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Shifting from Fragmentation to Integration: A Proposed Framework for Strengthening Agricultural Knowledge and Innovation System in Egypt

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Abstract: Agricultural knowledge and innovation system (AKIS) has a strong potential to enhance economic performance of farming and contribute to agricultural sustainability, as it may increase synergies and complementarity among actors. This paper is aimed to develop a proposed framework to strengthen AKIS in the study area based on the results of this study. This paper explores perception and views about strengthening AKIS in Dakhalia governorate of Egypt by applying a multi-actor approach. Quantitative and qualitative data were collected through face-to-face interviews and focus group discussion. This paper focuses on three structural dimensions, namely actors, interactions, and technologies, to describe the nature of innovation processes within AKIS. Results indicate that legal and regulatory frameworks, lack of infrastructure, and weak the role of intermediary organizations are the main barriers that AKIS faces. Linkages of contracting and public–private partnerships were viewed as main interactions required to strengthen AKIS. The analysis also explores the availability of innovation requirements at each actor, as well as the distributive technologies, that should be encouraged to build the capacity the agricultural sector. A proposed framework is developed based on the results of this study and the characteristics of the AKIS in the study area. This framework could be used for stimulating innovation and enhancing coordination between actors.

Keywords: agricultural knowledge; innovation system; interaction linkages; framework; sustainable agriculture; Egypt

1. Introduction

To meet the increasing demand of food and to respond to new market opportunities, agricultural systems worldwide need to be more sustainable by generating and applying new knowledge and innovations [1]. Innovation is seen as one of the main drivers of productivity, self-sufficiency, competitiveness, and profitability, and at the same time, a tool to ensure environmental sustainability [2,3]. Despite this, there is evidence that innovations are not widely adopted at scale, and the agricultural systems are not reaching its full potential in terms of innovation due to the approach adopted in managing resources, socioeconomic concerns, and policy regulations and measures [4,5]. This lack of innovation in agriculture has led to the question of how the agricultural innovations

are developed, spread, organized, and how the quality and relevance of these processes can be enhanced [6,7].

Historically, the framework that describes the process of knowledge generation and use in agriculture was dominated by a linear model (transfer of technology approach) [8]. This approach operated under the assumption that technology is developed by scientists, then extension services diffuse these innovations among farmers. This concept was further developed to agricultural knowledge system to illustrate the interactions of research, extension, and education with farmers [9,10]. With the need for rural competitiveness to allow agricultural systems to remain competitive in a changing socioeconomic environment, the concept of agricultural innovation system (AIS) was merged to reflect the importance of going beyond the creation of knowledge and highlights that innovation systems are social systems [11]. This thinking was developed over time toward promotion of agricultural system multifunctionality by supporting collective and integrated processes of multi-actors to co-produce innovations through interactions among all stakeholders in the agri-food chain [3]. Recently, the conceptualization of agricultural innovation systems to better support sustainability is called agricultural knowledge and innovation system (AKIS) [4,12]. According to EU [13], moving from the linear model of knowledge to AKIS is attributed to four drivers: Disconnection between farmers' indigenous knowledge, extension, and research; increasing concern for adverse environmental impacts associated with industrial agriculture in the policy agenda; multifunctional agriculture requires coordination and integration among different stakeholders; and restructuring reforms that have been implemented in research, extension, and education institutions.

The AKIS framework has been embedded in the policy agenda of many countries to explore and analyze solutions of complex agricultural problems [12,14–17]. AKIS is broadly defined as a network of individuals, enterprises, and organizations focused on developing innovations with regard to new products, new processes, and new forms of organization into economic use, together with policies and institutions that facilitate the way different stakeholders interact, access, share, exchange, and use knowledge [12,15]. This framework includes three essential elements: (a) A knowledge and education domain; (b) a business and enterprise domain; and (c) linkages between institutions that link the two domains [3].

According to Hermans et al. [18], a well-developed AKIS has seven main functions, including guidance of search, knowledge development, network formation and knowledge diffusion, entrepreneurial activities, market formation, resource mobilization, and creation of legitimacy and counteracting resistance to change. Therefore, it is important to diagnose AKIS at the level of a country, a sector, or a particular technology [15]. Such analysis is important to understand the constraints to innovation and technological change, role of innovation policies, and support structures and the governance of actor interactions in innovation [12,15].

In Egypt, the AKIS has three main domains: Research and education: Agricultural Research Center (ARC), Desert Research Center, universities, and vocational agricultural schools; intermediaries: The Central Administration of Agricultural Extension Services and its local branches (extension centers), private sectors, cooperatives, non-government organizations (NGOs); business and enterprise: Farmers, agricultural companies, traders, and other stakeholders in the agricultural value chain [19]. Different studies examined the structure dimensions of AKIS in Egypt and reached to number of problems and challenges that inhibit its efficiency and effectiveness in supporting innovation and sustainability to the agricultural sector. These problems include: Fragmentation and dominance of overall "technology transfer logics," lack of laboratory and research capability of research and development actors, weak interaction linkages among actors, trust among beneficiaries in scientific research results, absence of knowledge utilization initiative of university policy planners, absence of clear national plans for benefiting from agricultural innovations, and ineffective extension services [20–25]. These problems in AKIS has translated into a generally weak innovation system in Egypt. To address such problems, the objective of our empirical study is to develop a framework of AKIS at a regional

level (Dakhalia governorate). This analysis may be useful to enhance the overall performance of AKIS in the study area.

2. Conceptual Framework

2.1. The AKIS in the Dakhalia Governorate

The regional innovation system (RIS) concept was developed based on specific geographical space, local conditions, and structural patterns [17,26]. RIS has five basic structural dimensions: Actors, institutions, infrastructure (knowledge, physical, and financial), interactions, and technologies [12]. In the context of the present study, the AKIS in Dakhalia governorate (hereafter referred to as the DG-AKIS) is comprised of multiple actors, both in the public and private sectors. As shown in Figure 1, the framework includes three main domains: Farmer enterprises, intermediaries/bridging institutions, and research and education institutions. These domains contain the key actors in the AKIS that interact in certain ways to facilitate agricultural innovation development and access. However, their interactions are influenced by policy processes, support structure, and supply–demand structure [27]. Farmers and farmer cooperatives at the community level are the key actors of the farmer enterprise domain. Intermediaries domain include actors, such as governmental extension, NGOs, and private sectors. Mansoura University and ARC agricultural research stations are the key actors involved in the development, adaptation, and dissemination of agricultural innovations. In reviewing the strength of linkages between actors, only few linkages were seen to be strong. The majority of these linkages between actors were perceived to be weak, and non-existent linkages were observed in some cases.

