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DESIGNING A SUSTAINABLE BUSINESS MODEL FOR AUTOMATED SOLAR-PV DRIP IRRIGATION FOR SMALLHOLDERS IN GHANA

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ABSTRACT

Sustainable business model (SBM) research and practice has grown rapidly in the last two decades, not only showing the traits of an emerging research field, but also having an impact on business practices and government policies. Despite the wide-ranging academic and practical debates on SBMs, the academic literature still needs approaches specifically tailored to support the design of SBMs in developing countries, taking into account their characteristics, opportunities, and challenges. Our working paper aims to address these gaps in research and practice by proposing a framework supporting SBM design in developing countries. The SBM framework is composed of three main parts, i.e., value creation and delivery, value capture, and value proposition, and allows for an assessment of financial, economic, social, and environmental costs and benefits. It was applied to the case of small-scale irrigation in sub-Saharan Africa, specifically to a low-cost, automated solar-powered drip-irrigation technology, the ASPDI system, which was developed for small-scale vegetable farming in Ghana by an international research and innovation project. This research enabled a comprehensive ex-ante sustainability evaluation of the APSDI system and its associated business model in respect of its provision, covering the perspectives of technology providers, farmers, and society. The results of the evaluation highlight important issues related to the development, market diffusion, and farmer adoption of new small-scale irrigation technologies.

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1. INTRODUCTION

1.1 SUSTAINABLE BUSINESS MODELS

Sustainable business model (SBM) research and practice has grown rapidly in the last two decades, not only showing the traits of an emerging research field, but also having an impact on business practices and government policies (Lüdeke-Freund and Dembek 2017). Despite the wide-ranging academic and practical debates on SBMs, the academic literature still needs approaches specifically tailored to support the design of SBMs in developing countries, taking into account their characteristics, opportunities, and challenges (Sabatier et al. 2017). Our working paper aims to address these gaps in research and practice by proposing a framework supporting SBM design in developing countries. The framework is applied to an international development research and innovation project to implement an automated solar-powered drip irrigation (ASPDI) system for smallholder vegetable farmers in Ghana. Development cooperation is the ideal setting for testing and validating the framework, given the importance of impact evaluations in such contexts (Paul et al. 2018; Jiggins 1995).

The case study describes a business model that has been designed on the basis of a Green Cohesive Agricultural Resource Management (WEBSOC) research and innovation project carried out in southern Ghana from 2014 to 2019 (Andersen 2020). The project included on-station and on-farm testing, demonstration and monitoring of the ASPDI system applied to small-scale vegetable farming, analysis of the vegetable value chain, and focus-group and semi-structured interviews with irrigation experts and potential suppliers of the ASPDI system in Ghana.

The business model has been developed in consideration of three perspectives: those of the supplier of the technology (i.e., the firm that delivers the system as a complete package, directly to the farmers or to a retailer), the buyer/user of the technology (the farmer), and the wider society. The supplier of the ASPDI system in Ghana could be a variety of firm types: an established agricultural equipment/input supplier, a small or medium-sized enterprise (SME), a start-up created for this purpose, or an NGO.

The objective is to develop a business model (including all relevant data and analyses) that enables such an actor to make an informed decision regarding investing in bringing the system to market and attracting affordable investment finance from within the firm or from external sources. The perspective of the farmer (customer/user) is taken into account through analysis of the value proposition, specifically the value offering to the customer, which is a key element of the SBM framework. The social perspective involves assessing the socio-economic and environmental benefits and costs associated with the supply, use, and ultimate disposal of the technology.

1.2 THE BENEFITS OF SMALLHOLDER IRRIGATION

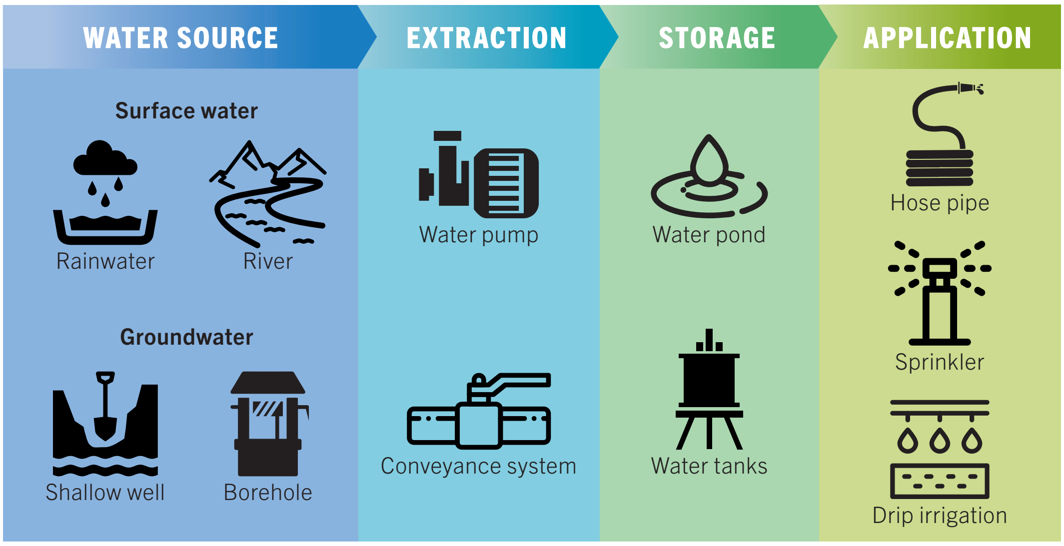
Irrigation may enable smallholder farmers to transit from subsistence farming towards commercialized production by raising crop yields, increasing produce quality, and enabling all-season farming. It can also improve nutrition and food security, especially in sub-Saharan Africa (SSA), whose population is expected to double from 1.07 billion in 2019 to 2.12 billion in 2050 (UNDESA 2019). Moreover, climate change means an increased need for irrigation, in particular water-efficient solutions such as drip irrigation, as prolonged periodic droughts and changing precipitation patterns are projected across the region (IPCC 2013). In areas of adequate access to water resources, efficient irrigation systems can ensure stable agricultural production despite infrequent precipitation, thus ‘climate proofing’ the agricultural sector (World Bank Group 2019). Hence irrigation is increasingly recognised as a key technology, not only to improve food security, livelihoods and agricultural transformation (Mendes D. M., Paglietti L., Jackson D. 2014; Shah and Keller 2014; FAO 2015), but also to reduce vulnerability to climate change (Batchelor and Schnetzer 2018; World Bank Group 2019; Nygaard and Hansen 2015).

