in urban areas.	[152]
6.	Local honey production through livestock farming and marketed through tourism programs	SDG #12 Responsible consumption and production	Honey Bee cultivation can be promoted as a local and foreign tourism business to increase regional development. Honey bee products and natural products from pollination increase food quality and the shelf life of more durable food.	[201,223,224]
7.	Diversity and the existence of bees in the forest and as members of ecological diversity are essential indicators of climate change	SDG #13 Climate Action	The impact of climate change can be monitored through the behavior, physiology and distribution of honeybees and the evolution of honeybee interactions with diseases.	[221,222,305]
8.	Bees contribute to improving the nutritional value of the plants they consume which makes it an alternative to fulfilling the nutrition	SDG #14 Life below water	Bee brood is a nutritious food containing high protein, fat and carbohydrate but low calcium. It also has phosphorus, magnesium, potassium, and trace minerals iron, zinc, copper, and selenium.	[306,307]
9	Bees contribute to saving forest lands by pollinating all species of forest plants, shrubs, and grasses. Sustainable reforestation and conservation can provide benefits and value for people's livelihoods and reduce poverty	SDG #15 Life on land	Bees play an essential role in conserving tropical forest lands.	[79]
10.	Forest communities work together, live side by side and share trees for harvesting forest bees and promoting shared welfare and health	SDG #17 Partnership for the goals	Tropical forest employment and income enable forest communities to work together to buy food to guarantee healthy throughout the year	[308]

This research underlines that there has been no comprehensive policy intervention from the government of Indonesia to facilitate the governance to support bee farming. Instead, bee farmers are faced with certification regulations issued by the National Agency for Drug and Food Control (BPOM). Bee farmers with limited knowledge and capital resources have difficulties developing honeybee businesses. BPOM and other institutions should facilitate honey farmers by providing training to comply with national management standards (SNI 8664:2018 for honey quality assurance) [309].

The Indonesian government can intervene to maintain honey production level and quality by (a) assisting farmers regarding the harvesting and post-harvest techniques to maintain honey quality and (b) fostering honey producer groups from production to marketing. The process of facilitating bee farmers should be focused on marketing [310] through market penetration and product development [197]. The government can also arrange participative policies in collaboration with *Badan Usaha Milik Desa* (Village owned Enterprise) and other parties by encouraging corporate social responsibility (CSR), for example, by strengthening honey bee farming capital.

4. Discussion

4.1. Production and Product Diversification

Indonesia's honey production level is poor compared to other countries known as honey producers and exporters worldwide, such as China, America, Argentina, and Turkey. Most of Indonesia's honey is harvested from natural forests, while honey-exporter countries' supply is obtained from beekeeping activities supported by horticultural agricultural activities [61].

The demand for honey in Indonesia is relatively high, reaching 7500 tons/per year, whereas the national honey production was only 4000–5000 tons/per year. Honey production in Indonesia has not met the domestic honey demand [3]. Indonesia is a honey exporter country, but Indonesia's honey export competitiveness is still low compared to ASEAN countries such as Thailand and Singapore [311]. Various strategic steps must be pursued to increase honey production, from collecting forest honey to beekeeping. Forest bees need to be maintained through sustainable forest area management, forest bee habitat conservation, colony management, and sustainable harvesting. It is necessary to map the distribution area of forest bees, potential colonies, and their habitats in forest areas. This is because the sustainability of production is largely determined by preserving their habitat in natural forests [88]. Traditional forest honey harvesting techniques are still inefficient due to the removal of the entire hive. Therefore, it is necessary to increase community capacity through education and training in sustainable forest honey management by implementing sustainable and hygienic honey harvesting [60].

The determining factors underlying the success and failure of beekeeping development projects highlight the need to understand better the knowledge and lessons learned from professionals working in apiculture development to better design, implement and facilitate beekeeping projects [312]. There is an opportunity to understand better how to optimize beekeeping programs and provide guidance to inform best practices by learning from the experience and insights of those involved in beekeeping development and marketing programs. Other studies stated that several strategies could be implemented in the business development of beekeeping, including human resources who have a high commitment to the development of honey beekeeping businesses and assistance from universities and related agencies [313].

