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Transdisciplinary participatory-action-research from questions to actionable knowledge for sustainable viticulture development

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Viticulture negatively impacts the environment, biodiversity, and human health; however, despite the widely acknowledged challenges that this intensive agricultural activity poses to sustainable development, measures to reduce its invasiveness are constantly being deferred or rebuffed. Constraints to change are linked to vine cultivation methods, the impacts of climate change on vine resilience and disease sensitivity, and socio-economic models, as well as growing criticisms from society. Research and training have thus far failed to provide solutions or mobilise stakeholders on a large scale. Such resistance to sustainable practices development calls into question the effectiveness of knowledge production systems and relations between scientists, winegrowers, and society: Have scientific disciplines overly isolated themselves from each other and from the wider society to the point of losing the capacity to incorporate alternative forms of knowledge and reasoning and achieve collaborative action? Herein, we describe our findings from a participatory action research project that began in Westhalten, France, in 2013 and ultimately spread to Switzerland and Germany over the next 6 years. We show that participatory action research can mobilise long-term collaborations between winegrowers, NGOs, advisers, elected officials, members of civil society, and researchers, despite differing visions of viticulture and the environment. The epistemological framework of this research promotes consensus-building by valuing complexity and dissensus in knowledge and reasoning such that all actors are involved in experimentation and the production of results. From these findings, consensus statements were collectively elaborated in qualitative and quantitative registers. Once acknowledged by the scientific community, these consensus statements became shareable knowledge. We propose that this renewed interdisciplinarity associating the human and social sciences with agronomic and biological sciences in collaboration with stakeholders produces actionable knowledge that mobilises and engages winegrowers to conceive and implement sustainable viticulture on a transnational scale.

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Introduction

With 7.5 million hectares of vines cultivated worldwide, viticulture is economically valued for its benefits to the production of wines and the picturesque landscapes it shapes for tourism and hedonism. However, as with all cases of intensive agriculture (Springmann et al., 2018), the viticulture sector's large-scale use of pesticides ranks it among the agricultural industries with the highest environmental impact. 'Conventional' viticultural practices involve the application of herbicides to soils and synthetic pesticides on vines to combat diseases and insects in 89% of the world's vineyard's areas. Although society has become increasingly mobilised against conventional viticulture practices (Wasley and Chaparro, 2015), the proportions of cultivated surfaces have changed very little (Muller et al., 2017). Resistance to more sustainable practices development is linked to concerns regarding the disease sensitivity of cultivated vines, which must remain in place for more than 15 years to yield quality wines and are vulnerable to increasingly frequent climatic disturbances. The wine industry's resistance to change is also due to their lack of input into sustainability policies, which often results in economically untenable regulations, norms, economic rules along with standard top-down advice and dictatorial training courses. Therefore, winegrowers are caught up in a complex system of constraints that locks them into conventional practices, and a widespread misperception that the situation can be resolved by 'letting nature take its course' further exacerbates the situation.

Organic and biodynamic viticulture practices, which account for 10% and 1% of the land surfaces dedicated to viticulture, respectively, have a reputation for lower environmental impact because they do not use herbicides and use natural products to ensure the health of the vines (Organisation Internationale de la vigne et du vin (OIV), 2020). However, in the case of France, efforts by agronomic advisors to initiate change through the implementation of demonstration workshops and trainings in more sustainable viticultural methods have mostly been implemented in a top-down manner, and consequently have failed to lead to the widespread adoption of such practices (Potier, 2014). In particular, trainings in organic and biodynamic techniques have only attracted a very few winegrowers who are already mostly convinced of the need for change. The French government's Ecophyto plan, initiated in 2008, designed a set of indicators to evaluate situation and mobilised agricultural education programs, among other measures, to promote the evolution of practices towards more sustainability, in fact exacerbated divisions between farmers and other actors, with the result being an increased rather than decreased use of pesticides (Guichard et al., 2017). In parallel with these actions, members of the plant sciences and agronomy research communities have translated the need for change in viticulture into initiatives for 'redesigning practices'; however, exemplary efforts have mainly been conducted on standardised, multi-instrumentalised experimental plots using sensors for air temperature, sun irradiance, and humidity sensors above the ground and in the soil, conductance apparatuses, automatic weighing machines, and apparatuses that measure water evaporation, among other sophisticated devices. As a result, questions and concerns abound about the value and legitimacy of these 'redesigned' practices and the possibility for their effective implementation in the real-world of vineyard plots.

