

Functional analysis of technological innovation systems for the digital transformation of agriculture: A quantitative multicriteria approach in the olive sector

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1 1 Introduction

2

3 The EU agricultural sector is currently facing a number of new challenges and pressures, such
4 as rising production costs and changing market and institutional demands [1, 2]. Climate change, water
5 scarcity and soil degradation are also increasing the risks to agricultural production [3-6]. One of the
6 most important opportunities (and challenges) for today's agriculture is the digital transformation (DT)
7 [7-13]. DT refers to the adoption and integration of digital technologies into the operation,
8 management and vision of the agricultural sector, and is considered a global priority [10]. DT has the
9 potential to revolutionise agriculture and contribute to the production of safe, sustainable and high-
10 quality food [14]. It can not only help farmers to "produce more with less", but also to combat climate
11 change [15-17]. Digital technologies related to sensing, geographic information systems (GIS), drones,
12 big data, artificial intelligence (AI), machine learning, robotics, the internet of things (IoT), e-commerce
13 and blockchain, among others, are radically transforming production, marketing and consumption [11,
14 18-22]. The applications of these technological innovations in agriculture are diverse, including smart
15 irrigation, crop and pest prediction, robotic pest treatment, smart harvesting, farm-to-table
16 traceability, logistics, and e-marketing, among many others [8, 11, 23, 24].

17 DT of agriculture is a complex and dynamic process involving many stakeholders and actors,
18 such as farmers, researchers, policy makers and technology providers [13]. Moreover, DT is not only
19 related to technology, but also involves changes in organisational, institutional and policy
20 arrangements that can influence its adoption and diffusion. Therefore, a systemic approach to these
21 digital innovations can be beneficial in identifying the roles and interactions of different actors and
22 how they can work together to promote DT. In addition, a systemic approach to DT can help to identify
23 the institutional factors that influence the adoption and implementation of digital technologies.
24 Innovation systems can be defined in different ways: they can be national, regional, sectoral, or
25 technological [25]. A technological innovation system (TIS) is a set of networks of actors and
26 institutions that interact together in a specific technological domain and contribute to the generation,
27 diffusion and use of variants of a new technology and/or a new product [26]. The concept of TIS dates
28 back to the 1990s, when the systemic approach was first introduced in the literature on the economics
29 of technological change [25, 27, 28]. This approach developed the preliminary notion of innovation
30 system functions and considered their usefulness for analysing change in technological systems, as
31 well as the role of actors, local networks and other aspects of success and failure in technology
32 development and diffusion [28, 29].

33 Functionalist approaches to innovation systems draw on a biological metaphor, comparing the
34 functioning of an innovation system to that of an organism, where the system cannot function properly
35 if its subsystems, such as organs and transport, are missing or do not work in harmony [30]. Several

36 studies have been devoted to defining the specific functions of a TIS [31], but the inventory of functions
37 proposed by Hekkert, Suurs, Negro, Kuhlmann and Smits [32] has been widely adopted by researchers
38 in the field [33] and has therefore formed the basis of this research. It proposes seven functions (the
39 "Seven Functions" model) that must be present in a well-functioning TIS [32]: (1) entrepreneurial
40 activities, (2) knowledge development, (3) knowledge diffusion through networks, (4) guidance of the
41 search, (5) market formation, (6) resources mobilization, (7) creation of legitimacy/counteract
42 resistance to change. This functional approach, unlike others such as the structural approach, has
43 rarely been applied to the analysis of agricultural innovation systems, but has been suggested as a
44 promising area for future research [30, 34].

45 Functional analysis of innovation systems in the literature, usually combined with structural
46 analysis, is essentially qualitative [9, 31, 35-43]. One study [34] adopted a purely functional analysis of
47 agricultural innovation systems, but also in a qualitative way. Moreover, all these aforementioned
48 studies do not break down the seven functions into subfunctions. Only a few papers [44-47] elaborate
49 and propose different subfunctions within each function of innovation systems. Furthermore, these
50 authors adopted a rather semi-quantitative approach and used a Likert scale to assess the innovation
51 system's performance in these functions and subfunctions. This scale typically ranges from 0 (no
52 performance) to 5 (very high performance). Fielke, Botha, Reid, Gray, Blackett, Park and Williams [36]
53 also used this scale, but only assessed functions, not subfunctions. In all cases, this is a semi-
54 quantitative approach, as the scale used is actually ordinal and not a rating scale. The use of categorical
55 scales raises the problem of incommensurability and the impossibility of comparing items in a decision-
56 making problem [48, 49]. On the other hand, Kao, Nawata and Huang [50] introduced a MCDA
57 (Multicriteria Decision Analysis) model by hybridising Bayesian theory and other approaches to derive
58 the performance on the seven functions and different subfunctions to promote the industrial
59 sustainability of IoT in Taiwan's smart manufacturing industry. However, these authors did not
60 integrate the performance of the TIS at the level of functions or at the global level. Also, Reina-Usuga,
61 Parra-López and Carmona-Torres [51] performed a quantitative structural/functional analysis of the
62 TIS for the DT in the Andalusian olive landscape from the perspective of knowledge-generating agents,
63 but only focused on one function (the "knowledge transfer" function). Furthermore, this work did not
64 go in depth in the development of a comprehensive methodological framework to assess the
65 functional performance of a TIS based on multicriteria analysis. In short, no previous study has adopted
66 a comprehensive quantitative multicriteria approach to the analysis of a TIS in general, and of a TIS for
67 the DT in agriculture in particular. The present study aims to fill these gaps in the literature.

68 The Analytic Hierarchy Process (AHP) [52-54] is a well-established and widely used discrete
69 MCDA technique that enables this quantitative multicriteria approach. The use of the AHP method in
70 research has increased in recent decades [55]. In particular, AHP has been used to assess the decision

71 factors underlying the adoption of cloud computing and to identify the factors influencing the adoption
72 of big data in Korean companies [56], as well as in the analysis of the main drivers of DT in the olive
73 sector in Andalusia [11]. However, its application in TIS studies is limited.

74 In this context, the objective of this manuscript is twofold: 1) to provide a comprehensive
75 methodological framework for the functional analysis of a TIS, based on AHP, which allows the
76 quantitative assessment of the performance of a TIS at subfunctions, functions and global levels; and
77 2) to illustrate the application of this framework to the case of the TIS for the DT of the olive sector in
78 Andalusia, the world's leading olive-growing region, providing insights for the design of public policies
79 to improve the performance of this TIS and strengthen DT in this agricultural sector. The
80 methodological framework and the case study could be of interest to researchers, policy makers and
81 agricultural practitioners from different fields and regions.

82

83 **2 Study setting**

84

85 **2.1 The olive sector in Andalusia**

86

87 The olive sector, which includes olive growing and related industries, represents an important
88 economic activity in Mediterranean countries. Specifically, Spain is the world's leading olive-growing
89 country, with 22.36% of the world's olive-growing area and 46.10% of the world's olive oil production
90 [57, 58], and the largest exporter of olive oil in the world [59]. Andalusia is Spain's leading olive-growing
91 region, with 62.50% of the olive-growing area and 76.83% of the country's olive production [58]. The
92 olive sector plays an important socio-economic role in the region [11, 51, 60], with olive oil accounting
93 for 15,7% of the total production of the Andalusian agricultural sector [61]. In addition, it generates
94 around one third of agricultural employment, of which between 20% and 60% are family businesses
95 [62, 63]. It also has a wide geographical presence, covering 28.77% of the agricultural area of Andalusia
96 [64]. Most of the olive grove is managed using a traditional extensive method (47.5% of the total area),
97 followed by steeply sloping olive grove (23.3%) and intensive and super-intensive olive grove (15.4%)
98 [62].

99 Despite the importance of olive growing in the region, the olive sector faces several challenges
100 that need to be addressed to ensure its long-term sustainability. These challenges include small farm
101 size, lack of professionalisation of the sector, lack of innovation among farmers, shift towards more
102 intensive farming practices, rising production costs, difficulty of mechanisation in mountainous areas,
103 price volatility, tariffs imposed by some importing countries and increasing global competition, among

104 others [1, 11, 51, 65, 66]. In this context, the DT can open up new opportunities from which the
105 agricultural sector can benefit [10-12].

106

107 **2.2 Digital transformation of the olive sector**

108

109 The literature on DT in the olive sector has mainly focused on technical aspects of technologies
110 used in smart agriculture, such as some related to the use of remote imagery to predict harvest timing,
111 harvest damage, irrigation needs and disease monitoring [67-77], IoT for smart olive crop monitoring
112 [78, 79], digital imaging for adulteration detection [80-83] and quality control [84], traceability of olive
113 oil [85, 86], and digital olfactometry [87, 88].

114 In the Andalusian olive sector, previous studies have analysed its capacity for technological
115 innovation. Thus, the innovation capacity of farmers linked to the technological packages of organic
116 agriculture [89, 90], integrated production [91] and other certified quality systems such as the
117 Protected Designation of Origin (PDO) [92, 93] and ISO 9001 [94] has been analysed. These studies
118 point to the generally low innovative attitude of olive growers in Andalusia, which functions as a fixed
119 system and is not very open to external sources of information. Therefore, the Andalusian olive sector
120 runs the risk of falling behind and losing competitiveness if it is not able to develop innovative business
121 models linked to DT. Despite the traditional lack of initiative in this area, there are reasons for
122 optimism, as both the European Union and government institutions at national and regional level have
123 shown strong support for DT, and several policy initiatives are already underway to promote DT in the
124 sector [11].

125 Studies on the specific case of DT in the olive sector from the perspective of innovation systems
126 are very scarce. In this field, Parra-López, Reina-Usuga, Carmona-Torres, Sayadi and Klerkx [11]
127 proposed a methodological framework for DT policy planning in the Andalusian olive sector. Their
128 results indicated that the opportunities and strengths of DT outweigh the weaknesses and threats,
129 with environmental issues being an important opportunity to promote DT. The only work from a TIS
130 perspective, as already indicated, is that of Reina-Usuga, Parra-López and Carmona-Torres [51], which
131 identified, from a structural perspective, the main knowledge sender and receiver actors in the TIS for
132 the DT of the olive sector in Andalusia, using Social Network Analysis (SNA) techniques. This work also
133 analysed the functional performance of the TIS, but with some limitations: it only analysed the
134 "knowledge transfer" function, not all seven functions; and it is based on the knowledge of a single
135 group of actors (universities and research centres). The present study is therefore a step towards a
136 comprehensive quantitative multicriteria functional analysis of the technological innovation system
137 for DT in agriculture in general and in the olive sector in particular.

138 **2.3 Boundaries of the TIS**

139

140 The boundaries of a TIS are the elements that define the scope and limits of the system. They
141 define the scope in which systemic interdependencies develop in a particular technological field [95].
142 The process of delineating the boundaries of a TIS is crucial in innovation systems studies and requires
143 careful consideration of the unique characteristics of each case [96]. In the case of the TIS for DT of the
144 olive sector in Andalusia, different dimensions were considered to delineate its boundaries [25, 96]:

- 145 – Technology dimension: The focus is on digital technologies currently available or with potential
146 for use in the olive sector, such as GIS, drones, AI, machine learning, IoT and blockchain. These
147 technologies can be applied in a variety of ways, such as smart irrigation, crop and pest
148 forecasting, robotic pest control, smart harvesting and farm-to-table traceability.
- 149 – Spatial dimension: The TIS is delimited at regional level, specifically the region of Andalusia, as
150 the most important olive growing area in the world (Figure 1). This focus on the Andalusian
151 region allows a sufficiently detailed level of analysis of a geographically, administratively and
152 politically homogeneous region.
- 153 – Product dimension: The focus is on olive oil, which is the main product of the olive sector.
154 Understanding the TIS in this context allows for a nuanced understanding of the specific
155 challenges and opportunities facing the sector.
- 156 – Time dimension: DT is a rapidly evolving field. Therefore, the focus is on the present and the
157 short and medium term, taking into account the latest developments in digital technologies and
158 their application to the olive sector, as well as the challenges and opportunities that are
159 emerging in the sector.
- 160 – Stakeholder dimension: This refers to the different actors involved in the DT of the olive sector
161 in Andalusia. The information on these actors has been obtained from the work by Reina-Usuga,
162 Parra-López and Carmona-Torres [51]. These actors include those involved in the olive value
163 chain, such as olive growers, production organisations and related industries for the production
164 of olive oil. In addition, there is a wide range of public and private actors who can contribute to
165 the digitalisation of the olive sector (Table 1).

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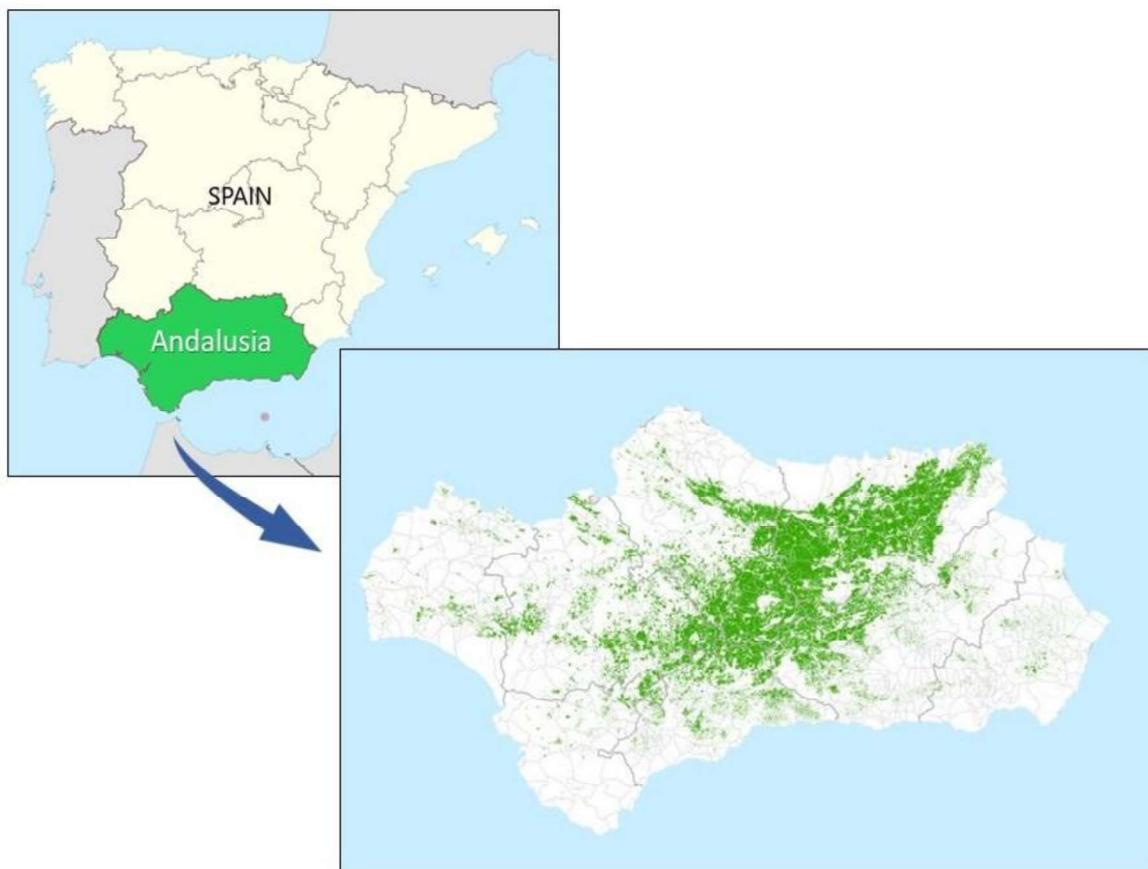
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Figure 1. The region of Andalusia and the distribution of olive growing



173

174 *Source: Based on <https://simple.wikipedia.org/wiki/Andalusia> and CAGPDS [97].*

