Agricultural Systems 190 (2021) 103103

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Crafting actionable knowledge on ecological intensification: Lessons from co-innovation approaches in Uruguay and Europe

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ARTICLE INFO

Editor: Guillaume Martin

Keywords:
Complex adaptive system
Social learning
Dynamic monitoring and evaluation
Socio-technical system
Sustainability transition experiments
Project pedigree

ABSTRACT

Context: Despite a wealth of analytical knowledge on factors and processes that operate to slow down or impede sustainability transitions in various sectors of society, design-oriented researchers face a lack of guidance on the 'how to' question for developing knowledge to support sustainability changes. From 2007, we crafted co-innovation as an approach for governance and management of change-oriented projects, combining three domains; a complex adaptive systems perspective, a social learning setting, and dynamic monitoring and evaluation.
Objective: This paper sets out to describe the co-innovation approach and draw lessons from its application in projects on ecological intensification in Uruguay and the European Union.
Methods: We used an analytical framework for evaluating sustainability transition experiments, which considers project features that provide insights into the contribution to sustainability transformations by project outputs, outcomes, processes and inputs, and their interactions. Empirical information on 6 cases from 3 projects was collected through in-depth interviews with former project staff, group discussion, and project documentation. This enabled a reflexive evaluation of co-innovation.
Results and conclusions: Outputs showed substantial variation among the cases despite a similar approach to project governance and management. More significant contributions to sustainability transitions were associated with in-depth project preparation, a focus at the farm-level instead of the crop or field level, connections during the project's lifetime with regional innovation system actors, and frequent facilitated interactions among project actors to reflect on results, wider system implications, and project direction. We discuss the results in relation to the three domains of co-innovation. To enhance the role of projects in destabilizing currently unsustainable systems we highlight: reconsidering the role of projects as a business model; stimulating institutional learning from previous change-oriented projects; and making funding more adaptive to evolving project needs.
Significance: With most of the budget for agricultural research-for-change spent through projects, how projects are conducted is a critical determinant of the rate of sustainability transitions. Effective disruption of unsustainable practices through project interventions requires rethinking linear cause-effect relations to include project governance and management approaches based on complex adaptive systems thinking, social learning settings, and monitoring geared to adaptation and learning.

1. Introduction

Rethinking agricultural production to enhance its societal contributions beyond food and feed production is a pivotal element in various scholarly sustainability transition proposals that involve redirecting or replacing dominant food production models. While they differ in the emphasis put on specific environmental, social and economic objectives, a common element in the proposals is their attention for synergistically managing ecological processes at the levels of field, farm and region, rather than controlling them through external inputs (e.g. agro-ecology - Altieri, 1999; ecoagriculture - Scherr and McNeely, 2008; ecological intensification - Doré et al., 2011; industrial ecology - Dumont et al.,

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https://doi.org/10.1016/j.agsy.2021.103103
Received 12 October 2020; Received in revised form 5 February 2021; Accepted 9 February 2021
Available online 18 February 2021

2013; biodiversity-based agriculture - Duru et al., 2015). Research may foster such sustainability transitions by producing knowledge that is usable in change processes by being robust as well as socially, culturally and geographically contextualized (Caniglia et al., 2017; Cash et al., 2003; Clark et al., 2011). Following Geertsema et al. (2016a), we refer to such context-specific knowledge that assists stakeholders in their decision-making to be better positioned to achieve their goals as actionable knowledge (cf. van Kerkhoff and Lebel, 2006; Wiek et al., 2012). With most of the research structured in projects, the way change-oriented research projects are organized and executed to produce actionable knowledge is, therefore, an important determinant of the rate of sustainability transitions.

In this paper, we consider the governance and management of research projects that aim to produce actionable knowledge for ecological intensification. More specifically, we aim to evaluate 6 cases from 3 change-oriented projects that one or several of the authors of this paper were involved in, using the perspective of sustainability transition experiments. In each project, co-innovation was adopted and developed as a common approach to project governance and management, and the projects thus offer a rich basis for learning on production of knowledge that is usable for sustainability transitions. In the remainder of this paper we will refer to project governance to mean the actors, networks and interactions put in place to bring about the project's aim, while project management refers to monitoring and analysing, and developing and implementing measures to keep the project on track. Ecological intensification comprises the smart use of biodiversity-mediated ecosystem functions to support agricultural production in a sustainable, affordable way, while reducing the environmental impact of agriculture and its dependence on non-renewable resources (Doré et al., 2011; Tittonell et al., 2016). Using ecosystem functions in agriculture implies context-specificity, as the biophysical endowment of fields, farms, and landscapes determine to a large extent what may be grown and which ecological interactions can be fostered. To produce actionable knowledge, research projects, therefore, find themselves operating in a research mode that accommodates both generic and specific knowledge, and does so in an inclusive manner to secure engagement with the stakeholder community (Geertsema et al., 2016b; Pohl and Hirsch Hadorn, 2008). Here we will refer to research projects that aim to bring about change in dominant societal systems as design-oriented or change-oriented projects, as opposed to analysis-oriented projects that aim to explain observed phenomena (e.g. Rossing et al., 2017).

A considerable body of research has analysed relations between science and society and developed 'requisite jargon and specialist debates' (Clark et al., 2016) that inform the creation of actionable knowledge. Insights highlight the importance of distinguishing hierarchies of systems that involve interactions among human and non-human components through feedbacks and feed forwards that adapt to changing conditions in highly unpredictable ways, and which components exhibit strong variation in their speed of adaptation. While such analytical approaches have provided important insights on system functioning (Klerkx et al., 2010), design-oriented scientists continue to grapple with the question how to shape projects to successfully mobilise knowledge for sustainable development (e.g. de Wildt-Liesveld et al., 2015; Coutts et al., 2017; Pereira et al., 2018). Fazey et al. (2018) denote the question 'how to' facilitate the transformative sustainability changes that are urgent as 'the most critical question for climate research', while Clark et al. (2016) conclude that 'more usable knowledge is urgently needed to help meet the challenges of sustainable development'. The latter authors denote the process of producing usable or actionable knowledge as 'crafting' thus emphasising that in their practice project leaders are faced with mobilising a combination of skills, theory and contextual sensitivity. Referring to design-studies literature, Prost et al. (2017) distinguish classical project management from emerging adaptive project-management approaches to describe progressing insights on how to conduct change-oriented projects. In a classical project management approach, goals defined at the start of a project are to be reached within the constraints of project time and budget. In an adaptive project-management approach, project interventions are seen as experiments and during the project learning-by-doing is emphasised, resulting in crafting – construction in situ – rather than 'rolling out' project outputs and outcomes. Innovation scientists rejected the usefulness of the linear project management model for fostering change over a decade ago (e.g., Ekboir, 2003; Smits and Kuhlmann, 2004; Pahl-Wostl, 2009). Nevertheless, the complexity of global problems is only slowly reflected in the governance and management of change-oriented agricultural research projects, not in the least because change-oriented projects involve changes in what are considered valid ways of producing scientific evidence (Caniglia et al., 2017). Only recently, the CGIAR abolished its systems programs, some of which were well underway in developing adaptive project-management approaches (Douthwaite and Hoffecker, 2017; Leeuwis et al., 2017).

In different sectors of society new forms of collaboration between sustainability scientists and other societal actors have emerged that involve experimental interventions in societal processes with the aim to produce science-based empirical evidence on sustainability transitions. In a review of such sustainability transition experiments Schäpke et al. (2018) identified forms of collaboration referred to as Real-World Laboratories, Sustainable Living Labs, Urban Transition Labs and Transformation Labs, each with their own profile in terms of contributions to transformation; shaping of the experiments; the degree of transdisciplinarity;, their long-term orientation and scalability; and contributions to learning. A common element among them is that they provide "spaces that facilitate explicit experimentation and learning based on participation and user involvement" Luedertiz et al. (2017), quoting (Voytenko et al., 2015). Such sustainability transition experiments may be classified depending on the level of researcher control over interventions and context - full, participatory, or beyond control, and depending on their experimental aim - sustainability problems or sustainability solutions (Caniglia et al., 2017). Building on transitions scholarship Luedertiz et al. (2017) emphasize the need for reflexive evaluation of such experiments, and propose an evaluative framework for cross-case learning to understand patterns of success of interventions to inform future actions. The framework distinguishes 24 features, i.e. salient assessment criteria, to describe and analyse four dimensions that reflect the logic model of project organization: outputs, outcomes, processes and inputs. The features were derived from a review of 61 individual cases of sustainability transition experiments and were tested and revised based on discussions at various international congresses. The authors designated the evaluative framework as generic, i.e. suited for different types of sustainability transition experiments; comprehensive, i.e. representing an experiment's ultimate outcomes as well as the underlying outputs, processes and inputs; operational, i.e. ready to be applied; and formative, i.e. supporting greater effectiveness and efficacy of experiments. At the same time, they referred to the framework as tentative, and invited reflection on its limitations and usefulness.

