Expert explanations of honeybee losses in areas of extensive agriculture in France: Gaucho® compared with other supposed causal factors

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Abstract
Debates on causality are at the core of controversies as regards environmental changes. The present paper presents a new method for analyzing controversies on causality in a context of social debate and the results of its empirical testing. The case study used is the controversy as regards the role played by the insecticide Gaucho®, compared with other supposed causal factors, in the substantial honeybee (Apis mellifera L.) losses reported to have occurred in France between 1994 and 2004.

The method makes use of expert elicitation of the perceived strength of evidence regarding each of Bradford Hill’s causality criteria, as regards the link between each of eight possible causal factors identified in attempts to explain each of five signs observed in honeybee colonies. These judgments are elicited from stakeholders and experts involved in the debate, i.e., representatives of Bayer Cropscience, of the Ministry of Agriculture, of the French Food Safety Authority, of beekeepers and of public scientists.

We show that the intense controversy observed in confused and passionate public discourses is much less salient when the various arguments are structured using causation criteria. The contradictions between the different expert views have a triple origin: (1) the lack of shared definition and quantification of the signs observed in colonies; (2) the lack of specialist knowledge on honeybees; and (3) the strategic discursive practices associated with the lack of trust between experts representing stakeholders having diverging stakes in the case.

Keywords: uncertainty, risk, honeybee, causality, imidacloprid

1. On causality
In a recent report on the emerging problem of honeybee decline, the French Food Safety Agency (AFSSA 2008) claims that there exist more than forty possible causes that might explain the observed trends of honeybee decline. This number illustrates the apparent complexity of contemporary environmental policy issues such as the loss of the world’s most important pollinator: the honeybee. Pollinators are crucial to 35% of the world’s crops (Klein et al 2007). To facilitate well-informed risk governance of such complex issues, there is an urgent need to increase the understanding of scientific and societal discourses on causality. Before exploring the particular case of honeybee decline, we first introduce the concept of causality.
This concept has been deeply discussed in epidemiology, other sciences, philosophy and law (Iversen et al 2008). Different models of causality exist in epidemiology, which Vineis and Kriebel (2006) divide into two classes. The first class are characterized by a linear monocausal pattern of explanation, based on the concept of a necessary cause (i.e., the disease does not develop in the absence of exposure to the agent). The second class are characterized by the concept of a causal web (i.e., a concurrence of different conditions is required to induce disease).

A widely used multi-causal model is the ‘pie’ model of Rothman. The idea is that a sufficient causal complex (a pie) is represented by a combination of several component causes (Rothman and Greenland 2005). The disease appears when the pie is completed. Such multi-causality provides the opportunity for removing only one or a small number of factors for preventing harm (Gee 2003).

Other causality models were developed in epidemiology but all have many limitations, mainly related to the low degree of accounting for interactions between causal factors, for their dynamic character over time, and for differences between individual and population levels (Valleron 2000, Vineis and Kriebel 2006).

There are also probabilistic numerical approaches for analyzing causal networks, such as Bayesian belief networks. These are often used for analyzing the complex probabilistic relationships between different variables (Iversen et al 2008). Bayesian networks are composed of three elements: a set of nodes representing system variables, a set of links representing causal relationships between the nodes, and a set of probabilities, for each node, specifying the belief that a node will be in a particular state given the states of those nodes that can affect it directly. By a process of updating the assumed probabilities by constraining them with observed data, Bayesian networks seek to find a hypothesis with the highest probability of being correct, given a specific set of available data and prior beliefs on causality (Welp et al 2006).

In environmental studies, research into causal relationships has the advantage of being able to test a hypothesis by building up experimental evidence in the laboratory under controlled conditions. In natural systems, many factors may interfere with the researcher’s ability to assess causality: the multitude of toxicants, their interactions with non-contaminant stressors, and the high biological variability. Furthermore, effects issuing from different stressors might not be comparable and their synergistic or antagonistic interactions may mean that their combined effects are greater or less than the sum of their individual effects. These gaps in knowledge add to those concerning compensatory processes that influence population dynamics, to the general lack of data, and to the difficulties associated with communication among several disciplines (Munns 2006).

Causal relationships are at the core of social debates on environmental changes because identifying causality also signifies placing responsibility on one or several stakeholders (Iversen et al 2008). In controversial cases, irreducible value judgments add to scientific difficulties for transforming causality in a Gordian knot for the public exchanges of arguments between the different stakeholders involved, and for the policy-makers.