1.3 KEY ELEMENTS OF IRRIGATION SYSTEMS

This and the following section are based on Hornum and Bolwig (2020). The physical elements and processes of an irrigation system may be categorized into *water source, water extraction, water storage,* and *water application* (Figure 1). This simple typology applies to irrigation systems of all sizes, but in the present context it provides an overview of how a small-scale irrigation system could be designed and a description of the main elements involved. The four elements make up an integrated system. While water source, water extraction and water application are all necessary elements, water storage is not always needed but may improve the efficiency of the system or prolong the period in which it can function, especially into the dry season, when rivers may dry up and/or groundwater levels sink.

Figure 1.

Typology of irrigation system elements, consisting of water source, water extraction, water storage, and water application.



Source: Hornum and Bolwig (2020).

Access to water is obviously a precondition for irrigation. In some areas the topography and the climate allow farmers to irrigate using a gravitational furrow system, whereby the water is led from an elevated storage facility via pipes or channels and applied to the plants via earth furrows in the field. If the land is located close to a river, lake or wetland, farmers can use this as a water source. Shallow wells may also be used where the water table is high, but they may not be a reliable or continuous water source. Water can also be accessed through boreholes. However, establishing a borehole is expensive and must follow formal procedures, including surveys of hydrological and geological conditions and authorization from the respective Water Resource Authority.

Extracting the water from the water source normally requires the use of a pump, powered by diesel, grid power, or solar PV. The water may be extracted and applied directly to the fields or led to a water storage facility (water pond or elevated tank), from where it can be applied via gravity or a pump. In some large irrigation schemes, water is delivered through a conveyancing system supplied with valves allowing each farmer to turn the water on and off. For low-pressure solutions like drip irrigation, water is normally lifted into a tank, from where it is distributed by gravity though drip lines to the individual plants. The sprinkler application technology requires a higher pressure, which can be generated using a pump or through connection to a large pressurized water-intake system where these exist.

1.4 IRRIGATION TECHNOLOGIES FOR AFRICAN SMALLHOLDERS

Smallholders in SSA use different technologies for irrigating their crops. Here we describe the most important ones in the context the ASPDI system evaluated in this paper, while noting that irrigation potentials, needs, and capabilities can vary significantly between countries, regions, communities, and individual farmers.

Non-manual forms of irrigation can be grouped into the following categories (Brouwer et al. 1990):

- surface irrigation, in which the entire crop area or most of it is flooded;
- sprinkler irrigation, which imitates rainfall;
- drip irrigation, in which water is dripped onto the soil above the root zone only;
- underground irrigation, where water is applied to the root zone by means of porous pots or pipes placed in the soil;
- sub-irrigation, in which the groundwater level is raised sufficiently to dampen the root zone.

Below we discuss the first three categories, the most relevant ones for smallholders.

In surface irrigation, either the entire field is flooded (basin irrigation), or water is applied to crops via small channels (furrows), siphons or strips of land (borders). Surface irrigation can be used for all crop types, with some variation dependent on the type of system, and it normally requires little equipment and maintenance unless pumps are used, especially in small-scale schemes. Hence, furrow irrigation can be an attractive option for smallholders, especially if oriented towards subsistence farming, where cash flows are limited.

Sprinkler and drip irrigation are mainly used for high-value crops destined for the market due to the investments in equipment (power source, pumps, pipes, drip lines, sprinkler heads etc.) that must be made by the individual farmer. Drip and sprinkler irrigation are technically more complicated technologies than surface irrigation, and maintenance requires technical knowledge. Hence, market-oriented rather than subsistence-oriented farmers are likely to be the most frequent users of these technologies (USAID 2016). Drip and sprinkler irrigation can have significant economic benefits, according to assessments of demonstration projects and other experience (Otoo et al. 2018; Shah and Keller 2014; FAO 1997; Gebregziabher et al. 2016). For example, adoption of drip irrigation can lead to 38% saved labour, 45% less water use, and an 110% increase in yield, according to one report (USAID 2016). However, to yield such benefits, irrigation solutions must be carefully tailored to the biophysical and socioeconomic contexts in which they are deployed.

1.5 AN AUTOMATED SOLAR-PV DRIP IRRIGATION SYSTEM FOR SMALL-SCALE VEGETABLE FARMING

The business model includes an automated solar-PV drip-irrigation (ASPDI) system developed by the WEBSOC project. The system is designed to irrigate a 500 m2 area, typically planted with vegetables, using a 12-volt DC pump submerged in a nearby water source (stream, pond, reservoir etc.) and powered by a 50-watt solar PV plate. The water is continuously pumped into an elevated, 210-liter tank as long as the sun is shining. When the tank is full, it flushes (empties) automatically through a siphon apparatus, and the water runs by gravity through pipes into the drip lines and is applied to each plant.

Due to its simple technical design, low cost and small area coverage, the system is appropriate for small-scale vegetable farming. Most components are available in retail shops in Ghana. The exception is the pump, which is not sold in Ghana today but must be imported specifically for this purpose, typically from China. Section 4.1 provides further details. The system has been tested on-station and on-farm in Ghana's central and eastern regions, which have a distinct dry season and a minor season with intermittent rainfall, in addition to a major rainy season.

1.6 PAPER STRUCTURE

Section 2 presents the analytical framework and section 3 the research method. Sections 4, 5 and 6 provide the main results of the designed SBM (value creation and delivery, value capture, and value proposition). Section 7 outlines the broader social benefits and costs associated with the supply and use of technology. Section 8 provides a discussion and conclusion.

2. THEORETICAL BACKGROUND AND ANALYTICAL FRAMEWORK

This section presents the theoretical background and analytical framework of the study. The section first presents definitions of the business model and the sustainable business model. It then conducts a review of literature and current practice to identify existing frameworks and approaches supporting SBM design, with a specific focus on developing countries. Based on this review, we put forward an analytical framework supporting SBM design in developing countries.

2.1 BUSINESS MODELS AND SUSTAINABLE BUSINESS MODELS

In practice, the concept of a business model (BM) has been increasingly used to describe and analyze the business logic of new organizational forms (Timmers 1998). During the last twenty years, the concept has also been progressively used in academia, particularly in connection with more established academic disciplines, such as strategic management (Magretta 2002; Teece 2010) and entrepreneurship (Morris, Schindehutte, and Allen 2005). One of the most widely used definitions of the concept is that of Osterwalder and Pigneur (2010, p. 14), who defined it as describing "the rationale of how an organization creates, delivers, and captures value".

More recently, the BM concept has also been adopted by corporate sustainability scholars, especially in relation to business model innovation, considered as a way to foster corporate sustainability through changes in the value creation, value delivery and value capture logics (N. M. P. Bocken et al. 2014; Schaltegger, Hansen, and Lüdeke-Freund 2016). Particularly, an SBM "helps describing, analyzing, managing and communicating (i) a company's sustainable value proposition to its customers and all other stakeholders, (ii) how it creates and delivers this value, (iii) and how it captures economic value while maintaining or regenerating natural, social and economic capital beyond its organizational boundaries" (Schaltegger, Lüdeke-Freund, and Hansen 2016, p. 268).

