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Article

Developing an evaluation framework for university-driven technology-based, innovation for inclusive development (UTI4ID) projects

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Abstract

From the evaluation literature related to research and innovation policy, calls have long been made for improved evaluation processes especially where projects and programmes may be evaluated from a systems perspective. Drawing on the literature of innovation systems and innovation for inclusive development (I4ID) this research proposes a state-of-the-art analysis framework, which can be used to evaluate University-driven Technology-based Innovation for Inclusive Development (UTI4ID) projects. In particular, this framework draws on 16 exploratory case studies of UTI4ID that leads to the development of typologies that can be used in future UTI4ID evaluations to better guide such efforts. We thus not only show that advances in the I4ID literature provides an ideal starting point for complexity cognisant evaluations, but also contribute an end-to-end framework to support such evaluations and populate a detailed guide for future UTI4ID projects.

Key words: innovation for inclusive development; evaluation; innovation systems; inclusive innovation; university; innovation for inclusive development system

1. Introduction and background

Innovation is widely considered a key driver of economic growth. At the same time, although certainly not the only factors, innovation and technology have been identified as major contributors to inequality through a complex network of political, economic, and social processes (Foster and Heeks 2013a). Hence, a burgeoning body of literature investigates how innovation processes and systems may be adapted to support more inclusive growth. This is referred to as 'social innovation', 'inclusive innovation', 'innovation for inclusive growth' (George, Mcgahan and Prabhu 2012), and 'innovation for inclusive development' (I4ID; Paunov 2013). These alternative innovation models regard marginalized communities not only as potential customers but also as business partners to be included in the innovation process so that they may ultimately benefit economically from the resulting innovations (George, Mcgahan and Prabhu 2012). In this article, we use the term 'Innovation for Inclusive Development' (I4ID) which can be defined as the improvement of living conditions and the creation of employment opportunities for poor and marginalized communities through the development of new products, services, processes, and business models specifically aimed at these communities (Kaplinsky and Morris 2001; Heeks, Foster and Nugroho 2014).

I4ID projects have their genesis in different contexts and are initiated by different actors—in this regard a small-scale research pilot project was launched in 2014 to investigate the dynamics of university involvement in I4ID in a developing country such as South Africa (Grobbelaar, Schiller and de wet 2017; Grobbelaar, Tijssen and Dijksterhuis 2017). The study focused specifically on University-driven projects that developed/used technology focused innovations to bring about inclusive development (referred to as University-driven Technology-based Innovation for Inclusive Development (UTI4ID) projects in this article). The study's conclusions were presented in the form of a research agenda to highlight further research focus areas. The authors suggested further research in UTI4ID on inter alia: (1) drivers, strategies, and innovation processes; (2) roles and capabilities of a wide range of actors that participate in the process; (3) the infrastructures required to support UTI4ID; (4) institutional factors such as intellectual property, the

process of co-creation and engagement with communities. Finally, it was also concluded that apart from exploring these dynamics, further research is needed to assess how these factors collectively contribute to UTI4ID generating successful external outcomes. In particular, a need was identified for a more formal approach to assess such outcomes and how such an approach will allow for structured learning and identification of good practices for similar projects in future. This article presents the follow-up work and is a first study to test and apply this comprehensive framework.

In this article, we therefore aim to contribute to the growing field of I4ID and I4ID project evaluation—with a focus on UTI4ID. First, we highlight the merits of using the innovation system (IS), and Innovation for Inclusive Development Systems (I4IDS) analysis approach as a foundation for assessing I4ID projects—something that has not received much attention in the evaluation literature to date. Second, we develop a best practice I4ID evaluation framework based on the IS and I4IDS literature, the concept of capital development and the well-known logic framework. Finally, we explore the use of the framework in the context of university-driven technology-based innovation for inclusive development (UTI4ID) projects. In particular, we apply the proposed framework to the evaluation of 16 UTI4ID projects to gain novel insights regarding the nature of UTI4D projects.

2. Problem statement

Authors such as Patton (2010) have long been advocating the inclusion of complexity in systems evaluations. From an evaluation perspective, complexity theory in social sciences deals with how complexity is generated through diverse actors that may hold different goals and have access to specific resources (Carol 1998). However, complexity theory remains a disparate field where little coherence exists in how to deal with complexity (Walton 2016). Within this context, there has been an increasing trend towards the use of developmental evaluations (Jolley 2014; Milley et al. 2018). Developmental evaluation seeks to guide evaluations of emergent and dynamic realities in complex environments. It acknowledges that behaviours are driven by learning, evolution and development (Tilley and Pawson 2000). Hence, the concepts of non-linearity; emergence; adaptation; uncertainty; change in dynamical systems; and coevolution become important.

There is evidence that evaluation approaches have been widened to include complexity principles (Milley et al. 2018). A key example here is the UK's Department for International Development's (DFID) broadening of their range of impact evaluations to evaluate systems considering the role of complex interactions in the systems within which interventions take place (Garbarino and Holland 2009; Stern et al. 2012).

It is from this perspective of complexity and systems evaluation that we specifically consider innovation. It is widely acknowledged that the development and implementation of innovations occur within a socio-cultural context (Mondal, Kamp and Pachova 2010). Freeman (1987) defined innovation systems (ISs) as 'networks of institutions, public or private, whose activities and interactions initiate, import, modify and diffuse new technologies'. The IS framework is used to define how actors and institutions work in partnership to exchange knowledge to develop, produce, and diffuse innovations. It is also a framework through which the complex interactions between elements are acknowledged as well as the feedback loops and non-linear behaviour that exists as a result of various actors' activities in these systems (Lundvall 1992; Wieczorek and Hekkert 2012).

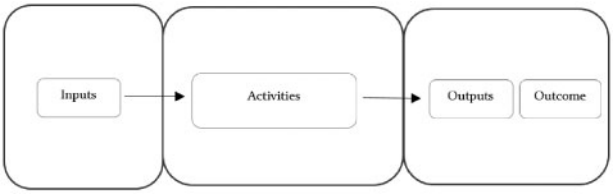

Figure 1. The logic framework serving as a basis for the UTI4ID evaluation framework.

There is a large evaluation literature on traditional ISs which includes the exploration of various indicators related to innovation performance on a systems level (Stenberg, Gustafsson and Marklund 1996; Edquist et al. 2018), the role of universities (Bölling and Eriksson 2016), and a large amount of studies on research impact (e.g. Snowball and Shackleton 2018; Temple et al. 2018). However, there is a limited evaluation literature on I4ID with most existing studies focusing on agriculture (Temple et al. 2018; Weißhuhn, Helming and Ferretti 2017). Certainly, utilizing I4ID from a systems and complexity perspective especially in developing country contexts is still completely underexplored (Botha, Grobbelaar and Bam 2016; Grobbelaar, Schiller and de wet 2017; Grobbelaar, Tijssen and Dijksterhuis 2017; van der Merwe and Grobbelaar 2018; van der Merwe, Grobbelaar and Bam 2019).

This article thus aims to present the development of a systems framework to guide the evaluation of I4ID projects, with a focus on UTI4ID projects in developing countries. One of the most prolific basic evaluation methodologies is the logic framework, which consists of four main steps: inputs, activities, outputs and outcomes (See Figure 1). By utilizing the familiar input>activities>outputs> outcomes structure of the logic framework the authors provide evaluation practitioners with a systematic approach to help develop program theories and formative and summative evaluations using a familiar setup and aligned with established funder requirements for project documentation. The contribution of this article is that the authors utilize a systems approach and aim to open up and explore the 'activities' section to view innovation from a complex systems perspective to assist the evaluation of I4ID projects. The authors also develop typologies for the outputs and outcomes aspect that will serve as a guide to assist evaluators to explore the various outputs and outcomes that may be generated through UTI4ID projects in particular. Specifically, we classify the outcomes of UTI4ID projects from the perspective of capitals created.

3. Methodology

The methodology followed to achieve these objectives were based on an established grounded theory-based approach aimed at the development of conceptual frameworks for complex social and multi-disciplinary phenomena linked to various bodies of knowledge (Jabareen 2009). The framework development process followed consists of four main stages namely: (1) Stage 1—Theoretical grounding; (2) Stage 2—Framework development; (3) Stage 3—Exploratory case studies, and (4) Stage 4—Integrated evaluation framework. Table 1 lists all the steps associated with each stage, the

Table 1. Description of research methodology

	Steps	Objective of steps	How the step is performed in this article
Theoretical grounding	Literature review on core concepts of IS.	Evaluate the state of the art of literature with respect to using ISs to evaluate the impact of project focused on improving I4ID.	In Section 4, the authors present the literature that pertains to the evaluation of ISs. The article introduces the component-function approach as an appropriate baseline approach.
Framework development	Develop a generic evaluation approach based on the state-of-the-art I4IDS frameworks.	Unpack the structure of the extended component-function framework tailored for I4ID impact evaluation.	Section 5, the extended framework's core steps are described and mapped out.
Exploratory case studies: a grounded typology construction process	By way of exploratory case studies, illustrate the application of the framework and develop typologies bottom-up to support the population of the framework.	1. Identify the components and functions present within UTI4ID projects from the sample. Identify systemic problems and design systemic instruments. 2. Develop output and outcome typologies from the UTI4ID projects in the sample.	Section 6 introduces the case studies. These case studies are conducted to gain insights into the specific components and functions present within UTI4ID projects. This is done in order to tailor the framework specifically for UTI4ID projects.
Conclusion: integrated evaluation framework	Present the integrated UTI4ID evaluation framework and reflect on its implications.	Present the integrated framework. Evaluate the implications of the developed framework for evaluation practitioners.	In Section 7 the output and outcome typologies are combined with the component-function framework in order to construct an UTI4ID evaluation framework.

objectives of each step and indicates where in the article this objective is presented.