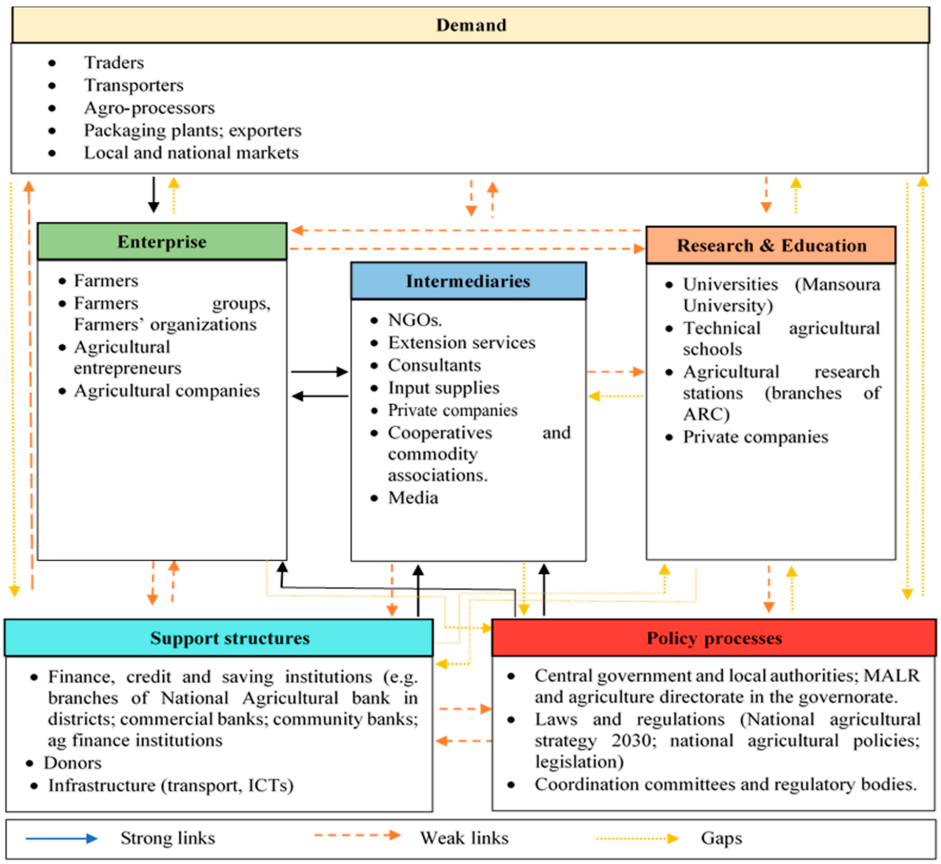

Figure 1. The agricultural knowledge and innovation system (AKIS) framework in the study area (Dakhalia governorate); Source: Naba [28] based on the agricultural innovation system (AIS) framework of Spielman and Birner [27].

2.2. Interaction Linkages between Actors

It has become clearly recognized that a single actor alone cannot solve many of the complex problems that the agricultural sector is currently facing. However, the involvement of different types of actors in the innovation processes is crucial to agricultural sustainability [29]. Consequently, linkages among actors is being promoted in a way that intersectoral innovation groups were organized to facilitate cooperative knowledge creation, knowledge flow, and knowledge sharing [30]. According to Kassem et al. [31], interaction linkages include relation, collaboration, and links between actors that are established for achieving common goals in less orchestrated ways. To promote interactions between actors, several forms were increasingly used to enhance collective or coordinated action, including multi-actor partnerships, territorial partnerships, and alliances, public–private partnerships (PPPs), and communities of practice (learning partnerships) [1,6,13].

2.3. Requirements of Innovation in the Agricultural Sector

To support the innovation processes in the agricultural sector, policy structure should ensure that measures target the appropriate level (national or regional) and intervention type (e.g., structural funding and incentives) [13]. Policy should also take into account the research and development framework. In other words, the facilitation of all procedures is needed to ensure the relevance of research outcomes with end users' needs [10]. This can be achieved by providing sufficient funding, incorporating PPPs in research and innovation, excellent research infrastructures, and collaborating with international partners [32]. In this context, EU [33] confirmed that fostering innovation requires implementing of five main principles: Empowering people to innovate, unleashing innovation in firms, creating and applying knowledge, applying innovation to address global and social challenges, and improving the governance of policies for innovation. Moreover, governments should develop innovative risk management strategies not only for the resilience of vulnerable rural households or small enterprises, but also for leveraging finance and investment [34].

2.4. Barriers to Development of the AKIS

System failures or inefficiency can form a blockade for innovation in the agricultural sector. Infrastructure is one of the main determinants that may hinder or facilitate the performance of the AKIS [15]. It includes a physical domain (roads, railroads, and telecommunication), knowledge infrastructure (research and development facilities), and financial infrastructure (investments) [28]. Furthermore, technical and organizational capacity of the actors to adapt and manage agricultural technologies is another barrier [12,15]. In the same sense, market structure plays a key role in arranging the supply and demand of information and knowledge in terms of the relationships between market parties [33]. Weak networks and connections between actors can also be detrimental for innovative performance [35]. Finally, lack of laws and regulations affect how actors interact with each other, which in turn may hamper innovation [36]. As Weber and Rohracher [37] noted, such barriers may negatively affect the capacity of innovation systems to coordinate policies, set priorities, engage users in setting research agendas, and monitor and evaluate progress against its goals.

3. Methodology

This study was carried out in the Dakahalia governorate in the northeast region of Egypt. The governorate has a total area of 3500 km^2 and a population of approximately 6 million, where an estimated 71.8% live in rural areas. The governorate is considered to have a desert climate. The average annual temperature is 20.5 °C, and it receives an average 56 mm annual rainfall. March and April are the wettest, whereas June, July, and August are the hottest months of the region. The governorate is divided into 22 districts, with 37% of the total area cultivated. The majority of crops is grown under a

surface irrigation system from a network of canals and channels of the River Nile. Rice, wheat, corn, Egyptian clover, Sugar beet, vegetables, and citrus fruits represent the major cropping pattern in the governorate [38]. This governorate was selected as a site for the present study, as it considered the largest governorate in terms of total agricultural land in the country (approximately 8.3%), as well as characterized by agricultural production diversity [39]. Moreover, the geographic proximity of this governorate to the research team facilitated good communication and collection of needed information.

The population of study consists of the employers in all actors of the DG-AKIS in the governorate. Seven actors (research, advisory, education, private sector, credit, farmers, and cooperatives) involved in different activities of the DG-AKIS were included in the study. Sampling was done separately for each of the different actors. Data were collected from the randomly sampled 125 representatives of all actors as follows: 15 researchers from research stations, 15 faculty members from the Faculty of Agriculture of Mansoura University, 15 directors of extension centers and heads of agricultural extension departments at the directorates, 10 headquarters of agricultural cooperatives, 10 representatives of head quarter of agricultural companies, 10 directors of agricultural bank branches, and 50 farmers. Prior to data collection, a pilot survey was conducted involving 5 representatives from each actor in the study area. The authors revised several statements to suit the results of the pre-test and objectives of this study. Consequently, the instrument was modified to its final version for data collection through face-to-face interviews during January–March 2019.

