Agricultural Systems 193 (2021) 103219

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

A functional analysis of the role of input suppliers in an agricultural innovation system: The case of small-scale irrigation in Kenya

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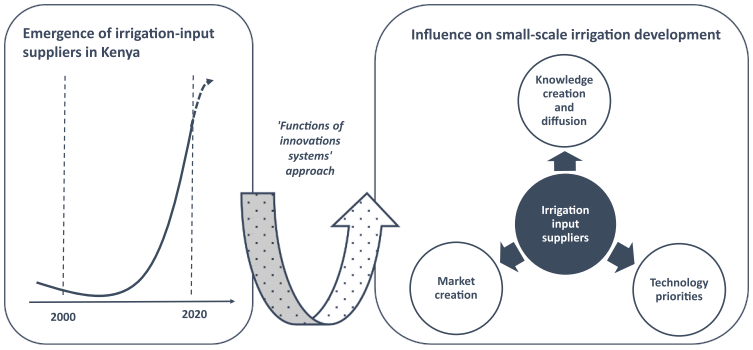
HIGHLIGHTS

- Input suppliers are important actors in agricultural innovation systems (AIS).
- We apply a 'functions' approach to study how input suppliers influence AIS.
- We present a case on suppliers of small-scale irrigation technologies in Kenya.
- Input suppliers influenced several functions in Kenya's small-scale irrigation AIS.
- The 'functions' approach enabled an in-depth analysis of input suppliers in AIS.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Laurens Klerkx

Keywords:
Agricultural innovation system
Small-scale irrigation
Input suppliers
Innovation system functions

ABSTRACT

CONTEXT: As a direct link between farmers and manufacturers of technologies, the characteristics and activities of input suppliers can be expected to play an important role in the generation and diffusion of innovations in agricultural systems. While the agricultural innovation systems (AIS) literature recognises the importance of input suppliers, there are few studies from the Global South assessing the nature and implications of their activities.

OBJECTIVE: The aim of this paper is to improve the understanding of how input suppliers can influence the functioning and development of AIS in the Global South.

METHODS: We first adapt the 'functions of innovation systems' framework to examine the role of these private-sector actors in an AIS, identifying three activity categories, through which input suppliers can influence the AIS: market creation for technological innovations, the creation and dissemination of knowledge, and influence on technology priorities. We then apply the framework to a case study of the small-scale irrigation sector in Kenya.

RESULTS AND CONCLUSION: The case study documents the emergence of a new cohort of irrigation-equipment suppliers during the period of strong growth in the market for small-scale irrigation technologies since 2000, and examines how they affect the small-scale irrigation agricultural innovation system (SIAIS). We find that Kenyan irrigation-input suppliers perform important activities and roles in the SIAIS aside input supply, notably provision of advisory services, improvement of the supply chain for irrigation technologies, introduction and adaptations of new types of irrigation equipment, and facilitation of access to farm credit. Irrigation-input suppliers

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https://doi.org/10.1016/j.agsy.2021.103219
Received 12 November 2020; Received in revised form 24 June 2021; Accepted 25 June 2021
Available online 9 July 2021

in Kenya thus play an important role in the functionality of the SIAIS, particularly regarding knowledge creation and dissemination.

SIGNIFICANCE: The novelty of the paper lies in its empirical assessment of input suppliers in the small-scale irrigation sector and its application of the functions framework. The paper shows that input suppliers can become effective agents of knowledge diffusion once the market has reached a sufficient size and documents how they contributed to knowledge development as they develop, adapt and test specific irrigation equipment. The paper also emphasises that input suppliers can form a key link between national AIS and foreign companies, as they bring in foreign expertise (know-how) to the market along with agricultural technologies. We therefore suggest that policy interventions in support of smallholder irrigation should seek leverage from the growth and capacities of input suppliers as a complement to public research and extension.

1. Introduction

Irrigation is a key technology for increasing agricultural productivity in the Global South, as it improves crop growth and crop quality in areas with irregular and low rates of precipitation (Xie et al., 2018). For smallholders, irrigation can be a transformational technology because of its potential to stabilize, increase and commercialize farm production, resulting in improved productivity and livelihoods (De Fraiture and Giordano, 2014; Izzi et al., 2021; Pittock et al., 2020). This paper examines smallholder irrigation in Kenya, where the market for small-scale irrigation is relatively well-developed for Sub-Saharan Africa (SSA) and there has been a considerable increase in the number of market actors in recent years (Mendes and Paglietti, 2015; USAID, 2016). Yet despite the large technical and economic potential of irrigation, use of irrigation technologies among smallholders remains low in Kenya (MALF, 2019; MWSI, 2019), as in other parts of SSA (Belder et al., 2007; Harrison, 2018; Oates et al., 2015; Venot et al., 2017). This suggests the existence of specific challenges or barriers to the development and diffusion of irrigation technologies among smallholders (Bjornlund et al., 2017; Froebrich et al., 2020).

In Kenya, the barriers include financial constraints (restricting access to credit to cover equipment and installation costs), a fragmented irrigation infrastructure (limiting access to irrigation water), uncertain agricultural market conditions (increasing the risks of investing in irrigation), inadequate natural conditions (e.g. water scarcities) and poorly functioning supply chains for irrigation technologies (limiting access to affordable and appropriate equipment) (Blank et al., 2002; GoK, 2013; Mendes and Paglietti, 2015; MWSI, 2019). Furthermore, barriers related to knowledge capacities locally are significant in respect of irrigation development among smallholders in SSA. That is because smallholders typically have little technical know-how and awareness of irrigation technologies (Mati, 2008; Mdemu et al., 2017), while public extension systems have often fallen short in providing the support and advisory services needed (Bjornlund et al., 2020; GoK, 2013). This has also been the situation in Kenya, where support services for smallholder irrigation have been inadequate (MWSI, 2019), and the extension system has lacked the technical capacity and services needed to raise awareness of, teach and demonstrate irrigation technologies among smallholders (Hornum and Bolwig, 2020; Kulecho and Weatherhead, 2005). This, in turn, has created a gap between technical capacity and smallholder needs (GoK, 2013).

Improvements in a range of factors and conditions for technological development and diffusion are thus needed to advance smallholder irrigation in SSA, including innovations in technologies, practices and business models, as well as improvements in infrastructure, markets and institutions at different scales (Froebrich et al., 2020). Agricultural Innovation Systems (AIS) have increasingly been used by scholars and development organisations as a framework for analysing and addressing the development and diffusion[1] of agricultural innovations in the Global South. AIS has been defined as *"a network of organisations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organisation into social and economic use"* (World Bank, 2007). Researchers have used the AIS framework to analyse the roles, activities and interactions of the many actors involved in creating, accessing and exchanging knowledge and technologies in AISs (Turner et al., 2016). These studies have explored how certain actors and conditions at different levels (country, sector, technology, or a combination of levels (Kernecker et al., 2021; Klerkx et al., 2012)) enable or hinder the diffusion of specific agricultural technologies (Hounkonnou et al., 2018; Ortiz et al., 2013; Yang et al., 2014). They thus provide insights into processes of agricultural innovation in different AIS and identifying sites of intervention for both governments and donors (World Bank, 2007).

Actors and their capacities, activities and interactions are the central components in studies of AIS (Spielman and Birner, 2008). Such actors include research organisations, regulatory bodies and extension services, as well as agricultural value-chain actors, particularly farmers, input suppliers, and food processors and distributors. Recently, there has been an increased interest in how actors outside the traditional research and extension system influence AIS (Klerkx et al., 2012; Knierim et al., 2015; USAID, 2019). In line with this trend, this paper focuses on suppliers of agricultural inputs and technologies (in short, input suppliers) as key actors in AIS. As a direct link between farmers (end-users) and technologies, input suppliers have power over the factors that shape the diffusion of these technologies, such as pricing, distribution networks, marketing and feedback from end-users (Lejars and Venot, 2017). Input suppliers are agribusinesses that manufacture, distribute and/or sell the inputs and equipment used in agricultural production (Rabatsky and Krause, 2017), such as seeds, fertilizers, tractors and irrigation systems. Input suppliers have connections to actors across the value chain, such as government organisations, international manufacturers, exporters

[1] Here we use the term 'diffusion' in the descriptive sense to denote the process whereby an innovation is increasingly adopted by the members of society (Rogers, 1995). In the AIS literature, the concept of diffusion is often associated with the 'transfer of technology' perspective and its more linear understanding of how innovations develop and spread across scales (i.e. from scientist to farmer) (World Bank, 2007). Contemporary AIS scholars instead see technical, social and economic change as the outcome of the whole innovation system (Klerkx et al., 2012), which is also the view taken in this paper. Some AIS studies, and in particular research on development initiatives, use 'scaling' instead as a concept to describe the dissemination and uptake of agricultural innovations (Minh et al., 2021; Schut et al., 2020), i.e. how innovations can go to 'scale' (Wigboldus et al., 2016)). However, we prefer the term 'diffusion', which is more widely used.

and other agribusinesses. As well as delivering the technology, input suppliers are in a position to provide information, develop and disseminate knowledge, mobilize finance and thus take part in agricultural innovations through their activities, capabilities and networks (USAID, 2019). Existing studies tend to focus on how input suppliers take part in agricultural extension and advisory systems (Faure et al., 2017; Zhou, 2015), and some observe that they have often fallen short of facilitating more systemic change among smallholders (Minh et al., 2020; Odame and Muange, 2011). Aside from research studies, international development organisations have supported input suppliers as a way to improve smallholder agriculture.[2] However, comprehensive analyses of how input suppliers influence other parts of an AIS are lacking.

