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Adaptive practices of researchers involved in low-tech co-innovation processes: Feedbacks from a multi-site experience with ICTs for irrigation systems

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A B S T R A C T

Despite their theoretical potential to increase yields and reduce water use, Information and Communication Technologies (ICTs) remain poorly used in irrigation systems, particularly at the farm scale and in smallholder farms. ICTs innovations still need to be adapted to each local context to be more accessible to farmers. Co-innovation through a "low-tech" approach can increase the fit of technologies to end users' needs and help farmers to make, maintain and reproduce technological objects. Nevertheless, for researchers, being involved in such co-innovation approaches can be challenging as they have to continually adapt technological interventions to the social and environmental conditions. With the aim of supporting researchers' adaptive practices, this paper proposes an original approach to bring a reflexive stance about how co-innovation unfolds within and across case studies. A methodology to assess the interplay between local contexts, technologies, and facilitation processes from a researcher' perspective was implemented on a multi-country action-research project. Several on-farm experimentations, under a given overarching "low-tech" approach, were documented through qualitative interviews with the researchers involved in their implementation. As in any co-innovation processes, the development of ICTs makerspaces in agricultural settings proposes an alternative way to put ICTs back in the service of farmers. While the process of adapting technology to micro-desires and microenvironments can help restore economic and social accessibility, it also involves a great deal of information and facilitation work. Hence, low-tech approaches are promising solutions to address irrigation efficiency challenges, but their implementation in real world contexts forces researchers to adjust, relocate efforts, develop new facilitating skills, which in turn produces shifts in their position. This research finally raises questions about how to drive change in complex contexts while respecting strictly limited timelines, and opens up perspectives for clustering initiatives and capitalize on researchers' feedbacks.

1. Introduction

The lasts decades have been marked by attempts to streamline and rationalize the irrigation process worldwide through calls for efficiency improvements, either by improving resource allocation with conservation policies or by increasing performances of irrigation systems through a panel of hydraulic technologies (see for instance Pérez-Blanco et al., 2020). While climate changes impacts on hydrology increasingly emphasize the demand for techniques modernization, discrepancies between the expected performance of conservation technologies at the field level and the amount of water actually saved are still existing and often important in several countries (Kuper et al., 2019; Van Der Kooij et al., 2013; Venot et al., 2017). Within a context of constrained water availability, physical water accounting is one of the solutions proposed to ensure performance targets are met (Grafton et al., 2018). In such context, Information and Communication Technologies (ICTs) offer many opportunities for agriculture initiatives (Aker et al., 2016), for example the accurate monitoring of water flows with remote sensors in irrigation areas (Ferrández-Villena and Ruiz-Canales, 2017; Nam et al., 2016; Sánchez-Sutil and Cano-Ortega, 2021).

In recent years, as ICTs were generally too expensive for the great majority of potential users, low-cost sensors were increasingly being developed (Adla et al., 2020; Placidi et al., 2020; Spinelli et al., 2019) so as to reduce costs and improve economic rationales. However, despite

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costs reduction ICTs remain poorly used in irrigation systems, particularly in smallholder farms. Different barriers to their adoption still remain: (i) practical evidence for the advantage of using ICTs is still insufficient (Berthold et al., 2021; Koech et al., 2021), (ii) ICTs still need to be adapted to each local context to be more accessible to farmers (Srinivasan et al., 2019), and (iii) the technical community involved to adapt the technology to local needs and capacities, such as suppliers, local craftsmen, fitters, experimented farmers or even researchers, remains crucial to be able to re-engineer the technology (Benouniche et al., 2014; Lejars and Venot, 2019). Hence, given the complexity of using these technologies in irrigation areas, including fabrication and maintenance, the provision of imported and standardized devices through global markets is not sufficient to increase accessibility of ICTs to farmers. While digital technologies can be enablers of on-farm experimentation (Lacoste et al., 2021) and increase transparency of water management (Sanchis-Ibor et al., 2024), alternative innovation pathways are required.

Many approaches attempt to move away from the linear innovation diffusion model, where technologies are black boxes developed by a few, mostly engineers and researchers, and then extended to stakeholders. The literature about agricultural innovation systems provides a comprehensive view on actors and factors that co-determine innovation (Klerkx et al., 2012b), recognizing the necessary move towards collaborative research models and co-innovation processes (Klerkx et al., 2012a). Such co-innovation processes challenge the role of researchers that develop technologies, in direct contact with the stakeholders who would benefit from the innovation. Researchers who support these co-innovation processes are indeed required to take on various roles (Botha et al., 2017), being experts and solutions designers, but also facilitators of interactions (Lejars et al., 2024). Embedding these roles is not easy and experiences with co-innovation are contrasted, as shown in several multi-country research projects (Botha et al., 2017; Ingram et al., 2020; Srinivasan et al., 2017; Vereijssen et al., 2017). Such move have long been identified as a participatory and negotiation challenge, highlighting the importance of communication and collaboration in innovation processes (Douthwaite et al., 2001; Hoffmann et al., 2007; Leeuwis, 2000, Leeuwis and Aarts, 2011). However, the focus on the enabling institutional environment and the fit of technologies within a sector (Klerkx et al., 2010) directed attention towards actors at the expense of the technologies themselves.

