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Jérôme Ballet, Damien Bazin, Boniface Komena

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Title Page

Unequal Capabilities and Natural Resource Management: The Case of Côte d'Ivoire

Author's name

KOMENA Boniface K., BALLETT Jérôme, BAZIN Damien

Affiliations

KOMENA Boniface K.

University of Bouaké, Côte d'Ivoire

&

BALLETT Jérôme

University of Bordeaux, Gretha, France.

&

BAZIN Damien

Côte d'Azur University, CNRS, GREDEG, France.

Complete hard mail

KOMENA Boniface K.

University Alassane Ouattara of Bouaké

Phone +225 31 00 00 39

BALLETT Jérôme

Phone+33(0)5 56 84 25 75

BAZIN Damien

Côte d'Azur University, CNRS, GREDEG

250, rue Albert Einstein, 06560 Sophia Antipolis, France Phone+33(0)4 92 00 11 91

or +33(0)4 93 95 41 13

Email addresses

KOMENA Boniface K.

Boniface_komena@yahoo.com

BALLETT Jérôme

jerome.ballet@u-bordeaux.fr

BAZIN Damien

Damien.BAZIN@gredeg.cnrs.fr

1. Introduction

Academic and professional interest in how innovations spread in society has long historical roots, going back to the work of Ryan and Gross (1943) and Rogers (1962) on the adoption and diffusion of innovations. Today, such processes of adoption or diffusion are generally labelled as the scaling of innovations. Innovations can be technologies, products, services and practices, but also organizational and institutional arrangements. Scaling refers to the increased use of innovations beyond the group involved in its initial design and testing. Scaling is considered important in the context of global investments in research and development to address societal challenges related to health, agriculture, and the environment. The scaling of innovations is particularly relevant to research for development (R4D) organizations that have a mandate to develop, test and validate innovations to achieve Sustainable Development Goals (SDGs) and to demonstrate to donors that their research innovations are adopted in society to show return-on-investment (Renkow & Byerlee, 2010).

Experience shows that achieving impact at scale is more complex and difficult than anticipated in intervention proposals (Alvarez et al., 2010; Thornton et al., 2017). Earlier conception that innovations could simply be transferred by intermediaries and change agents (e.g., extension officers or health educators) and then diffuse within communities of individual beneficiaries (Rogers, 1962) has been largely refuted (Röling, 1988; Leeuwis, 2004). Historians of technology, for example, argue that scaling of innovation involves competition between supporters of different technological solutions, and those who defend interests and sunk investment associated with incumbent technological systems (Geels & Schot, 2007; Schot & Geels, 2008). Others stress that the scaling of one innovation (e.g., using a new seed variety) depends on the simultaneous upscaling of other complementary practices (e.g., weeding, pesticide-use, distribution of inputs, credit provision) and the

26 downscaling of existing practices (e.g., the current dominant seed variety) (Wigboldus et al.,
27 2016). This dynamic also points to the existence of interdependencies among the people who
28 are involved in these practices (Leeuwis & Aarts, 2020). Moreover, several authors argue
29 persuasively that scaling of something in one domain (e.g., in agriculture) may have
30 implications for outcomes in another domain (e.g., in health) and that local level scaling
31 processes may influence, and be influenced by, dynamics at higher levels (Cash et al., 2006;
32 Giller et al., 2008; Schut et al., 2014; Wigboldus et al., 2016). In view of such
33 interdependencies, it has been argued that the development of scalable innovations depends
34 on conducive interactions in multi-stakeholder networks, wherein what may be desirable and
35 possible in one context, may be problematic and unfeasible in others (Cole et al., 2016; Hall,
36 2007a; Klerkx et al., 2012).

37

38 Individuals and organizations that have a mandate or the ambition to scale innovations could
39 benefit from complexity-aware models and operational and strategic decision support tools to
40 better guide and justify their scaling strategies and investments (Lanham et al., 2013; Patton,
41 2010; Westley & Antadze, 2010). Our review of the innovation and scaling literature has
42 revealed that there is no comprehensive framework that provides the scientific foundation
43 and key concepts for a set of tools, methods, and processes to guide the development,
44 implementation and monitoring of scaling strategies in the R4D practice. The objective of
45 this paper is to fill this gap by translating scientific insights and theories about innovation and
46 scaling into to a practical approach that provides guidance and recommendations for taking
47 innovations to scale.

48

49 To support interventions, we think it is important to think critically about how to realize their
50 scaling objectives by virtue of a stepwise and continuous process of understanding,

51 intervening and navigating complex interdependencies that influence the intervention’s
52 ability to achieve impact at scale. The approach presented in this paper – Scaling Readiness –
53 is centred around the ambition to assess the readiness of innovations to achieve specific
54 impact at scale, within a specific context, and develop, implement and monitor scaling
55 strategies to achieve those scaling objectives. Although developed and published in the
56 context of the agricultural R4D sector, it has been designed to support other R4D sectors as
57 well (e.g., health, environment, education). The notion of “readiness” refers to whether an
58 innovation has been tested and validated for the role it is intended to play in society. The
59 concept resonates with levels of technology readiness that have been proposed by the
60 National Aeronautics and Space Administration (NASA) of the United States, the European
61 Commission (EU) and technology studies scholars to assess advancements in technology
62 development, commercialization, and transition pathways (European Commission, 2014;
63 Verma & Ramirez-Marquez, 2006, Kobos et al., 2018). Thus, to accommodate these ideas,
64 we use the term “Scaling Readiness” in two ways: (1) as a brand name for a decision-support
65 process that we are developing and describing in this paper (capitalized), and (2) as a key
66 variable and measure for assessing the maturity and scalability of an innovation (not
67 capitalized).

68

69 Scaling Readiness contributes in meaningful ways to other frameworks and approaches that
70 have been proposed in relation to readiness and/or scaling (*inter alia* Kuehne et al., 2017;
71 Wigboldus et al. 2016). First, Scaling Readiness not only assesses the maturity of
72 technological innovations, but also of other types of innovations (including social,
73 institutional and political innovations), which enable a significant broadening of scope when
74 compared to technological readiness (Verma & Ramirez-Marquez, 2006). Second, Scaling
75 Readiness extends conventional readiness assessments by incorporating a measure of the

76 actual use of the innovations in the locations where scaling is desired and thereby grounds
77 readiness in the specific local context. Third, the scope of Scaling Readiness goes beyond the
78 PRactice-Oriented Multi-level perspective on Innovation and Scaling (PROMIS) assessment
79 from Wigboldus et al. (2016) by providing a hands-on and action-oriented process that
80 fosters collective decision-making, learning and strategizing. Furthermore, Scaling Readiness
81 reduces complexity into a single metric indicator that can also be used to assess changes in
82 scalability over time. Fourth, the emphasis on decision-support and complex
83 interdependencies distinguishes Scaling Readiness from the ADOPT approach proposed by
84 Kuehne et al. (2017), which essentially predicts adoption of a specific innovation based on
85 Rogers's (1983) perceived attributes of innovations (i.e., trialability, observability, relative
86 advantage, etc.) and several population characteristics in a given context. In summary,
87 Scaling Readiness aims to advance and complement other tools, approaches, and frameworks
88 by: (1) paying attention to both technological and non-technological innovations; (2)
89 considering contextual conditions; (3) providing hands-on decision support to address scaling
90 bottlenecks; and (4) by striking a balance between analytical complexity and practical
91 applicability.

92

93 This contribution is structured in five sections. Section 2 presents the key-concepts
94 underlying Scaling Readiness. Section 3 explains how Scaling Readiness key-concepts are
95 operationalized, measured and made actionable. Section 4 sketches the Scaling Readiness
96 process as we propose it and its potential use in the R4D sector. Conclusions and reflections
97 are presented in Section 5.

98

99 **2. Key concepts of Scaling Readiness**

100 This section presents key concepts that underlie Scaling Readiness and which guided the
101 design of our approach in terms of its requirements and measures. The key concepts of
102 Scaling Readiness are a combination of adapted, existing concepts and new concepts
103 introduced by the authors. We group them under five sub-sections that are linked to the five
104 steps proposed in Section 4.

105

106 **2.1 Scaling is subject to a specific spatial and temporal context**

107 A consistent finding across different sectors (e.g., health, agriculture, and the environment) is
108 that scaling is influenced by contextual conditions, and that ‘one-size-fits-all’ approaches are
109 unlikely to be effective (Schut et al., 2014; Sartas et al., 2019; Shelton, 2014; Thornton et al.,
110 2010; Levin, 1998; Innes & Booher, 1999). The innovation systems literature conceptualizes
111 innovation as the outcome of (changes in) interactions between networks of interdependent
112 actors and stakeholders, the socio-technical context in which they operate, and the rules and
113 institutions that govern their interactions (Klerkx et al. 2010). This finding suggests that an
114 innovation that may be appropriate and scalable in one context, may not fit another context.
115 Secondly, an intervention strategy that may effectively support the scaling of innovation in
116 one context, may not be effective in another context.