Studies of small-scale irrigation in the Global South have documented the presence and roles of local wholesalers and retailers of irrigation equipment in national agricultural-input markets (Abric et al., 2017; Colenbrander and van Koppen, 2013; Garb and Friedlander, 2014; Namara et al., 2014). Research has documented how these irrigation technology suppliers (ITS) undertake a range of activities, ranging from the provision of technology, including delivery and installation, to training in agricultural practices, the facilitation of credit opportunities, linking farmers to markets and training in business development (Lejars et al., 2017; Mashnik et al., 2017; MWSI, 2019). A few studies have addressed how ITS takes part in agricultural innovation processes. Lejars and Venot (2017) showed how local retailers in Morocco became important 'innovation intermediaries' for the expansion of drip irrigation technologies, while Minh et al. (2020) described how ITS in Ghana have both developed (e.g. customized and bundled packages of irrigation equipment and service) and utilized innovations to overcome challenges in respect of financing and agricultural extension. Given the limited empirical evidence, there is reason to explore further how ITS contribute to the generation and diffusion of small-scale irrigation technologies.

Against this backdrop, this paper aims to improve understandings of the role of input suppliers in the functioning and development of agricultural innovation systems in the Global South. We perform a case study of ITSs in Kenya and ask how they contribute to the generation and diffusion of small-scale irrigation technologies? To address the question, we investigate how these actors fulfil key innovation system functions (Hekkert et al., 2007) through an analysis of their activities, strategies, capabilities and networks. An ITS can be considered an agricultural-input supplier specializing in irrigation. We define ITS as firms that sell and/or produce irrigation equipment, either as their only business activity or as an important part of their business. We exclude engineering firms and consultants that do not produce or sell irrigation equipment.

The paper is structured as follows. Section 2 presents the conceptual framework used in the paper and describes how input suppliers may influence the functionality of innovation systems. Section 3 describes the development of the SIAIS with a focus on the emergence of ITS, as well as setting out the methods of data collection and analysis. In Section 4, we analyse the role of ITS in small-scale irrigation development, based on how they take part in and affect the functions of the SIAIS. Section 5 reflects on the applied approach and discusses the contributions of the paper, while Section 6 provides a short conclusion.

2. Conceptual framework

2.1. Functional analysis of AIS

In this article, we show how the 'functions of innovation systems' approach, or functions approach (Hekkert et al., 2007), can be used to analyse the performance of an AIS (Klerkx et al., 2012). The innovation process is influenced by the structural composition of the innovation system, that is, the presence of actors, institutions and their networks (Bergek et al., 2008). The performance of these structures determines how so-called innovation-system functions can be successfully realised as the outcome of interactions between the actors in the system (Hekkert et al., 2011). The functionality of an innovation system such as the SIAIS is described through the fulfillment of seven functions, namely *entrepreneurial activities, market formation, resource mobilization, knowledge development, knowledge diffusion, guidance of the search*, and *creation of legitimacy*, all of which are fundamental to technological and institutional change. Functional analysis therefore focuses on the processes that are important for innovation systems to perform well, and it can also elucidate how certain structures affect innovation-system functionality (Bergek et al., 2008; Hekkert et al., 2007).

Several functional assessments of AIS have been carried out in recent years. For example, Turner et al. (2016) and Lamprinopoulou et al. (2014) analysed AIS functionality nationally, while Eastwood et al. (2017) applied the approach to examine the role of public and private research and extension in precision-farming innovation systems. The approach has also been promoted as a promising avenue for investigating AIS in the Global South (Rajalahti et al., 2008), where functional assessments have been carried out to explain failures and identify opportunities to enhance the innovation capacity of specific AIS at the national-sectoral (Kebebe et al., 2015), regional (Minh, 2019) and technological levels (Schiller et al., 2019; Sixt et al., 2018).

In this paper, we use the functions approach to examine the role of a specific actor (input suppliers) in an AIS. We specifically analyse how input suppliers influence small-scale irrigation development in Kenya through three categories of activity, each covering several innovation-system functions: market creation for technological innovations, the creation and dissemination of knowledge, and influence on technology priorities.

2.2. Assessing the influence of agricultural input suppliers on innovation-system functionality

Innovation system functions can be assessed using proxy activities as indicators of the respective function (Bergek et al., 2008; Hekkert et al., 2007), while examining how actors take part in these activities can reveal how they contribute to each function. Hence, studying the activities of input suppliers and their interactions with other structures in the AIS enables us to identify the mechanisms through which the input suppliers can influence innovation system performance. To put this idea into practice, in the remainder of this section we describe how input suppliers can take part in AIS through their activities and interactions with other actors, and then review the existing research on input suppliers with regard to how they shape AIS functionality. The review is based on the literature on AIS (e.g. Kilelu et al. (2013), Knierim et al. (2015), Kernecker et al. (2021)) and small-scale irrigation development in the Global South (e.g. Abric et al. (2017), Froebrich et al. (2020), Lejars et al. (2017)).

Actors guide, support, generate, diffuse and adopt agricultural innovations (OECD, 2013) and consist broadly of individuals, groups, organisations and corporate actors (Knierim et al., 2015). As actors interact and share knowledge throughout the innovation process (Klerkx et al., 2012), unfolding these interactions can provide insights into how a particular innovation develops (Hermans et al., 2013). Actors can take on the roles of *developer, supporter* and/or *implementer of innovations*, roles that are dynamic because they entangle actors in changing settings that might either support or disable them (Kernecker et al., 2021). Here it is useful to distinguish between *product* and *process* innovations (Meeus and Edquist, 2006). Product innovations entail the introduction of a good or service that is new to the market or has improved features. In the case of SIAIS, this translates into an ITS producing, importing or adapting new irrigation technologies, as well as the auxiliary services

[2] Recent examples in Kenya include USAID's Kenya Agro-dealer Strengthening Program and UNDP's Agribusiness Supplier Development Programme.

they offer. Process innovations are new or improved business processes potentially effecting changes in organizational structure, marketing, external relations, or production and delivery methods.

Furthermore, it is important to consider how much power or ability an actor has to influence AIS performance. This can be understood through the concept of agency, defined as the actors' ability to intervene in and make a difference to the course of events, including the exercise of political, economic and institutional power (Smith et al., 2005). In this paper, we are concerned with the agency of input suppliers with respect to the performance of the SIAIS in Kenya.

Input suppliers can have links with multiple actors in the AIS, not just farmers, but also manufacturers, exporters, financers, R&D institutions, government agencies and donor organisations. These links can facilitate flows of funds, skills and knowledge, which can take place through market transactions and interactions in formal and informal company alliances, user-supplier networks, public-private partnerships, etc. (Meeus and Edquist, 2006). Based on existing innovation-system frameworks (Kuhlmann and Arnold, 2001; Spielman and Birner, 2008), for the purposes of this paper we have developed a framework that places input suppliers at the centre of the AIS and value chain for agricultural technologies and services (Fig. 1). In the framework, input suppliers have links to multiple actors in the AIS, both in the value chain for agricultural technologies and services and to other supporting actors. Furthermore, input suppliers and their links are embedded in an enabling environment, which denotes the range of institutional, economic and political conditions that are conducive for the innovation system and the diffusion of innovations (Nygaard et al., 2015). These broader framework conditions, such as agricultural product markets, the financial environment, agricultural and water policies, and informal institutions (i.e. attitudes, norms and behaviour) are important to take into account as they create incentives or disincentives for input suppliers and thus shape how they take part in AIS development. The framework is a conceptualisation of how input suppliers take part in and contribute to AIS functionality through their activities and interactions with other AIS actors and structures. Hence, we use it to analyse the role of input suppliers in (irrigated) AIS performance using the functions approach (Table 1). The following sub-sections unfold this framework and use it as a point of departure for discussing the contribution of agricultural input suppliers in the Global South to innovation system functions in the context of small-scale irrigation in Kenya.

