From Hive to Policy: The Sustainable Beekeeping Practices Index (SBPI) as a Decision-Making Tool

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Abstract

Sustainable beekeeping promotes sustainable food systems by ensuring crop pollination services and enhancing food availability and nutritional diversity. This study introduces the Sustainable Beekeeping Practices Index (SBPI), a composite index developed using Principal Component Analysis (PCA) to quantify the sustainability of beekeeping practices. The SBPI integrates key sustainability factors, including colony health, genetic diversity, environmental stressors, beekeeper management, and migratory beekeeping. The highest impact on sustainability comes from colony health and disease management (38.4%), reinforcing the importance of disease control as a primary factor for sustainable beekeeping. Genetic diversity and hive resilience (15.8%) play a significant role in ensuring the long-term adaptability of bee populations. Environmental stressors (7.7%), beekeeper management (5.8%), and migratory beekeeping (5.4%) contribute to a lesser extent but remain relevant to sustainability outcomes. The factor distribution highlights the need for targeted interventions on disease control and genetic diversity to improve beekeeping sustainability. The study offers valuable recommendations to enhance disease monitoring, genetic conservation, and environmental adaptation strategies to enhance the sustainability of beekeeping practices. The index can also be adapted to explore SBPI in other contexts and is a valuable analytical tool for training, certification, and policymaking processes.

Keywords: Beekeeping sustainability, Sustainable Beekeeping Practices Index (SBPI), Principal Component Analysis (PCA), Colony health, Genetic diversity, Environmental stressors

1. Introduction

The importance of apiculture and beekeeping stems from its contributions to food security, poverty alleviation, and climate change mitigation (González Pacheco & Barragán Ocaña, 2023). Similarly, Beekeeping provides multisystemic benefits (Etxegarai-Legarreta & Sanchez-Famoso, 2022). It generates goods and services that contribute to an increase in the per capita income of families, to the creation of jobs, both directly and indirectly and contributes to the sustainable development of rural areas (Aryal et al., 2020; Hanley et al., 2015; Klein et al., 2007a; Patel et al., 2021; Virgil & Simona, 2020). Beekeeping also contributes to the conservation of natural biodiversity and minimises pressure on forests (Leonhardt et al., 2013a; Winfree et al., 2011). Similarly, honey beekeeping produces essential, marketable, high-value products such as propolis, pollen, royal jelly, wax, and bee venom (Etxegarai-Legarreta & Sanchez-Famoso, 2022; Lazarus et al., 2021; Virgil & Simona, 2020). These products have several unique characteristics, depending on their botanical origin, such as local flora and nectar source (Bankova, 2005; Lazarus et al., 2021), geographical origin (Etxegarai-Legarreta & Sanchez-Famoso, 2022; Tsuda & Kumazawa, 2021) and beekeeping practices (Manson et al., 2022; Pocol et al., 2021).

Several studies highlight the importance of sustainable beekeeping practices in maintaining pollination services and enhancing agricultural productivity (Klein et al., 2007b; Potts, Biesmeijer, et al., 2010; Potts, Roberts, et al., 2010). Research indicates that managed beehives significantly increase crop yields and contribute to food security by supporting ecosystem services (Gallai et al., 2009; Leonhardt et al., 2013b). Additionally, beekeeping provides economic opportunities, particularly in rural areas, through honey production, beeswax, and other value-added products (Ricketts et al., 2008).
Similarly, studies emphasise the role of beekeepers in creating bee-friendly habitats and adopting organic management practices to reduce chemical exposure (Goulson et al., 2015). Beekeeping integration into agroforestry systems has been identified as a sustainable approach that enhances soil fertility, water retention, and carbon sequestration (Garratt et al., 2014). Conversely, climate change and habitat loss pose significant threats to bee populations (Abrol, 2012; Forrest, 2017; Marshman et al., 2019, 2019). Research highlights the adverse effects of changing weather patterns and land-use modifications on pollinator health and productivity (Pires & Maués, 2020).

Beekeeping is critical in promoting sustainable food systems by ensuring pollination services for a wide range of crops and enhancing food availability and nutritional diversity (Aizen et al., 2009). Sustainable beekeeping practices are essential for supporting the production of organic and pesticide-free food, aligning with consumer preferences for environmentally responsible food choices (Zoto et al., 2023). Sustainable beekeeping contributes to a more sustainable food system by promoting healthy ecosystems and reducing chemical use (Smith et al., 2019). Furthermore, the conservation of pollinators is linked to the long-term viability of food security, as declines in bee populations could disrupt agricultural output and reduce the availability of essential food resources (IPBES, 2019). Integrating sustainable beekeeping with responsible food consumption patterns can develop a more resilient and ecologically sound food system.

