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Abstract

There are high hopes that digital tools can help to reduce constraints to livestock development, which in turn promises to alleviate poverty and ensure food and nutrition security. Yet, little systematic evidence exists on the state of digital livestock in low- and middle-income countries and, subsequently, whether such high hopes are justified. In this paper, we combine a review of digital livestock tools in India and Kenya with three "on-the-ground" case studies: Herdman, a tool for Indian dairy organizations working with small-scale livestock keepers, facilitating data collection and supervision of field agents; Farmtree, a tool supporting medium-scale livestock keepers in India to manage their herds, and iCow, an e-extension tool for farmers in Kenya. For the review, we develop a conceptual framework that distinguishes different types of digital livestock tools: 1) "simple digital tools", providing generic information, 2) "smart digital tools", providing tailored information based on data entered by livestock keepers, 3) "smart and connected digital tools", using data from sensors, 4) "smart, connected and automated digital systems", which are coupled with robots, allowing for automation, 5) "digital tools for value chains", which enable the integration of value chain actors. The results suggest that digital tools provide many new options to address constraints to livestock development. So far, most tools are "simple digital tools", followed by "smart digital tools". Few tools are "smart and connected". "Smart digital tools" that only require smartphone ownership are the "sweet spot" for supporting digital livestock development, however, even embodied "smart and connected digital tools" can be of relevance for small-scale livestock keepers with appropriate organizational models. Most digital tools focus on dairy production, suggesting neglect of other types of livestock, and there are few tools for pastoralists. While digital tools are no silver bullets – and come with some new challenges such as data security and sovereignty concerns - they are likely to become a key pillar of livestock development in the near future.

Key Words

Farming 4.0., Digital Farming, Digital Livestock, Smartphones, Africa, India

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1. Introduction

Livestock development can contribute to alleviating poverty and to ensuring food and nutrition security, in particular, by addressing micro-nutrient deficiencies, which are pervasive in many low- and middle-income countries (Herrero et al., 2013; McDermott, 2010; Paul et al., 2020; Salmon et al., 2020). Yet, there are several constraints to livestock development, such as access to improved breeds (Ducan et al., 2013; McDermott, 2010), artificial insemination and veterinary services (Maleko et al.; 2018), pasture, fodder, and feeds (Maleko et al., 2018; Paul et al. 2020), output markets (Henderson et al., 2016), and knowledge and skills (Owen et al., 2012). There are high hopes that digital tools can help to reduce constraints to livestock development, while also reducing its ecological footprint (Birner et al., 2019). These hopes are fuelled by the fast spread of mobile phones and smartphones around the developing world, which has led to a surge of such digital tools (Baumüller, 2018; ITU, 2019; World Bank, 2016).

While there are high hopes regarding such digital tools for livestock development, little systematic evidence exists on the state of digital livestock in low- and middle-income countries and, subsequently, whether such high hopes are justified. This is in contrast to digital tools for crop farming, which are increasingly studied (Baumüller, 2018; Daum et al., 2021; Daum, 2019; Deichmann et al., 2016; Fabregas et al., 2019). Consequently, little is known about the types of digital tools available to livestock farmers in developing countries. Which types of value chains do these digital tools address? Which of the above-mentioned constraints to livestock development do they address? How sophisticated are these tools? Do they merely provide generic information, which is also otherwise obtainable? Or do they help to optimize livestock production?

To answer these questions, we review existing digital tools for livestock development in India and Kenya. India is an interesting case study country because it has witnessed several large-scale livestock development efforts. One example is the “white revolution”, also referred to as “operation flood”, which has made India the largest milk producer in the world (Dalal & Pathak, 2010). India also has a vibrant digital start-up scene (Kaka et al., 2019). Kenya is characterized by more limited livestock productivity compared to India, but is among the top dairy-producing countries within Africa, and has a large potential for further livestock production (FAO, 2019). Kenya is considered to be a Silicon Savannah, given its large amounts of ICT start-ups (Stroisch, 2018).

For the review, we combine findings from an extensive review of the existing literature, app databases, homepages as well as key informant interviews with representatives from the livestock sectors in India and Kenya. To obtain a deeper understanding of the realities “on-the-ground", we combine this review with three empirical case studies. In India, we studied the digital tool "Herdman Mobile" - a software for dairy cooperatives and companies working with small-scale livestock keepers, which helps to collect data on animals' health and track fertility using quick response (QR) codes and to supervise the organization's field staff. The other case is Farmtree, a digital tool supporting livestock keepers to manage their herds, focusing on fertility management and economics. In Kenya, we focus on iCow, an e-extension tool that sends livestock farmers free SMS alerts and advice on topics such as feeding and disease control.

2. Conceptual framework

Table 1 presents a conceptual framework that aims to provide a better understanding of the nature of digital tools available for livestock development. The framework is informed by an analysis of digital tools by Porter and Heppelman (2014). The following characteristics are used here to classify digital tools for livestock.

(1) Embodied versus disembodied digital tools

The distinction between embodied and disembodied innovations is well established in the agricultural economics literature (Sunding and Zilberman, 2007). According to an application of this distinction to digital tools in agriculture by Birner et al. (2021), embodied digital tools are integrated into a piece of farm equipment that can be sold. Examples are the sensors that are integrated into machinery, as in the case of a milking robot, or sensors that are attached to animals, as in the case of a rumen bolus. Disembodied digital tools, such as apps, are not integrated into a farm-specific piece of equipment. They still need a physical device to run, such as a smartphone, but since this is a general-purpose device, it is more difficult to develop business models for tools that are disembodied in this sense.

(2) Simple versus smart digital tools

Simple digital tools

Simple digital tools are services through which livestock keepers and other value chain actors can access generic information, such as advice on feeding and milking practices, using mobile phones or smartphones. Such mobile services are disembodied, as defined above, and they only require general ICT devices. Hence they are associated with limited costs and low entry barriers. Since all users access the same or similar data, scaling is possible with nearly zero marginal costs (Baumüller, 2018; Fabegras et al., 2019). Simple digital tools are considered to be "low-hanging fruits" and of particular relevance to smallholder farming (Daum, 2018). Yet, their capabilities (see below) are limited and due to their disembodied nature, private companies still face challenges in developing a functioning business model for such tools.

Smart digital tools

Digital tools that allow for the collection of farm and animal specific data are labeled "smart digital tools" in our framework. Collecting such information enables the provision of farm and animal specific decision-support. As further detailed below, farm or animal specific data can be collected and entered manually or in an automated way based on sensors.

- <u>Manual data collection and entry:</u> A farmer or another actor (e.g., an extension agent or Artificial Insemination (A.I.) technician) can manually enter data about an animal, such as the calving date or the milk yield, into a smartphone app. The SMS function of a feature phone can also be used for this purpose. The farmer may also use a disembodied tool (in the sense of the above definition), such as the camera function of their smartphone to enter animal-specific data, e.g., by taking a photo of a cow that shows symptoms of a disease. The GPS function of a smartphone can be used to record the location of an animal. In the case of the Herdman tool (further discussed below), the A.I. technician uses a smartphone to read a bar code or QR code on a tag attached to a cow and then manually enters data about that cow, e.g., the insemination date and type of semen used.
- <u>Automated sensor-based data collection and entry:</u> In this case, data is generated automatically using sensors, which can be located directly on animals, for example, as rumen boluses, neck collars, or leg bands with pedometers and temperature sensors (Wathes et al., 2008). These are embodied tools in the sense of the above definition. As mentioned above, sensors can also be integrated into livestock machinery such as milking robots. Sensor data can help to automatically monitor the health, fertility, and performance of animals (Jungbluth et al., 2017). For smaller animals, rather than using sensors for each animal, cameras or infrared imaging technology can be used (Benjamin & Yik, 2019). For pasture management, satellites and drones can be used to monitor animal movements and the status of pastures and water bodies (Bahlo et al. 2019).

(3) Isolated versus connected digital tools:

A farmer may use digital tools to collect data about their animals only for their own purpose without sharing the data with anyone. An example is the use of herd management software that runs on the farmer's computer and does not transmit data to anyone, not even the developer of the software. This is an example of a digital tool that can be classified as "isolated."