Just like BMs, SBMs have also received increasing attention in practice, with a vast variety of actors (e.g., consulting companies, business incubators, political parties; see Lüdeke-Freund and Dembek 2017) using the concept to support organizations in their sustainability transitions (Bolton and Hannon 2016).

2.2 SUSTAINABLE BUSINESS MODEL DESIGN

The widespread of the business model concept has been both accompanied and fostered by a proliferation of tools and approaches supporting the design (or redesign) of new (or existing) business models. The business model canvas (BMC), proposed by Osterwalder and Pigneur (2010), is one of the most widely used frameworks for conducting business model design, allowing entrepreneurs, investors and other stakeholders to easily visualize and comprehend the overall business logics, including key business operations, value proposition and value capture mechanisms (Cosenz 2017). The BMC consists of nine building blocks depicting the key components of a business model: value proposition, customer segments, customer relationships, channels, key partners, key activities, key resources, cost structure, and revenue streams (Osterwalder and Pigneur, 2010).

Building on the BMC and the framework proposed by Richardson (2008), Bocken (2015) and Bocken et al. (2018) propose an adapted sustainable business model canvas (ASBMC). In the ASBMC, the value-proposition building block is split into three value dimensions covering economic, social, and environmental types of value. Likewise, the value capture system considers not only economic sustainability but also the environmental and social sustainability of the adopted profit generation mechanisms. Despite the wide academic and practical debate over how to conceptualize SBMs, the academic literature still needs approaches supporting SBM design in developing countries.

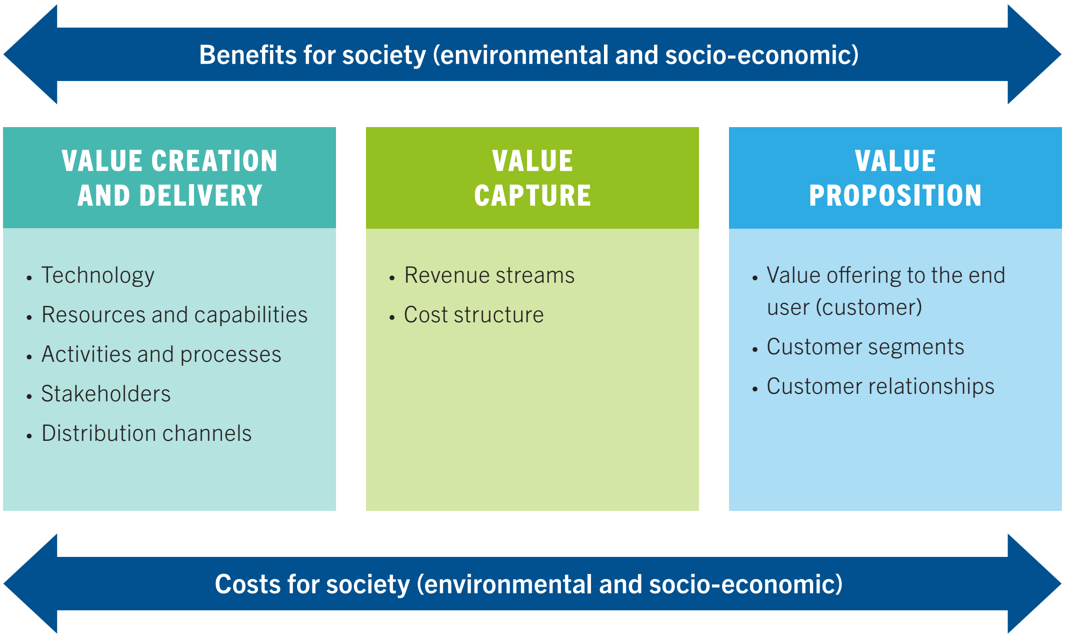
2. THEORETICAL BACKGROUND AND ANALYTICAL FRAMEWORK

In this study, we build upon the frameworks proposed by Richardson (2008), Osterwalder and Pigneur (2010), Bocken (2015), Bocken et al. (2018) and Schaltegger et al. (2016), as well as studies by Yunus, Moingeon, and Lehmann-Ortega (2010) and Sabatier et al. (2017), to propose a sustainability-oriented business model framework supporting the design of a business model for automated solar PV drip irrigation (ASPDI) for smallholders in Ghana.

The sustainable business model for the ASPDI system presented in this paper was designed in accordance with the framework outlined in Figure 2, which was itself adapted from Richardson (2008), Osterwalder and Pigneur (2010), Bocken (2015) and Bocken et al. (2018). In particular, the framework is composed of three main parts, presented in the columns 'value creation and delivery', 'value capture', and 'value proposition'. In addition, the costs and benefits for the whole of society are also assessed, represented by the horizontal arrows.

Figure 2.

Framework for sustainable business models in developing countries.



Source: Adapted from Richardson (2008), Osterwalder and Pigneur (2010), Bocken (2015) and Bocken et al. (2018).

3. DATA AND METHODS

This paper is based on research carried out between 2015 and 2019 in southern Ghana as part of the WEBSOC project (Andersen 2020). The data collection activities of relevance to this paper are summarized below. Details of other data collection activities are found in (Baidoo 2019; Baidoo and Ninson 2019; Danso et al. 2018; Baidoo, Ninson, and Bolwig 2020).

Data collection at research station over two seasons. Evaluation of the performance of the pump used in the ASPDI, measurements of siphon flow rates, and evaluations of the APSDI's water application uniformity (Danso et al. 2018). In addition, an economic evaluation of the system was carried out based on the annualized cost of ASPDI and the variable costs associated with growing okra in two consecutive dry seasons (Danso et al. 2018; Baidoo 2019).

Data collection at demonstration farms over two seasons. Data for on-farm profitability analyses were collected from fifteen demonstration farms during the dry season (November-March) and lesser wet season (August-October) of 2017. This included data on cost variables, i.e. the cost of land, labor and farm inputs (fertilizer, insecticides, and seeds), crop yields, and crop sales revenues. See (Baidoo 2019).

Semi-structured interviews with demonstration farmers. Semi-structured interviews were conducted with WEBSOC demonstration farmers in the Central and Eastern regions during farm visits made by the authors in January 2018, September 2018, March 2019, and November 2019. The interviews covered the farmers' experiences with using the ASPDI system, as well as various aspects of producing and marketing vegetables. See Baidoo and Ninson (2019) for details concerning these interviews and Annex 1 for a list of interviews.

Questionnaire-based interviews with visiting farmers on demonstration days. Two field days were held on contact farmers' fields where the ASPDI system was demonstrated to farmers in the local area (see section 4.2). On each field day, a two-page questionnaire was administered by the project team to all the farmers participating in the demonstrations. The questionnaire covered key characteristics of the farmer, of his/her farming operation (the focus on vegetables), and how he/she perceived the ASPDI system. Baidoo and Ninson (2019) presents the results of these surveys.