After developing the generic analysis framework, exploratory case studies were conducted to construct typologies for the purpose of mapping out various aspects of the evaluation framework as extensively as possible for UTI4ID projects (Kluge 2000). The typologies are developed through an empirically grounded approach from the bottom-up based on in-depth interviews with the project leaders of 16 UTI4ID projects. Finally, the constructed types are described in-depth and depicted, by reference to their attributes and possible causal links (Kluge 2000). This provides insights regarding the typical dynamics of UTI4ID projects and also illustrates how the framework might be applied to other I4ID environments.

Due to the geographic location of the authors, the selection of UTI4ID projects was confined to the four public research universities in the Cape Town and Stellenbosch environment namely, the *University of Cape Town* (UCT); *Stellenbosch University* (SU); *Cape Peninsula University of Technology* (CPUT); and the *University of the Western Cape* (UWC).

We started with a list of 5 projects identified during a pilot project and sourced a further 11 UTI4ID projects from an internet search on innovation projects at the four universities to arrive at a total of 16 implemented innovations for our study. Table 2 provides an overview of the projects in our sample.

4. Theoretical grounding

Apart from the well-established logic model, the framework we developed draws from three core concepts from literature. First, the component-functions approach to IS analysis and its adaptation to enable Innovation for Inclusive Development Systems (I4IDS) evaluation i.e. how traditional IS approaches have been adapted to enable I4IDS analysis. Second, a key aspect of the component-functions approach focussing on systemic instruments. Last, the classification of outcomes as capitals. Each of these are described in turn in the following sections.

4.1 IS frameworks: the component—functions approach

Innovation models have evolved from linear technology-push and technology-pull conceptualizations (Godin 2006) to models that acknowledge complex behaviours along with the importance of understanding the interactions between actors and feedback loops that may exist (Fagerberg, Mowery and Nelson 2005). This has given rise to the concept of 'Innovation Systems' which is prevalent in innovation and economic development thinking and practice (Edquist and Hommen 1999). Although the IS approach was originally applied to the national level it has evolved to also include other dimensions such as regional innovation system, sectoral innovation system, and technological innovation system (TISs). Of particular interest to this article is the TIS framework which focuses on understanding the interrelationships between technologies, actors, networks, and institutions and in doing so, seeks to answer how an innovation system around a particular technology 'functions' (Carlsson and Stankiewicz 1991; Bergek et al. 2015).

Two dominant approaches within the TIS domain are the components-based approach and the functions-based approach. The components-based approach is focused on the core components such as actors, interactions, knowledge and learning, innovation, institutions, and infrastructure (Rucker and Trah 2007). The components are acknowledged to shape how the system is performing and how actors act; it is useful to help identify the presence or quality of components but has been criticized to result in analysis that is quite static and only useful for post hoc analysis (Hekkert et al. 2007; Bergek et al. 2008).

Functional analysis emerged as a complementary approach to solely focussing on the components of the system (Lamprinopoulou et al. 2014). The *function-based approach* assists to explore the activities and functions that the system needs to perform for the IS to achieve its goals i.e. innovations are developed and diffused

Table 2. UTI4ID projects

Project	Description	University
A1	Design and construction of structural interventions in rural communities in SA. So far, they have built a roof-covered gathering space for a school and water platforms.	CPUT
A2	Incorporated service learning into a module that entails community mapping. The students and community participate in the mapping of the informal settlement.	CPUT
B1	SU Department of Aquaculture developed small-scale trout farming process that provided opportunity for farm workers to start their own trout farms without the ownership of land being a primary prerequisite.	SU
B2	Point-of-use microfiltration system for production of clean water. The devices are cost effective and uses gravitational force instead of external energy sources for filtration.	SU
B3	Explore the use of technological support for school learners who require human readers during tests and examinations, learners with reading disorders. The project replaced human readers with MP3 players that contained a pre-recording of the tests.	SU
B4	The development and implementation of a generic development platform that enables any individual to easily develop individual therapy software (tools) for autism spectrum disorders, without resorting to extensive software development.	SU
B5	The Research Centre is a collaborative research centre that consists of researchers from the university as well as co-researchers from the marginalized community. The centre executes several informal settlements upgrading projects.	SU
B6	This project explores alternative access to classroom teaching by exploring e-learning to promote inclusivity of students who have special learning needs that could be met by attending class 'outside' of the physical classroom.	SU
B7	An intervention which seeks uses SU Telematics Division's interactive satellite platform to provide supplementary support for learners in underperforming schools, especially in rural communities of SA.	SU
C1	This project focuses on the fishery sector. It is a mobile phone application that allows the fishing community to communicate and share data with scientists and vice versa.	UCT
C2	Developed affordable heart valves to treat rheumatic heart disease with heart-valve surgery.	UCT
C3	This project developed and implemented a device that detects a change in temperature within a shack and sets off a network alert to protect against fires.	UCT
C4	This project developed a mobile retinal camera to screen for diabetic vision impairment. It provides a cost-effective alternative to traditional methodologies.	UCT
C5	The design and construction of water platforms in a rural community in SA. These platforms provide cleaner, more efficient and safer water collection areas. The platforms are used for water collection and clothes washing.	UCT
D1	This project looks at healthcare communication. Sign support is mobile phone application that allows the pharmacist to 'speak' to a deaf patient, where without assistive technology they would not be able to communicate with each other.	UWC
D2	The design and development of a business case and mesh network in a remote rural community as a cost-effective alternative to traditional mobile networks.	UWC

(Hekkert et al. 2007). The functions refer to key processes in an IS that support structural components. Seven system functions are prevelent in the IS literature: [F1] knowledge development; [F2] knowledge diffusion/dissemination; [F3] entrepreneurial activities; [F4] influence on the direction of search; [F5] market formation; [F6] guidance of search; and [F7] creation of legitimacy (Suurs 2009; Wieczorek and Hekkert 2012), The functional approach allows for identifying blocking mechanisms that hinder the development and diffusion of innovations (Bergek et al. 2008; Blum, Bening and Schmidt 2015). Here the focus is on the achievement of activities and the non-linearity of the system as functions are interdependent along with multiple interactions between functions (Jacobsson and Johnson 2000). Several authors have argued that the functional analysis should be coupled with component analysis as functions cannot be altered without altering structural components—this approach is thus followed in this article (van der Merwe and Grobbelaar 2018).

As a next step and as far as developing an evaluation tool that makes use of the component-functions analysis approach, we consider the applicability of the TIS framework in an I4ID context. Foster and Heeks (2013b) explores whether/how the TIS should be modified to attain a framework for Innovation for Inclusive Development Systems (I4IDS) analysis. An I4IDS will have a different goal than the traditional TIS in that it will have to develop and diffuse innovations aimed at resource-poor individuals or groups in order to present a positive contribution to improved life conditions and upward mobility (George, Mcgahan and Prabhu 2012).

A range of authors has expanded the TIS functions to I4IDS, each one of these functions support I4ID processes (See Table 3) (Hekkert et al. 2007; Bergek et al. 2008; Rip et al. 2010; van der Hilst 2012; Grobbelaar, Gwynne-Evans and Brent 2016; Van Der Merwe and Grobbelaar 2016). In interest of space, we illustratively discuss Function 1: Entrepreneurial activities. This function is traditionally aimed at engaging traditional IS actors (typically businesses, government, and universities) to exploit possible business opportunities by leveraging off system components such as developing and sharing relevant knowledge of the innovation, developing relationships and linkages (often regulated through formal contracts), and create markets for the innovation. Within an I4IDS, this means that this function needs to be expanded and actors engaged with in this process need to be more inclusive, business opportunities need to be created for marginalized individuals. This has a range of implications for the kinds of engagement mechanisms, new business models, and the articulation of demand.

Although in practice ISs are not likely to be purely traditional or purely inclusive, it is insightful to consider the additional aspects to be integrated in the framework for alignment with I4ID principles in

Table 3. Functions of IS in the context of I4IDS

Function	How should these functions be refocused for I4IDS?
F1: Entrepreneurial activities	Involvement with and entry of marginalized individuals in entrepreneurial aspect, new actors involved in business planning, novel business models are required for sustainable engagement of marginalized.
F2: Knowledge development	This will entail new sources of knowledge, focus of knowledge development towards inclusivity concerns, research capacity development in non-traditional actors, new types of research collaborations, a 'new commons' through new considerations for IP protection.
F3: Knowledge exchange	Engaging with non-traditional actors will have implications for how knowledge dissemination takes place: i.e. the development of capacity for dissemination in new actors, exploring the implications of absorptive capacity in various actors, new dissemination methods.
F4: Guidance of search	Focus of considering opportunities e.g. inclusion of development concern in policies, recognition of constraints in planning, and support for strategic knowledge development.
F5: Market formation	How can innovations as a result of I4ID be made to become market-ready, gaining access to existing and new markets?
F6: Resource mobilization	Access to capital, access and development of human resources and appropriate financing and business models for I4ID.
F7: Creation of legitimacy	Commitment, engagement with community – ensure legitimacy and sustainability of relationships.

the University context. The suggestion is that the focus of each component from the traditional ISs perspective should be adjusted to incorporate a new 'constellation of actors' which (in the case of this article) means lower income communities to be included in the innovation process. This may entail for instance to engage traditional actors (e.g. universities) to embark on non–traditional activities (coordinating innovation platforms in a community) and to engage non-traditional actors in the innovation process (e.g. impoverished community members). Table 4 specifically evaluates how the adapted I4IDS perspective relates to the higher education sector draws on, inter alia (Foster and Heeks 2013b, 2015; Grobbelaar, Schiller and de wet 2017; Grobbelaar, Tijssen and Dijksterhuis 2017).