The results of previous measures strongly indicate a need for change in research methods, training, and advisory approaches; however, what roles can the sciences play in the development of sustainable viticulture and, more broadly, sustainable agriculture? How can we valorise knowledge from field experiences and different forms of reasoning, and expectations among various stakeholders, to produce new knowledge and mobilise for action? Are conventional research schemes capable of meeting the challenge of agricultural sustainability in the complexity of the global context? Should disciplines from the human and social sciences be associated with those in the agronomic and biological sciences, and if so, how and in what timeframe? How can productive interactions be established between scientific disciplines and actors of the agricultural industry, as well as the wider society? Among the possible paths, can a participatory sciences approach contribute to resolving such complex equation?

Participatory sciences ideally link researchers and society in what Latour (2009) called a 'parliament of things' that aims to contribute to the co-production of more comprehensive forms of knowledge and action for sustainable development. However, this approach remains questioned, partly because the polysemy of 'participatory sciences' ranges from minimal forms such as crowd sourcing to more intensive forms like participatory action research (Barbier, 1996), and more recently emerging modes are sometimes considered overly radical due to the high level of partnership between stakeholders and scientists (Ancori, 2005, 2012; Billaud, 2003; Billaud et al., 2017). As Filipe et al. (2017) noted, it is not always evident what is being produced through this process, under what circumstances co-production occurs, and what the implications are for participants. Many actors in the scientific community, in particular outside the human and social sciences, have questioned the legitimacy of participatory approaches in relation to standard forms of knowledge production, disdaining the actors involved in the formulation of questions in the co-production process, their treatment, and the production and validation of the conclusions (Ancori, 2005, 2012). As T. Kuhn et al. (1990) protested, 'it is unthinkable that actors other than researchers should have the legitimacy to ask the right questions'. Similarly, D. Graur (2007) highlighted the concern of many scholars that co-production poses a 'nightmare for the scientific community'.

However, in recent years, the devastating effects of climate change have forced governments, and scholars alike, to reconsider their approaches to achieving more sustainable practices. In the context of agriculture and other food producing industries, the devastating impacts of environmental deterioration have led to an increasing level of engagement with participatory action research (e.g., Guzman et al., 2013; Mapfumo et al., 2013; Shames et al., 2016). For example, Méndez et al. (2017) agroecology work in Central America demonstrated the importance of farmer/stakeholder participation in setting the research agenda and emphasised shared interest, a belief in collective power/action, commitment, humility, and trust and accountability as key principles of participatory action research. Apgar et al. (2017) conducted a comparative analysis of participatory action research projects with aquatic agricultural producers in Zambia, Bangladesh, the Solomon Islands and Cambodia, and concluded that applying principles of ownership, equity, shared analysis, and feedback characteristic of participatory action approaches fostered trust between scholars and local stakeholders and helped to effectively identify and exploit opportunities to achieve forms of more inclusive science and co-governance that enhanced stakeholder representation, distributions of leadership and authority, and accountability. Similarly, when describing participatory approaches among farmers in India, Iran and Peru, Pimbert et al. (2017, p. 101) highlighted the importance of overcoming 'disempowering mindsets, attitudes, and behaviours' in order to enhance the capacity for co-producing knowledge and collaborations towards ecological sustainability.

At the epistemological level, science and research are distinct (Latour, 2009), and questions arise regarding the validity and status of the assembled experience and new knowledge produced in the framework of participatory action research (Billaud, 2003; Billaud et al., 2017). Should such research begin with a multidisciplinary input entailing researchers meeting with a group of actors and developing a project with them, or should the opposite path be followed? Is it necessary to prioritise representativeness in the choice of stakeholders or their involvement in action in the field? How can we mobilise research in the medium-term to long-term? There are many challenges to overcome, which are often double constraints (Bateson, 1980). Which questions should be prioritised, since 'if there is no question, there can be no scientific knowledge' (Bachelard, 1999)?

