Bee farming system sustainability: An assessment framework in metropolitan France

Coline Kouchner, Cécile Ferrus, Samuel Blanchard, Axel Decourtye, Benjamin Basso, Yves Le Conte, Marc Tchamitchian

► To cite this version:

Coline Kouchner, Cécile Ferrus, Samuel Blanchard, Axel Decourtye, Benjamin Basso, et al.. Bee farming system sustainability: An assessment framework in metropolitan France. Agricultural Systems, 2019, 176, pp.102653. 10.1016/j.agsy.2019.102653 . hal-02618320

HAL Id: hal-02618320

https://hal.inrae.fr/hal-02618320v1

Submitted on 26 Oct 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

Version of Record: https://www.sciencedirect.com/science/article/pii/S0308521X18313052
Manuscript_f895de80b5bd83537050355e57ed3210

BEE FARMING SYSTEM SUSTAINABILITY: AN ASSESSMENT FRAMEWORK IN METROPOLITAN FRANCE

Coline Kouchner[a,b,c,d,*], Cécile Ferrus[a,b], Samuel Blanchard[a,b], Axel Decourtye[a,b,e], Benjamin Basso[a,b], Yves Le Conte[b,c], Marc Tchamitchian[d]

[a] *ITSAP-Institut de l'abeille, 84000, Avignon, France.*

[b] *UMT PrADE, 84000, Avignon, France*

[c] *Abeilles et Environnement, INRA, 84000, Avignon, France*

[d] *ECODEVELOPPEMENT, INRA, 84000, Avignon, France*

[e] *ACTA, 84000, Avignon, France*

* Corresponding author. Email address: coline.kouchner@inra.fr

ABSTRACT

Beekeeping is a long-standing production of livestock, which currently faces several technical and economic challenges such as high colony losses and highly variable honey yields. While the sustainability of current and future bee farms is at stake, the current research on agricultural sustainability assessment poorly considers the technical and management specificities of bee farming systems, systems that remain poorly understood. To fill this gap, we designed a sustainability assessment framework, in other words, a detailed and organised definition of the sustainability of bee farming systems, that identifies the current sustainability issues of these systems at the farm level. Through interviews and workshops, beekeepers and other stakeholders were involved in the design process to include a diversity of viewpoints on the definition of sustainability for bee farming systems, and to ensure the relevance of this assessment framework. The resulting framework highlights the current economic, social and environmental issues of bee farming systems and is organised into six dimensions. Three dimensions are farm-focused, and the three others consider the interactions of the farm with its environment, its territory and the beekeeping sector. That framework reveals the sustainability issues and factors that bee farming systems share with other agricultural sectors as well as their specific issues. In particular, the adaptive capacity of bee farming systems, including their flexibility, their diversity and the

© 2019 published by Elsevier. This manuscript is made available under the CC BY NC user license
https://creativecommons.org/licenses/by-nc/4.0/

learning capacity of the beekeeper, appeared to be a key factor in their sustainability, as is the case for other pastoral systems that have to cope with unpredictable changes in the availability of their feed resources on which they have little direct control. In addition, land management practices partly determine the quality and availability of floral resources, which are hard to estimate, and thus present specific concerns and opportunities in their management. This work provides the first sustainability assessment framework that properly considers the current issues and specificities of bee farming systems, thus providing an outlook on the sustainability challenges of these systems and a basis for the development of an on-farm sustainability assessment tool.

Keywords (max 6): apiculture, beekeeping, forage resource management, adaptive capacity, participatory design, multicriteria assessment

1. INTRODUCTION

While beekeeping is a livestock production that has provided honey and other bee products for thousands of years (Kritsky, 2017), it is poorly understood and studied as a professional agricultural activity. Beekeeping produces a diversity of products and services. In addition to producing agricultural goods (honey, royal jelly, propolis, pollen, wax…), beekeeping provides livestock to the beekeeping sector (queens, packaged bees, artificial swarms) and pollination services to crop farmers and society (Chauzat et al., 2013; Rucker et al., 2012). Around the world, these outputs and services depend on both non-professional and professional beekeepers, with the latter representing about 9 % of European beekeepers, for whom beekeeping activity is the main source of revenue (Chauzat et al., 2013). While professionals usually represent a small part of the total number of beekeepers, they often play a major role in the sector’s economy. In 2012 in France, professional beekeepers were the main providers of pollination services (FranceAgriMer, 2012), and although they represented only 4 % of the total number of beekeepers in 2016, they produced 65 % of the annual honey (FranceAgriMer, 2018).

In spite of these essential outputs and services, beekeeping is rarely considered in livestock sciences. However, the three dimensions of livestock systems as defined by Gibon et al. (1999) and Landais (1987) are relevant when describing bee farming systems: the farmer; the livestock; and the resources, including feed resources, energy, information or material. In bee farming systems, livestock refers to the beekeeper's honey bee stocks, which feed on surrounding floral and other feed resources (e.g. honeydew). The farm usually consists of a farmstead with storage and processing facilities, along with a variable number of apiary sites where colonies are located and which are usually rented to beekeepers by the landowners. Colony management mainly consists of queen and colony replacement, sanitary practices, feed management and the technical practices related to the different productions (e.g. honey harvesting or queen breeding). As in pastoral livestock systems[1], feed management is mainly based on the mobility of honey bee stocks, as the beekeeper has little control over the feed resources. Colony management also has to make up for the annual colony losses that beekeepers experience: high rates of colony losses have been reported around the world in recent years, with a strong variability across regions and years (Brodschneider et al., 2018; vanEngelsdorp and Meixner, 2010). In 2010-11, winter losses varied from 8 to 28 % in Europe (Chauzat et al., 2013), and from 19 to 38 % for professional beekeepers in the United States (vanEngelsdorp et al., 2012). Compensating for these losses to maintain a sufficient number of productive colonies requires the use of potentially time-consuming practices (e.g. colony splits). Besides this technical issue, the beekeeping sector also suffers from economic issues including a significant variability in honey production: in France, the annual average honey production for professional beekeepers varied from 14.4 kg/hive in 2014 to more than 30 kg/hive in 2015, due to climatic conditions (FranceAgriMer, 2016).

[1] According to Ayantunde et al. (2011), pastoralism includes several dimensions: an agricultural production system, a livestock-based livelihood strategy and a way of life. We here consider the agricultural dimension of pastoral systems, i.e. agricultural production systems which are characterised by mobility of animals.

In this context, the sustainability of current and future bee farms is a central challenge for the beekeeping sector. As in other agricultural systems, a better understanding of the main issues and factors of this sustainability could be provided by the use of sustainability assessment tools. Such tools allow the assessment of the performance of an agricultural system within a sustainability assessment framework, i.e. a detailed and organised definition of sustainability. A large number of these tools are already available, each of them including its own sustainability specification that depends on the agricultural sector, on the organisational level to assess (from cropping system to farm or regional level) and on the goals of the assessment (Binder et al., 2010; Bockstaller et al., 2009; Diazabakana et al., 2014). They cover a wide range of purposes: on-farm advice, self-assessment by farmers, research, policy advice, education, and certification (Schader et al., 2014). Among this diversity of scopes, farm-level tools can be used by farmers or extension services to identify the strengths and weaknesses of the farm, to consider possible developments and improvements in farm management or to assess and discuss the sustainability of a farm establishment project (de Olde et al. 2016). Despite this potential, to our knowledge, there is currently no suitable tool to assess the sustainability of bee farming systems. Sustainability assessment tools from other agricultural sectors are sometimes used by students or extension services, but according to their feedback, they frequently find that these tools lack relevance given the differences in management of bee farming systems compared to most agricultural systems, e.g. no land management and little control over feed resources, which thus confirms an interest in a sustainability assessment tool for the beekeeping sector.