4.2 Systemic instruments

Systemic problems refer to factors that inhibit the development of ISs (Hekkert, Negro, Heimeriks and Harmsen 2011). Several authors such as Carlsson et al. (2002) and Woolthuis, Lankhuizen and Gilsing (2005) argue that useful explanations for why an innovation system performs a function properly can be found by analyzing the system components. Wieczorek and Hekkert (2012) outlined two helpful perspectives: (1) whether the components are present or absent, and (2) whether there is a problem with the properties such as their capabilities or quality. They summarized a list of systemic problems from literature and conceptualized a set of systemic problem categories. These are summarized in Table 5.

Systemic instruments are tools that aim to improve the functioning of a system by solving systemic problems caused by components within the system. These systemic instruments aim to accomplish a set of goals. These goals are linked to the types of systemic weakness it is aimed at addressing. Table 5 draws on Foster and Heeks (2013b), Grobbelaar, Gwynne-Evans and Brent (2016), and Grobbelaar, Schiller and de wet (2017), Grobbelaar Tijssen and Dijksterhuis (2017) and provides an overview of such instruments linked to the problems they aim to address. Several of the systemic instruments centre on the notion of improving dialogue, vision, and strategy development, experimentation and the articulation of demand (van Mierlo et al. 2010).

4.3 Classifying outcomes as capitals

When considering the outcomes of projects, it is possible to classify such outcomes in terms of the human *capabilities* and *capital* that is developed (Sen 1997). In particular, Bebbington (1999) introduced five *capitals* (produced, human, natural, social, and cultural) as a means of improving interventions to ensure they resonate with the ways people make a living. These *capitals* are not only resources to be used, but provide people with the capability to engage with and change the world around them (Bebbington 1999). 'Capitals' can be defined as any type of resource that can produce other resources and when a resource is invested, it becomes a capital. A more recent instantiation of the capitals framework can be found in the work of Emery and Flora (2006), called the Community Capitals Framework (CCF). In their work, Emery and Flora (2006) find that increasing stocks of specific assets is insufficient, indeed an increase in the flow of assets that build stock in additional capitals is required to improve community capacity. They identify seven capitals, namely:

- Natural capital: Assets that abide in a particular location.
- Cultural capital: Reflects the way people 'know the world' and act within it.
- Human capital: Human skills, capabilities, and knowledge.
- Social capital: Connections within communities, networks, and the sense of belonging.
- Political capital: The ability to voice needs and have influence to achieve certain aims.
- Financial capital: Money.
- Built capital: Infrastructure and tangible buildings in a community.

More recent studies have also acknowledged the CCF's growing uptake in the study of development (Fernando and Goreham 2018) and community project evaluation (Hale and Carolan 2018). We align with this research by adopting the seven capitals to analyze development. Furthermore, given our study's context of UTI4ID projects, we add to these capitals two more capitals relevant from a university perspective—'academic capital'—which relates to all academic related outcomes; and 'business capital' with relates to the establishment of spin-out businesses/corporations.

Table 4. Evaluation of how I4IDS aspects relate to higher education sector (UTI4ID)

Component	Innovation for inclusive development systems	Higher education sector considerations
Goal	Socio-economic focus with some focus on the micro-level and improving livelihoods and quality of life	Enhancing the presence of university in supporting or leading I4IDS.
Actors	Often includes lower income participants, also informal sector participation; traditionally big focus on demand stimulation but increasingly also other aspects of the value chain	Non-traditional actors included; new roles of actors in the system; type of partners; competences and capabilities; community leadership engagement
Innovation	Often incremental and focus on diffusion; focus on solving local problems or meeting local demand; inclusion of marginalized in innovation process; reverse engineering also plays important role	Type of innovation; business models; sustainability and scaling-up; synergies and conflicting interests between university core missions
Learning	Contextualized learning, focus on diffusion and needs; learning about social processes, process of inclusion and formulation; guided by inclusive development related goals	Type of ideas and skills; type of (co-) creation processes and knowledge use; absorptive capacity by users; knowledge brokerage systems; intermediaries and learning spaces
Interaction	Needs to be open and socialized and include a wide range of participants along the value chain	Type of processes and mechanisms; level and nature of engagement; collaborative networks and partnerships; interactive learning spaces; student education; teaching/training of community members
Institutions	Complex mix of informal and formal; requirement for spaces to engage and build trust with new constellations of actors; regulatory environment crucial for allowing new approaches to traditional activities	Intellectual property rights, laws and regulations; ICT facilities; university policies and initiatives on societal engagement and local entrepreneurship; university incentive and reward systems for researchers; government subsidy systems and support systems

Furthermore, we adopt a general classification of socio-economic impact (referred to as 'outcomes' in our study) found in literature, namely, 'market' and 'non-market' outcomes. Market-based outcomes can be measured in terms of market related outputs such as increased income or employment created in a marginalized community. Non-market-based outcomes cannot be measured in monetary terms, rather these are rooted in social interactions and networks (McMahon 2009). We thus evaluate the identified capitals along both of these dimensions to ensure the full extent of the capitals are considered.

5. Towards a framework

This section describes the development of the evaluation framework. In alignment with several studies that have utilized the component-function approach, our framework consists of three overarching steps. These are outlined in Figure 2. Step 1 integrates the input (in this case, systemic instrument) and activities (functions) parts of the logic framework (while also identifying the components and functional problems), while the output and outcomes parts of the logic framework are separated in subsequent steps as in the traditional framework.

With specific focus on Step 1, the analysis starts by identifying the components of the system (Step 1.1). This is followed by the coupled component-function analysis (Step 1.2) which entails questions to enable systems performance analysis. Step 1.3 entails the identification of system failures. These failures inhibit/block learning and innovation by actors and can be classified based on the type of failure (presence or capacity). These failures are linked to system components. These blocking mechanisms can then be overcome by identifying the goals of systemic instruments (Step 1.4) and by means of systemic instruments that aim to influence the components and connections within a system to strengthen the performance of functions (Step 1.5). The Steps 1.2 to 1.5 of the analytical framework can therefore be summarized as shown in Table 6, with more detail regarding the evaluation questions for Step 1.2 presented in Table 7.

It is important to note that these categories do not suggest that for a system to perform effectively all these types of structures have to be present. It simply serves as a useful theoretical typology that can be applied to the assessment of systemic problems. This is then useful to allow for uncovering the emergent activities and barriers to the creation of new innovations and the diffusion of them. Common outputs and outcomes for UTI4D projects are developed through the exploratory case studies. These are presented in the following section.

6. Exploratory case studies: a grounded typology construction process

Exploratory case studies of 16 projects were completed to (1) explore the use of the component-function approach as an UTI4ID project evaluation approach and to inductively populate the systemic problems and instruments typology (Step 1 of the Framework) and (2) inductively identify outputs and outcomes of these projects in order to construct a typology for Steps 2 and 3 of the Framework (as outlined in Figure 2).

6.1 Component-function analysis (Step 1 of the framework)

The component-function framework was applied to the 16 projects introduced in the methodology section. This process followed the five stages shown in Figure 2.

6.1.1 *Step 1.1: Identify components.*

It is important to identify the structural elements within the UTI4ID projects before the functional assessment is undertaken, as a function can only be improved by changing one or more of the structural

Table 5. Systemic problems and instruments

Structure	Conceptualized systemic problem types	Goal of systemic instruments	Examples of systemic instruments
Actors:	Presence	Focus on the participation of several actors, especially lower income/marginalized actors to improve quality of life and living conditions.	Focus groups; feedback sessions; workshops; new types of partnerships; interactive actor involvement techniques; venture capital.
	Capabilities	Create spaces where actor capabilities can be improved to provide them with opportunities.	Training and education sessions; workshops; pilot projects; focus groups; feedback sessions; roadmaps
Interactions:	Presence	Stimulate and induce interaction that is open and socialized including both formal and informal actors.	Innovation platforms; collaborative research programmes; conferences; Bridging institutions (community liaison, local NGO).
	Quality	Block ties that are either too strong or too weak.	Training and education sessions; workshops; pilot projects; focus groups; feedback sessions; programme assessment and monitoring.
Institutions:	Presence	Stimulate the presence of formal and informal institutions that create a space that stimulates engagement and fosters trust with a new constellation of actors.	Memorandum/agreement; obligations; articulation of commitment; measures taken to build awareness.
	Capacity	Do not allow institutions to be too weak; monitored environment that allows new approaches opposed to traditional activities.	Agreements; regulations; principles; norms; standards.
Infrastructure:	Presence	Stimulate and induce the presence of different infrastructures that are contextualized and focussed on diffusion and meeting specific needs.	Knowledge and financial infrastructure needs to be put in place in order to construct a business model; access to capital through grants/loans/funding; various business models.
	Quality	Make sure that the infrastructure is of acceptable quality—in line with inclusive development goals.	Grant loans/funding to incentivize UTI4ID project and to employ full time staff members.

