Sustainability of beekeeping farms: development of an assessment framework through participatory research

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Abstract: *The concept of sustainability in agriculture has been translated into a range of operational evaluation frameworks at territory, farm or production system level. However, these frameworks are not adapted to beekeeping farms: what then can be called "sustainability" in the case of beekeeping farms? Which components of the apicultural system management and context have to be considered to describe and assess this sustainability? Our study, based on a participatory approach, aims at adapting the concept of sustainability to the specificities of beekeeping farms, in France and at developing an adapted framework to assess it at farm level.*

To take into account the diversity of situations of beekeeping farms and their social, economic and environmental particularities, professional beekeepers and other stakeholders from the beekeeping sector were involved in the specification of sustainability for beekeeping farms through individual interviews and collective exchanges. We present here the main themes to include in a sustainability assessment framework adapted to beekeeping farms, their similarities and differences compared to other sustainability assessment tools at farm level and the contributions of the design methodology to this result.

Keywords: *sustainability assessment, assessment method, apiculture, participatory design, France, professional beekeepers*

Introduction

While honeybee colonies have been managed for honey production for thousands of years, it has become a professional activity mainly within the last decades (Daberkow et al., 2009). Through apiculture, honeybee colonies provide both bee products (honey, royal jelly, propolis, pollen, queen and swarm production) and pollination services, because an important part of global food commodities depends on honeybee pollination (Klein et al., 2007). Among these products and services, honey is still the main production of the beekeeping sector. In France, the 20,000 tons of the produced honey supplies only half of the French annual consumption (FranceAgriMer, 2012). Professional beekeepers, defined as beekeepers managing 200 colonies or more (up to more than 2000 in France, ADA France, 2017), produce most of this honey. As in other European and North-American countries, they have to face important colony losses (vanEngelsdorp et al., 2012; Chauzat et al., 2013). In France, in 2010, about 20% of mortality of colonies for professional beekeepers has been reported, with a strong annual variability (Basso and Vallon, 2013; Chauzat et al., 2013). Moreover, honey production and prices may vary strongly from year to year, for example from 14.4 kg/hive in 2014 up to more than 30 kg/hive in 2015 (annual mean for beekeepers managing more than 150 colonies; FranceAgrimer, 2016). Given these uncertainties, achieving or maintaining the sustainability of their farms is a challenge both for current and future beekeepers.

In many agricultural sectors, thoughts and discussions about sustainability are fueled by the content and the use of sustainability assessment tools. Schader et al. (2014) describe a diversity of possible scopes for such tools: farm advice by advisors, self-assessment by farmers, research, policy advice, education, or certification. Among these scopes, farm advisory or self-assessment tools are used to assess the strengths and weaknesses of a given farm, as a basis for future developments and possible management improvements. Results of a sustainability assessment can be a starting point for discussing sustainability at the farm level (de Olde et al., 2016). Numerous sustainability assessment tools already exist (Binder et al., 2010; Diazabakana et al., 2014), with various goals, sustainability dimensions, scales or scopes. However, to our knowledge, no tool is currently fit to assess the sustainability of beekeeping farms, which usually do not have any land and depend on resources that beekeepers do not manage.

Given the numerous management differences between professional beekeeping and other agricultural activities, adjusting a sustainability assessment tool initially designed for other agricultural sectors was not relevant. Thus, we designed a new framework to define and assess the sustainability of beekeeping at the farm level that allows the development of a tool for an on-farm assessment of beekeeping farm sustainability. To ensure that the characteristics and the diversity of beekeeping farms were properly considered in this framework, we involved stakeholders from the beekeeping sector during its development. We present here the main components of beekeeping sustainability as defined with stakeholders, and compare them to other sustainability assessment frameworks.

Sustainability assessment tools usually classify ideas and concepts as multiple levels of a hierarchical tree. The terminology used in sustainability assessments to define these various levels is diverse (see de Olde et al., 2016). We follow here the SAFA guidelines when referring to the elements of sustainability assessment: dimensions as the highest levels of sustainability in the assessment tool, themes and subthemes as intermediate levels (FAO, 2014). We define criterion as the lowest and more detailed level, and indicators as the measurement variables used to assess the sustainability performance for the criteria.