Over the past years, our team crafted the concept of co-innovation through various design-oriented research projects on ecological intensification in Latin America and Europe (Albicette et al., 2017; Dogliotti et al., 2014a; Klerkx et al., 2017; Rossing et al., 2010). The intention of the co-innovation approach was to provide a framework for project governance and management that was responsive to the idiosyncrasies of our change-oriented projects' complex settings. Here, we consider these projects as cases of sustainability transition experiments: they constituted transformational interventions that built on existing efforts, created new actions, and added orientation to transitions. Furthermore, they followed a transdisciplinary research approach involving various actors in the experimentation process to reconcile contrasting objectives and positions, and to create ownership for solutions that aspired to be radically different from the status quo. Finally, all had the intention 'to create positive outcomes that are replicable, transferable, and scalable to society at large' (Luederitz et al., 2017; p.62). In all cases experiments on sustainability solutions were carried out subject to decision making negotiated between researchers and farmers, i.e. under participatory control.

With as ultimate goal to enhance the usefulness of research for sustainable development, in this paper we aim to analyse the extent to which the six sustainability transition experiments contributed to the evolving knowledge base on scientific contributions to sustainability transitions, as well as to practical insights for design-oriented research project governance and management. We do so by analysing the extent to which co-innovation across six cases of sustainability transition experiments in Uruguay and the European Union contributed to desired outputs and outcomes, and how this was accomplished in terms of processes and inputs. The analysis is reflexive to the extent that each author of this paper was involved in the development and execution of at least one of the projects. In the next section, we describe the history and evolution of the co-innovation approach. After introducing the analytical framework of the paper, we describe the cases and the methods. In the Results section individual and cross-case analyses are presented starting from the cases' outputs and connecting these to outcomes, processes and inputs. We end with a discussion of implications of the findings for governance and management of design-oriented projects.

2. Crafting co-innovation

2.1. Situating co-innovation

Following Goewie (1993), we distinguish between analysis-oriented research and design-oriented research. Both research strains start from perceived problems. Analysis-oriented approaches decompose these problems into researchable questions and mobilise procedures that enable elucidation of structure – function - purpose relations, thus arriving at new knowledge on causal relations. Design-oriented approaches, in contrast, translate the problem at hand into solution specifications and elaborate purpose – function – structure relations, to arrive at decisions on solutions. The two strains may be connected through exchanges of analytical knowledge and questions emerging during design that require analytical knowledge. Adopting an action-oriented agronomic and development viewpoint, Giller et al. (2008) developed the DEED research cycle, in which analysis-oriented ('Describe' and 'Explain') and design-oriented ('Explore' and 'Design') research steps are connected. Here we combine the DEED research cycle with the learning cycle of Kolb (1984) to express the role of research contributions to actionable knowledge development (Fig. 1).

Within sustainability science (Fazey et al., 2018; Pohl and Hirsch Hadorn, 2008) an emerging body of knowledge addresses the systematic cross-case learning from sustainability transition experiments concerned

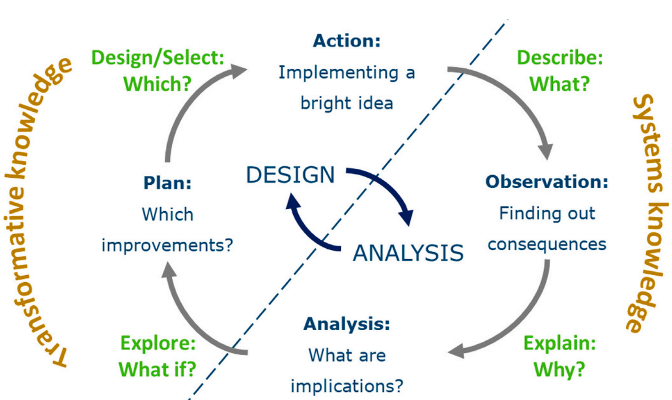

Fig. 1. Actionable knowledge cycle, which combines the experiential knowledge cycle (after Kolb, 1984) and the scientific knowledge development cycle (DEED – Describe, Explain, Explore, Design; Giller et al., 2008). Types of knowledge production distinguished in sustainability sciences are arranged around the cycle.

with sustainability problems and solutions in areas such as urban development, mobility, energy, or food. This type of analysis-oriented research is also denoted as transformation research producing systems knowledge, as opposed to transformative research that results in target (or: normative) knowledge showing the need and the options for change and their consequences, and transformative knowledge, which enhances reflection on project governance and management during project execution (Fig. 1).

2.2. The three domains of co-innovation

The term co-innovation, as described in this paper, was coined in the EULACIAS project (see below). The project developed on-farm analysis-and-design cycles in local co-innovation pilots to reverse unsustainable resource use and insufficient economic results by systemically rethinking farm livelihood strategies. Based on early experiences with interactive farming systems design in the Netherlands (Rossing et al., 1997; Vereijken, 1997; Wijnands, 1999) and participatory cropping systems design in Australia (Carberry et al., 2002; McCown, 2002), the project was structured in such way as to provide attention to both knowledge accumulation for and with the local co-innovation pilots, and to benefit from emerging insights on open innovation and evaluation for learning (Douthwaite, 2002; Douthwaite et al., 2003). Knowledge accumulation was addressed through thematic workpackages dealing with the elaboration of regional baselines and scenarios, and with farm-level baselines and evolution of sustainability indicators supported by modelling. Process management was harnessed in a Co-innovation workpackage led by the team from the International Center for Tropical Agriculture (CIAT) that had developed the Participatory Impact Pathway Analysis methodology for project design and learning-oriented monitoring (Alvarez et al., 2010). After 2 years of evolving the co-innovation approach, a visual representation was developed of its key domains (Fig. 2), including a complex adaptive systems approach, social learning setting and dynamic project monitoring. These domains have remained across the projects described in this paper. Operationalisation has depended on the project-specific constraints and progressive insights. We describe the co-innovation domains in the next paragraphs.

Reflecting a dynamic view of agricultural innovation systems (e.g. Hall et al., 2001; Klerkx et al., 2012; Leeuwis, 2004), the change-orientation of the EULACIAS project prompted a complex adaptive system (CAS) perspective. Initially developed for ecological and social-ecological systems (Levin, 1998), Douthwaite et al. (2002), and more recently, Douthwaite and Hoffecker (2017) used the CAS perspective to provide guidelines for what the latter authors called complexity-aware approaches to agricultural research. Following Axelrod and Cohn (1999), a CAS is described as consisting of agents, entities which can make things happen, along with artefacts (e.g., things, databases, stories) and strategies including values and norms that the agents use in their interactions with other agents and with artefacts. Evaluation of the results of these interactions leads to the selection of strategies or artefacts that are combined or copied, or to the invention of new ones. This evolutionary process introduces innovations, i.e. inventions as well as the way they are considered and used (cf. Prost et al., 2018). Douthwaite et al. (2002) and Douthwaite and Gummert (2010) introduced the term Learning Selection to describe the process by which the generated variation is evaluated and discarded, or remoulded and included in practices. The CAS perspective suggests that project design and management should (i) foster variation in agents, artefacts, strategies; (ii) stimulate variation in interaction patterns to generate novelties for the Learning Selection process; (iii) support selection processes to better allow survival and spread of the selection results (cf. Duru et al., 2015). The third consequence hints at the notions of 'anticipating niche and structural change' in the Reflexive Interactive Design approach (Bos et al., 2009; Bos and Grin, 2008) and 'anchoring' as described by (Elzen et al., 2012a).

Creating a social learning setting emerged as the second domain of

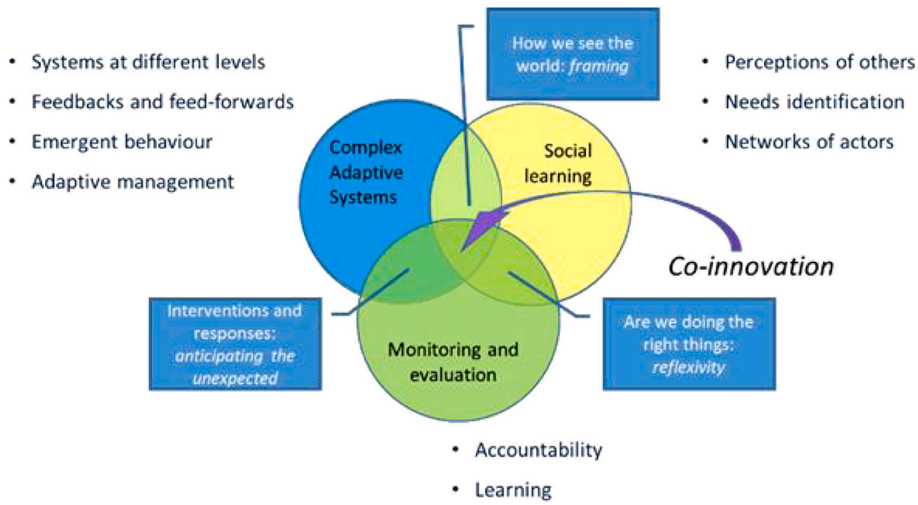

Fig. 2. Three domains of co-innovation, with keywords per domain and results emerging at their overlap. Adapted from Rossing et al. (2010), Dogliotti et al. (2014a) and Albicette et al. (2017).

co-innovation. We take social learning to refer to the way collaboration changes individual values and behaviour, in turn affecting collective culture and norms (e.g. Blackstock et al., 2007). The term has been used by a range of scientific disciplines, resulting in a wide variety of meanings and consequences (Wals and van der Leij, 2007). Ison et al. (2013) identified seven clusters of metaphors around which social learning could be considered. They concluded that rather than coming up with a unifying description, the richness of interpretations can be maintained for opening spaces for innovation. In the evolution of the co-innovation approach, creating social learning settings implied creating regularly recurring events with formats by which the diversity of project actors felt invited to share their perspectives on the results achieved, on the interactions with the other project participants, and on the direction of the project. Building on and contributing to the CAS perspective, this was meant to stimulate an evolving project language and framing of the problems and approaches taken on in the project, as well as enhancing trust among project actors.

