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Assessing impacts of agricultural research for development: A systemic model focusing on outcomes

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Abstract

Over the past decade, renewed societal demands on public research have been structured by various generic issues, while others are specific to the context of developing countries. In the first part of this article, after reviewing those issues, we examine how they reshape the analytical frameworks that structure the understanding of causal relationships between research activities, innovation processes, and the consequences of both for development. We used an impact pathway framework to assess innovation processes by looking at 13 case studies on research in agricultural and food sectors of developing countries. The results show the diversity of outcomes related to human capital, social capital, and knowledge infrastructure. Moreover, they show the systemic interaction between outputs, outcomes, and impacts. Based on this assessment, we demonstrate that the way impact pathways are framed and analysed needs to be improved to better consider the complex interactions between the diverse actors involved in innovation processes. Through a discussion of our results, we propose an analytical framework to help improve impact assessment methods for research activities.

Key words: impact pattern; agricultural technology; innovation system; evaluation; developing countries

1. Introduction

With population growth, increasing inequalities and migratory flows at the global level, and uncertainties due to climate change and natural resource depletion, the agricultural and food sectors face new challenges (Godfray et al., 2010; Lundvall and Lemaapages, 2014).[1] In parallel, scientific innovations in agriculture open up opportunities to advance technological and organizational changes that enable developing countries to improve living conditions and better meet their health, food, and energy needs. Nonetheless, agricultural research is called into question (Walker et al., 2010) because of the inability of technological models derived from the green revolution to achieve social inclusion for a growing workforce while also taking into account the often hidden environmental externalities they generate (Sumberg et al., 2013). In this context, improved understanding and functioning of the relationship between research and human development are critical to improve the contribution of science to societal challenges.

However, the definition of research activities is complex (Norman and Verganti, 2014). It may be linked to the nature of the institutions or organizations conducting the research: universities, technical institutes, companies, or civil society actors. It may be linked to the nature of the research activity: basic or applied. This complexity also depends on sector-specific development issues related to the modes of production (e.g. industrial, artisanal) or corporate concentration. De Jong et al. (2011) thus stress the wide variety of scientific approaches, and the difficulty of assessing the relationship between research and development.

Studies on this relationship address diverse topics such as analysis of the mechanisms linking academic research to societal demand (Bölling and Eriksson, 2016), study of the relationship between scientific production and the needs of companies (Wallace and Rafols, 2015), and assessment of the economic impacts of investment in research. Exploring the literature on assessing research impact shows the need to go beyond metrics-only approaches based on economic returns (Donovan, 2011) and reveals contrasting scientific communities.

The first—dominant—community focuses on financial evaluation of the impacts of research. It mainly uses models based on economic surpluses and cost–benefit assessments. The methods applied aim to verify research effectiveness by providing evidence through quantitative measurements (De Janvry et al., 2011). Counterfactual evaluation for instance seeks to attribute specific impacts by posing the question 'what would have happened in the absence of the programme?', therefore measuring to what extent the effect is caused by an intervention (White, 2010). In the agricultural sector, financial evaluation studies usually conclude that there is a significant return on investment in scientific research, with a rate of return varying from 10 to 30% since the 1970s (Renkow and Byerlee, 2010). Nonetheless there appears to be a paradoxical disconnect between increased investment in research and the slowdown in agricultural productivity gains observed in a number of contexts (Butault et al., 2015).

The economic returns-based scientific community is subject to various criticism (Bozeman 2011; Temple et al., 2016). A major concern relates to the explicit or implicit use of a linear concept of the innovation process based on non-recursive causal relationships between research investments, the development of new (mostly technical) products, and their transfer to users who are adopting them (Ekboir, 2003a; Mayne and Stern, 2013). Impacts are assessed mostly in economic terms at this user level (Pal, 2011).

These financial and/or quantitative evaluation approaches fail to take into account several important dimensions when explaining impact (Naudet et al., 2008). First, in a context in which numerous stakeholders are involved in the research and innovation process (De Jong et al., 2011), a shift is needed from the notion of attribution to that of contribution of research to impacts. The nature of interactions between stakeholders must be analysed to explain impacts (Morton 2015). Secondly, it is important to take into account the long term (Ekboir, 2003b; Leeuwis, Klerkx and Schut 2017). For example, impacts that are positive in the short term may become negative in the long term and vice versa, as studies in the field of medical research show (Wallace and Rafols, 2015). Finally, researchers face the challenge to produce analytical frameworks that integrate different disciplines (Belcher et al., 2016) and are not governed by the epistemic assumptions of a single discipline such as economics.

In response to these challenges, a second scientific community has emerged (Klerkx et al., 2012; Touzard et al., 2015). For this community, it becomes fundamental to understand the process that leads to impact (Horton and Mackay 2003), demonstrate the causal mechanisms at play, and identify the contribution of research in such process and in the generation of impacts, rather than to provide mere evidence and attribution of impacts. Spaapen and Van Drooge, (2011) highlight that the primary concern of evaluation is to learn and not to judge, which implies to focus on what goes on between researchers and other actors.

However, even if this second scientific community provides a better understanding of the mechanisms underlying causal relationships between research and development impacts of innovations, it is challenging to develop analytical frameworks that represent such mechanisms. The use of mixed methods that integrate quantitative and qualitative approaches is certainly more suited to understand such processes (Bamberger 2012; Berriet et al., 2014). Measurable indicators that validate causal links are useful to allow public actors and civil society to better understand systemic processes. In fact, the development of robust, measurable indicators reflecting the diversity of research impacts is central to determine the relevance, credibility, legitimacy, and inclusion of research (Belcher et al., 2016) or to assess impacts, whether using participatory approaches or not (White, 2010).

Authors in this second community put forward the systemic analysis of innovation processes that contribute to transform research results into development impacts (Laperche et al., 2008). Such systemic design departs from the linear technology transfer and dissemination concept (Kline and Rosenberg, 1986). Systemic approaches focus on actors' organizational structures and relationships, and boundaries and perspectives, for instance in rural communities (Klerkx et al., 2012), national territories (Temple et al., 2017), or economic sectors (Touzard et al., 2015). An approach that takes into account processes is the impact pathway approach, which shows the contribution of research to impacts by making explicit the causal links that lead from research outputs to the use, interaction and appropriation by stakeholders of these outputs—the outcomes—and which generate societal or environmental changes (Douthwaite et al., 2003; Colinet et al., 2012; Joly et al., 2015). Following Mayne (2001), Morton (2015) proposes a research contribution framework based on a contribution perspective to analyse both processes and outcomes. The author emphasizes the 'research uptake process' when research targets specific users and the 'research use process' when a larger audience interacts with or transforms research results. The framework highlights the complex processes of change in knowledge and skills of users to explain societal changes. Wiek et al. (2014) introduce a framework and a methodological scheme for capturing the societal effects of research, showing the importance of time to conduct impact assessment of research.