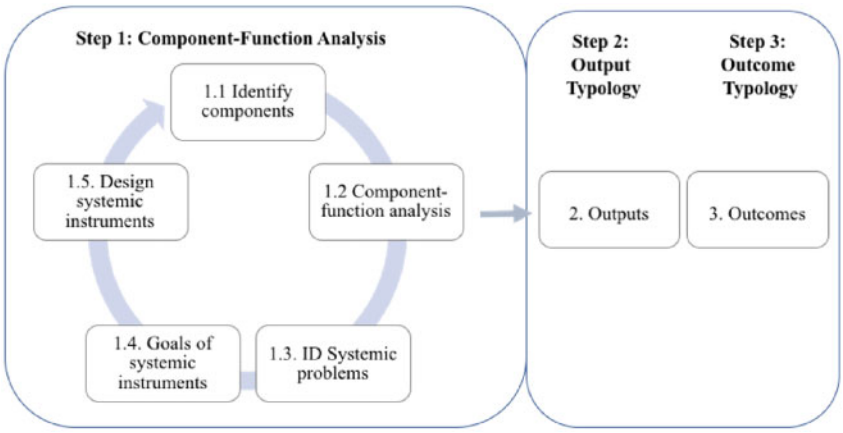

Figure 2. Proposed framework structure.

elements of the UTI4ID projects. We briefly describe the innovation system components and their capabilities as encountered in the UTI4ID projects.

6.1.1.1 Actors and relations. Using the framework outline developed in Section 6 we researched the actors involved and their contributions to the innovation. The main focus of relations that emerged from our case studies was on the nature of engagement and partnerships as enablers, the level to which the community was 'included' and the mechanisms of community interaction.

Each project in our sample is driven by a project champion. Similar to what was found in the study by Grobbelaar, Tijssen and Dijksterhuis (2017) we also found that in most cases the project champion is an academic dedicated to the advancement of development and equality. Student involvement was usually related to the completion of their theses or course work (PhD, Masters, or Under Graduate projects). Projects A1 (Design and construction of structural interventions) and A2 (Incorporated service learning into a module that entails community mapping) for instance formed part of a course syllabus where students were expected to design, develop

Table 6. Component-functions analytical framework adapted from Wieczorek and Hekkert (2012)

Step 1.2: Functional dynamics analyzed (absent, weak, too strong, etc.)	Step 1.3: Reason for functional dynamics		Step 1.4: Goal of systemic instruments	Step 1.5: Systemic instruments
For each systems function indicators are developed to guide function evaluation (see Table 7)	Systemic problems are identified by exploring components, their capabilities and intensity/presence		Evaluation questions for establishing systemic instrument goals	Design systemic instruments
F1: Entrepreneurial activities F2: Knowledge development F3: Knowledge diffusion F4: Guidance of search F5: Market formation F6: Mobilization of resources F7: Creation of legitimacy	Actor problems	Presence?	1. Are we encouraging and organizing involvement of a wide variety of influential actors?	• Focus groups; feedback sessions; workshops. • New types of partnerships. • Interactive actor involvement techniques.
		Capability?	2. Are we establishing spaces and methods for actor capability development?	• Training and education sessions; workshops; pilot projects; focus groups; feedback sessions.
	Interactions problems	Presence?	3. Are we motivating interaction opportunities between diverse actors?	• Innovation platforms; collaborative research programmes; conferences. • Bridging institutions (community liaison and local NGO).
		Capacity?	4. Are we avoiding networks that are either too strong or too weak for the specific requirements?	• Training and education sessions; workshops; pilot projects; focus groups; feedback sessions. • Programme assessment and monitoring.
	Institutions problems	Presence?	5. Do we have appropriate presence of (hard and soft) institutions for the specific innovation in focus?	• Presence of (hard and soft) institutions the specific innovation in focus.
		Intensity?	6. Are we avoiding institutions being either too strong or too weak for the specific requirement?	• Avoid institutions being either too strong or too weak for the specific requirement.
	Infrastructure problems	Presence?	7. Do we have adequate physical, financial and knowledge infrastructure?	• Motivate physical, financial, and knowledge infrastructure.
		Quality?	8. Are we effective at ensuring infrastructure quality to be sufficient?	• Ensure infrastructure quality to be sufficient.

and implement I4ID interventions. In two projects C3 (the development and implementation of a device that detects a change in temperature within a shack and sets off a network alert to protect against fires) the students were the inventors and project champions. The implementation of their innovation was supervised by a lecturer/member of faculty.

All of the UTI4ID projects in our sample were made up of both formal and informal partnerships between the project team (university) and other partners. Partnerships served as enablers by contributing in different ways. We found that other departments from the same university of the UTI4ID project mostly participate in co-research, i.e. the departments work together to enable the project. Other South African and international universities participate by sharing knowledge. The local (marginalized) communities allow the projects to be implemented in their communities and then provide feedback on the project. Most of the contributions from government, businesses, and NGO's were made in terms of funding.

Another important contribution from NGOs and local municipalities was pre-established relationships with the marginalized community members. In several of the projects in our sample (A1, B2, C1, D1, and D2) a member from the local NGO/municipality would serve as a community liaison that would communicate with the community on behalf of the project team. Three of these projects listed working through an NGO that has a pre-established relationship as a critical success factor as it decreases the time required to gain trust and increases the chance of acceptance of the innovation.

One of the main focus points under 'Relations' is the level of inclusiveness and the nature of engagement with the marginalized community. We divided the degree of community involvement into three categories based on whether they were included in the design, development, or implementation phase of the innovation. We found that all the projects provided an innovation that was implemented and 'consumed' by the marginalized communities. Only three of the projects included the community in the Design phase and six in the Development phase.

6.1.1.2 Infrastructure. As suggested by the framework we focused on knowledge infrastructure, financial infrastructure, and

Table 7. Analyzing functional performance of the I4IDS (extended from Hekkert et al. 2007; Bergek 2008; van der Hilst 2012; Wieczorek and Hekkert 2012)

Function	Indicators	Prompting questions—to characterize the effective performance of functions
F1: Entrepreneurial activity.	Entrepreneurship models	What model of entrepreneurship is engaged in (entrants or incumbent firms)?
	Project champion	What are the roles that the project champion fulfil?Are other functions (not fulfilled by project champion) delegated to other actors and to whom?
	Involvement of marginalized	When and how is the marginalized group involved in entrepreneurial activity as far as invention, design, development, production, distribution, or use?
	Businesses	Are there businesses involved, and what is the extent of involvement?
	Experimentation	How and through what means is experimentation of the innovation and its application conducted (tests/pilots)?
F2: Knowledge development.	Sources and process of knowledge development	What and who are involved in the process of knowledge development?Did the process include the marginalized group? How did learning take place? (learning-by-doing, learning-by-interaction, and learning-by-using)
	Knowledge infrastructure	Is the expertise, know-how and strategic information that is available sufficient? Considering various types of knowledge (technological, business, tacit and codified)—what needs to be better understood to make this innovation successful?
	Research collaboration	To what extent is there collaboration between the different users of knowledge? To what extent do various actors have access to requisite sources of knowledge?
F3: Knowledge diffusion/dissemination	Focus of diffusion	Is the focus of diffusion top-down or bottom-up? Is knowledge diffusions aimed at benefiting the marginalized group? Is knowledge development and diffusion demand-driven?
	Partnerships	Are there knowledge partnerships forming between various actors?
	Space for dissemination	Is there activity around creating spaces and places for knowledge dissemination (workshops, focus groups, etc.)
F4: Guidance of search	Targets	Which targets are being set regarding the use of the technology, are they realistic, are there strategies in place to meet these targets?
	Recognised constraints	What are the main constraints that inhibit or block the success of the project?
	Belief in growth potential	Does the project team have a belief in the growth potential of the solution? Is there any articulation of interest from marginalized community? How is this included in the programme vision and strategy?
F5: Market formation	Institutional infrastructure	Are there incentives to promote market formation (favourable tax regimes, environmental standards etc.)? Are there collaborative organizations and infrastructures to support I4ID?
	Market- readiness	Any existence of incentives for I4ID? Is the project creating spaces for innovations to become market-ready?
F6: Mobilization of resources	Access to capital	Does the project have access to capital? Where does this come from? Is the funding sustainable?
	Platform or stand-alone	Is the project part of an innovation platform where resources can be pooled from?
	Public spending	What share of the project budget is spent on public spending?
F7: Creation of legitimacy	Group confidence	Does the project and its output have a good reputation with the users of the product/service (quality, on-time, etc.)?
	Commitment	Does the project show commitment to the advancement of the marginalized group? Are there formal agreements/ memorandums set up that dictate the commitment of various role players and the University?
	Partnership forming	Are there partnerships forming? (government, NGO's etc.)? Is this sustainable?
	Business plan assessment	Is there confidence in the business aspects of the intervention i.e. has the business plan been assessed?
	Resistance to change	Is there resistance to change from the marginalized community?

management infrastructure. A key function of the university representatives in all of the projects in our sample was their knowledge contributions. They were the actors responsible for the technical know-how and expertise required to develop the technological innovations.

We observed a lack of institutionalization in our sample. Only 5 out of the 16 projects in our sample were embedded within an innovation platform. Such a platform provides institutional backup that promotes sustainability. If the project driver leaves, such a platform could enable continuity of the project. It also provides a basis where learning regarding 'what works and what does not' can be transferred to new projects or students that become part of existing projects, therefore increasing the absorptive capacity of the UTI4ID project.

All of the projects in our sample were dependent on funding from the university or other sources. Five of the projects were hybrids (i.e. combination of developmental/non-for-profit and for-profit) and aiming to become for-profit project (i.e. self-sustainable), but none have reached that point yet.

6.1.1.3 Institutions. Institutions refer to cultures, norms and regulations that influence both the actors in the system and the system as a whole. Two specific 'institutions' explored in our study were (1) open source versus commercial orientation and (2) the mechanism of community engagement used by projects.