Methodology

Preliminary choices and definition of the methodology

We first made preliminary choices for developing a sustainability assessment framework: system boundaries, users, objectives, spatial and temporal scope, and production level (Binder et al., 2010; Lairez et al., 2016). Possible objectives and boundaries were listed, then ordered. As a result, the framework is designed at farm level and mainly for farms with commercial beekeeping as the only agricultural activity. It is intended to be used by beekeepers along with advisors and by instructors in apicultural training, to assess the strengths and weaknesses of a farm or a farm establishment project, and as a possible basis for future developments and management improvements. The assessment focuses on the production of honey, bee products (royal jelly, propolis…) and other apicultural activities (queen selling, pollination…). Upstream and downstream sectors are not included as it is a farm-level assessment, but the relations of the farm with its territory are considered. The assessment is based on the situation of the farm at the time it is realized.

These choices were made by researchers and coordinators of professional beekeepers groups involved. We also planned collectively the different phases to implement to develop this sustainability assessment tool (de Olde et al., 2017; Lairez et al., 2015):

1. Context definition (preliminary choices)
2. Sustainability specification (sustainability goals, themes, subthemes)
3. Indicators selection
4. Method development (reference values, scoring and aggregation methods)
5. Tool development (interface, outputs)
6. Tests and improvements
7. Method dissemination

As a result of our preliminary choices, the main intended users for this sustainability assessment tool are beekeepers, advisors or beekeeping teachers. Along with other stakeholders, we involved these end-users in the development of this tool through a participatory methodology to enhance its suitability to end-users and allow us to include and balance a diversity of viewpoints on the sustainability of beekeeping farms (Binder and Wiek, 2007; Triste et al., 2014; Lairez et al., 2015).To this end, at the same time development phases were planned, we listed relevant stakeholders and planned at which step they had to be involved (Table 1).

The largest and most diversified panel of participants was included at the second development phase – specifying the sustainability goals of beekeeping farms – to provide the largest diversity of viewpoints on what these goals should be. However, some stakeholders that were initially suggested could not be involved at this stage, either because we could not find an available representative – this is partly the case of downstream beekeeping sector for which only honey selling cooperatives were represented – or because the way to involve them at the very beginning of the design was unclear – this was the case for farmers, consumers and society outside beekeeping sector. As a result, they did not contribute to the specification of sustainability but may still be consulted on specific topics at a later stage, e.g. quality and traceability assessment for the downstream sector.

Table 1. Planned steps to develop a sustainability assessment tool adapted to French beekeeping farms and stakeholders involved in different steps. When present, letters indicate the involvement of the researchers or stakeholders and the kind of involvement: A: animation, C: consultation, S: suggestion, V: validation. Background color reflects current progress: dark grey: finished work, light grey: work in progress, white: future work.

	Stakeholders and researchers involved at this stage							
Stage of development	Researchers	Advisors and experts from beekeeping and agricultural development	Commercial beekeepers	Beekeeping teachers in agricultural schools	Veterinary	Land managers	Beekeepers unions	Downstream beekeeping sector
Context definition	A, S, V	S, V						
Sustainability specification	A, S, V	S, V	S, V	S, V	S, V	S, V	S, V	S, V
Indicators selection	A, S, V	S, C, V	S, C, V	S, C, V	S, C	S, C	S, C	S, C
Method development	A, S, V	C, V						
Tool development	A, S, V	C, V	C, V	C, V				
Tests and improvements	A	C	C	C				
Circulation	A	A		A			A	

To specify how stakeholders could be involved during the successive development steps, we collected feedbacks from former leaders of several projects of agricultural sustainability assessment involving farmers, other stakeholders and experts through participatory research (Pottiez et al., 2013; Fourrié et al., 2013; FADEAR, 2014; Litt et al., 2014; Protino et al., 2015; Alaphilippe et al., 2017). Six semi-structured interviews were conducted to know the goals of the former project, including the goals and potential users of the developed sustainability assessment tool. We also identified during these interviews the initial partners of the project, the steps which were implemented to develop the tool and which participants were involved at these steps and how (interviews, meetings…). Last, we inquired about the possible feedback they received from participants to their project – either about the participatory methodology or about the resulting sustainability assessment tool – and about their own feedback about the participatory methodology they implemented.

This article describes the successive steps taken to specify sustainability for beekeeping farms and on its main results. Indicators selection and following stages are not covered by this work.

