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A system readiness approach to support the packaging and scaling of innovation bundles for farming systems transformation

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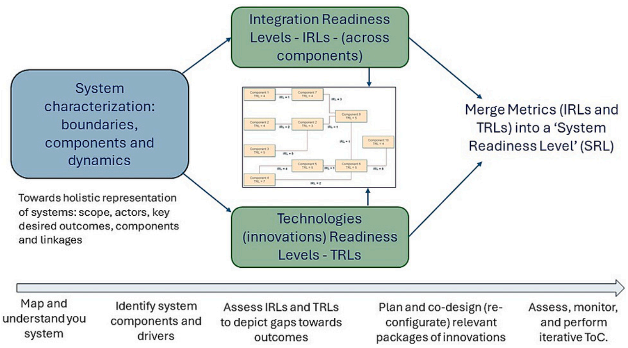
HIGHLIGHTS

- A "System Readiness" (SysR) framework was introduced to pilot and guide the transformation of farming systems
- There is a need for a paradigm shift from innovation-driven scaling to scaling activities that strengthen systems for inclusive innovation.
- Entry points for system transformation can now be identified and prioritized based on SysR.
- "Packaging for System Transformation" using SysR and "Scaling Readiness for Packaging Innovation" approaches can be complementary.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: A newly established 'systemic approach to technology packaging' for improved scaling has emerged in the literature. This approach suggests that core transformative innovations can be scaled more effectively through scaling readiness, which helps identify complementary innovations that support and facilitate the scalability of the core innovation. Since these packaging approaches start with single core innovations, we propose that they can benefit from the broader literature on sustainable agricultural systems transformation and readiness.
OBJECTIVE: The objective of this paper is to advocate for a more comprehensive packaging of innovations for sustainable agricultural system transformations by better understanding gaps in the agricultural system – and its capacity for change. This approach provides a stronger rationale for the selection of relevant innovations to be packaged together. We introduce the concept of agricultural 'system readiness' as a possible framework for guiding such bundles.
METHODS: The paper begins with a comprehensive literature review that identifies the current gaps in tools and methods to guide system transformation. It also focuses on the specific literature on innovation packaging for scaling, and builds on the gaps of existing approaches as a rationale for introducing the concept of system readiness (mostly used in infrastructure engineering), and adapting it to agricultural science. We also use illustrative hypothetical examples from mixed crop-livestock systems in the drylands to show how two approaches – 'packaging for scaling' and 'packaging for transformation' – can lead to different innovation packages.
RESULTS AND CONCLUSIONS: The concept of system readiness is introduced, defined and advocated. We show that it can help identify performance gaps in agricultural systems and guide better planning for system

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strengthening and integration. We conclude with possible complementarities between the two approaches of scaling and system readiness.

SIGNIFICANCE: The agricultural system readiness approach, as outlined in this paper, would be particularly beneficial for agricultural research-for-development, as well as other agricultural investment programs that seek to identify strategies for fostering sustainable transition in farming systems. Such programs would typically entail complexity-aware theories of change that focus on stimulating sustainable transformation pathways related to key target areas, such as agroecology, sustainable intensification, and system integration (e.g., crop-livestock integration and integrated pest management). The system readiness approach can support such programs through the identification, prioritization, targeting, and empowerment of the most significant (and transformative) system components by identifying respective innovations to be packaged.

1. Introduction

It has been argued that most theories of change (ToCs) designed and adopted by research-for-development programs assume that these programs can lead to impact through linear adoption pathways (Douthwaite and Hoffecker, 2017). However, more careful consideration has recently highlighted the need for a pragmatic (and programmatic) and comprehensive understanding of technology adoption and scaling, using enhanced approaches and methods that help to reach many beneficiaries in a more responsible and sustainable manner (Van Loon et al., 2020; Jacobs et al., 2021). These approaches guide agricultural research-for-development (AR4D) investments by identifying clusters of activities that allow core innovations to be clustered and adopted at very large scale.

Thus, progress has been made in raising awareness of scaling and incorporating systems approaches to identify scaling agendas and activities. However, these methodologies are still technology-focused[1] and adopt a commodity lens rather than embracing a broader vision of complex system transformation through enabling transition pathways that improve local contexts for inclusive innovations (Woltering et al., 2024). By considering the concept of 'sustainable system transformation' as an entry point for impact generation, key programmatic activities of AR4D programs will then shift to focus on the readiness of a system as a whole, rather than the readiness of a single technology (or innovation) supporting a given system component (or commodity).

The innovation systems literature defines 'innovation' as the outcome of (changing) interactions between networks of interdependent actors and stakeholders, the socio-technical context in which they operate, and the rules and institutions that govern their interactions (Klerkx et al., 2010). Enabling local contexts of innovation requires that these network interactions are well-designed, empowered, inclusive and effective in producing local innovations (Aranguren et al., 2009; Pike et al., 2010; Hoffecker, 2021; Bevilacqua et al., 2022) that 'benefit all' (Hoffecker, 2021). Accordingly, inclusive innovations are those that result from sustainable change in local innovation contexts, and that can empower and enhance the capacity of local actors to innovate (Hoffecker, 2021). Both pathways of innovations and scaling through AR4D projects should be harmonized and aligned to achieve greater and sustainable impact. One possible way to bring both pathways together in AR4D programs is to consider complexity-aware ToCs (Douthwaite and Hoffecker, 2017; Douthwaite et al., 2020),[2] where iterative scaling, based on evaluation, learning, and capacity sharing, is embedded in broader understanding of innovation systems and contexts with respective programmatic activities and adaptive management (Kilelu et al., 2013; Klerkx et al., 2010). As such, technology generation and scaling would be seen as endogenous tasks of the local agricultural innovation systems to be strengthened by the AR4D program. This paper focuses on these ideas and provides further arguments and concepts around them, presenting – in particular – a complementary framework for the design and implementation of inclusive innovation bundles based on the assessment of farming systems' components rather than scaling requirement and 'technology readiness'.

The paper introduces an early conceptualization of what is called system readiness (SysR) for AR4D programs, with a particular focus on farming systems (referring to the farm level). This refers to the assessment of the capacities, transformation bottlenecks, and readiness of local farming systems based on better understanding of their respective components. The SysR framework will be complementary to the technology readiness level (TRL) principle, which is used to assess the maturity of individual technologies, and currently forming the basis of many scaling approaches. TRL framework was recently extended to what is called a "multi-dimensional assessment of technology readiness" (or a balanced readiness level assessment", which assesses the readiness of a given technology from five dimensions including technological, market, regulatory, acceptance, and organizational readiness (Vik et al., 2021). However, this approach remains focused on the assessment of a single technology without addressing broader system components and transformation. In this paper, we advance the idea that a transformative bundle (Barrett et al., 2022; Geels and Schot, 2007; Meynard et al., 2017) of innovations for farming systems would be more effectively designed and implemented if supported by a SysR assessment rather than just technology readiness levels. We also argue that a SysR framework that takes into account the complex holistic dimensions and interactions within farming systems would lead to more sustainable and long-term transformation and impact.

