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Learning, reflexivity, decision-making, and behavioral change for sustainable viticulture associated with participatory action research

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Despite the abundance of compelling scientific knowledge about dramatic changes in climate, biodiversity and the environment, there is little change in human behavior. Do humans perceive and understand the gravity of the challenges at stake, or are they overwhelmed by adversity? The challenge may be in finding appropriate levers to involve stakeholders in a broader process of shared learning, while producing scientific knowledge, to overcome uncertainty, and achieving the expected collective action? In the field of viticulture, researchers, winegrowers, citizens and environmental associations have been involved in participatory action research projects, one located in Switzerland, one in Germany and two in France. All actors were involved, from the formulation of questions up to the production of knowledge, to address the issue of the negative impacts of viticulture on the environment and human health. Group workshops and individual interviews were conducted on each of the four sites, for a nine-year period. A collective workshop involving also actors outside the project was conducted, and followed by a trinational workshop bringing together actors from Swiss, German and French projects. The audio recordings and writings produced were transcribed. All texts were analyzed on the linguistic level, with textometric tools, while going back to the actors' initial quotes. Our results suggest that during the course of projects, more sustainable viticultural practices were designed, and implemented in the vineyard, on a large scale. Also, our analysis suggests that, in parallel to changes in viticulture practices, a new vocabulary, associated with different individual and collective reasoning, emerged in the discourse of the actors involved in projects. These major changes were associated with an inventiveness that developed within and beyond the groups. Because human reasoning changed in the context of participatory action research, we suggest that such a research format could address global issues, finally reaching awaited changes.

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Introduction

Humans have always lived in a world of uncertainties. Whereas the development of knowledge was purposed to allay future fears, increasing concerns about climate change, and more recently pandemics arose (Beck, 1986/1992; Callon et al., 2001). Indeed, our societies are faced with new problems involving "uncertain facts, contested values, high stakes, and urgent decision making" (Funtowicz and Ravetz, 1993). The public access to a mass of information, even disinformation, has almost put into question the legitimacy of research and scientific knowledge, which are now facing the rise of ultracrepidarianism and ipsedience (Hotez, 2021). Should we be more invested in the "knowledge of knowledge", i.e., how knowledge is produced as an escape from this constrained situation (Morin, 2014)? And, should this knowledge be produced exclusively by the research community and transmitted through standard training to society, following the deficit model (Callon, 1998, 1999)? However, the efficiency of this model to address the challenges of the 21st century is questionable, especially in cases regarding the environment, when the negative effects of the future of the biosphere are so dramatic (Springmann et al., 2018; IPCC Report 2021). Indeed, despite the alarming findings and the production of scientific knowledge, human behavior has remained relatively unchanged. Is there an issue in understanding human behavior in the face of adversity and beyond; or is it a question of seizing this challenge at the individual or group level, and ascertaining what levers should be used (Nielsen et al., 2021)? As far as the possible contributions of the sciences are concerned, the effort to be made concerns an increase in interdisciplinarity (Billaud, 2003). Although, it is unclear whether research institutes remain committed to issues of knowledge production (Schäpke et al., 2018; Irwin et al., 2018). Notably, did they consider the complexity of the social dimensions? Thus, has the knowledge produced been translated into action, and transformed the industrial, agricultural, and food systems, at the expected scales of space and temporality? Did economic, social, sometimes ecological, and often political levers not encumbered all hope? Thus, conventional agricultural practices, especially viticulture, adversely impact the environment and human health (Wasley and Chaparro, 2015). Efforts by governments, chambers of agriculture and farm advisory boards, training, and research to develop more health-and environment-friendly practices have been ineffective, so far (Guichard et al., 2017). Even if the many double constraints (Bateson, 1980) act as barriers, why did behaviors remain unchanged?

Morin addressed this complexity by proposing an ecology of action (Morin, 2013, 2017). This relies on a constructivist epistemology that "helps to confront error, illusion, uncertainty and risk" (Morin, 2000). Addressing complexity needs raising questions to generate relevant knowledge (Bachelard, 2011). However, Kuhn (1990) argued that only researchers have the legitimacy to question and produce knowledge. Clearly, this restriction removed all legitimacy from other forms of knowledge, reasoning, and commitment, and from actors, other than researchers. Yet, perhaps it is rather a matter of resolving the question of action in a situation of uncertainty (Callon et al., 2001), by involving the experience and rationality of actors other than those of the scientific community to form an "issue-driven" approach (Funtowicz and Ravetz, 1993) and inventing forms of collective mobilization.

Participatory sciences initiate a form of openness and have been developed to address global challenges (Billaud et al., 2017). Participatory projects emphasize society's willingness to engage in research and action (Resnik et al., 2015; Billaud et al., 2017; Burgess et al., 2017). Despite criticism of this method (Graur, 2007; Filipe et al., 2017), advances have been made, particularly on environmental issues (Mapfumo et al., 2013; Méndez et al., 2017), and the format has proved instrumental in advancing democracies (Latour, 2009). However, few of these participatory science projects provided hybrid collectives with the legitimacy to make inquiries and let them alone construct scientific knowledge from the data (Prost et al., 2012).

We implemented a participatory community project using a bottom-up model. We mobilized conventional, organic, and biodynamic winegrowers, environmental associations, elected officials, neighbors, and researchers in human sciences and agronomy-biology, to collective knowledge production. Despite their strong dissensus on the vision of viticulture and the environment, they developed a form of "participatory sciences" labeled "REPERE" Participatory Action Research (PAR; Moneyron et al., 2017). These stakeholders were heavily involved in the study, from the co-construction of questions to the production of a consensus statement, from collectively produced experimental data. This continued until the production of articles submitted for validation as scientific knowledge in agronomic and biological sciences (Soustre-Gacougnolle et al., 2018) and the humanities (Masson et al., 2021).