Sustainability specification

Viewpoints collection

The specification of sustainability goals and themes first consisted in individual interviews that allowed involved stakeholders to detail their own viewpoint on the sustainability of beekeeping farms. The ideas and viewpoints expressed in these interviews were then collectively discussed and organized.

Before conducting the individual interviews, common themes and subthemes of several sustainability assessment tools were gathered into a list. We included into this list dimensions, themes and subthemes from IDEA (Zahm et al., 2008), DEXi Fruits (Alaphilippe et al., 2017), "Diagnostic de l'agriculture paysanne" (FADEAR, 2014), and RefAB (Fourrié et al., 2013). This list also overlapped with themes and subthemes from the SAFA assessment tool (FAO, 2014) – considering themes and subthemes that are relevant at farm level –, "Diagnostic de durabilité du Réseau Agriculture Durable" (RAD, 2016) and DIAMOND (Litt et al., 2014). Four of these tools (IDEA, DEXi Fruits, Diagnostic de durabilité du Réseau Agriculture Durable, DIAMOND) consider three dimensions for sustainability: economic, environmental, and social. SAFA adds a fourth dimension: good governance. RefAB and the "Diagnostic de l'agriculture paysanne" consider cross-disciplinary dimensions: self-sufficiency, fairness, local development, diversity, resilience, transferability, quality and fair distribution of means of production. All of these dimensions were mentioned in the list. We excluded from the list some themes or subthemes that pertained to management issues which are irrelevant for beekeeping farms, e.g. directly related to land and crop management: nitrogen balance, soil erosion risks…

Individual interviews were conducted in two steps. First, the interviewed persons had the opportunity to develop their own viewpoint about what could be a sustainable beekeeping farm, based on the definition of "sustainable farm" as "economically viable, environmentally sound, and socially acceptable". In the second step, they had to express their opinion about the previously listed common sustainability elements: are these elements adaptable and relevant for beekeeping farms? We conducted twenty-eight interviews with beekeepers, beekeeping teachers in agricultural schools, coordinators of professional beekeepers associations and unions, experts from research and development in beekeeping and in other agricultural fields, and other stakeholders involved in the management of territories where beekeeping farms are settled, e.g. national parks managers.

Organization of sustainability goals

These interviews yielded 410 suggestions of separate sustainability elements. Suggestions undoubtedly expressing the same idea were merged together, resulting in 254 different final suggestions.

These 254 suggestions were presented and discussed during a workshop with the previously interviewed stakeholders. Successively, participants were assigned a random sustainability suggestion and instructed to place it in relation to previously placed suggestions on a board; physically close to previous suggestions if they were related or alone if no previous suggestions were related to the new one. When all the suggestions were placed, we collectively discussed and confirmed the thematic groups of suggestions that had emerged, and changed the place of some items if necessary, resulting in twenty groups.

Later, and without the stakeholders, we organized within each group every sustainability suggestion in relation to the others. Some experts among stakeholders were involved for specific questions in relation to the organization of each theme. Some groups were merged together during this organization. Some suggestions that were not goals of sustainability but rather specific means to achieve sustainability goals were eliminated from this hierarchical design, e.g. "Have several people working on the farm during beekeeping season" was considered as one mean among others that allows to face peaks in workload. For each theme and subtheme, we chose a suggestion from stakeholders as title when possible, or directly named the theme or subtheme when no suggestion from stakeholders was relevant

at this level of detail. The 15 resulting themes were then organized in relation to each other, into a single framework and some of them were merged again during this step.

Table 2 summarizes the successive steps that were realized and currently planned to achieve sustainability specification.

Table 2 : Successive steps taken to specify the sustainability of French beekeeping farms, and participation of stakeholders and researchers at the different steps.

Stage of development	Involved groups	Methodology	Outcomes
Compilation of sustainability elements from several tools	Researchers	Review of the tools content	List of sustainability elements
Viewpoints collection	Researchers, stakeholders	Individuals interviews	410 separated suggestions of sustainability elements
Merging of similar sustainability suggestions	Researchers	Review of suggestions from the interviews	254 different suggestions
Merging of sustainability goals into thematic groups	Researchers, stakeholders	Workshop	20 thematic groups
Organization within each thematic group	Researchers	Subtheme relatedness	15 organized themes
Organization of all themes into one sustainability framework	Researchers	Theme relatedness	First sustainability framework proposal
Discussion, modifications and validation of the sustainability framework	Researchers, stakeholders	Workshop	Validated sustainability framework (mental model of sustainability)

Comparison to other sustainability assessment frameworks

The comparison of the resulting framework was carried out against four existing agricultural sustainability assessment frameworks, which were chosen according to their building methodology. Two of them were designed through top-down methodologies (expert consultations): IDEA (Zahm et al., 2008) and SAFA (FAO, 2014); two were designed through bottom-up methodologies (stakeholders involvement): Diagnostic de l'Agriculture Paysanne (FADEAR, 2014) and sustainability assessment from Réseau Agriculture Durable (RAD, 2016).