There exists a conflict between the social development objective of 'providing open access to all' and the commercial and economic

Table 8. Functional analysis of Project B6

Pressing area	Indicators	Explanation (functions)	Score	Total Score	Solution/systemic instruments (components)
F1: Entrepreneurial activity	1. Project champion 2. Degree of community involvement 3. Experimentation	1. Present 2. Marginalized communities not included in Design and Development phases of the innovation 3. Moderate	+1 −1 0	0	Include community earlier: workshops etc.
F5: Market formation	1. Business models 2. Sufficient human infrastructure 3. Sufficient tech infrastructure 4. Sufficient financial infrastructure	1. No business models in place 2. Moderate 3. Present 4. Moderate	−1 0 +1 0	0	Business models need to be created in order to make project sustainable.
F6: Mobilization of resources	1. Access to capital 2. Access to human, physical and financial infrastructure required	1. Stand-alone projects, no platform from which to pool resources. 2. Stand-alone projects, no platform from which to pool resources.	−1 −1	−2	Relationships and networks need to be formed in order to create innovation platforms where resources such as knowledge and equipment can be shared.

notion of obtaining select rights to certain resources such as intellectual property (IP) rights'. We observed both cases within our sample. Some projects such as C1 (A mobile phone application that allows the fishing community to communicate and share data with scientists and vice versa.) and A2 (Incorporated service learning into a module that entails community mapping) made their intellectual property available on an open source basis where anyone has access to it. Project C1 (the fishery mobile application) for instance was given free access to the Salesforce© platform on which the application software was developed and project B6 (e-learning for students with special needs) was entirely facilitated on an open source live streaming service provided by Google called 'Hangouts on Air'. In these two examples technological innovation could be developed because resources such as knowledge, software, and platforms were freely shared. In these projects social impact was brought about by the use of the innovations themselves, but by also making these innovations freely available to the public, their design and development could also result in social impact. There were also projects in which IP rights played a critical role, especially in terms of commercialization. With the assistance and legal guidance of UCT's Research Contracts and Intellectual Property Services, Project C3 (the device that sends off an alarm when there is a fire in a shack) obtained copy rights for their software codes and UCT owns the technology patent. This project developed into a spin-off company that now develops and sells/provides the fire detection devices. This innovation leads to social impact once it has been implemented into and used by a community.

We discovered two trends in the way that the UTI4ID projects in our sample engaged with the marginalized community. In most of the projects, the project champions were the ones who developed a relationship with the community and were able to inspire and gain the trust and commitment of the community. The second mechanism used for community engagement was the use of intermediaries or community liaisons to approach the community. This mechanism reduced the time it took to gain trust and increased the adoption rate of the innovation.

6.1.2 *Steps 1.2: Component–function analysis.*

The authors analyzed the system functions of the UTI4ID projects by making use of a methodology defined by Hekkert et al. (2007). For each function, we constructed a list of indicators from literature. An evaluation was then done for each of the UTI4ID projects to determine the presence of indicators. When an indicator is present, it is postulated to have a positive contribution to the UTI4ID project success and thus represents a positive score. Some indicators are, however, not present, and their absence is seen as a limiting factor therefore the absence of an indicator is counted as a negative score. All indicators are weighted the same. Each function has a highest possible score. The positive and negative scores are added to each other and the comparison between the result and highest possible score for a specific function is used to identify areas for improvement. This study classifies Absent to Weak as 'not present' (−1) and Moderate to Strong as 'present' (+1) and indicators that are 'moderately present' are classified as moderate and given a score of 0. We argue that this is sufficient as the aim is to help the projects identify the main problem areas (See first two columns of Table 8).

To illustrate this approach, we focus on one example, namely project B6—which is a project from Stellenbosch University where researchers have used technology to provide education to learners with learning disabilities.

Table 8 below shows the three functions of project B6 that were identified during the interview process as 'problem areas'. The other functions have a total score > 0 and have been omitted from the table in the interest of saving space. We postulate in the framework that the following three indicators positively contribute towards Function 1: Entrepreneurial activity: (1) Project Champion, (2) Degree of community involvement, and (3) Experimentation. When mapping project B6 to these indicators we found:

1. There is a project champion present, a professor from the University of Stellenbosch. This individual was responsible for the vision of the project. The presence of the project champion earns a positive score of +1.

2. The community that the project was trying to reach, learners and teachers from marginalized communities, were not included in the design and development phases of the innovation. Since this indicator was not met, it was awarded a negative score of −1. During the interview the champion noted that adoption is one of their key challenges, we believe that the 'Degree of community involvement' indicator could help to identify this as an area for future consideration to encourage and facilitate the involvement of end-users from the start. This may help them take ownership of innovations and improve adoption rates.
3. Entrepreneurial activity can be analyzed using the amount of experiments conducted with the innovation. In project B6 a pilot project was deployed to serve as 'proof of concept'. Therefore, some experimentation was done with a minimum viable innovation in order to collect feedback and improve the innovation but no extensive experimentation was done, therefore it is awarded a score of 0.

When mapping the indicators for Function 5: Market Formation in project B6 these are (1) Business model, (2) Sufficient human infrastructure, (3) Sufficient technology infrastructure, and (4) Sufficient financial infrastructure we found:

1. For this case there was no business model in place, which indicates that sustainability and scaling are not high priorities for this project (there is no plan to fund the project after the pilot phase which is funded by the university). The absence of a business model therefore receives a score of −1.
2. The project has a champion and small team that are working together to design, develop, and implement the innovation. There is a gap however in the human infrastructure of the end users. This innovation requires a champion user from within the marginalized community who will support the implementation and provide feedback if there are challenges in using it. This indicator is awarded a 'moderately present' score of 0.
3. The project has all the technical infrastructure it requires (hardware, software, connectivity, etc.) and therefore receives a positive score of +1.
4. The pilot phase of the project is funded by the University of Stellenbosch. The financial infrastructure is therefore currently in place, but work will have to be done to ensure that this can be maintained post the pilot phase. This indicator therefore receives a moderate score of 0.

Based on the scores of these indicators this tool highlights the lack of a business model as a systemic weakness and would urge projects to ensure that the business model is developed in order to plan for a sustainable and scalable project.

The third Function that was identified as a 'problem area' in project B6 is Function 6: Mobilization of resources. The indicators from literature that would contribute to the success of this function are (1) access to capital and (2) access to infrastructure (human and physical). Project B6 does not form part of a specific research group or initiative within the University of Stellenbosch, it is a stand-alone project that was started by the project champion. The downside of this is that it does not form part of a platform from which it can pool financial, human, and physical infrastructure. The project therefore scored negatively on both access to capital and access to infrastructure.

6.1.3 *Step 1.3 to 1.5: Systemic problem identification and designed systemic instrument typology for UTI4ID projects.*

The value of the tool described above lies in identifying possible absence/weakness of an indicator. This can then be addressed through systemic instruments linked to the components of that function. The systemic problems therefore aim to explain the weak functional performance and with the use of systemic problem categories and instruments we could propose changes that need to be made to system components in order to address the systemic weaknesses identified. Exploratory data analyses were done for each project in our sample. Using the systemic instruments suggested during the exploration of each project, a typology of systemic instruments shown in Table 9 was constructed for the evaluation framework. We provide a few examples of how this analysis was done below.

As an illustrative example, in Project B6's case, we have identified that one of the functional problems is a lack of entrepreneurial activity, here indicators help to identify the specific systemic problems for a project (e.g. the absence of the marginalized community in design and development phase of the innovation). The suggested systemic instruments that can be used to solve this particular problem are (1) identify a focus group within the community with which to design, test implement the innovation. Host workshops and feedback sessions to get their input, (2) Consider new types of partnerships, for example in project B1 which aims to empower small scale fish farmers, the academic staff partnered with farmers and their farm workers by placing them on the steering committee of the project and sharing profits. This model ensured the participation of the farm worker as they were owners of the project, and (3) Cooperative research programs and bridging institutions. An example of where a bridging institution, specifically a community liaison was key to the involvement of the community was in project A1 (Design and construction of structural interventions in rural communities in SA) where the university staff connected with a community liaison (local NGO) to identify appropriate locations to implement structural interventions and all communication with the community was done through this NGO. This was very valuable because the community already trusted the NGO.

We used the interview transcripts from our 16 case studies and theoretical framework in Table 6 to inductively populate the possible reasons for function weaknesses and suggest systemic instruments that could address these weaknesses (See Table 9).

6.2 Constructing an output typology (Step 2 of the framework)

There are several beneficiaries involved in the UTI4ID projects, each with their own interests for participating, own set of inputs, expected outputs, and outcomes. By considering the specific beneficiaries separately, it is possible to identify failures not only in terms of functionality but also in terms of the actor(s) affected by the failure.

Four main beneficiaries were inductively identified from our sample of UTI4ID projects. These are (1) the members of the marginalized community—often the target group of the UTI4ID project; (2) the academics/researchers—the university staff members that drive the UTI4ID project (3) university students that are involved in the projects and (4) the broader university enterprise itself.