Even if impact pathway approaches highlight complex processes, they face difficulties in overcoming the linear linking of outputs, outcomes, and impacts, multiple interactions among actors, and feedback loops. More specifically they fail to adequately address the complex interactions between research and policy (Klautzer et al., 2011).

The scientific recognition of research in this second community renews the epistemological paradigm of impact evaluation in research for development. Nonetheless, a limiting factor to such recognition is the current gaps in the comprehension of the systemic nature of complex interactions between outcomes, innovation in terms of new actor configurations, sustainable development consequences, and actors' needs. These issues are beyond robust standardization, as needs are specific and hardly reducible to global indicators of increasing productivity or returns on investment.

This article contributes to fill these gaps by clarifying and formalizing the systemic dimension of these complex interactions. To this end, it adopts participatory approaches that involve innovation actors in the evaluation process itself. Such involvement is deemed necessary to identify impacts based on needs expressed by the users of research outputs.

The article proposes the construction of an analytical framework for the contribution of research to impacts. The framework is applied on research in the field of food and agriculture, although future applications in other fields can be devised to test its generalizability.

The focus is on the conditions under which agricultural research contributes to achieve major development goals, such as food security (Temple et al., 2015), improvement of agricultural and rural systems, contribution to environmental sustainability, and so on.

The framework is built from case studies conducted within a research project launched in 2013 by the French Agricultural Research Centre for International Development (CIRAD), and is hereafter referred to as the ImpresS (Impact of Research in the South) framework. The framework is the product of several iterations of reflection and testing within CIRAD and with its partners. It is inscribed within the community of thought focused on processes and contribution of research to impacts (Temple et al., 2016). The research herewith presented argues that the impact pathway approach needs to integrate complementary interactions between the diverse actors involved in innovation processes. Secondly, it focuses on the role of institutional and organizational components in the transformation of research outputs by stakeholders and the *effects* on directs stakeholders who make use of those findings (Dosi et al., 2006). The findings of the study herewith presented support these concepts both from a theoretical and a methodological standpoint. Finally, they show how a better understanding of causality can improve the assessment of research impacts.

The article first presents the methodology used to analyse the case studies, and then discusses the ImpresS framework based on the construction of an impact pathway, showing the central role played by outcomes and the complex interactions between outputs, outcomes, and impacts. Finally, it discusses the findings in light of improving the analytical framework for the assessment of research impacts.

2. 'ImpresS' or the development of a collaborative methodological framework

2.1. Key concepts and principles

2.1.1 Using an impact pathways approach

For ImpresS, agricultural research contributes to produce impacts through a complex multi-causal process that involves multiple stakeholders and is influenced by factors internal and external to the research and innovation process (Colinet et al., 2012; Klerkx et al., 2012). ImpresS applies a contribution analysis of causal relationships from research inputs to impacts (Morton, 2015), structured around the iterative reconstruction of 'impact pathways'. In Impress, the impact pathway framework proceeds by inference to reveal causal explanations linking inputs, outputs, outcomes, first-level and second-level impacts[2], as well as the internal and external factors contributing to generate impacts (Mayne, 2001). The innovation process and the resulting causal chain are complex and not necessarily chronological, with interactions and feedbacks between outputs, outcomes, and impacts.

The ImpresS framework partly relies on participatory impact pathways analysis (PIPA) (Douthwaite et al., 2003; Alvarez et al., 2010), applying it to *ex post* evaluation, a less common use of PIPA. Compared to this approach, ImpresS takes a broader and long-term view on the innovation process, focusing on an iterative method of systematization, validation, analysis, and actor feedback, with varying degrees of participation of diverse actors at different stages of the evaluation. Such iterative stepwise process allows to better illustrate the interactions, feedback loops inherent in the causal chain.

The ImpresS framework also shares common features with the one developed by the project ASIRPA (Analyse Socio-économique de la diversité des Impacts de la Recherche Publique Agronomique) which assesses the impacts of agricultural research in France (Gaunand et al., 2015). ASIRPA focuses on multi-directional processes and iterations across different stages of the impact pathway (Joly et al., 2015). ImpresS stems from the recognition of the specificity of CIRAD's research in partnership with developing countries. Compared to ASIRPA it has taken a step forward by implementing a participatory method which involves partners and major actors in all stages of the evaluation process, with varying degree.

2.1.2 A five-step evaluation process

ImpresS is a comprehensive, theory-based, and participatory framework to assess research impacts (Chambers, Pacey and Thrupp 1989; Triomphe et al., 2013) through a five-step process (Fig. 1):

- Preparation: Defining the perimeter of the case study and developing hypotheses about potential impacts, impact pathways, and innovation stories
- Confrontation: Framing the study with key stakeholders of the case study by discussing and validating the hypotheses developed in Step 1 and by developing a list of impact descriptors according to their own views and definitions of impact
- Construction: Collecting data through mixed methods to consolidate the innovation story and document the impact pathways and corresponding causal relationships among inputs, outputs, outcomes, and impacts
- Measurement: Assessing the first-level and second-level impacts by triangulating quantitative and qualitative data collected during Step 3 or originating from secondary sources
- Validation of results: Validating the final results (innovation story, impact pathways, impact assessment) with the case stakeholders' representatives

The key 'tools' used in these five steps reflect the main concepts and principles on which ImpresS relies. They include storytelling and timelines, stakeholder mapping, participatory impact definition, multi-stakeholder workshops, focus groups, and semi-structured interviews. ImpresS relies on three key concepts: participatory approach, capacity building, and public policies.

2.1.3 A participatory approach to impact evaluation

One of the guiding principles of ImpresS is to give an active role in the evaluation to the multiple stakeholders involved in or impacted by the innovation process. Such participation is strategic but challenging, due to ethical and operational considerations, especially in a developing country context. Nonetheless, the participatory approach allows to: (1) take into account a diversity of perspectives and the complexity of links between research results and impacts, both positive and negative (2) complementing as well as compensating for the unreliability or unavailability of, or restricted access to, secondary data, (3) decreasing the cost and duration of the evaluation procedure, (4) enhancing the usefulness and appropriation of evaluation results by concerned local stakeholders to inform ongoing innovation dynamics, and (5) inform researchers as to what stakeholders expect of research and innovation.