Viticulture is based on the strict use of emblematic grape varieties. These plants produce grapes for quality wines only after approximately 10 years of cultivation. Furthermore, they face recurrent fungal diseases that are now exacerbated by climate disruption that forces the use of even more pesticides than 15 years ago. Those pesticides are currently used in over 85% of the cultivated 8 million hectares, globally. However, despite a system of multiple constraints, winegrowers changed significantly their practices, as a consequence of the PAR projects. Winegrowers who practiced conventional viticulture have committed themselves to organic or biodynamic approaches, abandoned herbicides, greened their vineyards, and even profoundly rethought their practices. These viticulture practices have been applied to large areas, in conjunction with existing viticulture models (Masson et al., 2021; Henaux and Masson, 2021; Fig. 1). Although practices have changed little at the global level, the major changes illustrated in this study testify to a capacity to act in situations of uncertainty, and beyond constraints, among winegrowers engaged in PAR. The scientific register and an adapted epistemological framework developed with the transdisciplinary approach (Popa et al., 2015; Moneyron et al., 2017; Masson et al., 2021) have made it possible to consider the social register through mobilization. Thus, complexity was no longer an obstacle but became a lever. Beyond changes implemented in the vines, can the actors analyze the production of knowledge to identify "double constraints", in addition to other opportunities, to act in situations of modified uncertainty? Has there been reflexivity and cognitive changes among the actors involved in this PAR? In this study, 92 actors were involved in four international group projects over 7 years (Henaux and Masson, 2021; Fig. 1). We analyzed the discourses of the winegrowers involved in the projects with textometric tools, and conclusions were reinforced after come-back to initial texts. We present a synchronic analysis of discourses revealing local problematics and reasoning distinguishing the four groups. A diachronic analysis revealed changes in discourses and reasoning over time in the most long-term engaged group. We further analyzed the role of language in the development of ideas and changes in reasoning until an unexcepted inventiveness. Overall, our data highlighted a "reflection-in-action" and original cognition (Schön, 1994), suggesting that the epistemological and philosophical framework of PAR presided over profound changes in discourse and forms of reasoning that led winegrowers to act in situations of uncertainty. Consequently, they invented and developed new projects sequentially,

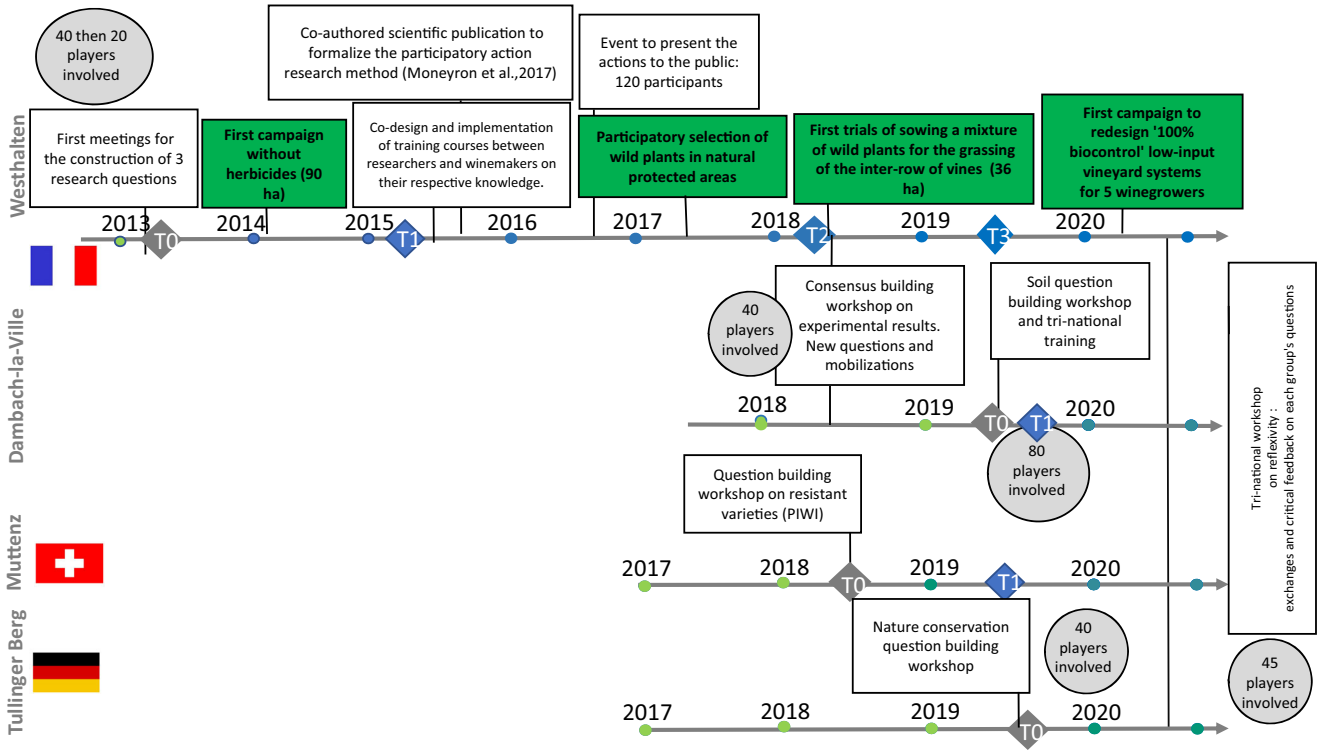

Fig. 1 Representation of the key stages of the four participatory action research projects. The actions and events, in addition to the main productions, were presented for the four project groups on a time scale. (T0) represents the moments of the workshops, and (T1–T3) represents the interviews during which the word corpora were produced. The number of actors involved at the beginning and in 2021 is in brackets (shaded circles). Workshops leading to data synthesis and article co-writing are shown in shaded rectangles. For the WES group: agronomic actions and changes in the field are shown in green rectangles, and areas committed at the beginning and in 2021 are in parentheses for a collective that cultivates a total of 200 ha. For the trinational workshop, 90 people were registered and COVID rules were forced to reduce to 40.

and in a short time frame, mobilized new researchers, in addition to diverse actors from society, and proposed responses to global environmental issues.