To analyze the existing situation of DG-AKIS, the questionnaire consisted of five sections to examine the three structural dimensions under investigation; actors (Sections 1–3), interactions (Section 4), and technologies (Section 5). The first section included the actors' acceptance level of developing the DG-AKIS. In this part, actors were asked to identify the importance level of developing the AKIS on a 5-point Likert scale ranged from 5 (very important) to 1 (not important at all). Furthermore, Actors were asked an open question about the benefits gained from strengthening the DG-AKIS. The second section included the functions of actors within the DG-AKIS. In this section, we formed an open question to illustrate the potential roles of each actor within the DG-AKIS. The third section consisted of barriers to DG-AKIS development. These barriers were mentioned from the actors' point of view by asking an open question. The fourth section included the interaction linkages based on literature review. In this section, the respondents were asked to identify each linkage's importance level on a 5-point Likert scale ranged from 5 (very important) to 1 (not important at all). Moreover, each actor was asked to explore the current linkages with other actors. Section five comprises the requirements of sustainable agriculture and innovation approaches. These were concluded from international literature and the Egyptian strategic plan 2030 [40]. In this section, surveyed actors were asked to identify the availability level of sustainable agriculture requirements in Egypt on a 5-point Likert scale ranged from 5 (very high) to 1 (very low). Furthermore, the respondents identified the importance of innovation approaches to Egyptian agriculture particularly at a governorate level, on a 5-point Likert scale ranged from 5 (very important) to 1 (not important at all). Finally, they were also made to express their views about the availability of sustainable agricultural requirements to each innovation approach.

We prepared the first draft of the suggested framework to strengthen the DG-AKIS after analyzing the findings of the questionnaire. This framework was reviewed during a focus group discussion, which was organized with 12 members who were previously invited to answer the questionnaire, having two representatives from each actor. The focus group discussion was facilitated by the first and third authors at Mansoura University. At the beginning of the discussion, a short presentation explaining the purpose of the meeting and findings of the first stage was introduced. Frequency, percentages, mean, and standard deviation were used to describe and present the results. Furthermore, relative weight (%) was calculated as follows [41]:

$$\frac{\sum Pi \times wi}{\sum n \times Wmax} \times 100. \quad (1)$$

(*Pi* = Each parameter amount; *Wi* = Each parameter weight; *Wmax* = the maximum weight that can belong to each parameter (2); and *n* = the number of each factor parameters).

4. Results and Discussion

4.1. Importance of Strengthening the DG-AKIS in the Governorate

The actors' views about the importance level of strengthening the DG-AKIS are illustrated in Figure 2. The findings show that the overwhelming majority of the respondents in all actors were in the category of very important and important. This result reflects the critical need to develop the current situation of the DG-AKIS from the actors' point of view. This is in line with the Egyptian strategic plan 2030's goal to develop AKIS' structural processes to enhance the competitiveness of the agricultural sector and influence the direction and speed of co-innovation [40]. This result was also in consistence with the study of Kamara et al. [42], who confirmed that actors give a high level of importance to enhance the functioning of the existing AKIS toward innovation and food security in Sierra Leone.

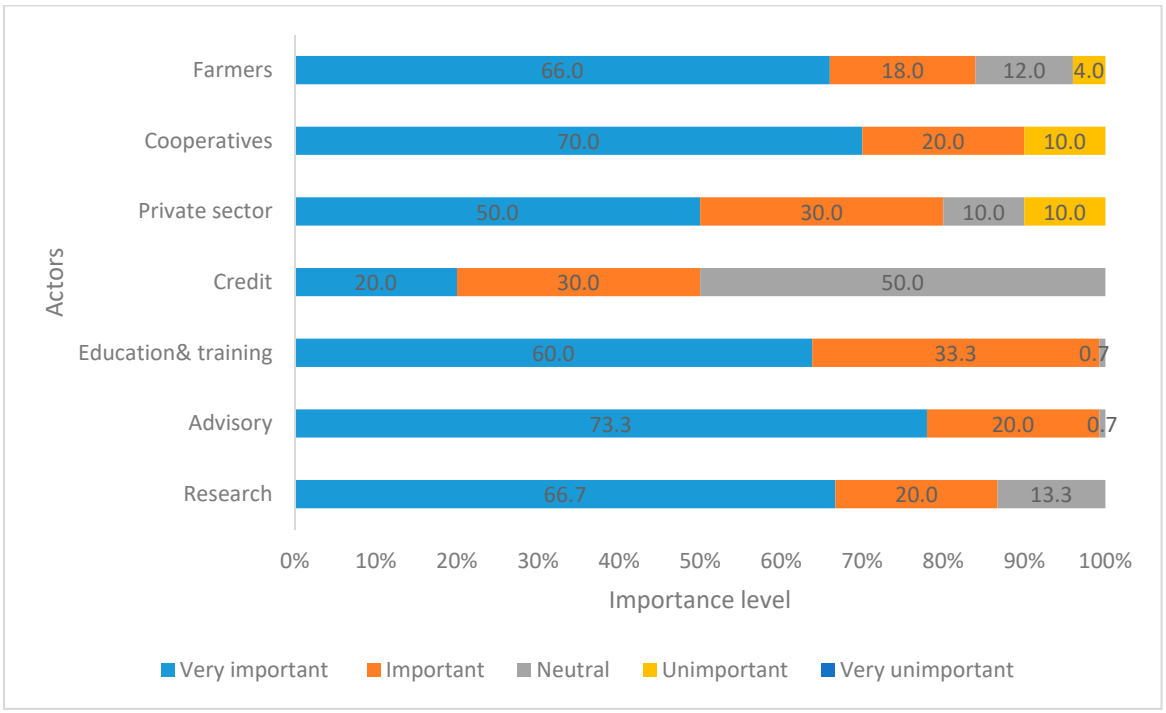

Figure 2. Importance of strengthening the Dakhalia governorate (DG)-AKIS.

The actors perceived different advantages of developing the DG-AKIS, as shown in Figure 3. The findings indicated that the aspects that are highly perceived (>80%) were those involved in the strengthening of DG-AKIS governance (88%), improving international market access (84%), and preventing anti-competitive practices in the market (81.6%). These results show that the existing DG-AKIS face structural problems that inhibits it to innovate and achieve sustainable agriculture. According to Pigford et al. [3], a well-designed AKIS is a key factor to better support the creation of innovation niches, which allows to implement different approaches and paradigms, such as smart farming, vertical farming, urban agriculture, bioeconomy, and local-based food systems. The findings are in line with Abebe et al. [43], who indicated that AKIS support could be performed by implementing reform processes that aim to improve information access, sharing, and utilization, as well as improving access to market and credit from the farmers' point of view.