In the face of such questions, with the objective of developing sustainable viticulture and, more broadly, sustainable agriculture, we propose the adoption of participatory approaches involving input from different communities, including growers and researchers from the natural, social, and human sciences to produce knowledge of different epistemological status. Aiming to develop participatory-action-research that defies the above-outlined constraints, since 2013, we have been engaged with a network of stakeholders of a wine-growing area around the commune of Westhalten (France). Together, we have developed a participatory research-action method based on a collective mobilisation of diverse actors (farmers, elected officials, advisers, researchers, consumer NGOs, nature protectionists, the public) carrying dissensus while collaborating to solve local problems that has since been labelled 'REPERE' by the Ministry of Ecology, Sustainable Development and Energy (Moneyron et al., 2017). The REPERE method aims to demonstrate the potential to achieve agricultural sustainability through a bottom-up approach, whereby embracing varying forms or knowledge is critical to achieve the co-construction of innovation and collective commitment, and social, historical and cultural dimensions are founding elements in the development of the reasoning of the actors, the achievements, and the image. This approach also recognises constraints to change as well as the resources to produce the expected changes. Relying on a specific epistemological framework that we collaboratively developed, this method enabled us to define consensus questions, leading to concrete results in the form of scientific publications and films as well as changes in practices in the vineyards. Thus, as documented in previous studies (Moneyron et al., 2017), participating winegrowers have abandoned the use of herbicides on 80 hectares of land and introduced grassing (i.e. covering the inter-row surface with an herbaceous crop to maintain soil structure and organic content and reduce erosion) based on local wild species on 37 of the 200 hectares they cultivate. These areas are in continuous expansion, which has laid the groundwork for a major shift in thinking towards more sustainable viticulture. As this article demonstrates, the participatory-action-research has led involved actors at all levels to identify the 'black holes' in their respective knowledges, and especially the gaps between their knowledges (Morin, 2000). They then became involved in building partial consensus on specific questions dealing with vine health and experiments to address those questions in their vineyards and research laboratories.

The remainder of the article is structured as follows. Following an overview of the methods, the next section encompasses three parts that describe the process of negotiating among varying knowledge paths to achieving consensus concerning directions toward change and elucidating constraints to change based on current conditions. This is followed by a section comprised of three additional parts that, respectively, reflect upon the process of (i) conceiving new questions, addressing emerging constraints, (ii) developing inter-relationships between actors and across disciplines, and (iii) ultimately validating these collaborative efforts through the production of a peer-reviewed article in a scientific publication. The final section describes a model that illustrates how this participatory action project negotiated between and mobilised different types of knowledge and training along with their modes of construction and associated reasoning.

Methods

Actors. This participatory research project involved a range of actors, encompassing winegrowers, nature conservation associations, councillors, village inhabitants, mayors, and researchers. Winegrowers included those using conventional, organic, or biodynamic agricultural practices; they sold their grapes via a winery or market their bottled wines for sale to the communes of Westhalten (WES) and Dambach-La-Ville (DLV) in France, as well as Tüllinger Berg (TUL, Germany) and Muttenz (MUT, Switzerland). Nature conservation NGOs included organisations located in WES, DLV, and TUL. In addition, the project involved members of local governments, including mayors (WES, DLV, TUL), institutes in charge of environmental protection at TUL, advisors for water agencies and viticulture-agronomy (WES, DLV, TUL, MUT), and actors in agricultural and viticulture training (WES, TUL, MUT). Researchers in education and training sciences, epistemology, agronomy, vine molecular physiology, weed science, and soil microbiology were progressively mobilised as the projects developed, and private companies specialising in seed production, the sale of vine health products, or metabolic analyses also contributed to the projects. All participants were informed of the purpose of the study and gave their consent to participate in the project, be interviewed, filmed, and audio-recorded, and have their excerpts published.

Workshops. Overall, around 100 meetings attended by a total of around 1000 people on a tri-national scale were held in the form of collective discussions on viticulture practices and vine health as well as visits to vineyards experimental trials (zero herbicide viticulture, grassing using wild seeds with local plant labels). Other workshops were also held for the co-construction of research questions and consensus statements. Research question construction relied on individual work in which each person expressed and re-transcribed the issues and difficulties that he or she faced during his or her personal or professional life. The hierarchy of difficulty was illustrated according to the colours of the rainbow with red representing the most challenging issues. Next, in a plenary session, each person had to explain his or her choices. The researchers then assembled the different coloured-cards according to theme. Interestingly it happened that green and red cards were used for the same theme, which suggested to the group that there was already experience to value (green cards) for answering the red cards (Moneyron et al., 2017).