To reexamine human relationship with technical objects, philosophers such as Gilbert Simondon (Simondon, 2017) or Yuk Hui (Hui and Lemmens, 2021) revealed the importance of considering that the usefulness of technical objects are consequences of their "concretization" or "localization". Actually, such posture is already declined in the agriculture sector to help farmers to make and reproduce objects and thus favor a form of "technical autonomy". For example, various PRIMA funded projects aimed recently at enhancing irrigation performances through experimentation of low-cost solutions at a farm scale,[1] acknowledging the socially mediating role of ICTs for and in irrigation systems. The umbrella concept of "low-tech" (Bihouix, 2020) can be useful to delimit the scope of such approach, meaning co-innovation processes that aim at developing technologies that are affordable for small farmers, and easy to make, repair and maintain (Almrott et al., 2025). For example, the low-tech approach is referred to in the co-development of low-cost sensors in irrigation areas to improve accessibility of ICTs (Vandôme et al., 2023). However, they seldom focused on the way the technology transforms the relationships between researchers and farmers, drawing lessons from the experiences of the researchers involved. Indeed, moving from "high-tech" – usually specified as advanced, effective, smart and digital – to low-tech devices – that can be made by users themselves – updates the questions raised by agricultural co-innovation scholars about the role of researchers involved in making technologies accessible to farmers—specifically, how they navigated social and technological challenges, adapted their methodologies, and what insights they gained regarding such innovation processes.

In this paper, we propose a reflexive analysis of the feedbacks from researchers involved in low tech co-innovation approaches. The objective is to capitalize on their experience and enable other researchers to integrate issues that can impact the success or failure of their co-innovation practices. As observers of collaborative and technological pathways (Daudin et al., 2025), the aim of this paper is to draw attention towards past and present technological actions carried out under a given overarching approach. Indeed, the current pace of development of ICTs in irrigated systems tends to overvalue services and products to the detriment of a reflexive stance on research and technological practices (Patrignani and Whitehouse, 2018). Firstly, a theoretical clarification of low tech approaches and the role of researchers these processes is proposed. Then, the analysis is implemented on a multi-site research project illustrative of the current move towards low-cost lean solutions at a farm scale. In particular, we captured researchers' adaptation mechanisms by looking at their own practices through interviews conducted during the co-innovation processes. The analysis specifically focuses on the interplay between local contexts, technologies, and facilitation processes. Finally, we discuss the usefulness of such socio-technical perspective to understand how co-innovation unfolds within and across case studies and support researchers' adaptation during co-innovation processes that modify their relationships with users and technologies.

2. Theoretical background: accessibility of technologies and the role of researchers

The question of how to put the technology back in the service of end users, as opposed to designing complicated technologies with ever better technical performances, is a line of thought that emerged in the 1930s (M. Bookchin) in a context of the criticism of technological development based on imitation and technology transfer operations. To make technology a factor of emancipation, appropriate technologies (Schumacher, 1978) consider the scale issue as crucial and promote development models based on simple techniques that are developed with communities. Rather than prescribing hardware-based solutions or marketable products to passive end users, appropriate or intermediate technologies favor simple, unsophisticated equipment, and repairable innovations that are adapted to social challenges and adaptable by end users. The concept of "low-tech", developed within the last decade by French engineers (Bihouix, 2020), builds on these movements aiming to integrate users' role in the adaptation of technologies to local needs. As an alternative approach to promote local autonomy and reduce production and consumption, the low-tech questions the link between users, objects and environments through three basic principles (Almrott et al., 2025): (i) useful – meeting basic needs; (ii) sustainable – robust and repairable; and (iii) accessible – simple and royalty-free. Hence, adaptation and tinkering are indicators of low-tech approaches and maintenance is the ultimate low-tech activity as it involves care (Denis and Pontille, 2025).

The low-tech approach is tied with the open-source movement considering that essential scientific knowledge and know-how must be free and widely distributed, thus implying alternative innovation paradigm that favors the building of an organization that integrates the needs of communities in the shaping of technologies. While initiatives based on the FabLab philosophy – free and open-source movements for the building of technologies tailored to local needs – are emerging to support the digitalization of agriculture (Ranwez et al., 2019), the theoretical background of low-tech approaches draws attention to co-innovation processes and participatory research to overcome adoption barriers. Indeed, the low-tech approach fully recognizes that technology is part of a social network in which expertise is passed on and put into practice (Meyer, 2023), trying to take advantage of the collective and distributed nature of the innovation. As a result, the role played by

[1] https://prima-med.org/wp-content/uploads/2022/06/Booklet-2021-fv.pdf

researchers in such processes goes beyond technical innovation designers or prescribers to include coordination and facilitation practices (Hoffmann et al., 2007). While it is today acknowledged that co-innovation processes change the prevailing logic of innovation systems and requires a shaking up of expectations about roles, responsibilities, and institutionalized processes (Paschen et al., 2021), too few studies propose practical guidance or feedbacks and lessons learnt by stakeholders throughout the process. For example, participation roadmaps may help improve the accessibility of digital technologies in agriculture (Pawera et al., 2024), but few studies assess the effective impact of participation on adoption of innovations.