2. Background: The need to move beyond scaling and innovation to focus on system transformation

AR4D programs are usually pilot projects that pave the way for enhanced institutionalization of successful innovations, processes, and approaches. They aim to generate evidence for the effectiveness of new approaches for meeting future food and nutrition security needs and fostering resilience, with the goal of guiding policy decisions (IFAD, 2024). However, despite successful AR4D interventions and investments globally, food insecurity continues to persist in many parts of Africa and Asia (Maru et al., 2018). Some suggest that the AR4D sector is subject to strong "path dependency" (Schut et al., 2020a, 2020b, p6), in that many leading organizations act according to predefined mandates and responsibilities (which thus define the priority commodities, thematic areas, and innovation objectives of their intervention) and not as systems and outcome-oriented priorities. In fact, the dependency on donor-funded projects has led many AR4D organizations to prioritize their own specific commodities and innovations at the center of the scaling efforts (Schut et al., 2020a, 2020b). Others suggest that the theories and pathways of these programs – which are meant to show the effectiveness

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[1] Mostly using the TRL (Technology Readiness Levels) as a benchmark for technology profiling and as a starting point for justifying the 'scaling road maps' of these technologies.

[2] These contrast to what Douthwaite and Hoffecker (2017) call "a pipeline ToC," where development impact is understood to be achieved through the sourcing, development, testing, adoption, and widespread dissemination of innovations and technologies. Complexity-aware ToCs are realistic ToCs that can account for complex system dynamics, as well as changing contextual conditions that can affect outcomes of the AR4D program (Pawson, 2013; Westhorp, 2012).

of particular interventions – have not been well-articulated, encapsulated in design, or tested (Douthwaite et al., 2003; Maru et al., 2018). This has resulted in a growing demand for alternative approaches to designing and evaluating interventions in complex systems (Maru et al., 2018), that can result in enhanced and more sustainable transformation and impact.

The pressure from AR4D donors to show impact and achieve scaling has further led some organizations in developing contexts to prioritize "quick wins" over investing in the medium- and long-term development of structural capacity for innovation and scaling in agricultural systems. This issue is discussed by, among others, Klerkx et al. (2010), Leeuwis et al. (2018), Sartas et al. (2020a, 2020b), and Schut et al. (2020a, 2020b). With many AR4D organizations managing multiple interventions, there is a growing need to demonstrate returns-on-investment and impact at scale (Renkow and Byerlee, 2010; Woltering et al., 2019; Van Loon et al., 2020). To address this, AR4D organizations have recently developed and are using scaling readiness (SR) concepts and measures (Sartas et al., 2020a, 2020b) to monitor and manage their innovation portfolio and direct their investments towards increased scaling, thereby reaching a greater number of beneficiaries. The scaling scan and the SR frameworks are examples of currently-used approaches (Sartas et al., 2020a, 2020b; Van Loon et al., 2020; Jacobs et al., 2021). They are grounded in systemic frameworks for appropriate innovation packaging, recognizing that these innovations require supportive environments and specific actions towards large-scale adoption. Identifying these supporting actions is usually clustered into a scaling road map or agenda, which then guides the AR4D investment to increase achievement and reach.

However, these existing frameworks can lead to linear ToCs (also referred to as 'pipeline ToCs' by Douthwaite and Hoffecker, 2017) if they are not preceded and enriched by iterative participatory approaches and system analysis to jointly identify transformative entry points and priority innovations. Linear ToCs in general are not effective for adaptive, transformative, and outcome-oriented objectives. These latter attributes are increasingly preferred by AR4D programs as they support local innovation systems in making a greater contribution to inclusive and sustainable development (Douthwaite and Hoffecker, 2017), forming social capital (Uphoff and Wijayaratna, 2000), and increasing skills and capacities for system experimentation and integrated actions. They also support the empowerment of existing skills and knowledge of actors to future contexts and challenges(Ayele et al., 2012; Hounkonnou et al., 2018). More recently, Schut et al. (2020a, 2020b) emphasized the need for a more outcome-oriented approach to scaling that transcends technology adoption. They introduced the need for a third wave of scaling science that focuses on understanding the "big picture" of scaling innovations, which will provide a more holistic view of the factors, conditions, causalities, and dynamics affecting innovation and scaling processes at the local level. This is in line with the literature on sustainability transition, that emphasizes the need for systemic approaches to transformation that go beyond a mere focus on innovation and scaling (Elsner et al., 2023; Stefani et al., 2022; Svare et al., 2023) to address the complexity of production systems and related contextual drivers (Elsner et al., 2023; Stefani et al., 2022; Svare et al., 2023). Schut et al. (2020b) propose four potential avenues for adopting a more systemic and outcome-oriented approach to scaling, including: 1. Mapping the primary livelihood and development challenges; 2. Conducting an inventory of diverse types of innovations with high scaling potential; 3. Developing a more nuanced understanding of the context-specific measures and conditions through which such innovations could be accessed; and 4. Identifying the key bottlenecks for scaling innovation packages and developing scaling strategies and partnerships to overcome them (Schut et al., 2020a, 2020b, p6). Other key frameworks such as the Multi-Level Perspective (Jayaraj et al., 2024)and the transition management (Loorbach, 2010) highlight the importance of integrating technological, social and policy changes for systems transformation (or transitions). Learning Systems and Behavioral Insights are also critical to fostering transformation, particularly in sectors such as agri-food systems where environmental and socio-economic dimensions need to be considered together (Elsner et al., 2023; Stefani et al., 2022; Svare et al., 2023).

In this paper, we advocate for a holistic approach to transformation that extends beyond innovation and scaling. We propose applying, and expanding, Schut et al. (2020a, 2020b) recommendations for developing a systemic scaling approach by mapping challenges, identifying high-potential innovations, and understanding the innovation context. This would require more comprehensive and structured system analysis frameworks that facilitate the iterative development and packaging of inclusive innovations aligned with principles of system transformation. However, in this paper we will focus only on frameworks for better understanding the complexity of farming systems (and its components) for effective bundling of transformative socio-technical innovations. We will also pay careful attention to endogenous innovation capacities within farming systems as key transformative factors contributing to the sustainability of AR4D program interventions. The paper will not, however, cover other drivers and broader system approaches that can support and enable system transformation in general.

3. Making the case: Scope and limitations of the SR framework

3.1. *Definition and presentation of the SR framework for innovation bundling*

In the broader literature, SR refers to the ability of an innovation or intervention to be successfully scaled up or expanded to reach a larger population or market (Mcdonald et al., 2006; Sartas et al., 2020a, 2020b; Bradley Dexter et al., 2021; Schut et al., 2022a). It typically involves assessing several factors, such as the scalability of the solution, the feasibility of it being scaling, the availability of resources and infrastructure needed to support the expansion, and the potential risks and challenges that may arise during the scaling process (Sartas et al., 2020a, 2020b; Schut et al., 2022a). Assessing SR can help to determine whether an innovation is suitable for scaling and identify areas that may need further development or improvement to support scaling.