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176

Table 1. Actors of the TIS for the DT of the olive sector in Andalusia

1. Olive grower	14. Agricultural input company
2. Cooperative / cooperative group	15. Digital technologies company
3. Non-cooperative group (Interoil, etc.)	16. Knowledge-generating agent (University, Public Research Organisation, etc.)
4. Protected Designation of Origin (PDO)	17. Knowledge transfer agent (Technology Centre, etc.)
5. Agricultural association (SAT, ATRIA, API)	18. Knowledge management agent (IDEA, RETA, etc.)
6. Agricultural organisation (UPA, COAG, ASAJA)	19. Public administration (agricultural delegation, OCA, county council, etc.)
7. Oli refinery	20. Financial institution (bank, savings bank)
8. Packaging company	21. Scientific and dissemination media (journals, internet, etc.)
9. Distributor	
10. Rural Development Group	
11. Communal Olive Heritage	
12. Interprofessional olive oil	
13. Private consultant	

177

178 *Source: Reina-Usuga, Parra-López and Carmona-Torres [51].*

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180

181 **3 Methodological framework**

182
183 **3.1 Definition and structuring of functions and subfunctions of the TIS**

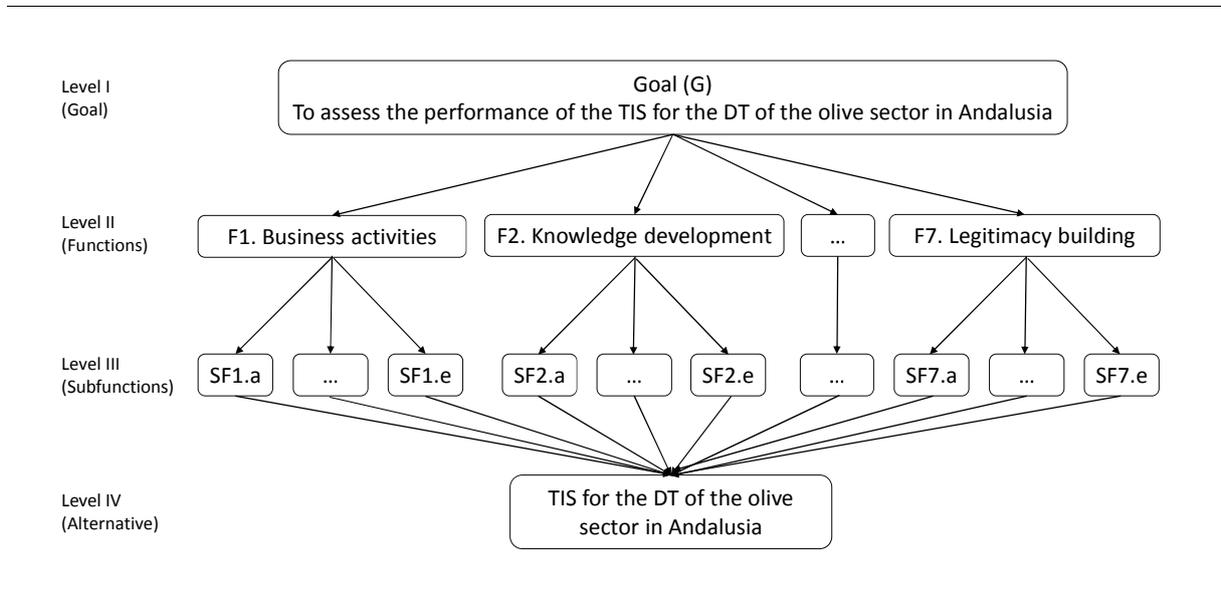
184
185 To carry out the functional analysis and assess the performance of the TIS for the DT of the
186 olive sector in Andalusia, an AHP model has been developed based on the functions and subfunctions
187 of a TIS. AHP is a quantitative multicriteria decision-making methodology that allows a discrete
188 decision-making problem to be decomposed into a hierarchical structure. This allows a complex
189 objective to be decomposed into a set of simpler subobjectives and to determine how each one affects
190 the decision objective [52-54]. The proposed AHP model consists of four levels (Figure 2):

- 191 • Level I: Corresponds to the main objective, or goal (G), to be achieved by solving the decision
192 problem. In this case, the aim is to assess the performance of the TIS for the DT of the olive
193 sector in Andalusia.
- 194 • Level II: Consists of the seven functions (F) of a TIS. The original functions [32] and subsequent
195 refinements [44-46] were used and adapted to the TIS for the DT of the olive sector in Andalusia.
196 The functions are:
 - 197 – F1. Business activities: Involvement of companies in the DT of the olive sector in Andalusia,
198 as well as their willingness to experiment with prototypes.
 - 199 – F2. Knowledge development: Availability and quality of knowledge related to the DT of the
200 Andalusian olive sector, as well as the degree of knowledge transfer to end users.
 - 201 – F3. Knowledge transfer: Availability and quality of knowledge transfer processes between
202 research centres, universities, ICT companies and end-users.
 - 203 – F4. Research orientation: Clarity and alignment of objectives among the actors of the
204 innovation system, as well as the degree of political support for DT in the Andalusian olive
205 sector.
 - 206 – F5. Market formation: Size of current and potential markets for digital technologies in the
207 Andalusian olive sector, as well as the presence of institutional incentives and barriers.
 - 208 – F6. Resource mobilisation: Availability of financial resources for knowledge development
209 and transfer, and willingness of companies to invest in DT.
 - 210 – F7. Legitimacy building: Willingness to adopt digital technologies in the Andalusian olive
211 sector, as well as the degree of coordination and diversity of the organisations involved in
212 the innovation system.
- 213 • Level III: Corresponds to subfunctions (SF), which are specific criteria within each function.
214 Based on previous studies dealing with subfunctions [44-47], specific subfunctions of the TIS
215 were adapted for the DT of the olive sector in Andalusia (Table 2).

- Level IV: Corresponds to the alternative to be assessed, i.e. the TIS for the DT of the olive sector in Andalusia.

218

219 **Figure 2. AHP model (simplified) for the functional analysis of the TIS for the DT of the olive sector**
220 **in Andalusia**



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222

223

Table 2. Functions and subfunctions of the TIS for the DT of the olive sector in Andalusia

Functions	Subfunctions
F1. Business activities	SF1.a. The number of companies involved in the DT of the olive sector in Andalusia is sufficient
	SF1.b. Interactions between the companies involved in the DT of the olive sector in Andalusia are sufficient
	SF1.c. The quality of the entrepreneurial initiative for the DT of the Andalusian olive sector is adequate
	SF1.d. Companies in the Andalusian olive sector are willing to experiment and implement prototypes
	SF1.e. Technological options for the DT of the Andalusian olive sector are available
F2. Knowledge development	SF2.a. The available knowledge is sufficient for the development of the TIS for DT in the Andalusian olive sector
	SF2.b. The quality of projects, research, patents and articles is sufficient for the DT in the Andalusian olive sector
	SF2.c. The actors generating knowledge on DT in the Andalusian olive sector are sufficiently active
	SF2.d. There is sufficient correspondence between the knowledge developed on digitisation and the real needs of the Andalusian olive sector
	SF2.e. There are sufficient beneficiaries of the knowledge developed in digitisation in the Andalusian olive sector
F3. Knowledge transfer	SF3.a. There are enough organisations transferring knowledge on DT in the Andalusian olive sector
	SF3.b. There is sufficient knowledge transfer between research centres/universities and ICT companies
	SF3.c. There is sufficient knowledge transfer between knowledge generating organisations (research centres and/or ICT companies) and end users (agri-food companies)
	SF3.d. The spaces for knowledge transfer (conferences, seminars, etc.) on DT are sufficient
	SF3.e. The quality of the DT transfer processes is satisfactory
F4. Research orientation	SF4.a. There is a clear and shared objective among the actors of the innovation system on how the DT should be developed in the Andalusian olive sector
	SF4.b. The objective of the DT in the Andalusian olive sector is adapted to the existing legislation
	SF4.c. There are sufficient programmes and policies (national and regional), which support the innovation system in the DT of the Andalusian olive sector
	SF4.d. The vision and expectations of the actors involved in the DT are sufficiently aligned to reduce uncertainties
F5. Market formation	SF5.a. The size of the current market for digital technologies in the Andalusian olive sector is sufficient
	SF5.b. The size of the potential market for digital technologies in the Andalusian olive sector is sufficient
	SF5.c. Institutional incentives for the formation of the market for digital technologies in the Andalusian olive sector are adequate
	SF5.d. Institutional barriers to the formation of the market for digital technologies in the olive sector are not a barrier to digital transformation
	SF6.a. There are sufficient financial resources for the development of knowledge in the DT of the Andalusian olive sector
F6. Resource mobilisation	SF6.b. There are sufficient financial resources for the transfer of knowledge on DT in the olive sector
	SF6.c. Companies in the Andalusian olive sector are willing to invest capital for the DT
	SF6.d. Public funding is sufficient for the operation of the TIS for DT
	SF6.e. Companies in the Andalusian olive sector have easy access to credit and/or financial products related to DT
	SF7.a. There is a willingness to adopt digital technologies in the Andalusian olive sector
F7. Legitimacy building	SF7.b. The degree of coordination between the actors involved in the TIS for DT is high
	SF7.c. The rules and regulations established for the participation and coordination between the actors of the TIS for DT are sufficient
	SF7.d. The spaces for coordination between the actors in the TIS for DT are sufficient
	SF7.e. The TIS for DT in the Andalusian olive sector involves a wide variety of organisations of different types with the capacity to generate/apply innovations

226 **3.2 Assessment of the performance of the TIS**

227

228 The next step is to assess the performance of the TIS at each of the functions/subfunctions of
229 the model and at the goal level. AHP allows for a quantitative assessment of the decision elements,
230 which makes it possible to prioritise the different types of elements, in this case functions and
231 subfunctions, on a ratio scale and to make them commensurable and comparable [98-100].
232 Furthermore, AHP allows for the inclusion of qualitative, subjective and intangible information (soft
233 data) in the evaluation process, e.g. in the form of expert knowledge, as well as quantitative
234 information and objective data (hard data) when available [101].

235

236 3.2.1 Local priorities and performances

237

238 For each node of an AHP model, i.e. the element and the sub-elements that depend on it, the
239 local priorities (and performances) of the sub-elements can be assessed based on objective data, if
240 available, or on subjective data in the form of expert knowledge and/or stakeholder preferences. In
241 order to assess the proposed model for the TIS for the DT of the olive sector of Andalusia, expert
242 knowledge was used due to the limited availability of objective data for Andalusia and the complex
243 nature of the issues under study. Specifically, 34 experts with different profiles and experience in the
244 field were interviewed by means of a structured questionnaire (see Annex I). The expert panel
245 consisted of 5 groups of experts/stakeholders: 1) 5 members from public administration, 2) 14 from
246 R&D organisations, 3) 5 from agri-food companies, 4) 5 from digital technology companies, and 5) 5
247 from other organisations supporting the olive sector.

248 The experts were asked to assess, to the best of their knowledge, 1) the local priorities
249 (importance) of the functions and subfunctions (ω_L) for the proper functioning of the TIS for the DT of
250 the olive sector in Andalusia; and 2) the performance (P_L) of the TIS for the DT of the olive sector in
251 Andalusia in each subfunction. Due to the high number of elements to be compared in some cases
252 (more than 7 ± 2), the assessment of priorities by the experts was based on the "direct rating" method
253 recommended in AHP [98, 102-104]. The rating scale ranges from 1 for very low priority/performance
254 elements to 9 for very high priority/performance [104]. The local priorities of each expert at each node
255 were normalised to sum to 1. All priorities and performances can be between 0 and 1.

256 The individual local priorities (and performances) given by each expert at each node were
257 aggregated for each group of experts using the arithmetic mean method of the priorities of each node
258 [105]:

$$259 \quad \omega_{L(g)} = \sum_{e=1}^E \omega_{L(e)} / E \quad P_{TIS(g)} = \sum_{e=1}^E P_{TIS(e)} / E$$

260 where $\omega_{L(g)}$ (and $P_{TIS(g)}$) are the local priority (and performance) of a given element for expert group g ;
 261 $\omega_{L(e)}$ (and $P_{TIS(e)}$) are the local priority (and performance) of this element for expert e belonging to group
 262 g ; and E is the number of experts in group g . The average assessment of a whole group of experts is
 263 considered to be more reliable than the individual assessment, as it minimises individual bias and the
 264 lack of knowledge of some individuals on a given topic. The average of the local priorities (and
 265 performances) of all expert groups (the average of the groups) was calculated in the same way as the
 266 arithmetic mean of the local priorities (and performances) of each expert group.

267 TIS performance in each function (for each expert group and for the average of the groups)
 268 was calculated as the weighted sum of the local priorities of the subfunctions under, i.e. depending
 269 on, their function and the TIS performance in each subfunction [106]:

$$270 \quad P_{TIS(f)} = \sum_{sf=1}^{sf(f)} P_{TIS(sf)} * \omega_{L(sf/f)}$$

271 where $P_{TIS(f)}$ is the performance of the TIS in function f ; $P_{TIS(sf)}$ is the performance of the TIS on
 272 subfunction sf ; $\omega_{L(sf/f)}$ is the local priority of subfunction sf in function f ; and $sf(f)$ is the number of
 273 subfunctions in function f . As mentioned above, experts were asked to assess the performance of the
 274 TIS on each subfunction ($P_{TIS(sf)}$).

275 Similarly, the performance of the TIS at the goal level (for each expert group and for the
 276 average of the groups) was calculated as the weighted sum of the local priorities of the functions and
 277 the TIS performance in each function. The local performance of the TIS at the goal level is equivalent
 278 to the global performance of the TIS at the goal level, or simply the global performance or performance
 279 of the TIS, since the functions are directly dependent on the goal. It is calculated as:

$$280 \quad P_{TIS(G)} = \sum_{f=1}^F P_{TIS(f)} * \omega_{L(f/G)}$$

281 where $P_{TIS(G)}$ is the global performance of the TIS; $P_{TIS(f)}$ is the performance of the TIS in function f ;
 282 $\omega_{L(f/G)}$ is the local priority of function f with respect to the goal; and F is the number of functions.

283

284 3.2.2 Global priorities of functions/subfunctions

285

286 The global priorities of the TIS subfunctions (for each expert group and for the average of the
 287 groups) were calculated in terms of their achievement of the objective by weighting their local
 288 priorities by the local priority of the function on which they depend:

$$289 \quad \omega_{G(sf/G)} = \omega_{L(sf/f)} * \omega_{L(f/G)}$$

290 where $\omega_{G(sf/G)}$ is the global priority of the subfunction sf ; $\omega_{L(sf/f)}$ is the local priority of the subfunction
 291 sf under function f ; and $\omega_{L(f/G)}$ is the local priority of function f with respect to the goal.

292 The global priorities of the functions are equivalent to the local priorities of the functions, as
293 these are directly dependent on the goal:

$$294 \omega_{G(f/G)} = \omega_{L(f/G)}$$

295

296 **3.3 Identification of critical functions/subfunctions**

297

298 Critical functions (and subfunctions) can be defined as those with 1) a high global priority, and
299 2) a high margin for performance improvement. That is, they are the most important functions and
300 subfunctions, according to the expert panel, and they have a large potential for performance
301 improvement. The Margin for Improvement (MI) can be mathematically defined as:

$$302 MI_{(f)} = 1 - P_{TIS(f)} \quad MI_{(sf)} = 1 - P_{TIS(sf)}$$

303 where $MI_{(f)}$ (and $MI_{(sf)}$) are the margin for improvement of TIS performance in function f (and
304 subfunction sf). MI measures the distance between the current TIS performance and the maximum
305 possible performance, i.e. 1.