Connected digital tools

Interesting opportunities arise if the digital tool is connected and data are shared with other actors. As Porter and Heppelman (2014: 67-68) show, data can be shared on a one-to-one, many-to-one, and many-to-many basis. We add the "one-to-many" direction to this classification. The following examples illustrate these possibilities.

- One-to-one: A farmer sends data, which were collected using a livestock app, to an advisor, who then provides animal-specific advice to this particular farmer.
- One-to-many: An advisory service sends general information (i.e. advice that is not farm or animal specific) to many users. This is the typical information flow of simple digital tools.
- Many-to-one: The developer of a digital tool, e.g., a smartphone app, collects the data from all farmers who use the tool, which is a common practice. Another example is a dairy cooperative that collects digital data from all its milk suppliers. If data are shared on a many-to-one basis, "big data" are created, which can be further used, e.g., for benchmarking the performance of a dairy herd, or for developing artificial intelligence tools.
- Many-to-many: Examples include WhatsApp groups of livestock owners or digital marketing platforms. Big data can also be generated from this type of connectivity.

Note that the connectivity of digital tools can be created in different ways. A farmer may use a feature phone, smartphone, or laptop that is connected to the internet to transmit digital data to other parties. Embodied digital tools, such as sensors that are integrated into machinery or attached to livestock, may also be equipped with connectivity functions that automatically transmit data not only to the farmer but also to other actors, such as the company that developed the respective digital tool.

Digital tools for value chains

Connected digital tools may allow farmers to integrate into livestock value chains, e.g., by linking them with input suppliers, service providers, and marketing companies. As this is an important feature of digital tools for livestock, we label digital tools that have this specific feature of connectivity "digital tools for value chains". Such digital tools may not only be used by the livestock keepers themselves, but also some other actors within the livestock value chain such as by the provider of advisory services, animal breeding companies, A.I. services, and employees of upstream or downstream companies, such as dairy processing companies or feed suppliers. Such tools can differ by the degree of technological sophistication, ranging from apps linking livestock keepers with input and service providers and sellers to more elaborate systems where sensors are used and data is flowing between different value chain actors. For example, cooperatives and processors may equip the animals of their farmers with sensors, generating data to optimize feeding, health, fertility, and breeding programs and use sensors at milk collection to control quality. Cooperatives and processors may also use sensors to test milk at collecting centers and use this data to determine payouts to farmers – which may be transferred using digital tools (McNamara et al., 2011). The data may also be used to inform extension agents about livestock diseases and to enable traceability for customers. Such tools for value chains may enable a degree of digitalization and integration at the collective level, which individual farmers are not able to achieve (Newton et al., 2020). In digitally enabled value chains, livestock keepers may become indirect beneficiaries of digital tools, which they do not directly use themselves. There is, however, also the possibility that other value chain actors gain an unfair advantage by getting access to the farmers' data.

(4) Capabilities of digital tools

Adapting the classification by Porter and Heppelman (2014) to the specific features of digital tools for livestock, we distinguish the following capabilities that digital tools may have:

- Information provision and exchange: Connected digital tools make it possible to transmit information from the livestock keeper to other actors in the value chain and, vice-versa, to receive information from them.
- Documentation, monitoring, and control: Livestock owners may use digital tools to collect data for a variety of purposes, such as monitoring the milk yield of their cows or documenting A.I. and calving dates. Likewise, other value chain actors, such as extension agents or A.I. service providers, may use digital tools for documentation and accounting purposes. Thus, digital tools facilitate documentation that would otherwise be conducted by pen and paper. Such digital monitoring data may also be used to exercise control functions. For example, a agency employing extension agents or A.I. service providers can use digital tools to monitor the field activities of their staff.
- Farm or animal specific advise: Smart and connected digital tools make it possible to provide farm or animal specific advise to the farmer. While the capabilities of information provision and exchange and documentation, monitoring, and control support farmer's decisions, farm or animal specific advice is usually more targeted and prescriptive than general decision support services. Such devises may differ concerning the level of sophistication.
- Rule-based decision support: This type of support is based on decision rules. For example, an app could alert the farmer to check whether a cow is in heat, based on the date of the last insemination of that cow. Since such advice is based on animal-specific data, it is more valuable to the farmer than general information about A.I. management.

- Sophisticated decision-support: If big data is created by connected digital tools (see above), decision-support can be more sophisticated. One example is benchmarking, which is providing advice based on comparing the performance of a farmers' herd with a group of similar herds. Of particular value to the farmer is advice that involves economic optimization. For example, an app could provide feeding advice based on animal-specific performance data and the costs of different types of feed. Such applications require some type of modeling, such as linear programming. The use of big data also allows for the use of artificial intelligence to provide decision support for optimization.
- Automation and autonomy: The highest level of capability is autonomy and automation, in which case automated systems take over the farmers' decisions and activities. Prominent examples in livestock production are the robots used for milking, feeding, and barn cleaning. Automation, by definition, requires digital tools that are embodied in farm equipment. Such tools can also be labeled "automated systems." For pastoral livestock production, such digital systems may rely on the use of drones with cameras to observe livestock and remote sensing to estimate crop biomass and subsequently guide animals to optimal pastures using virtual fences. Automated systems may span beyond livestock systems to also include non-livestock systems. An example of this would be management software for the whole farm, including crop and livestock production, which optimizes production based on machinery, animal, and soil based sensors, among others. Drawing a parallel to the concept of "Industry 4.0" (BMBF, 2013), such systems are referred to as "Agriculture 4.0".

Applying this classification category leads to the conceptual framework that is displayed in Table 1. Table 2 shows that most animal husbandry activities can be facilitated by digital tools with different levels of digital sophistication.

	Simple digital tools	Smart digital tools		Digital tools for value chains	Automated digital systems
		with manual data entry	with sensor-based data entry		
Description	Digital tools that provide general information	Digital tools that use farm/animal-specific data, based on manual entry	Digital tools that use farm/animal-specific data, based on sensors	Digital tools that connect different actors in a value chain	Digital tools that enable automated processes
Innovation type	Disembodied	Disembodied	Embodied	Disembodied or embodied	Embodied
Type of data collection/entry	None	Manual entry by livestock keepers or other actors, possibly using smartphone functions (e.g., QR code reader, camera, GPS measurement)	Data collection by sensors integrated into equipment or placed on animals (possibly in combination with manually entered data)	Data collection/entry manually or by sensors; transmission of data by the farmer or automated	Sensors integrated into the equipment, possibly in combination with other data sources
Direction of data flow	One-to-many	One-to-one; many-to-one; many-to-many	One-to-one; many-to-one; many-to-many	One-to-one; many-to-one; many-to-many	One-to-one; many-to-one; many-to-many
Capability	Information provision	All capabilities possible, except automation	All capabilities possible	All capabilities possible	All capabilities possible

Table 1. Types and characteristics of digital tools for livestock production

Source: Authors, based on Porter and Heppleman (2014)

Animal husbandry activity	**Simple digital tools**	**Smart digital tools**		**Automated digital systems**	**Potential benefits**
		with manual data entry	**with sensor-based data entry**		
Milking	Text messages or videos on milking practices	Recording of milk yields with smartphone apps, helping to monitor and optimize production.	Use of sensors to monitor milk quality and detect diseases	Milking robot, equipped with sensors to monitor milk quality and detect diseases	Improved animal health, performance, and welfare; traceability
Feeding	Text messages or videos on feeding practices and fodder production	Advisory apps to optimize feeding, based on data about animals and feeds entered by farmers into the app	Tools for precision feeding that use data entered by the farmer and data from sensors that monitor feed intake and movements.	Feeding robot, enabling automated mixing and feeding, based on animal-specific parameters and feed prices	Improved feeding efficiency; reduced feed cost; improved animal performance and health
Fertility management	Text messages or videos on fertility management	Tools to optimize fertility management based on data entered by farmers	Products for the early detection of animals in heat using sensors		Reduced calving intervals
Animal breeding and genetic improvement	Text messages or videos on the available potential bulls and the animal seed system	Digital recording of data from individual animals on traits of interest	Use of sensors to record data from traits that are otherwise difficult to record		Improved selection of potential breeding animals
Health management	Text messages or videos on how to prevent, identify and treat livestock diseases	Products allowing livestock keepers to take pictures of livestock diseases and identify diseases	Products for the early detection of diseases using sensor data		Early detection of diseases; reduced heath costs; reduced antibiotic use; improved animal welfare
Pasture management	Text messages or videos on how to optimally manage pastures	Pasture management software based on data entered by the farmer	Digital systems using drones with cameras to observe livestock and remote sensing to estimate biomass	Digital systems using drones with cameras to observe livestock and remote sensing to estimate biomass and subsequently guide animals to optimal pastures using virtual fences	Improved flexibility and efficiency; reduction of costs and losses