In the ImpresS framework, the participation of stakeholders is envisaged especially in three crucial phases: (1) participatory workshops at the beginning to refine impact pathways and the design of

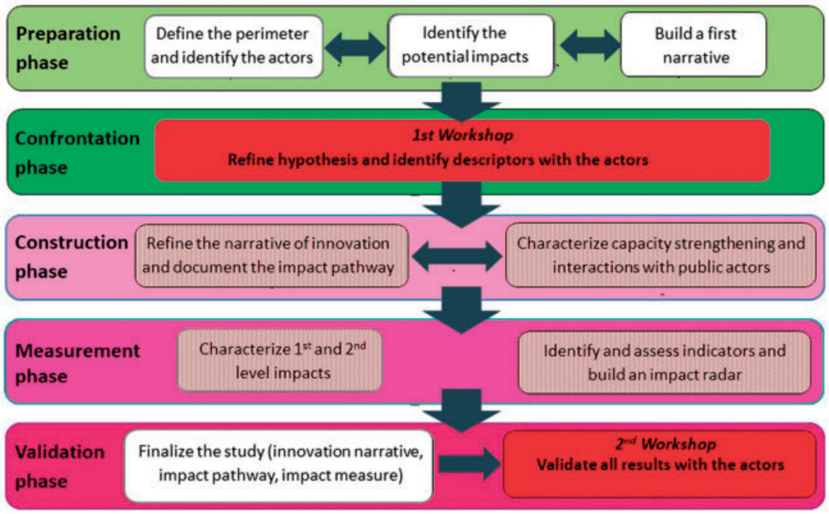

Figure 1. Five-step process of Impress.

the evaluation, (2) focus groups and interviews to collect impact related data, and (3) participatory workshops at the end of the evaluation to validate and incentivize appropriation of results.

Participatory approaches imply a reflection on the importance of the evaluation for different actors participating at different stages of the evaluation. The degree of participation and the evaluation credibility depend on the objective of the evaluation and who are the final users, but also the interest of actors in participating to the evaluation given the potential risk they incur by participating (Patton, 1990). In ImpresS, participating stakeholders are identified in two phases during the inception and framing steps. First, an exploratory survey is applied with key informants from institutions who were involved in the research process. This survey identifies the actors in the system in which the case study has operated. Secondly, during the workshop with actors identified through the survey, all stakeholders relevant to the innovation process are mapped out. At this stage, they are classified into: users (e.g. farmers, private enterprises, associations); intermediaries (e.g. extension services, certification agencies, trainers); and researchers.

Using a participatory approach to evaluation can reveal impacts not planned or considered by the major innovation players and can capture contrasting opinions of stakeholders who benefit from the innovation process and those who are excluded. During the participatory framing, stakeholders are asked to characterize the impacts using their own descriptors (Gaunand et al., 2015), which usually consist of short statements that reflect impacts they have felt or observed. These descriptors are collected verbatim during discussions with stakeholders and are then entered into a database and reformulated as impacts. In ImpresS, this reformulation was made based on contextual judgements on the case assessed. Sometimes the case-leading team made a post hoc determination. Alternatively, impacts were reformulated in real time in consultation with the stakeholders, allowing feedback discussions and adjustments.

Once formulated, impacts are consequently categorized in two levels: (1) first-level impacts affecting stakeholders who interact directly or indirectly with the innovation process (those with ties to researchers or major players in innovation), and (2) second-level impacts affecting stakeholders not directly involved in the innovation process and relating to changes in scale, together with the induced or knock-on effects often termed ‘spillovers’. In both cases, impacts are characterized using measurable indicators.

2.1.4 Focus on capacity building as a key factor contributing to impact

At several stages of the innovation process, in different ways and to varying degrees, research interacts with diverse stakeholders, for example advisory services, NGOs, farmers’ organizations, and private companies. Such interactions involve several types of learning processes: formal and informal, individual, and collective. These processes foster the design, appropriation, adaptation, and use of innovations, both of a technical and social nature. They build stakeholders’ capacity related to the innovations being developed and adopted, and generate a stronger capacity to innovate (Leeuwis et al., 2014; Casadella et al., 2017).

ImpresS stresses the need to map and analyse these capacity-building processes involving research all along the impact pathway as a way to trace its mediating role in achieving observed impacts. To this end, the ImpresS framework focuses on identifying and analysing key ‘learning situations’ (places and moment where learning processes occur) to understand their consequences in terms of outcomes or impacts.

2.1.5 Public policies

The institutional context is key to understanding the innovation process and the importance of its impacts (Hall et al., 2003). To address this issue, ImpresS also analyses the way public policies influence the innovation process (Schut et al., 2013) and how public policies are influenced by the results of research and the actions taken by other actors involved in the innovation process (Clark 2002; Spielman et al., 2009). Public policies were analysed through interviews with key participants in the innovation process. In the ImpresS framework, it is important to identify changes in policy priority, activity planning, subsidies and other forms of financing of the innovation process, and so on. Changes in policy debates and discourses are also important to identify, as well as strategic guidance for policymaking tools and implementation.

2.2. A case study approach

The ImpresS team opted to implement a case study approach (Yin, 1994), deemed well suited to in-depth inquiry of a social object bounded in time and space that aims to understand not only 'what happened?' but also 'how or why did it happen?' (Gerring 2004; Avenier and Thomas, 2015).

Each case study focuses on a unique innovation process that occurred or is taking place in a given area over a definite period, which started with a research intention and inputs, followed by innovation development shared between all stakeholders, and culminating in some innovation(s) being actually put to use or adapted and transformed by development actors and/or end users (usually, but not only, farmers), which produces a series of observable changes, positive or negative. Importantly, the ImpresS team did not focus on evaluating individual agricultural research projects *per se*, even though the starting point were innovations in which research was a fundamental actor either since inception or at later stages. The focus was rather on the innovation process: research activities were analysed in light of the innovation trajectory in which they were inserted. The time frame of each case study goes beyond that of a single research project and includes clusters of projects or R&D activities that fed the innovation process through time. The definition of clusters of projects is based on sharing a common feature within a delimited perimeter in terms of theme, time, and space, which is identified during Step 1 (Fig. 1).

To go beyond the limitations of single case studies and small samples, the ImpresS framework was systematically applied on 13 case studies exploring diverse contexts, innovations, and processes. Each case study was assessed by a team that included a CIRAD researcher as leader, a co-leader from national institutes in partner countries, mostly from the South, a master's student for a period of 6 months (in 12 cases of 13), and a methodology advisor from the ImpresS task force. All case study teams participated in training on the ImpresS approach received detailed guidelines, and were supported by an evaluation specialist throughout the inception, data collection, and analysis steps.

The 13 cases are diverse (Fig. 2), spanning four continents (eight cases in Africa, two in Latin America, two in Asia, and one in Europe), and a variety of innovation types (Table 1). Nine cases are *ex post* case studies, while four are *in itinere*, meaning that the innovation processes were still ongoing. Inclusion of the *in itinere* cases made it possible to consider emerging outcomes and impacts and to support the formulation of impact hypotheses and impact pathways scenarios, a step towards the development of an impact culture within the community involved in this project.