306 Finally, a Criticality Indicator (CI) is defined for each function (and subfunction) as follows:

$$307 CI_{(f)} = MI_{(f)} * \omega_{G(f/G)} \quad CI_{(sf)} = MI_{(sf)} * \omega_{G(sf/G)}$$

308 where $CI_{(f)}$ (and $CI_{(sf)}$) are the CI of function f (and subfunction sf); $MI_{(f)}$ (and $MI_{(sf)}$) are the margin of
309 improvement of the TIS performance on function f (and subfunction sf); and $\omega_{G(f/G)}$ (and $\omega_{G(sf/G)}$)
310 are the global priority of function f (and subfunction sf).

311

312 **4 Results**

313

314 In the following sections, the results for the average of the groups are presented. Due to space
315 limitations, results specific to the different expert groups are dealt with selectively. In any case, Annex
316 II presents the average results, while Annex III provides a breakdown by expert group.

317

318 **4.1 Priorities of functions and subfunctions**

319

320 This section presents the priorities, i.e. the importance, of the functions and subfunctions
321 according to the experts for the correct functioning of the TIS for the DT of the olive sector in Andalusia.

322

323

324

325 4.1.1 Local priorities of subfunctions

326

327 The in-depth analysis of the local priorities of the subfunctions provides insight into the specific
328 areas that experts/stakeholders prioritise within each function of the TIS for the DT of the Andalusian
329 olive sector. Within "Business activities" (F1), "Technological options for the DT of the Andalusian olive
330 sector are available" (SF1.e) received the highest local priority (0.2328) (Figure 3; F1. Business
331 activities), meaning that experts perceive the availability of technological options as crucial for business
332 activities in the context of DT. In contrast, "Interactions between the companies involved in the DT of
333 the olive sector in Andalusia are sufficient" (SF1.b) received the lowest priority (0.1754), indicating that
334 the adequacy of interactions between firms is perceived as less important within this function.

335 For the function "Knowledge development" (F2), the subfunction "The available knowledge is
336 sufficient for the development of the TIS for DT in the Andalusian olive sector" (SF2.a) received the
337 highest priority (0.2100) (Figure 3; F2), underlining the importance of the sufficiency of the knowledge
338 available for DT. "The actors generating knowledge on DT in the Andalusian olive sector are sufficiently
339 active" (SF2.c) was given the lowest priority (0.1881), which may indicate that the level of activity of
340 knowledge-generating agents is considered slightly less important in this respect.

341 Within "Knowledge transfer" (F3), the subfunction "The quality of the DT transfer processes is
342 satisfactory" (SF3.e) received the highest local priority (0.2200) (Figure 3; F3), which underlines the
343 perceived importance of quality over quantity in knowledge transfer processes. In contrast, "The spaces
344 for knowledge transfer (conferences, seminars, etc.) on DT are sufficient" (SF3.d) received the lowest
345 priority (0.1791), suggesting that the sufficiency of physical spaces for knowledge transfer may not be
346 as important as the quality of the transfer process itself.

347 For "Research orientation" (F4), the subfunction "The objective of the DT in the Andalusian
348 olive sector is adapted to the existing legislation" (SF4.b) had the highest priority (0.2645) (Figure 3;
349 F4), which shows the importance of compliance with legislation. The lowest priority was given to "The
350 vision and expectations of the actors involved in the DT are sufficiently aligned to reduce uncertainties"
351 (SF4.d) with a score of 0.2380, suggesting that experts might consider vision alignment slightly less
352 important compared to legislative compliance.

353 In "Market formation" (F5), "The size of the potential market for digital technologies in the
354 Andalusian olive sector is sufficient" (SF5.b) obtained the highest score (0.2894) (Figure 3; F5),
355 highlighting the importance of market potential in this context. "Institutional incentives for the
356 formation of the market for digital technologies in the Andalusian olive sector are adequate" (SF5.c)
357 received the lowest score (0.2212), indicating a low priority of institutional incentives compared to
358 market potential.

359 In "Resource mobilisation" (F6), "Companies in the Andalusian olive sector are willing to invest
360 capital for the DT" (SF6.c) was the highest priority (0.2281) (Figure 3; F6), illustrating the perceived
361 importance of business investment in DT. "There are sufficient financial resources for the transfer of
362 knowledge on DT in the olive sector" (SF6.b) had the lowest priority (0.1802), which might suggest that
363 financial resources for knowledge transfer are seen as less critical compared to business investment.

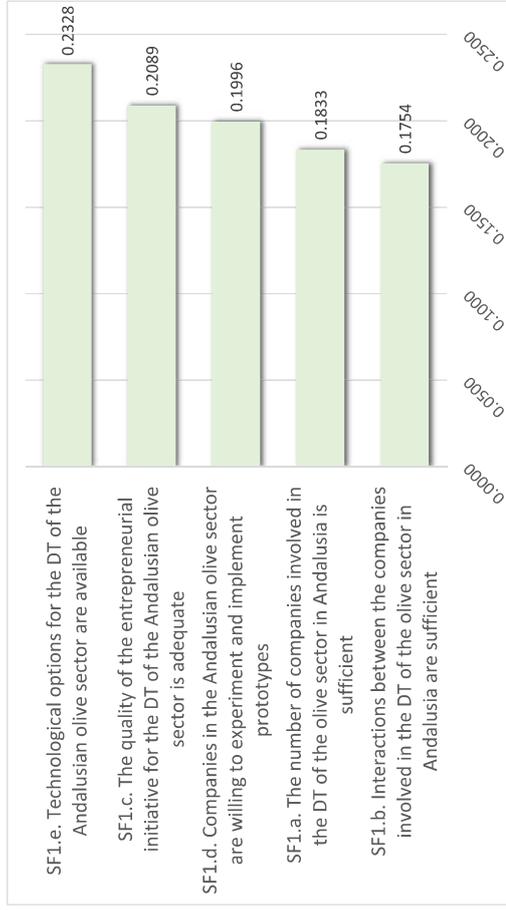
364 Finally, within the "Legitimacy building" (F7), "There is a willingness to adopt digital
365 technologies in the Andalusian olive sector" (SF7.a) received the highest priority (0.2273) (Figure 3; F7),
366 which underlines the recognition that without this initial willingness of all actors within the TIS, DT may
367 not achieve the expected benefits. In contrast, the subfunction "The rules and regulations established
368 for the participation and coordination between the actors of the TIS for DT are sufficient" (SF7.c) has
369 received the lowest priority with a value of 0.1713. This implies that the current perception is that the
370 existing regulatory framework, in terms of participation and coordination between actors, is considered
371 less critical, or is considered reasonably well established and sufficient.

372

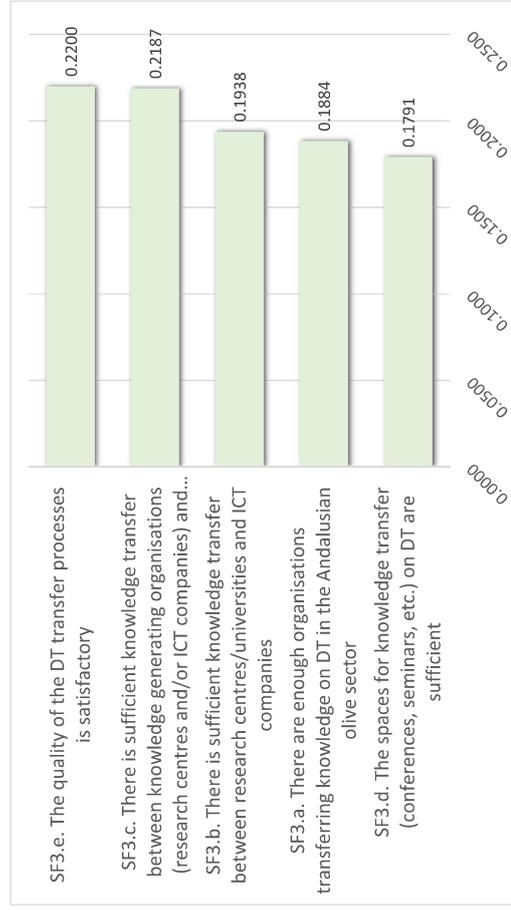
373

Figure 3. Local priorities of subfunctions within functions ($\omega_{L(sf/f)}$) (average)