Table 2. Examples of digital solutions for different animal husbandry activities
Source: Compiled by the authors

3. Research countries, methods, and sampling

3.1 Research countries

Table 3 provides an overview of the two focus countries of this study, showing some characteristics of the livestock sector and the status of digitalization. In both countries, a large share of the population is employed in agriculture (38% in Kenya; 43% in India) and the livestock sector contributes a significant share to the GDP (10% in Kenya; 4% in India) (see Table 3). In both countries, livestock farming continues to be dominated by small-scale livestock keepers (farmers and pastoralists in Kenya; farmers in India), however, there is also a trend towards more commercialized livestock production as well (FAO, 2019).

In Kenya, livestock production is dominated by cattle, comprising both dairy and beef animals, that contribute significantly to the agricultural GDP (FAO, 2019). Regarding dairy farming, the FAO (2019) estimates that approximately 40% of all farms practice "intensive" farming (zero-grazing), 45% produce "semi-intensively" (semi-grazing), and 15% are part of extensive, pastoral production systems. Most dairy animals are owned by small-scale livestock keepers (Odero-Waitituh, 2017). Regarding beef production, the FAO (2019) estimates that only 1% is produced in fed lots, while 45% is produced on pastures and ranges. Pastoralism is widespread in arid and semi-arid areas. Poultry production is characterized by smallholder farmers keeping free-range or backyard chicken and increasingly intensified industrial chicken production. Constraints to livestock development are limited access to feeds, breeding, credit, and output markets, and disease outbreaks, among others (Odero-Waitituh, 2017).

In India, dairy production is of particular importance as well. Beef production is less important, mainly because of cultural reasons, but poultry production is developing quickly, and some of the largest poultry factories in the world are located in India (Hellin et al., 2015). Regarding dairy production, India has heavily intensified dairy production over the last decades with the help of "Operation Flood", a large-scale program of the National Dairy Development Board (Dalal & Pathak, 2010), making India the world's largest producer of milk. 78% of the total bovines are owned by smallholder farmers who own less than 2 hectares of land (NSSO, 2013). Despite major advancements, India still struggles with many challenges for livestock development, including limited access to artificial insemination and veterinary and vaccination services, frequent disease outbreaks, concerns about food safety and standards, limited access to extension, finance, and insurance, a lack of optimized feeding strategies, deterioration of common grazing lands, and access to markets, among others (Paturkar, 2019). Jointly, these factors may explain why India's milk yield is still only half of the global average and the share of crossbred animals remains limited (17% in cattle) (Paturkar, 2019).

Table 3 shows that Kenya and India score similarly on the Mobile Connectivity Index of the Groupe Spécial Mobile Association (GSMA.) The index comprises digital infrastructure, affordability, consumer readiness as well as content and service and ranges from 0 to 100. Kenya (50 points) and India (55 points) are among the best performing countries in South Asia and Sub-Saharan Africa, respectively, but they are still far from most OECD countries (Bahia & Suardi, 2019). Smartphone ownership is rapidly rising in both countries, in particular in urban areas (Silver, 2019), but increasingly in rural areas as well (Bahia & Delaporte, 2020).

	Kenya	India
Country characteristics		
Population (million)	51	1353
Employment in agriculture (%)	38	43
Livestock		
Livestock share of GDP	10%	4%
Production (million tons)		
Beef	0,65	2,61
Poulty	0,03	3,62
Pigmeat	0,01	0,46
Milk	5	188
Yields (kg per animal)		
Cattle	234	103
Poultry	1,2	1,4
Pigmeat	65	35
Milk	340	1320
Digitalization		
Mobile Connectivity Index	50	55
Smartphone penetration 2018 (%)	21	37

Table 3. Livestock and digitalization in Kenya and India

All livestock data based on FAOSTAT (2018). Population data from World Bank (2020). Share of GDP in Kenya based on KALRO (2020). Data on smartphone penetration from Newzoo's Global Mobile Market Report (2018). Mobile Connectivity Index from Bahia & Suardi (2019).

3.2. Sampling and methods

3.2.1. Stocktaking

To identify the digital tools for the livestock sector in Kenya and India, we reviewed existing literature, screened app databases such as Google's Play Store, reviewed homepages, conducted key informant interviews with representatives from the livestock sector in India and Kenya to help point out relevant applications. The stocktaking only considered applications that were developed in the respective countries, thus livestock applications used in the two countries but developed in other countries were not considered. For the stocktaking, applications launched up to December 2020 were considered. Table 4 provides an overview of the different applications available.

Country	Name	Company	Goal and function	Livestock types	Collection of farm / animal specific data		Tool for value chains	Type of advisory service
					manual	sensors		
India	Dairy Husbandry Practices	NDDB	Extension	Cattle/dairy				
	Dairy Management ERP System	Shaurya Technosoft Pvt. Ltd	Tool for dairy organization to supervise service providers and collect data	Cattle/dairy	X		X	
	Dairy Vet Software	Shaurya Technosoft Pvt. Ltd	Tool for dairy organization to supervise service providers and collect data	Cattle/dairy	X		X	Rule-based
	e-GOPALA	NDDB	Herd documentation, monitoring, and control, extension, feed optimization, value chain integration	Cattle/dairy	X		X	Sophisticated
	FARM ERP	Shivrai technologies	Herd documentation, monitoring, and control	All	X			
	FARMTREE	Inhof technologies	Herd management and optimization	Cattle/dairy	X			
	HAR PASHUKAGYAN	Animal Husbandry Department, Haryana	Extension	Cattle/dairy	X			
	HERDMAN	Vetware Limited	Tool for dairy organization to supervise service providers and collect data	Cattle/dairy	X		X	
	INAPH Ration Balance Program	NDDB	Herd documentation, monitoring, and control, extension	Cattle/dairy	X		X	Sophisticated
	Livestoc	Amaze Brandlance Private Limited	Extension, value chain integration	Cattle/dairy			X	
	Livestoc Pro	Amaze Brandlance Private Limited	Tool to support veterinarians, paravets and artificial insemination	Cattle/dairy			X	Rule-based
	MOOO FARM	MoooFarm Pvt. Ltd.	Herd documentation, monitoring, and control, extension, value chain integration	Cattle/dairy	X		X	Sophisticated
	NDDB AGR	NDDB	Extension	Cattle/dairy				
	On-farm Feed Advisor	ILRI	Feed optimization	Cattle/dairy	X			
	Poultrac Tag-a-Shed	Vetware Limited	Flock documentation, monitoring, and control	Poultry	X			

	Poultrac Tag-a-Shed : Hatchery	Vetware Limited	Flock documentation, monitoring, and control	Poultry	X			
	TANAVUS Feed and cow weight calculator	Tamilnadu Veterinary and Animal Sciences University	Extension	Cattle/dairy				
	TANAVUS Sheep and goat farming	Tamilnadu Veterinary and Animal Sciences University	Extension	Sheep/goats				
	TANAVUS Training calender	Tamilnadu Veterinary and Animal Sciences University	Schedule extension events	All				
Kenya	AfriScout	Project Concern International	Pasture management	Cattle/dairy	X	X		
	Digi Farm (DigiSoko)	Safaricom	Extension, value chain integration	All			X	
	DigiCow	Farmingtech Solutions	Herd documentation, monitoring, and control	Cattle/dairy	X			Rule-based
	Digital AI	Farmingtech Solutions	Contact AI	Cattle/dairy				
	Digital Vet Systems	Farmingtech Solutions	Contact veterinarians	All				
	iCow (Soko)	Green Dreams TECH	Extension, value chain integration	All	X		X	Rule-based
	Indigenous KALRO Chicken	KALRO	Extension	Poultry				
	iShamba (Agritips)	Mediae Company	Extension	All				
	SmartCow	Intersoft Eagle	Herd documentation, monitoring, and control	Cattle/dairy	X			
	Usomi (Lulu)	Lulu	Herd documentation, monitoring, and control, value chain integration	All	X		X	