117

118 A range of different spatial conditions play a role here, including agro-ecological conditions
119 (Douthwaite et al., 2005) and the socio-institutional features of the innovation system in
120 question (Klerkx et al. 2010; Schut et al., 2016a). As well, several studies have noted that the
121 success of similar R4D interventions may vary considerably over time (Abrahams et al.,
122 2004; Baur et al., 2003; Delisle et al., 2005; Henderson, 2000; Laws et al., 2013, Sartas et al.,
123 2019). For example, in agriculture, the ‘green revolution’ is a good example of how the
124 scaling of uniform high input use in farming (e.g., fertilizers, improved crop varieties) had

125 differential impact over space and time (Evenson & Gollin, 2003; Hazell & Ramasamy,
126 1991).

127

128 Taken together, these studies imply that we cannot usefully make generic statements about
129 whether an innovation is ready for scaling or not. Thus, Scaling Readiness must assess
130 maturity and scalability in specific spatial and temporal contexts and provide context-specific
131 decision support to develop meaningful scaling strategies.

132

133 **2.1.1 Taking the scaling context and objectives of R4D interventions as** 134 **starting point**

135 Stating that an evaluation of scaling readiness must be contextual opens the question of what
136 and whose boundaries of context should be considered. This question relates not only to the
137 geographical location (space) and temporal horizon (time) to be taken into account but also
138 requires defining what may usefully scale and for what underlying objective. For instance, an
139 R4D intervention that aims to decrease vitamin A deficiency in rural communities in tropical
140 areas by scaling of vitamin A rich crops could consider supporting the development of three
141 alternative cropping systems and value chains (e.g., rice, banana and sweet potato) to address
142 the vitamin A deficiency problem¹. However, each crop has a different set of resource
143 requirements and will lead to different impacts depending on the context. Under similar
144 conditions, the same amount of vitamin A can be produced with the least amount of land if
145 rice is used, with the least amount of water if sweet potato is used, and with the least amount
146 of labour if banana is used. Thus, a scaling strategy for decreasing vitamin A deficiency
147 needs to consider other objectives and conditions as well. Yet another dimension of context

¹ For example through the Vitamin A rich golden banana (Buah, Mlalazi, Khanna, Dale, & Mortimer, 2016; Paul et al., 2017), golden rice (Paine et al., 2005; Welch & Graham, 2004) or orange flesh sweet potato (Low et al., 2007; van Jaarsveld et al., 2005).

148 concerns who are the expected beneficiaries from the scaling of the innovation. For example,
149 if women are defined as the main target group, then scaling an innovation that reduces labour
150 by women may make most sense.

151

152 While we realize that different views may exist on what the relevant geographies, objectives
153 and beneficiaries should be for a specific scaling initiative, the starting point of our approach
154 is to assess the scaling readiness of innovations based on the expected goals and impacts of a
155 specific R4D intervention (Kuehne et al., 2017; Cohen & Axelrod, 2001). We take this as a
156 practical and legitimate starting point given our purpose is to provide decision support to
157 R4D interventions. At the same time, we expect that the need to explicate such parameters
158 will foster critical reflection in situations where boundaries, scaling objectives and target
159 beneficiaries are not clearly defined. Those considerations will trigger further reflection
160 within R4D interventions on whether scaling is indeed feasible, desirable and responsible.

161

162 **2.2 Innovations scale as part of packages**

163 As indicated, innovation systems literature emphasizes that the upscaling of specific
164 innovations (e.g., a new crop variety) may simultaneously require the upscaling of other
165 innovations (e.g., a seed multiplication and distribution system), or the downscaling of
166 existing practices (e.g., use of the currently dominant crop variety) (Kilelu et al., 2013;
167 Wigboldus et al., 2016). These dynamics imply that innovations cannot be usefully scaled in
168 isolation but must be regarded as part of a collection of innovations, or an innovation
169 package. The innovation package then becomes the unit of analysis for assessing scaling
170 readiness.

171

172 **2.2.1 Packages include core and complementary innovations**

173 R4D interventions often focus on scaling a specific core innovation (e.g., a new drug or new
174 crop variety) that is assumed to contribute to a societal benefit. These core innovations often
175 form the heart of an R4D intervention. However, the scaling of core innovations is influenced
176 by interactions with other innovations or conditions that can be either enabling or
177 constraining. We refer to these other innovations as complementary innovations. For
178 instance, scaling a new animal vaccine (the core innovation) also requires (1) new vaccine
179 dosage and application practices; (2) certification from vaccine control agencies; (3)
180 establishing or improving vaccine delivery systems; and (4) education about vaccine
181 characteristics and use (the complementary innovations) (Curry et al., 2013; Paina & Peters,
182 2012).

183

184 What constitutes a meaningful and viable innovation package depends again on the context,
185 which implies that packages can change over time and are likely to differ across locations.
186 Similarly, the composition of an innovation package may need to vary for different
187 beneficiary groups. Using the animal vaccine example again, for countries where resource
188 poor populations are impacted by a specific animal disease, subsidized vaccine distribution
189 through public veterinary services may be an important complementary innovation to ensure
190 equitable and affordable access.

191

192 In sum, Scaling Readiness needs to take into account interdependencies between core and
193 complementary innovations and needs to support the characterization and definition of
194 innovation packages that are specific to the R4D intervention: its context, objectives, users
195 and beneficiaries.

196

197 **2.2.2 The scaling readiness of an innovation is a function of innovation**
198 **readiness and innovation use**

199 As mentioned in Section 1, the technology readiness levels proposed by NASA and the EU
200 are, in essence, a measure of the maturity of a technology wherein maturity is defined as a
201 demonstrated capacity to perform a specific function or contribute to a specific objective
202 within a specific research or development environment (e.g., in the laboratory, under
203 controlled conditions or under uncontrolled conditions). Levels of readiness range from an
204 ‘unproven idea’ to ‘innovation that is validated for use in an uncontrolled environment’ with
205 in-between gradations of ‘proof of concept’, ‘tested prototype’ and ‘demonstrated under
206 controlled conditions’.

207

208 However, in spite of this elaboration, the maturity scale is not sufficient for understanding the
209 potential of a core innovation and/or an innovation package as a whole and its readiness to go
210 to scale and contribute to the desired objectives. Many documented ready innovations have
211 failed to be used at scale, such as improvements to child and maternal health (Althabe et al.,
212 2008) and agroforestry management practices that use fodder shrubs or improve tree fallows
213 (Franzel et al., 2004). In addition, not every innovation may have a demonstrated capacity to
214 perform a specific function or have a desired impact. For example, multi-stakeholder
215 innovation platforms have been increasingly utilized in the agricultural R4D sector to
216 advance innovation and scaling, but evidence of their effectiveness to achieve impact is
217 scarce (Biermann et al., 2007; Cole et al., 2016; Sartas et al., 2018a; Servaes, 2016; Warner,
218 2006). To put it more simply, innovations with a low potential for achieving impact are
219 sometimes used at scale, whereas innovations with a high potential for achieving impact are
220 not necessarily used at scale. Thus, while it is important to capture the maturity of
221 innovations that are part of an innovation package (i.e., innovation readiness), it is also

222 necessary to incorporate additional variables if we want to fully understand and assess scaling
223 potential.

224

225 Inspired by innovation scholars (Geels & Schot, 2007; Leeuwis & Aarts, 2011) and network
226 science (Hermans et al., 2017; Sartas et al., 2018b), we argue that the scaling potential of a
227 core innovation and/or innovation package is – at a given point in time – also shaped by the
228 social networks in which the innovations are embedded, supported and used. In other words,
229 whether or not an innovation is likely to scale depends on who and how many users are
230 already using it, and how such users are positioned in the social network. Thus, it makes
231 sense to distinguish between network environments in which the innovation still receives
232 considerable support and protection (e.g., a project or intervention), and network
233 environments in which it has been used without any form of support (e.g., as part of
234 livelihood systems). This thinking aligns with the literature on strategic niche management,
235 which points to the importance of gradually reducing protection of innovation initiatives
236 (niches) over time and the ability of niche-level innovations to reconfigure dominant policies,
237 procedures and practices (regimes) (Hommels et al, 2007; Smith and Raven, 2012).