Questionnaire-based survey of farmers on willingness to pay for technology. Structured questionnaires were administered to collect willingness-to-pay data from vegetable farmers who had visited the contact farmers' experimental farm. Information regarding willingness to pay for and adoption of technologies was obtained using the contingent valuation method. This was based on the profitability of the on-farm experimental arrangements and on the hypothetical situation that the interviewee's productivity level would increase by certain percentage. See (Baidoo 2019).

Survey of vegetable prices. Farm-gate and trader-level prices of vegetables were collected from actors in the vegetable value chain in the Central and Eastern regions. Through questionnaire-based interviews and focus-group discussions, the minimum and maximum prices paid by assemblers, wholesalers, retailers and consumers of okra, garden eggs, tomato, cabbage, pepper, and onion were collected. The reference markets included Kade, Subi, Nkwantanang, Okumaning, Takorawase, Beposo, Antado, Kissi, Cape Coast, and Jukwa. Responses were sampled from a hundred respondents from both regions. Baidoo, Ninson, and Bolwig (2020) report on the survey.

Questionnaire-based survey of vegetable traders. About sixty traders of okra, garden eggs, tomato, cabbage, pepper and onion were interviewed in the study areas (Central and Eastern regions) using questionnaires. The interviews gathered information on the quality attributes that traders look out for in the marketing process and on marketing costs and profit margins. Baidoo, Ninson, and Bolwig (2020) report on these interviews and present the results of a broader analysis of the vegetable value chain.

Semi-structured interviews with vegetable traders. Semi-structured interviews were also carried out with vegetable traders in the Central and Eastern regions. Apart from the demographic information collected from these respondents, data on prices, marketing costs and profit margins were also collected. See (Baidoo, Ninson, and Bolwig 2020; Baidoo and Ninson 2019) for details and Annex 1 for a list of interviews.

Collection of data on cost of irrigation equipment. The cost of the ASPDI technology was monitored and recorded from the time the system was installed on the demonstration farms (Baidoo 2019). The cost of the equipment was computed from the water source to the last dripline (see section 4.1 below).

Semi-structured interviews with experts and stakeholders. Semi-structured interviews were conducted between January 2018 and March 2020 with stakeholders and experts, notably irrigation technology providers (suppliers), NGOs, farmers' associations, vegetable traders, and government agencies such as the irrigation authority and regional agricultural extension offices. Regular interviews were also conducted with the demonstration (contact) farmers to monitor and record their experiences with the ASPDI system. A complete list of these interviews is found in Annex 1.

4. VALUE CREATION AND DELIVERY

4.1 TECHNOLOGY: DRIP IRRIGATION

Many smallholders in SSA fetch water from nearby streams and ponds manually using containers to irrigate their farms. Manual irrigation is labour-intensive, inefficient and characterized by low productivity (Woltering et al. 2011). In this context, drip irrigation has been widely promoted as a promising and efficient irrigation technology. As the demand for water from agriculture continues to increase and the available resources decline (Zhu et al. 2011; Sijali 2001), drip irrigation technology has gained interest not only as a water-efficient irrigation technology, but also as an effective measure of poverty alleviation, as it increases productivity and enables the transition from subsistence to commercial farming (Venot, Kuper, and Zwarteveen 2017; Woltering et al. 2011; Postel et al. 2001). In Ghana, drip irrigation may be of particular interest as it can boost vegetable production during the dry and seasons, while increasing product quality and compete better with imported vegetables.

Based on the successful adoption of drip irrigation kits by small-scale farmers in Asia (Postel et al. 2001; Woltering et al. 2011), the concept of small-scale, low-cost drip irrigation systems has attracted interests in SSA, especially by governments, NGOs and donors (Belder et al. 2007; Wanvoeke et al. 2015; Andersson 2005; Sijali 2001). Consequently, numerous drip irrigation projects targeting smallholders have mushroomed across SSA (Shah and Keller 2002; Oates et al. 2015; Wanvoeke et al. 2017; Venot, Kuper, and Zwarteveen 2017). They have been mainly financed by international and bilateral donors, and implemented by government agencies (e.g. through national irrigation schemes) and NGOs, with the support of research organizations, and procurement of services from irrigation technology providers (Gross and Jaubert 2019; Wanvoeke et al. 2015).

Despite the optimism and efforts, there is sparse evidence on the extent of adoption of drip irrigation among smallholders in SSA (Oates et al. 2015). Some sources report that many drip irrigation projects have yielded disappointing results (Harrison 2018; Herbert, Clifford, and Hammon 2002; Belder et al. 2007), while the impact of other projects are still to be documented through systematic evaluations (Wanvoeke et al. 2015). In view of this, Venot et al. (2017) point at a paradox: there is a continuing interest and belief in the technology despite a lack of evidence of the impacts on the ground, a situation similar to the hype about the Jatropha nut as a major source of biodiesel observed during the 2000s (Nygaard and Bolwig 2017).

For small-scale farmers, many of whom are unfamiliar with irrigation technologies, drip irrigation can be expensive, laborious, and cumbersome to operate, which may explain the technology's limited diffusion SSA (Woltering, Pasternak, and Ndjeunga 2011; Sturdy, Jewitt, and Lorentz 2008; Harrison 2018; Wanvoeke et al. 2017).

AN AUTOMATED SOLAR-PV DRIP IRRIGATION (ASPDI) SYSTEM

To make drip irrigation easier to use for smallholders in sub Saharan Africa, Danso et al (2018) developed a low-cost solar-powered water supply system and integrated it with a drip irrigation system to make an automated drip irrigation system – the ASPDI system evaluated in this paper. The innovative feature of the system is a siphon device, which is installed in a 210-litre tank to start and stop the discharge of water to the drip irrigation pipes automatically, without any electronic control components. Annex 3 provides a diagram of the siphon system. Furthermore, it is a low-cost design, which was tested during the 2017-18 dry season by several farmers, who had success in terms of a higher yield of vegetables (Oppong Danso et al. 2018).

Figure 3.

Testing the ASPDI system at Kade research station. The water source, solar panel and submersible pump are located to the right, outside the picture.

Photo: Eric Oppong Danso.

The system consists of a low-capacity 12-volt DC submersible pump, which is directly powered (without AC/DC conversion) by a 50-watt solar panel to lift water into the 210-litre tank containing the siphon. The pump is placed in a 10-litre bucket or other container in the water source, and its intake is covered with a filter or mesh to avoid debris entering it. A wooden stand two meters in height supports the water tank in providing a gravity flow after discharge by the siphon to irrigate a drip irrigation system covering an area of 500 m2. See Figure 3.