Thus, beekeepers ensure sustainable pollination services, economic stability, and environmental resilience through hive management, disease prevention, and habitat conservation. Unlike indirect factors such as flora diversity and climate change, both are influenced by broader environmental and anthropogenic changes; beekeeping strategies and techniques are within the direct influence of beekeepers and policymakers. As such, assessing the sustainability of these practices is essential in proposing practical actions for improvement. Enhancing sustainable beekeeping practices can significantly impact crop yields, rural economies, and biodiversity conservation. This study aims to develop the Sustainable Beekeeping Practices Index (SBPI), an evidence-based tool for evaluating the sustainability of beekeeping operations. Analysing the sustainability of beekeeping practices through a comprehensive index can help them elaborate on key actions to improve the practice's long-term sustainability. The remainder of the paper is structured as follows: In the second section, the methodology is presented, in the third, the results are discussed, and the conclusions are presented in the last section.

2. Methodology

In alignment with the EU integration agenda's emphasis on environmental sustainability and food system resilience, this study aims to assess the sustainability of beekeeping practices in Albania. The analysis draws from beekeeper-level data collected across several regions and focuses on five critical domains of beekeeping sustainability.

2.2. Data Collection and Variables

Data were gathered through structured surveys administered to beekeepers operating across diverse ecological zones in Albania. The methodological approach consisted of two sequential steps.

In the first stage, a focus group was conducted with beekeeping experts, agricultural advisors, and environmental specialists to identify and validate the most relevant indicators of sustainable beekeeping. Drawing on insights from academic literature and field expertise, five key sustainability domains were defined.
In the second stage, a structured questionnaire was developed based on the selected indicators. Beekeepers were invited to assess the importance of each indicator, rating how crucial they believed it was for stakeholders, including policymakers, researchers, and practitioners, to consider in efforts to improve the sustainability of the apiculture sector. This participatory approach ensured that the SBPI reflects not only technical priorities, but also practical realities experienced by beekeepers on the ground.

The final variables were grouped into five thematic domains, as shown in Table 1.

Table 1: Sustainability domains and indicators

Domain	Key Indicators
Colony Health & Disease Management	Presence and control of pathogens (e.g., *Nosema ceranae*, *Ascosphaera apis*, *Paenibacillus larvae*, *Varroa destructor*)
Genetic Diversity & Hive Resilience	Queen bee origin, genetic exchange practices
Environmental & Climate Stressors	Urban encroachment, land-use change, and climate impacts
Beekeeper Management & Hive Maintenance	Technical skills, maintenance quality, and use of sustainable practices

Domain	Key Indicators
Migratory Beekeeping & Production Efficiency	Hive mobility, yield optimization, and resource efficiency

This bottom-up methodological design—combining expert input and practitioner validation—ensures that the subsequent Principal Component Analysis (PCA) and the resulting Sustainable Beekeeping Practices Index (SBPI) are grounded in context-specific realities and stakeholder relevance.

2.3. Index Construction Using PCA

A **Principal Component Analysis (PCA)** was conducted to identify latent dimensions of sustainability and assign statistical weights to each factor. The Sustainable Beekeeping Practices Index (SBPI) was constructed as a weighted linear combination of the principal components, normalized for interpretability. The formula is: $SBPI_i = w_1 X_{1i} + w_2 X_{2i} + \cdots + w_n X_{ni}$

Where:

- SBPIi is the index score for beekeeper *i*
- Xni are the normalized values for each factor
- and wn represents the proportion of variance explained by each component extracted from PCA

3. Results and Discussion

3.1. Contribution of Factors to SBPI

The PCA extracted five principal components aligned with the identified sustainability domains. Colony health and disease management emerged as the most influential factor, contributing 38.4% to the index. This underscores the central role of disease control in ensuring hive vitality and productivity. Numerous studies affirm that pathogens such as *Varroa destructor*, *Nosema ceranae*, and bacterial agents like *Paenibacillus larvae* are major drivers of colony collapse (Aizen et al., 2009; Garratt et al., 2014; Goulson et al., 2015; Kuliçi et al., 2023; Potts, Biesmeijer, et al., 2010). The prevalence of these diseases is often exacerbated by intensive agricultural practices and climate-induced stress, making their management pivotal for sustainability. Adequate disease control is not only essential for pollination reliability but also enhances the market value of apicultural products by reducing contamination risk (Kevan et al., 2007).

The second most significant contributor, genetic diversity and hive resilience (15.8%), highlights the importance of locally adapted bee stocks and queen rearing programs. Literature suggests that genetic diversity in honeybee populations is positively correlated with resistance to disease, improved foraging behavior, and climate adaptability (Jensen et al., 2005; Meixner et al., 2014; Pires & Maués, 2020; Raine et al., 2006).Reliance on imported queens, often with limited adaptability to local flora and climate conditions, has been linked to reduced colony survival and increased disease susceptibility (Bouga et al., 2011). Promoting local breeding programs can enhance the genetic integrity of bee populations while reducing dependence on external inputs—an essential step for building long-term resilience in the beekeeping sector (Pocol et al., 2021).