The first step in designing a sustainability assessment tool for bee farming systems is to define what sustainability means in these systems, i.e. to develop the sustainability assessment framework that will underlie the sustainability assessment tool (de Olde et al., 2017; Lairez et al., 2015). Here we present the development and main components of a sustainability assessment framework for beekeeping. This framework was developed along with professional beekeepers and other stakeholders from the beekeeping sector, in order to ensure a proper consideration of the current issues of bee farming system sustainability. This work was conducted in metropolitan France from 2016 to 2018.

2. METHODOLOGY

To design a sustainability assessment framework, preliminary choices have to be made, as detailed below: first, clarify the goals of the assessment framework, and second, define the design methodology.

2.1. Definition of goals

Intended uses and users, scopes and level of assessment, and system boundaries have to be defined before designing a sustainability assessment framework (Binder et al., 2010; Lairez et al., 2016). We made these choices jointly with coordinators of professional beekeeper groups during a workshop in April 2016. The possible choices were listed and ordered according to the identified needs of the beekeeping sector and professional beekeepers. The main choices were:

- **Objectives**: to provide a detailed and organised definition of sustainability of bee farming systems. This framework should allow the development of a tool that could be used to assess the strengths and weaknesses of a farm or a farm establishment project, and/or to provide a basis for reflection on possible developments and improvements of the farm through an on-farm assessment.
- **Considered systems**: we focused on current and future professional beekeepers, as sustainability becomes a central issue when beekeeping is a way to earn a living and not a hobby. The definition of a professional beekeeper varies from one country to another and usually establishes beekeepers as professional when they manage a minimal number of colonies or when beekeeping is their main source of income (Chauzat et al., 2013). Our sustainability assessment framework was designed for beekeepers for whom beekeeping is a significant economic activity, regardless of the specific number of colonies or level of income.
- **System boundaries and level of assessment**: farms where beekeeping is a commercial activity, including all apicultural activity generating revenue such as honey production, sale of other bee products (royal jelly, propolis, etc.), pollination services, or sale of queen or colonies. The level of

organisation is the farm, including its apiary sites, regardless of their distance to the farmstead. Consequently, the territory of the farm includes the geographical and social environment of both the farmstead and the apiary sites. The farm's interactions with its territory and other stakeholders of the beekeeping sector are considered (e.g. in relation to the availability of floral resources or the susceptibility of the farm to fluctuations in the honey market).

2.2. Methodological choices for stakeholder involvement

To develop sustainability assessment frameworks, participatory design methodologies are recommended by many authors to include a diversity of viewpoints (Binder et al., 2010; Lairez et al., 2015; Triste et al., 2014) and to gather a heterogeneous group to explore a diversity of opinions (van Asselt et al., 2001). Additionally, stakeholder involvement enhances the suitability of resulting frameworks to their intended uses and users, as the adaptation of the framework to the characteristics of the farm and to the goals and values of the farmer is among the key factors that make the assessment results relevant (Binder and Wiek, 2007; de Olde et al., 2016; Marchand et al., 2014). According to these recommendations, our assessment framework was designed along with beekeepers and other stakeholders involved with the beekeeping sector. Moreover, as bee farming systems are still poorly understood, a participatory design methodology seemed essential to properly identify the current issues in their sustainability.

We identified several types of relevant stakeholders:

- **From the beekeeping sector**: professional beekeepers; diversified beekeepers (professional beekeepers also having another agricultural or professional activity); coordinators of professional beekeeper groups; beekeeping teachers; beekeeper unions; representatives from the downstream beekeeping sector (honey selling cooperatives, bee product traders); veterinarians; and experts from apicultural development or research
- **Affiliated with the beekeeping sector indirectly**: national park managers and land managers

- Researchers or experts **from other agricultural sectors** working on sustainability assessment issues.

Among these identified stakeholders, the downstream beekeeping sector could not be involved due to the unavailability of representatives.

To identify the strengths and weaknesses of the different possible participatory design methodologies, we interviewed designers of other agricultural sustainability assessment frameworks that were set up in France in the last decade (Alaphilippe et al., 2017; FADEAR, 2014; Fourrié et al., 2013; Litt et al., 2014; Pottiez et al., 2013; Protino et al., 2015). The six telephone interviews were semi-structured and were conducted in May and June 2016. This allowed us to identify the design methodologies of these projects, the involved stakeholders and the respective roles of researchers and stakeholders in the design methodologies, e.g. decision-making processes. These results were used to choose the way in which to involve the stakeholders in our design methodology for the specification of the term sustainability, and to plan the successive steps of the methodology described below.

2.3. Design methodology for sustainability specification

The methodology unfolds in seven steps (from A to G) alternating research work and interactions with stakeholders. The stakeholders were involved at the three key steps of our design methodology (B, D, G, Figure 1): collecting as many suggestions as possible on the sustainability of bee farming systems through individual interviews, and building and validating an organised framework during two collective workshops. These three steps needed to be prepared and their results processed, thus defining steps A, C, E and F. The successive steps are described below.

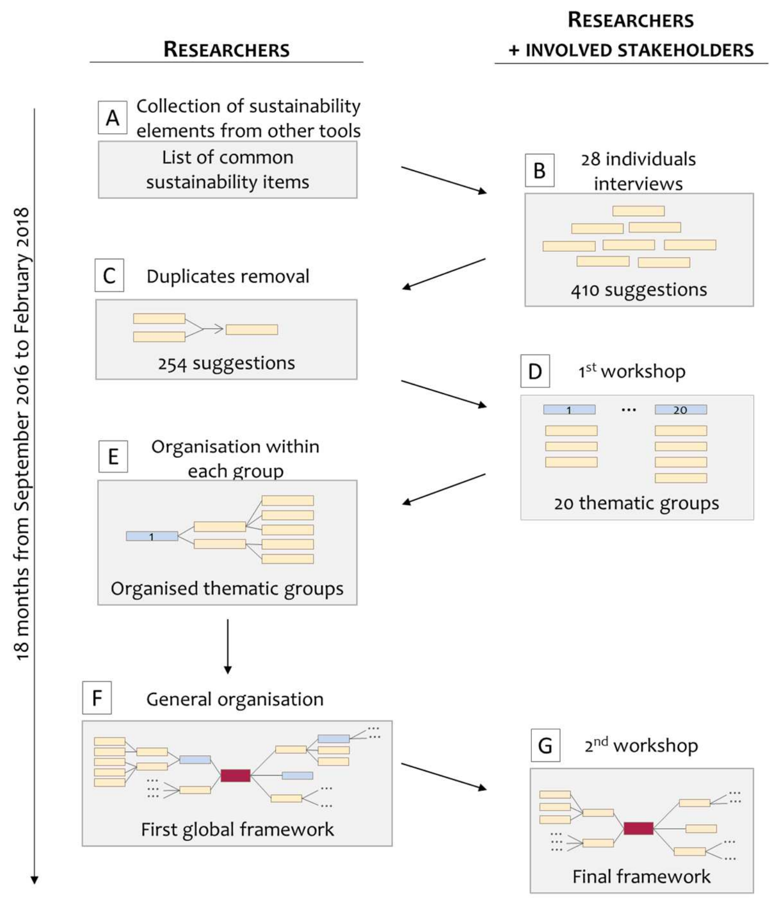


Figure 1: Successive steps (from A to G, see the framed letters) followed to obtain the sustainability specification for bee farming systems. The steps on the left were conducted by the researchers alone, and the steps on the right involved researchers, beekeepers and other stakeholders. At each step, the consequent achievement is mentioned in the grey frame.