Table 4. Digital tools for livestock development reviewed in Kenya and India

3.2.2. Case studies

In addition to reviewing the digital livestock landscape in India and Kenya, we conducted two qualitative on-the-ground case studies in India (on *Herdman*, see section 4.1.1. and *Farmtree*, see section 4.1.2.) and one in *Kenya* (on iCow, see section 4.1.3.). In the case of *Herdman*, we explored the experiences of a private dairy company in Maharashtra, which procures milk from around 100,000 dairy farmers. The company uses *Herdman* to provide better services such as artificial insemination and veterinary services to the farmers, monitor field agents, and collect data for breeding programs (see further details below). *Herdman* had been used for seven months when the study was conducted. To understand the experiences, opportunities, and challenges of *Herdman,* we interviewed different stakeholders at the company, including eight randomly chosen artificial insemination technicians (AIT) working with the company, two AI supervisors, two extension officers, two veterinarians (one from the company, and one from the government), four management staff, and six randomly chosen farmers. Also, we interviewed the founder and developer of *Herdman*.

In the case of *Farmtree*, we randomly selected 13 farms (2 owning less than 15 animals, 8 owning 15-100 animals, and 2 owning more than 100 animals) using the digital tools and interviewed the respective, farmers, farm managers, and laborers in Gujarat. Also, the app developer, one dairy consultant, one field veterinarian, and one representative from a feed company using the app were interviewed. The study on *iCow* (in Kenya) is based on three key informant interviews with representatives from iCow, 1 expert linked to the iCow platform, 7 dairy experts, and 4 dairy cooperative employees. 20 key informant interviews with male and female farmers who had used iCow before in a study by Mwita (2019) were randomly selected using the top five high milk yielding and lowest five milk yielding farmers in two counties. Also, four gendered FGDs with farmers who are currently using iCow were conducted. Farmers were randomly selected from the iCow database of registered users in Uasin Gishu and Nyandarua.

	Herdman (India)	Farmtree (India)	iCow (Kenya)	Total
Key Informant Interviews	26	16	35	77
Informants link to digital company	2	1	4	6
Informants link to implementing company	17	-	4	21
General experts	1	3	7	12
Farmers	6	13	20	39
Focus Group Discussions	-	-	4	4

Table 5. Overview of interviews and discussions in Kenya and India

4. Results

Section 4.1 presents a classification of the tools displayed in Table 4, based on the conceptual framework developed above. Section 4.2 describes the tools in more detail and Section 4.3 presents the results of the case study.

4.1. Overview of digital tools for livestock development

Figure 1 displays the years in which the digital applications reviewed were launched, showing a recent acceleration in the number of tools available to livestock keepers. Figure 2 provides an overview of the livestock species addressed by the digital tools in India and Kenya, suggesting a substantial focus on dairy production. Few digital tools are designed for poultry, sheep and goats, and no digital tool explicitly focuses on pig production. In India, the applications addressing poultry are *Poultrac Tag-a-Shed* and *Poultrac Tag-a-Shed Hatcheries* from Vetware Limited. These applications allow livestock keepers to record data on poultry flock management by scanning a QR code on the shed and subsequently entering data on the animals in the respective shed. In Kenya, the digital tool for poultry is *Indigenous KALRO Chicken* from the Kenya Agricultural and Livestock Research Organization, an application providing generic extension advice. The application for sheep and goats is *TANAVUS Sheep and Goat Farming* from the Tamilnadu Veterinary and Animal Sciences University, a digital tool providing text and pictures on sheep and goats to facilitate the work of extension agents.

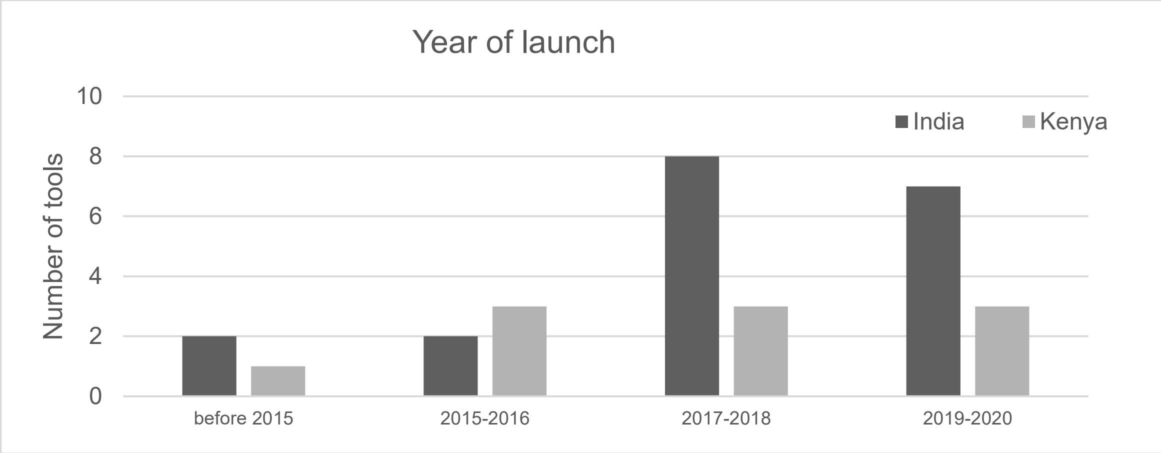

Figure 1. Year of the launch of digital tools

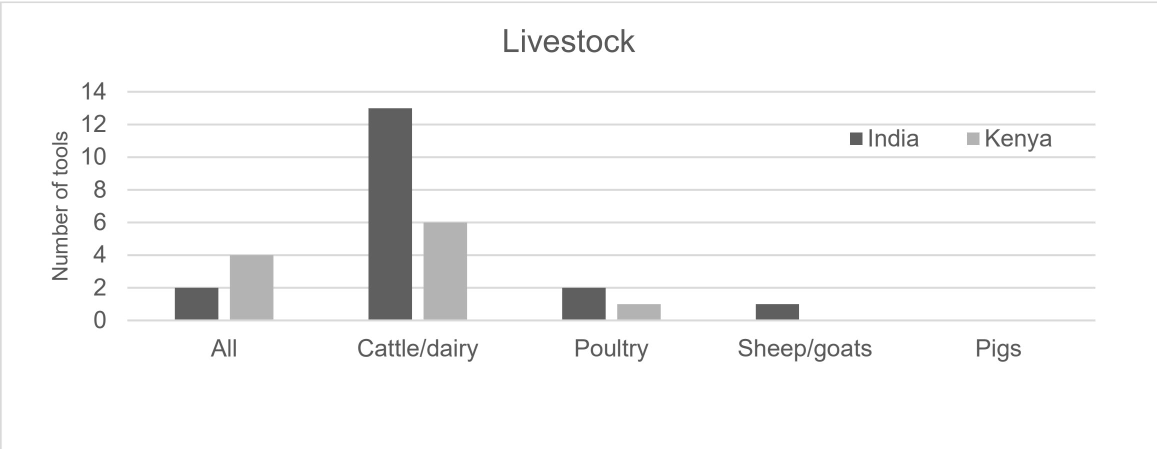

Figure 2. Type of livestock targeted by digital tools

Figure 3 shows that many digital tools offered in the two case study countries are “simple tools” as defined in our framework, providing generic, non-tailored information to livestock keepers (see section 4.2.1 for an overview). The majority of the digital tools are “smart” with manual data entry, according to our definition. They allow livestock farmers to enter some type of data, which facilitates monitoring and can be used to optimize production (see section 4.2.2 for an overview). We identified only one smart digital tool with sensor-based data entry (see 4.2.3) and there were no automated systems among the tools identified for our review. Three of the digital tools in India and two in Kenya belong to the category of digital tools for value chains (see section 4.2.4 for an overview).