The third domain of co-innovation, dynamic monitoring and evaluation, focused on which and how project results were produced, and used the results reflectively to establish whether project actors still agreed on project directions. Such use of monitoring has been referred to as formative evaluation (Blackstock et al., 2007; Wigboldus et al., 2016) and has been recognised as essential for sustainability transitions (Cundill and Fabricius, 2009; Fazey et al., 2018; Hegger et al., 2012; Pahl-Wostl, 2009). In addition, the projects mobilised resources for accountability evaluation as part of obligatory financial and technical reporting to donors. Finally, ex-post, summative evaluations were carried out to draw lessons from experiences, which aimed to contribute to social learning in the longer term. Blackstock et al. (2007) distinguished four purposes for evaluation; proving (to reveal efficiency or value); controlling (to demonstrate and maintain quality); improving (in relation to objectives); and learning (transforming the individual participant). Within co-innovation, proving provided the material for accountability, while the learning and improving purposes of monitoring and evaluation supported social learning within the CAS context.

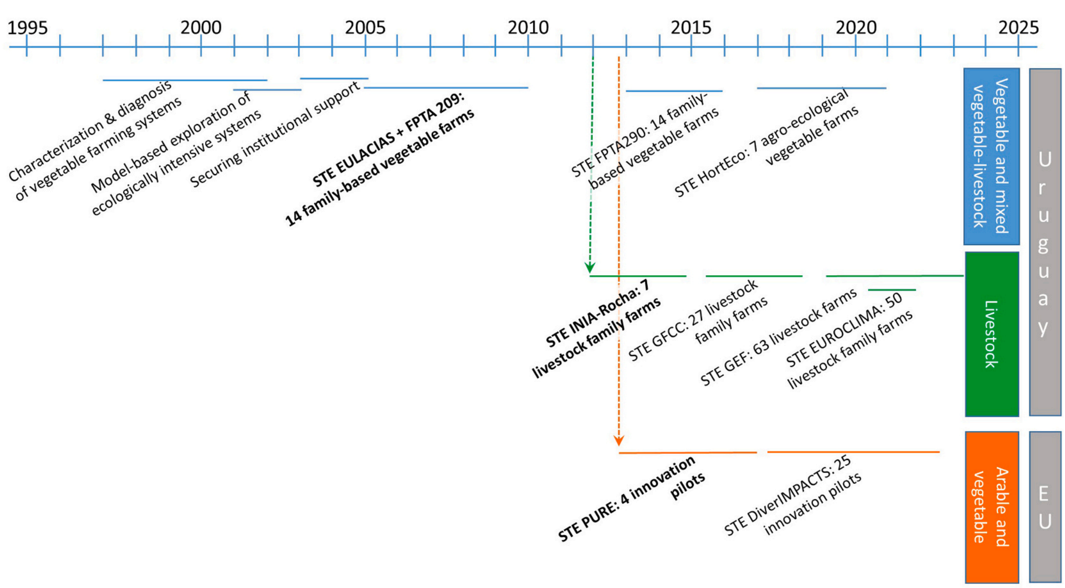

Fig. 3. Pedigree of co-innovation projects originating from the EULACIAS project. Timelines describing EULACIAS' pre- and post-project major activities, and implementation duration of the other projects. Projects in bold are part of this paper. STE is sustainability transition experiment.

2.3. Evolution of the approach

Since the EULACIAS project, co-innovation evolved through projects in Uruguay and in the European Union (Fig. 3). In Uruguay, new projects were developed with vegetable and mixed vegetable-livestock farmers, transferring the approach to other regions and actors, and capitalising on the knowledge built in the research team. Immediately after the EULACIAS project, a project in the livestock family farming sector was started, which is part of the empirical material of this paper (INIA-Rocha). Following from this experience, a number of projects were executed, some of them with international partners. Various projects were running at the time of writing. In the European Union, the co-innovation approach was further developed in a project on integrated pest management (IPM) solutions with 4 country innovation pilots (PURE). These experiences were scaled out in an ongoing project on crop diversification.

3. Analytical framework: project output related to outcome, process and input

Sustainability transitions and the transformational changes in practices and power structures that bring them about develop over large time frames (Geels and Raven, 2006), involving decades or generations. Evaluating the contribution of projects with time frames of 3 to 5 years to such ultimate aims is therefore faced with the inherent delay between the project's activities and the aspired consequences, challenging conventional scientific causation. Transition researchers have emphasized learning as part of transition experiments as the key mechanisms for appraising progress towards sustainability goals (e.g. Armitage et al., 2008; Fazey et al., 2018; Luederitz et al., 2017). Projects assume a dual role of generating changes as well as providing the means to learn about next change efforts. The latter requires iterative and reflexive monitoring and evaluation within and across projects designed for experimenting with sustainability transitions. To assess and explain the extent to which co-innovation-based project governance and management generated the desired effect on sustainability transitions towards ecological intensification, we adopted the preliminary evaluative scheme for sustainability transition experiments described by Luederitz et al. (2017). The evaluation scheme takes the frequently used logic model of project evaluation (McLaughlin and Jordan, 2010 in Luederitz et al., 2017) as the point of departure and asks the questions: What was generated (evaluative dimension: outputs); What was accomplished (evaluative dimension: outcomes); How was it completed (evaluative dimension: processes); and What was invested (evaluative dimension: inputs). Each of the dimensions was specified in terms of features that were derived from literature review of transition experiments; no details were provided, however, on the process of feature derivation. For the sake of clarity we represent the dimensions and their evaluative features in Table 1.

Starting from the outputs produced by the project, the analysis addresses the extent to which the outputs have resulted in desired outcomes, and have been supported by processes and inputs. Comparing these relations among sustainability transition experiments aspires to reveal patterns of relations between more and less effective interactions among project logic components to foster future project governance and management.

4. Description of the co-innovation cases and methods

4.1. The co-innovation cases

Three projects provided empirical material for this paper; EULACIAS, INIA-Rocha and PURE. In EULACIAS and INIA-Rocha, environmental, social and productive/economic sustainability problems were addressed, while PURE focused on environmental and economic problems. Solutions evaluated in the projects concerned ecological

Table 1
Salient features in four evaluative dimensions for appraising sustainability transition experiments (STEs). Summarized from Luederitz et al. (2017).

Evaluative dimension	Feature	Description
Outputs – direct results of STEs	Built capacities	Skills, abilities and crafts that enable people to act sustainably in everyday life: strategic competence in developing effective interventions; practical skills; interpersonal competence for building coalitions.
	Actionable knowledge	Evidence-supported and tested guidance for practical application to address a sustainability problem in context. Comprises three knowledge sources: analytical-descriptive knowledge about the sustainability problem; normative knowledge about the sustainability goals; transformational knowledge on most effect solutions
	Accountability	Ensuring participants' confidence and commitment to implement the actions selected in the STE, as illustrated by positive participant attitudes or formalised commitments.
	Structural changes	Physical changes: creation of new or changed buildings, infrastructures, technologies and products. Societal changes: creation of new or changed networks and organisations, values and norms, rules and policies, discourses.
	Facilitate uptake of experiments	Evidence that the sustainability solutions work beyond the specific STE conditions, in terms of transferability and scalability. Transferability: evidence that the lessons learned in the experiment are applicable in different contexts. Scalability: evidence that the experiment can be successfully repeated in a similar context (scaling out), or integrated at higher system levels (scaling up). Accounting for uptake for unintended desirable or undesirable consequences of the STE.
Outcomes – extent of contribution to sustainability	Socio-ecological integrity	Recognition of the interdependence of human well-being and bio-physical conditions, as witnessed by preventing degradation of ecosystem services and enhancing regenerative capacity of natural resources.
	Livelihood sufficiency & opportunity	Securing access of individuals and communities to what is needed for a decent life, both in material and social-psychological terms.
	Intra- & intergenerational equity	Developing choices that reduce the gap between rich and poor and enhance opportunities of future generations to pursue sustainable lives.
	Resource maintenance & efficiency	Creation of sustainable livelihoods for all by increasing use efficiencies and minimizing negative effects on the environment

(continued on next page)

Table 1 (*continued*)