The comparison was made by matching the first level subthemes from our resulting organized themes (or directly the theme when there was no subthemes) to the themes and subthemes of the other four frameworks. We considered here the 15 organized themes, before their integration into one global framework. Each of our subthemes was qualitatively classified in one of three levels:

- **Covered**: at least one of the themes or subthemes in other methods has a similar content to the considered subtheme.
- **Partially covered**: at least one of the themes or subthemes from other method takes into account the considered subtheme but strong adaptation is required for beekeeping farms, or the considered subtheme is only partially covered (one or more aspects of the subtheme is not covered).
- **Uncovered**: the considered subtheme has no comparable theme or subtheme in other methods, i.e. the content of the considered subtheme is specific to apiculture.

The comparison did not take into account the indicators of the considered tools but their themes and subthemes.

Results and discussion

Sustainability specification for beekeeping farms

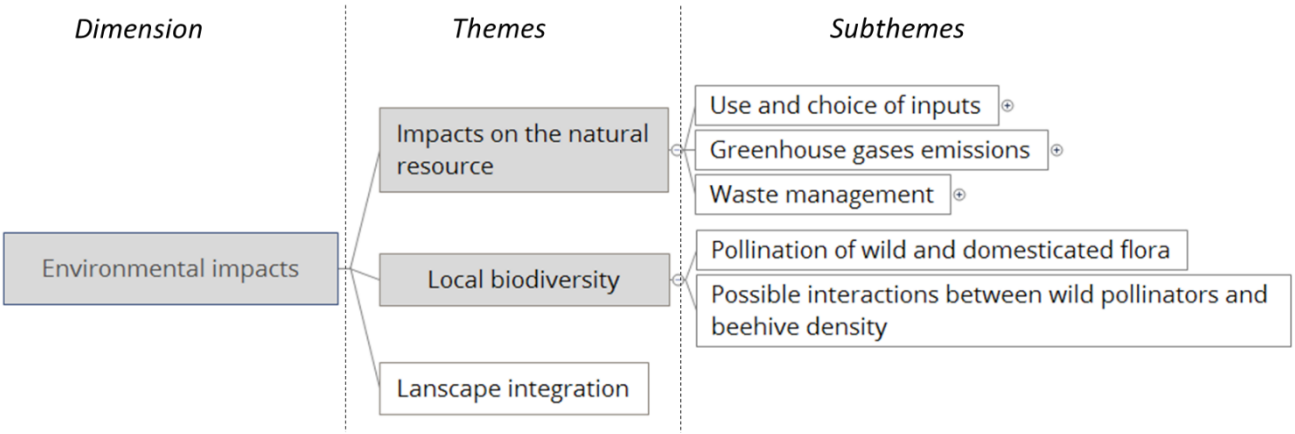
The organization of suggestions within each theme resulted in the merging of some themes whose contents were close, producing a total of 15 themes which were distributed among six dimensions. These themes and dimensions constitute altogether a possible definition for sustainability of the French beekeeping farms (Table 3). As the level of detail of the themes was diverse, the 15 themes from the first organization step appear at various levels of the final framework. E.g., “Quality of life” was a former theme that was directly turned into one of the main dimensions of the global framework, whereas the themes “Quality and traceability” and “Ethics” were merged into a single theme named “Quality”, which is included into a more general dimension. Several subthemes were combined within each theme, from generic issues (theme) to detailed items, e.g. for “Environmental impacts” (Figure 1).

Table 3. Themes included in sustainability of beekeeping farms, from initial work with stakeholders from French beekeeping sector and some later merging by researchers. Main contents of each theme are not exhaustive.