238

239 If innovations are used only by R4D intervention teams, their partners and beneficiaries who
240 are directly linked to or incentivized by the intervention, then the scaling potential is still low,
241 irrespective of the number of team members, partners and direct beneficiaries using those
242 innovations. When we frame the intervention in these terms, it creates a different perspective
243 on claimed scaling achievements such as “this new crop variety is used or adopted by 25,000
244 farmers in Zambia”. Such statements do not reveal much about the performance of the R4D
245 invention unless we are provided with information on who these farmers are and what was
246 their relation to the intervention. In other words, numbers tell only part of the story

247 (Woltering et al., 2019). Instead, the position of those using innovations in the innovation
248 network is a much better indicator of the innovation’s scaling potential. Such a variable also
249 captures whether the innovation users operate within a protected space (controlled
250 environment), or whether they use the innovation in more unprotected conditions
251 (uncontrolled environment) (Smith and Raven, 2012). Therefore, we propose a scaling
252 readiness variable that indicates in what type of networks an innovation or innovation
253 package is already being used. We will refer to this concept as innovation use.

254

255 Scaling readiness then becomes a function of innovation readiness and innovation use. In our
256 approach, we use these variables to generate diagnostic information relevant to scaling
257 strategy development. We will further elaborate and operationalise these variables in Section
258 3.

259

260 **2.3 Identify bottlenecks for scaling strategy development**

261 When we acknowledge that innovations scale as part of innovation packages, then the next
262 step is to try to understand which of the innovations limits the scaling of the innovation
263 package and what is the most resource-efficient strategy to overcome such bottlenecks.

264

265 **2.3.1 Innovations with low innovation readiness and use constitute**

266 **bottlenecks for scaling**

267 Liebig’s Law of the Minimum is a good way to explain the focus on the innovation package
268 as the unit of analysis for assessing its scaling potential. According to Liebig, plant growth is
269 limited by the nutrient in shortest supply (Austin, 2007; de Baar, 1994; Van der Ploeg, Böhm,
270 & Kirkham, 1999). Therefore, to analyse plant growth, it is necessary to know the relative
271 availability of all nutrients necessary for the growth of the plant, and to assess which of the

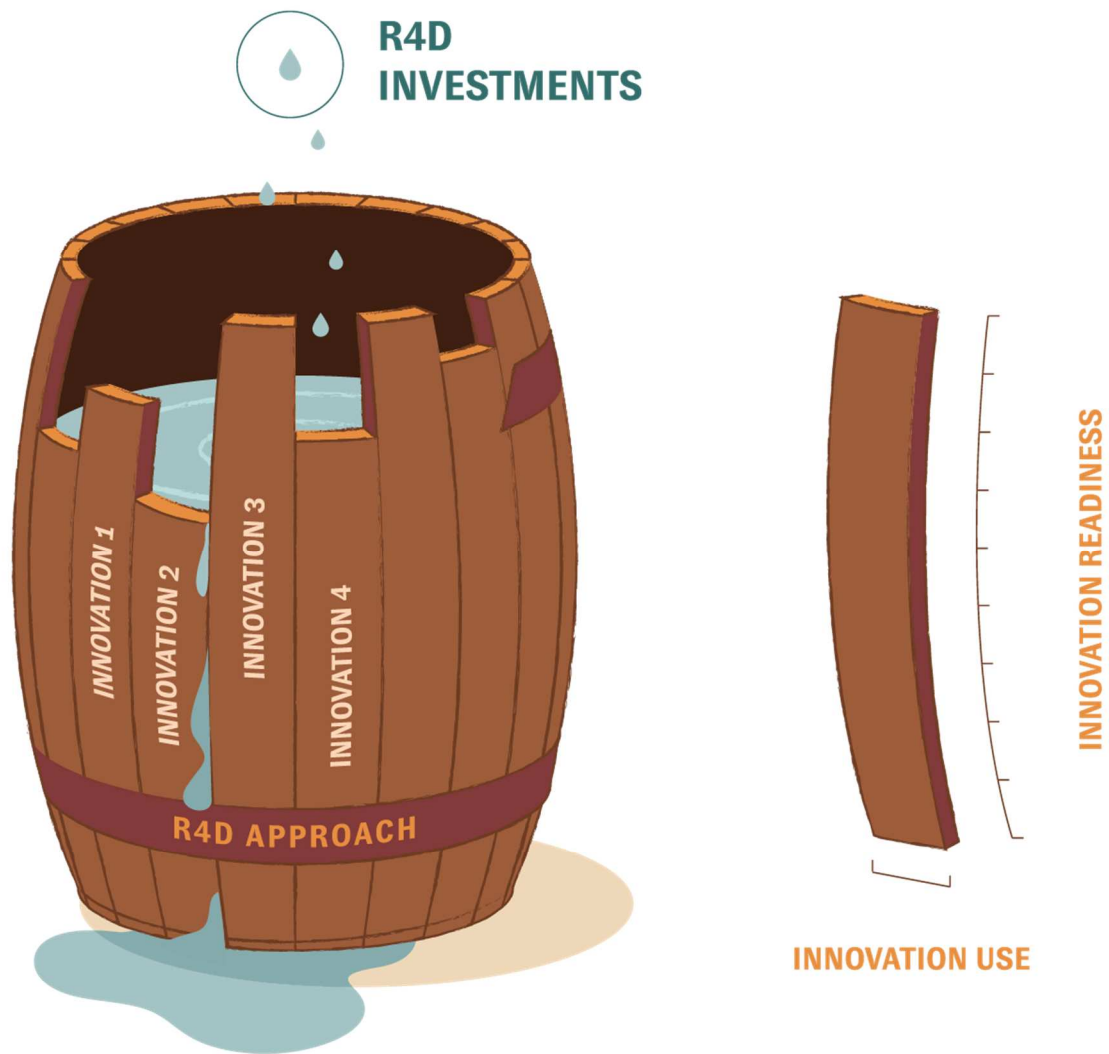
272 (micro-) nutrients is constraining efficient nutrient uptake. Similarly, the scaling of
273 innovations is limited by the core or complementary innovation in the innovation package
274 that are least developed, or, in other words, form the bottleneck.

275

276 This dynamic is illustrated in the adapted version of ‘Liebig’s barrel’ (Whitson & Walster,
277 1912) presented in Figure 1. Each individual innovation can be considered as a stave in the
278 barrel. Just as the capacity of a barrel with staves of unequal length is limited by the shortest
279 stave, so is the scaling potential of an innovation package determined or limited by the
280 innovation with the lowest readiness and use. Different staves are combined by a hoop (the
281 R4D approach) that binds staves as an innovation package. The length of each stave
282 corresponds with innovation readiness, and width of the stave corresponds with innovation
283 use. The higher and wider the staves are, the more water the barrel can hold. In other words,
284 the higher the readiness and use of the innovations, the higher the capacity of the innovation
285 package to achieve impact at scale.

286

287 **Figure 1.** Scaling Readiness Barrel to illustrate how innovation(s) with the lowest readiness
288 limit an innovation package’s capacity to achieve impact at scale.



289 Notably, Figure 1 has clear implications for strategy development and R4D investment. For
 290 example, the scaling of a drought tolerant crop variety may be limited by the absence or poor
 291 performance of a seed delivery system. One can continue to invest in plant breeding to
 292 improve a drought tolerant crop variety, but as long as the seed delivery system is not being
 293 improved, such an investment will not result in any impact at scale. In Figure 1, this
 294 innovation bottle next is illustrated by the water drops that drip into the barrel (the R4D
 295 scaling investment) and leak from the lowest stave. Thus, bottleneck analysis can form the
 296 basis for prioritizing resource allocation and investment in R4D interventions and can inform
 297 strategic and operational decision-making for scaling. Accordingly, Scaling Readiness must

298 be able to support the identification and prioritization of those innovations in a package that
299 form the bottleneck that prevents achieving a defined impact at scale objective.