Evaluative dimension	Feature	Description
	Stewardship and democratic governance	Provide arrangements that support individual and collective decision-making fostering on-going collective actions, social inclusion and ownership
	Precaution & adaptation	Acknowledgement of uncertainty, and anticipation and avoidance of unpredictable risks. Precautionary approaches and preparation for surprises.
Processes – sequences of actions conducted in STEs	Sequence of actions	In experimentation actions need to include: (i) baseline and goal for intervention; (ii) structured administration of the intervention; (iii) measuring effects; (iv) evaluation of effect against sustainability criteria; (v) providing evidence-based recommendations. These steps are evidenced in the project's planning.
	Sound methodology	Scientifically supported methods for the actions under the previous feature.
	Collaboration	Empowerment of collaborators through appropriate choice of mechanisms of collaboration, in the core transdisciplinary and inclusive.
	Reflexivity & learning	Structural iterative analysis of all components of the experiment to support (first and second order) learning.
	Transparency	Ensuring open and truthful reporting on intensions and actions, in support of researchers' accountability towards collaborators.
Inputs- contributions to and investments in STEs	Awareness	Ability and consciousness of participants of the need for radical real-world change.
	Commitment	Willingness, promise and positive attitude of participants to engage in radical rather than incremental change.
	Expertise	Professional skills and experiences of participants, such as related to experimentation and reflexivity, as well as on ethics and power relations.
	Trust	Mutual willingness to collaborate on equal footing among participants of the STE
	Support	Structural, financial and non-financial resources and assistance from public and private authorities.

intensification at farm and crop levels. In all projects, the co-innovation approach was applied for project governance and management. Projects characteristics are summarised in Table 2. An extensive description of project background, project organisation and working methods is provided in the Supplementary Materials.

The EULACIAS project addressed decreasing land and labour productivity and poor farmer working conditions on family vegetable farms in Uruguay by introducing long crop rotations, changes in organic matter management, and integration of beef cattle (Dogliotti et al., 2014b), as suggested by model-based explorations (Dogliotti et al., 2005). The INIA-Rocha project connected researchers with family livestock farmers on the Campos natural grasslands in Uruguay to improve and stabilise low productivity levels and family income, while maintaining or improving natural resources and labour productivity. Sustainability solutions evaluated included strategic changes in pasture-herd interactions to synchronise forage availability with cow and calf demands along the year and maximise forage and animal productivity (Albicette et al., 2017). The PURE project aimed to reduce the dependency on pesticide use in 6 major crops types by developing and implementing integrated pest management (IPM) solutions. Within PURE a small Co-innovation workpackage aimed to develop, implement and evaluate a co-innovation approach in four country innovation pilots equivalent to four cases in this study. Two cases had a primary focus on wheat (Denmark – DK and France – FR), the other two on vegetables (Germany – DE and the Netherlands – NL). Each case was headed by a local case study team of 2 or 3 (DE) researchers and/or advisors.

The cases were organised in different levels. Common to all projects was the level of the core project teams consisting of researchers and advisors. In EULACIAS and INIA-Rocha the core project team together with the farmers constituted a separate level, while in PURE these interactions were considered to be part of the activities of the local case study teams. Hence, while the core project teams in EULACIAS and INIA-Uruguay engaged with the farmers in redesign, the core project team in PURE took on the role of facilitating reflection on activities and direction in the local cases. EULACIAS and PURE included an international project team level. INIA-Rocha was constructed to have a level with an inter-institutional network that included the farmers, the core project team and national and local professional organisations on rural development.

In all cases, reflection on direction, progress and planning was structured around regular meetings at the various organisational levels. Methods included informal discussions during farm visits and Participatory Impact Pathway Analysis (PIPA; Alvarez et al., 2010) supported by tools from participatory action research (Macdonald, 2012) and Reflexive Monitoring in Action (RMA, van Mierlo et al., 2010b). Except for the informal discussions, all meetings were formally facilitated and monitored. Progress was monitored through complexity-aware indicators (cf. Britt and Patsalides, 2013; Douthwaite and Hoffecker, 2017), and more traditional agronomic approaches and performance indicators. The latter were based on MESMIS (López-Ridaura et al., 2002) in the Uruguayan cases. In PURE, teams used locally agreed protocols to measure performance.

4.2. Data collection and analysis

For the purpose of this study, change-oriented researchers or advisors from each of the three projects were approached to participate in the evaluation described in this paper. Each participant had been part of the team that implemented the co-innovation approach, acting as organisers, facilitators or project monitors (cf. van Mierlo et al., 2010a), and in some cases additionally acting as analytical researchers, mainly on agronomic topics. As part of the invitation, the purpose of the evaluative framework was explained by summarising the concepts and providing details of the features following Luederitz et al. (2017). Participants from each project were asked to revisit project materials, such as scientific evaluative papers, annual reports, or field notes to recall processes, events and outputs of the projects. In addition, they were asked to think about effects beyond the projects' lifetimes.

The EULACIAS project was evaluated by the first and last authors of this paper who acted as project coordinator and Uruguayan case study leader in EULACIAS, respectively. Individually, assessments for each of the features were drafted and compared in a working session to check for congruence and completeness. To evaluate the INIA-Rocha project, four research team members from INIA, the national research organisation responsible for the project, met during two working sessions to discuss the contribution of the project in terms of each of the features. The results of the sessions were discussed with the last author of this paper, who was involved in the INIA-Rocha project but not employed by INIA. To evaluate the four co-innovation pilots in PURE two members of the PURE supervising team (one of which is the first author of this paper) met on two occasions, based on a semi-structured interview guideline derived from the features of the framework. Similarly, semi-structured

Table 2
Characteristics of the co-innovation projects providing the empirical cases for this paper.

Project	Aim	System description	Participatory dynamics	Methods[1]	Complexity-aware indicators[2]	Performance indicators[2]	Timing and funding	Reference
EULACIAS – Uruguay	To reverse unsustainable use of natural and agro-resources and insufficient economic results by rethinking of entire livelihood strategies in a systemic way	Focus on farms. Formal networks at three levels: (i) Farm: 14 farms and 20 farmers, 2 advisors and up to 23 researchers; (ii) Local researcher and advisor team (up to 25 persons); (iii) International project team (around 30 persons). Informal contacts with professionals in family agriculture	Two-weekly visits to the farms by an advisor and a researcher; monthly local researcher and advisor team meetings; 6-monthly local research team reflection meetings; annual international project meetings.	Agronomic monitoring protocols. MESMIS diagnosis. PIPA (vision, network analysis, problem trees, logframe, Knowledge-Attitude-Skills-Aspirations). Reflection supporting approaches, e.g. peer review, fishbowl, world café	Changes in vision, problem trees, actor attitudes. Most Significant Change (MSC) stories. Ex-post analysis of new ways of working among (i) researchers and advisors; (ii) farmers.	Based on MESMIS: productivity, stability, reliability/ adaptability/ resilience, self-reliance. Farmer health and well-being.	2005–2010; INIA and EU-FP6, approx. 450 kU$S	Dogliotti et al. (2014b); Rossing et al. (2010)
Co-innovating for the sustainable development of family-farming systems in Rocha-Uruguay	To contribute to the improvement of family farming systems' sustainability, rural development, and improvement of farmers well-being	Focus on farms and their innovation support system. Formal networks at three levels: (i) Farm: 7 farms and farm families, 1 advisor and up to 15 researchers; (ii) Local research team including advisor (up to 15 persons); (iii) Inter-institutional network of national and local organizstions on regional rural development (up to 32 persons).	Monthly farm visits by the advisor, occasionally with a research team member; 6-monthly research team reflection meetings; 6-monthly meetings of the inter-institutional network.	Agronomic monitoring protocols. Interviews. MESMIS diagnosis. PIPA (vision, network analysis, problem trees, logframe, Knowledge-Attitude-Skills-Aspirations). Reflection supporting approaches from Participatory Action Research	Changes in vision, problem trees, actor attitudes. Frequent exit polls on satisfaction with overall achievements, project performance, future impact of results. Ex-post scientific review.	Based on MESMIS: productivity, stability, reliability/ adaptability/ resilience, self-reliance. Environmental and social indicators.	2012–2015; INIA, approx. 344 kU$S	Albicette et al. (2016); Albicette et al. (2017); Blumetto et al. (2019)
PURE - EU	To provide practical IPM solutions to reduce dependence on pesticides in selected major farming systems in Europe	Focus on 4 teams of 2 researchers/ advisors in 4 countries. Formal networks at three levels: (i) Local research/ advisor team (2–3 persons); (ii) Local network of farmers, advisors and researchers, maintained by the local teams; (iii) International co-innovation hosting team.	Four co-innovation workshops (after 6, 12, 24, 36 months) situated in country case area; 6-monthly reflection meetings between hosting team and local research/ advisor team.	Local agronomic measurement protocols. PIPA (vision, network analysis, problem trees, logframe, Knowledge-Attitude-Skills-Aspirations). Team dynamics and reflection supporting approaches from RMA, e.g. peer review, dynamic learning agenda.	Narratives on changes in actor attitude towards case study ambitions on reducing pesticide input; ex-post scientific review.	Based on local protocols, e.g. yields of IPM practices compared to conventional; farmer assessment of feasibility of IPM practices.	2011–2015; EU-FP7, 155 kU$S	Klerkx et al. (2017)

[1] References to methods: MESMIS – (López-Ridaura et al., 2002); PIPA – Alvarez et al. (2010)); RMA – van Mierlo et al. (2010b); PAR - Macdonald (2012); Knowledge-Attitude-Skills-Aspirations -Rockwell and Bennet (2004).
[2] On the difference between complexity-aware and performance indicators: Britt and Patsalides (2013); MSC - Davies and Dart (2005).

interviews were held with one member of the Danish case and one member of the French case. The interviews were audio-recorded and the results, coded in terms of the features of the evaluation framework were shared with the interviewees to check for validity and completeness. In all cases, topics beyond the framework features were encouraged in the spirit of the tentative nature of the framework.