The present paper presents a new method for analyzing causality in a context of social debate and its empirical testing using a case study. We approach a situation of controversy using the paradigm of ‘post-normal science’ (Funtowicz and Ravetz 1990, Van der Sluijs et al 2008). Post-normal science refers to issue-driven knowledge production in a context of hard political pressure, values in dispute, high decision stakes and high epistemological and ethical system uncertainties. It can be understood as a strategy for the production of relevant knowledge. Where normal science aims at establishing the ultimate truth or the final resolution of a scientific puzzle, post-normal science recognizes that as long as both scientific uncertainties and decision stakes are high, such an aim is in principle unachievable. Indeed it can be misleading and create false expectations to act as if the role of science in such issues is just to get the facts right. Key elements of post-normal science include the appropriate management of uncertainty and of quality, and the recognition of a plurality of perspectives and commitments amongst both experts and stakeholders, and the internal and external extension of the peer community.

We use, as an example of application of our new method, the case study of honeybee losses reported to have occurred in France between 1994 and 2004. This case study has indeed the characteristics of a post-normal situation of environmental change: hard political pressure, disputed values, high stakes decisions, and major system uncertainties.

New scientific practices are needed for these kinds of situations (Narasimhan 2007), and the post-normal paradigm recommends the appropriate management of uncertainty, the acknowledgement of the plurality of problem perspectives, and the extension of the peer community to include non-scientific actors (Van der Sluijs et al 2008). For assessing the degree of confidence (‘perceived uncertainty’) in the evidence concerning potentially causal relationships, we use the scale proposed by Weiss (2003), with experts possessing different types of knowledge (‘extended peer community’).

The application of the proposed method allows the identification of the origins of the social debate on causality. Our results show that the intense controversy which can be observed in confused, passionate and politically oriented public discourses is, in reality, much less intense when the arguments of different experts are structured and made transparent, factor by factor, sign by sign and using well established criteria for assessing causality.

The introductory section focuses on theories of causality and on the place of the present paper in relation to the existing literature. Section 2 presents the method and the underlying theoretical considerations. Section 3 presents the case study. The application of the method proposed to the chosen case study is described in section 4. We list the signs observed in honeybee colonies and the supposed causal factors, we present the questionnaire and the persons with whom it has been employed, and we explain the statistical tools employed for the identification of significant differences between the stakeholders’ answers and of discourse coalitions. Section 5 presents the results of the empirical test of the
method proposed. This includes the grouping of actors that use the same patterns of argumentation for the same causal relationships, and the agreement/disagreement between experts, by supposed causal factor. Section 6 further explores the origins of the differences found between experts, and we conclude in section 7.

2. The method for analyzing causality in a context of social debate

We propose the following steps for the analysis of discourses on causality in a context of controversy on the influence of several potentially causal factors:

- Clear identification and description of the signs (i.e., the end-points in honeybee colonies for which the causes have to be identified).
- Exhaustive identification of all the known factors, potentially involved in the signs described.
- Establishment of causality criteria and assessment of each of them, for the relationships between the factors (potentially causal) and signs, by the extended peer community.

Our method uses the nine criteria proposed by Sir Austin Bradford Hill (Hill 1965) for distinguishing between a chance association and a true cause and effect: strength of association, consistency, specificity, temporality, biological gradient, biological plausibility, biological coherence, experimental evidence, and analogy.

These criteria are used by epidemiologists and were tested in environmental risk assessment (Collier 2003). Their statistical use, for inferring causation when association is observed, has been criticized (Phillips and Goodman 2004), but their usefulness for the scientific inquiry on causal links, and the relationships between the available evidence and the actions to be taken, has been widely recognized (Phillips and Goodman 2006, Marshall 2005, Holt and Peveler 2006, Iversen et al. 2008).

In order to elicit the perceived degree of evidence on a potentially causal link by the extended peer community, the present paper uses the subjective scale proposed by Weiss (2003). This scale is intended as a communication tool to help increase the clarity and rationality of discourse in controversies in which generalists untrained in natural sciences must understand the merits of opposing arguments in disputes among scientific experts in order to make their own judgments better informed.

The use of this scale is appropriate for our case for several reasons:

(1) It seemed easy to understand and use for both scientists and non-specialists (which was confirmed in our study). Weiss estimates that the levels proposed correspond rather well to both the informal scale of uncertainty used by scientists in their everyday work and by ordinary people as they estimate the likelihood of one or another proposition.

(2) Is has enough levels for allowing the detailed and nuanced expression of different and sometimes divergent views (which would have been more difficult with for example a three-point or a five-point scale).

(3) The results can be easily interpreted, using non-parametric testing.

The hierarchy defined in table 1 is expressed as a ten-point ordinal scoring scale. The standards from the column ‘Convincingness of the evidence’ have been synthesized by Weiss (2003), drawing on different legal standards of proof used in US courts. This scale has been further developed by Weiss (2006).