In the agricultural innovation systems literature, the SR framework (Sartas et al., 2020a, 2020b) is a relatively new concept. It is defined as a stepwise system-based methodology that uses system theory to generate a comprehensive set of scaling-oriented decisions and activities for AR4D programs (Sartas et al., 2020a, 2020b; Schut et al., 2022a). SR explicitly applies and promotes an innovation systems perspective on scaling that includes attention for addressing systemic interdependencies, including those related to contextual organizational capacities which may enable the scaling of a given core innovation. The approach generates innovation packages consisting of a core innovation, complemented by other innovations (and/or technologies). The core innovation is here considered as the main purpose of the package. Complementary innovations would ideally be co-designed with relevant demand partners, during the implementation of the SR methodology to maximize the chances of the core technology being successfully scaled (and/or scalable). The SR framework builds on, but is distinct from, the TRL concept (Salvador-Carulla et al., 2024).[3] An innovative aspect of the

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[3] TRLs are a set of nine numerical scales used to assess the maturity of a particular technology or innovation. The higher the TRL, the closer the technology is to being ready for commercialization, deployment, or operational use.

SR framework compared to the TRL is that the former can be operationalized for institutional, social, and other types of socio-technical innovations. This makes it more attractive and applicable to social sciences, such as agricultural development and technology transfer (Sartas et al., 2020a, 2020b).

SR is now being applied worldwide and institutionalized in the One CGIAR global research-for-development' portfolio,[4] making its ongoing use and application important in guiding the major investments of this portfolio(Jacobs-Mata et al., 2022; Schut et al., 2022b; Kangethe et al., 2023). As part of this One CGIAR program portfolio, a wave of implementation of the SR framework is underway globally for a wide range of technical, social and policy innovations (Kangethe et al., 2023), aiming to achieve significant impact through improved scaling of key transformative technologies and innovations. A critical reading of the SR approach and tools is therefore needed to further enhance their contribution to maximizing impact.

3.2. Limitation of the SR in terms of empowerment of local innovation capacities of actors

The readiness of the innovation to achieve impact at scale differs according to local contexts (Sartas et al., 2020a, 2020b). According to the SR framework, part of this differentiation is due to the changing scaling priorities, ambitions and objectives of local actors over time. There is a clear indication here that the SR analysis has an 'eligibility timeframe', beyond which changing contexts may lead to new challenges that require a different analysis of the problem to map further 'scaling' objectives, ambitions and solutions. Repeated iterations of SR (which can be costly and dependent on the existence of an AR4D program) may then be better replaced (or complemented) by more robust investments in empowering local communities for improved inclusive innovation and scaling (Hoffecker, 2021).

There is also an acknowledgement that system transformation pathways are complex, and require deep understanding of system components and dynamics (Douthwaite et al., 2003; Douthwaite and Hoffecker, 2017), which in turn is the basis for effective co-design of relevant technologies and innovations. Other factors that can support the design of transformative pathways of systems are related to the local specificities of key system and landscape bottlenecks and constraints, the level of collective cognitive capacity and social capital of local actors, and the level of participation and inclusion of the poorest in the innovation processes (Hoffecker, 2021). By continuing to invest in the previous key enablers of system change, AR4D initiatives can be more effective in enabling and sustaining the dynamics of change in the systems, communities and landscapes in which they invest, compared to investing only in scaling up a core innovation with its complementary elements.

SR supports decision-making for developing, implementing, and monitoring effective scaling strategies, but it does not aim to 'reinvent the wheel' in terms of facilitating and sustaining interactions among innovation actors (which are key in inclusive, participatory, co-innovation processes), or navigating emerging system dynamics (Sartas et al., 2020b). SR is highly dependent on the capacities of facilitators and SR monitors to effectively foster learning, agreement, and collaboration in partnership settings (Sartas et al., 2020b). Iterative SR based on co-learning is proposed as a possible solution for learning and adapting the innovation process. This is unlikely to be affordable at the end of AR4D programs, especially in developing countries and contexts. Furthermore, SR considers monitoring and evaluation as processes to learn whether the bottleneck innovations (as opposed to contextual environments/attributes) have been addressed; if not, then the innovation packages are reconfigured (with different bottlenecks). In complex ToCs, iterative learning should result in adaptive implementation of broader activities (Maru et al., 2018; Schut et al., 2022b)that lead to favorable and empowered contexts for inclusive innovation (Kilelu et al., 2013; Douthwaite and Hoffecker, 2017; Douthwaite et al., 2020; Hoffecker, 2021) and system transformation, rather than just reconfiguring innovation packages to improve the scalability of core innovations.

Sartas et al., 2020a, 2020b) also state that SR aims to provide a hands-on and action-oriented process that fosters collective decision-making, learning and strategizing. However, it remains unclear how such a facilitation process and its resulting (intermediary) outcomes, such as collective action and co-learning, can be sufficient elements to stimulate a more holistic take on innovation (Woltering et al., 2024), which can effectively stimulate and support systems transformation. While the piloting of SR is still in its early stages, a good evaluation of the impact of its application on these intermediary outcomes would be valuable. Focusing on assessing the impact of SR on enhancing local contexts for inclusive innovation through social learning and social capital accumulation would be particularly relevant. This will better position SR into broader 'agricultural innovation systems' literature, and provide insight on how it would be useful along a more inclusive innovation process.

4. Perspectives from the 'trajectory of innovation' and 'inclusive innovation' concepts: Empowering enabling environments for innovations

This section suggests that AR4D programs must consider setting their ToC in a way that can support and empower the capacity of agricultural innovation system actors to innovate rather than only supporting the scaling of innovations to demonstrate impact. In line with this statement, (Kilelu et al., 2013) define a collective nature of innovation and stresses that innovation is a co-evolutionary process, resulting from alignment of technical, social, institutional and organizational dimensions. In fact, scaling approaches, which are not socially inclusive, are insufficiently geared towards responsible innovations (McGuire et al., 2024) and systems transformation (Woltering et al., 2024). Agricultural systems have always faced challenges of competitiveness, modernization, market access, climate shocks, and so forth (Hanson et al., 2008; Behera and France, 2016). These challenges are better addressed by local communities and actors who are more able to co-design better-performing, inclusive innovations (Fielke and Srinivasan, 2018; Šūmane et al., 2018). There is yet to be a consensus on the definition of inclusive innovation (Hoffecker, 2021). Theories of inclusive innovations have their roots in concerns about the equity outcomes of innovations, a topic that has been debated since the 1950s (Foster and Heeks, 2013; Chataway et al., 2014; Heeks et al., 2014). From this perspective, innovation systems encompass the array of actors—both directly and indirectly involved—in the innovation process. Consequently, innovation is seen as the outcome of these complex interactions among various stakeholders (Chataway et al., 2014). Early conceptualization of inclusive innovation refers to the inclusion of marginalized populations in the innovation process and increasing their benefit from it. Rothwell and Zegveld (1981) define six stages (each composed of a set of activities) involved in the development and diffusion of a specific innovation (see Fig. 1). In the case of agricultural innovation systems, the poorest populations are usually weakly integrated into this process, except for the use and recycling phases of the innovation (Matlon et al., 1984; Chambers, 1989; Anandajayasekeram and Gebremedhin, 2009; Knickel et al., 2009; Chindime et al., 2017). A stream of literature has focused on determining the aspects and levels of inclusiveness of