The role of research in these case studies often reflects project temporality as imposed by the evolution of investment in public research. The increasing funding of research through competitive 2–4-year grants forces research teams to plan short-term research activities. The methodological limitation arising from this donor-driven temporality is that the system of actors mobilized by the innovation process is linked to the partnership structure of financed projects. In many cases this imposes an impact pathway of the innovation process that starts with a research team formed as a result of a financed project. This potentially reduces the visibility of innovation determinants linked to other investments beyond those in research, such as those related to collaborative and peer-to-peer finance, or direct funding to innovators from international cooperation agencies, ministries, and private firms. The heterogeneity of the case studies chosen aimed at reducing such risk.

3. ImpresS results: Developing a systemic framework to assess the contribution of research to development

To analyse the 13 case studies, we harmonized the structure of impact pathways. This allowed us to construct a database of inputs,

Figure 2. Spatial distribution of the innovation cases.

Table 1. Case studies

Case name	Research focus	Impact status	Years covered	Geographic area	Type of partnerships	Assumptions types of major impacts
Tsetse eradication program	Animal health and ecological intensification of livestock production	*In itinere*	2007–16	Senegal	Research (PRO-North/South), farmers' organizations	Economic, health, social
Fonio post-harvest equipment	Innovation in post-harvest technology regarding fonio	*Ex post*	15 years	Mali/Burkina-Faso, Guinea	Research (PRO-North/South), NGOs	Economic, environmental, social
Pl@ntNet software for plant identification	Development of a collaborative identification platform of plants dedicated to data and knowledge sharing	*In itinere*	2009–14	Global Europe, Indian Ocean, South America	Research (PRO-North/South), NGO	Environmental, social
Biological control of the white grub	Development of integrated pest management to reduce infestations by a key insect pest of sugarcane (*Hoplochelus marginalis)*	*Ex post*	1980–2010	Réunion Island, Madagascar, Comoros, South Africa, Mauritius	Research (PRO-France), farmers' organisations, Industrial partners, local government	Economic, environmental, political
A participatory approach to residue recycling	Support to new organizational arrangements to manage green residue at territorial level for a better livelihood	*In itinere*	2011–14	Réunion Island	Research (PRO-France), farmers' organisations, industrial partners, local government	Social/territorial
Groundnut breeding for drought resistance	Groundnut breeding	*Ex post*	From 1985	Senegal	Research (PRO-North/South), farmers' organizations	Economic, social
Participatory sorghum breeding	Sorghum breeding with participatory research	*Ex post*	12 years	Burkina Faso	Research (PRO-North/South), farmers' organizations	Economic, social environmental
Manure management at farm level	Design of innovations related to manure management in mixed farming systems	*Ex post*	2008–14	Burkina Faso (Tuy region)	Research (PRO-North/South), farmers' organizations	Economic, social/territorial
Integrated and participatory water resource management	New arrangement and co-design of innovations for water resource management towards effective agricultural systems	*Ex post*	Phase 1	Indonesia, Central Java Province, Kali Pusur watershed	Research, industrial partners, farmers' organizations, local governments, NGOs	Economic, social/territorial
Genetic improvement of upland rice	Rice breeding and genetics	*Ex post*	Nearly 3 years	Madagascar (high-altitude areas)	Research (PRO-North/South), farmers' organizations, local governments, NGOs	Economic, social, environmental
Evaluation of animal health surveillance and control systems	Design of methods and tools for surveillance and control of animal diseases	*In itinere*	2009–14 (*In itinere*)	Vietnam (+ Southeast Asia + Egypt)	Research, veterinary services, national and local governments, international organizations	Political, health, economic, social
Control of the coffee berry borer with trap	Experiments and marketing of traps	*Ex post*	10 years	Dominican Republic (+ other Central America)	Development agency, farmers' organizations	Economic, environmental
Wine geographical Indications	Support to institutional and market innovation to promote local wine	*Ex post*	10 years since 2004	Brazil	Research, farmers' organizations, NGOs, national and local governments	Political, environmental, economic

outputs, outcomes, and impacts from all cases, and to conduct qualitative modelling and cross-cutting analyses.

The results generated by the case studies were analysed in terms of four interactions that structure the impact pathways:

- Interactions that generate feedback on research and outputs
- Interactions leading to outcomes, defined as cross-cutting resources that may come into play at different stages of the process
- Interactions that lead to impacts within the targeted user community and then at a higher level within supply chains and regional or national territories
- Interactions that produce effects on public policy

3.1. Interactions that generate feedback on research and outputs

In the ImpresS framework outputs are thoroughly characterized, including the process that generates them. While they can be prototypes developed exclusively by researchers in laboratories or research stations, they can also include interactions between the researchers and other stakeholders in a process of co-construction. Such interactions need to be characterized. In the context of a research project undertaken within a partnership, which characterizes CIRAD's modus operandi, such interactions are part of the research activity.

Outputs may be classified into two groups: outputs that are designed from the outset as finished products (examples: knowledge, methods, technologies) and those designed to encourage ownership of a 'product' by future users (example: an experimental network). The case study analysis showed that the latter arose mostly through co-production mechanisms between research and a diverse set of partners beyond the research community players. Table 2 shows how certain outcomes are in fact the result of situations of co-production of outputs between different actors (sustainability of monitoring network, platform for machine development, collaborative platform, and so on). This fact highlights the importance of participatory research in the generation of outcomes. However, the intensity of interaction may deeply vary according to the local context and the research strategy.

Four case studies serve to illustrate this (see Table 1): (1) fonio post-harvest equipment, (2) biological control of the white grub, (3) genetic improvement of upland rice (Raboin et al., 2014), and (4) participatory sorghum breeding (Vom Brocke et al., 2014). The two plant breeding cases were conducted differently. In the rainfed upland rice case, output generation depended on a partnership between research institutions (CIRAD and FOFIFA (Foibe Fikarohana momba ny Fambolena), the Malagasy national agricultural research institute),