3. The case study

Decline of honeybee colonies has been reported in many European countries (e.g. France, Belgium, Italy, Portugal, Germany, Netherlands, UK, Greece) and sometimes this has been related to seed-dressing insecticides, especially Gaucho® (active substance: imidacloprid) (Ministério da Agricultura do Desenvolvimento Rural e das Pescas 2000, Panella 2001, CARI 2003, COLOSS 2009). Recently, many American apiaries have suffered sudden colony losses. This phenomenon has been named colony collapse disorder. Given that the sign of disappearing adult honeybees recalled the signs found by French beekeepers, parallels with honeybee colony decline in France were drawn.

The French controversy started in 1994–1997, when beekeepers first reported alarming new signs in honeybee colonies: in the summer, during sunflower flow, honeybee colonies were suddenly and massively collapsing. Honeybees almost completely disappeared far from the hives and in some cases were dying in thousands in front of the hives. This mortality was accompanied by behavioral signs (trembling, keeping the tongue extended, excessive cleaning of the head and the antennae, etc.), and by a 30–70% loss in sunflower honey yield (e.g. beekeepers’ reports in Belzunces and Tasei (1997), CNEVA Sophia-Antipolis (1997), Pham-Delegue and Cluzeau (1998), Coordination des Apiculteurs (2001), Alétru (2003), GVA (1998–2008)). High honeybee losses were also reported in early spring. It was acknowledged that a new insecticide Gaucho® had been first used in sunflower seed-dressing in 1994.

Table 1. Scale of perceived degree of uncertainty (Weiss 2003, modified).

| Level (score) | Convincingness of the evidence |
|---------------|-------------------------------|
| 10            | Beyond any doubt              |
| 9             | Beyond a reasonable doubt     |
| 8             | Clear and convincing evidence |
| 7             | Clear showing                 |
| 6             | Substantial and credible evidence |
| 5             | Preponderance of the evidence |
| 4             | Clear indication              |
| 3             | Probable cause: reasonable grounds for belief |
| 2             | Reasonable, articulable grounds for suspicion |
| 1             | No reasonable grounds for suspicion |
| 0             | Impossible                    |

3 A legal standard of proof is defined as ‘the level of certainty and the degree of evidence necessary to establish proof in a criminal or civil proceeding’ (Merriam–Webster (1996), in Weiss (2003), p 29).

4 http://maarec.cas.psu.edu/ColonyCollapseDisorder.html
In 1999 a precautionary principle was applied, Gauchos® being banned in sunflower seed treatment. This ban was renewed in 2001 and in 2004, and in 2004 extended to maize® seed-dressing.

4. Applying the method to the chosen case study

4.1. Potential causal factors and signs

The analysis of the available documents (press releases, newspaper articles, other recordings of public statements of different stakeholders, etc.) suggested eight potential causal factors6 which different stakeholders considered responsible7 to a greater or lesser degree for the honeybee losses:

(H1) Imported queens, which might not be adapted to local conditions.

(H2) Unfavorable climatic conditions (during sunflower/maize flowering).

(H3) Intoxication with pollen and/or nectar foraged in areas with Gauchos® in sunflower and/or maize seed-dressing.

(H4) Intoxication with pollen and/or nectar foraged in areas with sunflower and/or maize which are not seed-dressed with Gauchos®, but which are grown in soil in which a Gauchos® seed-dressed crop was cultivated in the year n – 1.

(H5) Diseases and viruses (Noséma, Varroa, chronic bee paralysis virus (CBPV)), the development of pathogen resistance to disease treatments, lack of preventative treatment measures in certain hives, or inadequate treatment.

(H6) Inadequate or illegal use of pesticides and mixes of pesticides by farmers.

(H7) An insufficient quantity of pollen, as a consequence of intensive agricultural practices.

(H8) Changes in sunflower varieties.

We synthesized the effects observed in the field into a list of five signs:

(S1) Unusual yield loss of sunflower honey (30–80%).

(S2) Lethal signs uniquely during sunflower/maize flowering: sudden disappearance and sometimes mortality of foragers in front of the hives.

(S3) Sublethal signs following the sunflower/maize foraging: apathy, shivering, excessive self-cleaning, formation of mounds of perturbed honeybees on the ground, abnormal foraging behavior, and perturbation of comportment inside the hive.

(S4) Abnormal annual depopulations (more than 5–10% of the hives).

(S5) Excessive mortality during winter or at the beginning of the spring (more than 5–10% of the hives).

On the basis of the criteria for causation developed by Sir Bradford Hill (Hill 1965), eight questions were drafted, to elicit the expert perception of the causality relationship between the factors supposedly responsible for the damage to honeybee colonies and the signs observed in the field (table 2): 6

(1) Strength of the association (Q1): are the effects so great, in the presence of one factor, that we can justifiably rule out other factors?

(2) Consistency (Q2): has the effect been observed by different persons, in different places and circumstances?

(3) Specificity (Q3): is the exposure associated with a specific effect, as opposed to a wide range of effects?

(4) Biological gradient (Q4): are increased exposures associated with increased signs?