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[4] This portfolio is composed of 35 regional initiatives, each operating in a few developing countries and tackling specific development areas and commodities, while targeting five impact areas: climate action, nutrition and health, poverty reduction, gender equality and youth empowerment, and sustainable natural resources management). The total portfolio was pledged with more than 600 million USD in 2019. See here: https://www.cgiar.org/news-events/news/uncas-global-coalition-funds-cgiar/

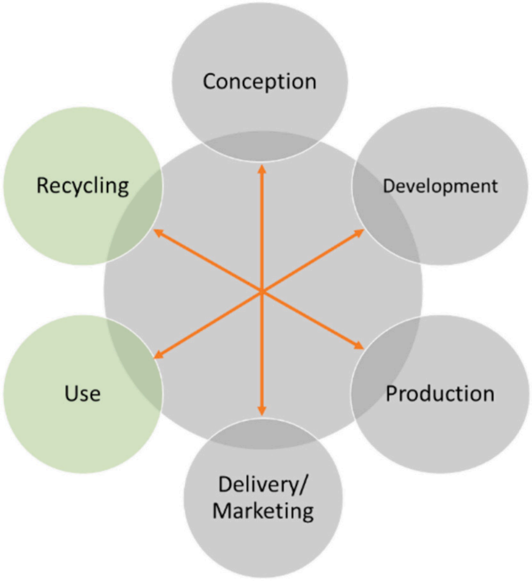

Fig. 1. Innovation cycle for the case of poor smallholder agricultural communities.

Adapted from Matlon et al., 1984; Chambers, 1989; Anandajayasekeram and Gebremedhin, 2009; Knickel et al., 2009; Chataway et al., 2014; Chindime et al., 2017).

Note: Green parts highlight the innovation cycle components the poor are trapped in.

marginal populations in the innovation process. Four aspects of inclusivity were emphasized by (Cozzens and Sutz, 2012). These are: 1) The inclusivity of innovation precursors, such as ensuring that the problems to be addressed by innovation are relevant to the poor; (2) The inclusivity of innovation processes, such as involving the poor in the development of innovative goods and services; 3) The inclusivity of innovation adoption, such as ensuring that poor consumers have the capacity to absorb innovations; and 4) The inclusivity of innovation impacts, such as ensuring that innovative goods and services have a positive effect on the livelihoods of the poor. See Heeks et al. (2014) for a more detailed description based on six levels of inclusion. More recently, Schillo and Robinson (2017) proposed definitions of inclusive innovation that describe inclusivity throughout the entire innovation process, encompassing people, activities, outcomes, and governance.

Finally, a comprehensive definition was provided by Hoffecker (2021) who refers to inclusive innovation as "*a collaborative and co-creative, multi-stakeholder approach to innovation that prioritizes the agency and leadership of groups that are traditionally excluded from innovation activities and from the benefits of economic development. Inclusive innovation processes rely upon the meaningful participation of people who are experiencing the challenges that the innovation process is intended to address and produce results that benefit those who are disadvantaged by the existing opportunity structures in their respective contexts*" (Hoffecker, 2021, p5). Even though this definition is not detailed and conceptualized, it remains one of the most pragmatic and relevant to agricultural innovation systems literature. The author built upon this definition for a comparative study of three ToCs of AR4D programs and their respective impact on enhancing the local capacities of communities for innovation. A middle-range conceptual model was developed, which can better explain the process of inclusive innovation in the case of agricultural systems, and its importance for generating intermediary outcomes towards wider impacts of AR4D programs. Hoffecker (2021)further identified that the most powerful (intermediary) outcomes (also called causal mechanisms of change) of AR4D programs – in terms of sustainable transformation – would be: collective cognition, consensus formation, social learning, and social capital strengthening.

5. Agricultural SysR analysis: Rationale and early definitions

5.1. *Rationale for a more system-focused assessment of readiness for inclusive innovation*

In earlier sections, we argued that AR4D investments should transition from isolated innovation delivery projects to enhancing the endogenous capacity of the system in terms of innovation and scaling. This shift aims to foster inclusive innovations that can effectively address key questions: What innovations are effective in specific contexts? Under what conditions do they thrive? For whom do they work best? And what outcomes do they achieve? Systems also need to be prepared for change in terms of organizational readiness and functioning. This involves emphasizing practical methods for advancing innovation implementation (Simpson, 2009) through the collection and application of improved information about the needs of various system components, resource availability, local actors' capacities, and other barriers. A SysR framework which can capture and analyze these types of information would thus guide the design of inclusive innovation packages that fit local demand, capacities and contexts. By considering technologies, households, communities, input providers, and their respective interactions as inherent components and endogenous processes of farming systems (Behera and France, 2023), an assessment of the readiness and capacities of these components would then reflect the extent to which actors use, process, build upon, and adopt new knowledge and related forms of social innovations. A SysR analysis that assesses and reflects on these elements would lead to concrete proposals for improving the interactions among these actors, thus empowering them for inclusive innovation processes.

5.2. *What is the SysR assessment framework?*

In the field of engineering, the SysR level (SRL) is a measure that describes the level of maturity of a particular system based on the degree of readiness and integration of its individual components and the technologies relevant to their reach. The SRL is often used in the context of engineering and technology development, particularly in the areas of aerospace, defense, infrastructure, etc. The concept is similar to the more familiar TRL. However, the SRL considers both the maturity of the technology itself and the readiness of the system as a whole. This includes factors such as the availability of supporting infrastructure, the training and expertise of the users, and the regulatory and policy environment surrounding the system. The SRL is typically measured on a scale of 1 to 9, with level 1 representing the lowest level of readiness and 9 representing full deployment and operation of the system (Austin and York, 2015). The specific criteria for each level may vary depending on the context and application of the SysR. Implementation of the SysR process can help to improve system management performance and assist decision makers in identifying programmatic and technical risk areas (Austin and York, 2015), as well as investment priorities to address system constraints.