2.2.1. *Market creation for technological innovations*

The innovation-system function of *market formation* is often understood as demand creation through policy interventions such as changes to the tax regime, investment regulations and infrastructure (Bergek et al., 2008; Hekkert et al., 2007), a process that is mainly carried out by the public sector. Yet studies of irrigation in the Global South stress how the presence of ITS is vital for a well-functioning value chain and hence for market creation. For example, Bosma (2016) demonstrates the importance of local suppliers in increasing the use of petrol pumps for irrigation in western Kenya. Lejars and Venot (2017) show how the evolving network of local retailers of drip irrigation enabled a rapid expansion of this technology in the Säiss region of Morocco, while Abric et al. (2017) observe how an organized network of suppliers of low-cost irrigation technologies successfully improved supply-chain development in Niger and Burkina Faso. Similarly, de Vries et al. (2006), (p. 24) note how an irrigation supplier in Kenya and Tanzania *"encourages and assists micro and small enterprises to distribute (as dealers or retailers) these technologies to make them widely available."* Moreover, Colenbrander and van Koppen (2013) found that the value chain for motorised irrigation pumps is underdeveloped in Zambia, reminding us that the lack of irrigation suppliers in rural areas remains a challenge in creating

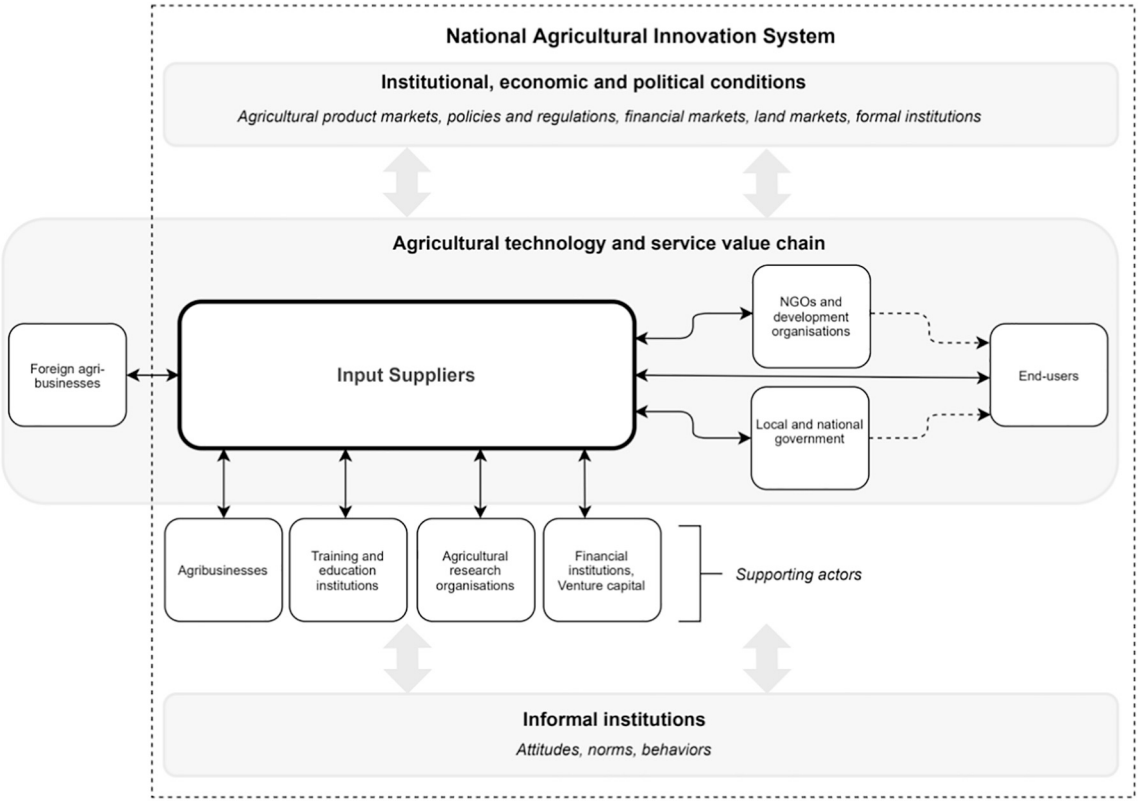

Fig. 1. Analytical framework: input suppliers and their connections to other actors and structures in an AIS in the Global South, i.e. actors in the value chain for agricultural technologies and services and supporting actors, as well as political, institutional, economic conditions and informal institutions that foster or impede innovation.
Source: based on Kuhlmann and Arnold (2001) and Spielman and Birner (2008).

Table 1
The role of input suppliers in AIS assessed through the seven innovation-system functions, with a focus on small-scale irrigation. The functions are grouped into three activity categories through which input suppliers can influence the generation and diffusion of agricultural technologies: market creation for technological innovations, the creation and dissemination of knowledge, and influence on technology priorities. Based on Bergek et al. (2008) and Hekkert et al. (2007).

Activity category	Innovation-system function	Function description	Indicators for examining the role of input suppliers
Market creation for technological innovations	*1.Entrepreneurial activities*	Entrepreneurs (such as farmers, agri-exporters, input suppliers, etc.) turn the potential of new knowledge, networks, and markets into concrete actions to develop and capitalize on business opportunities.	Entry of input suppliers, their activities, and how they experiment to exploit business opportunities
	2. Market formation	Market formation and demand creation through e.g. tax regime, change in regulations, and investment in irrigation infrastructure complementary to the innovation.	Input suppliers participating in (public) tendering processes, increase in imports due to change in tax regime.
	3. Resource mobilization	Activities related to mobilizing financial, human and physical resources needed.	Input suppliers involved with provision of loans, mobilization of technical capacities, and mobilization of new technologies.
Creation and dissemination of knowledge	4. *Knowledge development*	Process of learning and developing knowledge through formal research (e.g. at universities and research centres), the private sector (e.g. agri-input supplier, irrigation input suppliers), or at the individual level (e.g. farmers).	Participation in demonstration projects and pilots of technologies.
	5. Knowledge diffusion	The exchange of information through networks, where research and development (R&D) meets government and markets (including suppliers and end-user).	Training and support services to farmers, participation in farmer field days, and partnerships with public and private sector with provision of consultative services.
Influencing technology priorities	6. *Guidance of the search*	Activities that set a clear vision about the future of irrigation, e.g. national irrigation plans, bills, government targets around technologies. Also activities that positively affect the visibility and clarity of demands from farmers.	Awareness campaigns and success stories making the needs of farmers clearer.
	7. *Creation of legitimacy*	Advocacy to overcome potential resistance to a new technology (benefit of modern irrigation, i.e. drip irrigation versus incumbent, conventional furrow irrigation).	Input suppliers advocating for technologies.

markets for irrigation technologies among smallholders. Indeed, ITS can be an important way of articulating the demand for irrigation from smallholders (cf. USAID (2019)). Based on the above, we expect that a strong presence of ITS in both national and local markets is important for the creation of a well-functioning market for irrigation technologies.

Input suppliers also have power over what kinds of technology are available in the market and how fast new technologies are introduced in national markets, thereby influencing farmers' responses to new opportunities or requirements (World Bank, 2007). This suggests that input suppliers are in a position to influence *resource mobilization* in an AIS by introducing technologies to farmers. Moreover, studies of smallholder irrigation in the Global South have shown how ITS create a link between financial institutions and farmers by helping the latter access credit and subsidies (Abric et al., 2017; Babu and Zhou, 2015; Lejars and Venot, 2017).

Finally, researchers and practitioners have recently highlighted the provision of bundled packages of technology and services as key innovative solutions to boost irrigation development for smallholders (Nance et al., 2020). In Kenya, Kilelu et al. (2019) show how input suppliers may take advantage of the business opportunities created by the increased demand for advisory services from the growing middle class. Lejars et al. (2017) observe that ITS in Morocco have capitalised on absent or weak institutions regarding agricultural credit, training and technical advice. Therefore, input suppliers can be important to the function of *entrepreneurial* activities, and the entry of new firms is commonly used as an indicator of this function (Bergek et al., 2008).

2.2.2. Creation and dissemination of knowledge

Input suppliers can contribute to the creation and dissemination of knowledge in an AIS through the provision of extension and advisory services to farmers. They can also be an important source of technical knowledge for farmers (Aerni et al., 2015; Christoplos, 2010), as they provide advisory services as part of their marketing and sales activities (Faure et al., 2017; USAID, 2019). This function has been described as 'brokering as a side activity' (Kilelu et al., 2011; Klerkx et al., 2009). In the Global South, van Veldhuizen et al. (2018) observe that input suppliers are increasingly providing services to small and medium-size farmers, while Cristóvão et al. (2012) argue that these and other private-sector actors are increasingly being recognised as important providers of technical assistance and support services to farmers. This is in part because input suppliers are often the main or only connection between farmers and input markets (Stewart and Hyysalo, 2008), placing them in a privileged position to provide technical advice, market information and other services (van Veldhuizen et al., 2018). For example, Mirani et al. (2007) mention that suppliers of agricultural pesticides and fertilizers are the most influential sources of information about agricultural inputs for smallholders in India.

ITS are important actors in the local dissemination of knowledge relating to irrigation systems (Abric et al., 2017; Izzi et al., 2021; Mendes and Paglietti, 2015; MWSI, 2019), making them an important actor for *knowledge diffusion* in SIAIS. Hence, Wanvoeke et al. (2015) found that local ITS in Burkina Faso provide important agricultural services, and noted that many of these firms rely on donor-funded irrigation projects, which often pay for their services. ITS can also play an active role in reconfiguring technological innovations (Lejars and Venot, 2017), which can involve adapting or "translating" (Garb and Friedlander, 2014) the hardware to the local context, as Benouniche et al. (2014) reported for Morocco. These insights suggest that ITS take part in developing practical knowledge for the local context, although activities related to *knowledge development* might mainly be carried out in external markets and/or by public and private research institutions.

2.2.3. Influencing technology priorities

Input suppliers may influence technology priorities in agricultural markets, i.e. the acceptance of a technology and its preference over incumbent technologies among both technology end-users and policymakers. How irrigation technologies are perceived by various actors, especially the end-users, and whether there is a clear vision in the sector regarding technology priorities, are important factors in developing small-scale irrigation systems. As innovative technologies often meet resistance from established actors in the innovation system, actors will need to lobby and support the technology for the innovation system to develop (Hekkert et al., 2011). Hence, activities that help to influence priority-setting (*guidance of the search*) and enhance social acceptance of the technology (*creation of legitimacy*) are important to AIS functionality. As input suppliers attempt to bring specific technologies to market, their

advocacy of the benefits of technologies may help overcome resistance among smallholders and intermediate actors like development projects.