(5) Biological plausibility (Q5): is there any credible scientific mechanism that can explain the association?

(6) Coherence (Q6): is the association consistent with the past experience of the factors/signs?

(7) Temporality (Q6): did the exposure precede the effect?

(8) Experimental evidence (Q7): are there studies/experiments supporting the factor–sign association?

(9) Analogy (Q8): is the observed association supported by similar associations?

4.2. The questionnaire

Using a questionnaire (table 2), each person interviewed (during a meeting or by telephone) was asked to give a score to each question, i.e. to each combination of three elements: one of Bradford Hill’s criteria × a potential cause × a reported effect. They were asked to use the ten-point scoring scale of table 1 for answering.

In line with Funtowicz and Ravetz (1990), Wynne (1996) and Kloprogge and Van der Sluijs (2006) we took the position that both ‘institutionally recognized’ experts and knowledgable ‘lay’ individuals (e.g., beekeepers) are equally valuable and important in the process of constructing socially robust knowledge on environmental problems. The persons interviewed had been and/or are still directly involved in the debate on honeybee losses: representatives of Bayer Cropscience (2 persons), of the Ministry of Agriculture (3 persons), of the AFSSA (French Food Safety Authority; 2 persons), of beekeepers (20 persons; all but one were professional beekeepers, from French regions where the signs included in the questionnaire had been observed) and of public scientists (5 persons, working in public research, who were directly involved in studies of risks of imidacloprid to honeybees).

As we focus on the controversy having taken place in France, the persons interviewed in this study were exclusively French, with one exception—one expert from Bayer having been interviewed in Germany, in English. This was necessary to have at least two experts from this company having been significantly involved in the French debate.

The persons who participated from Bayer, the Ministry of Agriculture, the AFSSA and the public scientists played key roles in the debate. We stopped at a sample size of 20 beekeepers because of resource constraints and because we found that their views corresponded closely with the public statements issued by the beekeeping profession during the debate. All our beekeeper respondents had experienced problems in their own apiaries during the period concerned (1994–2004). They were identified on the basis of a ‘snowball’ procedure (each person was asked to supply the names of colleagues...
Table 2. Questionnaire applied during the interviews (example for one factor, namely H1).

| Potential cause / signs observed | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 |
|---------------------------------|----|----|----|----|----|----|----|----|
| Unusual yield loss of sunflower honey (≤50 to ≥60%) | **Answer** | 9 to 10 | | | | | | |
| Lethal signs uniquely during the sunflower/maize flowering: loss of foragers (mortality in front of the hive and disappearance) | | | | | | | | |
| Sublethal signs during and following the sunflower/maize flowering period: paralysis, loss of sense of orientation, apathy, slavering, excessive self-cleaning-up, formation of mounds of perturbed honeybees on the ground, abnormal foraging behaviour, and perturbation of the compartment inside the hive (i.e. covered cells filled in with nectar before the end of the honeyflow). | | | | | | | | |
| Abnormal annual depopulations (more than 5 %) | | | | | | | | |
| Winter mortality (more than 5 %) | | | | | | | | |
who had apiary problems). Most of them were involved in activities dealing with the profession as a whole (e.g., syndicalism), which was considered an advantage (as our intention was to ascertain the public attitude of the profession). They came from 13 departments (this is highly representative for the areas in France where the signs were observed) and on average had 25 years of experience in beekeeping (calculated up to 2007).

The interviews were carried out between September 2006 and March 2007.

4.3. Identification of significant differences between the stakeholders’ answers and of discourse coalitions

In order to test whether the answers given by the stakeholders are significantly different or, on the contrary, if they can be considered as being the expression of discourse coalitions, we used the Mann–Whitney $U$ test, which:

1. is adequate for the treatments of the ordinal data gathered in our fieldwork, which demand a non-parametric test;
2. allows two samples of arbitrary size to be compared;
3. is adequate for small samples;
4. is adequate for independent samples.

This test was applied to each pair of stakeholders (beekeepers–Bayer, AFSSA–Ministry, etc), for each particular answer. 3200 tests were completed, for the 10 pairs of stakeholders and for each of the 320 questions of the questionnaire. For each test, the null hypothesis ($H_0$) was: ‘There is no difference between the answers of the two stakeholders considered’ (here, each ‘stakeholder’ is a group of persons, that is: $N = 20$ for beekeepers, $N = 3$ for the Ministry, etc). A confidence level, of 0.05, has been considered (that is: we tested the null hypothesis that the probability that the answers of one stakeholder would be different from the answers of the second stakeholder is 0.05).