Over the last few decades, many books and articles have been published that draw attention to farmer experimentation and local innovation (Reij and Waters-Bayer, 2014). While it is largely acknowledged that farmers have developed agricultural innovations without the contributions of scientific methodologies (Richards, 1989), scientists are still often viewed as the guarantors of modern science, bearers of the "holy technical reason" (Pascon, 1980, p. 175). However, through the open manufacture and experimentation of low-tech innovation devices, researchers have to deal with "peasant rationality" and "take into account local uses, the sum total of the population's micro-desires" (Pascon, 1980, p. 174). In this situation, researchers are in the position of both guarantors of technical rationality and adapters to local practices and the sum total of users' desires. As such, the implementation of low-tech approaches calls for the continuous examination of what is understood or known by local actors, and the process thus changes the practices of researchers, struggling to make technologies accessible. Actually, the process of adapting technology to micro-desires and microenvironments is expected to help restore social and economic accessibility: the philosophy of sharing technical competencies through manufacturing workshops, or makerspaces open to all farmer whatever its resources or skills, reduces the price of the service compared to commercial sources and ensures local autonomy. However, sharing knowledge and empowering stakeholders who are considered less knowledgeable is a costly endeavor for researchers which still needs to be explored.

3. Material and methods

3.1. Case studies: low-cost sensors in the HubIS project

The HubIS research and intervention project (2020–2024) aimed at improving the performance of irrigation systems in eight sites across the Mediterranean region with the development of ICTs to monitor and model water flows in agricultural areas. Achievements and limitations of past experiences have shown that accessible technologies required bottom-up processes. Hence, to boost the emergence and adoption of ICTs in irrigation systems, the focus of the project was put on experimental sites where researchers and local actors co-develop, test, review, and disseminate new tools and services to farmers and Water User Associations (WUAs). The pilot sites were located in seven Mediterranean countries: four in the northern Mediterranean region (France, Spain, Portugal, and Greece) and three in the southern Mediterranean region (Morocco, Algeria and Tunisia). The low-cost co-innovation approach was declined in each site under the concept of "travelling FabLab",[2], which provided a useful physical and social framework for crystallizing the search for technological alternatives, economically and socially accessible.

The HubIS research teams were composed of agro-hydrologists who, before this project, had little or no experience in co-innovation processes, but who benefited from on-line training in concertation engineering[3] provided by a consultancy firm in the first year of the project. Following, all teams acknowledged innovation as the outcome of a mutual learning process in which stakeholders can and should be motivated to participate, whatever the stage of the technological development (Douthwaite et al., 2002). Once this background was established, the researchers tried to develop participatory approaches adapted to their context and to the stakeholders they were in relation with (mainly farmers and WUA managers).

Three types of ICTs were developed and implemented: i) remote sensing and modeling, ii) guidelines and remote services, and iii) ground sensors. Because technological interventions were very diverse, the paper specifically focuses on field scale experiments with connected sensors in three sites: the Crau plain in the South of France (water level sensors paired with a telecom system), Cap Bon in Tunisia (wireless monitoring of soil moisture) and the Gharb irrigated perimeter in Morocco (water meters and soil moisture sensors). Such sensors enabled real-time monitoring of water distributions, facilitating the understanding of surface and underground flows and filling quantification gaps.

While quantification of innovations impacts is not achievable within the timeframe of a single project for the reason that changes in irrigation practices are not stabilized, results in Tunisia (Vandôme et al., 2023) show that technologies that use embedded electronics, such as the Internet of Things (IoT), are technically feasible and have significant advantages over standard sensors. Compared to low-cost sensors that are developed with a co-innovation approach, commercial sensors appeared as black boxes because no information was given about which parameters may influence measurements. In France, demonstration and manufacturing workshops with stakeholders favored participation and learning beyond on-farm experimentations (Vandôme et al., 2024). A significant outcome of the co-innovation process is finally the shift from researchers' initial focus on economic factors towards farmers' social behaviors and willingness to experiment new technics (Kettani et al., 2025).

Finally, as in many other research and innovation projects, HubIS researchers were central actors in the co-innovation processes: they were those who make technological experimentation possible, by constantly interacting with stakeholders involved in the local irrigation community, either through consultation, in interviews, or in training and manufacturing workshops. While facilitation was demanding in terms of time and skills, they had accumulated considerable experience and learned important lessons, as well as experiencing frustration in relation to the original objectives.