As guidance regarding search activities are related to making the needs of technology users visible (Hekkert et al., 2007), input suppliers may also influence AIS functionality by advocating specific irrigation technologies and arguing how they benefit smallholders. Depending on their agency, these activities can create a positive agenda regarding the future of the technology and thus influence the priorities of other actors such as project- and policy-makers.

The functions approach, as set out above, can help identify and analyse the activities through which input suppliers take part in and influence an AIS, thereby enabling a nuanced analysis of the role of private-sector actors in the generation and diffusion of agricultural innovations in the Global South. In the following sections, we apply the approach to a case study of small-scale irrigation in Kenya.

3. Methods

3.1. Methods of data collection and analysis

Our case study is based on semi-structured interviews (primary data), complemented by a literature review (secondary data), a common method in AIS studies (Amankwah et al., 2012; Eastwood et al., 2017; Minh, 2019; Sixt et al., 2018; Turner et al., 2016). Using snowball sampling, we created a list of potential interviewees and scheduled interviews between December 2019 and January 2020. Twenty-seven interviews were conducted with a diversity of actors: ITS (7 interviews), farmers (5), research organisations (5), public-sector organisations (5), financiers (4), and a civil-society donor organisation (1) (see Supplementary Material A5). These stakeholders were included to achieve a comprehensive understanding of the functions and structures of the SIAIS.

The ITS we interviewed ranged from newly established small and medium enterprises (SMEs) to larger, well-established businesses. All were private firms trading in and/or manufacturing equipment used in irrigation, either as their only business activity or as an important part of their business. Interviews with public-sector organisations covered national (e.g. NIA and Ministry of Water & Sanitation and Irrigation (MWSI)) and county-level actors (the county irrigation department), while the research organisations were researchers from national universities, public agricultural research institutions and multilateral research organisations. Financiers included both commercial banks and private-sector investors. Focus-group interviews with two smallholder cooperatives (four and ten interviewees respectively) in community-based irrigation schemes were also conducted, along with ten farm visits and three informal interviews with smallholders.

Interview guides were developed for each stakeholder type and consisted of overarching questions with probing follow-up questions (see Supplementary material A6). The questions were designed to cover aspects of the conceptual framework with a focus on the development of the SIAIS and its actors, structure and interactions. The guides were continuously revised as more data were gathered to capture more relevant and more targeted responses. Each interview was conducted in person (24) or over Skype (3) by the first author and lasted between 45 and 90 min. The semi-structured interviews were audio-recorded and supplemented by notetaking during the interview. Follow-up emails were sent out to some interviewees to clarify issues and collect missing data.

The interviews were transcribed for analysis, and Atlas.ti 8 software (Version 8.4.15.0) was used to code interview responses based on system functions and issues related to the development of the irrigation market. This was done by manually screening the transcribed interview and grouped interview responses into the corresponding function, or into general information about the development of the small-scale irrigation sector. Secondary data, including national policy documents (GoK, 2013; JICA, 2013; MALF, 2019; MWSI, 2019), reports from international research centres (Mendes and Paglietti, 2015; Ngigi, 2002; Sijali and Okumu, 2002; USAID, 2016) and peer-reviewed literature on smallholder irrigation in Kenya (Kulecho and Weatherhead, 2006; Mati, 2008; You et al., 2014), were used to supplement the interviews and to gain important contextual insights about the irrigation sector and the development of the market for small-scale irrigation. Quotes from interviews are used to underpin the findings from the case study.

3.2. Introduction to case study: development of the Kenyan SIAIS

When analysing the SIAIS, it is important to identify its different phases of development, as the structures and functioning of the system evolve through the development and diffusion of small-scale irrigation technologies. Ideally, as the development of a (technological) innovation moves through four distinct phases – *pre-development, development, take-off* and *acceleration* – the structure and functioning of the innovation system vary between the phases (Hekkert et al., 2011). Hence, the presence and quality of specific actors will also vary according to the phase of technological development.

We analysed the development of the SIAIS in Kenya based on interviews and a review of documents, and used the four phases as a stylised model to look for general, long-term trends in a technology area (i.e. 'modern irrigation'). This development roughly can be divided into two phases, a *development phase (1960–1999)* and a *take-off phase (2000−2020)*. The first phase is characterised by a great increase in government- and donor-supported irrigation schemes or programmes, the second by the entry of an increasing number of private-sector actors into the irrigation market. Fig. 2 illustrates in a stylised way this development in the diffusion of modern irrigation technologies in Kenya (the dark-blue arrow), key features of the phases (bottom arrows), and entry of ITS. We note that technology diffusion in reality, and when considering shorter time intervals (and specific technological innovations, e.g. sensor-based irrigation technologies), is more complex and cyclical, and that the adoption of agricultural technologies might not be linear in the way implied by such idealisation (see e.g. Glover et al. (2019)).

The remainder of this section describes the development of the SIAIS during the two phases before analysing the business strategies of the ITS regarding their role in the innovation system today.

3.2.1. Development phase (1960–1999): government projects and donor support

Independence from Britain in 1963 marked the entry of the public sector into the development of irrigation in Kenya. Since then, irrigation development for smallholders has depended strongly on public-sector projects. The Irrigation Act of 1966 established the National Irrigation Authority (NIA), which was followed by an expansion of large-scale irrigation schemes. These schemes relied primarily on surface irrigation (furrow) and today include the Mwea, Bura, Tana, Ahero, West Kano, Perkerra and Bunyala schemes. While the total area covered by these schemes remained stable from 1975 to 2000, the period saw a large growth in small-scale (smallholder community-based) schemes, as well as private commercial schemes (large commercial farms) (Ngigi, 2002). From 1975 to 1998, the area covered by community-based schemes increased from 2400 ha to 34,650 ha, while private commercial irrigation schemes grew in area from 10,000 ha to 40,700 ha (Ngigi, 2002). The growth in community-based schemes especially can be attributed to the involvement of the government and international donors (Ngigi, 2002; Scheltema, 2002).

Modern irrigation technologies were deployed during these developments. Sprinkler irrigation was introduced in 1975 in a pilot scheme, the Kibirigwi Irrigation Scheme (Mwangi, 1990), being used throughout the 1970s and 1980s on coffee and pineapple plantations (Blank et al., 2002). During the late 1980s and early 1990s, sprinklers and drip irrigation were adopted by large-scale horticulture and floriculture farms, but not by smallholders due to the high costs involved

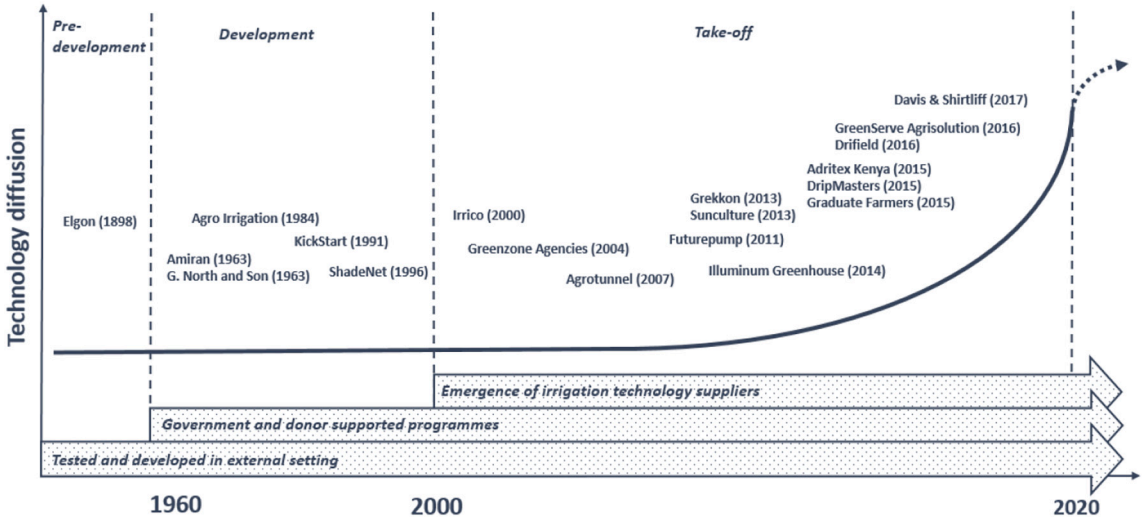

Fig. 2. Phases of development in the diffusion of modern irrigation technologies in Kenya, and overview of when irrigation companies in Kenya were founded or entered the sector.
Source: Based on Hekkert et al. (2011).

(Sijali and Okumu, 2002). Early activities with small-scale drip irrigation were carried out by Good Samaritan Christian missionaries from 1988. In 1996, the Kenya Agricultural Research Institute (KARI; today the Kenya Agricultural & Livestock Research Organization, KALRO) became involved in small-scale drip-irrigation technology through a community-development program in Eldoret (Sijali and Okumu, 2002). With support from USAID and the World Bank, KARI played the leading role in testing, developing and distributing drip kits during this period (Keller, 2014). By 2001, KARI had sold five thousand kits to Kenyan smallholders, the majority through small-scale irrigation projects involving donors, NGOs and government agencies. The perception arose during the 1990s that drip irrigation was effective in enabling agricultural intensification, saving water and improving incomes (Burney et al., 2013; Postel et al., 2001). This contributed to the creation of a positive attitude to drip irrigation that motivated many donors and NGOs to develop drip irrigation projects, especially in the arid- and semi-arid regions of the country (Sijali and Okumu, 2002). These trends in drip-irrigation resemble those observed for other small-scale irrigation technologies, in particular sprinkler irrigation and, more recently, solar PV pumps.