Effective improvement of SysR necessitates a comprehensive understanding of the time dimension and the evolutionary processes within the system, which refers to transition pathways in AR4D literature. The initial stages of this process are often referred to as TRLs, which are commonly utilized in research and development projects (see Fig. 2). There are other important steps to consider and borrow from this SysR assessment framework, including: 1) the Integration Readiness Level (IRL), which measures the degree of integration between two system components on a scale from 1 to 9 (see Fig. 2), and 2) three additional SysR metrics defined as follows: (a) Component SRL: This measures the readiness level of an individual component along with its integration links. (b) Composite SRL: This assesses the readiness level of the entire system or all of its components combined. The composite SRL is calculated by averaging the component SRLs and converting this value into a decimal format. (c) SRL measure: This is the overall readiness measure

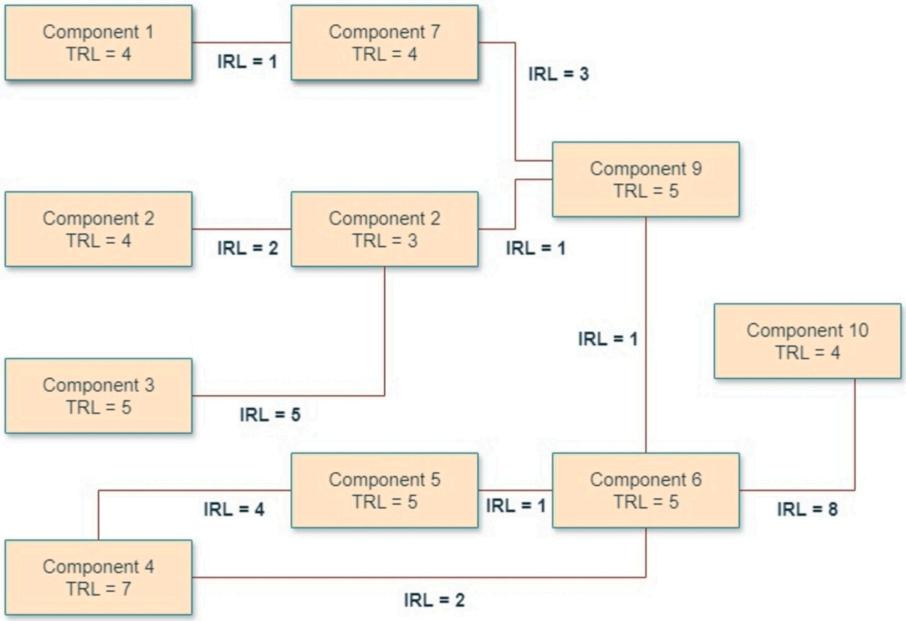

Fig. 2. Examples of TRLs and IRLs for a system composed of ten components.
Source: Austin and York (2015)

of the system, obtained by converting the composite SRL to a scale of 1 to 9, where 9 indicates the highest level of readiness. These steps are crucial components of the system engineering processes commonly utilized across various engineering domains.

Using IRLs is particularly important in the context of this paper. In fact, this concept is completely new to the agricultural systems literature. IRLs are supposed to assist the program manager (or system designer/engineer) in identifying system components and respective development areas that need additional investments towards integration and enhanced performances. This shift represents a fundamental change in mindset – from viewing technology as a limiting factor (and thus entry point) to recognizing constraints in upgrading and integrating system components. To effectively leverage this approach, it is essential to bundle key technologies and innovations that are particularly relevant for such integration (Barrett et al., 2022; Meynard et al., 2017). Woltering et al. (2019) refer to "a system component with low integration level", which needs to be supported by actions and activities, if we want to leverage the whole agricultural system in place. Examples will be provided in section 6 to better illustrate the benefits of this system assessment framework and its implication for innovation bundling in the case of a mixed crop-livestock system. Austin and York (2015) suggest that IRLs also provide means to reduce the risk involved in maturing and integrating components into a system. Thus, IRLs supply a common measure of comparison for both new system development and technology insertion (Sauser et al., 2009).

5.3. *Relevance of the SysR approach for agricultural systems design in the framework of AR4D programs*

The SysR Framework assists research and development project managers by providing a structured approach to understanding, planning and monitoring farming systems in a transformative way. In its broadest interpretation (Fig. 3), the SysR approach involves three key steps: understanding the boundaries of the agricultural system through co-identification of problems and context characterization; decomposing and mapping the system's (hard and soft) components, linkages and drivers to identify entry points for transformation; and conducting iterative ToC evaluations (using SysR metrics as a dashboard for progress) to assess and improve the readiness and integration of sociotechnical innovation bundles. By systematically assessing and updating SR, project managers can ensure that the innovation packages they are piloting are contextually relevant, sustainable and effective in promoting inclusive innovation contexts and long-term development outcomes (Barrett et al., 2022; Meynard et al., 2017). This broader understanding can be distilled into a more specific assessment methodology (dashboard) (as shown in Figs. 2 and 4), that can provide program managers and decision-makers with metrics of the maturity and

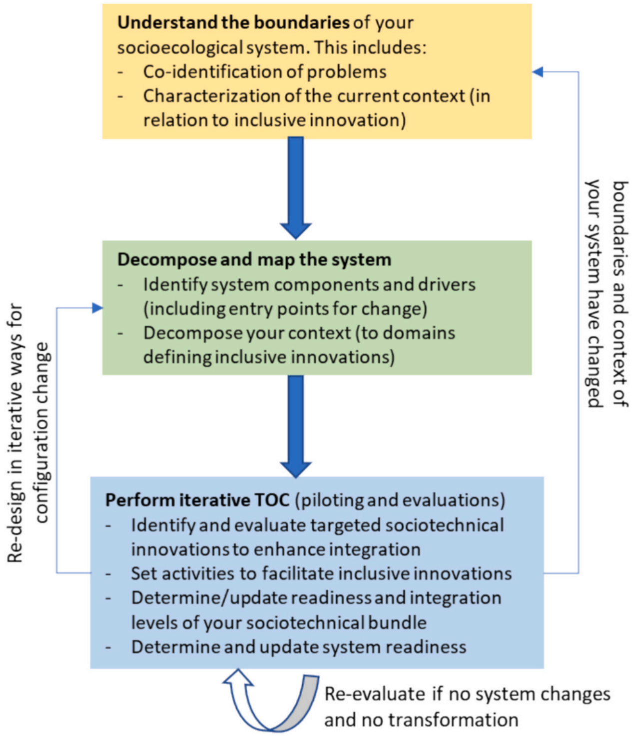

Fig. 3. Iterative SysR framework for pilot AR4D programs.
Source: Own elaboration based on Austin and York (2015)