For example, one ‘cell’ (of table 2) contains the stakeholders’ answers to a question: ‘Is it biologically plausible (HILL CRITERION) to say that 30%–60% sunflower honey yield loss (SIGN) is caused by the presence of unfavorable climatic conditions alone (FACTOR), when crops are not treated with Gaucho®?’. For this cell, the beekeepers gave 20 answers (that is 20 scores, each from 0 to 10), the Ministry of Agriculture gave 3 answers, etc. The Mann–Whitney test was applied, for instance, to these two groups of answers, here the 20 answers from beekeepers and the 3 answers from the Ministry, to ascertain whether they are statistically significantly different.

After the completion of all the tests, two methods were employed to synthesize the results:

(a) The calculation of the percentage of rejections of the null hypothesis, by pair of stakeholders and answer—both for the questions asked on Gaucho® ($H_3$), for all the other questions which did not include Gaucho® and for all the questions concerning diseases and viruses ($H_5$). (See figures 1–3.)

(b) The method of Bonferroni for multiple tests was used to calculate the differences between the answers of the stakeholders to a group of questions together. This method consists of a simple Mann–Whitney test for each question, considering a risk of 0.05 divided by the total number of questions. The null hypothesis in this case is: ‘There is no difference between the answers of the two stakeholders to all the questions together’. The null hypothesis is rejected when at least one simple test is rejected (meaning that the $p$-value is inferior to 0.05/No. of questions).

5. Results

5.1. Actors’ grouping and differences in arguing for the same causal relationships

The debate on causal relationships can be structured around two storylines, each defended by a ‘discourse coalition’ among several stakeholders:

1. The first is represented by beekeepers and scientists working in public research. Their arguments claimed that Gaucho® was the main contributor to the damage caused to honeybee colonies observed after 1994 in areas with seed-dressed sunflower/maize extensive crops. They stated that other causes might be involved in the honeybee problems in other areas in France (e.g., in mountain areas), but acknowledged that this was not the issue of the public debate relating to intensive agriculture areas. Their arguments were based on the results of field observations and of studies conducted in France after 1997 on the effects of imidacloprid on honeybees.

2. The second storyline argues for a non-causal relationship between Gaucho® and honeybees (in general, in France), articulating that other factors are to blame. This was represented by Bayer and AFSSA (the French Food Safety Agency) and is based on the lack of evidence of harm, citing their research, whose results did not reproduce the signs observed by beekeepers.

The position adopted by the Ministry of Agriculture was ambivalent, considering Gaucho® as one of several possible causes, with an unclear contribution to the final effects.

The results show that as regards the questions concerning Gaucho® alone ($H_3$), the number of questions for which there is a statistically significant difference between beekeepers and Bayer (88% of the questions), beekeepers and AFSSA (100%), beekeepers and the Ministry (80%) is much bigger than the number of questions for which there is a significant difference between beekeepers and public scientists (8%) (figure 1).

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8 It was found that question Q4.1 had been interpreted differently by the respondents, and many of them declared that they had not understood it. For this reason, it has been excluded from the treatment of the results. Note that in the group of scientists, one person was found to be an outlier: the scores given were consistently very low, even when this scientist declared that the degree of certainty was quite high. This can be attributed to a self-recognized extremely cautious nature, especially as regards public statements.

9 In France, scientists having permanent positions in national research institutes (e.g., INRA, CNRS) and universities are public servants. 100% of their salaries and a part of their functioning (sometimes equipment) expenses are funded by the public institution.
Also, one can see that there is no question on which there is a significant difference between AFSSA and Bayer, between AFSSA and the Ministry and between Bayer and the Ministry. On the contrary, there are high percentages of questions that show a significant difference between public scientists on the one hand, and, on the other hand, Bayer, AFSSA and the Ministry (60% of the questions, for each of the three pairs of stakeholders).

This pattern changes for the questions which do not refer to Gaucho®, but to all the other supposed causal factors (figure 2). The percentage of answers significantly different is much lower for all other factors together than for Gaucho® alone, between beekeepers and AFSSA (26.66% versus 88% for Gaucho®), and Bayer (52.66% versus 100%). This indicates that the focus of the debate is less on the influence of other factors on honeybee losses, and more on Gaucho®. Those defending a zero effect of Gaucho® use the existence of multiple factors able to produce honeybee losses everywhere in France as discursive means for indirectly arguing about Gaucho® in sunflower and maize areas.

In fact, the two discourse coalitions refer to two different problems.

One may note that beekeepers’ answers (figure 2) show significant differences more often than the answers of other categories of experts. This may be linked to the fact that for most of the eight factors (all excepting Gaucho® and, to a lesser extent, diseases), very little knowledge and no systematic monitoring were developed in France between 1994 and 2004. Thus, most of the information existing on these factors is from beekeepers and comes from their field experience.