The results of the individual assessments per project and the reasons for differences were then discussed among all authors of this paper to ensure a consistent interpretation of the framework features. Per case study and for each feature scores between 1 (no to hardly any contribution to the feature) and 5 (completely or strongly contributing to the feature) were agreed upon. The scores were used to support the cross-case comparison. While the scores supported summarising and visualisation of differences among projects, they were presumed to be considered only in combination with the accounts for each feature.

5. Cross-case findings

5.1. Outputs

Supported by a similar co-innovation project management perspective, the 6 cases developed distinctly to produce their output features (Table 3; details in Supplementary Materials). The two Uruguayan and the FR cases built output features that were supportive to sustainability transitions. The DE and NL cases were least able to do so, and the DK case took an intermediate position (Fig. 4).

The overall more effective cases (EULACIAS, INIA-Rocha, FR) resulted in *built capacities* among the participants on systemic solutions to persistent production problems, along with *actionable knowledge*. For instance, they developed approaches and tools for farm and crop level diagnosis and redesign, and for creating a project setting that enabled joint learning. The three cases demonstrated farmer-supported physical changes at the level of entire farms or (FR) of cropping systems. In the Uruguayan cases, changes were evidenced by quantitative measurements, in the FR case by quali-quantitative measurements as was custom in the study group. Participants in the cases were committed to implement the management changes (output features *accountability* and *structural changes – physical structures*). Such results were also found for the DK case, with farmers selecting IPM measures and implementing them on their farms, but these concerned crop-level changes (e.g. wide row spacing to facilitate mechanical weeding; cultivar mixtures to reduce disease pressure) implemented as part of on-farm technology demonstration. In the DE and NL cases, we found little indication of these project-attributable output features, except *built capacity* in the research teams.

Scores for *structural changes in the societal realm* and the features describing *facilitation of uptake* showed greater diversity. The outputs features *transferability* and *scalability*, defined by Luederitz et al. (2017) as part of uptake facilitation, were found to be supported by EULACIAS, INIA-Rocha and the FR cases through their connection with networks outside the project's core group. Results showed that in particular the way of working was transferable, with the broad domains of co-innovation being amenable to other types of sustainability transition experiments in agronomy or the wider food system (cf. Fig. 3). The limited outputs of the DK, DE and NL cases to *structural changes in the societal realms* are likely to have negatively affected wider uptake.

Among the *unintended effects*, co-opting of the term co-innovation occurred in all cases, with both positive and negative effects. The negative effects particularly concerned incomplete or incorrect interpretations of the notion, such as reducing it to 'working with farmers'. In the DK and FR cases positive unintended effects were found as a result of role changes between the advisors and the farmers. When given the mandate to set the agenda, the farmers were found to come up with new questions and ideas, which provided the facilitators with a new demand for knowledge. In addition, the farmers looked for help on solutions with actors that had not been identified before, thus creating a dynamic exchange network. Such farmer-initiated exchanges were not seen in the Uruguayan cases, possibly due to differences in education levels; Uruguayan farmers had mostly only attended primary school, while in Europe farmers received at least high school education and often also benefitted from (applied) university training. In the next sections we describe the other three dimensions of the sustainability transition experiments in relation to these outputs.

5.2. Outcomes in relation to outputs

All cases addressed *socio-ecological integrity*, *resource maintenance and efficiency* and *precaution and adaptation*, by stimulating agricultural innovation system, farm-level or crop-level changes to reduce reliance on external inputs and increase farmer autonomy. The cases that were more effective in producing outputs were also seen to be more effective in producing these outcomes: the results showed sustained commitment of the networks developed in EULACIAS, INIA-Rocha and FR to continue with the initiated sustainability transitions (Fig. 3). In the DK case, co-innovation remained supported by individuals from the case, but did not scale out or up, despite its performance in producing IPM outputs. The advisory organisation's institutional strategy favoured a technology focus, in which projects accompanied farmers with new or lesser-known technologies for some time, to move on to different technologies after the project. Considering the farm as a system comprising interacting components was regarded to be the role of the farmer rather than of the specialist advisor or researcher. In the DE and NL cases, the relative lack of outcome features had different origins. The institutional mandate of the DE research institute, being federal and analytically oriented, did not favour continuation of the co-innovation approach, which required ability to locally adapt knowledge in collaboration with end users. In the case of the NL team, the lack of clear outputs hampered the team in promoting the approach more widely. In addition, we found a lack of structures to enhance institutional learning within the NL team's project-driven organisation. This was also mentioned in the interviews with the DK case. Thus, while there were individuals who adopted a systemic perspective, this did not translate into sustainability outcomes at the level of their own organisations or with the farmers that were included in the projects.

The outcome features '*livelihood sufficiency & opportunity*' and '*intra- & intergenerational equity*' were not assessed for the European cases. In contrast to the Uruguayan cases that took a whole-farm approach, the field and crop level approach in the European cases gave little basis for assessing these outcome features.

5.3. Processes in relation to outputs

The cases all built on the co-innovation approach developed in the EULACIAS project in which processes supported the complex adaptive systems and social learning perspectives, and dynamic monitoring and evaluation.

The Uruguayan projects created an archetypical *sequence of actions* by starting from quantitatively measured baselines followed by monitoring and evaluation of the effects of the farm-level interventions. In the DE, DK and FR cases the sequence of actions conformed to a classical agronomic comparison of field-level experiments with and without interventions, where the interventions evolved from year to year depending on progressing insights. In contrast to the Uruguayan cases the other cases used the results for internal use, and did not publish them scientifically. This limited opportunities to evaluate the *soundness of the methodologies*.

Methods supporting the process feature *collaboration* differed only slightly across cases. Differences were particularly related to the strength of the relations built between the group of researchers or advisors on the one hand and the farmers and advisors on the other. Context and expertise – both part of the input features – were found to contribute to these differences. Collaboration in the DK and FR cases was

Table 3
Summary of salient features describing outputs, outcomes, processes and inputs in the 6 cases on co-innovation for fostering ecological intensification.

Evaluative dimension	Feature	EULACIAS	Rocha	PURE-DK	PURE-FR	PURE-DE	PURE-NL
Outputs	Built capacities	Beneficiaries: participating farmers, agronomic researchers, advisors, post-graduate students, but not with sociological researchers	Beneficiaries: farmers, agronomic researchers, advisors, post-graduate students, national policy makers and regional and local organisations	Beneficiaries: participating advisors and farmers	Beneficiaries: participating advisors and farmers, the regional advisory service and scientists	Beneficiaries: participating scientists and farmers	Beneficiaries: participating scientists
	Actionable knowledge	1. Farm system diagnosis; 2. Planning for farm system redesign; 3. Iterative testing and improving; 4. Shaping a co-innovation approach in context	1. Farm system diagnosis; 2. Planning for farm system redesign; 3. Iterative testing and improving; 4. Shaping a co-innovation approach in context; 5. Networking to scale up and out	1. Crop system diagnosis; 2. Planning for crop system redesign; 3. Iterative testing and improving; 4. Shaping a co-innovation approach in context	1. Farm system diagnosis; 2. Planning for farm system redesign; 3. Shaping a co-innovation approach in context; 4. Networking to scale up and out	None	None
	Accountability	Confidence and commitment evidenced by uptake of change proposals during the STE and various follow-up projects	Confidence and commitment evidenced by uptake of change proposals during the STE and various follow-up projects	Confidence and commitment built during the project not continued in next projects	Confidence and commitment evidenced by uptake of change proposals during the STE and various follow-up projects	Limited confidence and commitment built during the project; no continuation in next projects	No confidence and commitment built on sustainability solutions
	Structural changes	Physical: changes in crops and animals, cropping technologies and their planning; enlargement of buildings in some cases. Societal: new relations in farmer-advisor-researcher networks; new perspective on extension service and role of research; no effect on society at large.	Physical: changes in herd and grassland management technologies; enlargement of buildings in some cases. Societal: new relations in farmer-advisor-researcher-policy maker networks; new perspective on extension service and role of research; no effect on society at large.	Physical: changes in crop management technologies. Societal: little effect beyond project participants	Physical: changes in cropping patterns and technologies, but generally not at whole-farm level. Societal: new relations in farmer-advisor-researcher networks; new perspective on change-oriented research	Physical: inclusion of flower strips. Societal: farmer insight into usefulness of pest monitoring	None
	Facilitate uptake of experiments	Way of working but not the actual changes were transferable and scalable, with emphasis on scaling out, as evidenced by follow-up projects. No attention for unintended effects of co-option of 'co-innovation' concept	Like EULACIAS. Scaling up effects were stronger due to embedding in the regional and national innovation system. Unexpected positive effects of joint communication plans were successfully exploited	No activities were undertaken to secure uptake after the project's lifetime. Unexpected positive effects of giving farmers responsibility for the project's direction were exploited	Way of working but not the actual changes were transferable and scalable. Scaling out in new projects; scaling up by uptake of the approach in a new R&D unit. Unexpected positive effects of giving farmers responsibility for project direction were exploited	No activities to secure transferability or scalability; unexpected negative effects of statements in media were addressed	No activities to secure transferability or scalability; unexpected lack of interest among stakeholders addressed in various ways
Outcomes	Socio-ecological integrity	Positive effects on soil erosion, soil organic matter and less or no pesticide use by improved soil and crop management	Positive effects on grassland and meat productivity, and workload, while maintaining high levels of environmental indicators.	Some positive effects on pesticide use in wheat and oilseed rape.	Positive effects at the level of cropping systems management and awareness of systemic nature of persistent problems.	Greater knowledge of participating farmers on their natural resource base.	None
	Livelihood sufficiency & opportunity	Clear positive effects on family income and on farmers' rewards for labour compared to regional peers.	Clear positive effects on family income and on farmers' rewards for labour compared to regional peers.	–	–	–	