Step A. We first established a list of common sustainability items appearing in several sustainability assessment tools used in other agricultural sectors, namely crop-livestock farming (IDEA version 3: Zahm et al., 2008; “Diagnostic de l’agriculture paysanne”: FADEAR, 2014); fruit production systems (DEXi Fruits: Alaphilippe et al., 2017) and organic farming (RefAB: Fourrié et al., 2013). This list contained all of the dimensions of the considered tools, as well as their themes and subthemes (see Figure 2) when they could be relevant to beekeeping: we excluded some themes and subthemes that were obviously irrelevant due to management specificities, e.g. land or crop management: nitrogen balance, soil erosion risks, etc.

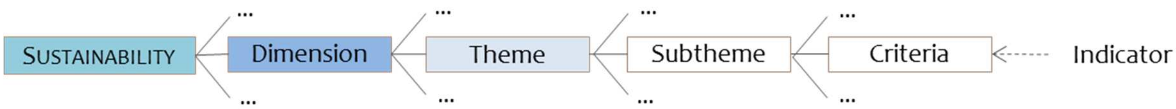


Figure 2: Terminology used to refer to the successive levels of the assessment framework, from the broadest (dimension) to the most detailed (criteria). Sustainability assessment frameworks are commonly organised as a hierarchical tree, with various possible terminologies for the successive levels: dimension, domain, pillar, issue… (see de Olde et al. 2016). We follow here the SAFA guidelines for referring to the different components of sustainability assessment, from dimension to subthemes (FAO, 2014). Indicators are the measurement variables used to assess the performance level for the criteria (the most detailed level of the framework).

Step B. The second step of sustainability specification consisted of individual interviews that allowed stakeholders to consider the sustainability issues in bee farming systems and to express their own viewpoint about them (Figure 1, step B). Twenty-eight interviews took place from October 2016 to February 2017, in different parts of France according to the location of the interviewee. Interviews were conducted in two parts. We first carried out an open discussion about the sustainability issues in bee farming, based on the definition of “sustainable” as “economically viable, socially acceptable and environmentally sound”. We then conducted a semi-structured interview during which the interviewee had to classify the common sustainability items (previously listed during step A) as: well adapted to the situation of beekeeping, not adapted but adaptable, or neither adaptable nor relevant.

Step C. The 410 suggestions for beekeeping sustainability items resulting from the interviews were reduced to 254 by removing the duplicates (Figure 1, step C).

Step D. The remaining 254 suggestions for sustainability were organised into thematic groups through a workshop gathering researchers and involved stakeholders in February 2017 in Paris, France (Figure 1, step D). The objective of the workshop was to gather into thematic groups the suggestions that were related to the same aspect of sustainability. In practice, a first suggestion, randomly chosen out of 254, was placed on a board, and the following 253 suggestions were picked one by one by the participants of the workshop and placed in relation to the previous ones on the board: either close to a previously picked, related suggestion, or alone if not related to any of the previous ones. When all of the suggestions had been placed, the resulting groups of suggestions were discussed collectively, modified when needed (reassignment of specific suggestions, group merging or splitting) and validated. A title was chosen for each group once it was validated.

Steps E-F. We organised the different suggestions in relation to each other, from the broadest to the most detailed, within each of the 20 groups resulting from step D (step E), before organising all of the groups into a single framework (step F). During this organisation, we merged some suggestions that were closely related, and some groups when they depicted directly related aspects of the farm (Figure 1, steps E-F).

Step G. The global framework was discussed in small groups of participants during a second workshop in February 2018 in Montpellier, France. The title and organisation of some themes or subthemes were modified when suggested by the participants, so as to reach a consensus among all the participants on the overall organisation and contents of the framework (Figure 1, step G).

3. RESULTS: A SIX-DIMENSIONAL FRAMEWORK

The resulting framework for bee farming system sustainability is structured in six dimensions. Three of which are farm-focused dimensions, according to the definition of “farm-focused sustainability” or “restricted sustainability” as sustainability of a farm “by and for itself through the use of sustainable practices” (Zahm et al., 2018, 2015): *Quality of life*, *Economic viability*, and *Ability to ensure production*. The other three dimensions consider the contribution of the farm to sustainable development at a larger scale, i.e. "extended sustainability" (Zahm et al., 2018, 2015), and the interactions of the farm with its social, environmental and economic environment: *Beekeeping sector and society issues*, *Environmental impacts* and *Local development and integration*. Each dimension includes three to four themes and a variable number of subthemes, possibly deeper subthemes, and criteria (see Figure 2). These six dimensions and their respective themes are presented in Figure 3 and detailed in the next paragraph. The complete framework is available as Supplementary material.

The usual economic, social and environmental dimensions are represented across these six dimensions, at the farm scale or at a larger scale.

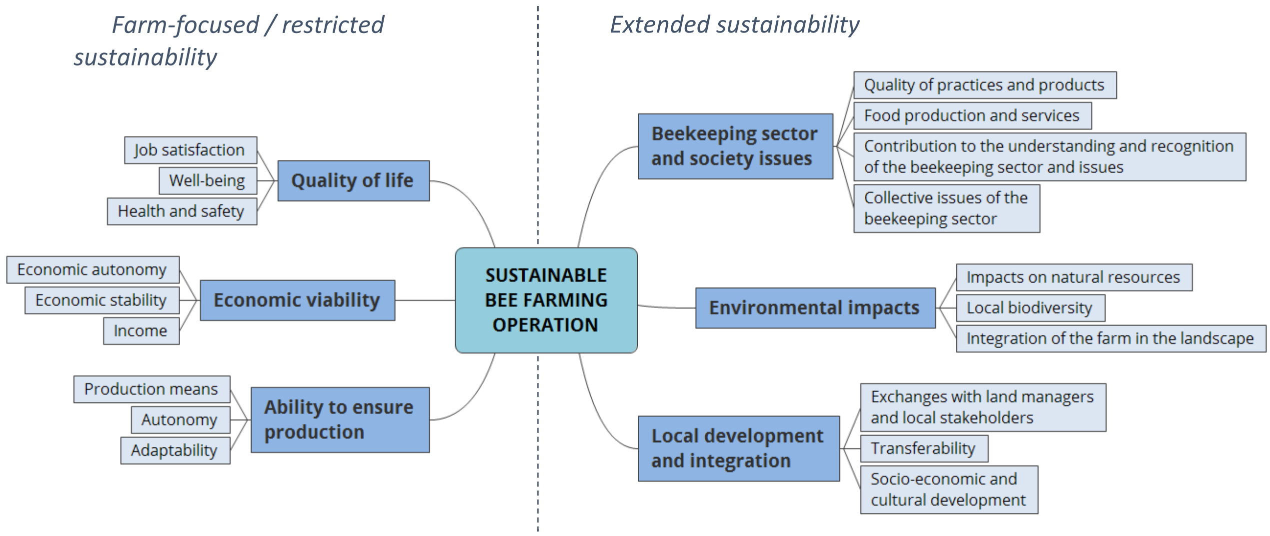


Figure 3: Dimensions and themes of bee farming system sustainability as defined by stakeholders from the French beekeeping sector. The six dimensions are either *farm-focused* or related to *extended sustainability* (Zahm et al., 2018, 2015)

Among the three farm-focused dimensions, our *Quality of life* dimension is quite similar to liveability, quality of life or other farmer-focused components than can be found in other sectors: job satisfaction, well-being, health and safety issues. *Job satisfaction* mainly consists of the match between the beekeeper's expectations and his/her work, in terms of farm management, exchanges, recognition, or pleasure at work. *Well-being* considers the beekeeper's work-life balance, including the possibility of taking vacations, and *health and safety* includes possible health issues (arduousness, stress, workload) and safety issues (fire and other on-farm risks).