Table 9. Steps 1.2 to 1.5—Functional analysis, systemic problem identification and designed systemic instrument typology for UTI4ID projects

Step 1.2: Functional analysis		Step 1.3: Systemic problems in functions	Step 1.4: Goals of systemic instruments	Step 1.5: Designed systemic instruments
Function	Indicator	Systemic problem	Systemic instrument goals	Systemic instrument
F1: Entrepreneurial activity	• Community absent in design and development phases.	• Actors: • Presence • Interactions: • Presence	• Induce and stimulate the participation of several actors. • Induce and stimulate interactions between diverse actors.	• Focus groups; feedback sessions; workshops. • Interactive actor involvement techniques. • New types of partnerships. • Cooperative research programmes; feedback sessions; bridging institutions (community liaison, local NGO).
	• Community unaware of the intervention in early phases.	• Institutions: • Presence	• Stimulate the presence of hard and soft institutions.	• Awareness campaigns; information campaigns.
	• Extent of experimentation is limited.	• Actors: • Capabilities • Interactions: • Quality • Infrastructure: • Quality	• Induce and stimulate the participation of several actors • Block or address ties that are either too strong or too weak. • Make sure that the infrastructure is of acceptable quality.	• Creating platforms for learning and experimenting, such as: training and education sessions; pilot projects; focus groups; feedback sessions. • Evaluation methods and tools; forecasting; technology assessments; pilots.
F2: Knowledge development	• No/weak interaction between community and university project team.	• Actors: • Presence • Interactions: • Presence	• Induce and stimulate the participation of several actors. • Stimulate and induce interactions between diverse actors.	• Focus groups; feedback sessions; workshops. • New types of partnerships. • Interactive actor involvement techniques. • Cooperative research programmes; feedback sessions; bridging institutions (community liaison, local NGO). • Creating platforms for learning and experimenting, such as: training and education sessions; pilot projects; focus groups; feedback sessions.
	• The community is not involved in the research process.	• Interactions: • Presence • Institutions: • Presence	• Stimulate and induce interactions between diverse actors. • Stimulate the presence of hard and soft institutions.	• Cooperative research programmes; feedback sessions; bridging institutions (community liaison, local NGO). • Awareness campaigns; information campaigns. • Training and education sessions; workshops; pilot projects; focus groups; feedback sessions.
F3: Knowledge dissemination	• No space/opportunities created for knowledge transfer.	• Actors: • Capabilities • Interactions: • Quality	• Create spaces where actor capabilities can be improved. • Block or address ties that are either too strong or too weak.	• Creating platforms for learning and experimenting, such as: training and education sessions; pilot projects; focus groups; feedback sessions. • Host demonstrations of technology in order to transfer knowledge. • Creating platforms for learning and experimenting, such as: training and education sessions; pilot projects; focus groups; feedback sessions.

(continued)

Table 9. Continued

Step 1.2: Functional analysis		Step 1.3: Systemic problems in functions	Step 1.4: Goals of systemic instruments	Step 1.5: Designed systemic instruments
Function	Indicator	Systemic problem	Systemic instrument goals	Systemic instrument
	• Lack of meaningful interactions that could result in 'learning-by-interacting'.	• Interactions: • Quality	• Block or address ties that are either too strong or too weak.	• Bridging institutions (community liaison, local NGO). • Management of interfaces. • Creating platforms for learning and experimenting, such as: training and education sessions; pilot projects; focus groups; feedback sessions.
	• Knowledge dissemination is top-down and not demand-driven; therefore, it is not 'inclusive'.	• Institutions: • Quality	• Do not allow institutions to be too weak.	• Stimulate demand articulation: bottom-up knowledge creation; co-creation models; training, information and education sessions.
	• Weak partnerships forming.	• Interactions: • Presence • Quality	• Stimulate and induce interactions between diverse actors. • Block or address ties that are either too strong or too weak.	• Innovation platforms; collaborative research programmes; conferences. • Stimulate demand articulation: bottom-up knowledge creation; co-creation models; training, information and education sessions. • Bridging institutions (community liaison, local NGO). • Management of interfaces. • Creating platforms for learning and experimenting, such as: training and education sessions; pilot projects; focus groups; feedback sessions.
F4: Guidance of search	• Vague targets for the use of technology, no M&E conducted beyond implementation.	• Institutions: • Quality • Infrastructure: • Quality	• Do not allow institutions to be too weak. • Make sure that the infrastructure is of acceptable quality.	• Stimulate strategy and vision development: bottom-up knowledge creation; co-creation models; training, information and education sessions. • Memorandum/agreement; obligations; articulation of commitment. • Provide infrastructure for strategic intelligence.
	• Marginalized community show some interest, but also vandalize the structures.	Institutions:Presence	• Stimulate the presence of hard and soft institutions.	• Awareness campaigns; information campaigns.
	• Limited belief in growth potential.	• Infrastructure: • Quality • Institutions: • Presence	• Make sure that the infrastructure is of acceptable quality. • Stimulate the presence of hard and soft institutions.	• Trend studies; programme monitoring methods and tools; surveys; questionnaires. • Awareness campaigns; information campaigns.
	• Lack of awareness of the innovation amongst the members of marginalized communities.	• Institutions: • Presence	• Stimulate the presence of hard and soft institutions.	• Awareness campaigns; information campaigns.
F5: Market formation	• No real incentive to promote market formation.	• Interactions: • Presence • Infrastructure: • Quality	• Block or address ties that are either too strong or too weak. • Make sure that the infrastructure is of acceptable quality	• Stimulate demand articulation: bottom-up knowledge creation; co-creation models; training, information and education sessions. • Grants/ loans/funding to incentivise UTI4ID projects.

(continued)

Table 9. Continued

Step 1.2: Functional analysis		Step 1.3: Systemic problems in functions	Step 1.4: Goals of systemic instruments	Step 1.5: Designed systemic instruments
Function	Indicator	Systemic problem	Systemic instrument goals	Systemic instrument
	• Unsustainable source of funding.	• Infrastructure: • Presence	• Stimulate and induce the presence of different infrastructures.	• Access to capital through grants/ loans/funding; various business models.
	• Lack of business plan development.	• Infrastructure: • Presence • Quality	• Stimulate and induce the presence of different infrastructures. • Make sure that the infrastructure is of acceptable quality.	• Knowledge and financial infrastructure needs to be put in place in order to construct a business model. • Access to capital through grants/ loans/funding; various business models.
	• Insufficient infrastructure (human, technological, financial)	• Infrastructure: • Presence • Quality	• Stimulate and induce the presence of different infrastructures. • Make sure that the infrastructure is of acceptable quality.	• Grants/ loans/funding to incentivize UTI4ID project and to employ full time staff members.
	• Have to create a new market.	• Institutions: • Presence	• Stimulate the presence of hard and soft institutions.	• Awareness campaigns to create demand (market) for these type of projects in marginalized communities.
F6: Mobilization of resources	• Stand-alone project that does not form part of an innovation platform from which it can pool resources.	• Interactions: • Presence	• Stimulate and induce interactions between diverse actors.	• Innovation platforms; collaborative research programmes; conferences.
	• Unsustainable source of funding.	• Infrastructure: • Presence	• Stimulate and induce the presence of different infrastructures.	• Access to capital through grants/ loans/funding; various business models.
F7: Creation of legitimacy	• No agreements/ memorandums that dictate the university commitment to the project, especially not after implementation.	• Institutions: • Presence • Quality	• Stimulate the presence of hard and soft institutions. • Do not allow institutions to be too weak.	• Memorandum/agreement; obligations; articulation of commitment.
	• Some resistance to change: the stakeholders cannot fully utilise the technology.	• Actors: • Capabilities • Institutions: • Presence	• Create spaces where actor capabilities can be improved. • Stimulate the presence of hard and soft institutions.	• Training and education sessions; workshops; pilot projects; focus groups; feedback sessions. • Host demonstrations of technology in order to transfer knowledge. • Awareness campaigns; information campaigns.
	• Weak partnerships forming.	• Interactions: • Presence • Quality	• Stimulate and induce interactions between diverse actors. • Block or address ties that are either too strong or too weak.	• Innovation platforms; collaborative research programmes; conferences. • Stimulate demand articulation: bottom-up knowledge creation; co-creation models; training, information and education sessions. • Bridging institutions (community liaison, local NGO). • Management of interfaces. • Creating platforms for learning and experimenting, such as: training and education sessions; pilot projects; focus groups; feedback sessions.

Table 10. Output typology

	Marginalized community	Academics/researchers	Students	University
Output typology	Access to information, alternative modes of education (more inclusive), built interventions, clean water and sanitation, designs, electronic communication, employment opportunities, improved nutritional status, inclusive medical treatment, increased income per capita, more practical layout of settlement, skills/capabilities	Awards, Conference presentations, Masters project, PhDs project, and publications	Conference presentations, Masters, PhDs, publications, practical experience, and course credits	Awards, Conference presentations, Masters, PhDs, publications, good reputation, and CSR

Interview transcripts were iteratively synthesized to construct an exploratory typology of outputs for each beneficiary group from the projects in our sample. The resulting typology is presented in Table 10. The Output Typology can be used when evaluating a project. The goal is to compare whether each of the beneficiary groups present in a project are getting advantageous outputs. By comparing a project's outputs to the typology, specific outputs that are applicable but not present can be identified.

One project that represent all four beneficiaries is project B2 which entailed the development and implementation of a point-of-use microfiltration system for production of clean water. In this project, the target group are communities who do not have access to clean drinking water with the output they receive being clean water. A professor from the department of chemical engineering was the project champion and had several students who were doing research on different parts of the project for their masters or PhD thesis. Both the academic and the students benefitted from the research because the case study can be used to publish articles, validate their innovation and pass their degrees. Last, the university benefits from the research when the findings of this project are presented at conferences, articles are published, and students graduate their master's and PhD degrees.

6.3 Construction of outcome typology (Step 3 of framework)

Drawing on what was discussed in the literature review in Section 4, the 'capitals' approach was utilized.