The obstacles to beekeeping are worker bee deaths related to climate, food sources, and pesticides [3]. Therefore, proper colony management is required, such as supplementary feeding [40]. Honeybee cultivation techniques, strong colony conditions, skills, and disease management are essential. The honeybee colony's performance is strongly influenced by the quality of the queen and the availability of nutrients [145,146]. Honey bee queen rearing is the most critical beekeeping practice for rapidly doubling bee populations and replacing old queens yearly to increase honey production [81]. The queen bee is the central part of the colony and regulates the honeybee population and colony unity [144]. Colony strength is indicated by the number of adult worker bees in the hive and flying activity around the nest entrance [54], while colony productivity is measured by honey production and pollen collection [101]. Honeybee colonies are fed pollen substitutes when natural pollen resources are scarce. Pollen is essential for honeybee health and colony development [100].

Honey bees are vulnerable to pests and diseases. The pest and diseases that threaten honey bees are summarized in Table 4. The pests that attack honey bees are *Varroa jacobsoni*, *Varroa destructor*, and *Tropilaelaps clareae*, which attack worker bees' pupae [314]. These pests' attack results in congenital disabilities or the death of bees which causes honey bee productivity to decrease. This pest can be controlled by treatment with chemicals containing the active ingredients fluvalinate, amitraz, and formic acid [191]. Another type of pest is the wax moth [315,316]. The caterpillar of the wax moth can destroy beeswax nests, then eat wax or nest, pollen, and honey. Wax moth attacks lead to colony migration but can be anticipated by modifying the size of the exit and entry of the bee hive [316]. The disease that attacks bees' combs includes the American Foul Brood caused by *Paenibacillus* and the European Foul Brood caused by the *Melissococcus plutonius* bacterium [317,318]. Treatment techniques include the application of the Tylosin tartrate substance [318].

Table 4. Pests and diseases of honeybees and stingless bees.

No	Type of Bees	Pests	Diseases
1	*Apis mellifera*	*Varroa jacobsoni*, *Varroa destructor* dan *Tropilaelaps clareae* [314]; wax moth [315,319]; beetle, ant, rodents, and lizards [319].	American Foul Brood [317,318].
2	*Apis cerana*	Wax moth, honey bear, and wash (*Vespa* sp.) [316]; ants, frogs, lizards, monkeys, tree rats, swallows, and tigers [320].	American Foul Brood [321].
3	*Stingless bee*	A dipteran fly *Hermetia illucens* L., civets (*Paradoxurus hermaphrodites* Pallas), bears (*Melursus ursinus* Shaw), and chimpanzees (*Pan troglodytes* Blumenbach) [322]; the maggots and adults of the phorid fly (*Megaselia scalaris* Loew) [47]; Mite *Carpoglyphus lactis* L. and the centipede *Scolopendra hardwicki* Newport (Chilopoda) [323]; Thomisus Spiders [324].	Yeast [47] and bacillus [325].

Honey dominates bee products sold in the market, and the products still lack innovation. Likewise, derivative products such as propolis and bee pollen have not been optimally managed to increase their added value. Post-harvest handling and processing need to be intensified to maintain honey quality. It is imperative to increase the innovation of honey-derived products to fill the domestic market, which is still dominated by imported honey products. Through supporting facilities and infrastructure, government support for beekeepers is needed to increase the productivity and quality of honey products [6].

In most cases in Indonesia, bee farmers still rely on food sources in forests or use agricultural land and plantations for beekeeping. There are some challenges to maintaining the availability of the feed area. One of them is the anthropogenic activities that may decrease the area and environmental quality, altering floral resource phenology that influences bees [182]. Developing beekeeping and its products is conducive to improving more sustainable forestry processes and products toward the bioeconomy transition. The forest-based bioeconomy is defined by Piplani and Smith-Hall, 2021, as economic activity ranging from cultivating, processing, and marketing forestry products and services, including timber and non-timber [24]. Since the nature of honey harvesting systems, both farmed and wild, is renewable [190], use natural resources [25], involves varied stakeholders [181], and strongly supports the sustainability of other sectors such as agriculture and plantations, the development of honeybee cultivation has high potential to support the transition towards a forest-based bioeconomy [24,188,189]. Indonesia's existing beekeeping system supports the vision of a forest-based bioeconomy as an increasingly sustainable sector, generating economic and social benefits while still contributing to environmental conservation [180].

4.2. Marketing, Economic Value, and Governance

Increasing the production of cultivated honey is critical in reducing honey imports in Indonesia. Intensification of beekeeping will significantly support the farmers in increasing their production [96]. The cultivation technology adopted from modern beekeeping can provide leverage for honey production. Modern beekeeping creates a bee habitat by providing feed sources with abundant pollen, avoiding feed crops that carry diseases to bees, using artificial beehives, and providing plants that flower throughout the year [47,48,93,187]. The support of post-harvest technology from harvesting, packaging, and distribution to consumers guarantees the quality of the honey [47]. Some beekeeping problems can be minimized by applying good harvesting technology through training or assistance and appropriate beekeeping equipment [92].