Economic viability includes the *Economic autonomy* of the farm (investment capacity, treasury) and its *Economic stability*, which mainly refers to the potential limiting of variability in economic results (via diversity of productions, guaranteed outlets, capacity to resist price variability). The *Income* subtheme considers the match between the beekeeper's income and his/her expectation and between the income and the time spent working.

The A*bility to ensure production* dimension includes several components that were identified as helpful to the beekeeper to ensure his/her production: suitable production means, autonomy of the farm, and adaptability of the farm. *Production means* includes livestock management issues, in particular the need to ensure a sufficient number of healthy colonies (selection, sanitary and loss management, suitability of the genetic background of the colonies), the access to feed resources for the colonies in suitable quality and sufficient quantity and the other main means of production (inputs, buildings and equipment, and workforce). A*utonomy* of the farm is made up of decision-making autonomy, technical autonomy (skills and knowledge, information, access to technical advice) and the integration into a professional network as a possible support. A*daptability* includes long-term adaptive capacity (e.g. if the main nectar flow becomes too uncertain) and annual adaptive capacity (flexibility of the management and practices to cope with annual environmental variability). This dimension reflects the challenges that beekeepers face to ensure sufficient production in the context of losses and production variability. It is related to *Economic viability* as production is the main economic outcome of the farm, but also includes technical and social issues (skills and knowledge, annual flexibility of the practices, etc.).

The other three dimensions are related to extended sustainability, and to the relationships between the farm and its territory and sector. As apiary sites can be set up far from the farmstead, several geographic areas may have to be considered in these dimensions.

First of the four themes of the *Beekeeping sector and society issues* dimension, *Quality of practices and products* includes three subthemes: the quality of practices (e.g. colony welfare), the traceability and transparency in the selling process, and the quality of products in terms of contamination risks, food safety and honey quality. *Food production and services*, through pollination and production of bee products, underscores the role of beekeeping in agricultural production. *Contribution to the understanding and recognition of the beekeeping sector and issues* reflects the common misinterpretation of professional beekeeping issues, both in society and in the agricultural world: while professional beekeepers feel to be viewed by society mainly as “protectors of biodiversity and honey bees”, they also want to be recognised as food producers, both by society and other agricultural sectors. This theme also integrates the putative role of the beekeeper in raising awareness about the principal issues in beekeeping and biodiversity. *Collective issues of the beekeeping sector* refers to issues that affect the entire beekeeping sector but that also depend on individual management and practices. These issues include the preservation of the genetic diversity of the honey bee, collective sanitary issues (mainly risks of introduction or spread of invasive pests) and professional issues (professional commitment and relations within the agricultural world).

Environmental impacts is a common sustainability dimension. As in other sectors, the stakeholders involved in the sustainability specification highlighted the *Impacts on natural resources* that are mainly related to greenhouse gas emissions (primarily due to trips to the apiaries, transhumance, and the geographical origin of the inputs). These potential impacts could also be due to the use of inputs (e.g. contamination risk due to the use of veterinary products) and to waste management. Even if they are difficult to quantify, possible impacts of beekeeping on *local biodiversity* were also mentioned: either positively through the pollination of wild and cultivated plants, or negatively in which a high density of honey bee colonies at a landscape scale may lead to competition for resources with local wild bees. The *Integration of the farm in the landscape*, which includes the integration of the farmstead and apiary sites and is mainly the integration of the buildings into their environment through their architecture or choice of material, is also considered in this environmental dimension.

Lastly, the *Local development and integration* dimension (Figure 3) considers the contribution of the farm to the sustainable development of its territory through *Socio-economic and cultural development* (valorisation and local sale of products, employment, local-level dynamics) and through the *Transferability* of the farm, i.e. the possibility to transfer the farm from one generation to another, and the transfer of knowledge and skills. Through the theme *Exchanges with land managers and local stakeholders*, this dimension also includes the need to raise awareness about the floral resource quality and availability among the land managers who have direct impacts on these resources through their management practices. If they are better informed and aware of their potential impacts, this could eventually lead to an improvement in the availability and quality of floral resources for beekeepers. Local stakeholders also include apiary neighbours, who should be made aware of possible risks and precautions to be taken with honey bees (e.g. risk of sting and possible allergic reactions) and be able to contact the beekeeper if needed (e.g. so that farmers can notify the beekeeper of a planned pesticide treatment). Finally, beekeepers who share the same territory should communicate about sanitary and genetic issues, such as the risk of invasive pests or the possible organisation of fertilisation areas, or other shared concerns.

4. DISCUSSION

The collective work conducted with beekeepers and other stakeholders involved with the beekeeping sector resulted in a six-dimensional framework that highlights the current issues of bee farming system sustainability. This definition of sustainability includes both sustainability elements that are shared with other agricultural sectors and elements that are specific to bee farming systems (Kouchner et al., 2018). Bee farming systems share their main social and economic issues with other agricultural systems, such as well-being or the need for a sufficient income, and some of their contributions to the sustainable development of their territory and sector, such as the transferability of the farm and the quality of their products. Conversely, a number of issues that are quite common in agricultural sustainability are absent from our framework, mainly the items related to land management and to common environmental impacts of agricultural practices on soil and water, e.g. nitrogen leaching risks.

Among the wide diversity of shared or specific sustainability items that make up our framework, here we focus on some key issues and factors of bee farming system sustainability. First, the adaptive capacity of the farm appeared to be essential for bee farming systems to be sustainable. In addition, we focus on forage management issues, such as forage availability and quality that are among the main sources of uncertainty in bee farming systems. These issues are partly shared with pastoral livestock systems, but with some specific issues and opportunities related to floral resource management.

Adaptive capacity, a key factor in bee farming system sustainability. Throughout our framework, many items at different levels (from themes to criteria, see Figure 2) highlight the importance of adaptive capacity for bee farming systems to be sustainable. In other agricultural systems, the level of resilience and adaptation also appear to be essential for a farm to achieve sustainability, given the dynamics and complexity of farming systems and the unpredictable changes they have to face (Darnhofer et al., 2010b; Scoones et al., 2007). Among the existing concepts related to the ability of farming systems to adapt and to cope with changes, the "adaptive capacity" can be defined as the ability to adapt the developmental trajectory of the farm and its management in order to address changing conditions, through a continuous integration of new knowledge (Milestad et al., 2012; based on Rammel, 2003). The three main properties that allow farming systems to increase this adaptive capacity according to Darnhofer et al. (2010) are embedded in our framework: the ability of the manager to learn and to integrate new knowledge into the farm management choices, the flexibility of the system and its diversity.

Among these three properties, our framework reflects the need for beekeepers to access information to maintain sufficient and up-to-date technical knowledge that can be integrated into their management practices. Regular exchanges with other beekeepers, a good information network and the availability of technical support are the diverse and complementary sources of information and learning mentioned by stakeholders that also appear in other agricultural sectors (Coquil et al., 2018; Thompson and Scoones, 1994). Exchanges and networks provide the needed information for long-term and short-term adaptations of practices, e.g. exchanges with other beekeepers can provide information on possible advantages of emerging beekeeping practices that could be implemented on the farm. In the short-term, transhumance dates for a remote migratory apiary can be adapted using information about the local weather conditions or connected hive scales that allow the beekeeper to remotely follow honey production (Lecocq et al., 2015). Such short-term changes in management practices also require decision-making autonomy of the beekeeper. All of these components of the sustainability of bee farming systems contribute to the *Ability to ensure production* dimension of farm sustainability, mainly through the *Autonomy* theme.