Seven consensus questions on the influence of viticulture practices on vine health were addressed during the consensus statement construction workshop (Soustre-Gacougnolle et al., 2018). Training sessions were conducted from 2014 to 2016 to ensure that everyone understood the nature of the experiments that would be conducted and the type of data that would be collected. For example, participants learned how to crush vine leaves in liquid nitrogen, extract ribonucleic acids (RNA), perform transcriptomic molecular analyses and interpret the results, as well as receiving instruction in secondary metabolites extraction and how to use gas chromatography followed by mass spectrometry (GC–MS) to characterise them. We visited the vineyards to assess soil quality, to carry out spade tests, and estimate vine vigour as well as disease pressure levels. All participants obtained training in biometrics and statistics. Depending on the topic, researchers, winegrowers, NGO members, or advisers were alternately learners and trainers in

Fig. 1 Synthesis of the responses of all stakeholders involved in the workshop for the vintages 2014–2016. Forty-two people were mixed and divided into three tables, each of which related to a different year's vintage. Participants engaged in debate with consideration for quantitative and qualitative data, starting with climate conditions, and laid the corresponding cards (thermometer and rain drops) on the panels for spring and summer. In the same manner, taking under consideration the researchers' biochemical and molecular analysis as well as observations and experiential knowledge from winegrowers and advisors, cards illustrating vine vigour (grapevine arm), vine defence activity (DNA molecule), secondary defence metabolites (flavonols), vine diseases (fungus when evaluated by winegrowers, and fungus with DNA molecule font when evaluated by molecular analysis) were laid on the panel, with brown and blue representing biodynamic and conventional practices, respectively. The different vine developmental stages ranging from budding in spring to ripeness in winter are illustrated on the *x* axis, and the intensity of values is arranged from low to high on the *y* axis.

the laboratories and/or the vineyards. To illustrate data, we used images with a blue background for vines grown in conventional practices and a brown for bio/biodynamics (Fig. 1).

During the period 2014–2016, workshops covered vineyard climate, vine plant development and health status (i.e. presence of downy mildew, powdery mildew, and five major vine viruses), and the activity of natural defences based on data collected during the three seasons. Each workshop table had a 2.5×1 m paper support with the different phenological stages of the vine during the year positioned on the abscissa and a scale of values (low–medium–high) on the ordinate. On 29 March 2018, a workshop was held for graphics construction, during which the graphics were projected in real time, made visible to the other tables, and used for intra- and inter-tables discussions and debates. The scientific article was written after this workshop and published in November 2018 (Soustre-Gacougnolle et al., 2018).

Data collection. All workshop discussions were filmed and audio-recorded. We also conducted open individual interviews on life-path and experience-building with 20 winegrowers at each place: Westhalten in 2014–2019 and Dambach-La-Ville, Muttenz, and Tullinger-Berg in 2018–2019. An interview focusing on vine health and viticulture practices was carried out at Westhalten in 2019.

A path to actionable knowledge

From experience paths to consensus statements (2014–2018). Our work with the winegrowers and scientists began with facilitating workshops on vine health and pesticides usage. During these workshops, three categories of stakeholders debated measures to ensure vine health: (1) conventional winegrowers, whose strategy was to control fungal diseases, viruses, and insects using synthetic pesticides, (2) winegrowers using organic or biodynamic practices, whereby the latter was believed to stimulate vine defences; and (3) researchers, who were accustomed to conducting their experiments in laboratories. The conclusions of each of the first two groups of actors were based on convictions and assertions, which are not acknowledged as scientific proofs, whereas members of the third group were challenged by the difficult problem of moving from conclusions obtained in a restricted and artificial environment (the laboratory and greenhouses) to recommendations that were applicable to the much more complex reality of the vineyards.

Although the winegrowers shared common paths to knowledge, i.e., knowledge based on personal beliefs or experiences, they often became embroiled in often heated debates regarding the most effective viticultural approaches and techniques. Thus, when one biodynamic winegrower argued that he 'stimulates the natural defences of the vine with a global approach, from the soil to the air,' conventional winegrowers retorted that he had no proof of this. At the same time, when the conventional winegrowers claimed that 'they protect the vines from diseases,' the biodynamic winegrowers argued that 'No, you are fighting against the diseases! It's very different; and it's not unlikely that the vine's defences will be weakened after all these chemical pesticides.' Nonetheless, a minimal consensus persisted between the two groups based on their common status as wine producers. For example, when we addressed the issue of the use of pesticides to control vine diseases, both groups of growers agreed that it was necessary to reduce the negative impacts on human health and the environment but firmly asserted that 'we have already done everything possible to use as little pesticide as possible.' During the same workshop, one winegrower asserted: 'In any case, you researchers, you study vine defences in your laboratories; you don't know what really happens in the field.' Indeed, as indicated above, the promising effects of natural stimulators of plant defences evinced in laboratories or greenhouses have not been demonstrated to sufficiently lower the quantities of pesticides when used in vineyards (Delaunois et al., 2014). Thus, the three categories of actors actually relied on differing evidence registers.