Indonesia has set a standard of honey quality, namely *Standar Nasional Indonesia* (SNI) for Honey. The SNI regulates that the honey must pass organoleptic and laboratory tests. The organoleptic tests constitute two main parameters, namely smell and taste. The laboratory testing involves 11 parameters, where all the types of honey essentially have similar measurement values. If Indonesian honey is to be marketed domestically or exported, it must comply with national standards, the requirements of export destination countries, and international criteria (Table 5).

Table 5. The parameters of Indonesia and international standards concerning honey quality.

No	Type of Tests	Unit of Measurement	SNI 8664 2018			CODEX STAN 12-1981
			Wild Bee Honey	Cultivated Bee Honey	Stingless Bee Honey	
A	Organoleptic test					
1	Smell		smell of honey	smell of honey	smell of honey	Honey shall not have any objectionable matter, flavor, aroma, or taint absorbed from foreign matter during its processing and storage
2	Taste		taste of honey	taste of honey	taste of honey	
B	Laboratory test					
1	The activity of diastase enzyme	DN	≥1 *	≥3 *	≥1 *	≥3 Schade Units
2	Hydrosimetilfurfural (HMF)	mg/kg	≤40	≤40	≤40	-
3	Water content	% *w*/*w*	≤22	≤22	≤27.5	-
4	Reduced sugar (calculated as glucose)	% *w*/*w*	≥65	≥65	≥55	≥45
5	Sucrose	% *w*/*w*	≤5	≤5	≤5	≤10
6	Acidity	ml NaOH/kg	≤50	≤50	≤200	≤50 meq acid/kg
7	Insoluble part	% *w*/*w*	≤0.5	≤0.5	≤0.7	-
8	Ash	% *w*/*w*	≤0.5	≤0.5	≤0.5	-
9	Metal contamination					Free from heavy metals in amounts that may represent a hazard to human health
	9.1 Lead (Pb)	mg/kg	≤1.0	≤1.0	≤1.0	
	9.2 Cadmium (Cd)	mg/kg	≤0.2	≤0.2	≤0.2	
	9.3 Mercury (Hg)	mg/kg	≤0.03	≤0.03	≤0.03	
10	Arsenic contamination (As)	mg/kg	≤1.0	≤1.0	≤1.0	-
11	Chloramphenicol	mg/kg	undetected	undetected	undetected	-

Remarks: (*) after harvested. Source: [309,326].

Stakeholders in the honey supply chain can form a community to save bees. The community has to engage honeybee farmers; honey traders at the village, sub-district, and district levels; village, sub-district, and district governments; and other parties. The honeybee rescue community was formed considering the degradation of the quality of the forest environment, especially in forested honeybee habitats. This is indicated by (a) the existence of shifting and slash-and-burn preparation of agricultural land, (b) utilization of the stems trees such as *Acacia leucophloea* and *Coryphae gebanga* that provide feed sources for bees for ruminants (cows and goats), and (c) climate change causes forest honey habitats to be trapped in hotspot zones that result in forest fires. Honeybee rescue communities can be formed at various levels ranging from farmer groups/villages to the district level. Another positive impact of forming these communities is the unity of information and bargaining positions related to price, quality control, and providing a hub location for product distribution to consumers.

Some communities believe that monofloral honey has specific properties needed in medications, so it has a higher price than multifloral honey [50,95]. Wild honeybees feed on diverse species of plants. Therefore, it is difficult to determine whether honey is monofloral or multifloral. It can only be determined by the melissopalynological analysis [50]. The analysis identifies the number and diversity of pollen grains in the honey [39,97]. The melissopalynological analysis is expensive and time-consuming. However, there is a need to comply with the requirements for selling honey on the international market. The simple method practiced by the farmer was to label the honey according to the dominant flowering plant near the colony. For example, in Gunung Mutis, East Nusa Tenggara Province, honey sellers only write two dominant species of food sources on the packaging label, namely *E. alba* and *E. urophylla*. Based on observation, there are 26 plant species available as food sources in that area [32].