3.2.2. *Take-off phase (2000–2020): growth in irrigation suppliers and technology commercialisation*

This section concerns the period from 2000 to 2020, when modern irrigation technologies entered a phase of broader diffusion (*take-off*), and a large number of ITS entered the market. The development of the market for small-scale irrigation equipment and services continued to depend on donor- or government-supported schemes during this period. Irrigation became an increasing political priority in Kenya, and the government published several strategies, policies and regulations impacting on the irrigation sector (see Supplementary Material A1).

The take-off phase saw growth in the area under irrigation: in 1990 the share of arable land equipped with irrigation stood at 0.99%, by 2000 it accounted for 1.58%, and in 2017 it reached 2.38% (FAO, 2020). This growth has been attributed especially to the development of community-based irrigation schemes, which today account for around half of the area under irrigation in Kenya (MWSI, 2019). At the same time, a large increase in the number of small and medium-size farmers adopting irrigation technologies occurred during this period, some as part of an irrigation scheme, others irrigating on an individual basis.[3] As one input supplier noted, "the growth in the smallholder area is much faster than in the traditional large-scale farms" (Interview 22). The growth in small-scale irrigation was partly driven by an increasing middle class investing in irrigation for rural or urban farming or back-yard gardening. This expansion of small-scale irrigation has promoted substantial growth in the market for small-scale irrigation technologies and services.

Alongside the increasing area under small-scale irrigation, this period also saw a significant increase in the number of irrigation equipment suppliers, especially from 2010. This study identified nineteen such suppliers operating in Kenya in 2020 (Fig. 2), including large irrigation retailers or wholesalers (trading companies), SME retailers or wholesalers, and equipment manufacturers (see Supplementary Material A2). Before 2000 there were only a few specialised ITS on the market, namely Amiran, G. North and Son, and Agro Irrigation, all large firms, while a large agricultural input supplier (Elgon Kenya) sold irrigation equipment as a minor part of its product portfolio. In addition, there were a few pipe manufacturers (including Shade Net, which also produces drip lines) and a small producer of manual pumps (KickStart). From 2000, however, twelve new suppliers entered the sector, nine of them after 2010. Among these new entrants, nine are SMEs and two (Davis & Shirtliff, and Irrico International) are large firms. This trend changed the size structure of the sector towards a higher share of small companies.

3.3. *Technological boundaries of the case study*

This paper focuses on modern irrigation systems and the equipment supporting these systems, which have often been mentioned as innovative approaches to improving food security and livelihoods in SSA and are promoted as low-cost, easy-to-operate, water-efficient technologies (Keller, 2014; Kulecho and Weatherhead, 2006; Sijali and Okumu, 2002; Woltering et al., 2011). Traditional smallholder irrigation practices in Kenya consist of manually fetching water from a river or other water

[3] The extent of individual irrigation is not known due to its informal nature and lack of survey data, but other studies from the Global South have demonstrated its importance (Beekman et al., 2014; Woodhouse et al., 2017).

body or using gravitational furrow systems. These practices are highly labour-intensive and limit the irrigated area, but they require few materials and little equipment, making them less interesting for ITS. Modern irrigation technologies, on the other hand, provide more business opportunities for the private sector (Hornum and Bolwig, 2020). They include drip and sprinkler irrigation, as well as the enabling components, notably water pumps (solar, fuel, grid-powered) and water-storage facilities, especially water tanks and dam-liners for water storage and harvesting (see Supplementary Materials A3 and A4).

4. Results: the role of input suppliers in small-scale irrigation agricultural innovation systems

This section analyses the contributions of ITS to small-scale irrigation development in Kenya in terms of how they influence SIAIS functionality through the three main mechanisms outlined in Section 2.2. It also summarises these findings based on the analytical framework (Fig. 1).

4.1. Market creation for irrigation technologies

4.1.1. Entrepreneurial activity

Entrepreneurial activities by ITS were evident in the *take-off* phase, with an increasing number of new entrants into the market since early 2000. This was in part due to a demand for irrigation equipment and services from donor- or government-supported irrigation projects, as it created a window of opportunity for ITS, whose entry as entrepreneurs did not occur until the market had grown to a sufficient size. ITS had a broad range of clients, including government institutions (e.g. Ministry of Agriculture, Livestock and Fisheries (MALF), MWSI, and county governments), international development organisations (e.g. African Development Bank, World Bank, bilateral donors), NGOs (e.g. World Vision, Care, International Committee of the Red Cross), retailers and farmers. As smallholders can be difficult to reach, individual sales to the small-scale segment were largely confined to commercially oriented smallholders and customers with another main occupation than farming. Consequently, sales to irrigation projects through framework contract agreements, especially in the small-scale segment, were an important share of total sales. Indeed, building networks and collaborating with public agencies, NGOs and donors was an important strategy for reaching the small-scale segment. This was especially the case for leading ITS such as Amiran, Irrico and G.North and Son, who have the capacity to deliver and install large quantities of irrigation equipment and offer training in its use: "We do a lot of tendering. For example, where county governments procure irrigation kits and greenhouses and, through us, take it to individual farmers" (Interview 22). Hence, ITS relied on an intermediate demand for irrigation equipment and consultancies from irrigation projects established by the government, development organisations and NGOs.

An ITS explained how it attempts to innovate its business model (*process innovation*) by connecting actors and services: "(…) there's a lot of creativity and innovation in most of the private sector. We are the people that interact with farmers, supply them with the technology and connect them to financial service providers and agricultural produce buyers. So, we are playing in the middle, looking for an innovative way to integrate all these solutions into one" (Interview 22). ITSs were also active in introducing new technological innovations to the market, i.e. new types of equipment and improvements or additions to existing technologies, this being important for the development of the SIAIS. Some Kenyan manufacturing companies engaged in product innovation, notably the low-cost solar PV pumps produced by SunCulture, FuturePumps and KickStart. However, most irrigation companies imported their equipment. ITSs also contributed to product innovation through the adaptation of imported irrigation systems to the local context. This took place through testing, giving feedback and providing data to foreign equipment manufacturers trying to introduce and adapt their products (e.g. water pumps) to the Kenyan market, as well as by bringing together different equipment and components into custom-made solutions: "That in a sense makes us traders, but also we remain open to develop our own solutions if we see a gap which we can fulfil in the irrigation space. (…) We work with other existing solutions out there in the market that we pilot, assess, and adapt so the product is a competitive solution to smallholder farmers" (Interview 22).

Some leading ITS also engaged in entrepreneurial activities, as they worked with public research organisations (KALRO) to develop and trial technical solutions adapted to a Kenyan context. A key motivation here was the perception that development projects often failed to introduce appropriate irrigation equipment, e.g. drip kits or sprinkler systems, as they were based "on the assumption that it is going to work here. Then it comes, it doesn't work. That is when we realized that probably we tweak it a bit" (Interview 23).

4.1.2. Market formation

Government- and donor-funded schemes were important for the *market formation* of irrigation technologies, as they created business opportunities for ITSs. Public-sector activities to expand irrigation infrastructure, such as dams or conveyance systems with an intake at each farm, also increased the volume of potential technology users, as a growing number of small-scale farmers gained access to irrigation water. Hence, the development of the market for irrigation equipment and services in recent years can in part be attributed to public-sector efforts to expand irrigation. While irrigation projects were an important part of ITS' business with smallholders, ITS also played an important role in these projects. One researcher explained how ITS are "effective in working with projects like ours to actually get to the rural area and then appointing engineers or technicians who could install the irrigation system" (Interview 18). Many ITS employed agronomists and other technical experts in irrigation at local branches across the country to ensure that they could deliver support services locally (Amiran, Irrico, Davis & Shirtliff, G. North and Son). Alternatively, external rural agents were used to perform this function (e.g. Greenserve Agrisolutions).

The growing ITS supply chain increased the demand for irrigation technologies and in turn had a positive influence on market formation. That is because ITS made an expanding variety of irrigation technologies available and accessible to smallholders. This finding coincides with other studies of small-scale irrigation in SSA (Abric et al., 2017; Colenbrander and van Koppen, 2013; Lejars and Venot, 2017; de Vries et al., 2006) showing the importance of local ITSs for the articulation of demand. The growth in the number of ITS and their physical presence, in particular in rural areas, was also an important complement to public-sector efforts to expand smallholder irrigation. One ITS representative confirmed that "(…) government or public institutions actually rely on the private sector to provide these technologies. Automation [automated irrigation systems] is just an example. A lot of innovations that will enable farmers to do better farming, they're not with the government. So they look up to the private sector to provide these technologies" (Interview 24). Indeed, ITS were important in ensuring the availability and provision of technology, but they also played a role in establishing niche markets for new irrigation technologies (linking with *entrepreneurial activities*).

4.1.3. Resource mobilization

ITS created networks between farmers and financial products, other ITS and produce buyers, thereby enabling a flow of resources along irrigated agricultural value chains. While *resource mobilization* is primarily seen as a task for government and development organisations, ITS not only took advantage of the market these activities created, they also actively resource mobilization financial and human resources to gain market share.