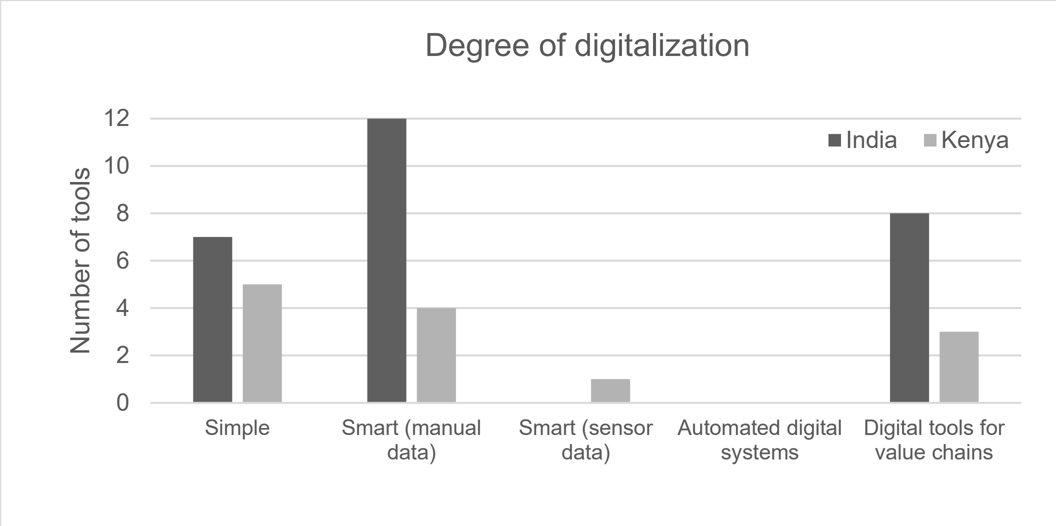

Figure 3. Type and nature of digital tools for livestock development.

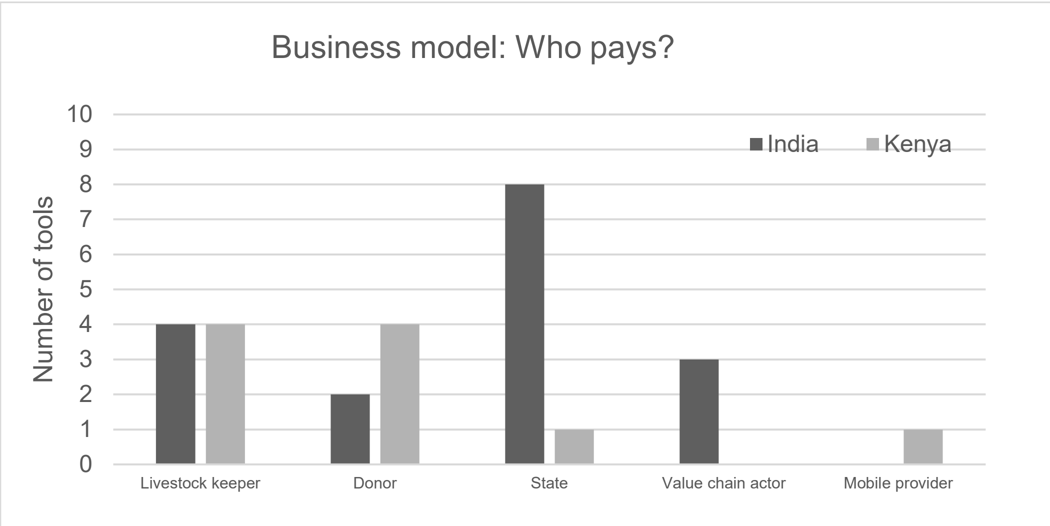

Figure 4. The business model of digital tools for livestock development.

Figure 4 shows that there are different business models behind digital tools. In one business model, livestock keepers have to pay for the service via subscriptions or on a pay-per-use base (4 of 19 digital tools in India and 4 of 10 in Kenya). Also very common are models where the digital tools are financed by governments or donors and livestock keepers get the digital service for free (10 of 19 digital tools in India and 5 of 10 in Kenya). Digital tools may also be offered to livestock keepers for free by processors or supermarkets that aim to increase product quantity or quality. Likewise, they may be offered by service providers, input providers, or processors whose primary aim is to promote products or collect data from users (3 of 19 digital tools in India). Lastly, in one case in Kenya, mobile network operators provide a digital tool for free to promote customer uptake and loyalty.

4.2. Types of digital tools for livestock development in developing countries

4.2.1. Simple digital tools

The following examples illustrate the role that simple digital tools play in India and Kenya. The app *Dairy Husbandry Practices (Hi)* of the National Dairy Development Board provides extension advice on basic dairy husbandry practices to livestock keepers. A similar tool called *Harpashukagyan* is offered by the Animal Husbandry and Dairying Department in Haryana. The app *NDDB AGR* also provides extension advice. However, unlike the other two examples, the advice is offered in the form of small videos, which users can start by scanning the QR codes printed with an accompanying picture on an overview sheet. This aims to enable illiterate livestock keepers to also use the application. An example from Kenya is *Indigenous KALRO Chicken,* an e-encyclopedia on poultry husbandry developed by the Kenya Agricultural and Livestock Research Organization. Another Kenyan example is *iShamba* by the Mediae Company*,* which provides generic extension advice and allows farmers to ask questions to experts by phone or SMS. Several other tools whose focus goes beyond providing extension advice still host text-based or video-based information on animal practices. For example, *Mooo Farm,* a digital tool linking farmers with other value chain actors (see section 4.2.4.), also provides e-learning videos as part of its smartphone application.

4.2.2. Smart digital tools with manual data entry

As explained above, smart digital tools provide livestock keepers with more tailored information as compared to simple digital tools by using data entered by the livestock keepers or other value chain actors. This helps farmers to monitor and optimize livestock performance. For example, *Farmtree* in India allows livestock keepers to record data on feeding, health, fertility, and yields of cows and buffalos, which facilitates monitoring and helps to optimize production (see also section 4.3.). *Livestoc* in India provides a similar service. *Poultrac Tag-a-Shed* and *Poultrac Tag-a-Shed: Hatchery* also allows farmers to record animal data. However, since these tools target poultry producers, data is not entered for each animal but each shed. *Mooo Farm* focuses on the recording of revenues and expenses, thus enabling better accounting.

ILRI's *On-farm Feed Advisor* helps farmers to optimize feeding strategies, based on data from the farmers and an optimization algorithm. However, in this case, data are not entered by farmers independently, but with the help of trained extension agents. *Herdman* is another example where farmers may benefit from farm or animal specific information provided by smart digital tools without the need to own smartphones. As further detailed below, *Herdman* helps cooperatives or processors that work with smallholder farmers to manage service providers such as A.I. technicians and veterinarians using the GPS function of their smartphones, on which the Herdman app runs. Moreover, service providers collect data on animal health and fertility using RFID codes, which can enhance the quality of service provision (see section 4.3 for more details). The digital tool *Dairy Vet Software* from Shaurya Technosoft Pvt. Ltd follows a similar approach.

In Kenya, *DigiCow Dairy App* from Farmingtech Solutions and *SmartCow* from Intersoft Eagle follows a similar approach to *Farmtree* and *Livestoc* in India: they enable livestock keepers to record animal and herd data and monitor and improve herd management and production. *iCow*, which offers both an SMS-based service and an application for smartphones, is a relatively data-light smart digital tool. While providing mostly generic animal husbandry advice, this advice reflects the lactation cycle of registered animals. However, this is only true for the tool's component on dairy farming. Most users interviewed for this study did not receive information based on the lactation cycle. For them, *iCow* is a simple digital tool. Users of the smartphone version of iCow can also talk to a trained veterinarian via the app (see also 4.1.3.).