For example, Project A1 entailed the design and construction of structural interventions in rural communities in South Africa. So far, they have built a roof-covered gathering space for a school and water platforms. When asked about the outcomes that the project team monitor and are aware of, we found that they all fall under the 'Market column', but it was clear from the interview that they have several unintended non-market related outcomes that are positively contributing towards all four the beneficiaries. Focusing on built capital, the market related outcome was that there are new buildings and water and sanitation. The unintended non-market outcome of the water platforms was that the community started using these spaces for community gatherings because it created a safe and cohesive environment.

Another example is Project C1 (mobile application that allows the fishing community to communicate and share data with scientists and vice versa). Intended outcomes for the marginalized community included access to electronic communication in order to share knowledge between fishermen and scientists (Built Capital.) The project champion noted that one positive outcome they did not foresee was that fishermen started using the application to communicate with each other. The buyers of the fish would frequently compare the fishermen's prices and in doing so forced each fisherman to decrease their prices. With the use of this application, the fishermen started working together to agree to a universal price that everyone would charge and in doing so they could no longer be exploited. This outcome falls under the non-market related Cultural, Social, and Human capital outcome categories. Trust and democracy were established between the fishermen, and knowledge was diffused beyond the initial intent of the project.

The Outcome Typology presented in Table 11 serves as a framework to classify outcomes in order to understand the effect that a project has had on a marginalized community. The value of this typology is to help projects identify and classify their outcomes. During the interviews we found that many projects are aware of and monitor the market related outcomes, but it is also important for them to recognise the non-market related outcomes (that can be both beneficial or detrimental to target audiences).

The value of constructing this typology therefore not only lies in classifying the outcomes that a project is aware of but also in investigating what other unintended outcomes the project could be having.

7. In conclusion: an integrated evaluation framework

Based on recent advances in the IS and I4ID literature, this research proposed a state-of-the-art analysis framework, for evaluating the outcomes of UTI4ID projects. In particular, this framework drew from 16 exploratory case studies of UTI4ID and through an empirically based grounded theory methodology, typologies are developed that can guide future UTI4ID evaluations. We thus show that advances in the I4ID literature provides an ideal starting point for complexity cognisant evaluations, but also contribute a framework to support such evaluations and populate a detailed guide for future UTI4ID projects. This also lays the foundation for future work that can further extend, validate, and refine the developed framework for other evaluation application contexts.

We provide a synthesized view of the integrated evaluation framework. The evaluator who wants to apply the framework to evaluate an UTI4ID project will do so in three steps (1) follow the methodology to guide the evaluation of the project components and functioning; (2) explore the outputs of the projects against the typology of project outputs for each beneficiary, and (3) explore the

Table 11. UTI4ID projects outcome typology

	Market	Non-market
Built capital	Water and sanitation; buildings; machinery; roads; electronic communication systems	Contribution to regional governance and planning; cohesive and secure environments; improved health care facilities/ treatment
Cultural capitals		Language; festivals; shared identityGreater cultural tolerance and enhanced democracy
Human capital	Jobs created; employability of graduated university students	Investments in people; learning, education, experiences, leadership development; improved health; improved safety; faster and wider diffusion of new knowledge
Social capital	Corporate social responsibility (CSR)	Sense of belonging; trust; networksCommunity capacity building
Political capital		The ability to influence the distribution of resources; voice; power; connections
Financial capital	Funding; grants and loans; investments; higher earnings/ cost savings	
Academic capital	Publications; conference presentations; R&D partnerships; degrees; research; invention	Faster and wider diffusion of new knowledge; networks
Business capital	Established businesses/corporations	

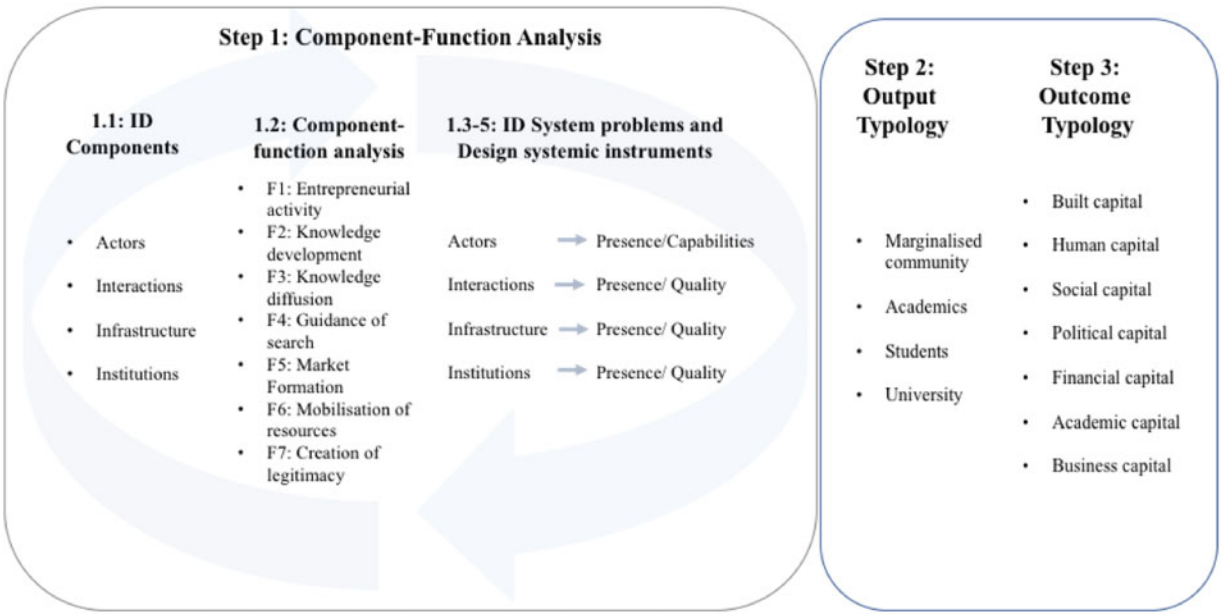

Figure 3. The integrated UTI4ID evaluation framework.

project outcomes against the typology of project outcomes. The culmination of these steps is presented in Figure 3.

The framework developed in this article may help evaluators to deal with complexity characteristics by acknowledging expert and lay input to the program theory and logic models, and by recognizing the adaptive, dynamic, and emergent nature of the initiative. The evaluation framework therefore provides a useful basis to conceptualize and develop initiatives. It is however necessary to have a consultative approach to ensure that the framework may be also be used to facilitate shared learning between project participants. Through the typologies, the framework will allow the evaluator to develop ideas around who to engage and get feedback from regarding actors, system function, outputs, and outcomes. This also allows the evaluator to explore causal assumptions regarding certain system failures.

Through taking a systems perspective the framework acknowledges that the system evaluation is more than sum of its components. The framework also provides a bottom-up approach to explore how emergent behaviours may assist in how relationships, interactions, and experience for different actors can be utilized—here the I4IDS framework as basis for the analysis is particularly useful. By drawing on the typologies developed, the evaluator may also explore unintended and anticipated events.

By utilizing the component-functions approach and by considering systemic instruments as interventions the proposed framework provides a novel way of dealing with non-linearity of interventions.

It is also useful to help generate ideas how to respond to systemic problems.

The framework may assist in identifying missing components and suboptimal functioning of the system to reduce uncertainty regarding outcomes while staying flexible around how to formulate a response. The framework will assist in providing a structure around who to engage, what they are contributing and why they behave the way they do.

This framework should be viewed as a 'living document' and can be adapted and amended as necessary by program staff. Limitations of the framework is it stands is that it has been populated from 16 case studies in the context of the Western Cape of South Africa and could therefore be expanded on in future. This can be done either by exploring more cases of UTI4ID projects or by applying it to I4ID initiatives more generally. In the latter case, especially the input output and outcome typologies may have to be adjusted as the objectives of these projects and also participants and beneficiaries may be very different. The general approach however is still be regarded as useful for a wider set of applications in the I4ID domain.

References

Bebbington, A. (1999) 'Capitals and Capabilities: A Framework for Analyzing Peasant Viability, Rural Livelihoods and Poverty', *World Development*, 27: 2021–44.

Bergek, A., et al. (2015) 'Technological Innovation Systems in Contexts: Conceptualizing Contextual Structures and Interaction Dynamics', *Environmental Innovation and Societal Transitions*, 16: 51–64.

Bergek, A., et al. (2008) 'Analyzing the Functional Dynamics of Technological Innovation Systems: A Scheme of Analysis', *Research Policy*, 37: 407–29.

Blum, N. U., Bening, C. R., and Schmidt, T. S. (2015) 'An Analysis of Remote Electric Mini-Grids in Laos Using the Technological Innovation Systems Approach', *Technological Forecasting and Social Change*, 95: 218–33.

Bölling, M., and Eriksson, Y. (2016) 'Collaboration with Society: The Future Role of Universities? Identifying Challenges for Evaluation', *Research Evaluation*, 25: 209–18.

Botha, L., Grobbelaar, S., and Bam, W. (2016) 'Towards a Framework to Guide the Evaluation of Inclusive Innovation Systems', *The South African Journal of Industrial Engineering*, 27: 64–78.

Carlsson, B., and Stankiewicz, R. (1991) 'On the Nature, Function and Composition of Technological Systems', *Journal of Evolutionary Economics*, 1: 93–118.

Carlsson, B., et al. (2002) 'Innovation Systems: Analytical and Methodological Issues', *Research Policy*, 31: 233–45.

Carol, H. W. (1998) *Evaluation: Methods for Studying Programs and Policies*. Upper Saddle River, NJ: Prentice Hall.