ITS mobilized human resources as they built up technical capacities within specific irrigation technologies. Through their partnerships with world leading irrigation companies (e.g. manufacturers like Netafim (Israel) and Jain Irrigation Systems (India)), they brought foreign

expertise to the market along with premium irrigation hardware. This was also the case for foreign-owned companies (e.g. Amiran or Kick-Start). Moreover, interviewees stressed that access to affordable finance was a key constraint on smallholders' ability to access new technology and that existing agricultural loan products were beyond their reach or unattractive to them. Therefore, ITS explored financial arrangements to reach more farmers, and there are several examples of technology being bundled with finance (Table 2). As suppliers developed financial solutions as a strategy or business model to reach larger numbers of farmers, these solutions can be regarded as organizational innovations (see Zott et al. (2011); Sarasini and Linder (2018)).

For example, some suppliers offered flexible payment plans, and most suppliers also had agreements with micro-financial institutions: "If you tell them [smallholders] that the cost of technology is $200, they don't have it, despite the fact that they need it. So we link them up with micro-financial institutions who can give them credit to access the technology (…)" (Interview 24). Several of the large irrigation companies connected with commercial banks offered some customers a payback arrangement subject to a risk assessment and a loan history. For example, Davis & Shirtliff designed a loan product for its solar pumps together with Equity Bank, whereby the company creates a project plan together with the farmer, who then takes the offer to Equity Bank for credit. For its greenhouse system, Irrico signed an MoU with KCB bank, setting up a buy-back guarantee for farmers. In cases of default, Irrico takes back the irrigation equipment (at a reduced price) to help the farmer pay back the loan. This works as an insurance for the farmer and mitigates the risk to the investment. These ITS assumed a brokering role linking smallholders "to some of the institutes who might be able to do financing" (Interview 22).

While most companies did not offer any formal financial packages bundled with their products, SunCulture and Futurepump had a pay-as-you-go model, where farmers pay for using the solar-PV water pumps on a use basis. These systems, built on ICT, are linked to usage meters, enabled by Kenya's well-developed mobile network coverage. Such innovative solutions seem to be an effective business model, as they make the irrigation equipment financially available to more smallholders. However, many smallholders could still not afford the bundled technology and services, despite ITS's partnership with financial institutions and their efforts to design credit solutions. While these innovative activities proved helpful in the diffusion of small-scale irrigation, support from donors, development finance institutions and government was still needed to close the affordability gap experienced by many smallholder farmers.

4.2. Creation and dissemination of knowledge

4.2.1. Knowledge development

ITS were also active in knowledge development, as they worked with public research organisations (KALRO) and NGOs to develop and test specific irrigation technologies. For example, ITS invested in pilots of irrigation equipment and co-developed knowledge through irrigation projects, thereby helping to adapt these technologies to the local context. Through such learning-by-doing activities ITS contributed to knowledge development (see Suurs et al. (2009)), as they built up technical capacities within specific technology segments. Moreover, ITS played a notable role in knowledge development through imports and the introduction of specific irrigation technologies. In fact, they were sometimes the leading experts in the latter technologies, making them an important source of information for agricultural research institutions. As one input supplier argued: "Of course, some of the technologies that we create or bring in at times get them flat footed. So, a number of times we are ahead with them with technology. That being the case, they also take time to learn from us" (Interview 23).

4.2.2. Knowledge diffusion

The irrigation sector experienced an increase in the range and volume of extension and advisory services offered by suppliers of irrigation equipment. Accordingly, all ITSs offered technical advice and consultancy services bundled with irrigation equipment as part of their sales and outreach strategy. This development was in part due to a demand created by the growing number of medium-size farms and middle-class customers who farm as a side business (see also Kilelu et al. (2019)). The demand for such private agricultural extension services grew as a result of an inadequate public extension system that lacked technical capacity in irrigation at the county level, according to several interviewees. For example, public extension agents did not have the technical knowledge to assist with repairs or common problems such as blockages or pipes clogging up. The public extension system had seen a decline since the late 1980s, mainly due to reduced funding for extension staff, and today the ratio of extension agents to farmers stands at 1:1000, compared to the desired level in the National Agricultural Sector Extension Policy (NASEP) of 1:400 (GoK, 2012). This situation created new business opportunities for the irrigation companies, for whom the provision of consultative and support services for irrigation schemes became a key part of their business.

The services provided by the irrigation companies ranged from support services delivered as part of the provision of technology and after-sales services to broader agricultural services, including crop management, business planning and linking to markets (see Table 2). The observed service provision also reflects the complexity of irrigation technologies and the need for the careful design of irrigation solutions to fit specific farm conditions and crop needs. Indeed, one supplier observed that selling irrigation technologies involves selling know-how, as these technologies were often new to farmers, while another noted: "We don't just sell our products, we sell solutions (….) In the case of small-scale farmers, a lot of them have no idea what they really want"

Table 2
Summary of customer support services provided by ITS in Kenya.

Service category	Support services	Description
Financial	Provision of financial services	Access to credit through loan products tailored with and offered through financial institutions, payback arrangements (subject to risk assessment), and pay-as-you-go finance models.
Technical	Training in and demonstrations of irrigation systems	Training in irrigation practices, including operation and maintenance of the equipment. Permanent demonstration site showcasing equipment to farmers, as well as participation in agro-fairs to undertake demonstrations.
	Design and installation of irrigation equipment	Customizing irrigation solutions to fit the needs of clients, as well as the installation of irrigation equipment.
	Provision of irrigation operation and maintenance service	After-sale maintenance of irrigation systems in cases of operational difficulties or malfunctioning equipment
Output and input markets	Provide market information and assist in marketing	Guiding farmers to identify and select from the available market options, including linking farmers to buyers (wholesalers and exporters).
	Provision of agri-inputs and training in crop management	Providing farmers with agricultural inputs (e.g. fertilizer and seeds) and training them in making optimal applications with an irrigation system (including fertigation and crop management).
Management	Management of farm production and economy	Helping farmers develop production and business plans, e.g. training and business advisory services.

(Interview 22). Hence, aside from informing customers about irrigation products and their potential, to varying degrees ITS offered suites of support services demonstrating, designing, installing, and assisting in maintaining and operating the irrigation equipment.

All the ITS had technical experts in-house and performed consultative services for individual customers. They also disseminated knowledge through public irrigation projects and during field days, where they took charge of demonstrations of technology. One supplier stated: "(…) the first thing we do in these projects is to create awareness through advocacy, as we want to get the critical mass aware of irrigation" (Interview 24). Many of the larger suppliers had formal agreements or MoUs through which they not only provided technologies but also disseminated knowledge. For example, Irrico partnered with MALF in demonstrating greenhouses and involved its staff in training the use of drip irrigation systems installed in greenhouses. ITS also signed MoUs with NGOs for the installation of and training in irrigation equipment, including drip kits and polytunnels, as part of different projects. They were aware that selling irrigation equipment needs to be supplemented with imparting and improving the skills, knowledge and capacities of farmers.

Technical expertise and service provision were thus clearly a means to compete for market share among the ITS and were a key factor in product differentiation. One ITS observed that service provision had become increasingly necessary to compete with the growing number of general hardware stores selling irrigation equipment (Interview 21). Hardware stores, however, sell separate parts and do not keep a broad product line in stock. Packaging irrigation equipment with support services was thus a way to differentiate one's business from these shops. For example, when buying a drip kit from Amiran, it comes with installation, training and an agro-support package for training in drip-irrigation practices. Service provision and technical expertise also allowed many ITS to engage in project design and implementation, thereby selling both products and services, and several of the ITS we surveyed had such projects outside Kenya.

ITS can thus be said to take part in agricultural extension in a situation where there is an inadequate public extension system often lacking sufficient technical knowledge of modern irrigation technologies. While ITS reached many smallholder farmers through projects in order to provide technology and services, the delivery of advisory services to individual non-commercialised small-scale farmers was more limited, as these farmers had little purchasing power. Hence, the for-profit, fee-for-service extension system was limited in the sense that it was (primarily) available to commercial farmers, who were willing and able to afford the advisory services (an issue also discussed by Christoplos (2010), Babu and Zhou (2015) and USAID (2019)). Regarding the quality of service provision, the larger companies especially showed high standards of technical expertise in specific technology segments (e.g. greenhouse installations, drip kit maintenance, the operation of overhead sprinklers), which in turn explains why they were able to tap into the increased demand for such services from public and donor-funded projects. They became important actors in extension systems for small-scale irrigation, and the packaging of technology and services was an important innovative solution boosting smallholder irrigation development. Indeed, Kenyan ITS fulfilled a prominent role in *knowledge diffusion* when the SIAIS was reaching the *take-off* phase.

4.3. Influence on technology priorities

4.3.1. Guidance of the search

The policy framework that enables and regulates the development of irrigation has expanded over the past two decades. Guidance in priority-setting was most prevalent in the *take-off* phase of innovation-system development and was primarily a function carried out by the public sector through the formulation of new policies and regulations. The public sector supported the development of both traditional and modern irrigation technologies, a possible reason for the irrigation companies lacking a clear vision that favoured emerging or modern irrigation technologies over incumbent ones (Interview 24).

One researcher pointed out that the Kenyan irrigation sector is highly privatised and that private-sector actors played an important role through their advocacy of specific technologies (Interview 16). In fact, sharing success stories and raising awareness entered into some ITS' marketing strategies, as confirmed by one ITS employee, who explained that "(…) the government, and the development partners, they primarily thought of seeds and fertilizer. They didn't think of irrigation until recently. Now what happened, through continued advocacy, we've been explaining in different forums the value and the importance of irrigation as a means to ending food insecurity in Africa" (Interview 27). This therefore left room for ITS to influence priority settings, and there were several examples of them advocating the promotion of low-cost irrigation solutions to smallholders, regardless of whether their motives were profit-oriented, social or both. While ITS may not have had sufficient agency to influence priority-setting as translated into policy creation, their advocacy and awareness campaigns regarding specific irrigation technologies did shape visions of the future of smallholder irrigation.