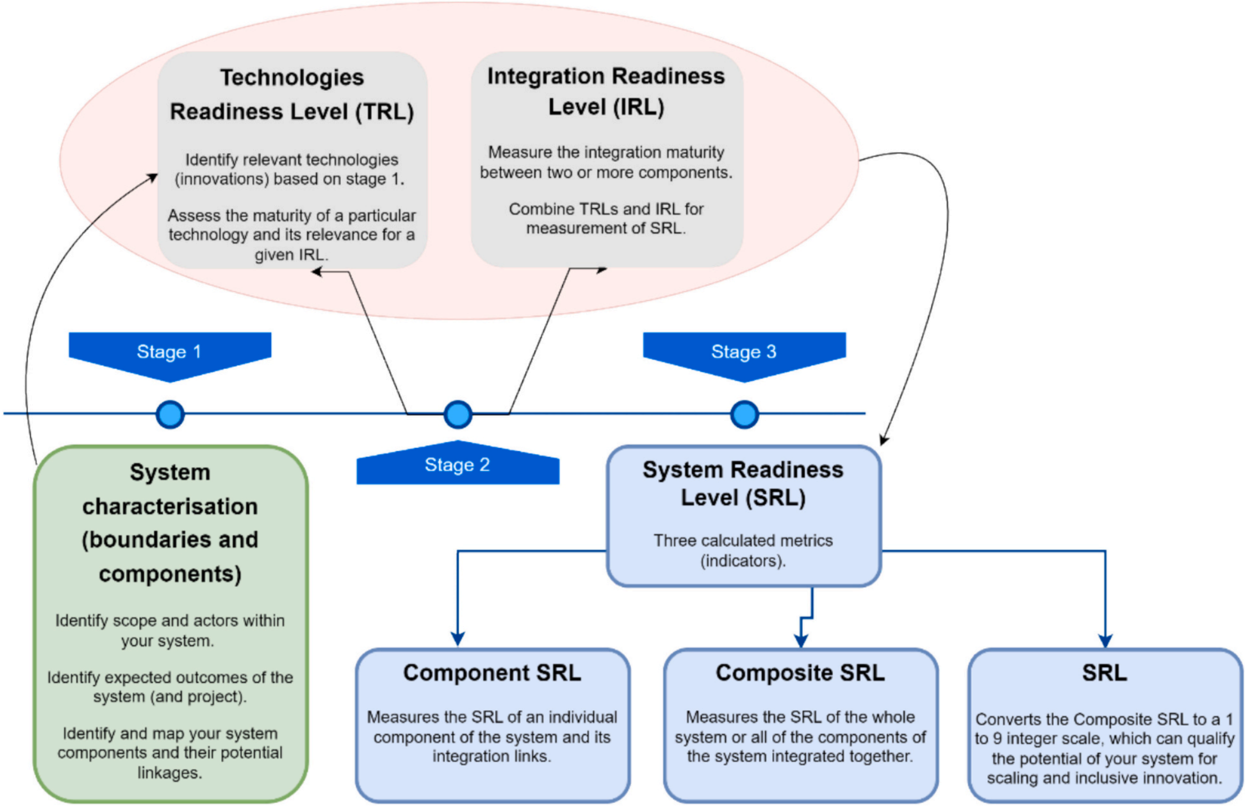

Fig. 4. Agricultural (socioecological) SysR assessment.
Adapted from Austin and York (2015).

integration that a particular component (e.g., crop, livestock, technology, household, farmer, market) has achieved with other components during the co-design, evolution, and monitoring of system transition pathways. The assessment of these individual components of the farming system is a critical part of achieving improved system performance management – by suggesting priorities for interventions, and activities for better integration of components if and when needed (Deolu-Ajayi et al., 2023). For example, an intervention to introduce new, high-yielding barley may fail because it does not take into account that farmers are using barley for food and feed/grazing. In such cases, it is crucial to evaluate the crop technology readiness within the broader context of integrating the livestock component into the system. This holistic approach ensures that all relevant factors are considered, enhancing the chances of successful implementation and overall system effectiveness.

Unlike system approaches for technologies scaling assessments, the SysR process provides a ‘whole system’ perspective, enabling better planning and traceability of performance and integration throughout the entire agricultural system and its components. This perspective is crucial for AR4D programs that aim to re-design agricultural systems through transformative, sustainable intensification pathways and scenarios – for example, where multiple system components and their respective contexts need to be considered and their interactions well understood for better articulation of innovation bundling and action research. The SysR process can be performed multiple times over the course of the farming system’s life cycle (see Fig. 3), enabling a comprehensive understanding of the system’s readiness for deployment and adaptation of the piloting process. An adaptation of the SysR process, based on Austin and York (2015), for farming systems analysis and design through AR4D program is suggested in Fig. 4.

The SysR process also provides several additional benefits that are not provided by traditional assessments of farming system tools and methods. It can measure the readiness of all farming system components, (current methodologies assume all elements equally critical, which needs further adaptation), and focuses on the readiness of integration between critical components internal to the farming system and external dependencies. While the first two SysR metrics (TRL and IRL) are assigned by the program managers and experts, the three remaining SysR metrics (component SRL, composite SRL, and SRL) can be calculated (Austin and York, 2015), to provide decision-makers with an overall view of the farming system’s readiness and aggregated level of performance. The SysR process is best performed early in the AR4D program to enable program managers to understand the scope of the farming system being designed (Fig. 4). SysR, as illustrated in Figs. 3 and 4, can be the basis for further conceptualization and testing in agricultural systems development to open further avenues of holistic analysis and co-design within the broader transformative AR4D arena.

6. A comparison of SR and SysR perspectives for transformation using a simple example of a mixed crop-livestock system

This section provides an illustrative example (Fig. 5) of a mixed crop-livestock system where a package of techologies (grouped using a systemic approach, such as SR) is promoted to enhance the scaling of a core (crop) innovation. If we remain focused on a scaling objective, the program managers, teams, and partners will then co-design a comprehensive set of activities aimed at piloting, testing, demonstrating, and developing capacities and policy dialogues around the designed core innovation (expressed as CT in Fig. 5) and its package of complementary innovations (T_n). By considering this technology-based entry point for the design of the program’s ToC, the impact of the designed activities and interventions will be channeled to varying degrees and intensities into the other system components (other than crops). For example, assuming the package promotes a core innovation of an improved, high-yielding cereal food variety, it may be that, during the technology packaging, farmers will highlight their preferences for high biomass and