Methods

The four REPERE groups predominantly consisted of winegrowers who harvest and/or produce wine with conventional, organic, and biodynamic practices, but also of researchers, associations, technical advisors, local elected officials and residents. The constitution of these four collectives differed each time. The Westhalten collective (France) was formed following the end of a technological evaluation project at INRA in Colmar between 2003 and 2010—a Local Monitoring Committee project (LMC et al., 2010)—and the meeting of Westhalten winegrowers, through the Westhalten winegrowers' union. This collective was constituted as an Economic and Environmental Interest Group (GIEE)—the GIEE of Westhalten—in 2015, GIEE labeled "REPERE" in 2017 within the framework of the Network of Exchange and Project on the Steering of Research and Expertise (REPERE) program of the Ministry of Ecological and Solidarity Transition, and then as an association called VITIREPERE in 2021 (Henaux and Masson, 2021). In addition, the winegrowers of Dambach-La-Ville (France) wished to form a REPERE collective following the request of winegrowers of Dambach-La-Ville in transition from conventional to organic and biodynamic viticulture who had attended the RAP REPERE meeting around the transcriptomic data of the "Health of the Wine" on March 29, 2018. The Muttenz (Switzerland) and Tüllinger Berg (Germany) collectives were formed, respectively in 2018 and 2019 in the framework of the AgroForm project of the European INTERREG program. The 'control group' consisted of 14 French winegrowers (not involved in PAR projects), growing their vines in either conventional, organic or biodynamic practices and interviewed in 2021.

Participation formats in REPERE projects. During different stages of the REPERE projects (see stages 1–3 and 7; see below), we recorded the conversations and retained only the winegrowers' speeches: for Westhalten (WES), the workshops occurred in 2014 (WEST0), followed by three rounds of interviews in 2015 (WEST1), 2018 (WEST2), and 2019 (WEST3). Regarding Dambach-La-Ville (DLV), the workshops occurred in 2019 (DLVT0) followed by a round of interviews a few months later. For Muttenz (MUT), the workshops were held in 2018 (MUTT0) followed by a series of interviews in 2019. Regarding Tüllinger Berg winegrowers, the workshops were held in 2019 (TULT0). The collective workshops were similarly designed according to an approach that crosses collective project management and life stories (Delbecq et al., 1975; Pineau, 1983; Moneyron et al., 2017). In practice, this RAP REPERE translates—as detailed in Moneyron et al. (2017) and Masson et al. (2021)—into a set of methodological devices: (1) a first workshop in which, with the help of seven colored cards, participants wrote problematic situations, classified these situations by order of importance (on the red cards are noted the themes that seem most important to them) and publicly argued their prioritization; (2) a second workshop devoted to the selection of one or more themes from a schema-balance sheet of the themes addressed in the previous workshop that was designed beforehand by the facilitator-researchers; (3) a series of individual open interviews explored the interests of the winegrowers on an individual basis—the individual interviews began with an "entry point" (e.g., winegrowing practices, problems encountered during the vintage, data sharing)

and subsequently opened up to their professional and life paths; (4) a third meeting that used the tripolar model to show the participants different sources of knowledge and thus arrived at a situation of reflexivity and produced a consensus question; (5) organization of ad hoc training following the needs expressed in the different workshops and interviews (spade test trainings, lab training); (6) a 2018' PAR workshop on the vine defense in biodynamic and conventional vine management (Soustre-Gacougnolle et al., 2018; Masson et al. 2021); and (7) a series of data restitution interviews (it is the same format as previous semi-directive interview, but the entry point of the interview is the scientific result—in our case, it was the principal component analysis (PCA) representation of silencing and defense genes' transcripts level of the winegrower's plot in the Health of vine project).

Discourses. The discourses were captured on notes, cards, and reports made from audio recordings of group workshops (T0, except for the control group where there were only interviews) and individual interviews (T1, T2, and T3) of the four groups-REPERE (Table S1). To ensure the reliability of the reports, we performed a textometric analysis for three text corpora comprising respectively automatically transcribed interviews using speech recognition software and the corresponding interview reports. We found no differences in meaning at the thematic level (data not shown); therefore, we chose to study the reports made from the recordings of the workshops and the interviews.

The corpora. From these speeches, three corpora were created for our study: (i) a corpus was created of four scores (the notes, and color cards of the collective meetings of the group of WES, DLV, MUT, and TUL; Fig.1; Table 1); (ii) a corpus consisting of four scores (1) the minutes, notes, and color cards of the collective meetings of the WES group; (2) the minutes of the individual interviews of the WES group conducted in 2015; (3) the minutes of the individual interviews of the WES group conducted in 2018; (4) the minutes of the individual interviews of the WES group conducted in 2019; Table 2; Fig. 2); (iii) and a corpus consisting of two scores (the reports of interviews conducted for the WES project group in 2019 and the reports of interviews conducted with conventional, organic and biodynamic winegrowers in 2021, uninvolved in the PAR project). All texts have been processed to eliminate as many irrelevant terms as possible without changing the order of the original sentences in the reports (data not shown).

Example. Original sentence: "I did a BTS viti-oeno in Beaune, a BTS viti-oeno in Beaune, a BTS S at the beginning. I was registered to be an engineer; my father is deceased. I took over the vines in 2000." (36 words). After sentence editing, the lemmas are: "degree, winegrower, enology, Beaune, beginning, registered engineer, father deceased, took vines" (11 words).

Further details on text processing are in Supplementary File 1.

Data analysis

Textometric indices. Two indices were used to account for the lexical evolution of the four REPERE groups: the SI and the analysis of similarity (ADS). The SI is a statistical index calculated according to a hypergeometric law that identifies the asymmetries of linguistic forms between the partitions of a previously defined corpus (Lafon, 1980). According to Heiden et al. (2015): "The exact calculation of the specificity index used in TXM is that of calculating the probability of the event appearing as many times as it is actually observed in the partition or even more frequently up to the size of the partition" (Heiden et al., 2015, p. 130). The calculation of the SI can be summarized in two equations (Heiden et al., 2015, p.130):

$$\begin{aligned}\text{Probspécif}\left(\text{card}\left\{A \in V | A \in p\right\} = f\right) &= \frac{C_F^f \times C_{T-F}^{t-f}}{C_T^t} et[A]C_n^k \\ &= \frac{n!}{k!(n-k)!};\ n! = 1 \times 2 \times 3 \\ &\quad \times \ldots \times (n-1) \times n\end{aligned} \tag{1}$$

$$\text{Probspécif}\left(\text{card}\left\{A \in V | A \in p\right\} \geq f\,\text{obs}\right) = \sum_{f=f\,\text{obs}}^{\text{card}\left\{A \in V | A \in p\right\}} \text{Probspécif}\left(\text{card}\left\{A \in V | A \in p\right\} = f\right) \tag{2}$$

Equation (1) corresponds to "(...) the probability that a form A appears f times in a part p of size t, with the form appearing F times in total in the entire corpus whose total size is T occurrences"—[A] "is the number of samples of k elements among n elements or the number of parts of k elements in a set of n elements" our translation (Heiden et al., 2015, p.130).