3.2. Methods

The methodological objective of this paper is to tackle structural problems frequently raised in development and action research head-on: the gap between technological innovations and realities on the ground and the inaccessibility of these innovations for farmers (high cost, high level of technicality, etc.). These gaps often lead researchers to adapt both their approach and their stance in such processes, with a view to focus on user appropriation, economic considerations, informal modes of experimentation and local knowledge. Hence, it is proposed to analyze how HubIS researchers made choices to operationalize the low-tech approach and adjusted their experimental setting, how they conceived and established co-innovation processes and how they navigated the opportunities and obstacles.

Interviews of HubIS researchers in spring 2023 aimed at identifying obstacles met during the technological implementation, the levers perceived, and the adjustments made to the co-innovation approach to enable the establishment of makerspaces in agricultural conditions. Interviews were conducted in a trustful relationship with researchers:

[2] https://www.umontpellier.fr/en/articles/linnovation-se-cultive-avec-mobilab

[3] https://www.lisode.com/en/

interviewers, and co-authors of this paper, were part of the project with the goal to provide support to researchers during and after their achievements. Two authors are from social sciences (a socio-economist and an agro-sociologist) and took part of the HubIS project with the initial task to follow-up the adoption of innovations, one author has a background in physics and took part of the project as the project manager. While the later maintained close and regular contact with the researchers throughout the process, the formers had a more distanced stance. None of us participated in the process of developing innovations in the field, but the combination of perspectives—both distanced and immersed—enabled us to decipher the challenges involved in implementing co-innovation processes in various contexts. More specifically, such perspectives helped us access to behind-the-scenes situations in order to capture the socio-material conditions that push researchers involved in the process of manufacturing quantification instruments with farmers to transform their practices.

This posture helped set a relaxed atmosphere during interviews and elicit implicit information about how researchers have developed appropriate skills and have learnt from the innovation process. By drawing attention on past actions, groups and motivations behind collective experiences, semi-structured interviews aimed at providing support for reflection more than two and a half years after the beginning of the project. The interviews took place in one meeting with each team, with a focus on three axes: i) innovations, actors and networks; ii) obstacles and limits to the innovation adoption process; and iii) reflective feedback on the process and socio-technical learning. Each interview with two or three interviewees was conducted by two or three interviewers. The axes were used to structure the discussion and provide a common interpretation framework for all pilot sites, but we extended our questions to adapt to the specificity of each context and to analyze it in detail. Gross results of the interview analysis were presented to the project's researchers at the final project meeting, during which additional informal interviews were conducted to further explore aspects that emerged from the initial interviews.

The interviews were transcribed and the information was sorted in order to describe practical achievements and measure the costs incurred by those responsible for intervention. The following analytical grid was followed to compare the case studies: 1) the technical tools used for the identification of local problems and needs and the implementation of co-innovation processes, 2) the setting up of makerspaces in agricultural conditions and the confrontation with local social and economic contexts, and 3) the extension pathways of co-innovation processes.

4. Results

4.1. Inception of co-innovation processes

4.1.1. Analytical tools for local problems identification

Local agrarian contexts were diagnosed (Degroote et al., 2025) to acquire a detailed understanding of agricultural dynamics and of the potential for technological innovation. Such diagnosis consists in taking stock of changes in agrarian systems and irrigation systems and identifying constraints to irrigation and problems facing the farmers, as well as envisioning potential solutions and innovations to overcome them. Reinforced by qualitative interviews with local actors, the idea was to support the emergence of innovations that meet the priority needs of farmers and managers.

> *"People in the Crau plain have been thinking about the problem of water management for a long time and looking for solutions […], something that emerged from the interviews quite rapidly was automation of the gravity-fed irrigation system […]. On the one hand, we identified the need to facilitate irrigation from the farmers' point of view, but on the other hand, from the point of view of the water managers, the objective was saving water at all costs […]. What we wanted to do first, was propose tools to measure, and consequently understand what was happening in these irrigated systems. So we started with simple informative sensors [at field scale]"* [4] *(researcher, France)*

Another analytical tool was used to characterize the performance of irrigation schemes: the Rapid Appraisal Process (Burt, 2002). This procedure can give a reasonably accurate and practical description of an irrigation system status and main problems, producing orders of magnitude of crop water needs all over an irrigation season. The Rapid Appraisal Process (RAP) allows for the identification of the bottlenecks of irrigation service within a farming system and can help design actions to improve irrigation practices. While in a HubIS case study it appeared particularly relevant to select potentially innovative solutions when combined with participatory approaches (Cameira et al., 2024), in the majority of study sites its implementation was not particularly useful for the design of ICTs experimentation. This tool even proved to be counterproductive in a HubIS case study. Whereas the RAP may show that an irrigation perimeter do not perform well, its presentation to water managers was perceived as a criticism of local competencies and skills. Hence, the RAP results can backfired on the researchers and their relations with water managers, preventing them from intervening, and jeopardizing the continuation of the project.

> *"I had problems with the Office [WUA] because we had done the RAP and the Office was not happy with the results. They even wrote a letter to the director of our institution" (researcher, Morocco)*

4.1.2. Participation of local actors

Multi-stakeholders' workshops were held to present researchers' initial ideas and to adapt the solutions based on stakeholders' feedback. While the objective of the first workshop was to obtain feedback from the farmers on the design through demonstrations, the next ones aimed at covering the manufacture, maintenance, and testing processes. Hence, the workshops were used to gradually give shape to the innovation.