4.2.3. Smart digital tools with sensor-based data entry

As shown in Figure 3, we identified only one smart digital tool that uses sensor-based data entry. This tool, which was applied in Kenya, is called *AfriScout.* The tool uses satellite-based remote sensing data to assess vegetation and water conditions and create localized grazing maps. These maps help pastoralists to improve migration decisions and pasture management. In addition to using sensor-based data, pastoralists can also manually enter data, for example, on dangerous predators or animal diseases, to warn other pastoralists.

4.2.4. Digital tools for value chains

Several digital tools in both India and Kenya aim to connect different value chain actors. In India, the digital tool *Mooo Farm* helps livestock keepers to buy inputs such as feeds and veterinary medicine, to contact veterinarians for online consultation or schedule appointments with them, and to apply for finance and insurance. The tool also supports livestock keepers to sell milk and animals. Similarly, the tool *Livestoc* from Amaze Brandlance Private Limited in India facilitates access to inputs and services and to sell outputs. In Kenya, *Digi Farm* provides a digital marketplace for farmers to buy inputs, access loans, and connect with potential buyers.

4.3. On-the-ground case studies

In addition to taking stock of the digital livestock landscape in India and Kenya, we conducted two on-the-ground case studies in India (on *Herdman*, see section 4.1.1. and *Farmtree*, see section 4.1.2.) and one in *Kenya* (on iCow, see section 4.1.3.). The three digital tools were selected because they have different objectives, approaches, and business models and can thus highlight the diversity of digital tools for livestock development. All tools were developed by start-ups. Their founders have different backgrounds, including livestock sciences (*Herdman*), computer sciences and business management (*Farmtree*), and social entrepreneurship (*iCow*). Perhaps reflecting these different backgrounds, each of the ICT applications tackles different constraints in livestock development and uses different business models. *Herdman* is purchased by dairy companies and cooperatives and aims to provide better services to their farmers and to supervise field agents. *Farmtree* helps medium to large-scale dairy farmers, who subscribe to *Farmtree's* services, to manage their herds. *iCow* focuses on the provision of extension advice to smallholder farmers and is free to its users, enabled by donor funds and support from a mobile communication network.

4.1.1 Herdman (India)

According to the classification developed above, *Herdman* is a smart digital tool with manual data entry. Through its combination with smartphones, the tool connects actors across the value chain. Connectivity is at present predominantly "many-to-one", even though the opposite direction is also feasible. In terms of capability, the tool is mostly used for documentation, monitoring, and control, but it has the potential to be further developed to provide rule-based and sophisticated decision-support.

Herdman was developed by Vetware Private Limited, a company founded by Dr. Abdul Samad, a veterinarian and retired dean of the Mumbai Veterinary College. He developed the tool from 2004 onwards with the financial support of approx. 20,000 US$ provided by a World Bank project. The plan was to develop an application to be used directly by farmers, but scaling was limited. Since few farmers were willing to purchase the tool, Vetware approached public actors, such as the extension system. Given the limited interest, the company then developed a digital system for cooperatives, producer companies, and dairy processors – who in turn work with farmers. In the *Herdman* system, dairy farmers do not use the digital tool themselves. A key element of the system is an ear tag that has a QR code printed on it, which makes it possible to uniquely identify every animal. In terms of our classification, the ear tag may be considered as an "embodied" element of *Herdman,* but the ear tag has no sensor attached and does not provide any connectivity by itself. However, the QR code can be scanned with a smartphone. Scanning of the code and entry of information is done by the staff of the organizations that farmers sell their milk to. According to Vetware, *Herdman* was, in 2020, used by five organizations, including dairy cooperatives and private dairy companies, mostly in the Southern states of India. Together, they had tagged and registered approximately 800,000 animals using the *Herdman* tool.

The dairy cooperatives and companies that have adopted *Herdman* employ their own A.I. technicians and veterinarians to provide services to the farmers from whom they procure the milk. Whenever providing any service, the A.I. technicians and veterinarians scan the QR code on the ear tag of the cow that they are dealing with and then manually enter data on fertility management (e.g., insemination, pregnancy, and calving details) and health (e.g., diseases, treatments and drugs, vaccination and deworming). This is all achieved via their smartphones. The data recorded data is then automatically transferred to a central database that is operated by the dairy company or cooperative, using the connectivity of the smartphone. The tool also functions offline in case there is no connectivity.

This way of collecting data makes it possible for the dairy cooperative or company to collect data not only on the cows but also on the activities of their staff, which can be used, e.g., for payment and accounting purposes. Using the GPS function of the smartphones used by the A.I. or veterinary staff, the system allows the organization to monitor the performance of their field staff, because *Herdman* records the position of the service providers when they go to farmers and scan QR codes. Their performance and efficiency can, thus, be monitored. At the same time, the data collected on individual dairy animals can be used to provide animal-specific advice on fertility management and health. Moreover, since such data is collected from hundreds of thousands of animals, the use of *Herdman* leads to the creation of big data. In principle, such data can support the dairy cooperative or company in decision-making regarding breeding, for example, by helping to assess the efficiency of sires. The data can also be used to predict the milk availability for the company in the next few months by knowing the number of pregnant animals. By enabling better services, the digital tool is expected to help the participating small-scale livestock keepers. The case study evidence showed that even though farmers did not record data themselves and only a few of them had smartphones, there were some attempts to send them text reminders on key activities (such as alerts on the need for pregnancy diagnosis checks and calving date). However, at the time of the study, such animal-specific advice was not provided on a large scale.

Overall, *Herdman* has the potential to improve several of the above-mentioned animal husbandry activities, especially by providing better access to artificial insemination and veterinary services and by facilitating improved breeding. The fact that the app has been adopted on a large scale (as mentioned above, covering 800,000 animals at the time of this study), can be considered a major achievement. Yet, the case study also revealed some challenges. Some may be considered minor. For example, some farmers were reluctant to tag their animals since ear tags are associated with non-payment of debts (based on the practice of banks to tag animals that are considered as collateral).

Ensuring data quality turned out to be a major challenge. A.I. technicians and veterinarians have strong incentives to enter data for which they receive payment, such as performing inseminations, pregnancy diagnoses, and treatments. However, they have fewer incentives to enter other data, such as calving dates or deaths of calves or cows. When such data are not entered, key parameters, such as calving intervals or calf mortality cannot be calculated. Such gaps can undermine the quality and usefulness of the big data generated and significant investment in data quality control appear to be required to avoid such problems, e.g., for monitoring of data entry by supervisors and incentive payments to staff for accurate data entry. Moreover, some important performance data, especially data on milk yields, were at the time of this study not collected by any of the organizations using *Herdman*. Since milking is done by hand, there is no obvious solution for the recording of data on milk yields. A.I. technicians and veterinarians (who are entering the data for *Herdman*) cannot observe milk yield, except if they were present at the time of milking. Farmers could report the milk yield to the technician, but they have an incentive to overstate the milk yield since a higher milk yield will increase the value of the cow. Hence, the value of the big data collected by *Herdman* for breeding purposes remains limited.

Lastly, there are also concerns about who has access to the data and who can use them. The case study evidence suggests that, so far, dairy companies and cooperatives use *Herdman* data effectively to monitor the activities of staff members who provide services to farmers, while the livestock keepers themselves did not yet have easy access to the data collected on their animals.

4.1.2 Farmtree (India)

Farmtree by Inhof Technologies is the second Indian tool included in our case study. In terms of the above classification, *Farmtree* is a smart digital tool with manual data entry. Currently, data are only shared with the company that developed Farmtree. In terms of capability, the tool is used for documentation, monitoring, and control and it provides decision support that can be characterized as sophisticated.

Farmtree was developed by Anil Mishra and Avik Sen after they had observed small-scale dairy farmers and analyzed their economic performance using simple excel spreadsheets. Identifying an untapped potential to enhance economic performance, Mishra and Sen developed *Farmtree*, a dairy management and analytics platform. *Farmtree* was supported with startup funding from the Indian Agriculture Research Institute but is now self-sustained on a subscription-based business model. The tool is free for up to five animals and many farmers reportedly try this demo version and then subscribe to the paid version which costs around INR 20 per animal and month (around 0.3 US$). To put this figure in context, Indian farmers receive around INR 30 per liter of milk sold from cross-bred cows.