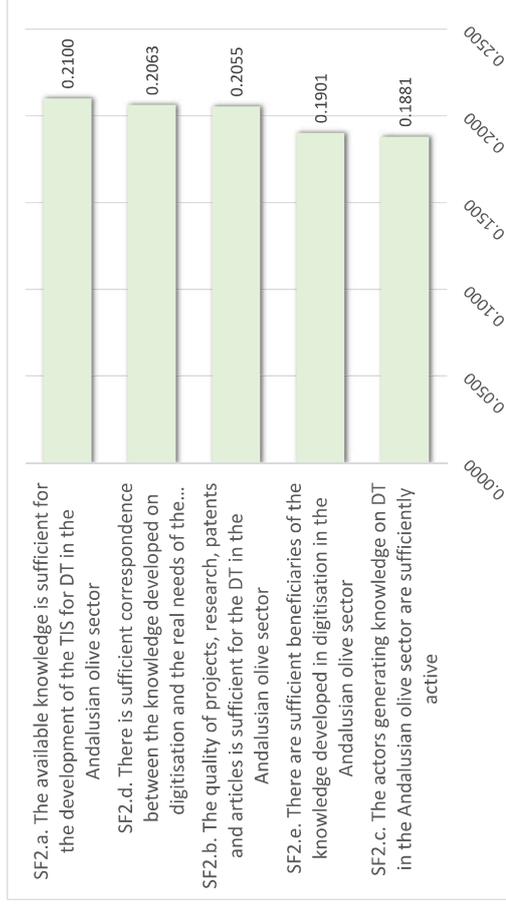
F1. Business activities



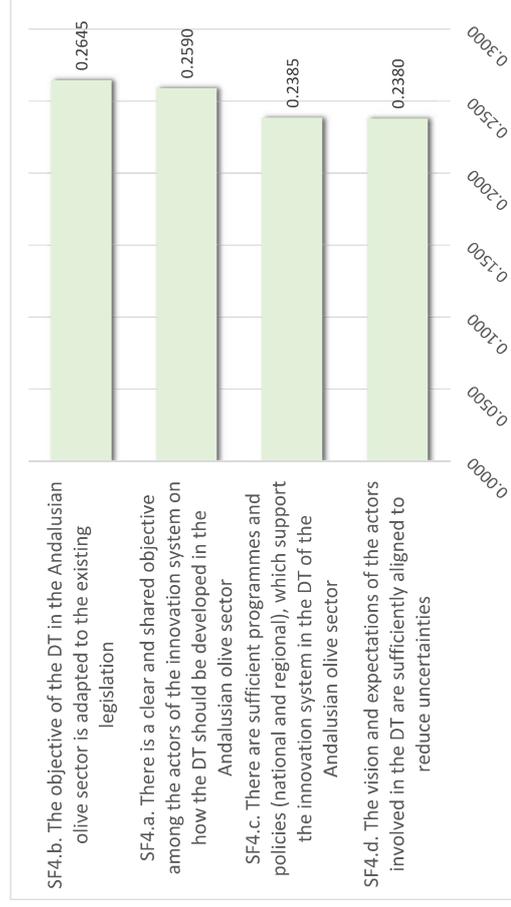
F3. Knowledge transfer



F2. Knowledge development

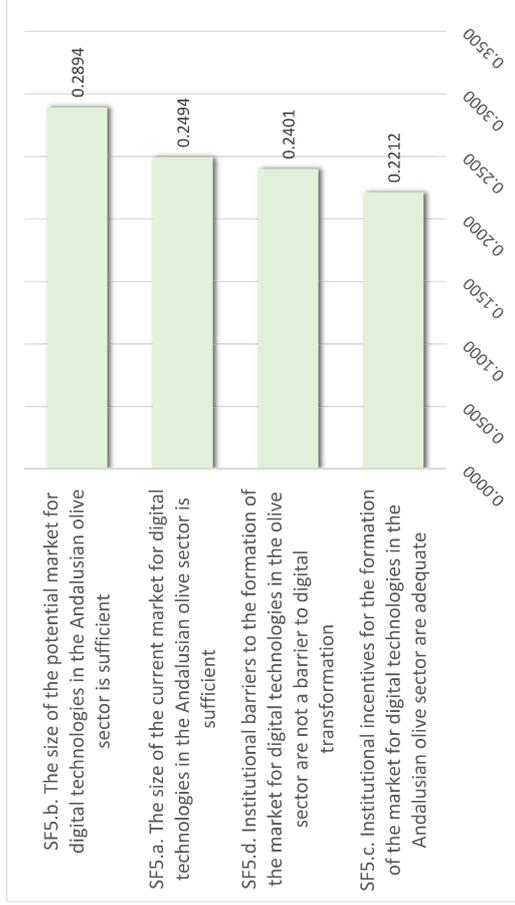


F4. Research orientation



383

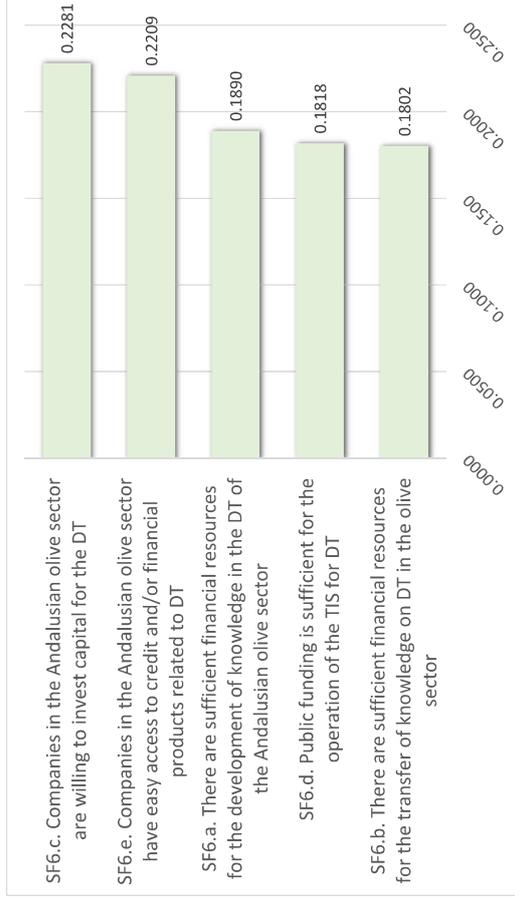
F5. Market formation



384

385

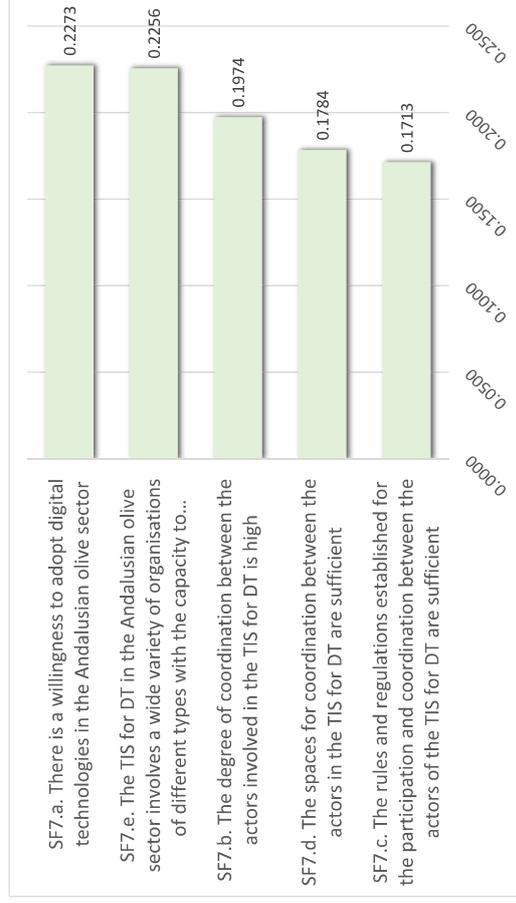
F6. Resource mobilisation



386

387

F7. Legitimacy building



388

389

390 4.1.2 Local priorities of functions

391

392 a) Average assessment

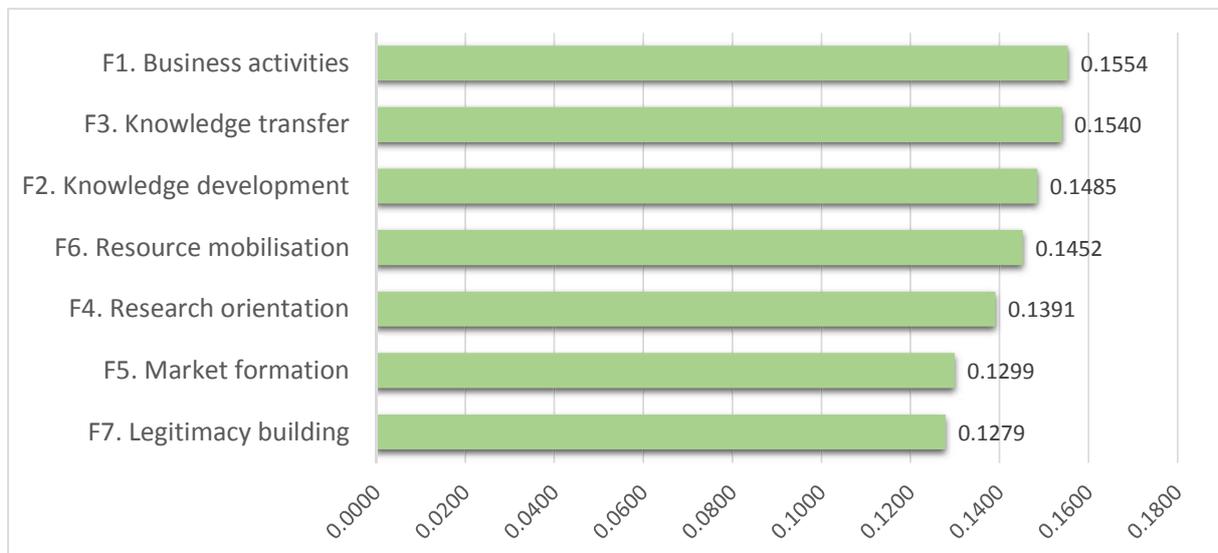
393

394 The highest local priority was given to "Business activities" (F1), with an average score for all
395 expert groups of 0.1554 (Figure 4). This high priority suggests that stakeholders consider the
396 involvement and interactions of various companies, their entrepreneurial initiatives and their
397 willingness to experiment and implement prototypes to be paramount for DT. In addition, its
398 subfunction related to the availability of technology options is also seen as critical, highlighting the
399 essential role of technology and business in driving DT. "Knowledge transfer" (F3) is rated as the second
400 most important function of the TIS, with a score of 0.1540.

401

402

Figure 4. Local priorities of functions ($\omega_{L(f/G)}$) (average)



403

404

405 In contrast, the function "Legitimacy building" (F7) received the lowest local priority with a
406 score of 0.1279. This suggests that, although stakeholders recognise the importance of willingness to
407 adopt digital technologies, coordination of actors and established rules and regulations, these aspects
408 might not be seen as immediate priorities compared to the more tangible aspects related to business
409 activities, knowledge development and transfer.

410 The functions "Knowledge development" (F2) and "Knowledge transfer" (F3) were assigned
411 similar local priorities, 0.1485 and 0.1540 respectively, indicating that these two areas are perceived as
412 similarly important for the DT of the olive sector. This result underlines the importance of not only
413 generating sufficient and high-quality knowledge, but also ensuring its efficient and effective transfer
414 between the different actors in the system.

415

416 *b) Groups assessment*

417

418 The results of the analysis of the local priorities of the different functions among the different
419 expert groups are presented in detail in Annex III.A. As seen above, the highest local priority for the
420 average of groups is given to "F1. Business activities" (0.1554). The highest score is given to "Other
421 organisations" (0.1698), indicating a special focus on business activities within this group. However, it
422 should be noted that this function is consistently rated with a high priority by all expert groups,
423 indicating a broad consensus on its importance.

424 On the other hand, "F7. Legitimacy building" (0.1279) and "F5. Market formation" (0.1299)
425 were identified as the least important functions on average across all expert groups. The lowest scores
426 for "F7. Legitimacy building" came from "Other organisations" (0.1061) and "Agri-food companies"
427 (0.1123), possibly indicating that these groups see less need for consensus building and agreement on
428 the digitalisation process among the different stakeholders within the TIS. However, it is crucial to note
429 that "Public administration" assigns relatively high importance to these functions, in particular "F7.
430 Legitimacy building" (0.1429) and "F5. Market formation" (0.1428). This suggests a different
431 perspective of the public administration, which seems to understand the relevance of market
432 formation and the establishment of legitimacy for the success of the TIS in the digitalisation of the
433 Andalusian olive sector.

434 In contrast, "F4. Research orientation" received a high local priority from "Agri-food
435 companies" (0.1563) and a low local priority from "Digital technology companies" (0.1247), suggesting
436 different views on the role of research in digitalisation. Agri-food companies might perceive research
437 activities as vital to generate new digital innovations, while other sectors, such as digital technology
438 companies, might place more emphasis on the application and adaptation of existing technologies,
439 thus attributing less priority to research.

440

441 4.1.3 Global priorities of subfunctions

442

443 The assessment of the global priorities of the subfunctions (for the average of groups) allows
444 an understanding of how each subfunction contributes to the global performance of the TIS for the DT
445 of the olive sector in Andalusia. All subfunctions can then be compared in terms of their global
446 priorities, and not only those of the same function in terms of local priorities. "The size of the potential
447 market for digital technologies in the Andalusian olive sector is sufficient" (SF5.b) received the highest
448 global priority (0.0376) (Figure 5). This underlines the importance that stakeholders give to the size of

449 the potential market for DT, and indicates a recognition that a large potential market can provide
450 significant opportunities for the DT of the olive sector.

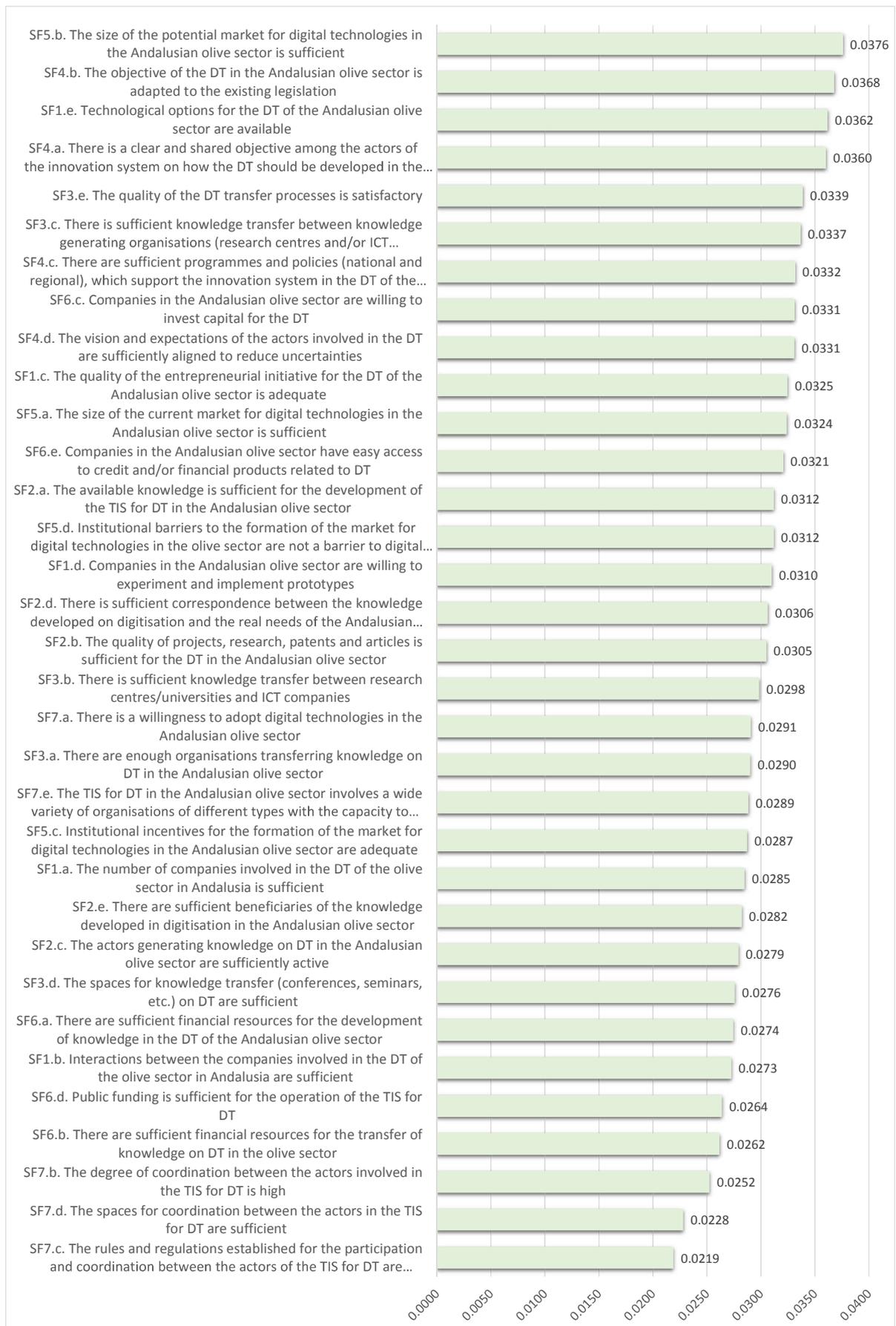
451 It is worth noting that the subfunctions with the highest global priorities belong to different
452 functions, namely "Market formation" (F5), as already mentioned, "Research orientation" (F4) and
453 "Business activities" (F1). "The objective of the DT in the Andalusian olive sector is adapted to the
454 existing legislation" (SF4.b) received a remarkably high global priority (0.0368). This shows the
455 importance that actors give to the adequacy of the objectives of the DT to existing legislation,
456 suggesting a recognition of the influence that regulatory frameworks can exert on the success of
457 innovation systems. On the other hand, "Technological options for the DT of the Andalusian olive sector
458 are available" (SF1.e) received a considerable high global priority (0.0362), highlighting the perceived
459 relevance of having a variety of technological options for companies participating in DT.

460 In contrast, "The rules and regulations established for the participation and coordination
461 between the actors of the TIS for DT are sufficient" (SF7.c) and "The spaces for coordination between
462 the actors in the TIS for DT are sufficient" (SF7.d) received the lowest global priorities of 0.0219 and
463 0.0228, respectively.

464

465

Figure 5. Global priorities of subfunctions ($\omega_{G(sf/G)}$) (average)



468 **4.2 Performance of the TIS**

469

470 This section presents the performance of the TIS for the DT of the olive sector in Andalusia in
471 subfunctions, functions and globally. These results provide a detailed assessment of the performance
472 of the TIS at different levels, highlighting the areas where the system is functioning properly and where
473 there are opportunities for improvement to facilitate the DT.

474

475 4.2.1 Performance of the TIS in subfunctions

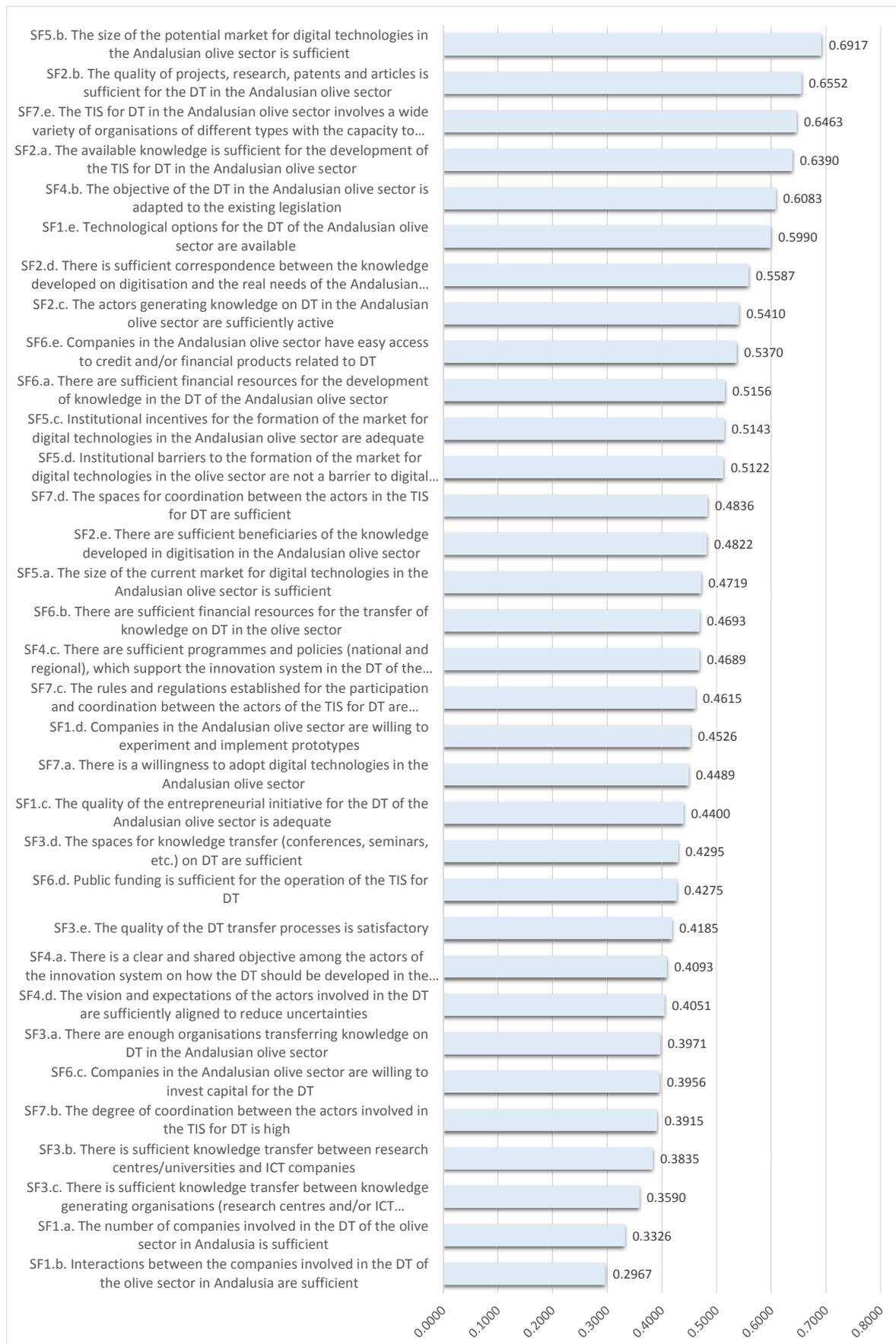
476

477 At the level of subfunctions, the highest TIS performance was observed in "The size of the
478 potential market for digital technologies in the Andalusian olive sector is sufficient" (SF5.b) with a
479 performance value of 0.6917 (Figure 6). This implies that experts consider the existing potential market
480 for digital technologies in this sector to be adequate, potentially meaning high levels of interest and
481 investment. The second highest performance of the TIS was given to "The quality of projects, research,
482 patents and articles is sufficient for the DT in the Andalusian olive sector" (SF2.b) with a value of
483 0.6552. This high performance indicates that the quality of existing research is perceived as
484 satisfactory, suggesting strong academic and intellectual property support for DT in the sector.