4.3.2. Creation of legitimacy

In the early stage of technology development, the expectation around specific irrigation technologies, such as drip irrigation, was shaped by research emphasising its promising potential (see also Venot et al. (2017) and Bjornlund et al. (2017)). Some ITS were engaged in such research in conjunction with development partners and public research institutions (see 4.2). They advocated the benefits of their equipment through marketing strategies, e.g. participation in field days, advertising on TV and social media, and stories of successful adoptions. As one input supplier explained: "We do a lot of marketing to be able to reach the consumers. We participate in a lot of exhibitions, farmers' events, training conferences and other outreach activities. Our teams on the ground don't just sit in the office, they're always on the move, going out looking for potential customers" (Interview 24). Such activities may also have influenced the greater social acceptance of these new technologies (*creation of legitimacy*) over incumbent irrigation systems (e.g. gravity-led furrow systems).

We therefore find that ITS were active in shaping end-users' positive expectations of the technology and contributed to enhancing the acceptance of irrigation technologies among farmers. In fact, creating legitimacy was part of the business strategy of some companies, and their advocacy of irrigation technologies became important as they grew in numbers during the take-off phase of the SIAIS. As ITS grew in numbers and their sales volumes increased, the ability of ITS to influence the expectations around modern irrigation technologies increased through their interactions and exchanges of knowledge with other actors, in particular policy-makers and technology end-users.

To summarize our results, ITS play an important role in the development and diffusion of small-scale irrigation in Kenya, due to their links with other actors and their position in the value chain for irrigation technologies and services (Table 3). ITS have created notable innovative solutions and activities, which tackle barriers that impede smallholder irrigation development. The growth in the numbers and volume of ITS was an important step in creating supply chains that improved smallholders' access to irrigation technologies, although we also note that access to technology is still limited in many rural areas. Moreover, ITS contributed to overcoming important knowledge barriers (i.e. technical know-how and awareness about irrigation technologies), as they performed a range of advisory services and marketing activities to reach farmers. They therefore complemented the inadequate public extension system, which had come to be characterised by limited capacity regarding modern irrigation technologies.

Table 3
The role of ITS in SIAIS performance, assessed through the seven innovation-system functions.

Activity category	Innovation system function	Conditions influencing ITS	ITS influence on SIAIS development
Market creation for irrigation technologies	Entrepreneurial activities	• Intermediate demand for irrigation equipment and consultancies from irrigation projects has created business opportunities for ITS and is instrumental in the business strategy of, in particular larger, ITS.	• Business model innovations (process innovation) by connecting actors and services. • Introducing new technological innovations to the market (imported or manufactured). • Learning to take advantage of latent demand as ITS bundle technologies with support services. • Packaging of technology and services were important innovative solutions for advancing small-scale irrigation. • Adaptations to imported irrigation systems fit to the local context.
	Market formation	• Government- and donor-funded schemes were important for the market formation of irrigation technologies, as these schemes created business opportunities for ITS. • Expanding irrigation infrastructure increased the number of potential clients for ITS. • Tax-based incentives to promote the development of the irrigation market, i.e. exemption from import duty and value-added tax (VAT) on irrigation equipment. However, lack of clarity regarding import regulations for spare parts and import tax exemptions for new products is still perceived as a problem by several ITS. • Development of dedicated irrigation institutions, e.g. NIA. • Expanding irrigation infrastructure (spearheaded by NIA) creates market for ITS. • Innovative ICT-based payment solutions (Futurepump and SunCulture 'pay-as-you-go'-model') enabled by well-developed mobile network coverage.	• ITS important for ensuring the availability and provision of technology. • Driver in establishing niche markets for new irrigation technologies. • ITS created networks between farmers and financial products, other ITS and produce buyers, thereby enabling a flow of resources by improving the value chain.
	Resource mobilization	• Access to credit is a key constraint on smallholders' ability to access new technology, as existing agricultural loan products are beyond their reach or unattractive to them. • Limited public extension resources and capacities regarding modern irrigation technologies left a need for advisory and support service for ITS to pursue.	• ITS took on a brokering role in linking smallholders with financial institutions, through partnerships, e.g. MoU's, with financial institutions for agricultural loan products. • ITS contributed to innovations in credit provisions as a mean to tap into latent demand. • Mobilization of human resources as ITS built-up technical capacities within specific irrigation technologies. • Technological innovations by foreign irrigation companies were introduced to the Kenyan market by ITS.
Creation and dissemination of knowledge	Knowledge development	• ITS utilized and accessed information about water resources, useful for identifying market potentials.	• Close ties with global leading irrigation companies with substantial capacity basis: know-how imported and embedded in Kenya's SIAIS as ITS collaborate with foreign irrigation companies. • Enhanced technical capacities among ITS as they learn from foreign irrigation companies. • ITS taking part in testing, adapting, and trialling irrigation systems with public research organisations.
	Knowledge diffusion	• Limited public extension capacities regarding modern irrigation technologies left a need for advisory and support services for ITS to pursue.	• ITS became important extension agents as they disseminate knowledge with technology provision, and packages advisory and support services with irrigation equipment. • ITS contracted for knowledge dissemination to farmers and training of local extension staff.
Influencing technology priorities	Guidance of the search	• Expanding policy framework making irrigation an increasing political priority. • Public sector supported the development of both conventional (e.g. furrow) and modern irrigation technologies, with a lack of clear vision that favours modern irrigation technologies over incumbent technologies.	• ITS' advocacy and awareness campaigns regarding specific irrigation technologies shaped visions of the future of smallholder irrigation. • Room for ITS to influence priority settings with several examples of ITS advocating and lobbying for the promotion of low-cost irrigation solutions to smallholders.
	Creation of legitimacy		• ITS active in shaping smallholder positive expectations of irrigation technologies. Influence increased with growth in volume and number, albeit effects may still be localised.

5. Discussion

5.1. Empirical contribution

This study has used a functional approach to analyse the role of ITSs in small-scale irrigation development in Kenya in terms of how they take part in and contribute to SIAIS functionality. We found that input suppliers can take on multiple roles in an AIS as they diffuse and sometimes generate innovations, especially by adapting technological innovations to the local context *(developer)*, empowering smallholders through access to credit and agricultural product markets (*supporter*) and providing technology (*implementer*). Below we elaborate on the contribution of these findings in light of previous research on input suppliers and AIS, roughly following the structure outlined in Table 3.

First, the role of input suppliers in AIS has also been approached through the concept of innovation intermediation (Howells, 2006), and several studies have assessed the role of intermediary actors in supporting agricultural innovation processes (Kilelu et al., 2011; Klerkx and Leeuwis, 2009; Lejars and Venot, 2017). In this regard, input suppliers fulfil multiple intermediary roles, i.e. knowledge dissemination, demand articulation, network-building and capacity-building, in addition to the delivery of inputs and equipment (USAID, 2019). In our case study, ITS were indeed active in building networks and linkages with other actors, although such cross-cutting activities did not easily fit into any of the seven functions. So, while consideration of the intermediary concept provides important insights into how actors support "any aspect of the innovation process between two or more parties" (Howells, 2006, p. 720), our application of the functional approach offers complementary insights into how actors influence the speed and direction of change of a technology (Eastwood et al., 2017).

Second, our study shows that input suppliers can contribute to market creation for agricultural technologies, especially through resource mobilization, demand articulation, and entrepreneurial activities. Kenyan input suppliers were important actors in making irrigation technology available, accessible and desirable to smallholders, in part due to their presence across the country, and in part by facilitating access to credit (see also Lejars et al. (2017)) and knowledge about irrigation. The ITS offered bundled packages as a key element of their business model, which aside from technology provision also included services and credit facilitation. They innovated this business model after realising that smallholders' demand for technologies was constrained by a lack of farm credit and limited knowledge about irrigated farming.

Third, the functional approach facilitated a systematic analysis of how input suppliers take part in the innovation process, which extends far beyond disseminators of technology and related knowledge. Our case study confirmed that input suppliers can become effective agents of knowledge diffusion once the market has reached a sufficient size (Izzi et al., 2021). While the public sector stimulated private-sector engagement and an increased demand for irrigation technologies, today ITS offer multiple services to farmers, ranging from support services delivered during technology provision and after-sales services to broader services such as agronomic advice and business planning. We thus posit that input suppliers can be an important complement to the public extension system, especially when the market has reached a *take-off* phase. We note here that earlier research (Garb and Friedlander, 2014; Gildemacher, 2012) has raised concerns that input suppliers may not have sufficient capacity or skills to deliver information to farmers and that there is no assurance of the quality of these services or the motivations behind them. While further analysis is needed to determine the quality of the services provided by the ITS in Kenya, our case study showed that ITS are generally capable of providing substantial support to smallholder irrigation development.

Fourth, Kenyan ITS not only contributed to knowledge diffusion, they were also active in the development of new knowledge through trials and adaptations of new-to-the-market technologies in partnership with research institutions, as well as by becoming leading experts in specific technologies. This finding does not lend support to the more pessimistic views of private actors' ability to fulfil such functions in SSA, for example, Musa (2009) arguing that the private sector is too weak to fill the gap in technological learning and R&D.