With the data accumulated over the years 2014–2016, we organised a workshop with 42 individuals, including 19 invitees external to the project. Participants were mixed and divided into three tables, each of which contained data for a different year's vintage. As one of the invited winemakers stated, 'When I arrived and saw all this, I understood that we were here to work.' We chose to begin the workshop with a study of the weather conditions that had prevailed during each of the three growing periods, which facilitated the involvement of all participants, and valuing both quantitative and qualitative criteria built a broad legitimacy. In the same manner, taking under consideration the researchers' biochemical and molecular analysis as well as observations and experiential knowledge from winegrowers and advisors, cards illustrating vine vigour (grapevine arm), vine defence activity (DNA molecule), secondary defence metabolites (flavonols), vine diseases (fungus when evaluated by winegrowers, and fungus with DNA molecule font when evaluated by molecular analysis) were laid on the panel, with brown and blue representing biodynamic and conventional practices, respectively. Each workshop table had a 2.5×1 m paper support, with the different phenological stages of the vine during the year positioned on the abscissa, and a scale of values (low–medium–high) on the ordinate (Fig. 1) The positioning of each image was a subject of debate, which enabled the expression of people's feelings and opinions and the emergence and acknowledgement of differences in their representations of the climate. Ultimately, the reality of the weather data and the numeric values forced participants to take all factors into account while being precise about the conclusions drawn by the collective, and participants finally reached a consensus for laying out the images illustrating rain and temperature (Fig. 1). Thus, during this first stage, all players were involved in drafting the rules of interaction, including the transcription of experiential knowledge and learning how to build agreement amidst dissension. During the workshop on vine health, levels of plant infection, and biochemical and molecular data on vine defence systems as well as winegrowers' assessments of disease symptoms in the vineyards and the intensity of leaves' greenness were discussed before laying out the corresponding images (Fig. 1). When all the data were obtained for the consensus questions of the project on vine health, we favoured the same input as for the meteorological data, proposing to the participants to explain how each had made their observations and obtained results. In this way, we again legitimised both the qualitative and quantitative dimensions of participants' experiences. These discussions evinced the difficulties that everyone, whether winegrowers, advisers, or researchers, had to overcome in order to produce useful data, and a better understanding of each other's' work emerged. This work also brought into play the categories of actors involved in the project, external to the community, who were intentionally invited. That said, two subcategories among the winegrowers were further clarified, with a particular differentiation emerging between those using biodynamic practices from those who preferred conventional practices, as well as from organic growers to a lesser extent. Statements such as 'If there are fewer pesticide sprayings, then the level of defences is higher' vs. 'Conventional has less active defence genes because there is less need for them' illustrated the debates argued between the tables. However, at the same time these categories were distinguished, the illustrations that we provided allowed them to interact, then to go back over their discourse and, despite their contention, to build a partial consensus, which was often reflected in identical or very similar positioning of the blue and brown-font pictures on the full panel (Fig. 1, 2014–2016). Inductive interpretations were immediately proposed and discussed among participants, requiring coordinators to engage in continuous and vigilant reorganisation of the workshop.

For the years 2014–2016, the complete figure for each vintage suggested that vine defences reached higher levels in disease-free biodynamically grown vine leaves and a stronger differential response under climate-related stress, compared with conventionally grown ones. In the presence of diseases, plant defence levels also reached higher levels in biodynamically grown vine leaves (Fig. 1, 2014–2016). By the end of the meeting, the collective of 42 people prioritised a consensus statement: the level of defences is higher in biodynamically grown vine leaves (Soustre-Gacougnolle et al., 2018).