485 At the other end of the spectrum, the subfunction with the lowest TIS performance was
486 "Interactions between the companies involved in the DT of the olive sector in Andalusia are sufficient"
487 (SF1.b) with 0.2967. This indicates a perceived deficiency in the quality and frequency of interactions
488 between the companies involved in the DT, which could potentially be a limiting factor. The next lowest
489 performing local subfunction of the TIS is "The number of companies involved in the DT of the olive
490 sector in Andalusia is sufficient" (SF1.a) with a score of 0.3326. This may indicate that there is a lack of
491 involvement of companies in the process of DT of the olive sector in Andalusia. This could be due to
492 various reasons, such as lack of awareness or understanding of the potential benefits of digital
493 technologies, financial constraints or perceived lack of relevance or applicability of such technologies
494 to their operations.

495

Figure 6. Performance of the TIS in subfunctions ($P_{TIS(sf)}$) (average)



498 4.2.2 Performance of the TIS in functions

499

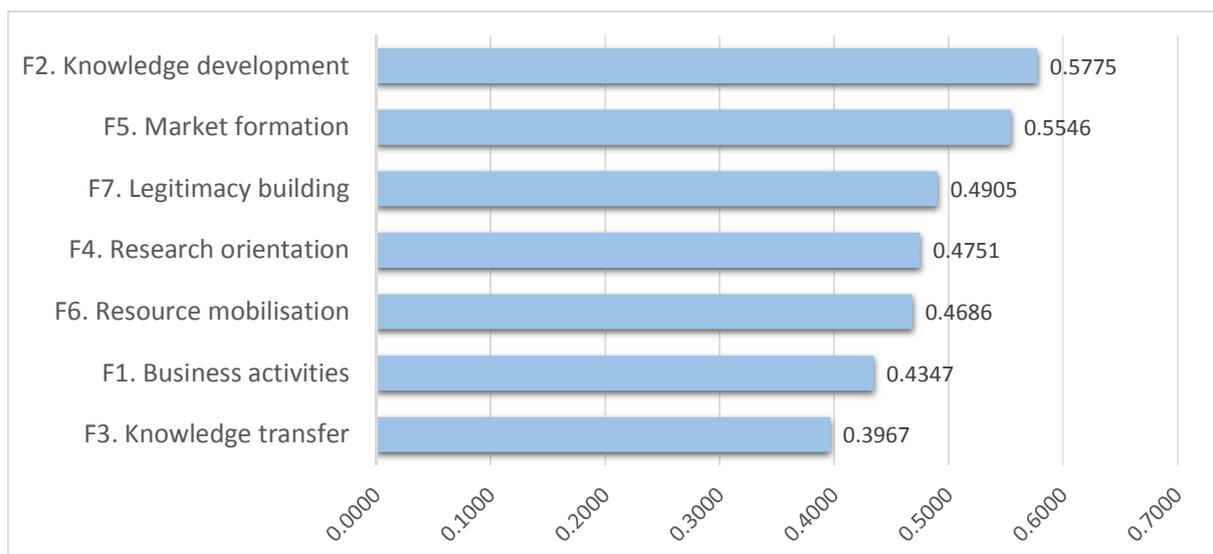
500 a) Average assessment

501

502 When examining the performance of the TIS at function level, it can be seen how each key
503 function of the TIS contributes to the global system's performance in fostering DT in the Andalusian
504 olive sector. The function with the highest performance of the TIS is "Knowledge development" (F2)
505 with a performance value of 0.5775 (Figure 7). This suggests that the Andalusian olive sector is
506 competently generating and fostering relevant knowledge and expertise, which is crucial to support
507 the evolution of DT efforts. The second highest performance is observed in "Market formation" (F5)
508 with a score of 0.5546. This indicates that the market for digital technologies in the Andalusian olive
509 sector is relatively well developed and favours the adoption and diffusion of DT.

510

511 **Figure 7. Performance of the TIS in functions ($P_{TIS(f)}$) (average)**



512

513

514 In contrast, the lowest performance is observed for the "Knowledge transfer" function (F3),
515 with a performance value of 0.3967. This points to possible shortcomings in the current mechanisms
516 and processes for disseminating and sharing knowledge relevant to DT. Such shortcomings could be a
517 major barrier to the effective implementation and scaling up of digital technologies in the sector.

518 Interestingly, in the function "Business activities" (F1), the TIS has a relatively low performance
519 of 0.4347, despite its great importance for DT (section 4.1.2). This may reflect the challenges in
520 achieving a strong level of involvement and commitment from companies in the sector, as well as
521 possible limitations in their willingness to experiment with and apply digital technologies.

522

523 *a) Groups assessment*

524

525 The results of the analysis of the TIS performance in the functions according to the expert
526 groups are presented in Annex III.C. The function "Knowledge Development" (F2) obtained the highest
527 average score of all expert groups, as shown above. This high valuation of their performance was
528 mainly due to the experts of "Digital technology companies" (0.7166), "Other organisations" (0.6362)
529 and "R&D Organisations" (0.6295), suggesting that these experts consider knowledge development for
530 the digitalisation of the olive sector in Andalusia to be highly effective.

531 On the other hand, the function "Knowledge Transfer" (F3) showed the lowest average score,
532 being the worst rated function by all expert groups, with the lowest score assigned by "Agri-food
533 companies" (0.3369) and "Public administration" (0.3646), showing the greatest concern regarding the
534 current state of knowledge transfer.

535 When looking at the expert groups individually, the scores provided by the "Digital technology
536 companies" consistently demonstrated a more optimistic view of the TIS performance across the
537 different functions, with scores typically above average. In contrast, the "Agri-food companies" group
538 was often the most critical, providing scores below average for most functions

539

540 4.2.3 Global performance of the TIS

541

542 The average performance of the TIS in achieving its goal was assessed as moderate (0.4833)
543 (Figure 8). The variations in the assessments of the different expert groups suggest varying
544 perspectives on the effectiveness of the TIS in achieving its objective of improving the DT of the olive
545 sector in Andalusia. The highest rating was provided by "Digital technology companies" (0.5482),
546 implying that these entities perceive the TIS to be reasonably effective in achieving its objective. One
547 possible interpretation of this result could be that digital technology companies have a more optimistic
548 view of the digitalisation process, possibly due to their direct involvement in facilitating this
549 transformation. In contrast, the lowest score comes from "R&D organisations" (0.3804). This lowest
550 rating suggests that R&D organisations may perceive significant shortcomings in the performance of
551 the TIS, which could reflect the challenges they face in translating their research results into real-world
552 applications.

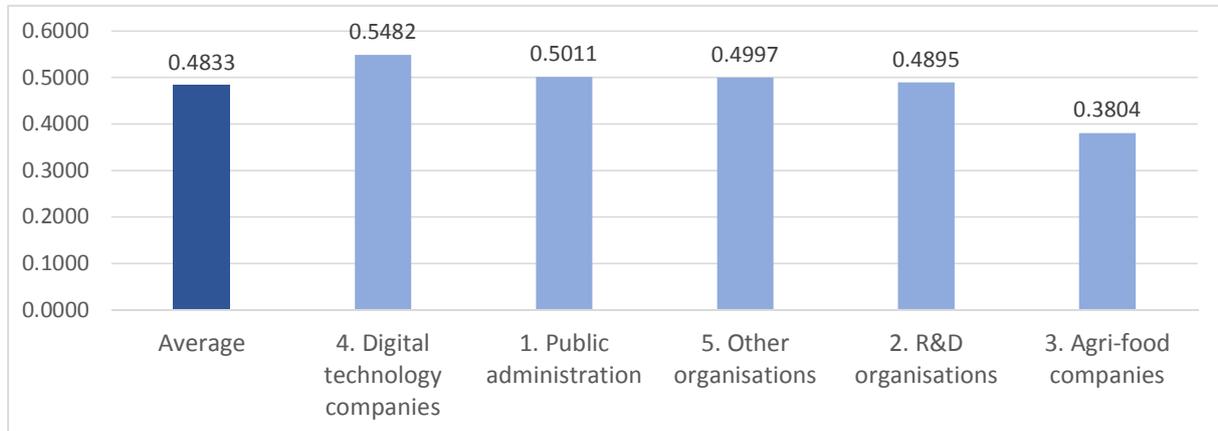
553 On the other hand, "Public administration" (0.5011), "Other organisations" (0.4997) and "Agri-
554 food companies" (0.4895) rated the performance as relatively close to the average, reflecting a more
555 balanced view. The relatively high score given by the public administration could be due to its
556 perspective on the efforts and strategies implemented to achieve the TIS goal. Overall, the variability

557 of performance scores across expert groups highlights the importance of understanding the unique
558 views of different stakeholders in the innovation system.

559

560

Figure 8. Global performance of the TIS ($P_{TIS(G)}$) (average and by expert groups)



561

562

563 **4.3 Critical functions and subfunctions of the TIS**

564

565 4.3.1 Critical subfunctions of the TIS

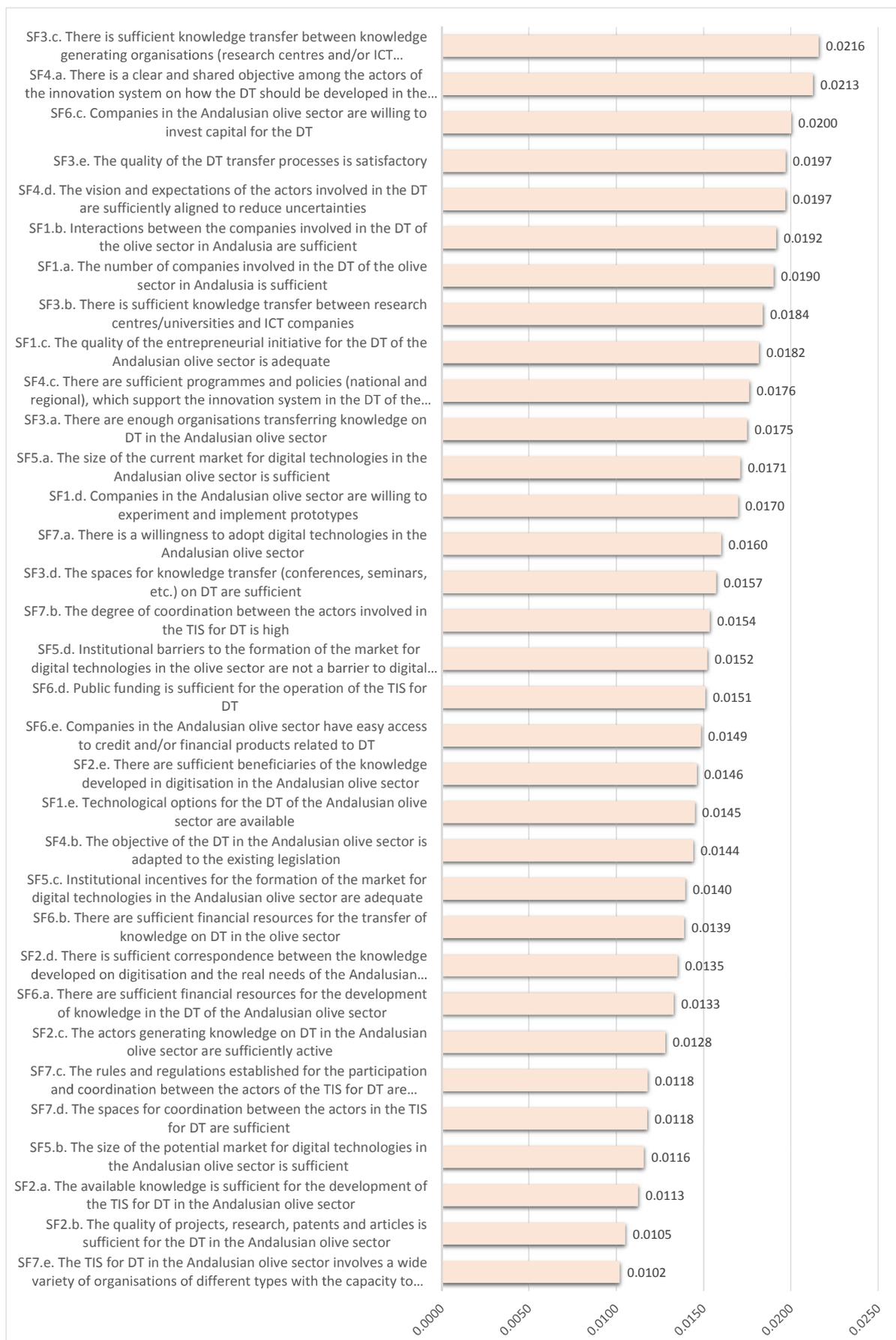
566

567 An examination of the Criticality Index (CI) for the different subfunctions of the TIS provides a
568 granular view of the specific areas that may require specific intervention to improve the effectiveness
569 of DT in the Andalusian olive sector. Thus, the most critical subfunction is "There is sufficient
570 knowledge transfer between knowledge generating organisations (research centres and/or ICT
571 companies) and end users (agri-food companies)" (SF3.c) with a CI of 0.0216 (Figure 9). This implies
572 that the promotion of solid channels of communication and collaboration between research
573 organisations, ICT companies and agri-food companies is fundamental to achieve successful DT in the
574 Andalusian olive sector.

575 The second highest CI is that of "There is a clear and shared objective among the actors of the
576 innovation system on how the DT should be developed in the Andalusian olive sector" (SF4.a), with a
577 CI of 0.0213. This points out the need to improve the shared vision of all stakeholders, an aspect that
578 could play an important role in coordinating efforts and managing uncertainties along the DT path.

579

Figure 9. Critical subfunctions ($CI_{(sf)}$) (average)



582 4.3.2 Critical functions of the TIS

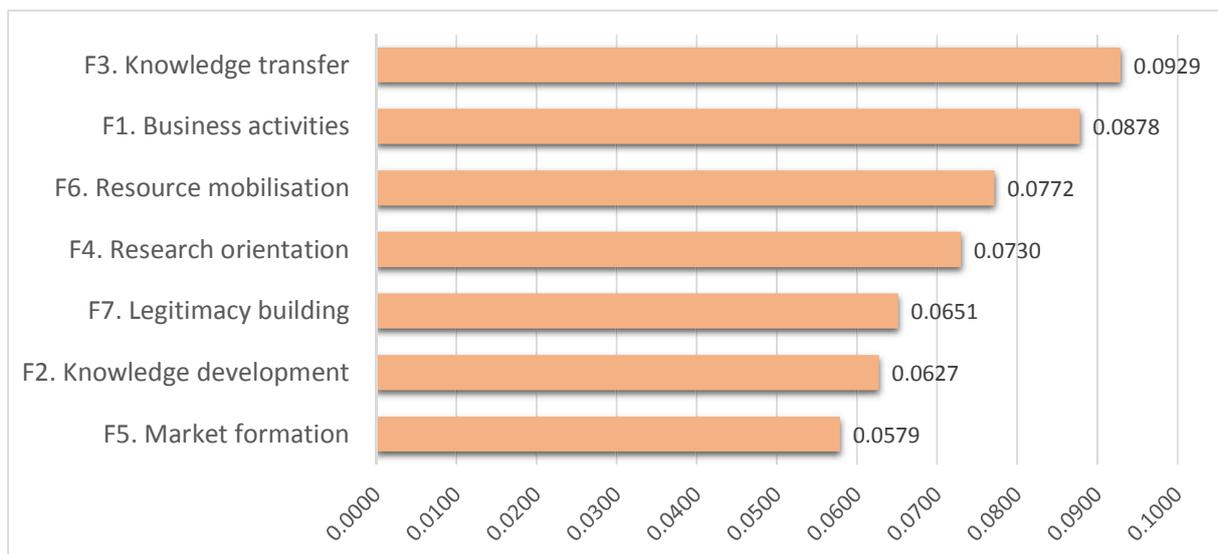
583

584 The most critical function is "Knowledge transfer" (F3), with a CI of 0.0929 (Figure 10). This
585 high CI underlines its central role in the system, suggesting that a more effective dissemination of
586 knowledge about digital technologies among the different actors in the sector is critical for the success
587 of the DT initiative, as well as highlighting the currently low performance of such knowledge transfer.
588 The second most critical function is "Business activities" (F1), with a CI of 0.0878. This highlights the
589 crucial role of entrepreneurial initiatives, collaboration between firms and their willingness to
590 experiment with new technologies. The high criticality of this function shows that entrepreneurial
591 activities need to be improved in order to foster successful DT within the Andalusian olive sector.