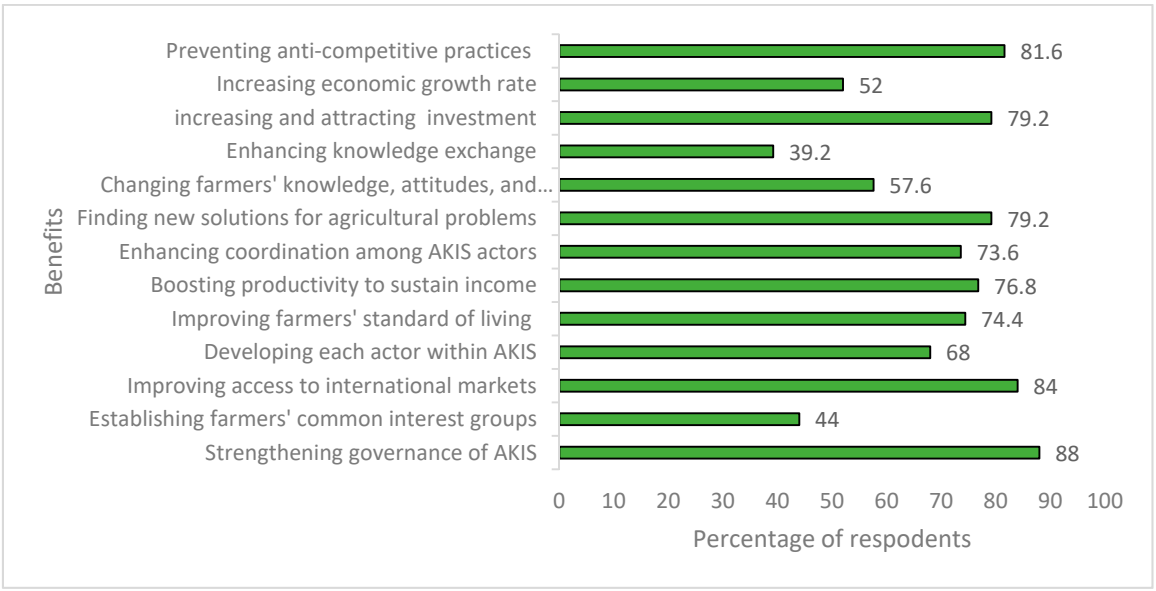

Figure 3. Main benefits gained from developing DG-AKIS.

4.2. Functions of Actors within the DG-AKIS

Actors presented their potential roles to develop DG-AKIS, as illustrated in Figure 4. Results revealed that 16 functions were identified by more than half of the actors. Some of these functions are accomplished by a collaboration between two actors or more, such as capacity building and training (research and advisory), solving agricultural problems (research and education), coordination among actors (advisory and cooperatives), financial support (credit and private sector), market linkages (private sector and cooperatives), building social capital among farmers (advisory and cooperatives), and natural resource management (cooperatives and farmers). Despite some of these functions being performed by the actors for several years, the actors highlighted that there is an urgent need to develop each function in terms of scope, quality of service, innovation, provisional methods and tools, promising methods, and linkages. This finding is supported by Hermans et al. [7], who found that each actor (or collaboration with other actors) performed one or two functions to spread their innovation both horizontally and vertically. However, he classified the network functions of actors into three main areas: (1) Learning and knowledge co-creation, (2) outscaling and innovation brokerage, and (3) upscaling and institutional entrepreneurship.

4.3. Barriers for Innovation in the DG-AKIS

The findings in Figure 5 showed a number of barriers that may hamper the development of the DG-AKIS. The complexity of legal and regulatory frameworks was ranked first as a main barrier for developing the DG-AKIS, with a percentage of 92.2%, followed by lack of financial support or incentives (76.8%), lack of awareness of the importance of DG-AKIS (64.8%), and the weak role of intermediary organizations among actors (64%). The findings reflect the high need of a new governance framework for the DG-AKIS. This includes legislative, informational, and organizational reform to increase the complementarity and synergy among actors. In reviewing literature, many countries have been facing complex problems to develop the AKIS. In Italy, Materia [44] revealed that the main challenges that inhibit AKIS to meet the future needs of European agriculture include the lack of an institutional coordination that engages both public/private institutions and research structures, lack of investment in the skills of human resources, and lack of strategic studies that address demand analysis and impact evaluation. A study conducted by Aerni et al. [45] in the tropical regions of Southeast Asia, Sub-Saharan Africa, and Central America showed that the major challenges for innovation include insufficient access to innovation, inadequate participation in innovation meetings,

environmental factors (desertification and climate change), and lack of accessible markets for value added products. Furthermore, Hermans et al. [28] confirmed that many innovation policies in the Netherlands are rather complex and not particularly well-suited to support collaboration and networking. Finally, a study conducted in Ethiopia by Kebebe [46] showed that missing innovation functions, such as entrepreneurship, knowledge diffusion, market development, and policy advocacy prevent stakeholders from taking advantage of productivity and profit opportunities offered by agricultural technology.

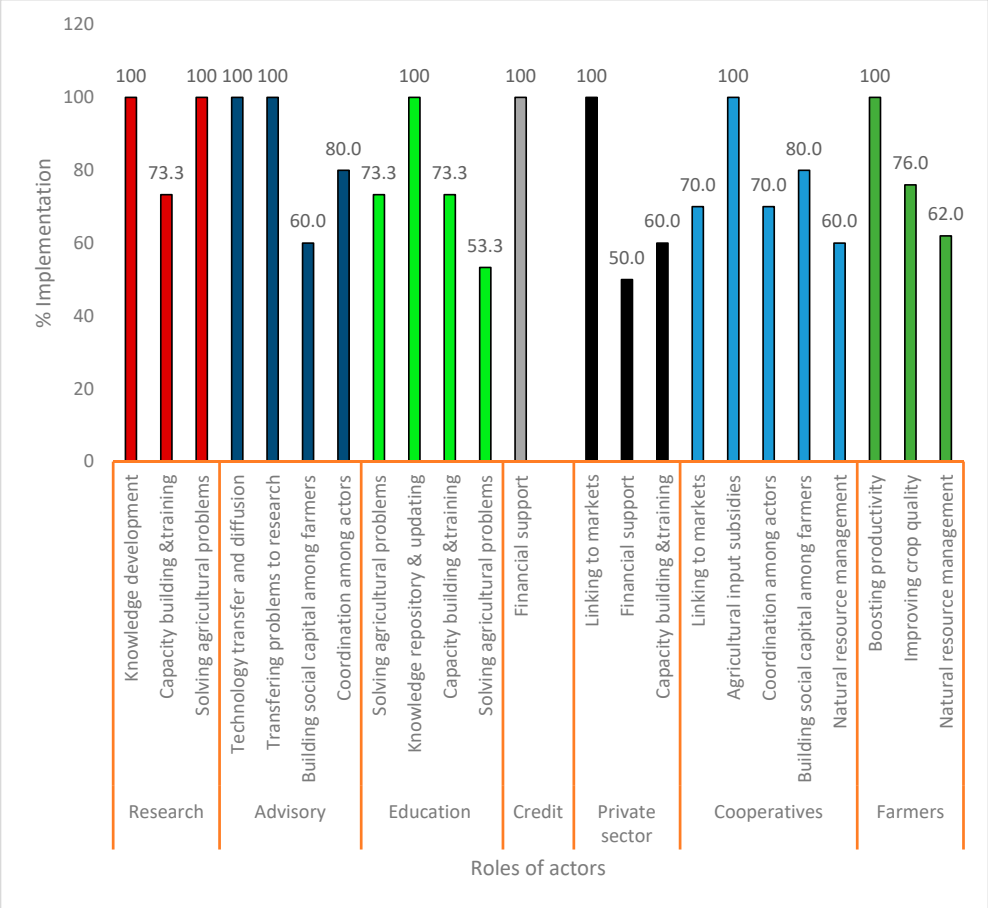

Figure 4. Potential roles of each actor in developing the DG-AKIS.