The submersible pump is a critical component of the system, as it is less easily repaired or replaced than the other components. The pump used in the ASPDI proto-type is of the TOPSFLO brand (*www.topsflo.com*), model TL-C01/S/PV-C12-2008, manufactured by the Chinese company TOPS Industry and Technology Co. It is a 12-volt (2.8 A, 33.6 W) DC pump and is part of TOPSFLO's TL-C series of micro-centrifugal pumps powered by brushless DC motors. The pump has a maximum flow rate of 20 litres per minute and a maximum water head of 8 meters. During the on-farm demonstration, the pump delivered a flow of 4.75 litres per minute at a height of 2.4 meters. The pump is designed for continuous working mode and has an ideal running time of 20,000 hours (about two years) (Topsflo 2017). In the on-farm demonstration, the pump has so far lasted for two years, being used in the dry and lesser rain seasons (maximum six months per year). The pump can be damaged if it is run dry, if the source water contains major particles, or if the polarity is reversed, all of which are realistic scenarios if the farmer is not properly instructed in its use.

Figure 4.

The TOPSFLO brushless DC water pump, model TL-C01-C, used in the ASPDI system.

Source: (Topsflo 2017).

The solar panel is another key feature of the system. We use a standard monocrystalline Yingli Solar-brand panel (*www.yinglisolar.net/en*) with a weight of ca. 4 kg, dimensions of 60 x 50 cm, and a life expectancy of 25 years (80% efficiency rate). It is placed on a wooden frame above the ground. A simple and easy-to-operate switch and wire connection to the pump is established to avoid short-circuiting the pump.

4.2 RESOURCES AND CAPABILITIES

EQUIPMENT

The materials required to build the ASPDI system include the following: a 50-watt solar panel, a low-capacity 12-volt submersible DC pump and switch, PVC pipes and fittings, a 210-litre tank, a wooden stand, and a standard drip kit, including filters. Except for the pump, which is not available in Ghana, all other materials can be obtained from domestic suppliers in Ghana. The PVC pipes and 210-litre tank are available in almost every village, and solar panels can be bought in the larger towns, while drip irrigation kits are sold only in the capital, Accra (see section 4.5.1), and a few large towns (e.g. by HTC Ghana in Tamale).

TRAINING AND SKILLS

Selling irrigation equipment generally requires significant technical customer support on the part of the supaplier due to the complexity of the equipment compared to most other agricultural inputs, such as seeds, pesticides, and fertilizers (int. 4, 6). Irrigation technologies must be carefully selected and designed to fit the scale, crop, water resource, and other key variables in each case (int. 6). The failure to provide adequate advice, training, and after-sales support to farmers will result in failed or underperforming irrigation and loss of customers (weakened customer relationships). Conversely, these services are costly for irrigation suppliers, incentivizing them to target larger customers (e.g. large farmers and projects) and in some cases to build local knowledge and capacity in areas of major demand. One supplier, for example, runs two demonstration farms in northern Ghana (int. 4), while another has trained local people (e.g. plumbers) in the assembly and use of its irrigation kit (int. 6).

In this context, we note that the ASPDI system requires minimum expertise to build and operate, which enables farmers to use and maintain it after a short training. The training can be provided by staff of the system supplier (firm, NGO, or project), by local trainers trained by the supplier, or by peer farmers. Plumbers can be used as local trainers and technicians, as they have general experience with piping and may subsequently benefit from maintenance jobs (int. 4).

A training centre has been established at the University of Ghana's Forest and Horticultural Crops Research Centre in the town of Kade, Eastern Region, where farmers and trainers can learn how to install and operate the ASPDI system and its various components. The centre has already trained local artisans in Kwaebibirem District in how to repair and carry out periodic maintenance of the system. Furthermore, two farmer-managed demonstration farms have been established in Kade and Cape Coast and have been used to train fifteen contact farmers and ten agricultural extension agents in the use of the system and best vegetable-farming practices.

On-farm demonstrations of the ASPDI system were also organized in March-April 2019 on the farms of two contact farmers. The first was held on 5th March in Antado village, Cape Coast (Central Region), and attracted the participation of 57 farmers from the surrounding villages. The second was held in Subi village, Kwaebibirem District (Eastern Region) on 27th April and was attended by sixty farmers. The demonstrations were designed to give the farmers first-hand information on the technology so that they could make an informed decision about whether to adopt it or not. Baidoo and Ninson (2019) report on these demonstration days.

ON-FARM HANDLING AND STORAGE

The system is light and can easily be disassembled and moved to other plots or stored. If it is not used for a long period (e.g. during the rainy season), the equipment, including the drip lines, should be collected from the field and stored indoors to avoid damage from animals, storms, UV radiation, etc. The small solar panel (ca. 4 kg, 60 x 50 cm) can easily be taken down and stored at night to avoid theft.

WATER AND LAND RESOURCES

Due to the pump's low capacity, operating the system requires a nearby water source, like a stream, lake, pond, or dug well, with a maximum vertical distance from the water surface to the top of the tank of five meters. In the on-farm demonstrations, the distance to the water source was typically five to ten meters, and the vertical distance was approximately two meters. Hence, the system is suitable for lands lying adjacent to an open water source or where the water table is high.

FINANCE

The ASPDI system is inexpensive, with an estimated retail price of GHS 1840 (USD 333) in the capital Accra (see section 6.1). This makes it more accessible to smallholders, who typically have limited savings and poor access to formal credit provision. Different sources of finance may be mobilized to facilitate farmers' adoption of the technology:

- Savings obtained through farm or off-farm activities. Many vegetable farmers earn off-farm incomes through, e.g., crafts or transport services, which may be invested in the technology (Int. 5). Once the system is in operation, farmers may invest their profits back into the irrigation system, thus improving acreage and capacity.
- Loans from informal sources such as relatives, friends, etc., although these may come with high interest rates.
- Formal, soft loans through the Ghana Agricultural Development Bank or micro-finance institutions.
- Development-project funding is often used to facilitate the demonstration, diffusion, and adoption of new agricultural technologies, and they can help develop supply chains by stimulating demand and building technical capacities. Potential funders of small-scale irrigation projects in Ghana at present include the USAID (through e.g. ACDI-VOCA), Koica (Korean international development agency), GIZ (Germany), and the Alliance for a Green Revolution in Africa (AGRA).

Agricultural equipment suppliers in Ghana only provide irrigation equipment on credit in rare cases and only to very trusted customers, typically large farmers. Commercial bank loans are not available to smallholders in Ghana for a number of reasons. In general, the commercial banks provide very little finance to the agricultural sector, and interest rates are very high – up to 25-30%.