592

593

Figure 10. Critical functions ($CI_{(f)}$) (average)



594

595

596 **5 Policy implications**

597

598 Based on the analysis set out in the results section, some key policy recommendations have
599 been established to address the challenges identified in the context of the DT of the Andalusian olive
600 sector. These recommendations are specifically designed to address the socio-economic and
601 technological realities of the Andalusian olive sector. These policy recommendations can serve as a
602 roadmap towards achieving DT, increasing competitiveness and ensuring long-term sustainability.

603 Firstly, a "Knowledge transfer improvement policy" emerges as an overriding need, mainly due
604 to the critical role played by the "Knowledge transfer" function (F3) in the DT process. Despite its
605 importance, the performance of the TIS in this area is insufficient, implying an urgent need for

606 interventions. This policy should aim at fostering interaction between research centres, ICT companies
607 and end-users (SF3.c), which has been identified as the most critical subfunction. By strengthening
608 these interactions, existing knowledge can be used more efficiently, accelerating the DT process.

609 Secondly, a “Business activity stimulation policy” is recommended due to the high priority and
610 low performance of the function "Business activities" (F1). This policy should especially work to
611 enhance interactions between the enterprises involved in the DT (SF1.b), which is of vital importance
612 given the high prevalence of small and family farms and enterprises in the region, and the overall need
613 for greater professionalisation of the sector.

614 Thirdly, the introduction of a “Resource mobilisation policy” is suggested, taking into account
615 the relatively low performance and high priority of the "Resource mobilisation" function (F6). Such a
616 policy could motivate companies in the olive sector to invest capital in DT (SF6.c), especially important
617 in the light of rising production costs and the increasing global competition faced by the Andalusian
618 olive sector.

619 The fourth policy suggestion revolves around a “Research orientation alignment policy” in light
620 of the criticality of "Research orientation" (F4). This policy should focus on establishing a clear and
621 shared objective for DT within the Andalusian olive sector (SF4.a), thus creating a coordinated
622 approach to DT, reducing wasted efforts and maximising synergies.

623 As a fifth policy recommendation, a “Legitimacy building policy” is proposed, especially aimed
624 at boosting the readiness to adopt digital technologies in the Andalusian olive sector (SF7.a). Although
625 the TIS performs relatively well in the "Legitimacy building" function (F7), the willingness to adopt new
626 technologies can directly impact the pace and extent of DT.

627 The sixth suggestion is a “Knowledge development policy" focused on connecting the
628 knowledge developed on digitalisation with the real needs of the Andalusian olive sector (F2.d). This
629 policy can guarantee the existence of adequate knowledge to support the ongoing DT process, allowing
630 it to develop smoothly and efficiently, which is crucial given the lack of innovation detected among
631 farmers in the region.

632 Finally, a “Market formation policy” should be considered, focusing on ensuring a sufficient
633 market size for digital technologies in the Andalusian olive sector (SF5.a). Although the TIS function
634 performs well in the "Market formation" (F5) function, a policy that encourages further market
635 expansion could provide a broader platform for new technologies and stimulate more DT. This is
636 particularly relevant given the region's potential to leverage its leadership in global olive production to
637 pioneer DT in the sector.

638
639

640 **6 Discussion**

641

642 **6.1 Methodological framework: Conceptual approach, strengths and limitations**

643

644 The present research on the DT of the agricultural sector proposes and applies a quantitative
645 methodological framework for the analysis of TIS grounded in a functionalist perspective. This
646 conceptual approach can enrich and complement the existing literature which predominantly applies
647 a structural approach [30, 34, 107], by offering integrated understanding of the functioning of TIS [30,
648 32]

649 Furthermore, this research uses a quantitative approach as opposed to the prevalent
650 qualitative approach traditionally adopted in structural/functionalist studies of TIS [35, 37, 42, 43]. The
651 TIS framework enabled a comprehensive understanding of the innovation system and its functions,
652 while the AHP added precision to this understanding by quantifying expert/stakeholder judgements
653 and preferences. The combined approach allowed for an objective, rigorous and reproducible
654 quantitative assessment of the TIS performance at the levels of subfunctions, functions and the overall
655 system. An interesting finding was the variation observed in the experts' ratings, which shows the
656 diversity of perceptions and priorities among the different groups. This, in turn, underlines the complex
657 and multidimensional nature of DT in the sector and the need for policies that can accommodate such
658 diversity.

659 However, the proposed methodological framework has certain limitations that need to be
660 taken into account. A fundamental limitation is that this model does not take into account the
661 interactions between functions and between subfunctions, which could have an impact on the
662 assessment of the TIS performance [32]. Analysis of functions and their interactions can inform policy
663 by identifying mutually reinforcing functions that accelerate progress, as well as missing functions that
664 hinder innovation [30]. In this context, the integration of the Analytic Network Process (ANP) into the
665 methodological framework could improve its ability to account for such dependencies [52]. Another
666 possible limitation is the static nature of the TIS analysis. Given the inherent dynamic nature of TIS,
667 this approach does not capture how the performance of different functions may change over time. A
668 process approach or sequence analysis, based on a longitudinal analysis of the TIS at different points
669 in time, could provide a more detailed understanding of the evolution of the system and the
670 effectiveness of various policy interventions [32].

671

672

673

674 **6.2 Empirical results: Validation of findings and implications for the wider context**

675

676 The results obtained are in general in line with the observations of Parra-López, Reina-Usuga,
677 Carmona-Torres, Sayadi and Klerkx [11] and Reina-Usuga, Parra-López and Carmona-Torres [51], who
678 observed a similar trend in their studies on innovation capabilities and opportunities for DT in the
679 Andalusian olive sector. These previous studies are less comprehensive and complete than the current
680 research, as previously discussed. In particular, they emphasised the potential of digitalisation in the
681 olive sector. This corroborates the findings of Hrustek [108], Rijswijk, Klerkx, Bacco, Bartolini, Bulten,
682 Debruyne, Dessen, Scotti and Brunori [10], and Mohr and Höhler [12], among others, who identified
683 DT as a crucial opportunity for agriculture. Given the characteristic context of the Andalusian olive
684 sector, it should be noted that the technological capabilities, socio-economic dynamics and traditional
685 farming methods present unique opportunities and challenges for DT. For example, the prevalence of
686 small farms and family enterprises can pose challenges for DT, as noted by Parra-López, Reina-Usuga,
687 Carmona-Torres, Sayadi and Klerkx [11]. However, this could also encourage the development of tailor-
688 made digital solutions that address these specific circumstances. Similarly, the wide geographic
689 distribution of olive growing in Andalusia and the resulting logistical challenges lend themselves to the
690 implementation of digital solutions, such as remote sensing and digital supply chain management [71,
691 72, 109].

692 In contrast to previous research highlighting a generally low innovative attitude among olive
693 growers in Andalusia [89-94], this research identified promising signals of openness to technological
694 innovation, especially in relation to DT. The results show that agri-food companies in the region are
695 recognising the indispensability of research activities for the creation of new digital innovations, while
696 expressing deep concern about the current state of knowledge transfer. This demonstrates an
697 increased awareness of and commitment to the innovation process in the olive sector. This divergence
698 could indicate a positive change in attitudes towards innovation within the Andalusian olive sector,
699 potentially due to increased EU, national and regional support for digitalisation [11].

700 On a broader scale, the results and their resulting policy recommendations have significant
701 implications for the DT of agriculture. The successful implementation of digital technologies in the
702 Andalusian olive sector can serve as a model for other agricultural sectors, especially those with similar
703 characteristics that share climate, economic and cultural importance, and rely on traditional
704 agriculture, have similar landscapes and socio-economic structures. By shedding light on the
705 mechanisms of DT in this context, the results provide practical ideas for advancing digitalisation across
706 the agricultural sector, a perspective echoed in the work by Rijswijk, Klerkx, Bacco, Bartolini, Bulten,
707 Debruyne, Dessen, Scotti and Brunori [10].

708

709 7 Conclusions

710

711 This study aimed to provide a methodological framework for the functional analysis of
712 Technological Innovation Systems (TIS) based on the Analytic Hierarchy Process (AHP), and to illustrate
713 the application of this framework to the case of the TIS for the digital transformation (DT) of the olive
714 sector in Andalusia, the world's leading olive-growing region.

715 By employing a functionalist perspective and using AHP for quantitative assessment, this study
716 adds value to the literature on TIS for DT in agriculture. It provided an innovative methodological
717 approach, offering a replicable and quantitative tool for assessing the performance of a TIS at both
718 function/subfunctions and system level. In doing so, this work contributes to the existing literature on
719 TIS, which predominantly employs structural and qualitative approaches. The methodological
720 framework could be adapted to various contexts and regions.

721 Furthermore, this study offers valuable insights for stakeholders ranging from researchers to
722 policy makers and agricultural practitioners. The case study illustrated a practical application of the
723 framework and offers contextual insights for the design of public policies to foster DT in the region and
724 beyond. The analysis revealed several critical areas in the functioning of the TIS for the DT of the
725 Andalusian olive sector, such as knowledge transfer, business activities and resource mobilisation.
726 Meanwhile, strengths were identified in market formation and knowledge development. Based on
727 these findings, a set of policy recommendations was developed that provide a roadmap for improving
728 the functioning of the TIS and strengthening DT within this vital agricultural sector. The variation in
729 expert assessments highlights the diversity of views and priorities, emphasising the complexity and
730 multi-faceted nature of DT in the sector, which requires inclusive policies. Practical ideas for
731 policymaking can be relevant to a wide range of stakeholders in diverse fields and regions. As the DT
732 of the agricultural sector continues to evolve, this research can help guide these developments
733 towards innovation and sustainability.

734 Looking ahead, there are several potential lines of research. While the quantitative and
735 functionalist approach used offers a perspective to explore the DT of the agricultural sector, its
736 limitations highlight the need for continued methodological development in this field. The use of other
737 MCDA techniques, such as the Analytic Network Process (ANP), could complement the current
738 methodological framework by taking into account cross-functional and sub-functional relationships. A
739 process approach or sequence analysis could provide a deeper understanding of the evolution of the
740 system and the effectiveness of policy interventions over time. Furthermore, a complementary and
741 comprehensive structural analysis of the TIS for the DT of the Andalusian olive sector, in addition to
742 the functional analysis offered here, could provide a holistic understanding of the system and of DT in
743 the olive sector.

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1031 ANNEXES

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1033 **Annex I. Performance of the technological innovation system for the digital transformation of the olive sector in Andalusia (Questionnaire)**

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1035 Seven functions, and several subfunctions within each function, were identified as the most important to determine the performance of the technological innovation system (TIS) for the digital transformation (DT) of the olive sector in Andalusia. Please rate them according to your knowledge:

- 1036 • In the first column, your degree of agreement with each of the statements corresponding to the subfunctions mentioned (1.a, 1.b, etc.) for the case of the TIS for the DT of the Andalusian olive sector, on a scale of 1 to 9 (where 1: very little agreement; and 9: total agreement).
- 1037 • In the second column, the relative importance of each of the subfunctions for the proper functioning of the function to which they belong, on a scale of 1 to 9 (where 1: very low importance; and 9: very high importance).
- 1038 • And in the third column, the relative importance of each of the 7 functions for the correct functioning of the TIS for the DT of the Andalusian olive sector, on a scale of 1 to 9 (1: very low importance; and 9: very high importance).

	Degree of agreement with the subfunctions of the system (1-9)	Relative importance of subfunctions of the system (1-9)	Relative importance of system functions (1-9)
F1. Business activities			
SF1.a. The number of companies involved in the DT of the olive sector in Andalusia is sufficient			
SF1.b. Interactions between the companies involved in the DT of the olive sector in Andalusia are sufficient			
SF1.c. The quality of the entrepreneurial initiative for the DT of the Andalusian olive sector is adequate			
SF1.d. Companies in the Andalusian olive sector are willing to experiment and implement prototypes			
SF1.e. Technological options for the DT of the Andalusian olive sector are available			

F2. Knowledge development		
SF2.a.	The available knowledge is sufficient for the development of the TIS for DT in the Andalusian olive sector	
SF2.b.	The quality of projects, research, patents and articles is sufficient for the DT in the Andalusian olive sector	
SF2.c.	The actors generating knowledge on DT in the Andalusian olive sector are sufficiently active	
SF2.d.	There is sufficient correspondence between the knowledge developed on digitalisation and the real needs of the Andalusian olive sector	
SF2.e.	There are sufficient beneficiaries of the knowledge developed in digitalisation in the Andalusian olive sector	
F3. Knowledge transfer		
SF3.a.	There are enough organisations transferring knowledge on DT in the Andalusian olive sector	
SF3.b.	There is sufficient knowledge transfer between research centres/universities and ICT companies	
SF3.c.	There is sufficient knowledge transfer between knowledge generating organisations (research centres and/or ICT companies) and end users (agri-food companies)	
SF3.d.	The spaces for knowledge transfer (conferences, seminars, etc.) on DT are sufficient	
SF3.e.	The quality of the DT transfer processes is satisfactory	
F4. Research orientation		
SF4.a.	There is a clear and shared objective among the actors of the innovation system on how the DT should be developed in the Andalusian olive sector	
SF4.b.	The objective of the DT in the Andalusian olive sector is adapted to the existing legislation	
SF4.c.	There are sufficient programmes and policies (national and regional), which support the innovation system in the DT of the Andalusian olive sector	
SF4.d.	The vision and expectations of the actors involved in the DT are sufficiently aligned to reduce uncertainties	
F5. Market formation		
SF5.a.	The size of the current market for digital technologies in the Andalusian olive sector is sufficient	
SF5.b.	The size of the potential market for digital technologies in the Andalusian olive sector is sufficient	
SF5.c.	Institutional incentives for the formation of the market for digital technologies in the Andalusian olive sector are adequate	
SF5.d.	Institutional barriers to the formation of the market for digital technologies in the olive sector are not a barrier to digital transformation	
F6. Resource mobilisation		

SF6.a. There are sufficient financial resources for the development of knowledge in the DT of the Andalusian olive sector		
SF6.b. There are sufficient financial resources for the transfer of knowledge on DT in the olive sector		
SF6.c. Companies in the Andalusian olive sector are willing to invest capital for the DT		
SF6.d. Public funding is sufficient for the operation of the TIS for DT		
SF6.e. Companies in the Andalusian olive sector have easy access to credit and/or financial products related to DT		
F7. Legitimacy building		
SF7.a. There is a willingness to adopt digital technologies in the Andalusian olive sector		
SF7.b. The degree of coordination between the actors involved in the TIS for DT is high		
SF7.c. The rules and regulations established for the participation and coordination between the actors of the TIS for DT are sufficient		
SF7.d. The spaces for coordination between the actors in the TIS for DT are sufficient		
SF7.e. The TIS for DT in the Andalusian olive sector involves a wide variety of organisations of different types with the capacity to generate/apply innovations		

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1044 Could you give us your general opinion on the functioning of the DT innovation system in the Andalusian olive sector (opportunities, barriers and/or future perspectives)?