Environmental and climate stressors contributed 7.7% to the SBPI, indicating that while beekeepers recognize their importance, these stressors are primarily systemic and more complex to manage individually. Habitat loss, pesticide exposure, and extreme weather events disrupt bee navigation, foraging patterns, and reproductive cycles (Abrol, 2012; Gallai et al., 2009; Kuliçi et al., 2023; Potts, Roberts, et al., 2010). These factors are strongly linked to broader land-use policies and climate adaptation strategies, emphasising the need for multisectoral interventions that protect floral resources and mitigate climate risks (Marshman et al., 2019). Although less directly influenced by beekeepers, these stressors create the ecological context within which all apicultural activity occurs.

Beekeeper management and hive maintenance contributed 5.8%, highlighting the importance of daily practices, including feeding, inspection, ventilation, and record-keeping, in maintaining colony health. Research demonstrates that experienced and technically trained beekeepers are more likely to detect early signs of disease, implement biosecurity protocols, and optimise hive conditions (Cini et al., 2025). Sustainable hive management also includes minimising chemical inputs and supporting organic production methods, which align with consumer preferences for eco-labelled products (Garratt et al., 2014; Zoto et al., 2023).

Lastly, migratory beekeeping and production efficiency accounted for 5.4% of the index. While migratory practices can increase honey yield and support pollination across multiple crops, they also introduce biosecurity risks and increase physiological stress on bee colonies (Kuliçi et al., 2023; Simone-Finstrom et al., 2014). The literature presents a nuanced view: while migratory beekeeping enhances short-term productivity, it may disrupt natural foraging patterns and elevate disease transmission if not properly regulated (González Pacheco & Barragán Ocaña, 2023; Kuliçi et al., 2023; Simone-Finstrom et al., 2022) . Therefore, sustainability in this domain depends on finding a balance between economic efficiency and ecological sensitivity.

These results emphasize that the sustainability of apiculture is a multidimensional challenge requiring interventions at multiple levels—individual, community, and policy. The SBPI framework not only quantifies sustainability dimensions but also provides a foundation for targeted policy and training programs that reflect the ecological, technical, and institutional aspects of beekeeping.

Table 2: Sustainability factor and its contributions

Sustainability Factor	**SBPI Contribution (%)**
Colony Health & Disease Management	38.4%
Genetic Diversity & Hive Resilience	15.8%
Environmental & Climate Stressors	7.7%
Beekeeper Management & Hive Maintenance	5.8%
Migratory Beekeeping & Production Efficiency	5.4%

Source: Authors

3.2 Policy Recommendations for Sustainable Beekeeping

Given the ecological, economic, and nutritional importance of beekeeping, both for Albania and worldwide, targeted policy interventions are essential to ensure its long-term sustainability. Globally, the decline in pollinators due to disease, environmental degradation, and unsustainable practices poses a threat to agricultural productivity and biodiversity. In Albania, where rural livelihoods and agrobiodiversity depend heavily on ecosystem services, beekeeping holds the potential to foster rural development, food security, and environmental resilience. To capitalise on this potential, policymakers should prioritise the enhancement of disease monitoring and control systems by establishing national surveillance programs for prevalent pathogens such as *Nosema ceranae*, *Ascosphaera apis*, and *Paenibacillus larvae*. Promoting genetic diversity through local queen breeding programs and regulating the over-importation of foreign queens will also strengthen hive resilience and reduce dependency on external inputs. Additionally, addressing environmental stressors through spatial planning, biodiversity-friendly farming incentives, and land-use regulations is vital to protect pollinator habitats. Improving beekeeper training and hive management by integrating sustainable practices into certification schemes can enhance technical skills while promoting organic production standards. Moreover, regulating migratory beekeeping by setting ecological thresholds and mobility guidelines will help balance productivity with ecosystem integrity. Importantly, with the advancement of AI tools and digital technologies, data collection and monitoring have become more precise and accessible. Policymakers now have the opportunity to integrate these tools into national strategies, enabling the development of real-time decision-making systems and tailored training programs. Using evidence-based tools like the Sustainable Beekeeping Practices Index (SBPI) allows for smarter governance and supports both institutional learning and adaptive management across the sector.

4. Conclusion

This study introduces the SBPI as a comprehensive tool for evaluating sustainable beekeeping. The index underscores the critical role of disease management while highlighting genetic resilience and environmental adaptation. Effective policy interventions targeting disease control, genetic conservation, and climate adaptation are crucial for enhancing sustainability in the beekeeping sector.

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