Table 2. Outcomes of the case studies

	Outcomes with feedback on research and outputs	Outcomes leading to first-level impacts on the first community of actors	Outcomes leading to second-level impacts and regarding adoption scale	Outcomes leading to impacts on institutions and policies
Human capital	New research front[a] Knowledge about constraints[e]	Empowerment of veterinary service[a] Enhancement of learning capacity[c] Increase in knowledge of biodiversity[g]	Enhancement of learning and implementation capacity: expertise and imparting knowledge[d,g,h]	Regional innovation policy[c] Promoting scientific culture[i]
Social capital creation networks and interactions between stakeholders	Sustainability of monitoring network[j] Platform for machine development[h] Collaborative platform[i]	Creation of networks: pest monitoring,[b] for: virus incubation,[j] testing of new varieties[e], GI (Geographical Indication) creation;[e] PO (Producer Organization) creation[h,k] Researcher/public service interaction: ministry, territorial community: surveillance, seed[a,b,e,g] Researcher/farmer interaction: individual, agricultural board,* OP[b,c,e,g,k] Intra-industry interaction: seed;[g] equipment manufacturer/processor[h]	Coordination between public services: health and veterinary,[j] researcher/technician/farmer interactions[e,k]	Professionalization of stakeholders' collectives (ability to work together)[h,k,l] New science/society relations[i]
Knowledge infrastructure	Virus isolation in the laboratory[j]	Participatory experimental arrangement,[c,f,k] participatory outreach[g] for plant identification,[i] virus monitoring protocol[j]	Number of manure pits[d] Mobile application: information sharing,[i] seed marketing method[g] Identify* need for vaccination[j]	Piloting of public intervention monitoring[a]
Impacts on development	New databases[i] Decrease in cost of information to identify plants[i]	Decline in diseases and parasitic attacks, health problems[a,b,f,l] Practical adaptation of agriculture: *elimination* of chemical treatment,[b] organic fertilization[c,d] New adoptions: varieties,[e,g] machines,[h] traps,[l] increased biodiversity[i]	Change of scale of first impacts Rehabilitation of old varieties[e,i] Certified seed production[g] Decrease cost of invasive plant control[i]	Ability to predict the future (reduced risks)—invasive plants,[i] viral pandemics in animals[j]

[a]Tsetse eradication in the Niayes region (Senegal); [b]Biological control of the white grub (Réunion Is.); [c]Organic residue recycling; [d]Manure management in agro-pastoral systems (Burkina); [e]Geographical indication; [f]Genetic improvement of upland rice for high altitude conditions (Madagascar); [g]Participatory sorghum breeding (Burkina); [h]Fonio post-harvest equipment (Burkina); [i]Pl@ntNet (world); [j]Evaluation of animal health surveillance and control systems (Vietnam); [k]Groundnut breeding and seed production (Senegal); [l]Coffee berry borer trap.

with no significant involvement of future innovation users in output production. The sorghum case, in contrast, consisted in participatory breeding of improved varieties whereby researchers, intermediaries, and prospective users contributed to the process of generating the outputs. In the case of the fonio huller, the stakeholder systems were different in Mali and Burkina Faso. In both countries, local research partnerships were strong. Only in Mali, however, did innovation benefit from a partnership with equipment manufacturers, who actively participated in the adaptation of the Huller prototype, the main output of the research. Finally in the case of biological white grub control, output production was the result of a close partnership between a number of research institutes and the private sector, a growers' syndicate and public authorities.

Iterative and multi-player processes allowed researchers to interact with those involved in the innovation process, adapt their action, and anticipate potential risks and obstacles. However, the process generating these outputs relates to facilitating interaction between players, which may then be akin to the definition of 'outcomes'. These nuances illustrate the difficulty to clearly separate outputs and outcomes in complex innovation processes where interactions are important. To address this difficulty, it is important to understand the system of interacting actors as soon as research outputs are developed (Röling, 2009).

3.2. Interactions leading to 'outcomes' for the innovation process

The linear innovation model is based on a relationship of simple causality between the generation of the research activity's outputs and the impacts. The term 'diffusion' is then used to describe the transfer of the output to users (Godin, 2014). The term 'outcome' is used to describe this diffusion process in terms of primary results. In this linear model, it may also relate to arrangements whereby agents can use the outputs and ease the impact pathway.

In the systemic assessment model we present in this article, we propose to define 'outcomes' as 'resources' that may be used by non-researchers at different stages in the process rather than only at the diffusion stage, as in the linear model. It may generate feedback effects in the generation of some outputs, in the adoption and transformation of technologies by actors, and in the process leading to first-level and second-level impacts. The outcomes can also help structure institutional and policy environments that affect technological development policies. The 13 case studies show that research is involved in the generation of these outcomes (Table 2), but the degree of involvement varies depending on the type of innovation process, and so must be evaluated from that point of view. The outcomes more frequently arise from a research activity and therefore, at least in part, from a research intention. The weight research activities carry in the innovation process varies with the place technology holds in stakeholders' innovations, partnerships, and strategies, as well as with the institutional context.

In the ImpresS framework, outcomes were formulated and identified during workshops and focus groups, but it was challenging to hierarchically classify heterogeneous outcomes through participatory methods. To harmonize the selection process, team leaders, and their partners were asked to select those outcomes that they deemed stronger and more robust in terms of their causal link to impacts as discussed in the participatory activities. This identification method is described in a methodological guide allowing its application within other contexts (Barret et al., 2017).

Through this method, 40 outcomes were identified from a set of 13 case studies. Four major outcome types were finally defined. The 40 outcomes are broken down in Table 2 with references to the four interactions that structure the impact pathway, as outcomes play a key role in each type of interactions. Thus, the first Column (A) records outcomes with feedback effects on research and outputs. The second Column (B) records outcomes leading to impacts on the first-user community. The third Column (C) records outcomes leading to second-level impacts related to the deployment of innovation, including take-up within entrepreneurial dynamics. The fourth Column (D) records outcomes leading to institutional changes and particularly public policies, including innovation-related policies.

The rows of Table 2 analyses the outcomes identified in the case studies, in light of the major 'problems' that characterize the systemic innovation process based on the framework of Wieczorek and Hekkert (2012). Thus, under this conceptual framework, the first row addresses human capital and capacity building; the second row focuses on social capital and the creation or improvement of networks or interactions between players in the system; the third row represents the creation or enhancement of knowledge infrastructure; while the fourth row sets out the main impacts on development.

Table 2 shows that outcomes related to human capital are present across the four columns and thus have effects on all of the stages of the impact pathway to varying degrees in each case study. This is a key contribution (involving research contribution), which will need further analysis. Various attributes of human capital (Kruss and Gastrow, 2012) may be identified in the case studies, namely:

- Ability to collaborate in collective actions: to identify complementarities and interact with players including researchers and donors; communicate; find ways of pooling resources between players; establish trade relations with private companies on a contractual basis; and implement participatory methods.
- Ability to learn: to test new solutions; implement new technology; and acquire and use new technological knowledge and information.
- Ability to engage in a political and strategic process: to diagnose problems and understand the constraints/opportunities of the environment; take into account power relationships between various actors defending different interests; establish power balances; negotiate and influence policy orientations; and imagine one's future role through projects and the adoption of strategies.

Similarly, Table 2 shows that outcomes related to social capital and knowledge infrastructure are present in the four columns and thus have effects on all of the stages of the impact pathway. A case on integrated control of tsetse flies in Africa illustrates this: veterinary services were empowered, as all agents attended trainings on tsetse ecology and control at the beginning of the project, while the transfer of geomatic tools by researchers allowed them to improve the efficiency of monitoring and control activities (Dicko et al., 2014).