300

301 **2.3.2 Strategies for overcoming bottleneck innovations must be realistic** 302 **and resource-efficient**

303 Once bottleneck innovations are identified, R4D interventions can pursue different options to
304 overcome the bottleneck and increase the impact potential of the innovation package. It is
305 important that strategies for overcoming bottleneck innovations should be realistic in view of
306 available time, human and financial resources. Here, we borrow from the organizational
307 science literature that provides various options for organizations to improve their
308 effectiveness and efficiency when faced with a constraint. Depending on the situation, they
309 can substitute some inputs for others (Wolf et al., 2001, Brach et al., 2012), outsource
310 operations (Roberts et al., 2013, Gunasekaran et al., 2015), choose to invest in design and
311 improvement (Tidd & Bessant, 2018, Snapp & Pound, 2017), or change the locations where
312 they operate (Lin et al., 2016, Reis et al., 2016). We recognize that applying such options in
313 R4D interventions may cause tension, as it can require a degree of flexibility that R4D
314 projects and programs, bounded by their context-specific objectives, may not have (e.g.,
315 Leeuwis et al., 2011, Schut et al., 2016a and Woltering et al., 2019). Nevertheless, it is
316 important that Scaling Readiness facilitates critical reflection, discussion and prioritisation on
317 a variety of strategic options to overcome bottlenecks to reach the expected objectives.

318

319 **2.4 Scaling requires multi-stakeholder agreement and coalition** 320 **formation**

321 We have seen that scaling involves the simultaneous up or downscaling of different
322 innovations or practices in a package, which implies that scaling inherently includes multiple
323 stakeholders. R4D interventions, therefore, cannot realize their scaling ambitions on their
324 own, but are dependent on other actors in the innovation system (Eastwood et al., 2017).
325 However, these other actors may not necessarily recognize this interdependence and may
326 pursue different and potentially even conflicting goals and interests (Wigboldus et al., 2016;
327 Sahay & Walsham, 2016; Galaz & Hahn, 2008), and, therefore, may not necessarily agree on
328 a proposed scaling strategy. For example, the most efficient short-term strategy for
329 addressing a bottleneck innovation related to the scaling of a drought-tolerant crop variety
330 may be to bypass working with government extension and/or seed systems that face severe
331 capacity constraints. However, this option may not be acceptable for other partners, or have
332 negative consequences for the long-term sustainability, credibility and impact of the R4D
333 organisation in that specific location or context. As a result of such tensions and
334 interdependencies in innovation systems and the inability of a single stakeholder group to
335 scale innovations in complex livelihood systems, scaling of innovation requires forging
336 agreements and accommodations among interdependent actors. There is a growing body of
337 evidence from different sectors that demonstrates this is a process that requires active
338 facilitation (Leeuwis, 2004; Giller et al., 2008).

339

340 **2.4.1 Coalition formation requires facilitated learning and negotiation**

341 Forging agreement among interdependent actors about scaling ambitions and scaling
342 strategies amounts to building effective coalitions for change (Biggs & Smith, 1998). A
343 coalition is a network of stakeholders that actively supports change in a particular direction
344 (Aarts & Leeuwis, 2010). The stakeholders may support the change for different reasons and
345 objectives, and there may be a continuation of tensions and disagreements on specific issues.

346 Two intertwined processes need to be facilitated. First, stakeholders need to *learn* about one
347 another's context and perspectives, discover how they depend on one another to fulfil their
348 ambitions, develop common starting points to build upon, and develop mutual relationships
349 and trust (Kahan & Rapoport, 2014). Second, in the process of reaching agreement, there is
350 likely to be tension and conflict, and typically these differences need to be settled through
351 *negotiation*. Negotiation is essentially a process of giving and taking amongst the participants
352 with regard to the proposed scaling objectives, pathways and desired outcomes.

353

354 In this context, Scaling Readiness must anticipate that scaling strategies cannot be usefully
355 imposed by R4D interventions on rational grounds (e.g., bottleneck assessments) and need to
356 offer facilitated spaces where interdependent innovation system actors can reach agreement
357 regarding the actions and strategies that can support effective scaling of innovation.

358

359 **2.5 Scaling is an emergent and unpredictable process of change**

360 Scaling is a complex process and R4D interventions operate under real and uncontrolled
361 conditions. This combination implies that stakeholders and intervention teams are likely to be
362 confronted with unforeseen developments and with activities that give rise to unintended
363 consequences and outcomes (Geels & Schot, 2007; Schot & Geels, 2008). Moreover, the
364 scaling context is bound to change continuously. Thus, R4D interventions require
365 mechanisms to capture and navigate the ever-changing environment in which they operate.

366

367 **2.5.1 Scaling processes require reflexive monitoring and learning**

368 Interactions among the innovations in an innovation package evolve with time (Hall & Clark,
369 2010; Pahl-Wostl, 2007; Paina & Peters, 2012; van den Bergh et al., 2011). The addition of
370 an innovation to an innovation package, or the improvement of an innovation with low

371 readiness for scaling, interacts with and influences other innovations in the package either
372 positively or negatively. As a consequence, scaling processes cannot be simply designed or
373 engineered at the onset of an R4D intervention by projecting the outcomes assuming linear
374 growth (Klerkx et al., 2010; Paina & Peters, 2012). For instance, a new soybean variety
375 introduced to a village by an R4D intervention can be used at scale and lead to an initial
376 increase in the income of farmers producing soybeans since they can sell their produce
377 (positive outcome). However, the success of this initial scaling of the soybean variety may,
378 over time, lead to the collapse of the soybean price and an eventual decrease in the income of
379 the farmers as overproduction results in a market glut (negative outcome) (Gilbert & Morgan,
380 2010). Sustaining that income growth may require additional innovations (e.g., enabling
381 access to export markets or local value addition) to continue ensuring positive impact, which
382 may not always be possible. In addition, the relations among partners in a scaling coalition
383 may change over time due to internal and external developments.

384

385 Scaling Readiness must be sensitive to emergent and unpredictable dynamics in two respects.
386 First, it needs to consider short-term horizons for the design and implementation of scaling
387 strategies by focusing on overcoming the key bottleneck innovations through concrete
388 activities and partnerships. Second, Scaling Readiness should promote continuous and
389 reflexive monitoring, evaluation and learning (Van Mierlo et. al, 2010) to assess whether the
390 scaling strategies had the desired effect over a long-term horizon, and to determine if the
391 bottleneck innovations were addressed. The diagnosis of a reconfigured innovation package
392 may result in the identification of new bottlenecks that require additional strategies and
393 further agreement between stakeholders.

394

395 **3. Measures of Scaling Readiness**

396 In this section we explain how to operationalise and measure the variables in our approach:
397 innovation readiness, innovation use and scaling readiness. As indicated in Section 2 these
398 variables can only be assessed contextually; that is, in connection with specific R4D
399 intervention goals that are pursued in a particular time and space. This condition implies that
400 an innovation may have a high level of readiness in one location, or at a specific moment in
401 time, or for a specific goal, but at the same time have a low readiness in a different location,
402 moment in time, or when directed toward a different goal. We do not elaborate in detail on
403 how these contextual features may be defined and characterised; however, there exist
404 standard ways of mapping innovation systems for specific sectors, such as for agriculture
405 (Schut et al., 2015).

406

407 **3.1 Innovation readiness measurement**

408 In the R4D literature, there are different scales for measuring the maturity of an innovation.
409 Although not all of them refer to the term readiness, these scales do capture the capacity of
410 innovations to perform a specific function, or contribute to a specific objective within a
411 specific context. Examples include service innovation readiness (Yen et al., 2012) and
412 technology readiness (Parasuraman, 2000; Richey et al., 2007; Sauser et al., 2008; Verma &
413 Ramirez-Marquez, 2006). We chose to build our measure of innovation readiness on the
414 technology readiness index developed by NASA (Parasuraman, 2000; Sauser et al., 2008)
415 which has also been adopted by the Horizon 2020 Programme of the European Union
416 (European Commission, 2014). This readiness index is one of the oldest available and has
417 been used for assessing the readiness of technological innovations, and for making strategic
418 research investments. We modified the index categories to make them suitable for assessing
419 both technological and non-technological innovations, thus transforming the technology
420 readiness index into a scale for assessing the readiness of all types of R4D innovations (Table

421 1). According to the innovation readiness scale, innovations evolve from an 'idea' (level 0)
422 toward being 'ready' (level 9) following a process of research, development, testing and
423 validation in controlled and uncontrolled conditions.