(continued on next page)

Table 3 (*continued*)

Evaluative dimension	Feature	EULACIAS	Rocha	PURE-DK	PURE-FR	PURE-DE	PURE-NL
	Intra- & intergenerational equity	Positive effects due to more equitable labour reward and enhanced economic and social performance, but no explicit attention.	Positive effects due to more equitable labour reward and enhanced economic and social performance, but no explicit attention.	–	–	–	–
	Resource maintenance & efficiency	Clear positive effects by more sustainable production methods.	Clear positive effects by more sustainable production methods.	Positive effects in one crop species, with an application in a second.	Positive effects by more sustainable production methods at cropping system level.	Positive effects of crop monitoring for pests and natural enemies.	None
	Stewardship and democratic governance	Positive effects of individual and group engagement in sustainability decision-making	Positive effects of individual and group engagement in sustainability decision-making with impact at a hierarchically higher level	Positive effects of individual but not of group engagement in sustainability decision-making	Positive effects of individual and group engagement in sustainability decision-making	Joint negotiation among previously disconnected levels of research and development, and farmers	None
	Precaution & adaptation	Changes inspired by social and biophysical unpredictabilities	Changes inspired by social and biophysical unpredictabilities	Changes inspired by social and biophysical unpredictabilities	Changes inspired by social and biophysical unpredictabilities	Changes inspired by social and biophysical unpredictabilities	Changes inspired by social and biophysical unpredictabilities
Processes	Sequence of actions	Full scientific process: baseline, design of intervention, implementation and monitoring, recommendations	Full scientific process: baseline, design of intervention, implementation and monitoring, recommendations	Component-based comparison of treatments with and without	Component-based comparison of treatments with and without	Component-based comparison of treatments with and without, in a demonstration format	Annual farmer plans with changes compared to a baseline but without rigorous monitoring
	Sound methodology	Structured procedures and adequate scientific methods	Structured procedures and adequate scientific methods	Structured procedures and methods for farmer demonstration	Structured procedures and methods for farmer demonstration	Structured procedures and methods for farmer demonstration	Farmer self-reporting
	Collaboration	Facilitation of collaboration among relevant stakeholders in the experimentation process	Facilitation of collaboration among relevant stakeholders in the experimentation process	Facilitation of collaboration among relevant stakeholders, with no attention for higher hierarchical levels	Facilitation of collaboration among relevant stakeholders in the experimentation process	Collaboration addressed a narrowly defined group of stakeholders in view of the sustainability problem at hand	Collaboration addressed a narrowly defined group of stakeholders in view of the sustainability problem at hand
	Reflexivity & learning	Approach stimulated both first and second order learning	Approach stimulated both first and second order learning	Approach stimulated both first and second order learning	Approach stimulated both first and second order learning	Approach stimulated both first and second order learning	Approach stimulated both first and second order learning
	Transparency	Openly published results and documentation of the decision-making process. Some mass media attention	Openly published results and documentation of the decision-making process. Strong mass media attention	Openly published results and documentation of the decision-making process	After a start with a researcher-agenda, open documentation of the decision-making process and published results	Difficulty in conveying intention of the experiment to the farmers and advisors; lack of transparency on position on pesticides	Difficulty in conveying intention of the experiment to potential actors
Inputs	Awareness	High initial awareness in the research and farmer teams of need for transformational change	High initial awareness in the research team of need for transformational change. Low initial awareness among the farmers	Attention focused on incremental change	Evolution from attention for incremental change to systemic change	Attention focused on incremental change with limited awareness of the co-innovation approach	Attention focused on incremental change with limited awareness of the co-innovation approach
	Commitment	High commitment to engage and continue the experiment	High commitment to engage and continue the experiment	High commitment for incremental change but less so for systemic change	High commitment to engage and continue the experiment	Limited commitment and only for incremental change	Limited commitment and only for incremental change
	Expertise	Adequate technical and participatory skills represented	Adequate technical and participatory skills represented	Adequate technical skills, with participatory skills growing over time	Adequate technical and participatory skills accruing over time	Emphasis on technical skills	Emphasis on technical skills
	Trust	High level of trust from start	High level of trust from start	Trust increased over the course of the project	High level of trust from start	Breakdown of trust due to researcher interview	Trust based on credibility of the organization

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Table 3 (*continued*)

Evaluative dimension	Feature	EULACIAS	Rocha	PURE-DK	PURE-FR	PURE-DE	PURE-NL
	Support	Adequate	Adequate	Financially and institutionally made possible by linking projects	Financially and institutionally strongly supported by linking projects	Financially and institutionally highly limiting	Financially and institutionally highly limiting

Dimension	Feature	EULACIAS	INIA-Rocha	PURE-DK	PURE-FR	PURE-DE	PURE-NL
OUTPUTS	Built capacities	4.5	4.5	4	4.5	2	2
	Actionable knowledge	4.5	5	4	4.5	1	1
	Accountability	5	5	4	5	2	1
	Structural changes - physical structures	5	5	4	4	2	1
	Structural changes - societal realms	4	4.5	3	4	1	1
	Facilitate uptake - transferability	5	5	2	5	1	1
	Facilitate uptake - scalability	4	4	2	4	1	1
	Facilitate uptake - unintended effects	3	4	3	4	2	2
OUTCOMES	Socio-ecological integrity	5	5	3	4	2.5	1
	Livelihood sufficiency & opportunity	5	5				
	Intra- & intergenerational equity	4.5	4.5				
	Resource maintenance & efficiency	5	5	3	4.5	2	1
	Socio-ecol. stewardship & democratic governance	4	4.5	3	4	1.5	1
	Precaution & adaptation	4	4	4	4	4	4
PROCESSES	Sequence of actions	5	5	4	4	3	2
	Sound methodology	5	5	4	4	4	2.5
	Collaboration	5	5	3	5	3	3
	Reflexivity and learning	5	5	5	5	3	3
	Transparency	4.5	5	4.5	4	2	3
INPUTS	Awareness	5	4	3	4	2	2
	Commitment	5	5	3	5	2	2
	Expertise	5	5	4	4.5	2	2
	Trust	5	5	4	5	2	3
	Support (incl. funding)	5	5	3	4	2	2

Fig. 4. Evaluative scheme for the 6 sustainability transition experiments, following Luederitz et al. (2017). Scores ranged from 1 (dark red) to 5 (dark green). The greater the score, the stronger the feature was brought out. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

similar to that in the Uruguayan cases, but collaborative arrangements in DE and NL were less firm (DE, affected by the 500 km distance between the team's location and participating farmers as well as the institute's mandate) or emerged very late in the project (NL, after connecting the case to an pre-existing farmer study group).

The co-innovation approach stimulated *reflexivity and learning* in the researcher-advisor core teams of the cases, as well as in the various combinations of core team and other actors, using methods derived from PIPA (Alvarez et al., 2010), PAR (Macdonald, 2012) and RMA (van Mierlo et al., 2010b), monitored using qualitative methods and/or entry-exit surveys. Differences found for this process feature, like for the previous one, related to the efficacy in translating learning into action to bring about desired outputs.

Regarding the process feature *transparency* we found differences in use of media and other supportive communication, in excess of the required or usual reporting through reports and open field events. Interviewees mentioned the importance of showing the approach to pave the way for structural changes and facilitate uptake. The INIA-Rocha and DK cases utilised videos and web-based media. In the EULACIAS, INIA-Rocha and FR cases the approach was discussed early-on not only with the participants but also with the embedding research and advisory organisations, by INIA-Rocha notably as part of a regional level in the project. Critical comments on pesticide use by the DE case study leader in a farmer magazine revealed a lack of convergence or transparency on the position towards pesticides, causing one farmer to leave the case. In both the DE and NL cases the intention of the activities – contributing to lesser dependence on pesticides – appeared to be not clear to the farmers, even though they appreciated having learned about insect monitoring in the field (DE) and exchanges on pest management with organic farmers (NL).