Reviewing the AKIS's case studies worldwide showed significant actions to overcome particular problems or barriers. According to EU report [47], supporting AKIS functions received special attention in Post-2020 EU programming period (2021–2027). This strategy includes four main groups of actions: Supporting the digital transition in agriculture; enhancing cross-thematic and cross-border interactive innovation; enhancing knowledge flows and strengthening links between research and practice; and strengthening advisory services and fostering their interconnection within the AKIS. Financing innovation and research is another challenge face developing AKIS. It takes different forms across the countries. Co-financing in New Zealand is one example on how to invest in research and innovation programs for improving sustainability in agri-food sector. The primary growth partnership (PGP) involves two ministries (the Ministry of Business, Innovation, and Employment and the Ministry of Primary Industries) and industry. An amount of NZD 70 million is invested annually by the government and industry. The PGP makes investments throughout the value chain, including research and development, technology transfer, education and skills development, product development, and commercial development [48]. Levy-based funding is another tool employed by South Africa, New Zealand, and The Netherlands. It tends to emphasize downstream solutions for the agricultural

sector by pooling resources and fund research and development specific for sector solutions. Furthermore, many case studies are moving toward competitive funds with clearly articulated government goals [49].

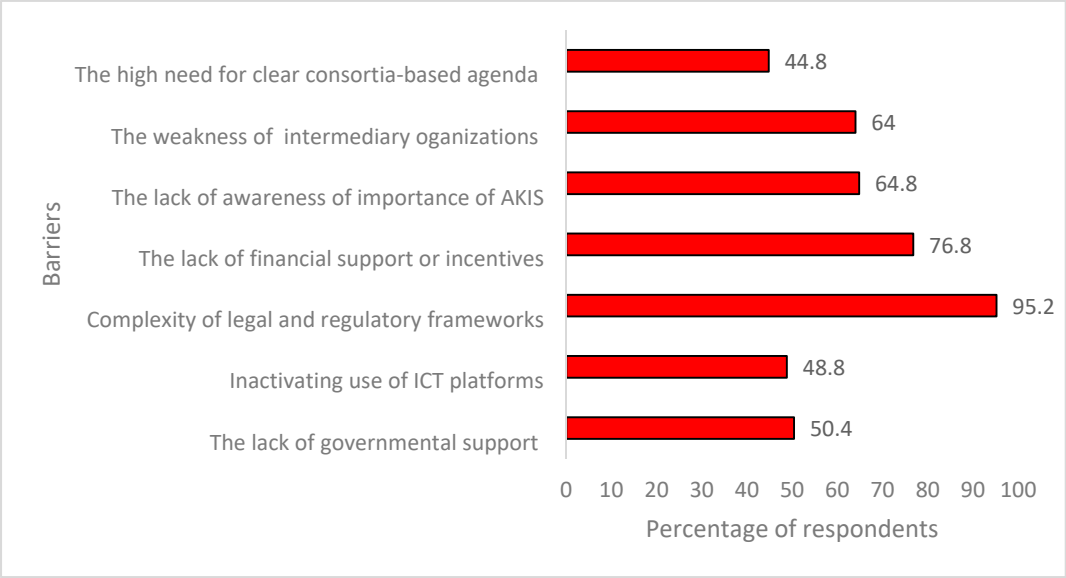

Figure 5. Barriers to the development of the DG-AKIS.

4.4. Linkages between the DG-AKIS Actors

The importance level of each linkage suggested to support the coordination and cooperation between actors is presented in Table 1. The results revealed that all linkages were in the category of high and moderate level of importance. The most important linkages, in descending order, were contracting (91.2%), partnerships (83.3%), activities (81.2%), and networks (80.9%). These results reflect the importance of implementing these different linkages according to the nature of relationships among actors. For more clarification, the potential linkage matrix between each two actors is illustrated in Table 2. Obviously, the number of potential linkages between two actors differed in terms of the services provided, size of finance, stakeholders, and scope of work.

The results showed that linkages, such as contracting, is viewed as highly important for financing innovation. As evidenced by Blum et al. [50], contracting with the private sector for service provision is not only more effective and efficient than public delivery of services, but also enhances the coordination between actors, increases innovation demands, and strengthens stakeholder involvement and capacities. One of the several forms of contracting is contract farming. Numerous studies have indicated the positive social and economic impact of contract farming in supporting vertical coordination. It enhances the farmers' productivity and quality of agricultural products, promotes farmers' participation in the agricultural value chain, minimizes transaction costs, creates new marketing channels, and effectively supports the interactions between actors [41–54]. Furthermore, the respondents confirmed that partnerships may act as systemic policy instruments to enhance the linkages between actors. Public–private partnerships (PPPs) are not focused on a particular actor; thereby targeting complex problems within the AKIS from a systems perspective [55]. This could be achieved by combining the capabilities of the private sector with the intellectual resources of research institutes [56]. According to Hermans et al. [18], there are several public benefits of partnering, including environmental and/or social benefits from sustainability innovations, contribution to economic growth, contribution to the knowledge economy, and increased employment opportunities. On another note, private benefits of partnering include increased production and productivity, reduction of costs and risks, and development of new products and market opportunities.

Table 1. Importance of each linkage from the actors' perspectives.

Linkages	Research	Education	Advisory	Private Sector	Cooperatives	Credit	Farmers	Overall Average	Rank
Contracting	100	100	86.7	90	70	100	92	91.2	1
Partnership	93.3	100	100	80	60	50	84	83.3	2
Platforms	46.7	80	80	100	70	100	66	77.5	5
Networks	93.3	100	100	80	60	60	72.8	80.9	4
Alliance	46.7	33.3	73.3	100	40	70	84	63.9	8
Advocacy linkages	40	40	66.7	60	40	70	70	55.3	9
Solidarity	53.4	93.3	50	70	40	100	96	71.8	7
Coordination committees	53.4	93.3	70	60	90	100	60	75.3	6
Activities (workshops, advisory programs, research projects, campaigns, etc.)	46.7	80	80	100	70	100	36	81.2	3

Table 2. Potential linkage mechanisms among actors of the DG-AKIS.

Actors	Research	Education	Advisory	Private Sector	Cooperatives	Credit	Farmers
Research	-	-	-	-	-	-	-
Education	Partnership-contracting-networks-alliance-platforms	-	-	-	-	-	-
Advisory	Contracting-Partnerships-platforms	Networks-activities platforms	-	-	-	-	-
Private sector	Partnerships-Networks	Partnerships-Activities	Partnerships-Networks -Activities	-	-	-	-
Cooperatives	Contracting	Contracting-Activities	Partnerships	Contracting	-	-	-
Credit	Contracting	Contracting-Activities	Contracting	Financing	Partnership	Financing-Solidarity	-
Farmers	Contracting-platforms	Contracting-Activities-platforms	Contracting-Solidarity-platforms	Contracting-Solidarity-platforms	Contracting-Solidarity	Financing-Solidarity	-

4.5. Requirements of Innovation in the DG-AKIS

The requirement availability of each actor to meet future needs of the DG-AKIS is presented in Table 3. The findings indicate that except for private sector and credit, the other actors indicated moderate and low level of availability regarding the requirements under investigation. Moreover, each requirement was noticeably not available for all actors. At the same time, each actor cannot achieve all requirements. This reflects the aim of AKIS development, which gives opportunity to integration by combining the capabilities of actors to achieve technological, social, and institutional changes. Several studies have examined the innovation requirements for agricultural sustainability. In Italy, Pascucci and de-Magistris [57] showed that knowledge and innovation, improved quality of advisory services within the regional AKIS, and support interaction between actors are most important areas to AKIS development. In this context, Turner et al. [12] presented blocking mechanisms that negatively influence the direction and speed of co-innovation in the New Zealand AKIS. These mechanisms included (i) competitive science in silos, (ii) laissez-faire innovation, and (iii) science-centered innovation. In the same sense, Minah [17] confirmed that the AKIS in Vietnam's northern uplands need to enhance its structural performance by implementing the following requirements: Knowledge and innovation, physical and funding infrastructure, developing capabilities and accountability of actors, increasing number of intermediary actors, and interactions among a broad range of actors.