425 **Table 1: Innovation readiness levels, basic descriptions and the type of science and evidence to support readiness level claims**

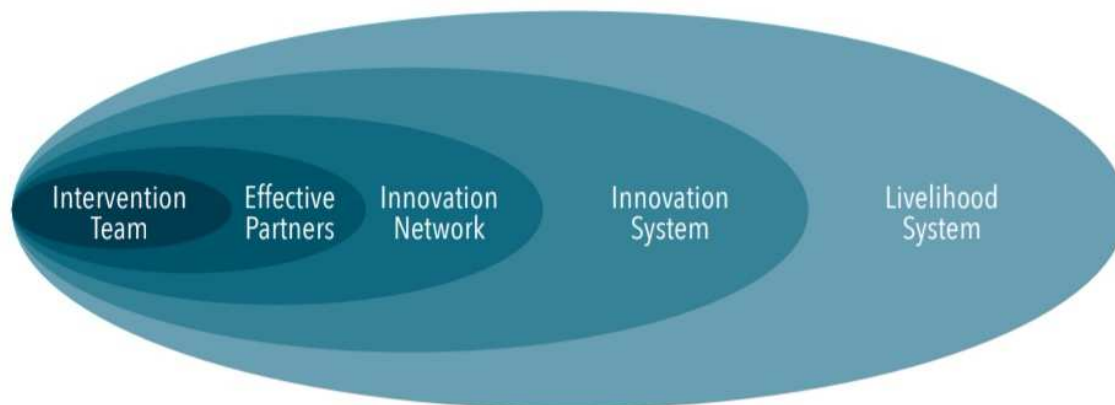
Innovation readiness score	Innovation readiness level	Description	Type of science	Type of evidence
0	Idea	Genesis of the innovation. Formulating an idea that an innovation can meet specific goal.	None	None
1	Hypothesis	Conceptual validation of the idea that an innovation can meet specific goals and development of a hypothesis about the initial idea.	Conceptual	Generic
2	Basic Model (unproven)	Researching the hypothesis that the innovation can meet specific goals using existing basic science evidence.	Conceptual	Generic
3	Basic Model (proven)	Validation of principles that the innovation can meet specific goals using existing basic science evidence.	Basic science	Generic
4	Application Model (unproven)	Researching the capacity of the innovation to meet specific goals using existing applied-science-evidence.	Basic science	Generic
5	Application	Validation of the capacity of the innovation to meet specific goals using existing	Applied	Generic

	Model (proven)	applied science evidence.	science	
6	Application (unproven)	Testing of the capacity of the innovation to meet specific goals within a controlled environment that reflects the specific spatial-temporal context in which the innovation is to contribute to achieving impact.	Applied science	Generic
7	Application (proven)	Validation of the capacity of the innovation to meet specific goals within a controlled environment that reflects the specific spatial-temporal context in which the innovation is to contribute to achieving impact.	Applied science (controlled)	Specific to intervention context
8	Incubation	Testing the capacity of the innovation to meet specific goals or impact in natural/real/uncontrolled conditions in the specific spatial-temporal context in which the innovation is to contribute to achieving impact with support from an R4D.	Applied science	Specific to intervention context
9	Ready	Validation of the capacity of the innovation to meet specific goals or impact in natural/real/uncontrolled conditions in the specific spatial-temporal context in which the innovation is to contribute to achieving impact without support from an R4D.	Applied science (uncontrolled)	Specific to intervention context

427

428 **3.2 Innovation use measurement**

429 Innovation use measures the current use of the innovations that compose the innovation
430 package in the specific spatial-temporal context where the R4D intervention aims to reach its
431 goals. This metric maps the use of core and complementary innovations by various groups of
432 stakeholders against their position in an innovation network (Figure 2). If only the
433 intervention team is using the innovation (that it has designed and tested), then the scalability
434 potential of the innovation is low. If other intervention teams and partners or aspired end-
435 users start using use the innovation (without being actively involved in its design and testing)
436 then the scalability potential is higher. Different types of innovations (e.g., products,
437 practices, services, organizational and institutional arrangements) may have different user
438 groups. For example, a farmer would be the typical end-user of a new crop variety, whereas a
439 seed multiplier would be the typical end-user of a system that promotes certified seed
440 multiplication. It is important to mention that typical end-users of R4D innovations, such as
441 farmers, can also be part of the intervention team or its effective partners if they are directly
442 engaged in the design and testing of the innovation, or incentivized by the R4D intervention
443 to use the innovation.



444

445

446 **Figure 2.** Stakeholder typology for those involved in innovation development, scaling and
 447 use, based on a network approach.

448

449 The stakeholder characterization follows a modified version of the innovation network-based
 450 typology offered by Sartas et al. (2018b).

451

452 The first group of stakeholders are those directly involved in innovation development, testing
 453 and validation and who have direct influence over the strategizing and implementation of the
 454 R4D activities. We refer to these stakeholders as the *intervention team* (Figure 2). In R4D,
 455 this group typically includes managers of the R4D interventions, researchers and research or
 456 development practitioners and support staff.

457

458 The first progression towards scaling is the use of the innovation(s) by the next group of
 459 stakeholders, who we call *effective partners*. Effective partners consist of stakeholders who
 460 directly collaborate with the intervention team within the R4D intervention. The key
 461 difference is that they do not have the same direct influence on the R4D activities as the

462 intervention team. They are effective in the sense that they make explicit contributions to
463 improving innovation readiness and/or the innovation use. Effective partners typically consist
464 of representatives of government, civil society, and the private sector, and representatives of
465 the innovation's end-users, such as farmers, patients, technicians or small-scale business
466 managers.

467

468 The next progression is the use of the innovation(s) by stakeholders who influence the R4D
469 intervention and its activities although they are not directly involved. We refer to this group
470 as *innovation network* stakeholders. They are typically the management of R4D organizations
471 and the effective partner organizations, such as Ministers and high-level officials, directors of
472 non-governmental organizations, CEOs of companies, or established opinion leaders.

473

474 A next progression is the use of the innovation(s) by stakeholders who are not collaborating
475 directly with the R4D intervention teams, effective partners, nor *innovation network*
476 stakeholders. These stakeholders do not have any direct connection with or influence on the
477 R4D intervention activities. However, their own work can have important implications for
478 scaling the innovation, as they are also in the business of developing, testing and validating
479 R4D innovations that can be complementary to or competing with the innovation. We refer to
480 them as stakeholders in the *innovation system* with are typically other R4D intervention
481 teams and their effective partners operating in the same spatial-temporal context.

482

483 A final progression towards scaling is the use of the innovation(s) by stakeholders who were
484 not involved in any R4D interventions or activities and had no influence on the R4D
485 activities. We refer them as stakeholders in the *livelihood system* since they include all the
486 remaining actors who are not part of innovation systems. Innovation use by stakeholders or

487 beneficiaries in the livelihood system is a key outcome for many R4D interventions that aim
 488 to scale innovations for achieving impact. Similar to innovation readiness, innovation use is
 489 measured using a 9-level scale (Table 2).

490

491 **Table 2.** Innovation use scores, levels and their basic description.

Innovation use score	Innovation use level	Description
0	None	Innovation is not used for achieving the objective of the intervention in the specific spatial-temporal context where the innovation is to contribute to achieving impact
1	Intervention team	Innovation is only used by the intervention team who are developing the R4D intervention
2	Effective partners (rare)	Innovation has some use by effective partners who are involved in the R4D intervention
3	Effective partners (common)	Innovation is commonly used by effective partners who are involved in the R4D intervention
4	Innovation network (rare)	Innovation has some use by stakeholders who are not directly involved in the R4D intervention but are connected to the effective partners
5	Innovation network (common)	Innovation is commonly used by stakeholders who are not directly involved in the R4D intervention but are connected to the effective partners
6	Innovation system (rare)	Innovation has some use by stakeholders who work on developing similar, complementary or competing innovations but who are not directly connected to the

		effective partners
7	Innovation system (common)	Innovation is commonly used by stakeholders who are developing similar, complementary or competing innovations but who are not directly connected to the effective partners
8	Livelihood system (rare)	Innovation has some use by stakeholders who are not in any way involved in or linked to the development of the R4D innovation
9	Livelihood system (common)	Innovation is commonly used by stakeholders who are not in any way involved in or linked to the development of the R4D innovation

492

493 **3.3 Scaling readiness measurement**

494 While innovation readiness and innovation use are assessed separately for different (core and
495 complementary) innovations in a package, the unit of analysis for assessing scaling readiness
496 is the innovation package as a whole. Following Liebig's Law of the Minimum (Figure 1,
497 Section 2.3.1), the overall potential of the innovation package to have impact at scale is
498 determined by the innovation in that package with the lowest innovation readiness and
499 innovation use score. As indicated earlier, this is assessed by multiplying the two separate
500 scores for each innovation in the package. The lowest score is referred to as the scaling
501 readiness score of the innovation package.