Flexibility refers to the ability to implement changes in farm management to face short-term or long-term changes. Operational flexibility, defined as the ability to implement short-term changes when facing unexpected events (Darnhofer et al., 2010a), is mainly based on farm management. In our framework, several items highlight that to face climatic uncertainties and colony loss variability, the beekeeper has to adapt his/her annual practices to the annual climatic conditions and to the needed replacement rate. For example, if the number of annual artificial swarms or package bees has to be increased to compensate for high winter losses, the beekeeper may choose to create additional swarms by splitting some colonies that would usually be dedicated to honey production. Climatic adaptation in a long-term perspective is also a necessity for beekeeping, as for other agricultural sectors (Altieri et al., 2015). For example, if one of the main harvested nectar flows becomes too uncertain or if the control of a new invasive pest requires major changes in livestock management, can the beekeeper reconsider his or her current system and implement the needed changes in farm management? This long-term flexibility or strategic flexibility (Darnhofer et al., 2010) is based on the possibility of changing the competences, the resources, or the structure of farm management in order to adapt to future or ongoing changes in its environment.

The diversity of a farming system, – including the diversity of its resources, products and production processes – strengthens the capacity of the farm to face variable conditions by spreading risks and providing alternative options (Darnhofer et al., 2010a; Martin and Magne, 2015). This diversity of resources, products and processes contributes to the *Economic viability* and *Ability to ensure production* dimensions of our framework. For example, selling livestock or pollination services in addition to honey production can secure the beekeeper's income as prices for these services are more stable than honey prices. As in other agricultural sectors (Chia, 2008), a diversity of marketing channels, can secure the sale of the products within the context of price fluctuations, and thereby contribute to the sustainability of the farm. Nevertheless, annual adjustments and the diversity of products and services may not be enough to ensure a sufficient income for the beekeeper every year. Thus, the economic activity of the farm should be structured such that the economic viability of the farm is not threatened by a few bad years, as it appears in our results.

Uncertainty of feed resources, a common issue in pastoral systems. Elevated uncertainty of the availability of feed resources and no direct control over these resources are among the the reasons for which bee farming systems, like pastoral livestock systems, need to be highly adaptive. Adaptive capacity also appears as a major factor in pastoral system sustainability, for a wide range of environments and livestock species: sheep and cattle pasture-based systems in the European Mediterranean basin (Bernués et al., 2011); small and large ruminant husbandry in arid and semiarid rangelands of Iran (Karimi et al., 2018), East and West Africa (Ayantunde et al., 2011) or Mongolia (Kakinuma et al., 2014); reindeer herding in Alaska (Rattenbury et al., 2009) and Scandinavia (Turunen et al., 2016; Tyler et al., 2007); yak and cow transhumance systems in the Himalaya (Aryal et al., 2014). If the ability to access feed resources is a major shared issue, pastoral and bee farming systems also share some key factors that enhance their adaptive capacity and sustainability.

Without direct control over feed resources, pastoral system management is mainly based on mobility in order to ensure sufficient feed for the livestock. This mobility is the main tool for optimising the use of feed resources in the territory, for adapting to the phenological stages of feed plants and for managing environmental variability in these systems (Aryal et al., 2014; Koocheki and Gliessman, 2005; Scoones et al., 2007). The mobility of the colonies is also the main component of the management of transhumant bee farming systems. In our framework, a sufficient number of available apiary sites and a suitable means of transport for the beehives are needed by the beekeeper to adapt the livestock location to the environmental conditions.

To allow this livestock mobility, the experience-based knowledge and skills of the farmer are emphasised as a decisive factor by many authors (among others Ayantunde et al., 2011; Tessema et al., 2014; Turunen et al., 2016). In our definition of bee farming system sustainability, the knowledge of the beekeeper about its territory, including all of the areas where apiaries may be located, and about the characteristics of the targeted nectar flows is essential for ensuring the choice of suitable location for the apiaries. Furthermore, the experience and skills of the beekeeper when starting his/her operation and the transfer of his/her knowledge and skills to future beekeepers before retirement contribute to farm-focused and extended sustainability, respectively. The importance of experience-based knowledge and the transfer of this knowledge to future beekeepers could be due both to the need for local knowledge, which is specific to the territory and environment of the farm, and within the context of France, as the French beekeeping sector currently offers little on-farm advice to beekeepers.

Issues and opportunities in floral resource management. Despite the challenges and sustainability factors they share with pastoral grazing systems, bee farming systems also encounter specific issues regarding the availability and quality of their forage resources. As floral resources are a co-product of crops and wild flowers, beekeepers do not have any direct control over these resources, and land management and agricultural practices are major factors in their availability and quality (Decourtye et al., 2010; Wratten et al., 2012). Among the consequences of land management practices on the quality of floral resources, the use of pesticides can have an impact on colony losses (vanEngelsdorp and Meixner, 2010) and is among the main topics of the scientific publications in apidology; between 2013 and 2016, 27 % of publications were related to pesticides (Decourtye et al., in press). However, the impacts of these agricultural practices are not directly mentioned in our results, but instead are included in the issues of colony losses, forage quality and the uncertainty of forage availability that demand a strong adaptive capacity on the part of bee farming systems. Despite differences in the operation size and management compared to the French context of our study, professional beekeepers in the United States encounter the same issues and adapt their management choices accordingly. In order to provide sufficient quality forage to their honey bees, they adjust their migration schedules so as to avoid certain mono-cropped areas and to limit the exposure to some pesticides, resulting in an indirect exclusion of beekeepers from some areas (Durant, 2019). In our framework, an indirect means for beekeepers to improve the availability and quality of floral resources is by communicating with land managers and farmers about the impacts of their practices on the beekeepers' floral resource needs (Allier and Gourrat, 2016).

Besides floral resource availability in the landscape, the quantity of forage that honey bee colonies can access in a given area also depends on the colony density, which may be difficult to estimate (many beekeepers share a same area, without sharing the location and number of their apiary sites which are often hidden in the landscape). The optimal density for a floral landscape is poorly documented but can be a concern (Ausseil et al., 2018). In some areas, hive overstocking has been reported to lead to a competition for floral resources, both between honey bee hives and between honey bees and wild bees (Al-Ghamdi et al., 2016; Henry and Rodet, 2018). In pastoral grazing systems, the management of carrying capacity may depend on a group of resource-users through common use, common management or regulation (Eychenne, 2008), and is central for optimising the use of resources and limiting the risk of overgrazing (Fratkin and Mearns, 2003). In contrast, within bee farming systems apiary locations are neither coordinated between beekeepers nor regulated, apart from a few countries or land managers (e.g., West Australia: Department of Parks and Wildlife, 2013); only the owner of the site has to agree. While the access to sufficient quality forage appears to be a key issue for bee farming systems to be sustainable, there are currently no tools or collective organisations to manage these resources. In our framework, the usefulness of a dialogue with other beekeepers in the same area is observed without any suggested practical action, and the management of the overall colony density of a given area is not mentioned. The need to adapt the colony number to the available resources is only discussed at the farm scale, within the beekeeper's own livestock. In the context of the U.S. with decreasing suitable forage areas due to agricultural and conservation practices, the competition between beekeepers for the access to foraging areas is also one of the mechanisms of exclusion of beekeepers from floral resources (Durant, 2019). Thus, our results highlight the lack of practical knowledge and the lack of collective management tools for beekeepers to manage the carrying capacity of floral landscapes and to optimise the use of floral resources. The possible competition with wild bees is identified in our framework as an environmental issue, inasmuch as there is an underlying conflict between beekeepers and wild bee advocates over access to pollinator habitat despite their common interests (Alaux et al., 2019; Durant, 2019). The position of these questions could therefore evolve with advances in knowledge and management tools.