Equation (2) corresponds to the equation for calculating the SI "(...) where A corresponds to the event identified; V corresponds to the set of possible events; p corresponds to the selected partition; f corresponds to the frequency of A in p (...) and f obs corresponds to the probability that A appears as many times as it is observed in" — our translation (Heiden et al., 2015, pp.129-130).

If the result of the comparison between the observed occurrence of the form and the theoretical occurrence of the form is above 0, the linguistic form is "overrepresented" or "overused." If the result of this comparison is below 0, the language form is "under-represented" or "under-used." For pragmatic issues, we considered only lemmas with SI over 3 as "overrepresented." Four SI classes were defined (3–4; 4–6; 6–10; >10). In addition, each of the partitions was subjected to similarity analysis by calculating the co-occurrence index (CI) represented by similarity graphs (maximum trees) according to graph theory (Degène and Vergès, 1973). In these similarity graphs, the thickness of the edges is proportional to the CI, and

Table 1 Word Specificity Indices in winegrowers' discourse at the project's start for the four groups.

	WES	DLV	MUT	TUL
Sup 10	spray			agriculture
6–10	grass		choice, PIWIS, variety	nature, social, landscape
4–6	observation	father, wine	sale	business, society, future, conservation
3–4	improvement, weed, plow, inner-row, all surface, hectare	passion, vintage, estate, day	cultivation, fungicide, label, customer, new, herbicide	development, viticulture

The calculations of SI (for the details of the calculations see the "Methods" section) were performed for word corpora collected during collective participatory action research workshops. These compared T0 stages for the four project sites of Westhalten (WES, France, 2014, words = 1125; DLV, France, 2019, words = 1543), Muttenz (MUT, Switzerland, Words = 1021), and the region around the Tüllinger Berg (TUL, Germany, words = 1328). SI was classified into four categories: between 3 and 4 included, between 4 and 6 included, between 6 and 10 included, and >10.

Table 2 Word Specificity Indices in winegrowers' discourse across the 7-year WES's project.

	T0	T1	T2	T3
Sup 10		hawkeed	product	practice, conventional
6–10	spray, grass	degree, work, father, training	spray, supplier	explain, winegrowers, wood
4–6	improvement	learn, question, wine, internship, enology, parent, day	necessary, reduce, silica, systemic, test, possible, leave	biodynamics, vigor, plot, graph, ellipse
3–4	erosion, evolution, remembrance	buy, friend, vision, school, problem	advice, example, bunch, horsetail, bordeaux, risk, chamber advisor, amendment, growth	

The SI (specificity Index) was calculated for the word corpora collected during individual interviews across the four successive stages of the Westhalten project (WEST0, in 2014, words = 1125; WEST1, in 2015, words = 6259; WEST2, in 2018, words = 3973 and WEST3, in 2019, words = 2892). SI was classified into four categories: between 3 and 4 included, between 4 and 6 included, between 6 and 10 included, and >10.

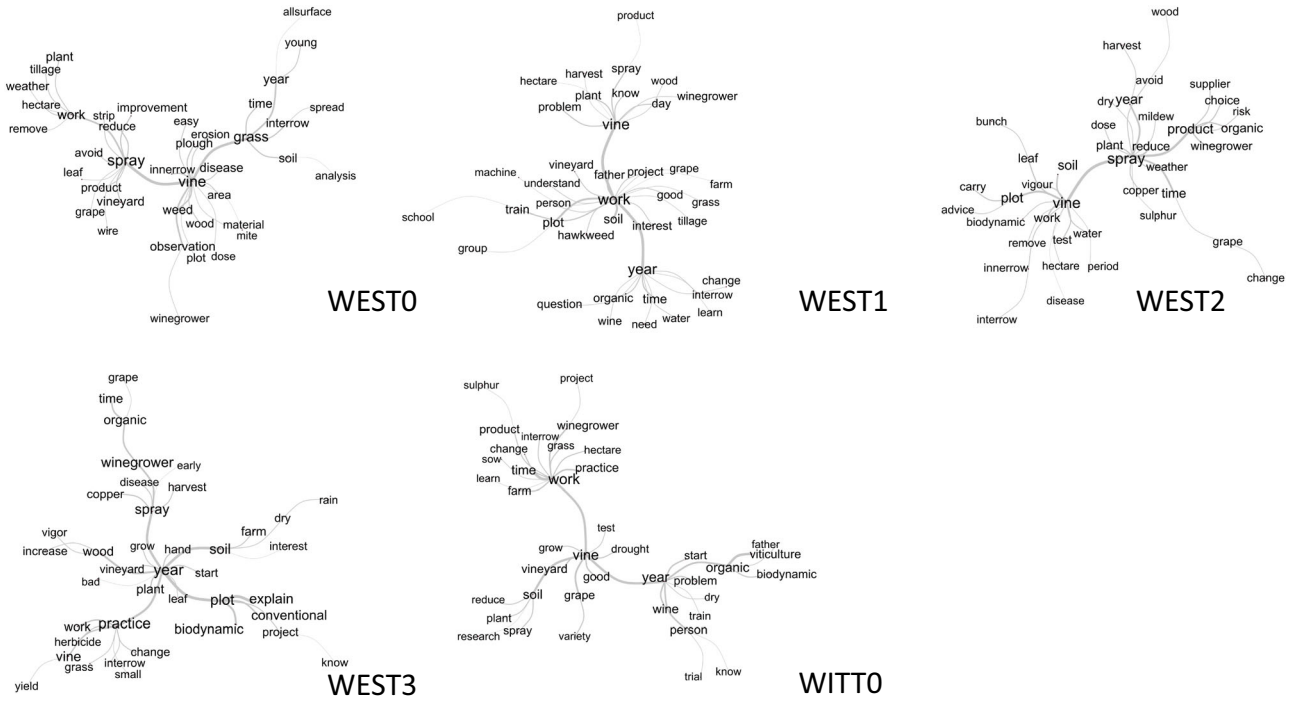

Fig. 2 Maximum trees of lemma similarity graphs for WES's project after 7-year-project and of witness group. The study was undertaken with iramuteq (www.irmauteq.fr) from the contents described in Tables 1–3 and S1, for the T0–T3 of WES and the T0 of WIT in France.

the size of the text of the vertices is proportional to its frequency. For practical and visual reasons, we selected only the first 40 lemmas of each text.