502

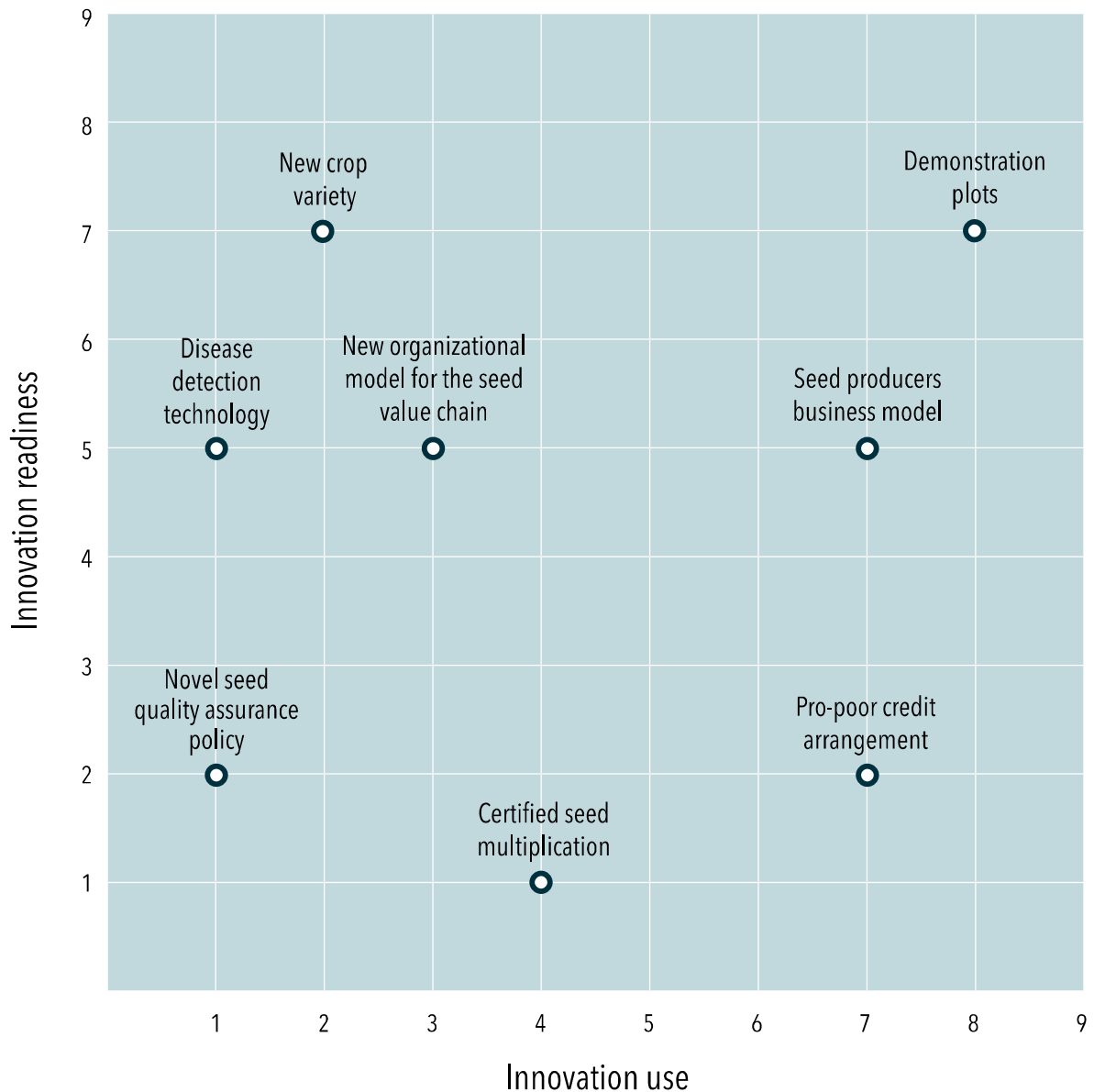
503 Innovation packages of which all innovations have been proven to work in real, uncontrolled
504 environments (innovation readiness level 8 or 9), and of which all innovations are already
505 used by many livelihood stakeholders (innovation use levels 8 or 9) have a high potential to
506 achieve impact at scale. We propose that innovation readiness and innovation use have the

507 same weight in determining the potential impact at scale of an innovation package. Having
508 one simple measure of scaling readiness allows for comparison and aggregation across a
509 portfolio of innovation packages and R4D interventions. The various measurements
510 discussed so far can be visualized as a two-dimensional graph (Figure 3) that presents all the
511 key concepts and measures of Scaling Readiness, using a stylised innovation package with a
512 new crop variety as the core innovation. This graph, in particular, represents the different
513 real-life innovation packages in root, tuber and banana cropping systems that have significant
514 coordination issues amongst stakeholders (Bentley et al., 2018). We are currently applying
515 Scaling Readiness in several R4D interventions that aim to scale agricultural innovations,
516 including the scaling of crop varieties, post-harvest technologies, digital decision-support
517 tools, and crop management practices.

518

519 **Figure 3.** Stylized example of an innovation package (with 8 innovations) that have been
520 assessed for their innovation readiness (y-axis) and innovation use (x-axis) specific to space,
521 time and R4D intervention goals.

522



523

524 In Figure 3 the overall scaling readiness of the innovation package is 2 based on the
 525 innovation with the lowest product of innovation readiness and use – novel seed quality
 526 assurance policy (innovation readiness = 2 * innovation use = 1). This innovation forms the
 527 bottleneck for this innovation package to contribute to impact at scale in a defined space and
 528 time and for a specific objective.

529

530 **3.3.1 Scaling readiness diagnosis merits independent and evidence-based**
 531 **assessment**

532 Now that we have presented the various measures in Scaling Readiness in more detail, it is
533 important to reflect briefly on how and by whom such assessments may be made. In R4D, the
534 design and scaling of health, agricultural, environmental and other societal innovations often
535 depend on continuous coordinated support from donor-funded interventions (Sartas, 2018a).
536 Sustaining this support depends on, among other factors, the perceived potential and impact
537 of the innovations at scale, and the progress achieved by researchers and innovation
538 developers during previous interventions. Therefore, such closely involved parties are likely
539 to have an interest in overstating innovation impact potential towards donors. This possibility
540 can create a conflict of interest when assessing innovation readiness and innovation use (Suri,
541 2011; Vera-Cruz, 2008). In Scaling Readiness, therefore, documented evidence (e.g.,
542 scientific papers demonstrating proof-of-concept, data collected through rigorous and/or
543 independent monitoring and evaluation systems) are required to support claims of innovation
544 readiness and innovation use levels. Whenever such documents are not accessible by the R4D
545 interventions, experts are requested to provide their judgements. We seek to minimize self-
546 reporting biases by encouraging the assessment of innovation readiness and innovation use
547 by independent experts (Grinstein & Goldman, 2006).