5.4. Inputs in relation to outputs

Awareness within the core teams of the need for a different way of collaboration with farmers was found to be high for the Uruguayan and the DK and FR cases. Awareness of the need for radical agronomic changes was generally less pronounced in the European IPM cases compared to the Uruguayan cases. The PURE project was structured around individual crops and therefore had built-in limitations to systemic change. Throughout the project, however, the farmer-led systems analysis in the FR case highlighted the need for whole-farm change, enabling the case to achieve the output features described earlier. In both Uruguayan cases, we found that the awareness of the core group of researchers and advisors of the need for systemic change caused other researchers and practitioners to join over the course of the project, as positive outputs became visible.

The level of awareness of the need for change, both in the way of working and in the agronomic realities, are reflected in the input feature *commitment*. As also suggested by Luederitz et al. (2017), the different levels of commitment were reflected in the output feature *accountability*, which in turn was nourished by *built capacities* and *actionable knowledge*.

Expertise for co-innovation was derived from process facilitation and teaching experiences in the core teams in the Uruguayan cases and in the PURE hosting team. The individual PURE cases differed strongly in expertise on process facilitation, with the scientific DE team having less and the teams with advisors having more expertise. Nevertheless, also the advisor teams commented that the systemic way of working was new to them and required adjustments in their role perceptions, from being the expert to being the facilitator, and in their contributions to agenda-setting, from technological proposals to systemic ones in which consequences of technologies were elucidated at the level of entire farms. Project entrepreneurship was found to be particularly important within the poorly funded PURE cases, where the DK and the FR cases managed to connect projects, people and funding streams within and across institutions to enhance financial inputs to the case.

We found high levels of *trust* among the various participants in cases with effective outputs in terms of the features *built capacities*, *physical structure changes* and *actionable knowledge* (EULACIAS, INIA-Rocha, DK, FR), but also for NL. Trust was associated with long-standing relations between core team individuals and their organisations on the one side and farmers and advisors on the other. Trust was also created by activities that addressed a feeling of urgency among the farmers and other actors. The NL case did not manage to identify such areas of urgency, and hence could not translate the existing trust into action. As shown in the DE case where an interview in a farmer magazine resulted in a strong decrease of trust, diverging worldviews need to be laid out explicitly to enhance transparency and trust.

Three types of *support* were found to have contributed to the outputs. First, institutional support was strong in the Uruguayan and FR cases. In Uruguay, EULACIAS and INIA-Rocha project results were taken as input by the government and by farmers organisations to develop research and extension programs for family farmers. In the FR case, the institutional support came through a specific structure (a mixed technical network or RMT by its French abbreviation) that stimulated joint work of scientists and other actors. For the DK case, we found that the case was tolerated within the institution, but that at national level questions were raised over the usefulness of the approach. In the DE and NL cases institutional support was not found. Second, budgets strongly affected the cases in Europe. The DK and FR cases started in the first year of the 4 year project while the DE and NL cases only started working with farmers 1.5 years into the project, forced by limited budgets. The DE team considered the case an option to enlarge the budget of the on-station analysis-oriented work on IPM in vegetables that was part of another work package. The budget issue also affected the NL case. Only towards the end of the project, the NL case overcame this by connecting to ongoing innovation projects, thus revealing project entrepreneurship. Budgets in the Uruguayan cases were more adequate, and through securing additional funds teams of up to 25 (part-time) researchers and advisors fostering the co-innovation work could be supported. Third, an essential source of support was the endorsement by the actors at the start of the cases in Uruguay, resulting from the extensive discussions on results of model-based explorations of sustainability transitions and the shared vision developed in INIA-Rocha through a rapid rural appraisal. These preparatory steps laid the groundwork for *awareness*, *commitment*, *trust* and the ensuing outputs. Such support was also secured in the FR case when the agenda-setting was transferred to the farmer group.

6. Discussion

Based on the co-innovation approach for governance and management of sustainability transition projects, we systematically compared 6 cases from Latin America and Europe in terms of 24 indicators. We found significant differences traceable to input features that determined the efficacy of the project interventions in terms of outputs and outcomes. This finding suggests that more careful construction of projects in terms of initial awareness, commitment, expertise, trust and support provides necessary conditions for more effective transition experiments. Furthermore, governance structures differed among the three projects, with less (PURE) or more (Uruguay) involvement of the targeted farmers in the projects, an explicit level to connect to wider networks (INIA-Rocha), or an international level (EULACIAS, PURE). The building of networks to connect a project's core activities to the broader institutional community was found to contribute positively to the continuity of the sustainability transition efforts. In terms of the three domains of co-innovation (Fig. 2), the results thus point to differences in identification of the complex adaptive systems to work in and to the degree to which social learning was facilitated within those systems, supported by monitoring and evaluation.

Each of the features of the analytical framework may be studied in detail in itself. Different studies have addressed e.g. the influence on positive outcomes of sustainability research by individual awareness, expertise and commitment (Neef and Neubert, 2010), institutional context (Klerkx et al., 2017), roles of stakeholders (Blackstock et al., 2007; Kilelu et al., 2013; Reed, 2008), or system definition (Klerkx et al., 2012; Schot and Steinmueller, 2018). While such analytical approaches provide conceptual or evidence-based elements for inclusion in sustainability transition experiments, they lack a holistic approach to project governance and management that supports the design of sustainability transition experiments (e.g. Beratan, 2014; Clark et al., 2016; Coutts et al., 2017; Douthwaite and Hoffecker, 2017; Fazey et al., 2018; Kok et al., 2019; Lacombe et al., 2018; Nassauer and Opdam, 2008). Recent policies that aim to transform dominant food systems such as the Farm to Fork strategy of the European Commission (European Parliament, 2020), multi-actor oriented approaches in projects under the Horizon 2020 and Horizon Europe research programmes (EIP-AGRI, 2017) and system-oriented projects of the CGIAR (Leeuwis et al., 2017) provide a strong demand to address the 'how to' question that has for long been considered to be at the margins of the realm of science (Fazey et al., 2018). Coutts et al. (2017) evaluate an approach to innovation in the New Zealand agricultural sector, also called co-innovation. In their approach, networking and interactive learning among heterogeneous actors targeted at organisational change are emphasised and described by nine principles that define a 'space for co-innovation'. These principles provide a useful specification for the social learning setting we have described here (Fig. 1). Our results show the importance of a complex adaptive systems perspective with attention for creating a project legacy by anchoring activities, and monitoring and evaluation as additional domains. Coutts et al. (2017) conclude that among the five projects they evaluated especially the ones that addressed problems of greater complexity and from a position of greater room for manoeuvre, i.e. more conducive input features, benefitted from a co-innovation approach. These conclusions support our framing of co-innovation as a method for governing and managing systemic rather than incremental change as part of sustainability transition experiments. In this sense, co-innovation bears more resemblance with the concept of collaborative adaptive management (Beratan, 2014).

The pedigree of projects in Fig. 3 suggests that co-innovation as an approach may be called scalable, in this case interpreted as geographically expanding (Douthwaite et al., 2003). Notwithstanding its popularity among research donors, such descriptive label hides relevant contextual factors that affect outputs and outcomes, as shown in this study. In line with the postulate of a project as a complex adaptive system operating within a complex adaptive problematic situation, co-innovation should be considered as a way of project governance and management that is to be adapted and re-adapted to each project context. The results show the importance of facilitating change-oriented (research) project managers through adequate project inputs and processes. Scaling co-innovation then revolves around creating conditions for scaling rather than pushing a (project governance and management) technology (Wigboldus et al., 2016).

6.1. Revisiting the co-innovation domains

We found four interacting organisational layers at which the co-innovation dimensions (Fig. 2) were implemented. These comprised (i) the local primary subject of the sustainability transition experiment; (ii) the local agricultural innovation system actors; (iii) the local core project team driving the sustainability transition experiment; (iv) the international core project team driving the co-innovation approach. We found continuity of the sustainability transition experiments and apparent success to be associated with a whole-farm rather than a crop-level perspective in layer (i); formal inclusion of (in INIA-Rocha), or at least informal involvement with (EULACIAS, FR) the local agricultural innovation system actors in layer (ii); frequent engagement of the core team from layer (iii) with the subject of the sustainability transition experiment in layer (i), which was supported by physical and social proximity; pre-existing links of the core team in layer (iii) with the subject of the sustainability transition experiment in layer (i) to facilitate project preparation; and, adoption of methods across layers to enhance transparent and inclusive reflection on aims and progress of the sustainability transition experiments. The international layers in EULAUCIAS and PURE were important for developing and fostering the co-innovation outlook and creating reflection spaces that enabled the project managers to get away from their everyday concerns. In the INIA-Rocha project, this role was fulfilled by the local core project team capitalising on expertise gathered during the EULACIAS project. This emphasises the usefulness of portfolio building across projects to enable learning on approaches and tools, and to benefit from networks.