Softwares. For the calculation of SIs, the TXM textometry software (version 0.8.1) was used (Heiden et al., 2015). For the calculation and representation of co-occurrences, Iramuteq software (version 0.7 alpha 2) was used: Iramuteq is a structuring textometry software that segments the corpus and the submitted corpus partitions into Elementary Contextual Units (ECUs; 40 words by default; Table 3; Loubère and Ratinaud, 2014a). We used the "lemmatization" function for both of these programs. This function reduces several words into a linguistic unit (also called a lemma)—for example, the words "train," "trained," and "training" will be considered part of the lemma "train."

Method of analysis and interpretation. For each of the partitions of the different corpora, the reading and interpretation strategy is as follows: (1) the highest SI in a partition is identified; (2) the lexical community of the lemmas with the highest SI is observed. Subsequently, by returning to the text (concordance and reading of the original text) we explain what this lexical community refers to. In addition, we mention what the non-specific but strongly present lemmas refer to when putting into perspective the pedoclimatic and socioeconomic specificities of each group.

Results

To analyze stakeholder's reasoning and acknowledge the changes that occurred in the course of the PAR projects, we studied the discourses of winegrowers categorized into four groups (WES, Westhalten, and DLV, Dambach-La-Ville, in France; MUT, Muttenz, in Switzerland; TUL, Tüllinger Berg, in Germany). These groups were compared against winegrowers, not involved in the projects, from Alsace, and growing their vines in either conventional, organic, or biodynamic practices (WITT0 2021; see the "Methods" section), at the different stages of the projects. Two complementary textometric indices were used: the specificity index (SI) and the analysis of similarity (ADS; Leblanc, 2015). The first indicated the basic linguistic forms (or lemmas) specific to a part of the corpus for a defined corpus of texts. The second showed the association with the most frequent lemmas, which allowed us to consider the lexical community of lemmas-centralizing (the lexical community referred to the words associated with a central lemma as "lemma-centralizing").

Table 3 Word Specificity Indices in winegrowers' discourse in 2019 for WES's project and winegrowers not involved in PAR project.

	WEST 3	WITTO
Sup 10	plot, wood	
6–10	explain	wine
4–6	conventional, vigor, spray	viticulture
3–4	herbicide, cooper, ellipse, similar, farming	people, problem

Comparison of WEST 3 stage's with T0 of a control group of winegrowers not engaged in participatory action research projects (WITT0, 2021, words = 6391). SI were classified into four categories: between 3 and 4 included, between 4 and 6 included, between 6 and 10 included, and >10.

Synchronic analysis of discourses revealing local problematics and reasoning. Using textometry and reading the text of each minute, together with considering the colored cards produced in the workshops (Moneyron et al., 2017), we compared the discourses of the four groups, at the project start. At the level of the SI for T0 (Table 1), WEST0 and TULT0 groups both had SI lemmas greater than 10: "spray" and "agriculture", respectively. Within an SI range of 6–10, we found the lemmas "observation" for WEST0, "choice", "PIWIS", and "variety" for MUTT0; and "nature", "social", and "landscape" for TULT0. The first overused lemmas for DLVT0, "father" and "wine" appeared only in the SI interval between 4 and 6. Thus, SI suggested a strong difference in discourse for WEST0 and TULT0, when compared to MUTT0 and DLVT0 (Table 1). When using similarity graphs, lexical communities were highlighted around specific lemmas: For WEST0, around the lemmas "vine", "grass", "spray" and "work". For DLVT0, around "work" and "wine". For TULT0, around "work", "variety", "wine", and "vine". For MUTT0, around "work" and "agriculture." When analyzing the context of discourses from the group's workshops (WES), the two most specific lemmas referred to "treatments" and "weed control." The first was used with very different intentions, ranging from the desire to reducing pesticides usage "Decrease in treatment volumes. Try to better target treatments by zone", and the description of their use "I went through the treatment period without protection: without information and personal protection. We were told: there is no danger". Weed control is an issue specific to Alsace, and it is historically used as a means of combating soil erosion and degradation (Grégoire and Tournebize, 2004), for more effective viticulture practices. For example, the problem of competition for water against vines by grassing was addressed, with the idea of replacing the most commonly used grassing (Ray-Grass) with another, expected to be less aggressive "Drought follow-up: competition in water/grassing on rows; try it with local plants that are less greedy because rye in young plantations is too water-hungry". The use of this lemma also referred to the risk of mudslides on the Westhalten estate, during thunderstorms (Moneyron et al., 2017). Thus, data suggested the methods tackle local-specific issues. During the collective interviews with the DLV group, all winegrower's claimed soil was a priority issue and expressed their willingness to address it as a tight-knit collective. However, a word cloud analysis (data not shown) suggested that the most commonly used word was of a winegrower's name, which on its personal basis was promoting the soil issue "How to perpetuate our work tool, how to make the vine feel good and suffer as little as possible from drought, water management with a living soil?". This suggested "soil" was an unconscious collective choice. The textometric analysis supported this view by showing a low SI for "soil" and a lack of collective consensus in DLV. This was further illustrated in individual interviews, with frequent lemmas "father" and "wine". These two lemmas referred respectively to a source of knowledge and personal motivation "I could see from my father's work that bringing life back into our vineyards could only help them…", and to the representation of the quality of the wine, which is opposed to a vision of the winegrower devalued by the general public "The image that is given for our wines or alcohol makes me sick and makes our customers feeling guilty". To conclude for DLV, winegrowers' discourse is characterized by an idea of wine, terroir, and society. In Germany, at the Tüllinger Berg, the most specific lemma referred to relationships between agriculture and society "an uncertain future for agriculture due to the social pressure in the public of the notion of agriculture", or the notion of conservation of protected areas, "nature conservation versus agriculture". In addition, there is controversy, specific to Tüllinger Berg, posed by the cohabitation of protected and cultivated areas, and strong competition for prime residential land. In Muttenz, Switzerland (Kanton of Basel-Land), the most specific lemmas had a lower rank than those of WES and TUL. However, they referred to dilemmas about the cultivation of PIWIS, i.e., disease-resistant vine varieties (https://PIWIS-international.de). The group's enthusiasm for growing these varieties was evident "Good location of the farm, PIWIS cultivation is good, many helpers", however, there was concern about the effect on society and consumers, "will there be a demand for such wines?", thereby illustrating challenges in a changing market awaiting for either organic, vegan, or new PIWIS development, "what will be in demand in the future?", or is there a risk of rejection due to the out of standard taste of these wines. Thus, the positive image of PIWIS in the population, associated with much lower pesticides, is balanced by a lack of acceptance of those varieties by customers, because of their taste and flavors. Altogether this gave a puzzling picture partly preventing the cultivation of the PIWIS.