The method of Bonferroni (multiple tests) gives similar results, but these are less powerful in terms of possibilities of interpretation:

- For the pairs beekeepers–AFSSA, beekeepers–Bayer and beekeepers–Ministry, the two stakeholders in each pair answer significantly differently to the 25 questions on Gaucho® together (confidence level: 0.05/25 = 0.002). For the other pairs of stakeholders, nothing can be said.
- The beekeepers answer significantly differently from the Ministry, for all the questions, concerning all the other factors excepting Gaucho®, together (confidence level: 0.05/150 = 0.0003). For the other pairs of stakeholders, nothing can be said.
5.2. Agreement and disagreement between experts, by supposed causal factor

Our results indicate that the actors generally agree that the association between each of five factors alone (of the eight studied) with the lethal and sublethal signs observed (S2 and S3) is not biologically plausible, not verified in the field or unknown (answers to the question Q2.2 and Q5.2; table 2). The factors are: honeybees’ genetic origin, unfavorable climate, lack of pollen, illegal/inappropriate use of pesticides and changes in sunflower varieties.

These results are interesting, because in public discourses these factors were presented as being plausible causes of honeybee losses by representatives of the ‘no effect of Gaucho®’ storyline. However, the scientific details of the influence of these five factors on the particular signs found in extensive sunflower and maize areas were never addressed in the public arena. These results show that, publicly, some experts can use different definitions of the problem being addressed and thus induce an incorrect understanding by the public.

Regarding lethal and sublethal signs (S2 and S3), the most important differences between the two discourse coalitions concern two criteria: 1. The specificity of the association; diseases can appear throughout the year, without determining these signs. To explain why the signs appear during sunflower/maize flowering, Bayer and AFSSA proposed the following scenario: in areas with extensive crops of sunflowers, honeybees have no food alternative between the rape and sunflower flowerings and, therefore, colonies are weak before sunflower nectar is available and are exhausted during the period when it can be collected because of the high work intensity. These factors would therefore contribute to their greater susceptibility to diseases compared with the rest of the year. Beekeepers question the validity of this scenario as some of them have portable rather than fixed hives and therefore between the flowering of rape and that of sunflower their honeybees visit many other flowers, such as wattle, blackberry and chestnut. Yet despite this availability of pollen, their apiaries still presented the signs. Also, beekeepers state that in several cases the hives suffering the signs during sunflower flowering had been pathologically checked before the flowering and given a clean bill of health (Préfecture de la Vendée 1997, Alétru 2003, Philippe Vermendere, in AFSSA 2002). No scientific evidence was provided for the possible correlation between the lack of pollen, honeybee diseases and signs like those reported.

The actors denying a causal relationship between Gaucho® and the signs provided no other causal explanation that fits the information communicated by beekeepers about the specificity of lethal and sublethal signs for sunflower/maize flowering. 2. The coherence of the association; no new disease that could be linked with the signs observed has been identified in French hives since 1994. AFSSA and Bayer hypothesized that the resistance of Varroa mites to fluvalinate that was found in Italy in 1995–1997 (Trouiller1998) must have spread to France; and that these mites are vectors of the CBPV. These two actors argue that CBPV could have produced signs similar to those reported. The beekeepers, however, contended that the signs of CBPV differ from the signs that they observed during sunflower and maize flowering.

The public scientists cited Tentcheva et al (2004), who identified CBPV in only 28% of the French hives studied, in which honeybees did not present the signs of disease. They have shown that bee virus infections occur persistently in bee populations despite the lack of signs, suggesting that colony disease outbreaks might result from environmental factors that lead to activation of viral replication in bees. Regarding the hypothesis of the transmission of CBPV by Varroa, Tentcheva et al (2004) show that CBPV was not isolated from any of the samples of Varroa collected. This shows that the contribution of Varroa to the dissemination of this virus, if any, is small. These authors have also shown that this virus has no seasonal pattern but appears erratically during the year. Also, Faucon et al (1995) showed that the efficacy of the treatment (fluvinate) for Varroa mites in French hives was still 100% in 1994, whereas Italian colonies were already showing
resistance. The beekeepers and public scientists argued that whereas honeybee diseases might theoretically influence the colony in the long run (e.g., annual depopulations, winter mortality), this was not a biologically plausible explanation for the specificity of the lethal and sublethal signs observed during summer. Diseases could manifest more intensely when honeybees have a low immunitary defense, due to imidacloprid. Beekeepers formulated this hypothesis several years ago and launched a call for research and further studies (Aletru 2003).

It is interesting to find that most beekeepers do acknowledge that other factors alone, and particularly diseases and illegal/inappropriate use of pesticides, could theoretically have an influence on three of the five signs, i.e., the loss of sunflower yield, annual and winter mortality. However, they have appreciated the influence of these factors (other than Gaucho®) as being of low relevancy in the field during the sunflower/maize flowering between 1994 and 2004. Beekeepers have not defended a ‘unique hypothesis’ for all honeybee losses, everywhere and any time, but have referred to Gaucho® seed-dressed sunflower and maize areas.