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Annex II. Priorities of functions/subfunctions and performance of the TIS for the DT of the olive sector in Andalusia (average)

AHP elements (goal, functions and subfunctions)	Local priorities of functions/subfunctions (ω_l)			Global priorities of functions/subfunctions (ω_g)			Performance of the TIS (P_{TIS})			Criticality Index of functions/subfunctions (CI)		
	Level I	Level II	Level III	Level I	Level II	Level III	Level I	Level II	Level III	Level I	Level II	Level III
	Level I (Goal)			Level II (Functions)			Level III (Subfunctions)			-		
	1.000	1.000	1.000	1.000	1.000	1.000	0.4833	0.4347	0.0878	0.190	0.0192	0.0182
Goal	1.000	1.000	1.000	0.1554	0.1554	0.1554	0.1554	0.1554	0.1554	0.4347	0.0878	0.0190
F1. Business activities												
SF1.a. The number of companies involved in the DT of the olive sector in Andalusia is sufficient				0.1833	0.0285	0.0285	0.0285	0.0285	0.0285	0.3326	0.0190	0.0190
SF1.b. Interactions between the companies involved in the DT of the olive sector in Andalusia are sufficient				0.1754	0.0273	0.0273	0.0273	0.0273	0.0273	0.2967	0.0192	0.0192
SF1.c. The quality of the entrepreneurial initiative for the DT of the Andalusian olive sector is adequate				0.2089	0.0325	0.0325	0.0325	0.0325	0.0325	0.4400	0.0182	0.0182
SF1.d. Companies in the Andalusian olive sector are willing to experiment and implement prototypes				0.1996	0.0310	0.0310	0.0310	0.0310	0.0310	0.4526	0.0170	0.0170
SF1.e. Technological options for the DT of the Andalusian olive sector are available				0.2328	0.0362	0.0362	0.0362	0.0362	0.0362	0.5990	0.0145	0.0145
F2. Knowledge development				0.1485	0.1485	0.1485	0.1485	0.1485	0.1485	0.5775	0.0627	0.0627
SF2.a. The available knowledge is sufficient for the development of the TIS for DT in the Andalusian olive sector				0.2100	0.0312	0.0312	0.0312	0.0312	0.0312	0.6390	0.0113	0.0113
SF2.b. The quality of projects, research, patents and articles is sufficient for the DT in the Andalusian olive sector				0.2055	0.0305	0.0305	0.0305	0.0305	0.0305	0.6552	0.0105	0.0105
SF2.c. The actors generating knowledge on DT in the Andalusian olive sector are sufficiently active				0.1881	0.0279	0.0279	0.0279	0.0279	0.0279	0.5410	0.0128	0.0128
SF2.d. There is sufficient correspondence between the knowledge developed on digitalisation and the real needs of the Andalusian olive sector				0.2063	0.0306	0.0306	0.0306	0.0306	0.0306	0.5587	0.0135	0.0135
SF2.e. There are sufficient beneficiaries of the knowledge developed in digitalisation in the Andalusian olive sector				0.1901	0.0282	0.0282	0.0282	0.0282	0.0282	0.4822	0.0146	0.0146
F3. Knowledge transfer				0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.3967	0.0929	0.0929
SF3.a. There are enough organisations transferring knowledge on DT in the Andalusian olive sector				0.1884	0.0290	0.0290	0.0290	0.0290	0.0290	0.3971	0.0175	0.0175
SF3.b. There is sufficient knowledge transfer between research centres/universities and ICT companies				0.1938	0.0298	0.0298	0.0298	0.0298	0.0298	0.3835	0.0184	0.0184
SF3.c. There is sufficient knowledge transfer between knowledge generating organisations (research centres and/or ICT companies) and end users (agri-food companies)				0.2187	0.0337	0.0337	0.0337	0.0337	0.0337	0.3590	0.0216	0.0216
SF3.d. The spaces for knowledge transfer (conferences, seminars, etc.) on DT are sufficient				0.1791	0.0276	0.0276	0.0276	0.0276	0.0276	0.4295	0.0157	0.0157
SF3.e. The quality of the DT transfer processes is satisfactory				0.2200	0.0339	0.0339	0.0339	0.0339	0.0339	0.4185	0.0197	0.0197

F4. Research orientation	0.1391	0.1391	0.4751	0.0730
SF4.a. There is a clear and shared objective among the actors of the innovation system on how the DT should be developed in the Andalusian olive sector	0.2590	0.0360	0.4093	0.0213
SF4.b. The objective of the DT in the Andalusian olive sector is adapted to the existing legislation	0.2645	0.0368	0.6083	0.0144
SF4.c. There are sufficient programmes and policies (national and regional), which support the innovation system in the DT of the Andalusian olive sector	0.2385	0.0332	0.4689	0.0176
SF4.d. The vision and expectations of the actors involved in the DT are sufficiently aligned to reduce uncertainties	0.2380	0.0331	0.4051	0.0197
F5. Market formation	0.1299	0.1299	0.5546	0.0579
SF5.a. The size of the current market for digital technologies in the Andalusian olive sector is sufficient	0.2494	0.0324	0.4719	0.0171
SF5.b. The size of the potential market for digital technologies in the Andalusian olive sector is sufficient	0.2894	0.0376	0.6917	0.0116
SF5.c. Institutional incentives for the formation of the market for digital technologies in the Andalusian olive sector are adequate	0.2212	0.0287	0.5143	0.0140
SF5.d. Institutional barriers to the formation of the market for digital technologies in the olive sector are not a barrier to digital transformation	0.2401	0.0312	0.5122	0.0152
F6. Resource mobilisation	0.1452	0.1452	0.4686	0.0772
SF6.a. There are sufficient financial resources for the development of knowledge in the DT of the Andalusian olive sector	0.1890	0.0274	0.5156	0.0133
SF6.b. There are sufficient financial resources for the transfer of knowledge on DT in the olive sector	0.1802	0.0262	0.4693	0.0139
SF6.c. Companies in the Andalusian olive sector are willing to invest capital for the DT	0.2281	0.0331	0.3956	0.0200
SF6.d. Public funding is sufficient for the operation of the TIS for DT	0.1818	0.0264	0.4275	0.0151
SF6.e. Companies in the Andalusian olive sector have easy access to credit and/or financial products related to DT	0.2209	0.0321	0.5370	0.0149
F7. Legitimacy building	0.1279	0.1279	0.4905	0.0651
SF7.a. There is a willingness to adopt digital technologies in the Andalusian olive sector	0.2273	0.0291	0.4489	0.0160
SF7.b. The degree of coordination between the actors involved in the TIS for DT is high	0.1974	0.0252	0.3915	0.0154
SF7.c. The rules and regulations established for the participation and coordination between the actors of the TIS for DT are sufficient	0.1713	0.0219	0.4615	0.0118
SF7.d. The spaces for coordination between the actors in the TIS for DT are sufficient	0.1784	0.0228	0.4836	0.0118
SF7.e. The TIS for DT in the Andalusian olive sector involves a wide variety of organisations of different types with the capacity to generate/apply innovations	0.2256	0.0289	0.6463	0.0102

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Annex III. Priorities of functions/subfunctions and performance of the TIS for the DT of the olive sector in Andalusia (by experts groups)

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A. Local priorities of functions/subfunctions (ω_i) (by experts groups)

Goal	Average	1. Public administration organisations	2. R&D organisations	3. Agri-food companies	4. Digital technology companies	5. Other organisations
F1. Business activities	0.1554	0.1464	0.1494	0.1517	0.1596	0.1698
SF1.a. The number of companies involved in the DT of the olive sector in Andalusia is sufficient	0.1833	0.1847	0.1972	0.1813	0.1821	0.1715
SF1.b. Interactions between the companies involved in the DT of the olive sector in Andalusia are sufficient	0.1754	0.1845	0.1770	0.1656	0.1589	0.1910
SF1.c. The quality of the entrepreneurial initiative for the DT of the Andalusian olive sector is adequate	0.2089	0.2012	0.1824	0.1997	0.2232	0.2379
SF1.d. Companies in the Andalusian olive sector are willing to experiment and implement prototypes	0.1996	0.2119	0.1763	0.2334	0.1947	0.1815
SF1.e. Technological options for the DT of the Andalusian olive sector are available	0.2328	0.2177	0.2671	0.2200	0.2411	0.2181
F2. Knowledge development	0.1485	0.1466	0.1444	0.1490	0.1493	0.1532
SF2.a. The available knowledge is sufficient for the development of the TIS for DT in the Andalusian olive sector	0.2100	0.1963	0.1877	0.2003	0.2362	0.2297
SF2.b. The quality of projects, research, patents and articles is sufficient for the DT in the Andalusian olive sector	0.2055	0.1836	0.2062	0.2167	0.2362	0.1847
SF2.c. The actors generating knowledge on DT in the Andalusian olive sector are sufficiently active	0.1881	0.2090	0.1918	0.1841	0.1688	0.1867
SF2.d. There is sufficient correspondence between the knowledge developed on digitalisation and the real needs of the Andalusian olive sector	0.2063	0.2090	0.2083	0.2064	0.1842	0.2235
SF2.e. There are sufficient beneficiaries of the knowledge developed in digitalisation in the Andalusian olive sector	0.1901	0.2021	0.2060	0.1926	0.1746	0.1754
F3. Knowledge transfer	0.1540	0.1502	0.1615	0.1518	0.1454	0.1612
SF3.a. There are enough organisations transferring knowledge on DT in the Andalusian olive sector	0.1884	0.1904	0.2043	0.1842	0.1950	0.1683
SF3.b. There is sufficient knowledge transfer between research centres/universities and ICT companies	0.1938	0.1959	0.2035	0.1624	0.1904	0.2167
SF3.c. There is sufficient knowledge transfer between knowledge generating organisations (research centres and/or ICT companies) and end users (agri-food companies)	0.2187	0.2081	0.2119	0.2209	0.2133	0.2395
SF3.d. The spaces for knowledge transfer (conferences, seminars, etc.) on DT are sufficient	0.1791	0.1856	0.1821	0.1691	0.1807	0.1779
SF3.e. The quality of the DT transfer processes is satisfactory	0.2200	0.2200	0.1982	0.2634	0.2206	0.1976

F4. Research orientation	0.1391	0.1318	0.1376	0.1563	0.1247	0.1450
SF4.a. There is a clear and shared objective among the actors of the innovation system on how the DT should be developed in the Andalusian olive sector	0.2590	0.2581	0.2373	0.2409	0.2473	0.3113
SF4.b. The objective of the DT in the Andalusian olive sector is adapted to the existing legislation	0.2645	0.2401	0.2801	0.2717	0.2780	0.2527
SF4.c. There are sufficient programmes and policies (national and regional), which support the innovation system in the DT of the Andalusian olive sector	0.2385	0.2731	0.2505	0.2396	0.2297	0.1999
SF4.d. The vision and expectations of the actors involved in the DT are sufficiently aligned to reduce uncertainties	0.2380	0.2287	0.2321	0.2479	0.2450	0.2361
F5. Market formation	0.1299	0.1428	0.1350	0.1164	0.1316	0.1238
SF5.a. The size of the current market for digital technologies in the Andalusian olive sector is sufficient	0.2494	0.2528	0.2347	0.2310	0.2483	0.2800
SF5.b. The size of the potential market for digital technologies in the Andalusian olive sector is sufficient	0.2894	0.2528	0.2888	0.2596	0.2621	0.3836
SF5.c. Institutional incentives for the formation of the market for digital technologies in the Andalusian olive sector are adequate	0.2212	0.2582	0.2300	0.2320	0.2211	0.1648
SF5.d. Institutional barriers to the formation of the market for digital technologies in the olive sector are not a barrier to digital transformation	0.2401	0.2363	0.2464	0.2774	0.2685	0.1716
F6. Resource mobilisation	0.1452	0.1393	0.1402	0.1625	0.1432	0.1409
SF6.a. There are sufficient financial resources for the development of knowledge in the DT of the Andalusian olive sector	0.1890	0.1803	0.2313	0.1945	0.1864	0.1525
SF6.b. There are sufficient financial resources for the transfer of knowledge on DT in the olive sector	0.1802	0.1956	0.1901	0.1697	0.1864	0.1594
SF6.c. Companies in the Andalusian olive sector are willing to invest capital for the DT	0.2281	0.2255	0.1806	0.2779	0.2271	0.2294
SF6.d. Public funding is sufficient for the operation of the TIS for DT	0.1818	0.2050	0.1924	0.1599	0.1829	0.1686
SF6.e. Companies in the Andalusian olive sector have easy access to credit and/or financial products related to DT	0.2209	0.1936	0.2056	0.1980	0.2173	0.2901
F7. Legitimacy building	0.1279	0.1429	0.1318	0.1123	0.1462	0.1061
SF7.a. There is a willingness to adopt digital technologies in the Andalusian olive sector	0.2273	0.2114	0.2186	0.2923	0.2141	0.1999
SF7.b. The degree of coordination between the actors involved in the TIS for DT is high	0.1974	0.1952	0.2160	0.1506	0.2071	0.2180
SF7.c. The rules and regulations established for the participation and coordination between the actors of the TIS for DT are sufficient	0.1713	0.1806	0.1670	0.1435	0.1873	0.1781
SF7.d. The spaces for coordination between the actors in the TIS for DT are sufficient	0.1784	0.1954	0.1669	0.1558	0.1809	0.1931
SF7.e. The TIS for DT in the Andalusian olive sector involves a wide variety of organisations of different types with the capacity to generate/apply innovations	0.2256	0.2174	0.2316	0.2577	0.2106	0.2109

B. Global priorities of functions/subfunctions (ω_{ϕ}) (by experts groups)

Goal	Average	1. Public administration	2. R&D organisations	3. Agri-food companies	4. Digital technology companies	5. Other organisations
F1. Business activities						
SF1.a. The number of companies involved in the DT of the olive sector in Andalusia is sufficient	0.0285	0.0270	0.0295	0.0275	0.0291	0.0291
SF1.b. Interactions between the companies involved in the DT of the olive sector in Andalusia are sufficient	0.0273	0.0270	0.0265	0.0251	0.0254	0.0324
SF1.c. The quality of the entrepreneurial initiative for the DT of the Andalusian olive sector is adequate	0.0325	0.0295	0.0273	0.0303	0.0356	0.0404
SF1.d. Companies in the Andalusian olive sector are willing to experiment and implement prototypes	0.0310	0.0310	0.0264	0.0354	0.0311	0.0308
SF1.e. Technological options for the DT of the Andalusian olive sector are available	0.0362	0.0319	0.0399	0.0334	0.0385	0.0370
F2. Knowledge development						
SF2.a. The available knowledge is sufficient for the development of the TIS for DT in the Andalusian olive sector	0.0312	0.0288	0.0271	0.0299	0.0353	0.0352
SF2.b. The quality of projects, research, patents and articles is sufficient for the DT in the Andalusian olive sector	0.0305	0.0269	0.0298	0.0323	0.0353	0.0283
SF2.c. The actors generating knowledge on DT in the Andalusian olive sector are sufficiently active	0.0279	0.0306	0.0277	0.0274	0.0252	0.0286
SF2.d. There is sufficient correspondence between the knowledge developed on digitalisation and the real needs of the Andalusian olive sector	0.0306	0.0306	0.0301	0.0308	0.0275	0.0342
SF2.e. There are sufficient beneficiaries of the knowledge developed in digitalisation in the Andalusian olive sector	0.0282	0.0296	0.0298	0.0287	0.0261	0.0269
F3. Knowledge transfer						
SF3.a. There are enough organisations transferring knowledge on DT in the Andalusian olive sector	0.0290	0.0286	0.0330	0.0279	0.0284	0.0271
SF3.b. There is sufficient knowledge transfer between research centres/universities and ICT companies	0.0298	0.0294	0.0329	0.0247	0.0277	0.0349
SF3.c. There is sufficient knowledge transfer between knowledge generating organisations (research centres and/or ICT companies) and end users (agri-food companies)	0.0337	0.0313	0.0342	0.0335	0.0310	0.0386
SF3.d. The spaces for knowledge transfer (conferences, seminars, etc.) on DT are sufficient	0.0276	0.0279	0.0294	0.0257	0.0263	0.0287
SF3.e. The quality of the DT transfer processes is satisfactory	0.0339	0.0331	0.0320	0.0400	0.0321	0.0319