5. CONCLUSION

Due to a participatory design methodology that involved professional beekeepers and other relevant stakeholders, our work resulted in a definition of bee farming system sustainability that properly considers the current issues of these systems and reflects the viewpoints of the involved stakeholders. The six dimensions of the designed framework include economic and social issues that are shared with other agricultural sectors, at the farm, sector and territory levels, as well as elements that are specific to the beekeeping sector. Among the main economic, social and environmental issues of bee farming systems, our six-dimensional sustainability assessment framework reveals the importance of their adaptive capacity, which depends on the flexibility of their management practices, on the ability of the beekeeper to learn, and on the diversity of the system. As pastoral livestock systems, bee farming systems have to cope with uncertainties as their forage resources are highly dependent on climatic conditions and land management practices, and for migratory beekeepers, the mobility of the livestock is an essential component of their feed management. Besides quality issues that are mainly related to agricultural practices, the availability of floral resources also depend on colony density, which is currently hard to estimate, while there is no collective management tool of floral resources.

Although this sustainability assessment framework was designed in France, most of its elements appeared to be related to the management and technical issues of bee farming systems in general and should be readily adaptable to other contexts. This framework will be the basis for a future sustainability assessment tool, as indicators still need to be developed and reference values provided. It provides a better understanding of bee farming systems, their current challenges and their future research needs: as the livestock management practices to cope with colony losses or on-farm work organisation, many of their sustainability issues at the farm level remain poorly studied.

ACKNOWLEDGMENTS

We greatly thank all of the partners of the project and all of the beekeepers and other stakeholders that were involved in this project, as well as Rodolphe Sabatier for his helpful comments on an earlier version of the manuscript. We are also grateful to the anonymous reviewers for their helpful comments, and to Cynthia McDonnell for the English revision and her great help to translate the complete framework.

FUNDING

This work was supported by the French Ministry of Agriculture program [CASDAR, Durapi program n°5567]; and the Association Nationale Recherche Technologie [CIFRE n°2016/0304]. The funding sources had no involvement in conducting the research.

Declarations of interest: none.

REFERENCES

Al-Ghamdi, A., Adgaba, N., Getachew, A., Tadesse, Y., 2016. New approach for determination of an optimum honeybee colony's carrying capacity based on productivity and nectar secretion potential of bee forage species. Saudi J. Biol. Sci. 23, 92–100. https://doi.org/10.1016/j.sjbs.2014.09.020

Alaphilippe, A., Angevin, F., Guérin, A., Guillermin, P., Vélu, A., Zavagli, F., 2017. DEXiFruits, un outil d'évaluation multicritère des systèmes de production de fruits : d'un modèle de recherche à un outil terrain co-construit. Innov. Agron. 59, 205–2012.

Alaux, C., Le Conte, Y., Decourtye, A., 2019. Pitting Wild Bees Against Managed Honey Bees in Their Native Range , a Losing Strategy for the Conservation of Honey Bee Biodiversity. Front. Ecol. Evol. 7. https://doi.org/10.3389/fevo.2019.00060

Allier, F., Gourrat, M., 2016. Co-concevoir des solutions techniques entre apiculteurs et cultivateurs. Innov. Agron. 53, 49–62.

Altieri, M.A., Nicholls, C.I., Henao, A., Lana, M.A., 2015. Agroecology and the design of climate change-resilient farming systems. Agron. Sustain. Dev. https://doi.org/10.1007/s13593-015-0285-2

Aryal, S., Maraseni, T.N., Cockfield, G., 2014. Sustainability of transhumance grazing systems under socio-economic threats in Langtang, Nepal. J. Mt. Sci. 11, 1023–1034. https://doi.org/10.1007/s11629-013-2684-7

Ausseil, A.G.E., Dymond, J.R., Newstrom, L., 2018. Mapping floral resources for honey bees in New Zealand at the catchment scale. Ecol. Appl. 28, 1182–1196. https://doi.org/10.1002/eap.1717

Ayantunde, A.A., de Leeuw, J., Turner, M.D., Said, M., 2011. Challenges of assessing the sustainability of (agro)-pastoral systems. Livest. Sci. 139, 30–43. https://doi.org/10.1016/j.livsci.2011.03.019

Bernués, A., Ruiz, R., Olaizola, A., Villalba, D., Casasús, I., 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. Livest. Sci. 139, 44–57. https://doi.org/10.1016/j.livsci.2011.03.018

Binder, C.R., Feola, G., Steinberger, J.K., 2010. Considering the normative, systemic and procedural dimensions in indicator-based sustainability assessments in agriculture. Environ. Impact Assess. Rev. 30, 71–81. https://doi.org/10.1016/j.eiar.2009.06.002

Binder, C.R., Wiek, A., 2007. The role of transdisciplinary processes in sustainability assessment of agricultural systems, in: Agriculture, I.I. of S.D. and S.C. of (Ed.), Common Practice. Proceedings and Outputs of the First Symposium Fo the International Forum on Assessing Sutainability in Agriculture (INFASA). Bern, pp. 33–48.

Bockstaller, C., Guichard, L., Keichinger, O., Girardin, P., Galan, M.-B., Gaillard, G., 2009. Comparison of methods to assess the sustainability of agricultural systems. A review. Agron. Sustain. Dev. 29, 223–235.

Brodschneider, R., Gray, A., Adjlane, N., Ballis, A., Brusbardis, V., Charrière, J.D., Chlebo, R., Coffey, M.F., Dahle, B., de Graaf, D.C., Maja Dražić, M., Evans, G., Fedoriak, M., Forsythe, I., Gregorc, A., Gręda, U., Hetzroni, A., Kauko, L., Kristiansen, P., Martikkala, M., Martín-Hernández, R., Aurelio Medina-Flores, C., Mutinelli, F., Raudmets, A., A Ryzhikov, V., Simon-Delso, N., Stevanovic, J., Uzunov, A., Vejsnæs, F., Wöhl, S., Zammit-Mangion, M., Danihlík, J., 2018. Multi-country loss rates of honey bee colonies during winter 2016/2017 from the COLOSS survey. J. Apic. Res. 57, 452–457. https://doi.org/10.1080/00218839.2018.1460911

Chauzat, M.P., Cauquil, L., Roy, L., Franco, S., Hendrikx, P., Ribière-Chabert, M., 2013. Demographics of the European apicultural industry. PLoS One 8, e79018. https://doi.org/10.1371/journal.pone.0079018

Chia, E., 2008. La flexibilité relationnelle : rôle des réseaux, des groupements et des associations d'éleveurs, in: Dedieu, B., Chia, E., Leclerc, B., Moulin, C.-H., Tichit, M. (Eds.), L'élevage En Mouvement. Flexibilité et Adaptation Des Exploitations d'herbivores. Paris, pp. 135–142.

Coquil, X., Cerf, M., Auricoste, C., Joannon, A., Barcellini, F., Cayre, P., Chizallet, M., Dedieu, B., Hostiou, N., Hellec, F., Lusson, J.-M., Olry, P., Omon, B., Prost, L., 2018. Questioning the work of farmers, advisors, teachers and researchers in agro-ecological transition. A review. Agron. Sustain. Dev. 38–47.

Darnhofer, I., Bellon, S., Dedieu, B., Milestad, R., 2010a. Adaptiveness to enhance the sustainability of farming systems. A review. Agron. Sustain. Dev. 30, 545–555. https://doi.org/10.1051/agro/2009053

Darnhofer, I., Fairweather, J., Moller, H., 2010b. Assessing a farm's sustainability: Insights from resilience thinking. Int. J. Agric. Sustain. 8, 186–198. https://doi.org/10.3763/ijas.2010.0480

de Olde, E.M., Bokkers, E.A.M., de Boer, I.J.M., 2017. The Choice of the Sustainability Assessment Tool Matters: Differences in Thematic Scope and Assessment Results. Ecol. Econ. 136, 77–85. https://doi.org/10.1016/j.ecolecon.2017.02.015

de Olde, E.M., Oudshoorn, F.W., Sørensen, C.A.G., Bokkers, E.A.M., De Boer, I.J.M., 2016. Assessing sustainability at farm-level: Lessons learned from a comparison of tools in practice. Ecol. Indic. 66, 391–404. https://doi.org/10.1016/j.ecolind.2016.01.047

Decourtye, A., Alaux, C., Le Conte, Y., Henry, M., in press. Bees' conservation in global change: a retrospective and prospective analysis of research. Curr. Opin. Insect Sci.