Dimensions	Themes	Main contents
Beekeeping sector and society issues	Quality	Quality and traceability of products, ethics and apicultural practices
	Food and services production	Pollination and food production
	Contribution to the understanding and recognition of beekeeping sector and issues	Contribution to the awareness of the beekeeping sector realities and issues among the general public and among other agricultural sectors
	Collective stakes of beekeeping sector	Involvement in collective structures, contribution to collective stakes of the sector as genetic diversity or prevention of introduction of invasive pests
Economic viability	Income	Match between the real income and the beekeeper’s expectation, between the income and the time spent
	Economic stability	Ability to face price variations, diversity of products and outlets
	Economic autonomy	Self-financing ability, capacity to invest
Environmental impacts	Local biodiversity	Contribution to and potential impacts on local biodiversity
	Impacts on the natural resource	Greenhouse gases emission, waste management, use and choice of inputs
	Landscape integration	Landscape integration of buildings
Local development	Exchanges with land managers and local stakeholders	Relationship and exchanges with land managers, neighbourhood, other beekeepers
	Socio-economic and cultural development	Production of local bee products, participation in local economy, in social and cultural development
	Transferability	Transferability of the farm, transferability of the beekeeper’s skills and knowledge
Ability to ensure the production	Production means	Match between beekeepers’ goal and constraints and production means: livestock management, quality and quantity of available resource, material resources
	Autonomy	Technical autonomy, independent decision-making, information and training possibilities, exchanges between beekeepers
	Adaptability	Adaptability to annual and long-term changes
Quality of life	Job satisfaction	Meeting of beekeeper’s expectations, happiness at work

Wellbeing	Workload and time off
Health and safety	Safety and health risks, risk control

Figure 1: Example of organization within a sustainability dimension. White items represent suggestions from stakeholders; grey items represent titles that were chosen by researchers when organizing suggestions within the



dimension

Comparison to other sustainability assessment frameworks and possible influences from design methodology

The comparison of our subthemes to other sustainability assessment tools revealed that 18 to 26% of them were well covered by each of the four selected tools (Table 4).

Table 4: Coverage levels of subthemes of sustainability specification for beekeeping farms by compared tool. E.g.: 18% of beekeeping sustainability subthemes are covered by IDEA themes or subthemes, 26% are partially covered, 56% are uncovered. AP stands for "Diagnostic de l'Agriculture Paysanne" sustainability assessment tool; RAD for the sustainability assessment tool from "Réseau Agriculture Durable".
Overall coverage: percentage of subthemes of our sustainability specification that are covered or partially covered by at least one of the four other tools, or not covered by any of them ("uncovered").

Coverage level	Top-down designed tools		Bottom-up designed tools		Overall coverage
	IDEA	SAFA	AP	RAD	
Covered	18%	18%	26%	23%	39%
Partially covered	26%	36%	36%	15%	33%
Uncovered	56%	46%	38%	62%	28%

A large part (38%) of our subthemes were well covered by at least one of the four other compared tools, one third (33%) was partially covered by at least one of the four other tools. More than a quarter (28%) were not covered by any of the four other tools.

Among partially covered subthemes, some differences were linked to technical or management differences between beekeeping and other agricultural sectors. For example, "Quality of life" is a common theme in sustainability assessment tools but includes some items that were specific to beekeeping farms: difficult working conditions linked to night-time transhumances, health risks directly linked to beekeeping such as the regular handling of heavy hives.

This was also the case of potential environmental impacts, which were different for beekeeping farms. Positive impacts related to pollination of wild plants and crops were mentioned, as well as positive impacts through society awareness of biodiversity issues when beekeepers communicate about the preservation of bees and biodiversity. Possible impacts of greenhouse gases emissions was a shared subtheme between all of the four tools and was also present in our framework, but most of the common themes and subthemes of the environmental dimension, often related to land management, were absent from our subthemes. In contrast, a coverage analysis between four sustainability assessment tools made by de Olde et al. (2017) revealed that coverage was higher for the environmental dimension than for the social and economic dimensions. Thus, environmental impacts appear as a main difference between the sustainability specification for apiculture and for other agricultural sectors, due to technical and management differences.

Uncovered subthemes were mainly linked to skills and knowledge (e.g. transferability of skills and knowledge, availability of skilled employee), beekeeping sector stakes (beekeeping sector and bee products image, recognition of beekeepers' profession by society and by other agricultural sectors) and to livestock and production issues (livestock replacement, ability to cope with unpredictable annual productions).