Farmtree allows livestock keepers to monitor the performance of the overall herd and individual animals. Using the *Farmtree* software, the farmer registers each animal and provides information on species (cattle or buffalo) and breed as well as other details, such as lactation stage and age, among others. The farmer then enters daily for each animal the milk yield, revenues for milk and the sale of animals, and all costs related to feeding, fertility management, health, and purchase of animals. This data entry allows farmers to monitor the economic performance of their animals and their herd and, *Farmtree* processes the data entered by the farmers in such a way that they can monitor a wide range of performance parameters, such as insemination efficiency, calving intervals, milk yields (e.g., daily yields, days of peak yields, and total yield per lactation), feed performance as well as economic parameters (e.g., monthly profitability, per-unit costs of milk). Livestock keepers can also identify 'profit-making' and 'loss-making' animals. As this decision support is based on animal-specific economic calculations of profitability, it can be characterized as sophisticated in terms of the framework presented above. *Farmtree* also allows farmers to better understand fertility problems. The tool has a feature that informs the farmer through SMS and email alerts about the required date of outstanding activities, such as A.I., pregnancy check, vaccination, deworming, and drying. This feature helps the farmer to manage each animal and it can also be used to assign duties to laborers.

Twelve out of the thirteen farmers who were visited for the case study reported that *Farmtree* helped them to increase milk yields and improve overall economic performance. For example, farmers mentioned that the data and information helped them to select the best animals for next-generation calf production and to replace animals that were not performing, thereby reducing the cost of production. Some challenges were observed, as well. At the time of the study, the digital tool was only available in English. Moreover, some farmers reported that it was difficult for them to understand some technical terms. This problem is more pronounced when data is entered by farm laborers whose education is limited. Similar to the case of *Herdman*, the possibility to derive valuable conclusions from the data depends on data quality. Overall, farmers can be expected to have strong incentives to enter good data since they directly benefit from accurate information. Yet, farmers or farm laborers reportedly sometimes fail to regularly update the data, which leads to wrong conclusions about economic performance. In some cases, farmers may not follow the advice given or necessary services, such as A.I. or veterinary services, are not available on time. *Farmtree* has access to the farmers' data, which in aggregated form can also be considered as big data.

4.1.3. iCow (Kenya)

One of the most well-known digital tools for livestock development internationally is *iCow*, an e-extension tool offered by GreenDreams Tech for farmers in Kenya, Tanzania, Ethiopia, and Nigeria. In terms of the framework presented above, iCow can either be used as a simple digital tool or as a smart digital tool with manual data entry. In the latter case, iCow can provide rule-based decision support. If the farmer does not enter farm or animal specific dates, the tool serves to provide technical information and to link actors across the value chain.

iCow was developed in 2010 as a service to monitor cattle pregnancy through a cow gestation calendar. Today, *iCow* provides information to farmers on different aspects of livestock production such as feeding, disease control, and milking. The information can be accessed from feature phones and smartphones. The majority of users access the information through feature phones (around 110,000 farmers in Kenya alone). One of the key features is SMS information sent three times a week to subscribers on topics of their choice.

As its name implies, *iCow* offers information on dairy cattle. However, it also provides information on poultry, camels, small ruminants, pigs, rabbits, donkeys, and fish. Contrary to what the name suggests, iCow is not restricted to livestock. The application provides a diversity of information ranging from crops, trees, and soils, to insects and farmer health. i*Cow* also offers a virtual marketplace (*iCow Soko*), where subscribers buy inputs and sell livestock and livestock products. Moreover, there is a function that enables livestock keepers to locate veterinary and artificial insemination officers in their area. Users can also contact a resident veterinarian (*Dr. iCow*) through an SMS to which Dr. iCow responds with a direct telephone call. *iCows*' feature phone version requires farmers to be literate. The smartphone version contains more audio-visual elements. For example, farmers can listen to recorded advice, watch recorded videos, and access a gallery of photographs. However, navigating through the application itself still requires literacy. *iCow* is currently provided for free through a partnership with the mobile provider Safaricom, but previous versions required subscribers to pay between 3-5 Kenyan shillings (0.03 to 0.05 USD) per SMS. For comparison, farmers received around 30 KSH per liter of milk.

The interviewed farmers reported that much of the information from *iCow* was 'new' to them and helped them to validate existing practices, adopt new practices, and/or discard other practices. For example, livestock keepers reported adopting new disease management practices such as spraying and deworming and to follow more hygiene management practices. Farmers also discarded some problematic practices such as deworming while cows are pregnant, feeding ash to trigger heat, or feeding salts for humans to cattle, which lack some essential minerals required by the animals. The knowledge obtained through iCow reportedly helped farmers to obtain higher yields, reduce animal diseases, and achieve better animal health.

Overall, respondents evaluated the *iCow* messages as easy to understand. However, in some instances, abbreviations, technical terms, and coding prevented understanding. For example, 'sheep breeding' is sometimes abbreviated with 'SHBR'. The respondents also appreciated the portability of the information ("iCow is always in your pocket"; "iCow is there 24/7"). However, all of the respondents lost their phones at some point in time and consequently lost much of the information. While most of the interviewed users found the information helpful, around 20% of the respondents reported that the *iCow* information is not helpful or that they do not trust the information. Users also argued that some information is not "actionable". For example, *iCow* made them aware of the potential of using improved seeds for fodder production, but they could not find dealers selling such seeds. In other cases, financial constraints limited adoption. It is also interesting to note that *iCow* is famous for providing cow- and poultry tailored advice based on cow- and poultry calendars. However, out of the i*Cow* users interviewed as part of the focus group discussions, only three farmers used the calendar function and received advice on this basis.

5. Discussion and conclusion

The review of the digital landscape for livestock in Kenya and India and the on-the-ground case studies provide insights that are of general relevance for digital livestock tools in developing countries, as discussed in this section.

5.1 Harnessing the underutilized potential: From simple to smart digital tools with decision-support

The stocktaking has shown that most of the currently used tools are "simple digital tools" (i.e. tools that provide generic information) and "smart digital tools with manual data entry" (i.e. tools that use farm or animal specific information that is entered manually by the farmer using a feature phone or a smartphone). Only one "smart digital tool" was identified that used sensor-based data entry. While “simple digital tools” can certainly help small-scale livestock keepers, the findings of our review point to an untapped potential to use more sophisticated digital tools for livestock development. Given the diversity of smallholder farming systems, providing farm and animal specific advice has a unique potential for promoting development. “Smart digital tools” can unlock this potential by allowing livestock keepers to enter data and potentially by drawing more on the sensors that are either embedded in smartphones or attached to animals and livestock equipment. So far, most digital tools focus on dairy production, neglecting other types of livestock. Moreover, there are few tools for pastoralists, suggesting another untapped potential. Overall, the results point to the transformative power of digital tools. However, there are also some challenges, which are discussed below.

Many of the reviewed tools were classified as “simple digital tools”. They provide generic (not farm or animal specific) information. In principle, such information is also available through non-digital means, such as extension advice, leaflets, or other extension material, including newspapers, farm magazines, and books. For example, *iCow* sends farmers general information on feeding practices and animal hygiene, among others. While such tools are characterized by low levels of digital sophistication, they may nevertheless have large benefits, because many livestock keepers lack such information due to limited access to agricultural extension, for example (Maleko et al., 2018; Owen et al., 2012). The traditional extension system is often patchy because it is costly to reach farmers in a remote place (Nakasone & Torero, 2016). Moreover, extension services are confronted with diverse governance challenges that limit their effectiveness (Birner & Anderson, 2007). Importantly, using print media, such as leaflets of farmers’ magazines, involves a far higher cost than sending digital information. As “simple digital tools” provide non-tailored information that can be scaled so easily, they are considered to be the “low-hanging fruits” of digital services, as mentioned above (Aker, 2016; Daum, 2019). The *iCow* case illustrates this point. One also has to emphasize one particular advantage of such services. While the advice provided is not farm or animal specific, the farmer can still decide what types of advice (e.g., related to what type of livestock or what type of crop) he or she wants to receive. Such a request for tailored content is not possible when signing up, e.g., for a farm magazine.