Decourtye, A., Mader, E., Desneux, N., 2010. Landscape enhancement of floral resources for honey bees in agro-ecosystems. Apidologie 41, 264–277. https://doi.org/10.1051/apido/2010024

Department of Parks and Wildlife, ., 2013. General Conditions for using Apiary Authorities on Crown land in Western Australia.

Diazabakana, A., Latruffe, L., Bockstaller, C., Desjeux, Y., Finn, J., Kelly, E., Ryan, M., Uthes, S., 2014. A Review of Farm Level Indicators of Sustainability With a Focus on CAP and FADN.

Durant, J.L., 2019. Where have all the flowers gone? Honey bee declines and exclusions from floral resources. J. Rural Stud. 65, 161–171. https://doi.org/10.1016/j.jrurstud.2018.10.007

Eychenne, C., 2008. Les éleveurs et l'estive : pour une approche compréhensive des pratiques pastorales. Natures Sci. Sociétés 16, 131–138.

FADEAR, 2014. Le manuel de l'agriculture paysanne, Média Pays. ed. Bagnolet.

FAO, 2014. Sustainability Assessment Of Food and Agriculture Systems. Guidelines Version 3.0, Food and A. ed. Rome.

Fourrié, L. (ITAB), Cresson, C. (ACTA), Letailleur, F. (CA S., Sautereau, N. (CA V., Willot, M. (FNAB), Berthier, C. (IFV), Vallas, M., 2013. RefAB : Des références pour les systèmes agricoles biologiques : proposition d'un cadre méthodologique innovant. Innov. Agron. 32, 271–284.

FranceAgriMer, 2018. Observatoire de la production de miel et gelée royale, Les synthèses de France AgriMer.

FranceAgriMer, 2016. Observatoire de la production de miel et gelée royale, Les synthèses de France AgriMer.

FranceAgriMer, 2012. Audit économique de la filière apicole française, Les synthèses de France AgriMer.

Fratkin, E., Mearns, R., 2003. Sustainability and Pastoral Livelihoods: Lessons from East African Maasai and Mongolia. Hum. Organ. 62, 112–122. https://doi.org/10.17730/humo.62.2.am1qpp36eqgxh3h1

Gibon, A., Sibbald, A.R., Flamant, J.C., Lhoste, P., Revilla, R., Rubino, R., Sørensen, J.T., 1999. Livestock farming systems research in Europe and its potential contribution for managing towards sustainability in livestock farming. Livest. Prod. Sci. 61, 121–137. https://doi.org/10.1016/S0301-6226(99)00062-7

Henry, M., Rodet, G., 2018. Controlling the impact of the managed honeybee on wild bees in protected areas. Sci. Rep. 8. https://doi.org/10.1038/s41598-018-27591-y

Kakinuma, K., Okayasu, T., Jamsran, U., Okuro, T., Takeuchi, K., 2014. Herding strategies during a drought vary at multiple scales in Mongolian rangeland. J. Arid Environ. 109, 88–91. https://doi.org/10.1016/j.jaridenv.2014.05.024

Karimi, V., Karami, E., Keshavarz, M., 2018. Vulnerability and Adaptation of Livestock Producers to Climate Variability and Change. Rangel. Ecol. Manag. 71, 175–184. https://doi.org/10.1016/j.rama.2017.09.006

Koocheki, A., Gliessman, S.R., 2005. Pastoral Nomadism, a Sustainable System for Grazing Land Management in Arid Areas. J. Sustain. Agric. 25, 113–131. https://doi.org/10.1300/J064v25n04

Kouchner, C., Ferrus, C., Blanchard, S., Decourtye, A., Basso, B., Le Conte, Y., Tchamitchian, M., 2018. Sustainability of beekeeping farms: development of an assessment framework through participatory research, in: 13th European IFSA Symposium. Chania (Greece).

Kritsky, G., 2017. Beekeeping from Antiquity through the Middle Ages. Annu. Rev. Entomol. 62, 249–264. https://doi.org/10.1146/annurev-ento-031616-035115

Lairez, J., Feschet, P., Aubin, J., Bockstaller, C., Bouvarel, I., 2016. Agriculture et développement durable - Guide pour l'évaluation multicritères, Educagri é. ed. Versailles, France.

Lairez, J., Feschet, P., Botreau, R., 2015. Construire sa propre méthode d'évaluation, in: Lairez, J., Feschet, P., Aubin, J., Bockstaller, C., Bouvarel, I. (Eds.), Agriculture et Développement Durable - Guide Pour l'évaluation Multicritère. Dijon/Versailles, p. 226.

Landais, E., 1987. Recherches sur les systèmes d'élevage - Questions et perspectives.

Lecocq, A., Kryger, P., Vejsnæs, F., Bruun Jensen, A., 2015. Weight Watching and the Effect of Landscape on Honeybee Colony Productivity : Investigating the Value of Colony Weight Monitoring for the Beekeeping Industry. PLoS One 1–14. https://doi.org/10.1371/journal.pone.0132473

Litt, J., Coutelet, G., Arroyo, J., Bignon, L., Laborde, M., Théau-Clément, M., Brachet, M., Guy, G., Drouilhet, L., Dubois, J.P., Grossiord, B., Hérault, F., Fortun-Lamothe, L., 2014. Evaluation de la durabilité et innovations pour des ateliers CUNIcoles et PALMipèdes gras plus durables : projet CUNIPALM. Innov. Agron. 34, 241–258.

Marchand, F., Debruyne, L., Triste, L., Gerrard, C., Padel, S., Lauwers, L., 2014. Key characteristics for tool choice in indicator-based sustainability assessment at farm level. Ecol. Soc. 19. https://doi.org/10.5751/ES-06876-190346

Martin, G., Magne, M.A., 2015. Agricultural diversity to increase adaptive capacity and reduce vulnerability of livestock systems against weather variability - A farm-scale simulation study. Agric. Ecosyst. Environ. 199, 301–311. https://doi.org/10.1016/j.agee.2014.10.006

Milestad, R., Dedieu, B., Darnhofer, I., Bellon, S., 2012. Farms and farmers facing change: The adaptive approach, in: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research into the 21st Century: The New Dynamic. pp. 365–385.

Pottiez, E., Dennery, G., Cresson, C., Lescoat, P., Bouvarel, I., 2013. AVIBIO : une méthode et un outil pour évaluer la durabilité des filières avicoles biologiques. Innov. Agron. 30, 13–25.

Protino, J., Magdelaine, P., Berri, C., Méda, B., Ponchant, P., Dusart, L., Chevalier, D., Dezat, E., Lescoat, P., Bouvarel, I., 2015. OVALI : un outil pratique d'évaluation de la durabilité des filières avicoles. 1- Evaluer l'existant pour identifier des marges de progrès, in: Onzièmes Journées de La Recherche Avicole et Palmipères à Foie Gras. Tours, France.