Table 3. The availability of the requirements of sustainable agriculture at each actor.

	Research	Education	Advisory	Private Sector	Cooperatives	Credit	Farmers
Knowledge and technology	100	100	44.4	100	33.3	×	66
Governance	57.8	88	33.3	100	33.3	93.3	×
Training and capacity building	62.2	93.3	33.3	93.3	33.3	×	×
Input subsidies	×	×	×	×	40	×	×
Credit support and financing	×	×	×	×	×	90	×
Self-help	44.4	57.8	×	93.3	33.3	×	×
Risk management	×	×	×	90	×	×	×
Access to local and international markets	×	×	×	96.7	×	×	70.7
Mobilization of investment	×	×	×	90	×	×	×
Environmental sustainability	×	×	×	×	33.3	×	×
Sustain income, quality, and production	×	×	×	96.7	×	×	74.7
Quality control systems	33.3	×	×	86.7	×	×	×
Coordination among actors	×	40	40	66.6	36.7	×	×
Power of bargaining	×	×	×	83.3	43.3	×	×
Effective advisory services	×	33.3	33.3	×	×	×	×

(×) not available, as mentioned by the actors.

The foregoing results reflect the critical need for building the actors' capacity by adopting new innovation approaches and paradigms to achieve such requirements. The actors surveyed determined the importance level of the innovation approaches to achieve innovation requirements within the DG-AKIS (Figure 6), as well as the requirement availability level of sustainable agriculture for each

innovation approach (Table 4). The actors prioritized smart farming, good agricultural practices, and value chain development to be implemented or to increase the scale within DG-AKIS along with several innovations. However, the transformation to future agri-food systems requires transition to new disruptive technologies and perspectives [58]. These include trends associated with Agriculture 4.0 and AgriTech, such as nanotechnology application, genome editing, alternative plant, or insect-based proteins, cellular agriculture, synthetic food production, aquaponics, vertical agriculture, and smart farming technologies (artificial intelligence, robotization, internet of things, and drones) [59–65]. At the same time, there are other paradigms less associated with high-tech methods, such as social farming, community supported agriculture, urban farming, care farming, agro-ecology, and regenerative agriculture [66–68]. Such trends guide the direction of transitions and investments in the AKIS [3,69].

There are different case studies on how governments invest in the agri-food value chain innovation to enhance its competitiveness. Andalucía initiative in Spain is one of the examples to show how IoT technology can improve quality and increase yield. This platform involves the use of sensor data, cloud-based systems for monitoring, and early warning systems to control pests/diseases [70]. Farmlab 2030 was another emerging approach in Portugal. It is a collaborative laboratory for the agriculture sector for monitoring, data sharing, and certification system. This initiative has a focus on bigger farms to increase the recognition and credibility of farms [71]. In the same vein, Teagasc is a new mechanism to support the advisory services across Ireland by a range of digital tools. This management decision support tool is used by more than 3000 farms across Ireland by combining data from different sources [72]. Furthermore, France developed a national database combined to innovative ICT tools in the poultry sector called "BD Avicoleis". It is aimed to establish the traceability all along the production for poultry industries to increase productivity and quality [71].

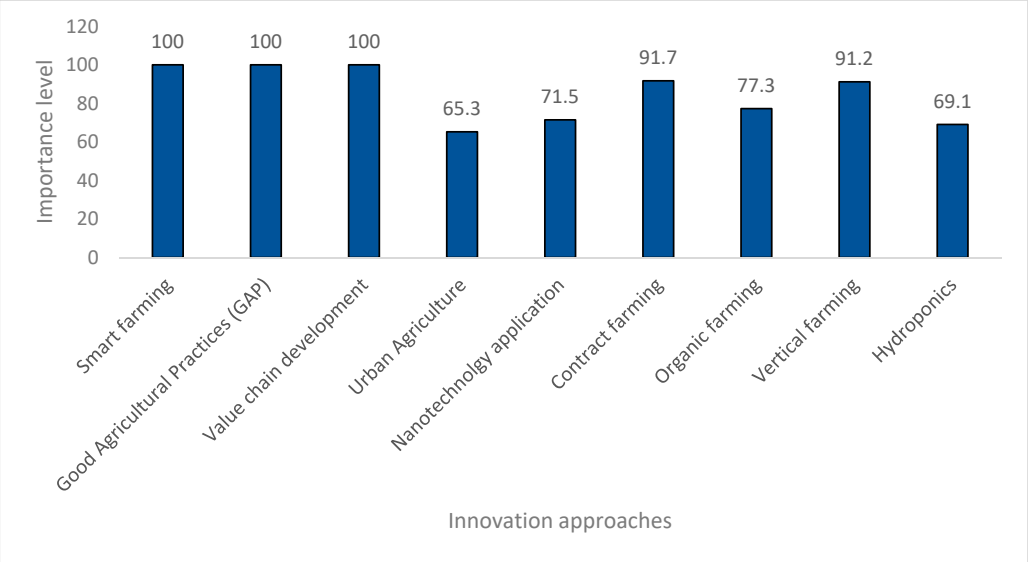

Figure 6. Importance of innovation approaches to the DG-AKIS.

4.6. Suggested Framework for Developing DG-AKIS

We suggested a framework for developing DG-AKIS as presented in Figure 7 according to the foregoing results and the findings of the focus group discussion. This framework is aimed to achieve six main objectives including, activating interaction mechanisms among the DG-AKIS actors, supporting information flow among the DG-AKIS actors, meeting the needs and requirements of sustainable agriculture, improving the standard of living, sustainable rural development, and food security, generalizing the idea of strengthening the DG-AKIS in the other governorates, and finally modernizing Egyptian agriculture.

Table 4. Availability of the requirements of sustainable agriculture in each approach.

Requirements	Smart Farming	Good Agricultural Practices (GAP)	Value Chain Development	Urban Agriculture	Nanotechnology Application	Contract Farming	Organic Farming	Vertical Farming	Aquaponics
Knowledge and technology	•	•	•	•	•	×	•	•	•
Governance	•	•	•	•	×	•	×	×	×
Training and capacity building	•	×	•	•	•	×	×	×	×
Input supplies subsidies	×	×	•	•	×	•	×	×	×
Credit support and financing	•	×	×	×	•	×	×	×	×
Self-help	×	×	×	•	×	×	×	×	×
Risk management	×	×	×	×	×	×	×	×	×
Availability of markets and access	×	•	•	•	•	•	•	•	•
Mobilization of investment	•	×	×	•	•	×	×	×	×
Environmental sustainability	•	•	×	•	•	×	•	•	•
Sustain income, quality, and production	•	•	×	•	•	×	•	•	•
Quality control systems	•	•	•	•	•	•	•	•	•
Coordination among actors	×	•	•	•	•	•	•	•	•
Power of bargaining	×	•	•	×	×	•	×	×	×
Effective advisory services	•	•	×	•	•	×	•	•	•

Source: Authors' elaboration; (•) available; (×) not available.