During interviews, HubIS researchers emphasized the importance of pre-existing relationships with local actors to launch the participatory processes. Indeed, the fact that researchers involved in the project had already collaborated with local actors helped to speed up the setting of workshops.

> *"It would have been slower if we had chosen another area, and we would have spent at least a year interviewing people, getting to know them and seeing whether or not they were willing to take part [in experimentations]" (researcher, Tunisia)*

Although the relations between water managers and researchers were very favorable at the start of the project and helped lever its inception at the different sites, the collective level (Water User Association, WUA) was not always decisive for experimentations. Actually, several researchers stressed the importance of previous experimentations, or the existence of experimental farms, for the choice of pilot sites.

> *"Several years of surveys and experiments meant we had detailed knowledge of this sector, [which explains] the decision to use this knowledge to set up the HubIS project in this area" (researcher, Morocco)*

> *"The Domaine du Merle is a place that has been bringing together a large number of stakeholders around water management for a long time, and is quite dynamic. This is why we opened the Fab Lab at the Domaine du Merle […] What is more, a researcher from Institut Agro has been living there for more than 20 years [to manage water flows], all the local actors know him" (researcher, France)*

[4] All the quotes in this paper were translated from the French by the co-authors.

Finally, it was sometimes necessary to bring both the WUA and the farmers on board for the set-up of experimentations. However, the line may be very narrow between economic interests of water sellers and the implementation of ICTs for water conservation. In such case, previous partnerships between researchers and local managers may prove to be a constraint to conduct farm-scale experiments in their territory. Indeed, researchers had to find incentives for WUA managers to prevent them from "sabotaging" their work.

"The idea is that […] if the farmers irrigate collectively [with water from collective networks], the WUA will be able to improve its management. And if the farmers irrigate collectively using this [hydraulic] network, it will reduce the pressure on the water table. We are in the process of raising people's awareness, not just in the workshops, but even in our interviews, we are trying to find out why people prefer to use wells. […] We also have a parallel question: 'what suits the WUA?'. It is always a case of give and take. We need to mobilize all the actors" (researcher, Tunisia)

4.2. ICT makerspaces in agricultural settings

4.2.1. Acquisition of electronic equipment

The development of low-cost innovation requires the acquisition of electronic components and IoT devices that may not be available in certain contexts. Actually, researchers were obliged to import such equipment from China, or place orders online via platforms such as Ali Express. In the case of Northern countries, despite the disruption caused by the Covid pandemic in 2020–2021, the project's researchers had no difficulty in ordering equipment online, and were optimistic about the development of this type of industrial capacities in Europe.

"Low-tech equipment [IoT devices] is accessible, anyone who wants to order it can have the necessary components delivered to their home within a week. The only problem for us is that most of it comes from China […], the prices are quite volatile: it is still low cost but if there is a disruption somewhere [in the value chain] that can change overnight" (researcher, France).

In Southern countries, the acquisition of electronic devices and low-cost equipment strongly depended on the existence of a hardware market and the development of young startups. In some cases, startups that produce this type of technology are rare or not very well known. Thus, ordering and importing the equipment from China may be restricted. For example, the researchers in the Moroccan team had to go through their acquaintances in France to obtain components via Ali Express.

4.2.2. Adaptation of technological interventions

Researchers' adaptation to environmental conditions and farmers' needs and micro-desires occurred during the co-innovation processes. Table 2 below summarizes their adaptive strategies at the sites on which this paper puts a particular emphasis.

In France and Tunisia, low-cost sensors based on IoT technologies and connected to a network server (open-source hardware and communication protocol) were tested. In France, the objective was to combine the stakeholders' individual motivation to achieve a collective impact by both avoiding excessive surface drainage and reducing round trips in the field (less labor and night shifts required). Still, the sensors only provide information:

"A flow meter in the canal that says how long irrigation has been underway, and provides a record of the duration: all that is only information - it doesn't necessarily help make decisions. However, it does help understand the system. Detecting water downstream of the plot is a direct decision-making aid, but it is not yet automated." (researcher, France).

In Tunisia, a subsidy policy supported the switch from gravity-fed irrigation to drip irrigation, but farmers continued to irrigate according to their water turns (i.e. for 4 successive hours). The objective was to design tools to adapt irrigation practices to the sandy soils in Cap Bon, where the optimal solution would be to split the inputs as much as possible. Although researchers linked the behavior of the low-cost probe to the soil water status (calibration) and adapted the communication channel to the farmers' needs (by enabling direct reading of the soil water status in the field), farmers did not use the information to decide when and how long to irrigate. Rather, the probe only proved to be useful to the researchers to reconstruct irrigation schedules.