4.3 ACTIVITIES AND PROCESSES

The main activities and processes involved in the value creation of the ASPDI technology are the following:

- The equipment producer designs and manufactures the equipment, often in interaction with research institutions and private consultants.
- The irrigation technology supplier sells the technology. We use the term 'technology supplier' or simply 'supplier' to describe the firm that delivers the ASPDI technology as a complete kit or package made up of several components. The technology supplier may be an equipment producer or an agricultural trading firm (input supplier), and may sell the equipment either directly to the farmer or through an intermediary (shop or agent).
- The financier provides credit to farmers, if needed.
- The technology supplier or an extension agent trains the farmer in using the technology.
- The technology supplier, farmer or extension agent assembles and installs the technology.
- The farmer operates the technology and fits it to his farming system.
- The farmer maintains the technology, with assistance if needed.

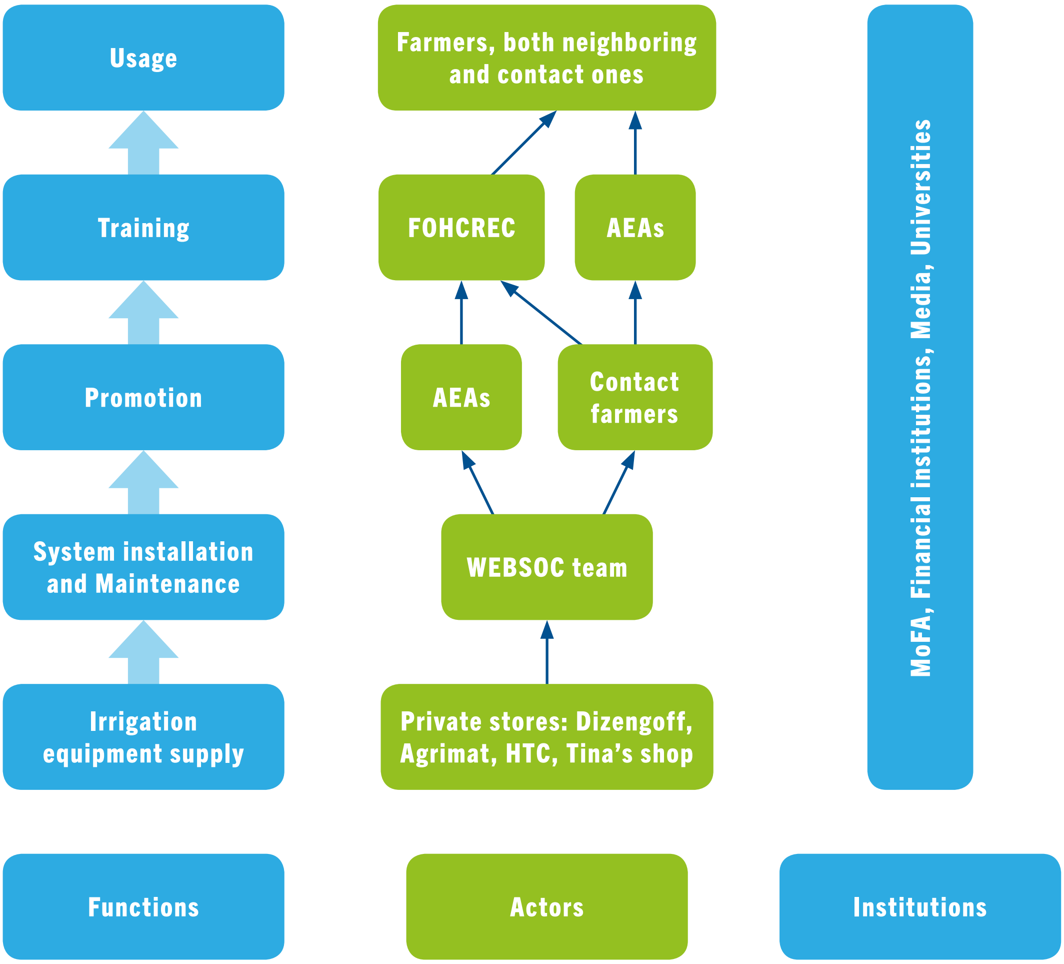
The next section elaborates on how different stakeholders carry out these activities.

4.4 ROLES AND EXPERTISE OF STAKEHOLDERS IN VALUE CREATION PROCESS

In this section, we describe the key stakeholders or actors involved in the creation of value related to the ASPDI system in the WEBSOC project, along with their roles and expertise. Figure 5 below shows the actors involved in the chain of value-creating functions involved in supplying and using the system, along with the supporting institutions.

Figure 5.

Value chain map of key stakeholders.



Source: the authors.

FARMERS

Smallholders are key to the value-creation process. So-called contact farmers or demo farmers host and operate samples of the irrigation systems on their farms, to which local farmers are invited to observe and learn. The farmers also serve as peer agents in the technology diffusion process (Bell et al. 2018; Sampson and Perry 2019; Gathiaka 2016). Farmers willing to adopt the irrigation technology can influence their colleagues to acquire the system. They also have expertise in vegetable production, which has been tested with the system.

AGRICULTURAL INPUT SUPPLIERS

The agricultural input suppliers AgriMat Ghana, Dizengoff Ghana and HTC Ghana are the main wholesalers and retailers of irrigation equipment in Ghana, including drip kits, drip lines, sprinklers, tubes and fittings, pumps, solar panels, etc. Similar equipment is sold by the Ghanaian pipe manufacturer Interplast, which set up an irrigation department in 2017. In August 2019 Interplast started the production of drip lines and drip tapes and in 2020 put its first drip kit on the market. PumpTech Ghana specializes in the sale of water pumps with a focus on high-end pumps imported from Germany (Lorentz) and Denmark (Grundfos), which, however, appear to be too expensive for smallholder use. All these firms also provide technical advice and after-sales support to customers. They have expertise in the design, installation, operation, maintenance, and repair of irrigation systems for all farm sizes. See section 4.5.1 for more details.

FINANCIERS

Financiers are an important source of the cash needed to acquire an irrigation system, as farmers often have few or no savings. Financiers may be private investors and/or financial institutions. Development projects run by development agencies or NGOs also play an important role in providing financial support to smallholders together with technical and organizational support. Private investors can also acquire such systems and rent them out to farmers for a fee. Financiers could also support research and development aimed at improving irrigation systems. However, these roles and functions were not investigated in this study. See section 4.2 for more details on finance.

AGRICULTURAL EXTENSION AGENTS

Agricultural extension agents (AEAs) play a major role in diffusing agricultural innovations (Ntshangase 2018; Pan, Smith, and Sulaiman 2018) by informing and training farmers (or organizing training) in agricultural practices, technologies, markets, and credit. During field demonstrations of the ASPDI system, AEAs from MOFA aided effective communication of the benefits of the system. AEAs have particular expertise with good agricultural practices, technology diffusion and adoption, and in organizing farmers for field demonstrations. They possess deep knowledge of the conditions, problems, preferences, strategies, and farming practices of smallholders in their areas of operation.