Figure 3 shows that the percentage of answers significantly different is lower for diseases than for Gaucho®, between beekeepers and AFSSA (44% for diseases versus 88% for Gaucho®), beekeepers and Bayer (44% versus 100%), and beekeepers and the Ministry (80% versus 52%). The divergent answers mainly concern the influence of the diseases on lethal and sublethal signs.

6. Discussion

Depending on their life and professional experiences, different stakeholders have different types and levels of knowledge, and therefore different assessments of causality criteria. Moreover, whereas socio-economic stakes are high, value judgments and interests may also influence these assessments. Consequently, one or several causality criteria can have a more important role in the debate. Clearly structuring their arguments using causality criteria can therefore help in identifying the origins of the controversy and addressing them in the process of decision-making.

The application of our method to the chosen case study shows two ‘discourse coalitions’:

(1) One, represented by Bayer, AFSSA and partially the Ministry, make reference, in their public discourses, to all honeybee losses (everywhere in France, in all seasons). They do not particularly focus on sunflower and maize areas, or on the specific signs observed by beekeepers in these areas. However, they make reference to other potentially causal factors in arguing for a non-causal relationship between Gaucho® and honeybees.

(2) The second, represented by beekeepers and public scientists, affirm the determinant role of Gaucho® in honeybee losses found in sunflower and maize areas, all stating that many causes, among which diseases must require particular attention, can lead to honeybee losses all over France. Some beekeepers also point to the sublethal action of imidacloprid and to its possible synergic effects with diseases.

In this particular case study, the differences in assessment of causality criteria by the experts interviewed (section 4) have a triple origin:

- (1) the lack of shared definition and quantification of the signs—which mainly influence the assessment of the criteria 1, 2, 3, 4 and 6;
- (2) the lack of specialist knowledge on honeybees (e.g., statements which are biologically unfounded)—which mainly influence the assessment of the criterion 5;
- (3) the strategic discursive practices (e.g., statements which have no experimental proof) associated with the lack of trust between experts representing stakeholders having diverging stakes in the case; this last aspect mainly influences the assessment of the criterion 8.

For example, such an analysis realized during the debate could have shown that the most important aspects to address in decision-making were:

- Describing in detail and monitoring the evolution of signs in the field.
- Paying particular attention to the level of expertise in honeybee biology of the experts involved in assessing the available evidence and producing the needed knowledge.
- Making the socio-economic stakes of the different actors involved clear and transparent, in order to promote a well-informed and balanced process of decision-making.

Below, we detail each of the three aspects for the case study of honeybee losses in France.

6.1. Lack of shared definition and quantification of the signs

A question at the end of the questionnaire aimed at synthesizing the views of experts about the contribution (%) of each cause to the final effects found during the years 1994–2004 (the sum of the percentages given for different causes is 100%); see figure 4.

In the description of honeybee problems during the sunflower flowering, the answers to this last question: ‘What is the magnitude of the signs observed by beekeepers in the field between 1994 and 2004?’ yielded differences of up to threefold between groups of stakeholders. For example, beekeepers mentioned possible losses of sunflower honey yield of 0–30% of average yield in normal conditions (meaning in sunflower crops not treated with Gaucho®). These figures were arrived at on the basis of their own experience.

The same question (‘What were the sunflower honey yield losses found by beekeepers between 1994 and 2004 Gaucho®-treated areas compared with the average yield in crops not treated with Gaucho®?’) posed to Bayer. The experts representing this stakeholder gave figures ranging from 30% to 60%. The Ministry of Agriculture’s response to the same question was 50%. These last two stakeholders could not provide a reference for these statements.

10 A synergic effect between imidacloprid and Nosema has recently been confirmed in a study by Alaix et al (2010).
Another question asked about the losses of foraging bees found in the field by beekeepers during sunflower flowering for crops not treated with Gaucho®. Whereas the beekeepers gave figures between 1% and 5%, the Ministry of Agriculture gave a figure of 40%, and Bayer a figure of 33%. For the beekeepers, the difference compared with Gaucho®-treated crops was very important (the average percentage that they declared was 89%—compared with a mere 1%–5% for untreated crops), whereas for the Ministry of Agriculture and for Bayer there was no difference between Gaucho®-treated and untreated crops.

The most important difference between the stakeholders relates to lethal and sublethal signs. For certain actors, as for one expert from Bayer, the sublethal signs observed can characterize most of the diseases, can be included in the classic signs found in honeybees and are ‘like for humans, the nose running, the fever and the throat pain’. In other words, this actor considers that this sign is not at all specific. By contrast, for beekeepers, sublethal signs are highly specific and had never seen before 1994. The scores given by public scientists also indicate specificity for the lethal and sublethal signs.