Technical or structural specificities of beekeeping can explain why some subthemes were not covered by any of the four studied tools. For example, livestock replacement is a problem for many beekeepers, as they have to face more important and less predictable annual losses than other livestock productions. Similarly, the lack of technical advice services for professional beekeepers could explain that technical skills and exchanges between professional beekeepers appeared as an important factor. Still, poor coverage of some subthemes does not seem to be related to beekeeping specificities. For example, "Contribution to the understanding and recognition of beekeeping occupations" (subtheme from "Beekeeping sector and society issues" dimension) or "match between real income and beekeeper's expectation" (included into "Income" theme and "Economic viability" dimension) are uncovered items while not being identified specificities of beekeeping. Design methodology through involvement of various stakeholders could explain the place of these issues in sustainability specification, as bottom-up designed tools (Diagnostic de l'Agriculture Paysanne, RAD) also covered more subthemes than top-down designed tools (IDEA, SAFA).

Among the whole content of sustainability specification for beekeeping farms, almost all of the 254 different elements came from the first step of the interviews, in which the interviewed person could freely express his or her own point of view on farm sustainability. Only 15 suggestions were not spontaneous but built on elements from the previously-established list of sustainability components. All of the other 239 were suggested spontaneously by at least one of the interviewed people, including most of the elements from the list of sustainability components. Most of the elements from this list were kept in the sustainability specification for beekeeping farms, even if some of them were strongly adapted to fit beekeeping specificities. Only four elements from the list were totally set aside (Table S1 in Supplementary material). Still, some elements from other sustainability assessment tools were considered as technically inappropriate for beekeeping and set aside from the list before the interviews, e.g. when directly related to land and crop management. Thus, these four elements cannot be considered as an exhaustive list of elements that would be quite common in other sustainability assessment tool but absent in ours.

Even if some of the suggestions were raised by almost every interviewed person, e.g. "to ensure a sufficient income for the beekeeper", most of them were only raised by one to three persons out of the 28 interviewed people. The diversity of stakeholders involved in the process thus appeared as a key element explaining the high number and the diversity of the

sustainability goals and themes, which is consistent with recommendations to include a diversity of viewpoints when designing a sustainability assessment tool (Binder and Wiek, 2007; Binder et al., 2010; Triste et al., 2014; Lairez et al., 2015). Van Asselt et al. (2001) also pointed out the importance of gathering a heterogeneous group, in terms of backgrounds and type of actors, to explore a diversity of viewpoints and opinions. In our case, interviewed people formed a heterogeneous group in terms of background (beekeeping experience, economic skills…) and type of stakeholders (leaders from beekeepers unions, land managers…), which contributed to the diversity of the collected suggestions about sustainability.

Besides the diversity in involved people, the involvement methodology could also account for the extent of suggestions we collected for sustainability of beekeeping farms. Before the collective step, the individual interviews, although time-consuming, allowed each of the interviewed stakeholders to develop their own viewpoint in details. This resulted in a high number of sustainability suggestions, and made the involvement of a diversity of stakeholders easier as it allowed us to include viewpoints from participants who were not ready to come to workshops but agreed to an interview, e.g. leaders of beekeepers unions. It increased the diversity of included viewpoints, and ensured a similar consideration for every suggestion regardless of who it came from. However, it also increased the difficulty of organizing workshops as some people would only agree to an interview but were not ready to come to a workshop. In addition, as interviews were carried out with people from all metropolitan France, geographical difficulties arose when organizing workshops.

From the interviews we realized with former leaders of sustainability assessment projects, it appeared that the involvement of stakeholders in these former sustainability specifications mainly consisted in workshops or other collective exchanges. These collective exchanges from the beginning of sustainability specification allow each participant to be aware of others' suggestions and viewpoints, which can help reaching a consensus (van Asselt et al., 2001; Slocum et al., 2006). However, former leaders highlighted that it could also reduce the scope of the debated subjects as some collective discussions turned out to be focused on specific aspects. Our methodology avoided this bias as viewpoints of participants were only exchanged at the first workshop we organized, where every participant discovered all the suggestions for sustainability specification from the interviews. The workshop consisted in discussions focused on the organization of the sustainability goals that were collected during the interviews, and every suggestion made during the interviews was included. As a result, the absence of some interviewed participants at the workshop did not prevent us to include their viewpoints. Thus, while the content of the sustainability specification mainly came from the consultation step (i.e. interviews), the workshop allowed every participant to discover the diversity of suggestions for sustainability of beekeeping farms and to take part in the organization of this content.