A diachronic analysis revealing changes in discourses and reasoning over time. This section provides empirical evidence on the evolution of the discourse of the WES group's winegrowers, after the 7-year project (Table 2). From the comparative analysis of the corpora corresponding to the four stages of the project, with the exception of the T0 stage, lemmas of SI >10 emerged, as for T1, with "hawkweed"; "product" for T2, with "practice" and "conventional" for T3. The first two overused lemmas of the T0 partition, "spray" and "grass," appeared in the SI interval between 6 and 10. In this same interval, we found "degree", "work", "father", and "training" in T1; "spray" and "supplier" in T2; and "explain", "winegrowers" and "wood" in T3. Interestingly, "spray" was overused in both T0 and T2. Altogether, we observed an increase in SI, in addition to a diversification of vocabulary, suggesting interest in all viticulture practices, illustrating the importance of explaining and understanding these practices, through the project. At the level of similarity graphs (Fig. 3), there were at least four lexical communities for WEST0 around "grass", "wine", "spray" and "year"; three lexical communities for T1 around "wine", "work" and "year"; three lexical communities for T2 around "wine", "product", and "spray"; and three lexical communities for T3 around "year", "practice" and "plot." These changes in lemmas suggested further evolution of the discourse in the course of the project. Altogether, our analysis suggested winegrowers have departed from a technical vision to consider more global questions of viticulture practices, experimentation, and resilience, despite facing highly variable vintages and strong constraints, mainly associated with climate disorders. The comparative analysis between the discourses of Westhalten's group (WEST3, stage 4) and those from winegrowers uninvolved in such projects (WITT0) supported our conclusions. Indeed, the lemmas "plot" and "wood" reached SI higher than 10 (WEST3), while the maximum SI was 6–10 with "wine" in WITT0. For comparison, in this range (6–10 SI), we found, "explain" and "conventional" for WES. The lemmas "plot" and "wood" had relatively low SI (4–6

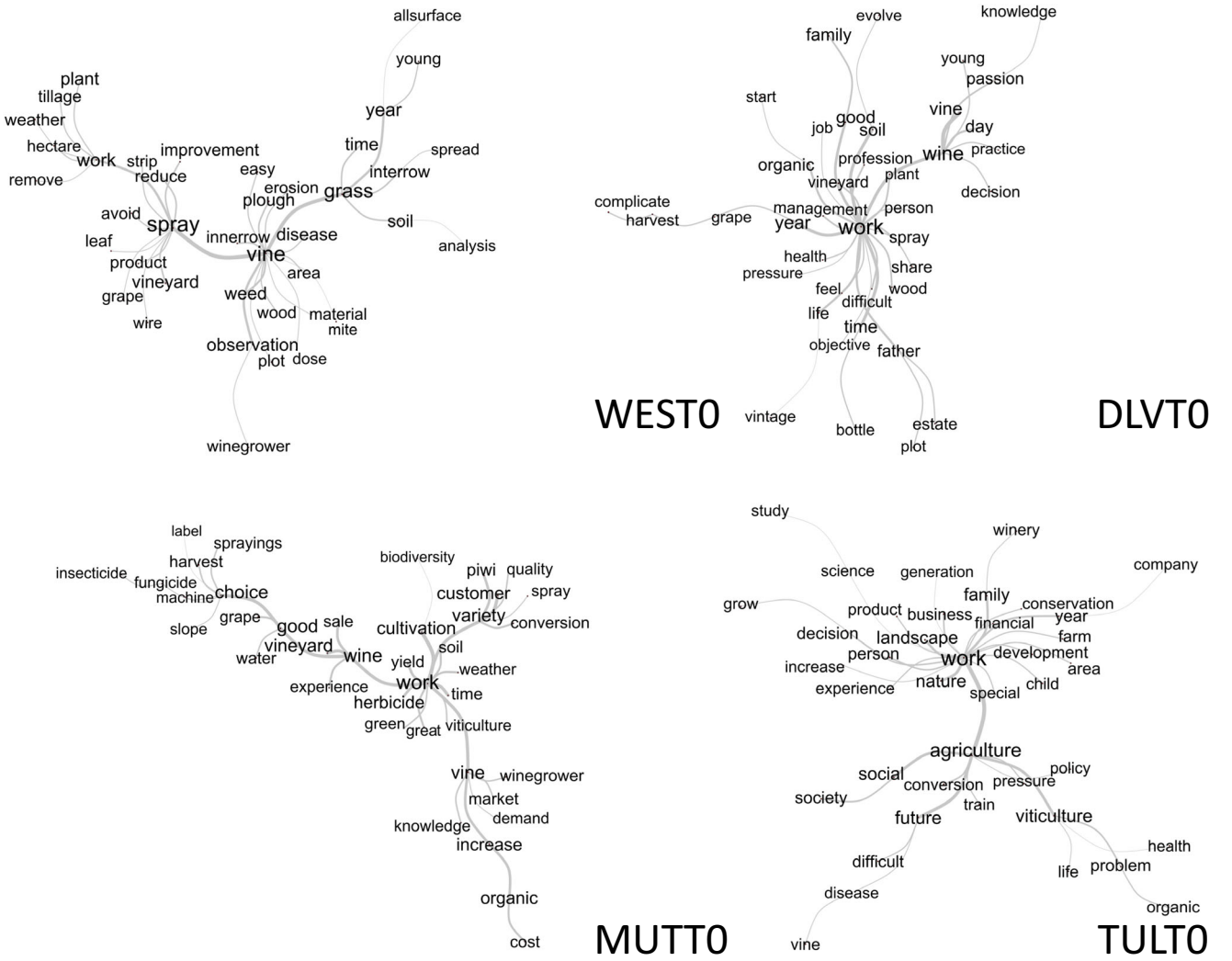

Fig. 3 Maximum trees of lemma similarity graphs for the four groups at the project's start. The study was undertaken with iramuteq (www.irmauteq.fr) from the contents described in Tables 1–3 and S1, for the T0 of the project groups: WES and DLV in France, MUT in Switzerland, and TUL in Germany.