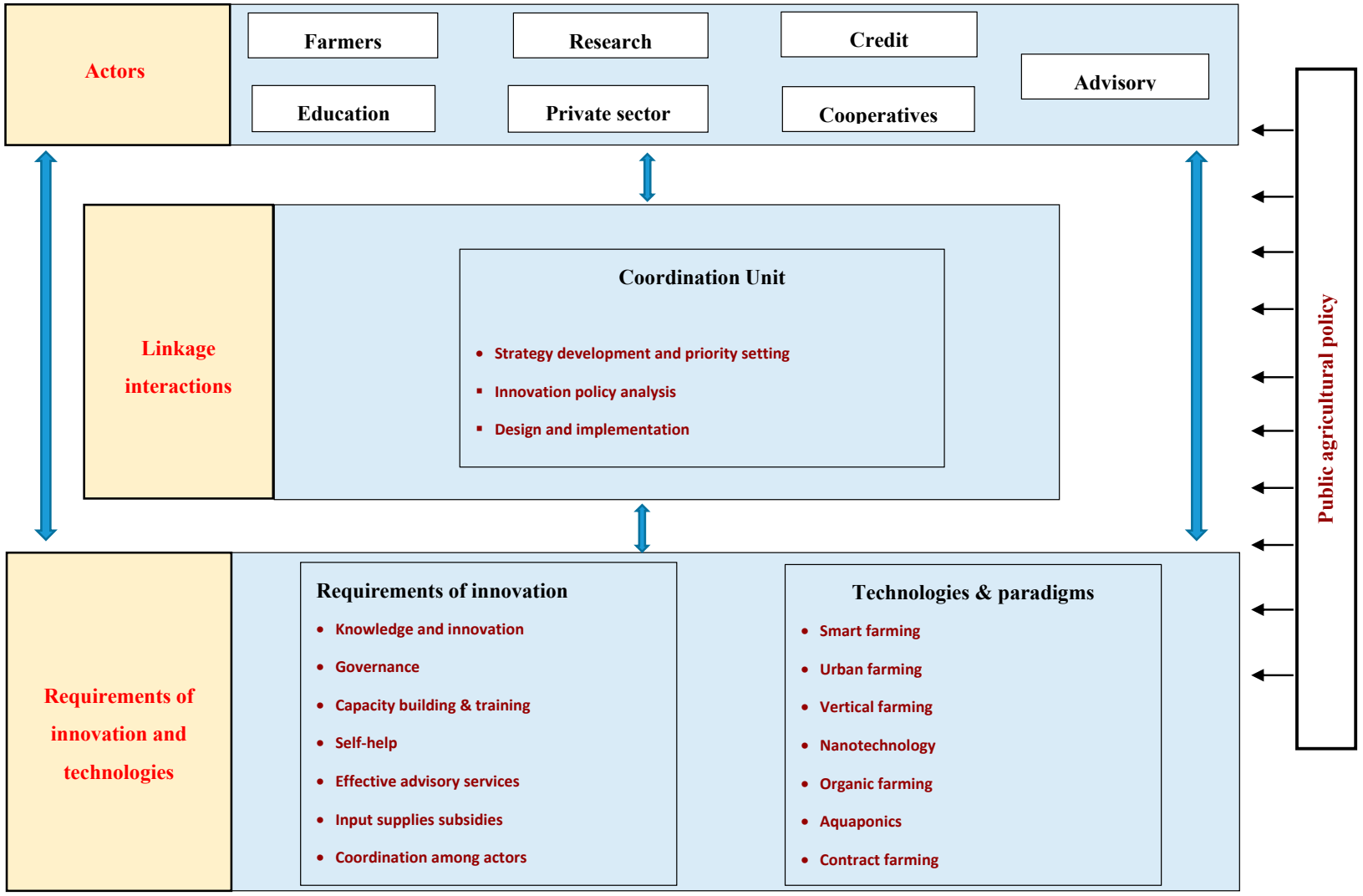

Figure 7. Suggested framework for developing the DG-AKIS.

The structural dimensions of the framework included the following three components.

4.6.1. Actors

All actors surveyed (research, education, advisory, private sector, cooperatives, credit, and farmers) are involved in each innovation approach by utilizing the available strong points of the requirements needed for successful implementation. The specific roles of each actor within DG-AKIS are illustrated in Appendix A.

4.6.2. Interaction Linkages

This dimension includes interacting linkages to ensure synergy and complementarity among the DG-AKIS actors, such as networks, partnerships, contracting, transactions, and activities. The suitable linkage mechanisms among the actors that were revealed from the conclusion drawn from the results of the focus group discussion are illustrated in Appendix A. In the case of PPPs, the partnership protocol will be prepared between public entities (research–education–extension) and private entities (companies–agricultural bank–cooperatives–farmers). The local government will be playing a key role in sustaining a partnership by following the solidarity mechanism for all DG-AKIS actors. At this level, interaction linkages will be supported and guided by the coordination unit. This unit will be established at the governorate level with representatives from each actor. According to the findings of the focus group discussion, five key functions of the DG-AKIS Coordination Unit were identified, such as strategy development and priority setting; innovation policy analysis; design and implementation; managing programs and resources; and innovation financing, including innovation system management, information management, and knowledge sharing. During the focus group discussion, actors mentioned two challenges that should be addressed to achieve the unit's functions. The first issue is designing a digital platform to facilitate knowledge exchange among the DG-AKIS actors and announce new events. Furthermore, designing suitable structures for each linkage based on the legislative and regulatory framework to ensure mutual cooperation and coordination among the actors.

Some countries have established core networks to facilitate the governance of the AKIS at national and regional levels. These networks include a Ministry coordinating unit similar to the one proposed in this study, in which different entities are grouped by the level of coordination at which they work. In Canada, Agriculture and AgriFood Canada (AAFC) (Ministry-level), Agri-Innovators Committee (Advisory Committees to Ministry-level), Provincial departments of agriculture (Agency-level Coordination), and Value Chain Roundtables (Industry-level) are grouped together to form a core network [73]. In the Netherlands, Ministry of Economics, Agriculture, and Innovation (Ministry-level), Knowledge Chambers Advisory Council for Science and Technology, The Council for Environment and Infrastructure, Innovation Network (Advisory Committees to Ministry-level), and Top Sectors, Bioconnect (among others), Levy-based funding mechanisms (Industry-level) are integrated in a core network administrated by a coordinating unit [72]. Another example of integration in South Africa; Department of Science and Technology (DST), Department of Agriculture, Forestry, and Fisheries (DAFF) (Ministry-level), National Advisory Council on Innovation (NACI), National Agricultural Research Forum (NARF) Centre for Science, Technology and Innovation Indicators (CeSTII), Agricultural Research Council (ARC) (Advisory Committees to Ministry-level), Technology Innovation Agency (TIA) (Agency-level Coordination), and Technology Innovation Agency (TIA) (Industry level) [74].