Social and societal issues (local development and exchanges with local stakeholders, agricultural sector stakes, quality of life) were more detailed in our sustainability specification for beekeeping farms than in other studied sustainability assessment tools, but were also better covered by the two studied bottom-up designed tools. The increased importance of social and societal issues in bottom-up designed tools may reflect their importance in farmers' and other stakeholders' viewpoints. Thus, the appropriate inclusion of these themes into sustainability specification may improve the match between the value judgments embedded in the tool and those of its potential users (i.e. farmers or beekeepers), which appears as one of the major factors that make assessment results relevant for its users (de Olde et al., 2016).

When comparing several sustainability assessment tools, farmers pointed out the importance of the contextualization of the assessment and its adaptation to the characteristics and goals of the participating farms (Marchand et al., 2014; de Olde et al., 2016). Considering the numerous specific items included in our sustainability framework for beekeeping farms, involvement of beekeepers and other stakeholders has been central to ensure the suitability of this framework.

Next steps: from a theoretical framework to an operational assessment tool

Our work resulted in a shared mental model of sustainability of beekeeping farms. To be able to use this framework to assess the sustainability of a farm, further development steps are scheduled (see Table 1), including the selection or development of indicators measuring the fulfillment level of each sustainability criterion and method development (scoring and aggregation method, references values). As some criteria are also found in other sustainability assessment tools, indicators to assess their fulfillment level could be the same than in these tools or could only require a slight adaptation, e.g. economic indicators. Other themes and criteria are specific to beekeeping farms and require specific indicators. Last, some subthemes or criteria may be difficult to assess in practice at the farm-level, e.g. due to a lack of knowledge to set reference values. As a result, some criteria that contribute to the mental model may have to be set aside in a first version of an operational tool. The development of indicators, their selection and method development will be carried out with involved stakeholders (see Table 1) on a participatory basis.

Conclusion

This work resulted in the first definition of sustainability adapted to beekeeping farms, in France, which includes six main sustainability dimensions. This framework shares some elements with other sustainability assessment tools, e.g. economic aspects, but also emphasizes some technical or structural specificities of beekeeping farms. In particular, the environmental effects of apiculture differ from those of other agricultural sectors, and social and societal issues have an increased importance, which is partly linked to skills and to the availability and transmission of knowledge. Finally, these results also point out the contribution of a participatory methodology for specifying the sustainability of a given sector and context. As this sustainability framework was designed for and with French professional beekeepers, its content may not be fully adapted to other countries, where beekeeping sector issues may differ and thus require an adaptation of the framework. However, we expect that these adaptations will be of less extent than the work of adapting an assessment tool designed for other agricultural activities, because the described framework already includes the specificities of the beekeeping activity.

Our suggested framework represents the diversity of perceptions of beekeeping farms sustainability and is a basis for the development of an assessment tool usable by advisors and beekeepers. A great body of work highlights that the involvement of relevant stakeholders is a key factor to ensure the suitability of such tools to its future uses and users (Cerf et al., 2012; Prost et al., 2012; Triste et al., 2014; Lairez et al., 2015; de Olde et al., 2016). Thus, the next development steps of a sustainability assessment tool adapted to beekeeping farms will also involve beekeepers and other future users of such a tool.

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Supplementary material

Table S1: Elements from other sustainability assessment tools that were discussed during individual interviews and that were not kept in the sustainability specification for beekeeping farms. Only elements that were set aside are listed in this table.

Sustainability element	Main content	Given reasons for non-consideration (non-exhaustive list)
Sharing of means and volume of production	Farming area compared to the estimated minimum farming area for the agricultural sector: would it be possible for another farmer to earn a living if the area was shared?	Not considered as relevant for beekeeping in the present state of knowledge
Access to inputs and equipment	Accessibility of inputs and farm equipment for the beekeeper	Not considered as a potential issue for beekeepers
Expected durability of the farm	Likelihood of the farm still existing in 10 years, which contributes to local development and employment	Not considered as relevant. Local development and employment are considered but not in a temporal dimension.
Optimal use and enhancement of the space	Balance between stocking and resource	Not considered as relevant for beekeeping in the present state of knowledge