F4. Research orientation							
SF4.a.	There is a clear and shared objective among the actors of the innovation system on how the DT should be developed in the Andalusian olive sector	0.0360	0.0340	0.0327	0.0376	0.0308	0.0452
SF4.b.	The objective of the DT in the Andalusian olive sector is adapted to the existing legislation	0.0368	0.0317	0.0385	0.0425	0.0347	0.0367
SF4.c.	There are sufficient programmes and policies (national and regional), which support the innovation system in the DT of the Andalusian olive sector	0.0332	0.0360	0.0345	0.0374	0.0286	0.0290
SF4.d.	The vision and expectations of the actors involved in the DT are sufficiently aligned to reduce uncertainties	0.0331	0.0302	0.0319	0.0387	0.0305	0.0343
F5. Market formation							
SF5.a.	The size of the current market for digital technologies in the Andalusian olive sector is sufficient	0.0324	0.0361	0.0317	0.0269	0.0327	0.0347
SF5.b.	The size of the potential market for digital technologies in the Andalusian olive sector is sufficient	0.0376	0.0361	0.0390	0.0302	0.0345	0.0475
SF5.c.	Institutional incentives for the formation of the market for digital technologies in the Andalusian olive sector are adequate	0.0287	0.0369	0.0311	0.0270	0.0291	0.0204
SF5.d.	Institutional barriers to the formation of the market for digital technologies in the olive sector are not a barrier to digital transformation	0.0312	0.0337	0.0333	0.0323	0.0353	0.0213
F6. Resource mobilisation							
SF6.a.	There are sufficient financial resources for the development of knowledge in the DT of the Andalusian olive sector	0.0274	0.0251	0.0324	0.0316	0.0267	0.0215
SF6.b.	There are sufficient financial resources for the transfer of knowledge on DT in the olive sector	0.0262	0.0272	0.0267	0.0276	0.0267	0.0225
SF6.c.	Companies in the Andalusian olive sector are willing to invest capital for the DT	0.0331	0.0314	0.0253	0.0452	0.0325	0.0323
SF6.d.	Public funding is sufficient for the operation of the TIS for DT	0.0264	0.0286	0.0270	0.0260	0.0262	0.0238
SF6.e.	Companies in the Andalusian olive sector have easy access to credit and/or financial products related to DT	0.0321	0.0270	0.0288	0.0322	0.0311	0.0409
F7. Legitimacy building							
SF7.a.	There is a willingness to adopt digital technologies in the Andalusian olive sector	0.0291	0.0302	0.0288	0.0328	0.0313	0.0212
SF7.b.	The degree of coordination between the actors involved in the TIS for DT is high	0.0252	0.0279	0.0285	0.0169	0.0303	0.0231
SF7.c.	The rules and regulations established for the participation and coordination between the actors of the TIS for DT are sufficient	0.0219	0.0258	0.0220	0.0161	0.0274	0.0189
SF7.d.	The spaces for coordination between the actors in the TIS for DT are sufficient	0.0228	0.0279	0.0220	0.0175	0.0264	0.0205
SF7.e.	The TIS for DT in the Andalusian olive sector involves a wide variety of organisations of different types with the capacity to generate/apply innovations	0.0289	0.0311	0.0305	0.0289	0.0308	0.0224

C. Performance of the TIS (P_{TIS}) (by experts groups)

	Average	1. Public administration	2. R&D organisations	3. Agri-food companies	4. Digital technology companies	5. Other organisations
Goal	0.4833	0.5011	0.4895	0.3804	0.5482	0.4997
F1. Business activities	0.4347	0.4891	0.4661	0.3813	0.5219	0.3279
SF1.a. The number of companies involved in the DT of the olive sector in Andalusia is sufficient	0.3326	0.2889	0.3077	0.3778	0.4000	0.2889
SF1.b. Interactions between the companies involved in the DT of the olive sector in Andalusia are sufficient	0.2967	0.3333	0.3056	0.2667	0.2667	0.3111
SF1.c. The quality of the entrepreneurial initiative for the DT of the Andalusian olive sector is adequate	0.4400	0.5778	0.4444	0.3333	0.5556	0.2889
SF1.d. Companies in the Andalusian olive sector are willing to experiment and implement prototypes	0.4526	0.5556	0.4630	0.4889	0.4889	0.2667
SF1.e. Technological options for the DT of the Andalusian olive sector are available	0.5990	0.6444	0.7063	0.4000	0.7778	0.4667
F2. Knowledge development	0.5775	0.5065	0.6295	0.4048	0.7166	0.6362
SF2.a. The available knowledge is sufficient for the development of the TIS for DT in the Andalusian olive sector	0.6390	0.5778	0.7063	0.3556	0.8444	0.7111
SF2.b. The quality of projects, research, patents and articles is sufficient for the DT in the Andalusian olive sector	0.6552	0.5111	0.6984	0.4444	0.8444	0.7778
SF2.c. The actors generating knowledge on DT in the Andalusian olive sector are sufficiently active	0.5410	0.4889	0.6825	0.4222	0.5556	0.5556
SF2.d. There is sufficient correspondence between the knowledge developed on digitalisation and the real needs of the Andalusian olive sector	0.5587	0.5778	0.5714	0.4000	0.6889	0.5556
SF2.e. There are sufficient beneficiaries of the knowledge developed in digitalisation in the Andalusian olive sector	0.4822	0.3778	0.5000	0.4000	0.5556	0.5778
F3. Knowledge transfer	0.3967	0.3646	0.4313	0.3369	0.4533	0.3970
SF3.a. There are enough organisations transferring knowledge on DT in the Andalusian olive sector	0.3971	0.3556	0.4524	0.3556	0.4444	0.3778
SF3.b. There is sufficient knowledge transfer between research centres/universities and ICT companies	0.3835	0.3111	0.4286	0.3778	0.3778	0.4222
SF3.c. There is sufficient knowledge transfer between knowledge generating organisations (research centres and/or ICT companies) and end users (agri-food companies)	0.3590	0.3111	0.3730	0.2889	0.4889	0.3333
SF3.d. The spaces for knowledge transfer (conferences, seminars, etc.) on DT are sufficient	0.4295	0.4222	0.4365	0.3111	0.5111	0.4667
SF3.e. The quality of the DT transfer processes is satisfactory	0.4185	0.4222	0.4701	0.3556	0.4444	0.4000

F4. Research orientation	0.4751	0.5409	0.4257	0.3437	0.5459	0.5303
SF4.a. There is a clear and shared objective among the actors of the innovation system on how the DT should be developed in the Andalusian olive sector	0.4093	0.5111	0.3131	0.2667	0.4667	0.4889
SF4.b. The objective of the DT in the Andalusian olive sector is adapted to the existing legislation	0.6083	0.6000	0.5139	0.5000	0.7333	0.6944
SF4.c. There are sufficient programmes and policies (national and regional), which support the innovation system in the DT of the Andalusian olive sector	0.4689	0.6444	0.4444	0.2778	0.4889	0.4889
SF4.d. The vision and expectations of the actors involved in the DT are sufficiently aligned to reduce uncertainties	0.4051	0.3889	0.4141	0.3111	0.4667	0.4444
F5. Market formation	0.5546	0.5550	0.5515	0.4344	0.6472	0.5741
SF5.a. The size of the current market for digital technologies in the Andalusian olive sector is sufficient	0.4719	0.5111	0.5152	0.4000	0.5111	0.4222
SF5.b. The size of the potential market for digital technologies in the Andalusian olive sector is sufficient	0.6917	0.6222	0.7475	0.6000	0.8000	0.6889
SF5.c. Institutional incentives for the formation of the market for digital technologies in the Andalusian olive sector are adequate	0.5143	0.5111	0.5051	0.3778	0.6222	0.5556
SF5.d. Institutional barriers to the formation of the market for digital technologies in the olive sector are not a barrier to digital transformation	0.5122	0.5778	0.4000	0.3556	0.6444	0.5833
F6. Resource mobilisation	0.4686	0.5476	0.4383	0.3588	0.4431	0.5723
SF6.a. There are sufficient financial resources for the development of knowledge in the DT of the Andalusian olive sector	0.5156	0.5778	0.5000	0.3333	0.4444	0.7222
SF6.b. There are sufficient financial resources for the transfer of knowledge on DT in the olive sector	0.4693	0.5111	0.4907	0.2444	0.3778	0.7222
SF6.c. Companies in the Andalusian olive sector are willing to invest capital for the DT	0.3956	0.4444	0.3333	0.4889	0.4222	0.2889
SF6.d. Public funding is sufficient for the operation of the TIS for DT	0.4275	0.5778	0.4040	0.2889	0.4444	0.4222
SF6.e. Companies in the Andalusian olive sector have easy access to credit and/or financial products related to DT	0.5370	0.6444	0.4444	0.3556	0.5185	0.7222
F7. Legitimacy building	0.4905	0.5155	0.4910	0.4316	0.5151	0.5088
SF7.a. There is a willingness to adopt digital technologies in the Andalusian olive sector	0.4489	0.4889	0.4444	0.4889	0.3778	0.4444
SF7.b. The degree of coordination between the actors involved in the TIS for DT is high	0.3915	0.3333	0.3796	0.2889	0.4889	0.4667
SF7.c. The rules and regulations established for the participation and coordination between the actors of the TIS for DT are sufficient	0.4615	0.4889	0.4074	0.4444	0.4667	0.5000
SF7.d. The spaces for coordination between the actors in the TIS for DT are sufficient	0.4836	0.5333	0.4848	0.3556	0.5556	0.4889
SF7.e. The TIS for DT in the Andalusian olive sector involves a wide variety of organisations of different types with the capacity to generate/apply innovations	0.6463	0.7111	0.7037	0.4889	0.6889	0.6389

D. Criticality Index of functions/ subfunctions (CI) (by experts groups)

Goal	Average	1. Public administration	2. R&D organisations	3. Agri-food companies	4. Digital technology companies	5. Other organisations
F1. Business activities	0.0878	0.0748	0.0798	0.0939	0.0763	0.1141
SF1.a. The number of companies involved in the DT of the olive sector in Andalusia is sufficient	0.0190	0.0192	0.0204	0.0171	0.0174	0.0207
SF1.b. Interactions between the companies involved in the DT of the olive sector in Andalusia are sufficient	0.0192	0.0180	0.0184	0.0184	0.0186	0.0223
SF1.c. The quality of the entrepreneurial initiative for the DT of the Andalusian olive sector is adequate	0.0182	0.0124	0.0151	0.0202	0.0158	0.0287
SF1.d. Companies in the Andalusian olive sector are willing to experiment and implement prototypes	0.0170	0.0138	0.0142	0.0181	0.0159	0.0226
SF1.e. Technological options for the DT of the Andalusian olive sector are available	0.0145	0.0113	0.0117	0.0200	0.0086	0.0198
F2. Knowledge development	0.0627	0.0723	0.0535	0.0887	0.0423	0.0557
SF2.a. The available knowledge is sufficient for the development of the TIS for DT in the Andalusian olive sector	0.0113	0.0121	0.0080	0.0192	0.0055	0.0102
SF2.b. The quality of projects, research, patents and articles is sufficient for the DT in the Andalusian olive sector	0.0105	0.0132	0.0090	0.0179	0.0055	0.0063
SF2.c. The actors generating knowledge on DT in the Andalusian olive sector are sufficiently active	0.0128	0.0157	0.0088	0.0159	0.0112	0.0127
SF2.d. There is sufficient correspondence between the knowledge developed on digitalisation and the real needs of the Andalusian olive sector	0.0135	0.0129	0.0129	0.0185	0.0086	0.0152
SF2.e. There are sufficient beneficiaries of the knowledge developed in digitalisation in the Andalusian olive sector	0.0146	0.0184	0.0149	0.0172	0.0116	0.0113
F3. Knowledge transfer	0.0929	0.0954	0.0918	0.1006	0.0795	0.0972
SF3.a. There are enough organisations transferring knowledge on DT in the Andalusian olive sector	0.0175	0.0184	0.0181	0.0180	0.0158	0.0169
SF3.b. There is sufficient knowledge transfer between research centres/universities and ICT companies	0.0184	0.0203	0.0188	0.0153	0.0172	0.0202
SF3.c. There is sufficient knowledge transfer between knowledge generating organisations (research centres and/or ICT companies) and end users (agri-food companies)	0.0216	0.0215	0.0215	0.0238	0.0159	0.0257
SF3.d. The spaces for knowledge transfer (conferences, seminars, etc.) on DT are sufficient	0.0157	0.0161	0.0166	0.0177	0.0128	0.0153
SF3.e. The quality of the DT transfer processes is satisfactory	0.0197	0.0191	0.0170	0.0258	0.0178	0.0191
	0.0730	0.0605	0.0790	0.1026	0.0566	0.0681

F4. Research orientation

SF4.a. There is a clear and shared objective among the actors of the innovation system on how the DT should be developed in the Andalusian olive sector	0.0213	0.0166	0.0224	0.0276	0.0164	0.0231
SF4.b. The objective of the DT in the Andalusian olive sector is adapted to the existing legislation	0.0144	0.0127	0.0187	0.0212	0.0092	0.0112
SF4.c. There are sufficient programmes and policies (national and regional), which support the innovation system in the DT of the Andalusian olive sector	0.0176	0.0128	0.0192	0.0270	0.0146	0.0148
SF4.d. The vision and expectations of the actors involved in the DT are sufficiently aligned to reduce uncertainties	0.0197	0.0184	0.0187	0.0267	0.0163	0.0190
F5. Market formation	0.0579	0.0636	0.0605	0.0658	0.0464	0.0527
SF5.a. The size of the current market for digital technologies in the Andalusian olive sector is sufficient	0.0171	0.0176	0.0154	0.0161	0.0160	0.0200
SF5.b. The size of the potential market for digital technologies in the Andalusian olive sector is sufficient	0.0116	0.0136	0.0098	0.0121	0.0069	0.0148
SF5.c. Institutional incentives for the formation of the market for digital technologies in the Andalusian olive sector are adequate	0.0140	0.0180	0.0154	0.0168	0.0110	0.0091
SF5.d. Institutional barriers to the formation of the market for digital technologies in the olive sector are not a barrier to digital transformation	0.0152	0.0142	0.0200	0.0208	0.0126	0.0089
F6. Resource mobilisation	0.0772	0.0630	0.0787	0.1042	0.0797	0.0603
SF6.a. There are sufficient financial resources for the development of knowledge in the DT of the Andalusian olive sector	0.0133	0.0106	0.0162	0.0211	0.0148	0.0060
SF6.b. There are sufficient financial resources for the transfer of knowledge on DT in the olive sector	0.0139	0.0133	0.0136	0.0208	0.0166	0.0062
SF6.c. Companies in the Andalusian olive sector are willing to invest capital for the DT	0.0200	0.0174	0.0169	0.0231	0.0188	0.0230
SF6.d. Public funding is sufficient for the operation of the TIS for DT	0.0151	0.0121	0.0161	0.0185	0.0145	0.0137
SF6.e. Companies in the Andalusian olive sector have easy access to credit and/or financial products related to DT	0.0149	0.0096	0.0160	0.0207	0.0150	0.0114
F7. Legitimacy building	0.0651	0.0692	0.0671	0.0638	0.0709	0.0521
SF7.a. There is a willingness to adopt digital technologies in the Andalusian olive sector	0.0160	0.0154	0.0160	0.0168	0.0195	0.0118
SF7.b. The degree of coordination between the actors involved in the TIS for DT is high	0.0154	0.0186	0.0177	0.0120	0.0155	0.0123
SF7.c. The rules and regulations established for the participation and coordination between the actors of the TIS for DT are sufficient	0.0118	0.0132	0.0130	0.0090	0.0146	0.0094
SF7.d. The spaces for coordination between the actors in the TIS for DT are sufficient	0.0118	0.0130	0.0113	0.0113	0.0118	0.0105
SF7.e. The TIS for DT in the Andalusian olive sector involves a wide variety of organisations of different types with the capacity to generate/apply innovations	0.0102	0.0090	0.0090	0.0148	0.0096	0.0081

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