and 6–10, respectively). The graph of similarity for WITT0 was organized around "work", "wine", "year" and "soil," and thus resembled the T0 observed for the four project groups. For WES, after a 7-year project, the question of viticulture practices has become a true subject, as illustrated by the discourses around the word "practice" with precise technical proposals. Rising of the word "plot" suggested a concern about experimentation. The lemma "explain" pointed to the expectation of experimentation for the understanding of organic and biodynamic practices. These same expectations applied to the lemma "spray". The lemma "year" reflected a form of helplessness (sometimes) or a strong concern about inter-annual changes, notably because they were exacerbated by severe climate disruptions. The quotes below illustrate the changes in discourses that occurred over time with the WES group. Starting at T0 "he noticed that the organic matter content of his soil was tending to decrease. He usually does 6 sprays a year.", then T1 "(…) I had a question in a group, he wanted to come with us [WES's group] to have a lower cost, by decreasing herbicide's usage [the hawkweed], that's what I was also saying to the water agency, if they want to do that, they have to do their own project", T2 "it's mostly the salesman who makes the choice of the product. He also knows the regulations, and informs if a product has been recently banned" and finally T3 "[X] told us that [X] felt that some organic and biodynamic winemakers were very critical of the conventional winegrowers at the March 18th meeting". These quotes are in accordance with textometric analysis for the 4 time points.

In the individual interviews of WEST1, "hawkweed" referred to the grassing of vine inner- rows with the plant *Hieracium pilosella* L., which was proposed by a winegrower, as an alternative to herbicides. Following large-scale experimentation in their vineyards, the discourses evolved from apprehension "Project Pilosella is not safe at all, it's not a sure thing: the Germans are giving up: too competitive, the implantation is difficult: need to pick it up with a pickaxe to ventilate it, so that it takes its position relative to other weeds", to optimism, "Pilosella is more of an alternative to tillage. I'm convinced that we have to go in this direction. Without the landmark project, I would have gone slower." The lemmas "training" and "degree" were prioritized and referred to training and learning: "training is very interesting, we're making a lot of progress." Subsequently, a series of training courses designed as co-eco-training, i.e., training courses aiming to increase awareness of the diversity of knowledge sources that each member can contribute to, was developed. Furthermore, such training contents and methods have subsequently been implemented and shared beyond the group. In addition, as part of this project, winegrowers entered the laboratory to conduct the same experiments in plant molecular biology that scientists

performed on vine leaves, taken from their vineyards (Moneyron et al., 2017). Conversely, researchers attempted spade testing, a common practice the group's winegrowers used to quickly assess the quality of their soil. In the WEST2 individual interviews, the lemma "product" had the highest SI and referred to fungicides, thereby also pointing to strong questions: Who supplies the products (i.e., fungicides, insecticides, herbicides)? Do growers have confidence in their products? Who advises them? Although these lemmas were already in T0 and remained central in T2, the similarity graph (Fig. 3, WEST2) suggested that, in the meantime, a reflection occurred on the use of those products, in particular with respect to organic viticulture "considers that it is not only the immediate impact of the product that has to be considered: it is better to spray once with a systemic (pesticide) than 5 times with an organic one when the rain washes it after each pass. This results in a much lower dose of product in the soil, not to mention the fuel saved, and the reduced soil compaction. Ecology is not only organic/non-organic: the label is not everything, and it is not by trying to have it at all costs that we pollute less."

During the individual WEST3 interviews, the data about the expression of genes involved in vine defenses were presented in connection with the co-constructed "Health of the Vine" project. This was highlighted in an interview with a winegrower in transition from conventional to organic "Here I'm close to the biodynamics/organics [results] and there I'm close to the conventional practices [results]. So, all [practices] are the same!?" These results in vine defense gene expression showed the winemaker that molecular studies illustrated a change in the defenses in the vines. Also, "plot" referred to the moments when the winegrowers shared the history of their plots. For example, a winegrower gave an overview of principal component analysis (PCAs, a statistical analysis, and its representation used for comparative analysis of expression levels of vine defense genes, see Soustre-Gacougnolle et al., 2018) ellipse on one arid-limestone-plot, often subjected to violent gales. This suggested that the winegrowers of the project reached a better understanding of the differences between conventional and biodynamic practices, throughout the discussion of data about vine defense gene expression levels. The diachronic analysis carried out with the WES group suggested an evolution of discourse and reasoning over time. We will illustrate below how these profound changes influenced collective inventiveness in the framework of a participatory workshop open beyond the WES group.

Language in the development of ideas and change in reasoning until inventiveness. In the course of a multi-stakeholder workshop (held in 2018) a consensus statement from qualitative and quantitative experimental data on "vine health project" was reached (Masson et al., 2021). Faced with the latter, it stated that vine defense systems were more active and responsive to abiotic and biotic stress in biodynamically grown vines than in those grown under conventional practices (published after this workshop, Soustre-Gacougnolle et al., 2018). Yet, the winegrowers questioned biodynamics: Can one change from conventional winegrowing practices to biodynamics, without undertaking the mandatory 3 years of organic viticulture, and then the further year to have the Demeter label (https://www.demeter.fr/professionnels/conversion/)? All answered: "It's impossible, nobody ever did that!". This—impossibility—initiated lively debates, from which emerged questions on the importance of the different pillars of biodynamic practices. Criticisms reached the issue of considering (or not) the rhythms of the planets, i.e., one of the theoretical principles of biodynamics if one acknowledges the anthroposophical philosophy associated with it (Steiner, 1924/1958). Paradoxically, this is not requested by the "Demeter" label! The only usage of 500 and 501 preparations are due (500 and 501 are compost-derived, and silicon-based preparations, respectively, https://demeter.net/) (Table S2). Biodynamics was also criticized, namely because discourses shared about the preparation of horn silica (501) claimed that 501 would be there to "capture the light" and thereby strengthen the vine. However, this is an irrefutable argument as defined according to Karl Popper, and therefore it was not a candidate for scientific investigation (Popper, 1953/1985). The researchers brought and discussed scientific data on the role of silica in plant health that the winegrowers were unaware (Fauteux et al., 2006; Van Bockhaven et al., 2013; Markovich et al., 2017). These debates illustrated both the constraints linked to the implementation of practices, the lack of knowledge sharing, and the public ignorance of scientific data already published, in addition to the social constraints linked to the representation of biodynamics, among the conventional wine industry, and even within society. Indeed, these constraints, including the anthroposophical theory associated with biodynamics, likely restrain transitions from conventional to biodynamic practices, whose surfaces do not cover more than 1–1.5% of the vineyards, globally. In response to these debates, winegrowers have been inventive in formulating a new question: can vine health be ensured by using exclusively the application of 500 and 501 preparations and compost, together with copper and sulfur, to control downy and powdery mildews, respectively (Fig. 4, Table S2)? Interestingly, in the course of the project, winegrowers in conventional practices committed part of their plots to address the questions illustrated above. Yet, they refused to claim the Demeter label to keep "their relations with other actors in the sector" and therefore named this project "biocontrol". Furthermore, they included in this viticulture practice redesign all the advances made so far by the WES project, thereby establishing plots, never found elsewhere, i.e., cultivating without herbicides,