Monitoring and evaluation were found to have provided insights for learning within and across the governance levels. Other studies also point out the importance of learning for systemic change (Coutts et al., 2017; Cundill and Fabricius, 2009; Pahl-Wostl, 2009; van de Kerkhof and Wieczorek, 2005). Qualitative indicators that were part of PIPA, RMA or pragmatically gleaned elsewhere, such as the Most Significant Change stories (Davies and Dart, 2005) collected in EULACIAS, provided material for reflection, connection and trust building. The more successful cases combined qualitative indicators with quantitative indicators on baseline and changes in their STEs, and in this way they were able to provide evidence on the successes or trade-offs of their interventions, which helped the production of longer-term outcomes (EULACIAS, INIA-Rocha, FR). Quantitative indicators were selected locally, based on available frameworks such as MESMIS for Latin America or based on standing procedures such as in FR. We found no evidence of lack of consensus on the selection of quantitative indicators as reported by de Olde et al. (2017), who consulted scientist-experts around the world on the most important criteria for selecting indicators for robust sustainability assessment. The locally adapted indicator sets revealed progress that was salient for the cases but precluded generic scientific conclusions due to differences between the indicator sets. Thus, rather than aiming at a one-size-fits-all approach to indicators for measuring local change as well as for scientific comparisons, specific indicators may be needed that describe change at more aggregate levels to reveal social and bio-technical progress (Turnheim et al., 2015), for example in terms of mid-level theories of change (Douthwaite and Hoffecker, 2017). In addition, the FR case suggested that qualitative complexity-aware indicators may be more important during initial development stages of a sustainability transition experiment, when the experimental design is being negotiated.

Input features were found to strongly affect outputs. In EULACIAS and INIA-Rocha supportive inputs were built during the pre-project preparation phase, which resulted in agreement on system definitions and approaches that resonated with the sense of urgency among the participants and legitimised the subsequent sustainability transition experiments (Clark et al., 2011). EULACIAS benefitted from a whole-farm modelling study (Dogliotti et al., 2005), while INIA-Rocha built on a rapid rural appraisal that was jointly designed and agreed with regional actors (Albicette et al., 2017). The FR case started from a system definition that lacked alignment with the perceptions of the farmers, but adapted its strategy to develop a jointly supported experimental plan. Scholarly work on lock-ins onto unsustainable trajectories resulting from an oversimplification of system definitions (e.g. IPES-FOOD, 2016; Meynard et al., 2018; Vanloqueren and Baret, 2009) shows the potentially severe consequences of early fixation on a particular system specification. Interestingly in this respect, the DK case initially developed much faster than the FR case. Still, its system definition remained close to traditional experimental design based on crop-specific biophysical traits, and ultimately lacked outputs that allowed socio-technical changes. Adaptation after the start of a project is often considered a failure. However, as the FR results show even in a context where participants have a collective working history, progressing insights may draw on the core team's adaptative capacities to change the course of action. These results reflect Neef and Neubert (2010) suggestions to evaluate project team composition based on disciplinary knowledge, experience with interactive approaches and process expertise.

6.2. Impediments to projects as a means to destabilise the status quo

Our findings impact on the understanding of projects as activities that are designed to solve a specific problem within specified constraints of budget and time. Projects designed as sustainability transition experiments may be seen as interventions to destabilise the unsustainable status quo by providing evidence on the degree of unsustainability as well as on the availability of alternatives (Fazey et al., 2018; Luederitz et al., 2017). As a single successful project will have limited impact on destabilising conventional practices and informal power structures (Geels and Raven, 2006; Nevens et al., 2013), sustainability transition experiments will need to be designed as successive projects that build on earlier experiences with changes brought about in the incumbent systems. There are various institutional impediments to such a take on project-based change (Fazey et al., 2018). The first is the time needed for project preparation. Our results confirm the importance of project preparation to secure the various input features (Klerkx et al., 2017): in the three successful cases between 1 and 3 years were spent on system characterisation and diagnosis at different levels. Here we identify three additional impediments: the tension in organisations between doing projects as a means of organisational survival versus as a means to solve societal problems. Secondly, a lack of institutional learning of research and development organisations and donors. And thirdly, contractual arrangements by donors that lack adaptive capacity.

Research and advisory organisations are increasingly focused on project acquisition for economic survival, as illustrated by the cases in PURE (cf. Klerkx et al., 2017). Rather than building a consistent portfolio of projects and programs on specific sustainability transition experiments, projects are seen as a means to secure the organisation's cash flow. This trend is justified by a perception of science as value-free and available to anyone willing to pay. It builds inefficiencies for advancement to sustainable development. It may work counterproductively by not capitalising on built networks, expertise and methods but rather 're-inventing the wheel' in subsequent projects (e.g. Turnheim et al., 2015). Capturing the lessons from previous work, i.e. learning institutionally, would also fit the idea of organisational survival and would allow to retain capacities developed even from disconnected project efforts, as e.g. argued by Watts et al. (2007) for the mission-driven CGIAR centres (but see Leeuwis et al. (2017) on its lack of uptake). Institutional learning, however, is resource demanding in organisations where project acquisition and project execution take priority. Implications for the research and development donor community thus are that new initiatives should reveal continuity with existing physical, social, and knowledge structures through pre-project building of networks and connections to previous local initiatives. Moreover, research and development donors can support sustainability transition contributions from projects by developing funding themes that require transdisciplinarity in approaches in contrast to the multi-disciplinary approach found in PURE. In a similar way as capacity was built for long-term ecological experiments (Brown et al., 2001; Likens, 1989), current global problems require the development of long-term socio-ecological sustainable transition experiments integrating different systems levels.

The final impediment we note is the inflexible contractual arrangements that prevail in donor funding. Once included in a consortium, a sustainability transition experiment and its actors will remain until the end of the funding term. Experiments, however, may fail and consortium actors may develop different priorities than to devote energy to the STE. While sustainability transition experiments also provide insights when they fail, the principle of learning selection (Douthwaite and Gummert, 2010) calls for termination of experiments that do not show the capacity to mobilise adequate levels of input and process features. Such risk of 'losing the project' will stimulate organisations to consider whether projects contribute to strategic goals, or are just part of 'doing projects' as a business model. Together with more systemic calls for proposals donors may use such penalties to leverage commitment and expertise from project participants.

6.3. Methodological considerations

The tentative framework for sustainability transition experiments guided data collection on the six cases. Its structure based on the logic model proved accessible to the interviewees. Individual features were sometimes found to overlap and difficult to disentangle – e.g. *actionable knowledge* is revealed by taking action, which is also covered by *accountability*, and close to *physical structural changes*. Information on governance structures may be addressed more specifically as part of the Processes dimension to enhance insights on system identification (Beratan, 2014; Duru et al., 2015). Moreover, information on the assumptions on how the experiment would achieve its objectives, or its Theory of Change, would help to compare approaches as was shown by Douthwaite and Hoffecker (2017), and would reveal the relation to scaling out, scaling up or, more generally, anchoring the experiments' outputs (Elzen et al., 2012b).

The interviews for this study did not include actors from the DE and NL cases due to their unavailability. Instead we combined previous information reported in Klerkx et al. (2017) with reflections from the leader of the international hosting team and information from interviews with the DK and FR teams. We are convinced that this reflexive approach has done justice to also the DE and NL cases.

7. Conclusions

With most of the budget for agricultural research-for-change spent through projects, how projects are conducted is a critical determinant of the rate of sustainability transitions. The analysis revealed how co-innovation, as an approach to change-oriented project governance and management, led to effective outputs for sustainability transitions. It also showed that the approach in itself is not sufficient. The cases illustrated the importance of thorough attention for preparation of the actual change-oriented work to arrive at legitimate interventions at system levels that enable transcending extant sustainability problems. Problems of low production and environmental deterioration in our cases were consistently only overcome by addressing them not at the field but at the farm level. Capacity building and changes at societal levels were associated with connections to salient actor networks beyond those involved in the on-farm work. The FR case showed that such preparatory work could even take place during project implementation if the project team can capitalise on existing knowledge and networks.

The complexity and uncertainty associated with sustainability transition experiments will require project entrepreneurs that are able to connect people and resources in response to emerging requirements. The cases also showed that financial requirements associated with successful projects are substantial. To fulfil the need of donors for quick wins, projects may need to build portfolios of small wins (Termeer and Dewulf, 2019) in addition to system-wide radical changes.

The adoption of co-innovation as a common project governance and management perspective across a range of projects (Fig. 3) will enable additional analyses of its evolution and skill in fostering sustainability transition experiments. Rather than considering it as 'scientists working with farmers' our results show the importance of considering all three domains: complex adaptive systems, social learning and dynamic monitoring for reflection.

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.

Acknowledgements

The authors would like to thank all the farmers, advisors, researchers and other agricultural actors that contributed to the crafting of co-innovation. Thanks are due to the interviewees from the PURE-IPM project. WAHR thanks the PURE-IPM project funded by the 7th Framework program of the European Union under grant number 265865 and the DiverIMPACTS project funded by European Union's Horizon 2020 research and innovation program under grant agreement No. 727482 for financial support. WAHR and SD thank the EULACIAS project, funded by the 6th Framework INCO-Dev Program of the European Union under grant agreement 032387, and the HortEco project funded by NWO-WOTRO under grant agreement W08.250.304 for financial support. SD thanks the FPTA 209 project, funded by INIA, Uruguay. MMA, VA, CL and AR thank the INIA-PF07 project for financial support.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2021.103103.

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