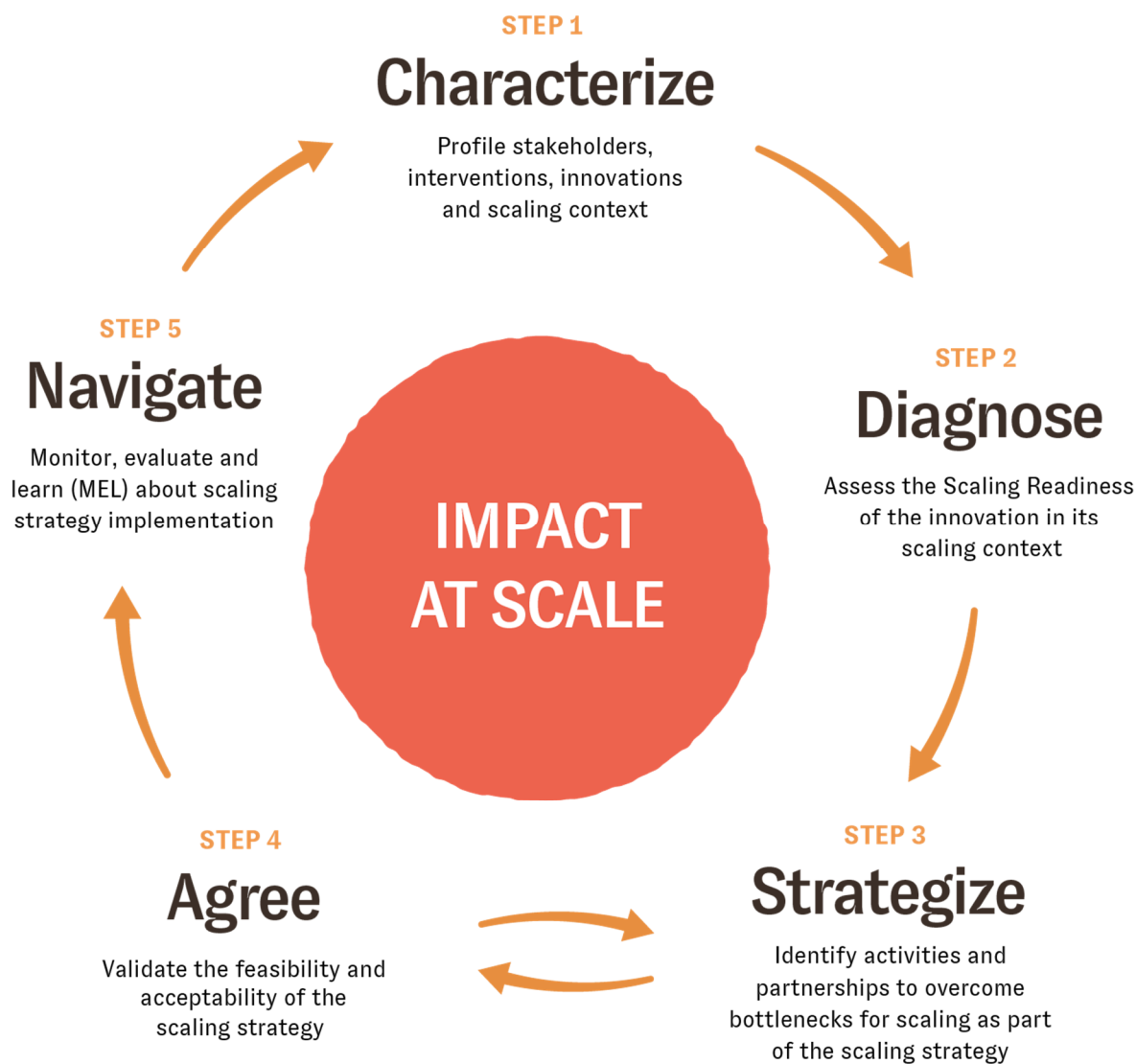
548

549 **4. Proposed practical uses of Scaling Readiness**

550 In this section we discuss how Scaling Readiness and its key concepts and measures can be
551 used in practice to contribute to more efficient scaling interventions in R4D. Our discussion
552 is informed by initial testing and validation of the key concepts of Scaling Readiness through
553 several pilot cases (Sartas et al., 2017b).

554

555 **4.1 Proposition 1: Scaling Readiness can support the**
 556 **development of better-informed scaling strategies for R4D**
 557 **interventions**



558
 559 **Figure 4.** Scaling Readiness proposes a stepwise approach to support the development of
 560 better-informed scaling strategies for R4D interventions (Sartas et al., 2020).
 561

562 One of the aims of Scaling Readiness is to support a complexity-aware, decision-making
 563 process that assists R4D interventions in developing, implementing and monitoring scaling

564 strategies in a structured and evidence-based way. To this end, we propose an iterative cycle
565 of five steps that builds on key concepts, measures and requirements discussed so far (Figure
566 4).

567

568 **Step 1: Characterization** - This first step is to characterize the innovation system in the
569 spatial and temporal context in which scaling is to deliver impact. Characterization supports
570 R4D intervention teams by clearly defining their goals, available resources (time, budget) and
571 scaling objectives. This step also supports unpacking innovation packages by identifying the
572 core and complementary innovations that are required to contribute to impact at scale. The
573 failure to unpack innovation packages has frequently been reported as a key constraint for
574 enhancing scaling and impact in the R4D sector (Mangham & Hanson, 2010; Moore et al.,
575 2015; Paina & Peters, 2012). In Scaling Readiness, visualizations of different innovations and
576 their interdependency are used in both conceptual and empirical ways, which was highly
577 appreciated by R4D intervention teams involved in the initial testing and validation of
578 Scaling Readiness.

579

580 **Step 2: Diagnosis** - Diagnosis supports independent and evidence-based assessment of the
581 individual innovations in the package in terms of their innovation readiness and innovation
582 use. This step subsequently helps to identify bottleneck innovations that keep the innovation
583 package from contributing to the defined goals and impact in a particular context. Schut et al.
584 (2016a) reported how R4D actors and organisations are often unable or unwilling to work on
585 the real (often institutional) bottlenecks for innovation and scaling, as they perceive this to be
586 outside of their organisation's mandate or their personal comfort zone. Stronger evidence-
587 based identification of bottlenecks for innovation and scaling may translate into real action by
588 R4D establishments to invest in activities and partnerships to overcome these bottlenecks.

589

590 **Step 3: Strategize** - The diagnosis of the innovation package and the identification of scaling
591 bottlenecks is meant to kick-start a process of scaling strategy development. The position of
592 the bottlenecks in the Scaling Readiness graph provides valuable information on what kinds
593 of investments, activities and partnerships are required to improve its innovation readiness
594 and/or innovation use. For each innovation with low readiness or use (Figure 3) the
595 intervention team can discuss how the innovation can be moved along the x-axis (e.g., What
596 strategies can be used to access and engage other innovation networks?) or along the y-axis
597 (e.g., How can we generate further evidence about the innovation’s capacity to contribute to
598 impact?). Similarly, the strategic options listed below support critical reflection of how to
599 best overcome the bottlenecks to scaling, and the type of partnerships that can effectively
600 support these actions:

- 601 1. **Substitute**: Can the bottleneck be replaced by another innovation with higher
602 readiness and/or use in the given context?
- 603 2. **Outsource**: Are there any organizations or external experts that can more efficiently
604 improve the Scaling Readiness of the bottleneck?
- 605 3. **Develop**: Can the intervention team improve the readiness and/or the use by investing
606 available intervention capacities and resources?
- 607 4. **Relocate**: Can the intervention objectives be realized more effectively if the
608 intervention is implemented in another location where innovations have higher
609 readiness and use levels?
- 610 5. **Reorient**: Can the objective or outcome of the intervention be reconsidered if
611 addressing the bottleneck is not possible and relocation is not an option?
- 612 6. **Postpone**: Can scaling the innovation package be achieved at a later point in time?

613 7. **Stop:** If none of the above strategic options are feasible, should the team consider
614 stopping the intervention?

615 These strategic options are ranked in terms of the resources necessary to implement them
616 from the least to most resource demanding. To achieve maximum efficiency, R4D
617 interventions are advised to use the least resource demanding option to address bottleneck
618 innovations. Strategic options 1-3 focus on addressing the core or complementary innovation
619 with the lowest innovation readiness or use (the bottleneck). Strategic options 4-6 focus on
620 finding improved conditions for the intervention as a whole and in a different space
621 (relocate), objective (reorient), or time (postpone). Strategic option 7 is a last resort when
622 finding better conditions is not possible.

623

624 **Step 4: Agree** - The proposed draft scaling strategy needs to be shared and agreed upon with
625 the broader R4D intervention partners and other stakeholders, such as donors. This step
626 ensures sufficient buy-in for the proposed strategy and validates whether the implementation
627 of the strategy is technically feasible and socially and politically acceptable. If the draft
628 scaling strategy is found unfeasible or undesirable, then the strategic options mentioned
629 above should be reconsidered, and the team moves back to Step 3. When the scaling strategy
630 is agreed upon, then a scaling action plan needs to be developed to provide details of the
631 types of partnerships and activities to address the core bottleneck(s). Available time and
632 financial resources will determine whether overcoming the bottleneck within the boundaries
633 of the R4D intervention is realistic, and if it merits additional resource mobilization efforts.

634

635 **Step 5: Navigate** - If agreement is reached on a scaling strategy and a scaling action plan, the
636 implementation and monitoring of the agreed-upon activities begins. Scaling Readiness
637 facilitates and monitors the scaling strategy and action plan implementation through a process

638 of reflexive monitoring and learning. This process requires that R4D intervention teams
639 periodically reflect on the implementation of the scaling strategy and action plan and update
640 these plans, if necessary, to guide implementation towards the desired results. Monitoring can
641 be based on short-term feedback loops that guide the implementation of the scaling action
642 plan, but also on long-term feedback loops to see if the scaling strategy has had the desired
643 effect in terms of increasing the scaling readiness score. This long-term loop would require
644 going through another Characterization (Step 1) and Diagnosis (Step 2) effort.

645

646 **4.2 Proposition 2: Scaling Readiness can support the** 647 **management of R4D portfolios and investments**

648 Many organizations involved in the R4D sector manage not just one, but multiple R4D
649 interventions as part of their portfolio. With increasing pressure to show returns on
650 investment and impact at scale (Renkow & Byerlee, 2010, Woltering et al., 2019), these R4D
651 organizations can use the key concepts and measures of Scaling Readiness to monitor and
652 manage their R4D portfolio and guide investments to increase the overall scaling readiness of
653 their innovation and scaling investments. This can be accomplished in two ways.