In Morocco, the Gharb scheme was originally designed for sprinkler irrigation systems but the use of drip systems led to problems of water delivery. The original idea, which was to measure the flow rate in the pipes, was not possible because all the pipes that make up the irrigation network are underground and consequently cannot be accessed. Moreover, the use of soil-moisture sensors was not suitable due to the nature of the soils, as one researcher pointed out:

"The Gharb soils are very heavy. The cracks can reach 3–4 cm in width. If you put a moisture sensor [in that kind of soil], it won't measure anything" (researcher, Morocco).

4.2.3. Perception of the low-cost equipment by future users

While the use of low cost sensors could make the technology accessible to small-scale farmers, the perception of low-cost equipment by future users is a challenge that all the research teams had to face to varying degrees.

"When you show them a product and say, "here it is, 10 euros and you can do it yourself" a lot of people react by saying "yes, but does it work? How can I be sure that it works, that I'm not going to wake up one morning and find water running everywhere" (researcher, France)

While the high-tech products can be seen as reliable, robust and precise, the low-cost handmade devices are considered to be unreliable, easily broken and makeshift. This situation forced researchers to conduct experiments using commercial equipment to demonstrate that the results obtained with low-cost sensors were similar. The situation also obliged them to make low-cost sensors free of charge to farmers to encourage its use check its reliability.

Table 2
Adaptive strategies to environmental conditions proposed during the innovation process.

Site	Users' needs	Irrigation conditions	Technologies tested	Adaptation actions
Semi-arid Crau plain, France	Alert farmers when water reached the end of their plots	Frequency and duration of events to evaluate irrigation performance	Flowter sensor in open canals and water detection sensors downstream	Adaptation to farmers' needs (alert sent by text messages) and skills (design simplification)
Gharb scheme, Morocco	Problem of flexibility of water delivery service	Collective network in which all the pipes are underground (i.e. not accessible) and soils that crack	Nothing was tested, neither water meters nor soil-moisture sensors	Progressive adaptation to environmental and institutional conditions
Haouaria scheme, Tunisia	Improve irrigation practices by using drip irrigation	Adapt the frequency and duration of irrigation events to sandy soils and reduce pumping of groundwater	Capacitive soil moisture sensor calibrated in the laboratory	Adaptation to farmers' practices (direct reading of the soil water status in the field) and to WUA expectations

"It is true that it is very difficult to get farmers to buy equipment themselves, even at low cost. That is why we had this idea of creating the FabLab in the GDA [WUA], in the first stage to give the equipment to people until we made sure the innovation really spreads. I think the more people try it, the more confident they become over time. That is why I said the idea of the FabLab is also to make some of the equipment available to farmers through the GDA. We hope that if this innovation really works, if it is disseminated successfully, people will start to take an interest, and maybe they will be interested in buying [the equipment]" (researcher, Tunisia)

Organizing sensor manufacturing workshops proved instrumental to overcome the negative perception of the low-cost devices:

"I found that getting the farmers involved in the manufacturing process and then building the devices themselves meant that, in the end, everyone left with a finished product that they could test themselves. They thought it worked well. In general, they finished the workshop by saying "OK, I have seen that it works, I am interested" and they leave with the intention to install it at home. So I think that if we had not held these manufacturing workshops, the mistrust would remain, because that's what happened to the startup that was there before us" (researcher, France).

Finally, the mobilization of low-cost sensors, and their manufacture, reduced the distance between the world of research and the realities of the field.

"We were seen as scientific researchers, but not as researchers who arrive on the scene and merely tinker in the field. On the contrary, we were seen as researchers who were not too disconnected through this posture" (researcher, France)

4.3. Extension pathways of co-innovation processes

Once the proof-of-concept is achieved and when the adoption process begins to stabilize, the provision of extension services placed the researchers in difficult situations. On the one hand, researchers felt compelled to respond to the increasing requests made by the farmers with whom they had built up a relationship of trust, and to whom they owed a sort of 'debt' because they welcomed the researchers and were open to their experimentations (answering questions, hosting field trials, taking part in workshops). On the other hand, researchers had other commitments in the meantime, and were unable to respond to all the requests, which have led to frustration.

"We did not achieve 100 % autonomy for farmers. Nobody is there to give them a helping hand. It is something that takes time in reality. The adoption of innovation in a 3-year project like this one, is not enough time to provide support for farmers to enable them to become independent" (researcher, France)

Some teams identified activities that would extend the impact of the project and ensure the dissemination of innovations beyond the limited duration of the project. For example, training of WUA technicians and managers were thought as a relevant strategy for future projects, but depending on their interests and availability.

"It would have been really useful to have a WUA employee who accompanied us throughout the development, […], learning at the same time as we learned […] it also depends a lot on people and their willingness: is there anyone with the right profile who is interested in doing this? Is the WUA prepared to free up one day a week to dedicate to this? (researcher, France)

Other teams emphasized the importance of maintaining close links with institutional actors, particularly those in the administrations and agencies responsible for water management. Indeed, the risks of misunderstanding and misinterpreting research results are always present and can compromise the continuity of any project.