The complementarity of the various outcomes regarding human and social capital helps to strengthen the innovation process and implies necessary assets to initiate a development process. No externalities (spillover effects) of this type were however documented in this study.

3.3. Interactions leading to impacts

This section analyses how research contributes to a large diversity of impacts. The systemic assessment model emphasizes the usefulness of a context-based assessment. It means that the evaluation is embedded in the context in which research operates. Moreover, the use of a participatory approach leads to identify impacts in a non-standard way and to provide context-related impacts.

Impact assessments for research and development projects are conducted to assess the actions carried out in relation to targets set by stakeholders outside the innovation process (donors, policymakers). The impacts are often identified a priori according to expert opinions and measured based on an assessment framework defined in a generic manner (Organization for Economic Co-operation and Development, 1998). Consequently, the list of impacts to be assessed is often limited to standard measures, such as, but not only, income or productivity. The participatory approach to identify impacts perceived by innovation stakeholders enables us to move away from pre-established frameworks and to analyse impacts that have been little explored in the literature. When analysing the empirically identified impacts, we observe that 63 impacts are common to a number of cases, while 51 are case-specific Fig. 3. These numbers show the usefulness of participatory assessments, which facilitate context-specific analysis and in-depth understanding of impacts.

To systematize and be able to compare impacts, we categorize them, as shown in Table 3.

The impact indicators identified with the participatory approach go beyond standard measures. The ImpresS framework ensures they are measurable in contexts where very little secondary data exist. It has often been necessary to avoid generic indicators such as the 'increase in income', which are difficult to identify for small producers who do not monitor their costs and benefits. Doing so has, for example, led us to use a proxy for income such as 'observable expenditure'.

Indeed, some development impacts cannot be matched to those referenced in the literature; these are unforeseen impacts, not all of them beneficial, and some of which may even spark controversy on trade-offs between impacts that are negative at the individual level, for example on chemical inputs sellers, but represent overall positive impacts for society.

The participatory identification and validation of impacts drew us to define first-level and second-level impacts. First-level impacts pertain to the user community in direct interaction with research and the innovation process. They arise, for example, from the use of improved varieties or fonio hulling machines in intervention areas of the research projects or where the innovation process has taken place. The adoption rate also generates feedbacks on further outputs and outcomes. For instance, in the case of participatory sorghum breeding, increasing adoption rates drove specialization of producers in selected seeds. This meant that researchers could in turn use these as seed supplies instead of producing them. The result is a reduction in the cost of seed production for all stakeholders and a redistribution of financial means on priority outputs within research institutions. Increasing the number of adopters also helps strengthen capacity-building modules and diversify experimental areas for such trainings. Future publications by ImpresS will detail such feedback loops.

3.4. Interactions with public policy

One often forgotten contribution of research is its impact on public innovation policies. Such innovation policies are characterized by the conditions that strengthen societal capacities: social, education, fiscal, scientific and technological support policies (Casadella et al., 2017). Indeed, by producing knowledge on the causal relationships between investment in research and development, research guides public incentives or regulatory constraints, which become elements

Table 3. Impact fields

Economic opportunities, turnover, and employment of enterprises
Production and productivity
Quality of services
Culture and living conditions
Households and small producer incomes and costs
Food security and quality of products
Information access and legitimacy of new issues
Capacity to innovate
Institutions and public action
Environment, natural resources, and biodiversity
Animal health

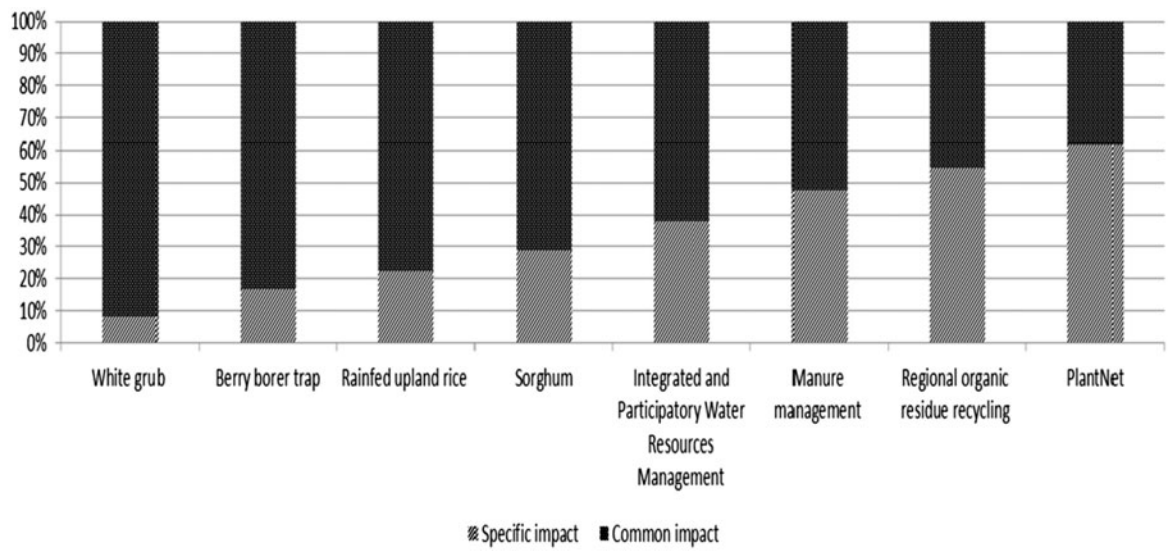

Figure 3. Distribution between specific and common impacts in the cases.

of the macroeconomic environment guiding technology pathways for development.

Here we illustrate how research is influenced by public policies and how research may influence public policies. Policymakers are involved at various points in the innovation process, and interactions occur at different levels of the impact pathways: input level (research and innovation policies), output level in partnership with national research, outcome level (capacity building among politicians), and impact level (change in sectoral policies or scale of innovation).

Four types of interactions were identified. First, finalized research produces rigorous factual results (outputs), which, once adapted and available to policymakers, can inform their choices. The ability of policymakers to mobilize such knowledge depends strongly on contextual dynamics and resources. In our sample, only the *in itinere* case study 'Health Surveillance in Vietnam' explicitly sought (Baudon et al., 2017) to have an impact on policy. In that case, researchers aimed to influence political decisions by proposing the use of new health surveillance assessment tools by State veterinary services. In the *in itinere* case study 'organic residue recycling on Réunion Island', researchers' endeavours had already led to a change in European agri-environmental measures and the positioning of organic fertilization as a priority on Reunion Island. Research outputs and outcomes contributed therefore to the elaboration of norms or new policy decisions.