Revealing constraints to changing practices. Wine growers ranked disease symptoms in 2016 as 'very strong' and positioned them beyond the maximum on the *y*-axis (Fig. 1, 2016). In contrast, molecular analyses by researchers suggested low levels of downy mildew and powdery mildew infections (Fig. 1, 2016). Despite these diverging assessments, it is remarkable that the scientists' results implicitly remained a point of reference. Winegrowers went back on their discourse, concluding that the disease pressure depicted in the image was due not only to the observed symptoms but also to the influence of information and training organisations, the Chamber of Agriculture, the wine council, press articles, and their neighbours. Winegrowers who spray pesticides faced pressure from the other direction in the form of a public that is increasingly clamouring for more environmentally friendly practices; for example, if hikers or other passers—by who are external to the viticulture community observe pesticide spraying, then the winegrower risks being criticised or reported via phone calls to the police, the village major, or NGO representatives. However, as a number of winegrowers expressed, 'When you see your neighbours spraying pesticides, you say to yourself: I have to go too; everyone said there would be a lot of disease!' This discussion showed that the growers' rather static definition of vine health and their associated management decisions was the result of complex interactions that extended beyond simple biological fact to encompass social realities. Another winegrower argued that 'the pressure is not the quantity of disease, it's the stress in relation to it.' At the end of the debate, the winegrowers referred to years of similar climatic conditions and concluded that climate disruption had the greatest impact. Thus, when subjected to the double test of social critics and climate change, reacting to adversity is no longer effective: 'With these climate changes, we have situations that have never happened, I don't see how we can anticipate.' Winegrowers' knowledge and experience, as well as their reasoning, are losing their prevalence. The unfortunate consequence is that spraying with pesticides has since increased.

A relationship to life forms in which waging war is the only way of thinking. Vine diseases were omnipresent in the discourse. Experienced as a constraint, they served as a unique prism of reflection. The continuous resurgence of this issue in the workshop blurred the debate and generated a regression of collective reflection, regressing everyone to their standard reasoning, like a rubber band that has reached its limits. Common assertions resurfaced, such as 'yes, but biodynamic vines have higher levels of defences because they have more diseases; they are poorly protected,' and 'these vines are not healthy, they are pale green.' In response, the researchers again demonstrated that defences levels were highest in biodynamically grown plants, even in disease-free conditions, and they explained that although there was little difference in chlorophyll-associated green colour between practices, the light green colour of biodynamically grown vine leaves was the result of the attenuation by yellow pigments called flavonols, which contribute to the vine's defences against climatic disturbances or vine diseases (Soustre-Gacougnolle et al., 2018). Iteratively reintegrated into the discourse, the new knowledge invalidated the assertions that fed the dissent and rejected the recurrence of vagueness and the unique thought framework and subjectivity prevailing in viticulture, because each group member recognised the knowledge they had contributed to build.

New questions, transnationality and transdisciplinarity

From consensus statements to new questions. Following the production of the first consensus statement, debates were characterised by inductive reasoning entries, such as hypothesising a role for the horn silica preparation, a finely ground crystal quartz that is dynamised in water before spraying (Biodynamic Federation, 2020; Fauteux et al., 2006), or proposing to search for a causality for an observation without being able to fix an idea, which undermined efforts toward a holistic approach. An agronomy researcher brought the collective back to the initial holistic vision of the project by explaining how system-trials are conducted in agronomy and elucidating the strengths of this approach. His explanations calmed and consolidated the collective, which abandoned the search for causality for other priorities. Debates developed further through questions such as 'if the vine has more active natural defence systems, do they drop at some point?', 'in spring, in the young bud, is it already like that?', 'but then if we change viticulture practices, when does it change, this level of defences in our vines?' and 'the vines, do they know that they are biodynamic?' Gradually, a consensus was built on a new question about temporality. At the same time, the collective again revealed a black hole of knowledge for winegrowers and researchers alike. Indeed, the researchers lacked scientific knowledge on the temporality of changes in the regulation of vine defences from one year to the next and when practices change. In the search for scientific publications, we hypothesised that pre-immunisation, whereby vines could be pretreated with inducing agents that stimulate genetic defence responses to form chemical or physical barriers against the invasion of pathogens (Kothari and Patel, 2004), could resolve or at least partly address our newly raised question. Indeed, pre-immunisation was found to promote faster responses against climate-related stresses and diseases. Results suggested that through the production of small interfering RNAs (siRNAs), which combine with proteins to attack viral RNAs and provide protections against environmental perturbations, pre-immunisation results in epigenetic changes that serve as 'memories' imprinted on plants' genomes (Crisp et al., 2016), as in the case of poplars or rice in response to water stress (Raj et al., 2011; Garg et al., 2015). However, this topic continues to be intensely debated in the scientific community (Pecinka and Mittelsten-Scheid, 2012), and nothing concerning grapevines has been identified to date.