The case of *iCow* also illustrates the downside of simple digital tools: it is difficult to find sustainable business models, as is well-known in the literature (see, e.g., Fabregas et al., 2019). One has to acknowledge that generic information is also distributed through popular social media platforms, which are not covered in this review. Youtube, for example, offers an abundance of self-help learning videos for livestock farmers in both India and Kenya. Farmers can select the videos they want to watch. Moreover, many of these videos are created by livestock farmers themselves, who are thus very familiar with the problems encountered on the ground. This may also create trust among the viewers.

The results suggest a great potential to use “smart digital tools”, that provide tailored advice to farmers, based on data entered by the farmer. While data entry is possible even with simple feature phones, as was the original idea in *iCow*, the fast spread of smartphones in many developing areas simplifies data entry and creates opportunities to record additional types of data. “Smart digital tools” are emerging in both India and Kenya. The case study of *Farmtree* in India shows that a smartphone application for farmers that helps them to collect and analyze data can facilitate their monitoring and decision-making on feeding strategies as well as fertility and health management. Improving these animal husbandry activities simultaneously has a strong potential to increase milk yields and, thus, the performance of dairy farmers (Maleko et al., 2018; Owen et al., 2012). The review also shows that the opportunities for optimization offered by “smart digital tools” remains underutilized. In particular, most of the digital tools identified for this review did not provide sophisticated decision-support, and even rule-based decision support was limited, so far. “Smart digital tools” have the advantage that they are disembodied and require little upfront investments for farmers. Provided that farmers feed such tools with good data and that the optimization advice is based on sound algorithms and modeling, such tools have a large potential to improve livestock production. One should, however, not underestimate the investment that is needed to provide sound decision support. Even rule-based support (e.g., on feeding) requires sound technical subject-matter knowledge, which may not easily be available to the developers of digital tools, who often have a background in computer sciences or marketing, rather than livestock sciences. Hence, a collaboration between start-ups, public sector research and extension organizations may be essential to develop tools that provide adequate decision support.

5.2 Ensuring the quality of farm and animal specific data

Even where farmers do not yet own feature phones and smartphones, which would enable data entry, “smart digital tools” may still be used, if service providers, e.g., A.I. technicians enter the data, as the example of *Herdman* shows. *Herdman* helps dairy companies and cooperatives to provide better services by collecting animal data from their smallholder farmer’s animals and to better supervise field agents by using QR codes (printed on the ear tags of the cows treated by the field agents) and GPS (available in the smartphones of the field agents). The big data based on individual animal records thus generated could provide new opportunities for animal breeding, especially where phenotypes are combined with genotype data (that could be used for genomic selection). The case study shows, however, that low quality or incomplete entry of animal-specific data may undermine the usefulness of such endeavors. Our case study of *Herdman* indicates that the agents who enter data, in this case, A.I. agents and veterinarians, need to have the right incentives to record *all* relevant data accurately. So far, they are only incentivised to enter data that are linked to their payments (such as an A.I. that was performed), but they have no inherent incentives to enter other data that are relevant to calculate performance parameters, such as calving dates. Moreover, solutions to enable accurate recording of data on milk yields still need to be developed to fully use the potential of such tools for breeding purposes. "Smart digital tools" can be applied to obtain data on individual animals, which can be used for animal breeding and genetic improvement. With appropriate genetic evaluation software and models that account for the production systems and environmental factors, such digital tools could provide a ranking of the potential sires for the next generation in a selection program. Such initiatives could draw out important synergies between new digital technologies and across-country genetic improvement endeavors like the African Dairy Genetic Gains (ADGG) program (Mrode et al., 2020; Opoola et al., 2020).

One major challenge to make digital tools truly "smart" is to create incentives for livestock keepers to enter data correctly, which was shown to be a problem in all three case studies. This is problematic as the low quality of the entered data may lead to digital advice that is either not useful for farmers or – in the worst case – negatively affects livestock production. This is one of the reasons why the automated collection of data through sensors could help. However, such tools typically require more upfront investments as they involve embodied technologies (i.e., sensors) that must be applied reliably. Our review identified one digital tool that can be classified as smart and relied on sensor-based rather than manual data entry. This tool was *AfriScout* from Kenya, a tool to improve pasture management using satellite data. Livestock farmers who want to use this tool just need smartphones.

5.3 Addressing concerns related to digital tools: The "digital divide" and the threat of "data grabbing"

While the use of digital tools offers many new potentials for livestock development, digital tools are also associated with concerns. In particular, there are debates on whether such tools can cause a "digital divide" and disadvantage smallholders, or whether, on the contrary, they may reduce the disadvantages faced by smallholders (Aker, 2016; Klerkx & Rose, 2020). The results of the review and the case studies show that most tools rely on literacy. In particular, all tools that require data entry by farmers require both alphabetical and digital literacy. In many cases, they also require familiarity with technical terms. This may lead to the exclusion of some types of farmers from digitalization, potentially contributing to a digital divide. Simplifying user interfaces, reducing technical jargon, and using pictorial, audio, and video elements may help to address some of these challenges (Daum et al., 2019).

A digital divide may also emerge because the information provided is “actionable” to different degrees by small, medium, and large scale livestock keepers (Aker et al., 2016; Daum, 2019). For example, when providing information on better feeding strategies, large farmers may utilize the information, while small farmers become informed but cannot act since they face additional constraints, such as lack of finance. In general, information alone may not be sufficient to enhance livestock productivity when other external factors beyond the farm determine outcomes. For example, *iCow* users acknowledged the value of receiving information on alternative seeds for fodder production, but the main constraint was access to the supply of such seeds in the market. This insight points to the need for accompanying non-digital efforts on livestock development as many structural barriers cannot be addressed with digital tools alone.

There are also concerns related to data security, privacy, ownership, and sovereignty (Daum, 2019; Fraser, 2019; Wolfert et al., 2017). *Herdman* is an interesting case in this regard. As shown by the case study presented here, *Herdman* was used by a private company to collect data from small-scale livestock keepers. This company provides both inputs and services to the farmers and purchases their outputs. (Note that *Herdman* is also used by cooperatives). On the one hand, *Herdman* has the potential to improve services to smallholders and the big data obtained provides new opportunities for breeding programs. Too stringent data policies may prevent such potential from being harnessed. On the other hand, there are increasing concerns about the consequences of big data from smallholders entering the hands of big companies (Bronson & Knezevic, 2016; Prause et al., 2020; Wolfert et al., 2017). Fraser (2019) describes such a process as “data grabbing”. Taking a more nuanced perspective, one may argue that farmers should retain the right to decide with whom they share data – which may well be large companies if they consider such a data exchange to be beneficial to them. What appears problematic are situations where farmers share data with organizations without being aware of it or situations where they can become “locked into” working with specific companies. This may lead to “path dependencies, power asymmetries between farmers and agribusinesses, and a loss of bargaining power for farmers” (Birner et al., 2019, p.62). Governments across the world face the challenge of finding appropriate policy tools to address data security, privacy, ownership, and sovereignty concerns, while at the same time ensuring that the potentials of digital tools can be harnessed.

5.4 Concluding Remarks

Overall, the study suggests that digital tools for livestock have great transformative power in developing countries, thus contributing to alleviating poverty and ensuring food and nutrition security while reducing livestock's ecological footprint. The review suggests that the market is largely driven by local entrepreneurs, who have created a vibrant landscape of digital tools, characterized by innovation and experimentation. It is highly encouraging that a wide variety of digital tools are already in the hands of small-scale livestock keepers in the developing world. The public sector could help to harness the full potential of such digital tools, in particular by investing in research that enables sophisticated decision support and by protecting farmers' rights to their data. While digital tools are not a silver bullet, they are likely to become a key pillar of livestock development in the near future.

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