Secondly, there can be strong interactions between researchers and public authorities at the level of output production when there is a solid partnership with local research institutes or in participatory research projects with a pronounced institutional dimension. Researchers in national institutes usually play an advisory role to public sector decision-makers; in such cases, by working with these national institutes, their research partners interact indirectly with policy makers. For example, in the case 'Genetic improvement of upland rice' in Madagascar, the national research institute FOFIFA's change in reporting relationship in the early 2000s, from the Ministry of Research and Education to the Ministry of Agriculture, strengthened CIRAD's development advisory role *vis-à-vis* FOFIFA. Similarly, research sometimes enables networking of several institutional actors even at the output level. A clear example is the case of white grub control on Réunion Island, where the institutional context facilitates the interaction of institutional actors with researchers: DAAF (the Food, Agriculture and Forest Directorate), the territorial community (Conseil Général de la Réunion), a professional organization (FDGDON), the Chamber of Agriculture, and the town halls all cooperated to seek a solution to the crisis that had affected the sugarcane sector (Wassenaar et al., 2015).

Thirdly, researchers' engagement within the political process can also lead to an improvement in policymaking skills. Research opens new horizons for decision-makers and so helps improve their ability to develop policies and take informed decisions. Thus, in the Brazilian geographical indications case (Wilkinson, Cerdan and Dorigon, 2017), researchers carried out trainings for some 200 institutes including the National Industrial Property Institute (INPI) and the Ministry of Agriculture (MAPA).

Interaction with authorities may be in other cases minimal, however. The case of groundnuts in Senegal (Clavel et al., 2013) shows that successive research projects over several decades have had little influence on policymakers, as structural adjustments and dismantling of agricultural programmes have come and gone.

Finally, interactions between researchers and politicians during the innovation process can generate feedback effects on research inputs, as new innovation and research policies are put in place. For example, the reforms to improved seed varieties certification in Madagascar have been instrumental in advancing genetic research in agronomy and indispensable to plant breeding activities.

In some cases, interaction between researchers and authorities is lacking or constrained by the institutional context: institutional instability, different types of capacity needed, lack of resources, and even cultural differences. In Vietnam, for example, rules, norms, and values (organizations' bureaucratic and hierarchical operation) make it difficult for research to influence public policy. On the other side, in Indonesia, once the local government lost tax income from a multinational company (Danone), it did not implement a legal framework for conflict resolution, which is a pre-requisite for institutional innovations led by researchers.

4. Discussion: A systemic model to assess the impacts of research

The results presented above show the usefulness of a systemic model to assess the contribution of research to impacts. The structure of such a model is based on interactions between the various components of an impact pathway. Under this systemic model, the terms 'inputs', 'outputs', and 'outcomes' are defined not in a standardized way according to their a priori nature but primarily on the basis of their objective: to create favourable conditions for innovation. Hence, they are classified according to their role in the innovation process rather than their nature.

Table 2 highlights the variety of outcomes with their influence on different segments of the impact pathway. This leads us to design a graphical representation (Fig. 4) of the impact pathway that shows all the links between the outcomes and the other segments of the impact pathway including feedback loops.

This model recognizes two major types of interaction, represented by distinct arrows in Fig. 4. The first type of interaction (Actor system) describes the relationships between the actors' system (e.g. researchers, brokers, entrepreneurs) and the various components of the impact pathway (e.g. outputs, outcomes, impacts). Depending on the innovation process and the nature of the component, the research contribution can be 'unique' or 'shared' with different actors.

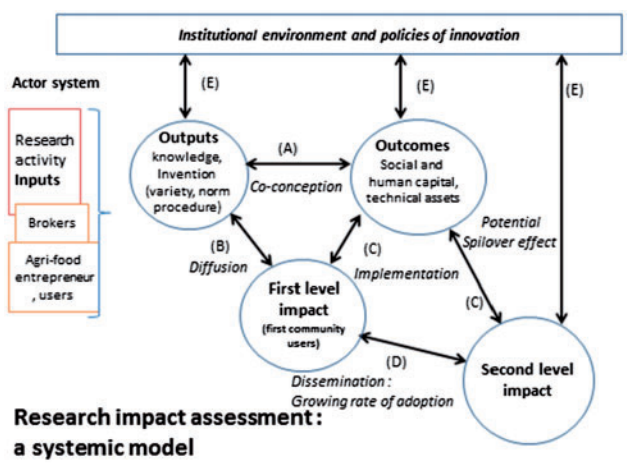

Figure 4. A systemic model for assessing the impact of agricultural research.

Additionally, the model takes into account that outputs frequently result from a co-production between research and other stakeholders. This co-production can happen by design (participatory research) or as a response to encourage ownership of the outputs.

The second type of interactions (Arrows A–E) describes the interactions between the various components of the impact pathway. Each interaction represents a complex process. The diversity of these processes explains the causal relationships between the research activity, the innovation process, and the impacts on development.

Arrow A highlights the interactions between *outputs* and *outcomes*. In some cases, outputs (e.g. a new variety of peanuts) structure the generation of outcomes (e.g. a network of farmers producing seeds). In other cases, outcomes are necessary for the co-conception of subsequent outputs that are created further in the innovation process by the interaction between actors (an innovation platform to co-produce a new way to manage manure).

Arrow B focuses on innovations that may still result from a linear 'diffusionist' logic. The outputs are directly transferred to users, sometimes with the intervention of intermediaries, but without a role for research. Arrow C refers to the way in which outcomes may be put to use, produce impacts at the level of a first-user community, and directly contribute to a change in scale beyond that community. Those outcomes have an important role in creating favourable conditions for adoption of research findings. We call it 'implementation'.

The fourth interaction (Arrow D) will not be discussed in detail here. It relates to the conditions for a change in scale. It includes scaling out and scaling up (Douthwaite et al., 2003) and the spillover effects (e.g. externalities from increased interactions among actors generated by research activity) that take place outside this central model. This change of scaling usually involves a step beyond the first-user community (users directly or indirectly linked to research activities) towards impacts in the second-user community (users not linked with research). This spatial or organizational change means an increase in the rates of adoption and their impacts.

Finally, the last interaction (Arrow E) shows how research activities generate changes in institutional frameworks, as they percolate into the innovation process: standards (product and process quality) and rules (e.g. intellectual property, various evaluation methods). These research activities influence public policies, and in particular innovation policies. The public policies in turn regulate access to the resources necessary for actors (entrepreneurs, organizations, civil society) to contribute to the innovation process.

This systemic model offers an original way of representing causality and feedback mechanisms between various components of impact pathways. It also shows the complexity of the interactions that structure it.

The model out forward has several advantages over existing models: (1) it highlights the central role of outcomes in the production of impacts; (2) it shows the systemic interactions between outputs, outcomes, and impacts putting an emphasis on feedback, and (3) it illustrates that different pathways are possible to produce impacts.