4.6.3. Requirements of Innovation and Technologies

This dimension involves nine innovation approaches to achieve sustainable agriculture, such as smart farming, nanotechnology, vertical farming, aquaponics, organic farming, contract farming, urban agriculture, value chain development, and GAP. To better implement such technologies, different requirements should be available to modernize Egyptian agriculture. According to the study's

findings, 13 main requirements are essential as follows: Knowledge and innovation, governance, capacity building and training, subsidizing input supply, credit support and finance, self-help, risk management, market access, effective advisory services, coordination among actors, quality control systems, environmental sustainability, and mobilizing agricultural investments.

There are some limitations associated with the implementation of the framework. This framework is extremely difficult to be activated without establishing some procedures. These procedures include setting a national strategy to support the DG-AKIS activities and obligating each actor to cooperate according to a preliminary testing format. Another procedure is suggesting protocols/agreements/contracts among DG-AKIS actors. These arrangements should specify the needed functions, whereas each actor should execute a particular node. Moreover, it must include setting attainable initiatives to build the capacity of each actor with assistance from other actors. Finally, a supervision system should be formed by the support unit to monitor and evaluate the executed activities and determine their social and economic impacts. The next biggest limitation is the sustainable finance. Accumulating sufficient funds to implement all the suggested activities is crucial to strengthen the framework. There are different sources of funding that could be utilized to finance DG-AKIS activities, such as public finance, international funds (donor organizations for research projects, etc.), private finance (private sector, cooperatives), credit facilities and loans from agricultural banks, and self-finance utilizing the cost-sharing approach.

However, our study had some limitations that should be acknowledged. First, we collected data from seven actors and did not include other actors involved in the DG-AKIS, so we could not present the holistic picture of innovation processes undertaken within the DG-AKIS. Second, we were unable to assess infrastructure of actors as one of main structural dimensions. This has an effect on exploring the actors' capability to interact and determine the capacity building that is needed. Third, the presented conceptual framework was only reviewed by a few groups of actors rather than experts in the field or policy makers. Thus, it is considered as a preliminary model for discussing, reviewing, and modifying.

5. Conclusions

The present study offers new insights for strengthening the interaction linkages within regional AKIS in Egypt, as perceived by a range of actors, such as farmers, cooperatives, research, advisory, credit, education, and private sector. The contribution of this paper is two-fold; first, providing insights into the functioning of a regional AKIS. Second, it deepens the literature on structural–functional innovation systems analysis by suggesting a framework that illustrates how regional dimensions, coupled with structural elements, could enhance the functioning of a regional AKIS. The multi-actor approach used in this study allowed us to obtain information on innovation processes that was relevant to diverse actors and structural dimensions of the system. Results indicated that the actors had a positive view toward developing the DG-AKIS. Potential roles mentioned by the actors to strengthen this system confirm three main points; upgrading the DG-AKIS ensures benefits for all actors, tasks specificity ensures efficient and effective performance of roles and tasks, and weak points in each actor could be complemented by strong points of other actors. Actors also perceived a broad range of barriers to development. Partially, these barriers could be overcome by a better design of linkage interactions between the actors, capacity building of actors in terms of the innovation requirements in the agricultural sector, and adoption of new emerging technologies. It was also concluded that PPPs are the most suitable interaction linkage from the actors' point of view. These partnerships could be effective between partners if it well prepared in a formal way and the local government implements the solidarity mechanism in case of conflicts. The current level of the requirements of sustainable agriculture in each innovation approach identified by the actors reflects the gaps that should be taken into account to formulate capacity building strategies for supporting innovation processes within the DG-AKIS. The findings of the focus group discussion confirm that coordination in innovation systems relies on governance. In other words, there is a need for a coordination unit in the DG-AKIS. This unit could enhance the policy coordination, which is concerned the determination of

priorities, the development of a clear, consistent, and agreed set of policies, and putting these policies into practice. Furthermore, supporting administrative coordination, which concerns the problem of synergy and complementarity among actors. Consequently, the outcome of coordination unit could be seen in different ways such as increase the efficiency of funding in the short term, manage the issues related to agricultural innovation, and integrating institutions. The study also revealed that the proposed framework can be used as a tool to link functions to the structure of an innovation system. This framework can be empirically implemented to enhance the synergy and complementarity among the AKIS actors. To achieve that, the study recommends some essential procedures that should be implemented, including collecting data at all levels of the suggested framework, improving the availability of a conducive environment in achieving the principles of synergy and complementarity among actors, formalizing a contract form regarding each linkage mechanism, testing this format in a specific geographical area, and summarizing the learned lessons. Further research is recommended to assess and analyze whether innovation processes are affected by the scale of the different infrastructural dimensions (research and development, financial, or physical) of actors.

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Appendix A

Table A1. Suggested linkage mechanisms among the DG-AKIS actors based on the suggested framework.

Actors	Research	Education	Advisory	Private Sector	Cooperatives	Farmers
Research	-	Activities				
Education & training	Partnership	-	-	-	-	-
Advisory	Paternalistic	Activities	-	-	-	Networks
Private sector	Contracting-partnerships	Activities	Networks	-	Contracting-activities-partnerships	Contracting-activities-partnerships
Cooperatives	Contracting	Activities	Partnerships	Contracting	-	Contracting
Credit	Financial transactions	Activities	Financial transactions	Financial transactions	Financial transactions	Financial transactions
Farmers	Activities	Activities	Contracting	Contracting	Contracting	-

Table A2. Tasks of DG-AKIS actors based on the suggested framework.

Actors	Representatives (Governorate Level)	Tasks
Research	- Horticulture research station. - Soil, water, and environment research station. - Plant protection research station. - Animal production research station. - Field crops research station. - Food technology research station. - Cotton research station. - Agricultural engineering research station.	- Production of agricultural innovations. - Capacity building & training. - Solving agricultural problems. - Provision of consultancy services.
Education	- Faculty of Agriculture, Mansoura University. - Secondary Agricultural schools. - Development Support Communication Centre.	- Production of agricultural innovations. - Capacity building & training. - Preparing qualified graduates to labor force. - Applied education based on new research outcomes.
Advisory	- Extension centers. - Extension department at agricultural directorates.	- Technology transfer. - Transferring problems to research. - Broker among AKIS actors. - Provision recommendations to the farmers. - Giving assistance in farm management. - Monitoring and evaluation implementing recommendations. - Planning, implementing, and evaluation of different extension methods and programs.
Private sector	- Agricultural companies. - Export companies. - Packaging plants	- Provision of input supplies. - Provision of technological facilities. - Linking to local and international markets. - Capacity building & training. - Investment. - Financial support for other actors.

Table A2. *Cont.*

Actors	Representatives (Governorate Level)	Tasks
Cooperatives	- Directorate of agricultural cooperatives. - Central agricultural cooperatives. - Agricultural cooperatives.	- Provision and subsidizing input supplies. - Linking farmers to markets. - Provision of agricultural machinery. - Broker among AKIS actors. - Financial support and loans to other actors. - Technical services. - Social services (women empowerment- Environment protection … etc.)
Credit	- Agricultural bank in the governorate and its branches in (12) districts.	- Financial transactions (credit facilities- deposit- withdrawal- loans … etc.)
Farmers	- Farmers in the governorate.	- Implementation of recommendations. - Increasing productivity. - Enhancing crop quality. - Application of disruptive technologies. - Conservation of natural resources.

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