Fifth, Kenyan ITS played a key role in the transnational diffusion of innovations. They formed a key link between the national SIAIS and foreign irrigation companies, and through the latter, the global innovation system (Binz and Truffer, 2017). ITS had partnerships with foreign irrigation manufacturers, bringing in foreign know-how along with hardware, and were thereby instrumental in increasing the volume and variety of irrigation equipment on the Kenyan market. For example, the case study identified at least eight imported different drip kits, as well as a broad range of spare parts and accessories.[4] Some ITS, moreover, were active in regional export markets, thereby enabling the transfer of knowledge and technologies to other developing countries (Hornum and Bolwig, 2020). Hence, while previous research has focused on ITS's technology provision and support services locally (Abric et al., 2017; Colenbrander and van Koppen, 2013; Lejars and Venot, 2017), we emphasise here their role in mobilizing resources from non-domestic actors and argue for a stronger focus on this international dimension when examining the role of input suppliers in AIS development.

Sixth, our analysis of Kenyan ITS's contribution to the 'guidance of the search' and the 'creation of legitimacy' functions suggests that input suppliers can positively influence the perception and prioritisation of irrigation technologies through interactions and knowledge exchange with other actors in the AIS.

The above discussion suggests that input suppliers can co-develop, utilize and disseminate knowledge through interactions and partnerships with public and other private actors. They can also play a key role in transnational knowledge transfers. This indicates that input suppliers can have considerable agency in relation to an AIS, to which they bring expertise, resources and innovations in technology, service provision and 'bundled' business models. In our case study, this agency depended on the market having grown to a certain size.

Other studies from SSA have noted how ITS have been unable to drive systemic change due to their short-term, market focus (Minh et al., 2020). In Kenya, ITS cater for the whole country through different strategies, including distributor networks, local branches, wholesale, and extension agents, but their presence is still limited outside the major cities and high-potential areas (see also Odame & Muange (2011, p. 1). And while ITS have been important for market creation in the SIAIS, the rate of adoption of small-scale irrigation technology is still low in absolute terms. Hence, if ITS have the potential to foster transformational change among smallholders (Otoo et al., 2018), this potential still needs to be realised through substantial upscaling. Here the rapid market penetration within and outside Kenya of solar-PV pumps produced by ITS with social-driven missions (Futurepump and Sunculture) provides some ground for optimism.

5.2. Theoretical implications

The functions approach was originally constructed from a broad innovation-system perspective and for developed-country contexts. This has led to questions regarding whether the framework can be applied to developing countries without specifying their characteristics (Edsand, 2019) or analysing a specific type of innovation system in a specific setting (Minh, 2019), while others deem the functions approach suitable as it is for studying innovation systems in developing countries (Sixt et al., 2018; Tigabu et al., 2015; van Welie et al., 2019). These studies typically focus on identifying 'systemic problems' (Wieczorek and

[4] The brands were Dayliff, JAIN, Power, Rivilus, NETAFIM, Azud, Eurodrip, and Bhavani Drip. In comparison, Ngigi et al. (2001) identified five drip kits, two of which were sold by the public research institution KALRO.

Hekkert, 2012) through structural-functional assessments, thereby expectedly delivering a context-specific and comprehensive analysis of a specific innovation system. Based on our study of an AIS in Kenya using the seven predefined functions, we find the functions approach useful for understanding how input suppliers influence AIS development in the Global South.

The functions approach was developed to assess the performance of innovation systems and the factors that influence it (Bergek et al., 2008), rather than determining the role of specific actors. It is typically applied to examining how conditions in the innovation system influence actors' innovation capacity, as opposed to studying how actors take part in fostering the innovation system. An exception is the study by Barnard et al. (2009) showing how firms shape national innovation systems a developing country context. In this light, our case study provides an opportunity to reflect on the applicability of the functions approach for understanding the contribution of a specific actor to a specific innovation system. The role of input suppliers was challenging to determine in relation to some functions, in part because the scope of a function in its original conceptualisation did not cover such private-sector actors. For example, the function of *market formation* is understood as involving activities that influence the growth of new technologies in niche markets and is typically mapped through the introduction of tax regimes, new environmental standards, or subsidies (Hekkert et al., 2007). Hence, the activities used to express the market-formation function are typically associated with policy-level interventions that create favourable conditions for specific technologies. This does not leave much room for explaining the importance of a private-sector actor and its activities for supply-chain development or the creation of local markets for the technology.

Similarly, the *guidance of the search* function is often mapped on the basis of indicators of activities in which private-sector actors are not normally involved, such as the creation of regulations and policy targets, which are deemed to create a clear vision and mutual expectations among stakeholders regarding a specific technology. However, we observe that the function is about making the needs of the technology-users visible (Hekkert et al., 2007). This makes it relevant to consider the activities of private-sector actors, such as marketing success stories or advocating technology needs.

Altogether, we find that the functions approach can be a useful framework for guiding an actor-centric analysis of an AIS, despite this not being its original purpose. Given that this paper reports on a single case study, future research could test how valid this claim is by applying the approach to a broader range of AIS and to other types of actors in the Global South.

5.3. Implications for policy

Our study suggests that a strengthening of public-private collaboration would enable a market-led development in fostering systemic changes in irrigated value chains. ITS may be spearheading the commercialisation of innovations, but some coordinating mechanism is needed if they are to have an impact at scale. Kenyan ITS already collaborate with a range of actors, including policy-makers, researchers, NGOs, financial institutions and manufacturers, but deliberate efforts to facilitate and enhance this collaboration and knowledge-sharing within the SIAIS could both increase ITS agency and strengthen the SIAIS more generally. The inclusion of ITS in dialogue forums, e.g. innovation platforms (Schut et al., 2018) and consultative policy processes, would not only allow them to access and utilize information, but would also serve as a coordinated and formalized structure through which they can take part in harnessing innovations (Pittock et al., 2020) and building innovation-system functionality. Here they could partake in the co-creation of knowledge and influence technology priorities, advocating and sharing experiences with market-led technology diffusion. Dialogue through such multi-stakeholder platforms can create a space for the collaboration and mobilization of resources, thereby advancing the market-led diffusion of small-scale irrigation (Minh et al., 2020).

Our study further indicates a need to train smallholders and extension staff in understanding modern irrigation technologies. Here, public-private collaboration can be used to leverage the knowledge of ITS in planning or performing dedicated and specialised training (cf. Eastwood et al. (2017)), thereby enhancing knowledge development in the SIAIS. Relatedly, national agricultural extension systems could be enhanced by capitalizing on the capacities of a growing number of ITS and the services they offer. To do so, policy interventions in Kenya should strengthen their links with other actors, including project developers, to achieve economies of scale and continue to expand the irrigation infrastructure, thereby increasing the number of smallholders with access to irrigation water. This would in turn increase the customer base for private irrigation firms, with ripple effects on the rest of the economy.

6. Conclusion

This paper has aimed to contribute to the understanding of the role of input suppliers in agricultural development in the Global South by exploring how these actors can influence the functioning an AIS. This was done through a case study of ITS in Kenya. The paper used a 'functions' approach to explore how these actors took part in the SIAIS and in turn contributed to different aspects regarding the development and diffusion of small-scale irrigation technologies. The novelty of the paper lies in its empirical assessment of input suppliers in the small-scale irrigation sector and its application of the functions framework in this context. While the role and importance of input suppliers in smallholder agriculture in the Global South are relatively well-established in existing research, this paper shows how input suppliers can contribute to the performance of an AIS.

We have have shown that input suppliers can be important actors in AIS functionality, especially when the market reaches a take-off phase characterised by a growth in sales volumes and in the numbers of ITS. In Kenya's SIAIS, the number ITS increased significantly between 2000 and 2020 from a low base, changing the size structure of the sector in the direction of more small companies. The expanding market for irrigation equipment and services in Kenya was driven by donor- or government-supported irrigation schemes and by a growing number of medium-scale farms and part-time farmers from the urban middle-class. The resulting increased demand for equipment and consultancies stimulated the entry of more suppliers.

We also found that Kenyan ITS perform important activities and roles in the SIAIS aside from input supply, notably provision of advisory and consultancy services, improvement of the supply chain for irrigation technologies, introduction and adaptations of new types of irrigation equipment, and facilitation of access to farm credit. Our study confirmed that input suppliers can become effective agents of knowledge diffusion once the market has reached a sufficient size and documented how they contribute to knowledge development as they develop, adapt and test specific irrigation equipment. Furthermore, input suppliers can be notable actors in the market creation of agricultural technologies: in Kenya ITS were instrumental in respect of entrepreneurial activities, as they searched for innovative solutions to reach more smallholders. Furthermore, we found that ITS took part in market formation, as they improved the availability and provision of technology and established niche markets for new irrigation equipment, and also mobilized resources, as they brought foreign expertise to the market along with irrigation technologies. We thus argue that input suppliers can serve as important brokers between global and national AIS. Finally, we suggest that policy interventions in support of smallholder irrigation should seek leverage from the growth and capacities of input suppliers as a complement to public research and extension.

Funding source

This work was supported by the UNEP DTU Partnership and the research project *Technology, Markets and Investment for Low Carbon and Climate Resilient Development* (TEMARIN), funded by the Ministry of Foreign Affairs of Denmark.

Declaration of Competing Interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2021.103219.

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