4.3. Social and Environmental Value

Honey is a traded commodity and a source of livelihood that is managed based on the sociocultural traditions of rural communities. Conventional management is carried out by much local wisdom and traditional rituals in harvesting and utilizing forest honey. Many traditional rituals indicate that aside from honey's economic function, it also promotes the sociocultural and ecological value that strengthens human-forest relations. Various community groups still maintain wild honey harvesting rituals to recognize their tradition and maintain honey production. On the other hand, honey cultivation technology outside the forest area has developed and is an essential aspect of the community economy. This development can cause a shift in the value of sociocultural traditions in honey management due to the dominance of economic interests. Efforts to maintain the balance of sociocultural values and economic values are needed. The sociocultural approach is highly sustainable and is a strategic partner in forest ecosystem management to support honey production. The simplification of using forest honey as an economic commodity will only impact shifting sociocultural values and the intrinsic value of forest ecosystem services for humans. Therefore, revitalizing honey management policies considering the local wisdom is essential to sustain the synergy of sociocultural and economic values in honey management.

The synergy of socio-cultural and economic values of honey utilization is expected to have ecological implications in strengthening mutually beneficial relations between honeybees and forests. Bees act as pollinators that contribute to the natural regeneration process of plants and forest ecosystems. A balanced forest ecosystem will increase the benefits of ecosystem services to support the ecological role of its ecosystem sub-components, one of which is bees. This relationship will have implications for the role of bees and forest ecosystems in supporting the achievement of the SDGs (Table 3). Honeybees improve agricultural and food production, pollination services, energy, and conservation [15,70,327–330]. The enormous value of honey's benefits to humans has encouraged local community efforts to conserve bee nests and feed tree species, including *Myristica* sp., Ficus sp., cotton-tree flowers (*Bombax malabarica*), white-barked Acacia (*Acacia leucophloea* (Roxb). Willd), and *Schleichera oleosa* on Timor Island. Protecting some key plant species for honeybees has implications for protecting forest ecosystems and their supporting ecosystems.

Protecting forest and aquaculture ecosystems for honey production is part of a bioeconomy strategy. Conventionally, the bioeconomy has been applied through various local wisdom that governs community-based natural resource management. However, it requires strengthening its implementation to synergize with economic development amidst the threat of global climate change. Therefore, a landscape-based approach and some environmental attributes benefit the sustainability of forest resources and honey production [43,90]. The ecosystem services of honeybees as the primary pollinators also determine the development of natural resource-based economic resources. In addition, some plant species' regeneration relies heavily on bees' pollination services to provide services to humans and the surrounding ecosystem.

5. Conclusions

Indonesia, a tropical area, has a high diversity of honeybees and stingless bees. Both produce honey and other products. As a part of many cultural practices in many traditional communities, beekeeping practices have been developed for centuries. The four main bee species in Indonesian honey production are *Apis mellifera*, *Apis cerana*, *Apis dorsata*, and stingless bees. Every bee species has preferences for food sources, so they have different foraging behavior. The availability of food sources for bees is crucial for bees' lives, and beekeeping contributes significantly to the sustainability of respected plants and vice versa.

Honey production and diversification of wild bees and beekeeping products have begun to develop in Indonesia, such as in community-based forestry programs. However, the production is still not sufficient to fulfil the domestic demand. The existing and potential international markets are still promising. Beekeeping provides economic benefits to the beekeeping community and has also been proven to deliver the same benefits to the traders, processors, and industries that use it. The usage of this bio-resource is essential, given the tendency of the global transition to the forest-based bioeconomy, shifting from timber extraction to NTFPs utilization while maintaining sustainability. Beekeeping can be a prosperous alternative to developing a forest-based bioeconomy in Indonesia.

Bees contribute significantly to the process of plant regeneration, which has implications for the sustainability of the ecosystem and environmental services. During collecting nectars, the bees also pollinate plants, the most significant contribution of bees to the sustainability of agriculture and the ecosystem. Ecosystem services have multidimensional implications, especially for the livelihoods of local communities that depend on honey production. The sustainability of ecosystem services affects the dynamics of social factors, especially the role of humans in protecting the forest as essential habitat for honeybees. This mutually beneficial relationship has implications for the sustainability of forest ecosystem management, including the ecosystem services produced and the community's livelihood sources, primarily since the value of the benefits of honey production for various humanitarian purposes is still maintained.

Author Contributions: A.H.H., Y.A., G.P., I.W., R.M., A.F., G.S.S., R.F., A.P.T., G.N.N., A.S., A.A., C.R.K., S.S., H.K. (Hery Kurniawan), M.Y.H., R.W., E.E.K., R.B.H., T.B., H.D.S., Y.N., B.d., T.K.W., M.T., S.B.P. and H.K. (Harlinda Kuspradini) made equal contributions to data collection; conceptualization; methodology; analysis; validation; manuscript writing, review, and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No additional datasets have been used.

Conflicts of Interest: The authors declare no conflict of interest.

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