Rammel, C., 2003. Sustainable development and innovations: lessons from the Red Queen. Int. J. Sustain. Dev. 6, 395–416. https://doi.org/10.1504/IJSD.2003.004210

Rattenbury, K., Kielland, K., Finstad, G., Schneider, W., 2009. A reindeer herder's perspective on caribou, weather and socio-economic change on the Seward Peninsula, Alaska. Polar Res. 28, 71–88. https://doi.org/10.1111/j.1751-8369.2009.00102.x

Rucker, R.R., Thurman, W.N., Burgett, M., 2012. Honey bee pollination markets and the internalization of reciprocal benefits. Am. J. Agric. Econ. 94, 956–977. https://doi.org/10.1093/ajae/aas031

Schader, C., Grenz, J., Meier, M.S., Stolze, M., 2014. Scope and precision of sustainability assessment approaches to food systems. Ecol. Soc. 19, 42. https://doi.org/10.5751/ES-06866-190342

Scoones, I., Leach, M., Smith, A., Stagl, S., Stirling, A., Thompson, J., 2007. Dynamic Systems and the challenge of Sustainability, STEPS Working Paper 1.

Tessema, W.K., Ingenbleek, P.T.M., Van Trijp, H.C.M., 2014. Pastoralism, sustainability, and marketing. A review. Agron. Sustain. Dev. 34, 75–92. https://doi.org/10.1007/s13593-013-0167-4

Thompson, J., Scoones, I., 1994. Challenging the populist perspective: Rural people's knowledge, agricultural research, and extension practice. Agric. Human Values 11, 58–76. https://doi.org/10.1007/BF01530446

Triste, L., Marchand, F., Debruyne, L., Meul, M., Lauwers, L., 2014. Reflection on the development process of a sustainability assessment tool : learning from a Flemish case. Ecol. Soc. 19, 47. https://doi.org/10.5751/ES-06789-190347

Turunen, M.T., Rasmus, S., Bavay, M., Ruosteenoja, K., Heiskanen, J., 2016. Coping with difficult weather and snow conditions: Reindeer herders' views on climate change impacts and coping strategies. Clim. Risk Manag. 11, 15–36.

https://doi.org/10.1016/j.crm.2016.01.002

Tyler, N.J.C., Turi, J.M., Sundset, M.A., Strøm Bull, K., Sara, M.N., Reinert, E., Oskal, N., Nellemann, C., McCarthy, J.J., Mathiesen, S.D., Martello, M.L., Magga, O.H., Hovelsrud, G.K., Hanssen-Bauer, I., Eira, N.I., Eira, I.M.G., Corell, R.W., 2007. Saami reindeer pastoralism under climate change: Applying a generalized framework for vulnerability studies to a sub-arctic social-ecological system. Glob. Environ. Chang. 17, 191–206. https://doi.org/10.1016/j.gloenvcha.2006.06.001

van Asselt, M.B.A., Mellors, J., Rijkens–Klomp, N., Greeuw, S.C.H., Molendijk, K.G.P., Jelle Beers, P., van Notten, P., 2001. Building Blocks for Participation in Integrated Assessment: A review of participatory methods. ICIS Work. Pap. I01–E003 31, 71 S.

VanEngelsdorp, D., Caron, D., Hayes, J., Underwoord, R., Henson, M., Rennich, K., Spleen, A., Andree, M., Snyder, R., Lee, K., Roccasecca, K., Wilson, M., Wilkes, J., Lengerich, E., Pettis, J., for the Bee Informed Partnership, ., 2012. A national survey of managed honey bee 2010-2011 winter colony losses in the USA: results from the Bee Informed Partnership. J. Apic. Res. 51, 115–124. https://doi.org/10.3896/IBRA.1.53.1.01

vanEngelsdorp, D., Meixner, M.D., 2010. A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. J. Invertebr. Pathol. 103, S80–S95. https://doi.org/10.1016/j.jip.2009.06.011

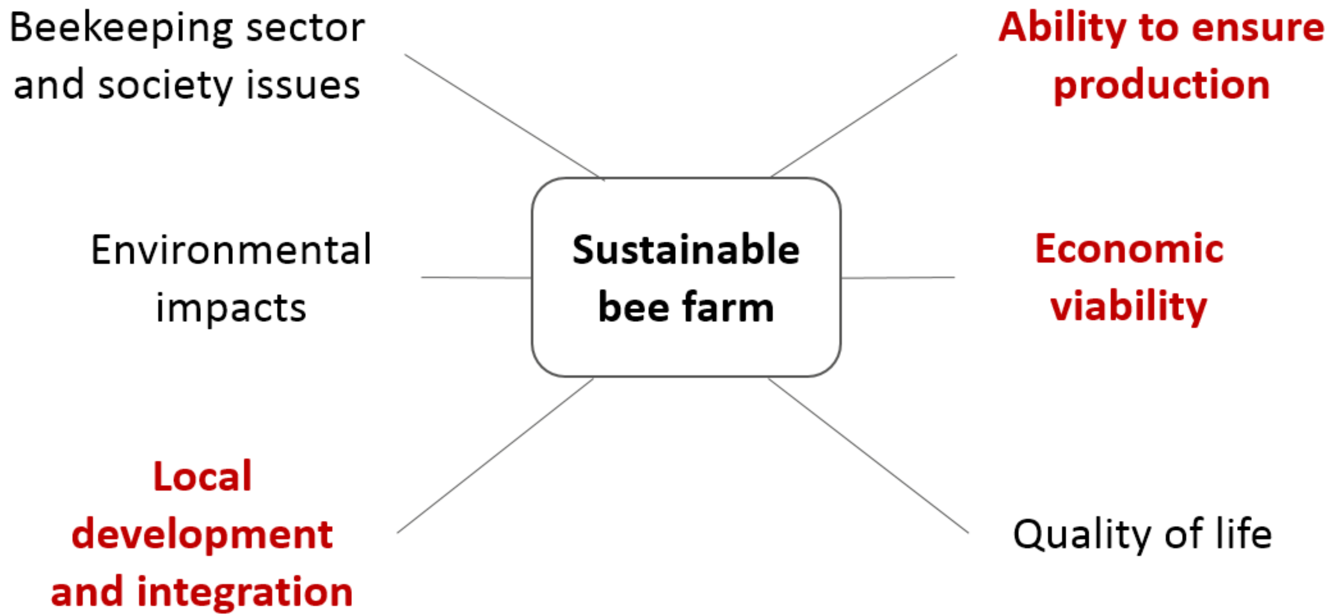
Wratten, S.D., Gillespie, M., Decourtye, A., Mader, E., Desneux, N., 2012. Pollinator habitat enhancement: Benefits to other ecosystem services. Agric. Ecosyst. Environ. 159, 112–122. https://doi.org/10.1016/j.agee.2012.06.020

Zahm, F., Alonso Ugaglia, A., Barbier, J.-M., Boureau, H., Del'homme, B., Gafsi, M., Gasselin, P., Girard, S., Guichard, L., Loyce, C., Manneville, V., Menet, A., Redlingshöfer, B., 2018. Evaluating sustainability of farms: introducing a new conceptual framework based on three dimensions and five key properties relating to the sustainability of agriculture. The IDEA method version 4, in: 13th European IFSA Symposium. Chania (Greece).

Zahm, F., Alonso Ugaglia, A., Boureau, H., Del'homme, B., Barbier, J.M., Gasselin, P., Gafsi, M., Guichard, L., Loyce, C., Manneville, V., Menet, A., Redlingshofer, B., 2015. Agriculture et exploitation agricole durables : état de l'art et proposition de définitions revisitées à l'aune des valeurs, des propriétés et des frontières de la durabilité en agriculture. Innov. Agron. 46, 105–125.

Zahm, F., Viaux, P., Vilain, L., Girardin, P., Mouchet, C., 2008. Farm Sustainability Assessment using the IDEA Method. From the concept of farm sustainability to case studies on French farms. Sustain. Dev. 16, 271–281. https://doi.org/978-1-894784-05-4

A SIX-DIMENSIONS FRAMEWORK TO ASSESS BEE FARMING SYSTEMS SUSTAINABILITY



Dimensions that most contribute to the adaptive capacity of the bee farming system under threats (colony losses, production variability, price fluctuations)