Emergence of new constraints and mobilisation of new actors. While this new line of questioning was being constructed, new constraints were revealed, as it had been the case formerly on the development of herbicide-free viticulture, and on the development of grassing from wild-plant seeds (also see Moneyron et al., 2017). The question about temporality required studying the vines in the course of the changing practices time-period. However, the Westhalten winegrowers had all been engaged in conventional or biodynamic viticulture practices for more than 15 years.

At this point, winegrowers from Dambach-La-Ville who had been invited to the workshop announced they were thinking about changing from conventional to organic and biodynamic methods and asked to join the project, as the participatory action research being conducted in Westhalten had inspired them to commit to change now. Their mobilisation was impacted by a concomitant consideration of the social and technical/biological dimensions of network formation, which is described as the art of *interessement* actor-network theory (Akrich et al., 2006; Callon, 1986). Subsequent developments showed that this *interessement* made it possible not only to examine the question of temporality, but also triggered new reactions among the original Westhalten group, who appeared to want to 'reclaim control' of what was originally their project. Even as these newly mobilised actors provided a solution to the issue of temporality, in the following months, the original participants reacted by announcing that they too would shift from conventional viticulture to organic and biodynamic practices on complete vineyard estates, a large part of their estates, or plots and even considered implementing a 100% biocontrol solution. Thus, practices were changed on a third of the plots on the French side, and the project thus expanded from 14 plots on one site to 33 plots on two sites (Fig. 2). This reorganisation of the actors around a changing project was based on interdisciplinary knowledge in a space–time that structured reflexivity, itself an initiator of mobilisation.

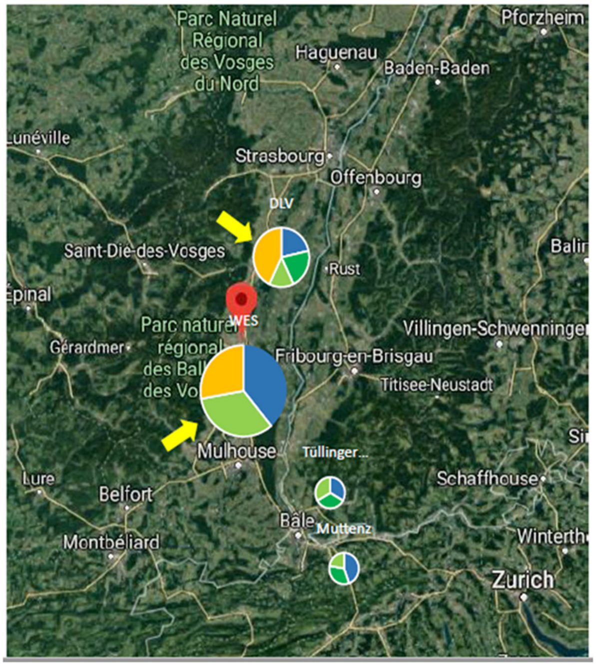

Fig. 2 The 49 vineyard plots involved in the Vine health trinational project. The number of vine plots involved in the trinational project on wine health are represented at scale with 19, 14, 8, and 8 plots in Westhalten (WES, France), Dambach La Ville (France), Tullinger Berg (TUL, Germany), and Muttenz (MUT, Switzerland), respectively. Blue, dark green, and light green represent conventional, organic, and biodynamic practices, respectively. In Westhalten and Dambach La Ville, pictures resembled those at Muttenz and Tullinger Berg, at the beginning of the project with 13 plots in Westhalten and nine in Dambach la Ville. As a result of the participatory action research, the number of vine plots increased to 33 in these two places and some winegrowers shifted from conventional to either organic, biodynamic, or 100% biocontrol practices in 2018–2019, as illustrated in orange.

From a situated participatory-action-research project to interrelationships at a trinational scale. What began as a group project centred in Westhalten in 2013 became within 6 years a network of projects in France, Germany (Tullinger-Berg) and Switzerland (Muttenz) mobilising 92 actors in four groups united by their commitment to the same participatory-action-research method. Among these groups, some winegrowers committed their plots to the current viticulture practice-change project, thus bringing the network of studies on the influence of viticulture practices on vine health to 50 plots across three countries (Fig. 2). As new questions emerged, the trinational groups progressively solicited the involvement of diverse scientific disciplines in the humanities as well as agronomy. A project on grassing using local wild plants from a Natura 2000 protected area mobilised botanists and phytosociology experts in Westhalten, and a project on