RESEARCHERS AND RESEARCH STATIONS

The Forest and Horticultural Crops Research Centre (FOHCREC) of the University of Ghana, located in Kade in the eastern part of Ghana, also provides training for farmers and for individuals wanting to go into farming. The training is largely experiential and hands-on, being designed for individuals to pursue farming as a business and thus enhance the growth of the food sector. The centre hosts an up-scaled version of the ASPDI system for purposes of teaching, research and on-site demonstration. The centre is run by an agricultural engineer from the University of Ghana, who invented the system's automated water-discharge system. The Department of Agricultural Economics and Agribusiness, in the University of Ghana, has also trained two agricultural economists (MSc and PhD) in the deployment, operation, and monitoring of the ASPDI system on farmers' fields and in organizing on-farm demos and training sessions. Researchers from the University of Cape Coast have also been trained in operating the system and in performing yield analyses, plant experiments, and soil analyses on irrigated vegetable fields. Comprehensive studies of the ASPDI system and its economic and agronomic effects have been published in scientific articles and included in MSc and PhD theses (see Andersen 2020). This research-based knowledge and capacity was created in collaboration with Aarhus University and the Technical University of Denmark, a collaboration which will continue until at least 2024. Altogether, strong science-based expertise is available to support any public or private organization deciding to develop and diffuse the ASPDI system further.

4.5 VALUE DELIVERY: DISTRIBUTION CHANNELS

Value delivery here refers to distribution channels, that is, how the technology or product is physically delivered to the end-user (farmer), including logistics, sales channel (shops located in cities or rural towns), use of local agents to access customers etc. (see section 6.3).

4.5.1 SUPPLIERS OF IRRIGATION EQUIPMENT IN GHANA

Annex 4 presents an annotated list of the suppliers of irrigation equipment in Ghana that are deemed to be the most likely adopters of the ASPDI business model proposed in this paper. The suppliers consist of five firms trading in agricultural and/or water equipment (Agri-Mat, Dizengoff Ghana, HTC Ghana, PumpTech Ghana, and DENG Ltd) and one manufacturer (Interplast) of plastic pipes and recently also of drip kits.

4.5.2 RURAL AGRICULTURAL INPUT SHOPS

Small agricultural input shops can be found in most rural towns in Ghana, these being more accessible to smallholders than the large shops found in Accra or in the other large cities (e.g. Kumasi, Tamale, Takoradi). According to the major suppliers of irrigation equipment, few local agricultural-input shopkeepers have the technical expertise to sell irrigation equipment such as drip kits or to enjoy the trust of these suppliers in this respect (e.g., HTC Ghana, Interplast and Dizengoff). On the other hand, of the large suppliers, only one (HTC Ghana) has shops in smaller towns, possibly because it sells a range of products (e.g. construction equipment) besides agricultural inputs. Hence, there seems to be a rationale for increasing small-town agricultural shopkeepers' knowledge of irrigation technologies to enable them to retail this technology and bringing it closer to farmers. We did not conduct a comprehensive survey of rural agricultural input shops, but Annex 4 presents an example from Cape Coast that illustrates the kinds of shops that are found in rural towns in Ghana.

5. VALUE CAPTURE

5.1 COSTS

Cost refer here to all the expenses associated with procuring equipment, storage, assembly, sales and marketing, distribution, communication, training, after-sales service, maintenance (optional), and the cost of credit.

The cost of the equipment and materials needed to build and install the ASPDI system on a 500 m2 vegetable plot is provided in Table 1 below. Ghanaian retail prices are used. In the case of the pump, which is not sold in Ghana, we use the online price (GHS 175) and add an estimated 100% (GHS 175) for the pump to reach the retail trade in Ghana.

It can be seen that the retail price for the whole system is GHS 2017. This includes the water-supply system as well as the drip system (in the form of a ready-to-use drip kit). In order for the system to be ready for use on the farm, we estimate the cost of packaging and transporting the equipment to the farmer's field (GHS 100) and the cost of installation (202 GHS – this may be reduced if the farmer does the installation him- or herself). This brings the price 'on farm' to GHS 2319. Finally, we assume 10% maintenance costs per year. A further breakdown of the costs into specific items is presented in Annex 2.

Table 1.

Cost of establishing the ASPDI system on a 500 m2 vegetable plot. Retail prices in GHS.

Item	Cost (GHS)	Comments
50 watt (12 V) solar panel and accessories	350	Accra retail price
12 V solar pump (TOPSFLO brand)	175	Online retail shop in China
Import cost of solar pump (freight, import duty, VAT, Ghana retail margin)	175	Estimated as 100% of the online retail price
Solar pump accessories	165	Including 100 m hose pipe
Water tank (barrel) and platform	160	Accra retail price
12-meter PVC pipes	68	Accra retail price
Other pipes, fittings and accessories	183	Accra retail price
Total cost of automated water supply system	**1276**	
500 m2 drip kit (ready to use)	850	Accra retail price (incl. 17.5% taxes). The brand Ingreen from Interplast
Total cost of equipment	**2126**	**Accra retail price**
Packaging and transport to farm	100	Estimated
Installation (labour and tool hire)	213	Estimated as 10% of equipment costs
Total cost 'on-farm'	**2439**	**Cost of equipment, transport and installation**
Maintenance cost (per year)	244	Estimated as 10% of 'on-farm' cost
Grand total, 1st year	**2683**	**Sum of 'on-farm' cost and one year of maintenance costs**

Source: authors' computation from data collected through interviews with retailers.

Explanation of Table 1:

- The total equipment cost (GHS 2126) does not include the additional sales and marketing costs that the technology provider may incur in order to sell the ASPDI system to many smallholders, nor do they cover additional margins that may be needed to incentivize the supplier to sell the system as a whole. See section 5.2 below.
- The costs exclude the costs of land and farming.
- The cost of the pump is the online retail price. To estimate the retail price in Ghana, one must add freight costs, VAT, import duty, and the retailer's margin. These costs have been estimated at 100% of the online price, i.e. GHS 175, so the total retail price of the pump in Ghana becomes GHS 350. This cost might be reduced through economies of scale.
- The cost of the drip kit is the retail price of the drip kit produced by the Ghanaian pipe manufacturer Interplast, this being the least expensive on the market currently. The price ex. tax is GHS 720. The taxes are VAT 12.5%, NHIL 2.5% and GETFUND 2.5%. All customers in Ghana must pay these taxes, including farmers and other businesses.
- See Table A1 for details of the components of the ASPDI system.