"When I started my surveys, Mr F was working at the Office [WUA], and he was a great facilitator for the fieldwork, the surveys, the data acquisition, and so on. However, the situation has changed a lot since he stopped working at the Office, we are having a hard time obtaining data, we are having a hard time getting out into the field, we are having a hard time finding [operational] information" (researcher, Morocco)

5. Discussion

In practice, the low-tech approach took diverse forms across HubIS study sites, but all in all, the researchers have realized the value of participatory processes for the constant fine-tuning of technological interventions. The results show that as co-innovation actors, researchers were confronted with a variety of realities on the ground, which made them constantly question the approach and adapt to local contexts and needs of actors. Hence, the methodology proved relevant to capture researchers' adaptation mechanisms from their own perspective, how they managed to make ICTs innovation more accessible to farmers, and in turn how the low-tech approach changed their stance in the innovation process. In this section, we successively discuss about participation in co-innovation processes, transaction and reputation costs generated by the low-tech approach, and evolving roles of researchers.

5.1. Participation in co-innovation processes

The results show that the accumulation of knowledge and capitalization on previous projects facilitated access to the field, facilitated communication with the stakeholders, helped build trust, and generally speeded up the diagnostic phases. Hence, to ensure successful implementation of co-innovation processes, preparation is decisive: in the case of new actors with whom the research teams have never previously collaborated, the building of trust is crucial, as already observed in many other participatory processes (Hassenforder and Ferrand, 2024). Still, local research teams primarily had a technical background, and some training was necessary to develop capacities and skills for organizing and managing a transdisciplinary approach (Froebrich et al., 2020). Actually, researchers' interviews indicate that driving technological development and getting stakeholders to actively participate is a difficult balancing act. Indeed, all research teams did their best to ensure stakeholders participation, but in practice the technological developments were also driven by the project milestones. Hence, to ensure the adequate implementation of participatory processes in each site, researchers would definitely have required additional support. Actually, researchers' engagement in facilitation processes has been studied since the 1950s (Klerkx et al., 2012a), but the move towards collaborative models and agricultural extension requires efforts that are too often underestimated.

Another issue arose about stakeholders' level of engagement within the course of the innovation process. Findings suggest that the success of the participatory approach depended on the continuing commitment of the researchers, as well as of the farmers, and on their ability to follow the process. For example, sometimes only a few researchers form the cornerstone of the participation process, and it can be difficult to maintain makerspaces and keep up participation without them. This does not mean that all the actors, farmers or researchers, have to be involved all the time and for the very long time, but that researchers have to reflect on which type of engagement is the most relevant (Leeuwis, 2000) and in which phases participation is crucial (Neef and Neubert, 2011). Actually, while participation may help develop technologies that better match users' needs, and may encourage feelings of ownerships, it can nevertheless be a double-edged sword. Indeed, inadequate management of stakeholder relationships as well as inadequate involvement and support of stakeholders can have a negative impact on end-users' engagement and attitudes (Schillings et al., 2024).

Finally, the investigation shows the importance for researchers to link up or strengthen one or more permanent groups or people to ensure continuity and monitoring of actions over time. Indeed, the question of who takes over is crucial: actions to continue to provide training and support are keys to success as technological experimentations were aimed at changing everyday practices. Hence, the issue of long-term commitment is important, as it breaks with the short-term approach that is typical of many funded projects.

5.2. Low-tech approach

While researchers' activities in digital agriculture generally consist of assembling, testing, understanding and supporting technology development, in the low-tech approach the co-design of innovations, the calibration of technical devices, the control and ownership of innovations by farmers, the organization of manufacturing and training workshops, and the importing of low-cost devices are all operations that require time and slow down the innovation process per se. Research findings indicate that a responsible, sustainable, and ethical approach to ICT (Patrignani and Whitehouse, 2018) is highly time-consuming as iterative processes of co-learning, at each stage of the innovation process, are keys to adapt technologies and render them accessible. Moreover, results indicate that the catalyzers of innovation processes (Hoffmann et al., 2007) were not the project researchers themselves. Instead, an engineering support service took this role in France (Vandôme et al., 2024) and Tunisia (Vandôme et al., 2023). Indeed, the use of low-cost open and connected sensors often requires more advanced metrology knowledge than when using traditional sensors, as shown for stormwater monitoring in France (Cherif et al., 2024).

At its core, the low-tech approach, declined to ICTs for irrigation systems, challenges conventional monitoring methods and inspires new ways of doing things appropriate for their context (Almrott et al., 2025). However, measurements using low-cost sensors are of variable quality and sometimes questionable in comparison with classical monitoring devices. The HubIS results showed that it is possible to achieve low costs while maintaining sufficient confidence in the data produced, but care must be taken as calibration is not always easy to perform and frequent maintenance is necessary. Hence, the diffusion of ready-made innovations do not apply to such low-tech sensors, and adoption constraints switch from economic factors towards willingness to understand how to adapt each sensor to local social and environmental conditions. As a result, even if the original price of the IoT devices is low, the information and transaction costs can be high. Indeed, bottom-up perspectives involve a great deal of information and communication work, and back-and-forth processes between researchers and farmers is demanding in terms of time, resources, and facilitation skills for researchers. While transaction and information costs related to technological adoption by farmers have been captured in agent-based models more than two decades ago (Berger, 2001), the costs of leveraging people and knowledge capacity require constant attention.