Fig. 3 The tetrahedron model illustrates the different types of knowledge and training, their modes of construction and the reasoning associated with them. Summit 1 comprises hetero-training (others teach us), whereby knowledge is developed from research based on hypothetical-deductive reasoning. The second summit illustrates the entries related to the environment, i.e., eco-training (I build knowledge and I learn with and from the environment). The third summit concretises the learning and content resulting from personal reflection, i.e., the self-training (I learn by thinking on my own). The fourth summit represents collectively produced knowledge and is associated to all different forms of reasoning in play (we learn from and with others). (modified from Moneyron et al., 2017).

disease-resistant vine varieties requiring lower pesticides usage involved plant physiologists and plant geneticists in Muttenz, and a project on the influence of viticulture practices on soils and the resilience of vines to water stress due to climatic disturbances invited soil scientists and soil microbiologists to Dambach-La-Ville. A project in the Tullinger-Berg studying the interactions between protected and cultivated areas in relation to viticulture practices is currently calling upon scientists in ecology and socioeconomics, among others. These four projects all aim to develop a more sustainable viticulture and are committed to developing further on hundreds of hectares on a trinational scale, thus illustrating the construction of what Audoux and Gilet (2011) referred to a shared-world between habitats, cultivated areas, and protected natural areas being built on the premise of a vision of sustainable development on a large scale.

The summit model: relationships between actors and between disciplines that are renewed

In support of this participatory-action-research, we developed a tetrahedron model that illustrates the different types of knowledge and training, their modes of construction and the reasoning associated with them (Fig. 3). Summit 1 comprises heterotraining (others teach us), whereby knowledge is developed from research based on hypothetical-deductive reasoning. A second summit illustrates the entries related to the environment, i.e., eco-training (I build knowledge and I learn with and from the environment). A third summit concretises the learning and content resulting from personal reflection, i.e., the self-training (I learn by thinking on my own) (Legroux, 1989; Pineau, 1989, 2003; Moneyron et al., 2017). Finally, during the participatory action research project, hidden constraints were transcribed into new questions, an agreement on their prioritisation was built, and all participants were involved in resolving these questions and producing data. Thus, at the end of the workshop that led to the consensus statement, a fourth summit representing collectively produced knowledge and its associated reasoning and training modes became concrete (Fig. 3).

Our experience suggests that activating links between these four summits resolves questions of legitimacy and epistemological status through interdisciplinary scientific collaboration. The acknowledgement of the consensus statement in the form of a published scientific article (see Soustre-Gacougnolle et al., 2018) led to long-awaited recognition by the scientific community, thereby evincing the ability of participatory action research to produce knowledge capable of feeding the hypothetico-deductive system, and formalising a return to the first summit. That said, the tensegrity (related tensions) between these four summits was constantly in flux due to the ongoing interactions between the actors and their networks amidst newly emerging issues and the prevalence of their forms of reasoning. The setting of new questions and the implementation of adapted training courses valued this tensegrity even as it resolved it. Thus, actors on their own, as well as the group, were brought back to the barycentre of the model. In response to this tensegrity, all of the involved actors reorganised their thinking and reasoning as if these interactions were shaping and transforming them (the allosteric model, Giordan, 1994, 1997).

The advances accruing of such research are therefore not solely engendered by their biological or social results, but rather by 'the reflexive nature of their enunciation' (Barthes, 1984). As one winegrower at the 2018-workshop stated, 'It's not decreed from above, and it gives us the opportunity to ask the right questions.' Reflexivity is therefore a question of imagining an exit from this system of constraints, while also offering an expression to those who wish to be actors in the innovations of their practices (Prost et al., 2012). Viewed as a constraint at the beginning of the project, complexity has evolved into resource. The progressive diversification of the actors involved, from winegrowers to elected officials and site neighbours to new researchers, contributed to address enhancing complexity, as well as implementing changes in the field in real time, although this final stage is reputed to be the most difficult. Scientific disciplines, which are specialised out of a need for excellence, are wary of taking into account entirety and complexity. Herein, we show that it is possible for the sciences to take on new roles in the generation and resolution of questions in the black holes of knowledge, in collaboration with other stakeholders. Thus, these disciplines can be transformed to engage in a functional transdisciplinarity and emerge in a renewed research format. Thus, this participatory action research brings to life Latour's (2009) 'parliament of things' by relying on an ethic of creating new ideas and contributes meeting the global challenges of sustainable development.

Data availability

All data generated or analysed during this study are included in this published article.

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Competing interests

The authors declare no competing interests.

Additional information

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