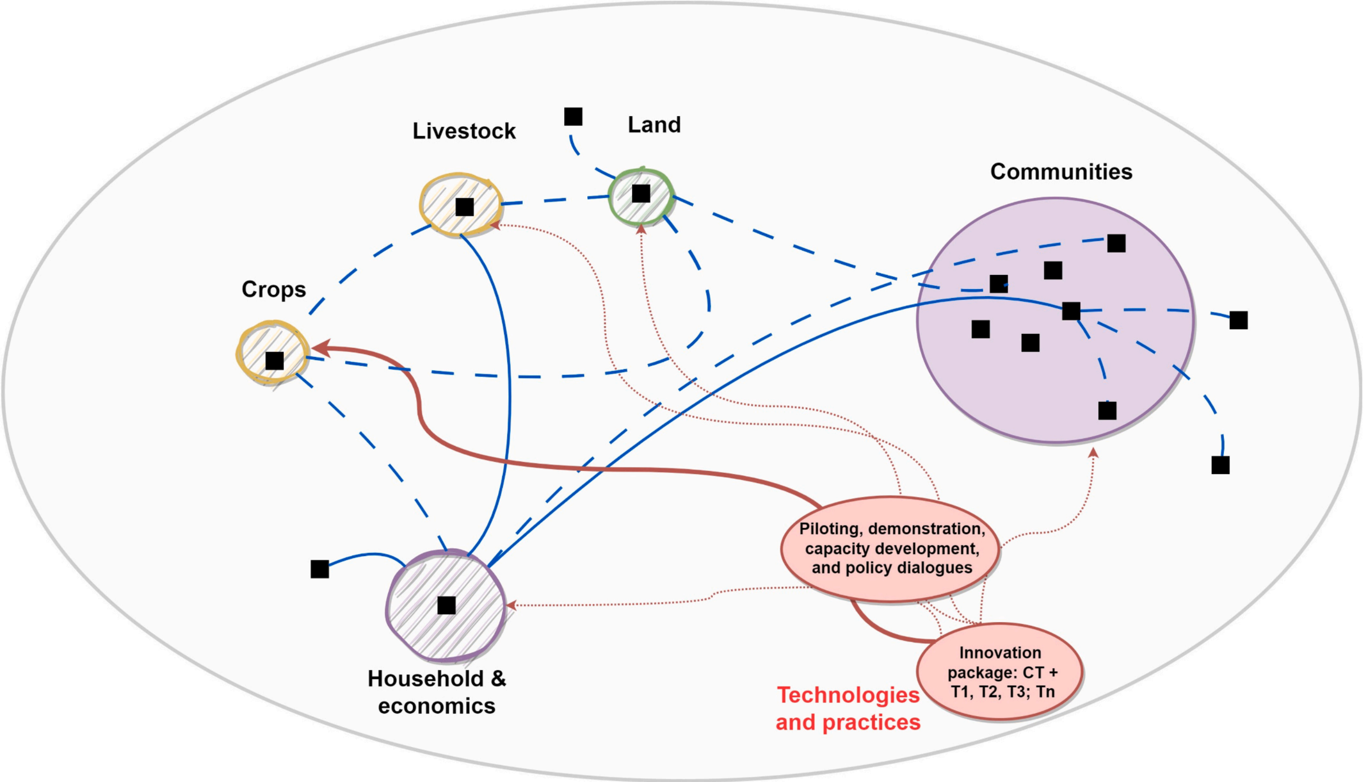

Fig. 5. Illustration of technology packaging using a system approach without consideration of component empowerment and SysR.
Notes: 1) Piloting, demonstration, capacity development and policy dialogue can be carried out for any of the innovations identified in the package, but these are identified based on the need to scale up a 'core innovation' for a given crop. 2) The core (crop) innovation is the one represented by the solid red line. 3) The dashed red lines show secondary impacts of the designed innovation package (i.e., complementary innovations that are expected to support the scaling of the core crop innovation) on other system components. 4) The agricultural system components (dashed blue lines) in this figure are not addressed by the AR4D initiative and thus remain poorly configured and integrated, with low system performance and linkages.

residue traits that are important for their livestock. Thus, crop breeders and system designers will take this perspective into account and deliver a high-biomass crop variety, and the SR teams will complement this new variety with a suite of innovations to support its scaling. However, concentrating solely on this entry strategy for system transformation will only address one aspect of the livestock system, such as improving summer feeding for the herd. While this improvement is a vital initial step, it will not sufficiently tackle the broader challenges facing the livestock component. A more comprehensive and holistic Theory of Change (ToC) would illustrate how this feeding intervention interacts with other critical factors, such as market access, veterinary care, and farmer training. By focusing only on crop traits and varieties, the resulting 'transformative capacity' of the innovation packages may be limited to increased cereal yields and livestock feeding.[5]

In Fig. 6, a different approach would directly adress all key system components by looking at their key challenges and the different priority innovations needed to support their empowerment and readiness for integration (IRL) with other components of the system (similar to Fig. 2). With this in mind, and by repeating the innovation targeting and prioritization process for each component of the system, we can then design innovation packages that are more aligned with the priorities of system components. These can further contribute to improving the integration levels between the components (IRLs) as well as the overall SysR. For example, following this technology packaging perspective, an AR4D program aiming at sustainable intensification of a crop-livestock system will address key constraints of the livetsock component, which could be an animal health issue or a problem of low genetic performance of animals that affects feed valuation. This entry point for improving the readiness of the livestock component is combined with the identification of key challenges of the crop system component, for example, low crop productivity – requiring high-yielding varieties. The resulting package will then consist of higher-yielding varieties, but will also promote more relevant technologies for livestock productivity, such as consideration of biomass production from crops, promotion of legume forages in crop rotations, support for vaccination and herd health management aspects, genetic selection of animals to improve their overall productivity, and so on. The importance of the biomass and crop residues of any crop variety will thus be identified in the 'livestock component' readiness assessment (especially when we look at livestock to crops IRL), rather than simply being an additional criterion to promote the adoption of high-yielding crop varieties. By co-identifying and packaging key transformative innovations for each of the agricultural systems components using the SysR framework, a more consolidated and transformative transition pathway can be developed by AR4Ds for the systems in place, thus, leading to stronger crop-livestock integration and sustainable intensification. A holistic mapping of systems with their human, social, policy and institutional dimensions can even result into more inclusive packages (as suggested by Cozzens and Sutz, 2012). These packages can effectively combine capacity elevation and institutional arrangements with technologies, thus also contributing to enhancing innovation capacity within the system.

7. Conclusions and perspectives

This paper emphasizes the idea that the entry point for system transformation needs to be carefully co-identified and prioritized based on strong SysR, which includes and considers all key system

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[5] The example remains simplistic for illustrative purposes.