Finally, leveraging people and knowledge capacity through low-tech approaches can be an issue for researchers' legitimacy. Indeed, the robustness of scientific knowledge traditionally relies on sophisticated, precise, tested and certified technological devices, and therefore on high tech. Hence, if low-tech aims to reduce asymmetries in terms of access to technological innovations, their manipulation by scientists can influence how these researchers are perceived both by farmers and by other researchers in the scientific community. Interviews indicate that in some contexts, a scientific researcher "doesn't tinker" because tinkering is not perceived as the prerogative of scientists. Some researchers revealed that they had "the feeling to be low tech scientists", especially compared to their scientific peers (outside the project). While the issue of researcher's legitimacy is not new in participatory projects (Bobbé, 2014; Mazzocchetti, 2007), the notion of low tech reinforced the problem of researcher's perception of his/her legitimacy in the development process.

5.3. Evolving roles of researchers

As observed in many projects implementing co-innovation processes in the agriculture and irrigation sectors (Botha et al., 2017; Srinivasan et al., 2017; Vereijssen et al., 2017), the low-tech co-innovation approach transformed the relationships between researchers and other stakeholders. Through the exchanges generated within the makerspaces, farmers and researchers share their respective knowledge and experience, and/or co-produce new ones. In this way, different types of knowledge (scientific, professional, practical, etc.) are placed on the same footing, leading to mutual capacity building and reciprocal changes, in particular the ability to mobilize one another to bring about the desired changes. The research stance is thus dynamically 're-de-constructed', with experience in the field affecting not only the researcher, but also those involved in the field through their questions, formulations and expertise. Such transformations imply a constant reflection on their positions, roles, and functions in the co-innovation process (Hermans et al., 2013; Klerkx et al., 2010).

Finally, in the low-tech processes, the researchers produced knowledge they shared with the stakeholders and, at the same time, they also had to ensure that local knowledge and practices was taken into account. They were therefore both producers and transcribers of knowledge (Daré and Venot, 2016), which imply distance, objectification, but also the capacity of being part of the innovation process and provide guidance and support to farmers. This "support" can take a wide variety of forms beyond the mere production of knowledge. It may include giving advice, developing methodologies, leading the innovation process itself, and so forth. The most relevant aspect is that all the researchers interviewed made the same observation: their involvement leaves neither the researchers nor the participants "unscathed". However, for researchers, it involves negotiating both what is expected of them by the other stakeholders (funders, project partners and scientific managers) and their own position in the research and support system (Barnaud et al., 2017). Like experiences of participatory action research (Cornish et al., 2023; Lejars et al., 2024), researchers may find themselves torn between the scientific objective and the improvement of technology performance, and the very diverse expectations or visions of what science and scientific interventions or knowledge might be for the stakeholders with whom they work.

In terms of prospects, clustering initiatives in the field of low-tech would help researchers involved in disparate case studies as it requires them to develop an adaptable mindset and flexibility in learning capacities. Embedding such position needs to be supported by reflective methodologies, inviting researchers that face such challenges to take a step back and reflect on their evolving roles.

6. Conclusions

Many research projects currently aim at improving irrigation efficiency through experimentation of low-cost technological solutions at a farm scale, but all face a range of challenges related to the participatory processes and the willingness of researchers to favor farmers' technical autonomy. In this paper, we examined the role of researchers involved in making ICTs accessible to farmers by exploring how low-tech co-innovation processes transformed the relationships between researchers, farmers and technologies. Specifically, the low-tech approach presents many advantages but also requires many adaptations from researchers in order to navigate the imbrication of social and technological challenges. The reflexive analysis of the feedbacks from researchers involved in such approach across different study sites proved useful to trace their adaptive practices and better grasp how co-innovation unfolds within and across case studies. While the process of adapting technologies to micro-desires and microenvironments can help restore economic and social accessibility, it also involves a great deal of information and communication work and back-and-forth processes between researchers and farmers. Although the emergence of alternative organizational arrangements is unpredictable, such reflexive analysis can help researchers in their future projects. Finally, the low-tech approach declined to ICTs in and for irrigation systems supports quantification of irrigation performances while also favoring an alternative framing of technological innovations, a smooth development process with existing technologies and in line with local practices.

CRediT authorship contribution statement

Kevin Daudin: Writing – original draft, Investigation, Conceptualization, Writing – review & editing, Methodology, Formal analysis, Project administration. **Zhour Bouzidi:** Methodology, Conceptualization, Writing – review & editing, Investigation, Writing – original draft, Formal analysis. **Caroline Lejars:** Writing – original draft, Conceptualization, Writing – review & editing, Investigation, Methodology, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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