6.2. Lack of specialist knowledge on honeybees

Our results show that some of the scores given by expert actors are supported by explanations which are biologically incorrect. For example, one stated that the low nutritive value of sunflower pollen eaten by foragers could be a factor in the outbreak of the CBPV during this flowering period. However, it has long been known from the scientific literature that foragers do not feed on pollen—only the nurses

A summer worker honeybee lives about six weeks. Three days after being laid, the egg becomes a larva, which in turn becomes an adult honeybee after about 17–19 days. During its life, the honeybee fulfills several ‘tasks’ in the hive. At first it cleans the hive and nourishes the larvae, then after 10–14 days it stores the collected nectar and pollen, ventilates the hive, covers the cells to some extent the larvae do. Another example is one expert actor who confused the disappearance of foragers with swarming.

This shows the importance of the criteria chosen for including experts in risk assessments important for decision-making. These experts should be specialists in the field (i.e., having published on the subject addressed in the risk assessment, in peer-reviewed good quality international journals). Their discipline should be appropriate for the intended assessment (e.g., an expert in botany will be less appropriate for understanding the risk of sublethal effects on honeybees than an apidologist).

Our study also revealed that a distinction must be made between the criterion of the biological plausibility (criterion 5, which is theoretical) of an association and its manifestation in real field conditions (criteria 1, 2, 3, 4 and 6). We found that actors with limited field experience and/or limited contact with beekeeping were not able to make this important distinction. For these actors, the ‘when’ and ‘where’ of the signs have no place in their discourse, and they may confuse, for example, depopulations found in extensive crops of sunflower/maize with those found in mountain areas, summer depopulations with annual depopulations, winter mortalities with abnormal winter mortalities, etc. This finding shows the key importance of taking account of local knowledge in the definition and assessment of environmental risks, from the very earliest stages of defining the research protocols and conducting risk research (Maxim and Van der Sluijs 2007, Corburn 2007).

6.3. Patterns of strategic discursive practices

The tensioned relationships between the different stakeholders can lead to illogical patterns in the scores given. For example, some interviewees gave high scores (>6) but were not able and cleans the colony. It can also secrete beeswax and build new cells. After it is 18 days old, it can be a guardian. From then until death, the honeybee is a forager, and works outside the hive, collecting pollen and nectar.
to cite observations or experimental evidence supporting their statements, and sometimes were not able to give a biologically plausible explanation which they themselves considered satisfactory. Despite being unable to justify the score that they gave, some respondents nevertheless stuck to their score. The ‘evidence’ for one potential causal relationship or another expresses, in the words of an expert, a ‘conviction’, even if in some cases there is as yet no biological explanation. This is, for example, the case for the scores an expert gave to the relationship between diseases and the lethal and sublethal signs.

We found that part of the debate on ‘multi-causality versus Gaucho®’ was due to confusion, to strategic discursive practices and to passionate attitudes regarding persons from the ‘opposite camp’. The arguments developed by experts establish a certain place in the political arena and become, in time, immovable. The experts themselves are trapped in the socio-political position associated with an argument and stop inquiring about its plausibility. Thus, for example, one expert said that the exercise that we proposed ‘pushes (one) to think, to realize that there are things that we have been repeating for years, which are now part of our convictions, whereas in fact they are not substantiated by concrete evidence. But they are part of our discourse, and we know that our opponents are doing the same, when they build their discourse. We tried to say to ourselves that we have to be coherent and have a scientific justification for what we are saying, but I realize that as soon as we speak about hypotheses other than Gaucho®, we are playing the same game as the others’.

Our results (section 5.2) showed that in public discourses, some expert actors can present as being plausible hypotheses which are not scientifically validated and thus downplay a correct understanding of the problem by their listeners. Not all experts are equally attentive to the robustness of the scientific support for the hypothesis that they evoke.

This indicates that decision-making should always be based on ‘contradictory expertise’, in which all the competent scientists are able to communicate their results and assess the statements of the others.

Furthermore, experts involved in risk assessments should be asked to declare their conflicts of interest. These statements should be public and easily available to anyone asking, and in our opinion they should lead to the refusal of participation of these experts in risk assessment committees concerning products of companies that market them.

7. Concluding remarks

Often, in controversial situations (such as the one described here), the political positions and the arguments of the stakeholders involved become polarized and immovable. A real dialog is therefore very difficult because agreeing to a compromise solution sometimes supposes changing one’s views on the problem, which can be tricky in such public debates. One of the creators of the paradigm of post-normal science, Ravetz (2007), characterized the essence of such a real dialog by the term ‘negotiation in good faith’. In the light of our findings, this proposal translates into a research question: that of what potential procedures like those described here, which help structure, communicate and find the reasons for divergent expert statements, have for achieving ‘negotiation in good faith’? This would amount to a test of whether greater self-awareness of their own subjectivity would make stakeholders more appreciative of the legitimacy of the other stakeholders in the common description of causal patterns of environmental problems.

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