654

655 First, through its standardized measures, Scaling Readiness can support comparison of
656 different innovation packages for particular spatial and temporal contexts and goals.

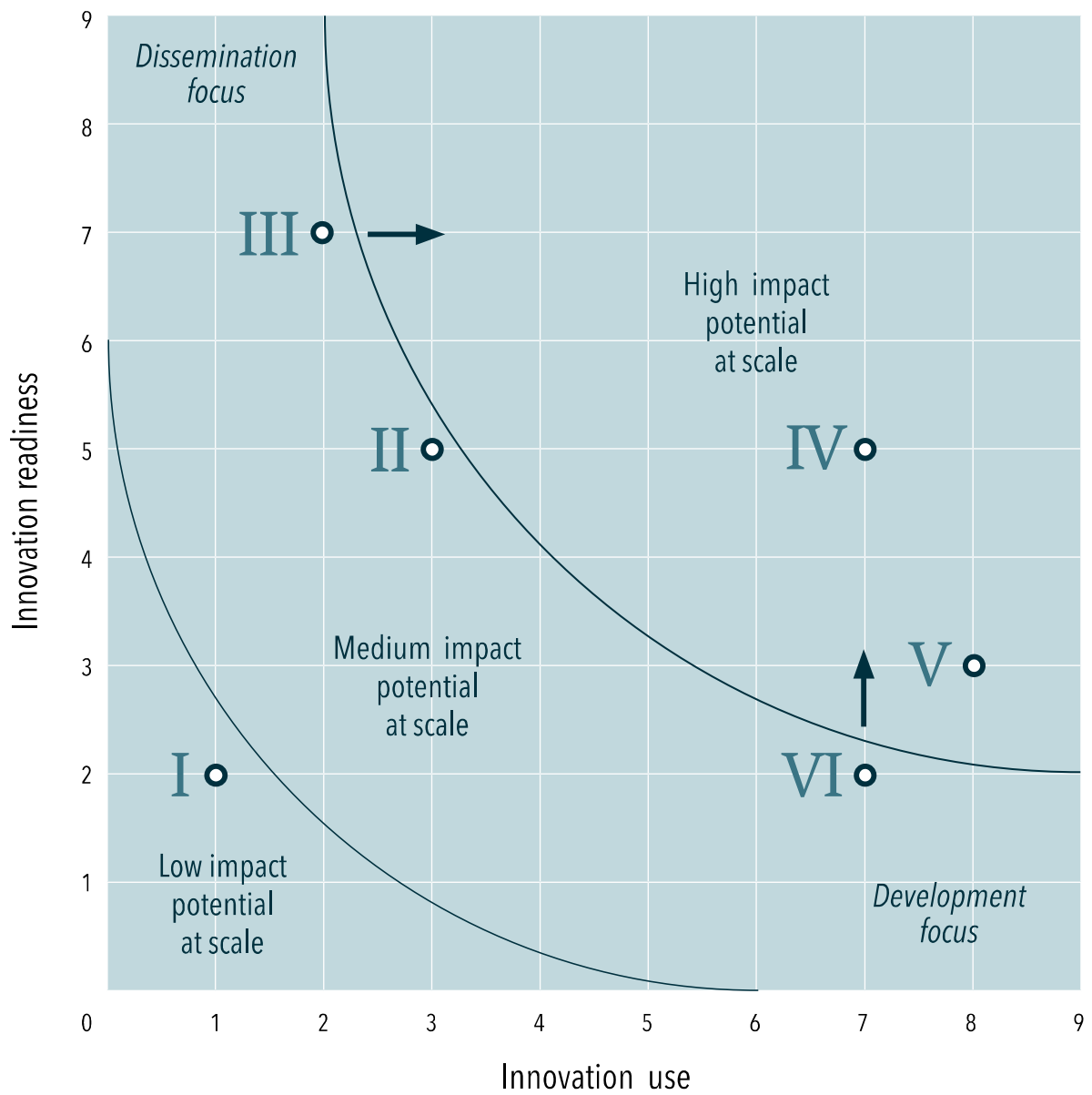
657

658 This advantage can help R4D organizations identify the innovation packages with the highest
659 potential to achieve impact at scale. It can also be useful for R4D portfolio managers and
660 decision-makers to consider *impact potential at scale* zones to compare different innovation
661 packages (Figure 5) and the type of investments that may be required to further improve its
662 scaling readiness. Innovation packages with same scaling readiness scores might need very

663 different strategies and partnerships to improve their readiness or use. For example, in Figure
664 5, although bottlenecks in innovation packages III and VI are positioned in the *medium*
665 *impact potential at scale* zone, the required strategies to bring them to the *high impact*
666 *potential at scale* zone can be different for each package. For innovation package III,
667 investments with a focus on dissemination to increase the innovation use are required,
668 whereas for innovation package VI, investments with a focus on developing and increasing
669 innovation readiness are desirable. This comparative analysis may facilitate resource
670 allocation decisions or prioritisation of investments in R4D organizations that have both
671 research (increase innovation readiness) and delivery (increase innovation use) mandates.

672

673 **Figure 5.** Impact at scale zones that indicate the relative position of innovation packages and
674 their scaling readiness specific to space, time and R4D intervention goals.



675

676

677 Based on their bottleneck diagnosis (Step 2 of Scaling Readiness), an innovation package can
678 be positioned in a *low impact potential at scale* zone (innovation package I), in a *medium*
679 *impact potential at scale* zone (innovation packages II, III and VI), or in a *high impact*
680 *potential at scale* zone (innovation packages V and IV). Based on its overall score,
681 development-focussed investments in improving innovation readiness or dissemination-
682 focussed investment in improving innovation may be prioritised (Figure 5).

683

684 Second, using Scaling Readiness continuously can reveal if the scaling readiness of an
685 innovation package increases, stays the same, or decreases over time as a result of R4D
686 investments. This information can help portfolio managers make smarter decisions about
687 where to prioritise their investments. For example, innovations packages with rapidly
688 increasing scaling readiness could be allocated extra investment. Innovations packages with
689 significant investment but without significant progress in terms of their innovation readiness
690 and/or use can be put on hold or stopped. This use of Scaling Readiness can also facilitate so-
691 called stage-gate management of an innovation portfolio in which the scaling readiness
692 scores can inform decision-makers and/or R4D donors whether or not an investment has
693 resulted in the desirable increase in innovation readiness and/or innovation use.

694

695 Here it is important to emphasize that the scaling readiness of individual innovations and
696 innovation packages can increase or decrease due to a variety of factors. Readiness and use of
697 complementary innovations in an innovation package – for example innovations that provide
698 access to finance or to markets – may change as a result of a financial crisis or the bankruptcy
699 of an important agricultural processor in a specific region. Although such factors are beyond
700 the direct influence of the R4D intervention team, they need to be taken into account as they

701 may form new bottlenecks for scaling innovation which may require a reorientation of
702 resources, activities and partnerships.

703

704 **5. Conclusion**

705 Scaling of innovations is the outcome of complex dynamics in innovation and livelihood
706 systems. Realistic scaling strategies need to recognise the characteristics of complex systems
707 dynamics. To connect the science and the practice of scaling, there is a need to develop
708 complexity-aware models that can guide operational and strategic decision-making on scaling
709 of innovation in R4D. Scaling Readiness incorporates key concepts and measures to: (1)
710 characterize innovation systems, R4D interventions and their scaling goals, and innovation
711 packages; (2) diagnose the scaling readiness of innovation packages as a function of their
712 innovation readiness and innovation use; (3) support strategy development to overcome the
713 main bottlenecks for scaling; (4) guide stakeholder agreement and coalition formation to
714 overcome bottlenecks to scaling; and (5) navigate R4D interventions in effective scaling
715 action through reflexive monitoring and adaptive management. In doing so, Scaling
716 Readiness has the potential to enhance the scaling performance of R4D interventions and can
717 support portfolio management of innovations and scaling investments.

718

719 The initial testing and validation of Scaling Readiness key concepts, measures and practices
720 within pilot projects in the agricultural R4D sector has been very promising and R4D
721 intervention teams, to date, have greatly appreciated the stepwise and action-oriented process
722 that Scaling Readiness facilitates. A next step for Scaling Readiness is the development of
723 Scaling Readiness methods, processes and tools to improve strategic and operational
724 decision-making in R4D interventions. Documenting the rigorous application of Scaling
725 Readiness in R4D interventions and analysing its contribution to the intervention's scaling

726 performance is required to demonstrate its essential value to enhance impact in the R4D
727 sector.

728

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734

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741

742

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