The findings from the 13 case studies show that the generation of outcomes is fundamental to the innovation process to ensure that research outputs are useful to societal change. They confirm that research activities play a key role in the generation of different outcomes that contribute to impacts on development. This role cannot be assessed through methods solely based on attribution of impacts. The model instead reveals the complexity of the contribution of research, as proposed by other studies on the assessment of the societal impacts of research (Morton, 2015). The weight of outcomes in the process varies. It depends on the predominant nature of the innovation (technological, institutional, and so on) or on the institutional context where it develops. The model proposed (Fig. 4) allows the possibility of linear impact pathways where outputs are directly adopted by the first-user community without mobilizing outcomes. However, such linear pathway did not emerge from the case studies.

The proposed systemic and participatory model to assess the innovation process aims to show in a rigorous way the contribution of research to impacts. It is developed in the empirical field of agricultural research. Further applications to other fields can be devised to test its generalizability. In relation to other analytical studies adopting impact pathway approaches in international agricultural research (Alvarez et al., 2010; Schuetz et al., 2017) or French research (Joly et al., 2015), this proposal has a key specificity. It places special emphasis on stakeholder participation in building the impact pathway, identifying impacts, and highlighting the complexity of interactions and their feedback loops.

The literature on innovation systems tends to represent their structure through the actor system or the configuration of interactions that link different actors of the innovation process. This type of analysis focuses on the nature of interactions but provides little understanding of mechanisms. Focusing the analysis on systems means either describing an existing reality or building a model representing reality. This article adopts such systemic approach. The proposed model represents the system beyond the focus on actors to a focus on mechanisms that articulate different phases of the innovation process.

Verifying the systemic complexity of these mechanisms relies on two observations (Morin, 2015). The first is that the nature of relations between phases is interactive. Causality goes both ways between elements. Therefore the generation of research outputs might arise from outcomes which act retroactively on the mechanisms of adoption and adaptation by first-level users or on its improvement by research activities. The second observation is on the experimental mechanisms that increase the frequency of interactions between phases of the innovation process. Table 2 shows the pivotal role of social capital and the creation of actor networks in structuring the capacity to adopt and adapt outputs by users. The sequence between phases of output production, outcome generation, adoption, and impacts does not follow a logic or predefined temporal sequence. Each case study analysed showed a specific configuration of interaction and temporality.

A cross-cutting element structuring the system relies on collective learning mechanisms. From an epistemological point of view, the existence of a system relies on a final aim that directs interactions between the different elements (Crozier and Friedberg, 1977). The heuristic hypothesis of the study herewith presented is that such aim is the generation of complementary actions that allow the circulation of information, learning, and knowledge between the three phases of the innovation process: emergence, implementation, and dissemination. In light of other works (Bawden, 2016), some dimensions of this systemic process could not be verified in the case studies. This gap does not invalidate the representation of the impact pathway in a systemic way. Conversely, it opens interesting research opportunities to make these other dimensions explicit.

5. Conclusion

The ImpresS framework developed by CIRAD was applied to a sample of 13 case studies. This framework is based on a systemic model to analyse impact pathways and emphasizes stakeholders' participation in their evaluation. The preliminary analysis of the 13 case studies highlights the importance of interactions between researchers and other actors throughout the innovation process to generate outputs, outcomes, and contribute to impacts. Such interactions take place at all levels of the impact pathway. The application of the ImpresS framework allowed us to draw four types of interactions: (1) joint production of outputs with other actors with feedback loops from outcomes to outputs; (2) interactions that generate outcomes, whether in the form of organizational resources or actors' capacity building, and often resulting from researchers' mediation; (3) interactions for the identification and characterization of research impacts, including expected and unexpected impacts, and (4) interactions that impact public policies. The structure and complexity of actor networks and the intensity of research contributions differ depending on the type of innovation and the phase of the innovation process. However, the role of research appears relevant in all steps of the process: conceptualization, implementation, and sometimes dissemination. The results also show how the outcomes generated are key to enable impact generation, especially through capacity-strengthening activities.

With regard to research adopting similar approaches in the agricultural field, we propose a new representation of the impact pathway, built and analysed in a participatory way, showing the diversity of interactions between its elements, including feedback loops between outputs, outcomes, and impacts. The model highlights the key role of outcome generation showing the diversity of interactions between outcomes and other components of the impact pathway.

In the agricultural sector, such a comprehensive analysis would help research institutions to better orient their investments and plan their activities towards impact.

The systemic impact pathway model proposed emphasizes the important role played by institutions in terms of networks (of individuals or organizations) and by policies that shape technological pathways (Geels, 2004).

The ImpresS framework and the impact pathway model proposed are complementary to conceptual frameworks of research evaluators who apply the impact pathway approach (Douthwaite et al., 2003; Alvarez et al. 2010; Joly et al., 2015). It nevertheless places special emphasis on stakeholder participation in the construction of impact pathways and the identification of impacts. It also diversifies the tools available to assess the impacts of research by developing a comprehensive approach adapted to the contextual specificities of research in the field of agriculture. By embracing and highlighting complexity, it reinforces the critiques to overly mechanistic monetary assessment approaches. It nevertheless needs to be further applied and refined to provide more robust impact assessment in systemic evaluations. For instance, several causal links within the impact pathway derive from actor stated knowledge and information. To increase robustness of the method, improved validation and quantification methods are needed.

This article's contribution aims to renew the pool of impact assessment methods for research activities (Mårtenssona et al., 2016) and, ultimately, gain support of national and international donors for the use of evaluation methods that embrace complexity (Douthwaite et al., 2017). Moreover, by gaining a better understanding of how to build desired outcomes to achieve impacts, researchers shall be better able to frame research questions, implement research protocols, and anticipate strategies to increase relevant interactions all along the impact pathway. This also implies strengthening the 'impact culture' within research organizations, improving their ability to sustain fruitful interactions throughout the research process, and ultimately learning to improve their contribution to impacts.

Notes

1. The authors thank the anonymous reviewers who have greatly improved the articles through their suggestions and demands of clarification to better present results.
2. Inputs: The resources used by the research team to produce scientific results and products; outputs: the results produced by the research team (publications, technical novelty, etc.); outcomes: appropriation of those results by beneficiaries or intermediate stakeholders that lead to technological adaptation, new rules, and new organizations; first-level impacts: impacts of the use of the innovation(s) on the stakeholders directly or indirectly interacting with research; second-level impacts : scaling out or scaling up of this innovation to other territories and audiences; spillovers. The concept of impact used is 'Positive and negative, primary and secondary long-term effects produced by a development intervention, directly or indirectly, intended or unintended' (Organization for Economic Co-operation and Development, 1998).

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