Fig. 4 A plot of redesigned viticultural practices resulting from winegrower's inventiveness. In this Pinot Noir vineyard, we reached a complete rethinking of practices, following the REPERE participatory research-action project. Under the vines, herbicides were abandoned in favor of very moderate tillage, and the acceptance of rare weed growth. The grassing of the inter rows, which requires a lot of mowing (still visible on the image on the left and on the right), has been abandoned in favor of grassing with wild local plants (picked from a nearby moor) that are mowed only once a year (center). The method of pruning for the vines has been changed in favor of pruning that takes longer to carry out, but that favors the flow of sap and thus the resilience of the vine, over the long term (pruning according to F. Dall). Finally, the fight against diseases, downy and powdery mildews with synthetic fungicides has been abandoned for a project using biocontrol, inspired by biodynamics practices, with 501 and 500P, and moderate doses of copper and sulfur (so-called biocontrol project).

using mild tilling practices and grasses in the inter-row consisted of wild plants collected from a nearby Natura 2000 moor (Moneyron et al., 2017; Masson et al., 2021; Henaux and Masson, 2021) with official local wild plant label, thereby inventing a new viticulture practice.

Discussion

Our data suggest that discourses and rationales can highlight, and illustrate, socio-economic and pedoclimatic conditions specific to the locations in Switzerland, Germany, and France, where the projects were held. This precision was essential for further project development, as highlighted through the WES project. With this later, the development of new discourses and reasoning after 7 years suggested reflexivity, especially since significant large-scale changes have been developed in viticulture practices during the same period (Henaux and Masson, 2021; Fig. 1). Indeed, reflexivity has been addressed in the literature, however not with quantitative data, but mostly on the qualitative level (Fook, 1999; D'cruz et al., 2007; Hand et al., 2019). Here, we hypothesize that parallel changes in reasoning and practices were linked to reflexivity. With the WES project, this reflexivity was complex, as illustrated by the contribution of the group in the construction of theoretical models to consolidate the project path, and to the changes in reasoning, these models contributed to (i.e., the Tetrahedron and Argonaute, in Moneyron et al., 2017; Masson et al., 2021). Reflexivity is also illustrated in the collective risk-taking-in-action and innovation the group has reached, as illustrated in our studies. Schön (1994) called such reflexivity "reflection-in-action", while Heather D'cruz et al. (2007) specified that "reflexivity is defined as a critical approach to professional practice that questions how knowledge is generated and, further, how relations of power influence the processes of knowledge generation (…) [and] (…) acknowledge the dynamic relationships between thoughts and feelings: how thoughts can influence feelings and vice versa." Based on discourse production, i.e., the history of the REPERE projects (Fig. 1), we suggest that this reflexivity-in-action is constructed through the prism of the scientist's intervention, the project development, and the winegrowers' experiential knowledge and active engagements. Language analysis illustrates new ideas arising, as much as this new language contributes to new ideas' construction.

In the field of cognition and learning, computational and neurobiological studies of human cognition often involve decision experiments, and they highlight that as complexity increases, task multiplicity enhances learning (Tomov et al., 2021). In addition, neurobiology studies showed that learning requires complex systems and adapted paradigms (Gershman and Ölveczky, 2020). Therefore, one may wonder if the participative-research-action, and particularly the REPERE format illustrated in this paper (Barbier, 1996; Moneyron et al., 2017; Masson et al., 2021) offers a system that accounts for complexity for studies of cognition and paradigms changes invoked (Gershman and Ölveczky, 2020).

The context of viticulture lacks consensus on practices that would be both greener and responsive to winegrowers' multiple constraints. And standard schemes of research and formation have failed unlocking this issue so far. In contrast to standard schemes on human cognition, relying on decision systems about possible choices, the PAR regime offers other paths to study—and develop—human decision-making rationale. Indeed, PAR proposes an epistemological framework that provides greater legitimacy to actors (non-researchers) in building and addressing questions. In addition, PAR is soliciting original learning formats during the research process to the point of inventiveness (Pineau, 1989; Masson et al., 2021). Neurobiology studies went further on issues of human behavior. They illustrated, after neuroimaging, that regarding the environment, when asking people to reduce bad habits concerning the environment, or proposing to adopt more virtuous practices, mobilized distinct regions of the brain (Brevers et al., 2021). Is it more difficult to erase bad habits from one's memory than to engage in new ones, or even to imagine them? Here, winegrowers were actors in the changes that society expects of them, even if no one knows exactly what "good viticultural practices" should be. Moreover, within the framework of participatory action research, winegrowers developed an autonomy of thought and creativity that facilitated the redesigning of practices. Are specific areas of the brain linked to innovation and action solicited in PAR projects? Is the "working memory" also solicited, and with it, the reasoning and learning skills (Sauce et al., 2021) that promoted behavioral change and would be favored by an ad hoc heuristic to address the challenges of sustainable development? Beyond this, we suggest that PAR research may unlock other and more global issues that rely on changes in human reasoning.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to preserving the privacy of stakeholders involved in the project but are available from the corresponding author on a reasonable request.

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Competing interests

The authors declare no competing interests.

Ethical approval

Only anonymized interviews and/or written documents were used for this study. No other human material was used.

Informed consent

All participants were informed that their interviews will be used in scientific research. Consent was obtained from all participants and/or their legal guardians by a written document.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-023-01690-2.

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