Edquist, C., and Hommen, L. (1999) 'Systems of Innovation: Theory and Policy for the Demand Side', *Technology in Society*, 21: 63–79.

Edquist, C., et al. (2018) 'On the Meaning of Innovation Performance: Is the Synthetic Indicator of the Innovation Union Scoreboard Flawed?', *Research Evaluation*, 27: 196–211.

Emery, M., and Flora, C. (2006) 'Spiraling-Up: Mapping Community Transformation with Community Capitals Framework', *Community Development*, 37: 19–35.

Fagerberg, J., Mowery, D. C., and Nelson, R. R. (2005) *The Oxford Handbook of Innovation*, vol. 1, Oxford University Press.

Fernando, F. N., and Goreham, G. A. (2018) 'A Tale of Two Rural Cities: Dynamics of Community Capitals during a North Dakota Oil Boom', *Community Development*, 49: 274–91.

Foster, C., and Heeks, R. (2013a) 'Analyzing Policy for Inclusive Innovation: The Mobile Sector and Base-of-the-Pyramid Markets in Kenya', *Innovation and Development*, 3: 103–19.

Foster, C., and Heeks, R. (2013b) 'Conceptualising Inclusive Innovation: Modifying Systems of Innovation Frameworks to Understand Diffusion of New Technology to Low-Income Consumers', *European Journal of Development Research*, 25: 333–55.

Foster, C., and Heeks, R. (2015) 'Policies to Support Inclusive Innovation', working paper; <http://hummedia.manchester.ac.uk/institutes/gdi/publications/workingpapers/di/di_wp61.pdf> accessed 31 July 2019.

Freeman, C. (1987) *Technology and Economic Performance: Lessons from Japan*. London: Pinter Publishers.

Garbarino, S., and Holland, J. (2009) 'Quantitative and Qualitative Methods in Impact Evaluation and Measuring Results', *Social Development Direct*, 1: 1–51.

George, G., Mcgahan, A. M., and Prabhu, J. (2012) 'Innovation for Inclusive Growth: Towards a Theoretical Framework and a Research Agenda', *Journal of Management Studies*, 49: 661–83.

Godin, B. (2006) 'The Linear Model of Innovation: The Historical Construction of An Analytical Framework', *Science, Technology, & Human Values*, 31: 639–67.

Grobbelaar, S. S., Gwynne-Evans, N., and Brent, A. C. (2016) 'From Enterprise Development to Inclusive innovation - A Systemic Instruments Framework for Regional Innovation Support', *African Journal of Science Technology Innovation & Development*, 8: 233–46.

Grobbelaar, S., Tijssen, R., and Dijksterhuis, M. (2017) 'University-Driven Inclusive Innovations in the Western Cape of South Africa: Towards a Research Framework of Innovation Regimes', *African Journal of Science, Technology, Innovation and Development*, 9: 7–19.

Grobbelaar, S. S., Schiller, U., and de wet, G. (2017) 'University-Supported Inclusive Innovation Platform: The Case of University of Fort Hare', *Innovation and Development*, 7: 249–70.

Hale, J., and Carolan, M. (2018) 'Framing Cooperative Development: The Bridging Role of Cultural and Symbolic Value between Human and Material Resources', *Community Development*, 49: 360–79.

Heeks, R., Foster, C., and Nugroho, Y. (2014) 'New Models of Inclusive Innovation for Development', *Innovation and Development*, 4: 175–85.

Hekkert, M., Negro, S., Heimeriks, G. and Harmsen, R. (2011) *Technological Innovation System Analysis: A Manual for Analysts*. Utrecht, NL.

Hekkert, M. P., et al. (2007) 'Functions of Innovation Systems: A New Approach for Analysing Technological Change', *Technological Forecasting and Social Change*, 74: 413–32.

Jabareen, Y. (2009) 'Building a Conceptual Framework. Philosophy, Definition, Procedure', *International Journal of Qualitative Methods*, 8: 49–62.

Jacobsson, S., and Johnson, A. (2000) 'The Diffusion of Renewable Energy Technology: An Analytical Framework and Key Issues for Research', *Energy Policy*, 28: 625–40.

Jolley, G. (2014) 'Evaluating Complex Community-Based Health Promotion: Addressing the Challenges', *Evaluation and Program Planning*, 45: 71–81.

Kaplinsky, R., and Morris, M. (2001) *A Handbook for Value Chain Research*. Ottawa: International Development Research Centre.

Kluge, S. (2000) 'Empirically Grounded Construction of Types and Typologies in Qualitative Social Research', *Qualitative Research*, 1.

Lamprinopoulou, C., et al. (2014) 'Application of an Integrated Systemic Framework for Analysing Agricultural Innovation Systems and Informing Innovation Policies: Comparing the Dutch and Scottish Agrifood Sectors', *Agricultural Systems*, 129: 40–54.

Lundvall, B.-A. (1992) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers.

McMahon, W. (2009) *Higher Learning, Greater Good: The Private and Social Benefits of Higher Education*. Boston: Johns Hopkins University Press.

Milley, P., et al. (2018) 'The Evaluation of Social Innovation: A Review and Integration of the Current Empirical Knowledge Base', *Evaluation*, 24: 237–58.

Mondal, M. A. H., Kamp, L. M., and Pachova, N. I. (2010) 'Drivers, Barriers, and Strategies for Implementation of Renewable Energy Technologies in

Rural Areas in Bangladesh—An Innovation System Analysis', *Energy Policy*, 38: 4626–34.

Patton, M. Q. (2010) *Developmental Evaluation: Applying Complexity Concepts to Enhance Innovation and Use*. Guilford Press. ISBN - 9781606238721.

Paunov, C. (2013*) Innovation and Inclusive Development*. Paris, France: OECD Publishing, p. 67.

Rip, A., Joly, P., and Callon, M. (2010) 'Reinventing Innovation', *In Maarten Arentsen Governance and Innovation*, 2006: 1–13.

Rucker, A., and Trah, G. (2007) *Local and Regional Economic Development. Towards a Common Framework for GTZ's LRED Interventions in South Africa*. Eschborn: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) <http://bdsknowledge.org/dyn/bds/docs/600/GTZ%20LED%20SA%20Manual%202007.pdf>.

Sen, A. (1997) 'Editorial: Human Capital and Human Capability', *World Development*, 25: 1959–61.

Snowball, J. D., and Shackleton, C. M. (2018) 'Factors Enabling and Constraining Research in a Small, Research-Intensive South African University', *Research Evaluation*, 27: 119–31.

Stenberg, L., Gustafsson, E., and Marklund, G. (1996) 'Use of Human Resource Data for Analysis of the Structure and Dynamics of the Swedish Innovation System', *Research Evaluation*, 6: 121–32.

Stern, E., et al. (2012) 'Broadening the Range of Designs and Methods for Impact Evaluations', DFID Working Paper 38, London.

Suurs, R. (2009) *Motors of Sustainable Innovation: Towards a Theory on the Dynamics of Technological Innovation Systems*. Utrecht, Netherlands: Utrecht University.

Temple, L. et al. (2018) 'Assessing Impacts of Agricultural Research for Development: A Systemic Model Focusing on Outcomes', *Research Evaluation*, 27: 157–70.

Tilley, N., and Pawson, R. (2000) 'Realistic Evaluation: An Overview', *The British Journal of Sociology*, 49: 331.

van der Hilst, B. (2012) *Inclusive Innovation Systems: How Innovation Intermediaries Can Strengthen the Innovation System: A Case Study of Vietnam*. Utrect University <https://dspace.library.uu.nl/handle/1874/256564> accessed 29 July 2019.

Van Der Merwe, E., and Grobbelaar, S. S. S. (2016) 'Evaluating inclusive innovative performance: The case of the eHealth system of the Western Cape Region, South Africa' *PICMET 2016 - Portland International Conference on Management of Engineering and Technology: Technology Management for Social Innovation Proceedings, Honolulu, HI, 4–8 September 2016*.

van der Merwe, E., and Grobbelaar, S. S. (2018) 'Systemic Policy Instruments for Inclusive Innovation Systems: Case Study of a Maternal mHealth Project in South Africa', *African Journal of Science, Technology, Innovation and Development*, 1–18, DOI: 10.1080/20421338.2018.1491678.

van der Merwe, E., Grobbelaar, S., and Bam, W. (2019) 'Exploring the Functional Dynamics of Innovation for Inclusive Development Innovation Systems: A Case Study of a Large Scale Maternal mHealth Project in South Africa', *Innovation and Development*, 1–22, DOI: 10.1080/2157930X.2019.1567884.

van Mierlo, B., et al. (2010) 'Learning towards System Innovation: Evaluating a Systemic Instrument', *Technological Forecasting and Social Change*, 77: 318–34.

Walton, M. (2016) 'Expert Views on Applying Complexity Theory in Evaluation: Opportunities and Barriers', *Evaluation*, 22: 410–23.

Weißhuhn, P., Helming, K., and Ferretti, J. (2017) 'Research Impact Assessment in Agriculture - A Review of Approaches and Impact Areas', *Research Evaluation*, 27: 36–42.

Wieczorek, A. J., and Hekkert, M. P. (2012) 'Systemic Instruments for Systemic Innovation Problems: A Framework for Policy Makers and Innovation Scholars', *Science and Public Policy*, 39: 74–87. DOI: 10.1093/scipol/scr008.

Woolthuis, R.K., Lankhuizen, M., and Gilsing, V. (2005) 'A system failure framework for innovation policy design', *Technovation*, 25: pp. 609–19.