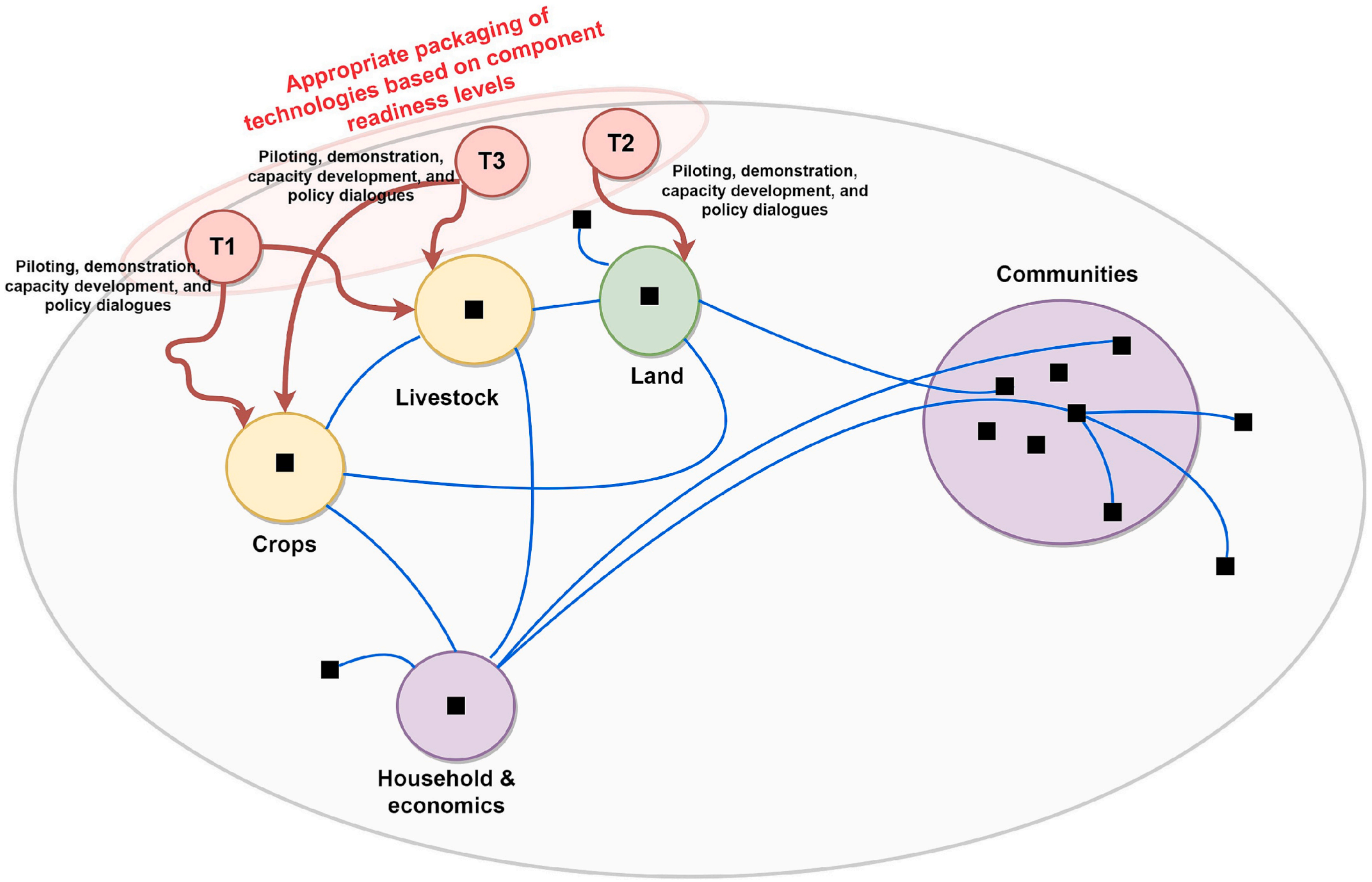

Fig. 6. Illustration of technology packaging based on a SysR framework and on targeting system components readiness and integration.
Notes: 1) The strategy within a SysR framework is to improve the performance of each production system component through appropriate and targeted technologies and innovations. 2) The co-design of innovations with local actors must give priority to these innovations, which can lead to a stronger dynamic and better integration of these most important and key transformative system components. 3) Packaged technologies and/or innovations need to be systematically coherent, compatible, and form a coherent innovation package that can enhance the overall system performance and put it on a sustainable transformation path. 4) The overall system and all relevant system components will thus benefit from the planning process for these interventions and from the resulting transition path to be developed.

components. SR provides a useful comprehensive system approach for packaging innovations, but care is needed about how to start the SysR exercise and how to co-identify the system component needs, as well as the core technologies, complement, and scale. Thus, this paper supports the idea that there is no single entry point to transform a system, but we should rather consider empowering the system on many key strategic fronts including its capacity for inclusive innovation. This can be achieved if we adopt an SysR framework, as initially conceptualized in this paper. The process of SysR analysis and enhancement is also more in line with the concept of inclusive innovations compared to the concept of core innovations. Inclusive innovations can be considered as an endogenous function of the farming system by considering key componenets such as communities, technologies, households, infrastructure, and networks as part of the SysR analysis.

However, both approaches of ‘packaging for system transformation’ and ‘SR for packaging innovations’ can be complementary at certain stages of AR4D program implementation. This is especially the case when SysR diagnosis is completed and the targeted identification and prioritization of entry points for component empowerment and integration is identified. Then, SR can be used to strategically guide the scaling road map agendas for the identified key transformative innovations. There is, however, a need for future studies that can better conceptualize the boundaries, scale of operation, and timing of both frameworks for enhanced AR4D programs.

This paper also emphasizes the need for better and in-depth thinking about building the scaling capacities of partners and local stakeholders while piloting iterative ToCs. What we see today is rather a process of ‘supporting the scale of an innovation or an innovation package’ as being part of a linear adoption of ToCs, which will not necessarily result in more favorable local contexts of inclusive innovations. The concepts presented in this paper will benefit from further development and discussion with research and development communities on improving social learning and capital in relation to system transformation. Simplified tools and methdologies of SysR that can be timely and efficiently applied to support AR4D programs are still to be developed and tested.

Finally, one of the limitations of this SRL framework is that it combines the IRL assessment, which measures the maturity of integration between two or more components, with the TRL measures of relevant technologies (identified in stage 1 – Fig. 4) needed to upgrade each of these components. It is, however, important to expand the SRL towards a more flexible approach with less focus on ‘technologies’ and more consideration of other types of organizational, social and policy innovations. Such a shift will also be necessary for a stronger adaptation of SysR to agricultural and environmental science to cover additional ‘invisible’ layers of socio-ecological systems, such as mental models, capacities, power dynamics, and relationships in relation to technological interventions. This is in line with Leeuwis et al. (2021), who suggest a reorientation of investments in food system transformation, with greater attention to addressing the social, institutional and political dimensions of innovation and transformation. Accordingly, it would be relevant to explore how SysR (conceptualized in this paper at the farm level) can be further extended to reflect exogenous system interactions and boundaries, but also to reflect the more elaborated understanding of systems as complex multi-dimensional systems rather than simple interactions between components (Leeuwis et al., 2021). It is finally important to clearly and practically link the SysR approach to co-identified desirable system outcomes, which can then lead to more elaborated and directed transformation processes.

Declaration of generative AI in scientific writing

The Author used AI [Chat GPT] in this paper, particularly and only for [English editing and text structing]. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

CRediT authorship contribution statement

Aymen Frija: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

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

Data availability

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

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