REGIONAL DIFFERENCES IN COSTS

The cost of establishing the ASPDI system varies from region to region. It was generally cheaper to set up the system in the demonstration sites in the Eastern and Central regions than in the Volta Region. The average cost of setting it up in the Eastern region was GHS 2361, in the Central Region GHS 2266, and in the Volta Region GHS 2564. A key factor here was differences in the availability of natural wood for the construction of the platform for the water tank. In the Eastern and Central Regions most of these materials were readily available and farmers provided the platform for free, while in the Volta Region sawn wood was purchased and local artisans were employed to construct the platform. Another factor affecting the cost was the proximity to a water source. This is because the longer the distance between the source of water and the water reservoir, the more hose pipe and other accessories are needed to bring the water to the farm, which increases costs.

PROCUREMENT AND STORAGE COSTS

The main procurement cost is for the solar pump, which needs to be imported into Ghana specifically for this purpose. Unless other products from the overseas supplier can be shipped in the same container, the technology supplier is left with the choice between air freight (which is expensive) or buying large quantifies to fill a container (incurring storage and credit costs and the risk of ending up with an unsold surplus).

SALES AND MARKETING COSTS

There can be large costs associated with reaching the smallholder customer segment, which is spread over large areas and rarely go shopping for agricultural inputs in the cities, where irrigation technology-providers have their retail outlets, or attend agricultural trade fairs. This study did not quantify these costs, but we expect that fixed costs (e.g. operating local retail shops, training agents, and advertising) make up a significant share of such costs, implying the need to sell large quantities to make a profit from investments in sale and marketing for the smallholder segment. The low purchasing power of smallholders also reduces suppliers' incentives to undertake such investments.

For purposes of exposition, we assume here that the sales and marketing efforts needed to reach the smallholder segment at a sufficient scale will cost 15% of the total equipment price of GHS 2019, i.e. GHS 303.

5.2 REVENUE AND PROFIT

The equipment cost of the water-supply system is GHS 1276, while the retail price of the drip kit is GHS 850, giving a total equipment cost of GHS 2126 (Table 1 above). To this we add the cost of sales and marketing activities (15% of equipment costs or GHS 319), bringing the total cost to GHS 2445 at retail prices in Ghana.

For purposes of exposition, we assume that the technology supplier adds a margin of 10% of GHS 2445 (i.e., GHS 245) as a sufficient incentive to sell the system, which brings the final price of the equipment to GHS 2690 (Table 2). This margin is in addition to what the supplier might earn from the difference between the wholesale and retail prices of the components (which we could not estimate). A margin may also be made on service and maintenance, but that is not considered here.

If the suppler sells 1000 units at a price (including taxes) of 2690/unit, his/her total margin (profit) is GHS 245,000, while on 10,000 units sold the profit would be GHS 2,450,000. These estimates do not account for possible losses due to, for example, faulty equipment, cancellation of orders, unsold stock, thefts, etc., nor do they factor in the cost of credit/finance.

Table 2.

Costs, revenues and margins for the technology supplier, based on Ghanaian retail prices.

#	Item	GHS per unit	GHS for 1000 units	GHS for 10,000 units
A	Total cost of equipment1	2126		
B	Sales and marketing costs (15%)2	319		
C	Total cost (A+B)	2445		
D	Supplier's margin (10% of C)3	245	245,000	2,450,000
E	Final price (C+D) (gross revenue)	2690	2,690,000	26,900,000

Source: authors' computation from survey data (2017). Notes: 1 Calculated from the Ghana retail price of all components (Table 1). 2 Estimated, see section 5.1. The cost of credit is not included.

6. VALUE PROPOSITION

6.1 VALUE OFFERING TO THE END USER (FARMERS)

This section summarizes analyses performed under the WEBSOC project that can shed light on what kind of value the ASPDI system offers to farmers and thus if and why farmers are likely tao acquire the system if they are enabled to do so. This includes analysis of on-station and on-farm performance of the system, costs and benefits, willingness to pay, and analysis of the vegetable value chain.

6.1.1 SUMMARY OF FARM BENEFITS

- Enables year-round farming, including in the dry season, when prices are higher.
- The automated gravity-based water-discharge mechanism, combined with the continuous operation of the solar PV-powered pump, means that the crop is irrigated throughout the day even if the farmer is not present in the field.
- The solar PV power source requires no fuel or maintenance (except cleaning).
- The system is inexpensive to acquire and set up. The retail cost price, including taxes, of the whole system, including a drip kit, is estimated at GHS 2439 (Table 1) installed on the farm and ready to use. There are no cash operation costs (only labour).
- Easy to use and maintain following initial set-up and a short training.
- Can be moved around the field and between fields (no fixed infrastructure).
- Drip irrigation saves water, giving it an advantage where water resources are limited.
- Drip irrigation means less water run-off and less soil erosion.
- Drip irrigation reduces weed infestation compared to sprinkler irrigation, as only the crop is irrigated.

6.1.2 FARM-LEVEL PROFITABILITY FROM USING THE ASPDI SYSTEM

Both short-term and long-term revenues and profitability of the ASPDI system were computed based on its deployment in two communities in Central and Eastern regions. The crop-growing seasons in which the data were collected were the lesser rainy season from September to November 2017 and the dry season from December 2017 to March 2018. There was full irrigation in the dry season.

SHORT-TERM FARM PROFITABILITY

The short-term profitability of using the ASPDI system on a 500 m2 vegetable plot was calculated as the net farm income. All numbers were scale up by a factor of twenty from 500 m2 to 1 ha.

Table 3 below gives the results and indicates that using the ASPDI system is profitable, having produced a net farm income of 25,204 and 15,141 GHS per ha respectively for the two communities in the dry season of 2017-18. Scaled down to 500 m2, i.e. the size of the system, net farm income is respectively GHS 1260 and 757.

Table 3.

Profitability of one okra crop using the ASPDI system in the dry season of 2017-18. GHS per hectare.

	Jukwa	Okumaning
Variable cost	4480	4200
Depreciated fixed costs	5622	6095
Gross income	35306	25437
Net farm income	25204	15141
Gross margin	30826	21237

Source: authors' computation from survey data (2017). Notes: 1 Calculated from the Ghana retail price of all components (Table 1). 2 Estimated, see section 5.1. The cost of credit is not included.

Explanation of Table 3:

- Numbers were scaled up by a factor of twenty from 500 m2 to 1 ha.
- Jukwa is in the Central Region, Okumaning in the Eastern Region.
- Variable cost = variable cost of production per crop, i.e. chemical inputs, labour for weeding, harvesting etc.
- Depreciated fixed costs are the annualized fixed (investment) costs, taking account of wear and tear of equipment, which results in the depreciation of its value to zero over a maximum of ten years. For example, the pump has completely depreciated after five years. The fixed costs include the costs of the irrigation equipment (including the platform), installation, and renting the land. The fixed costs vary between Jukwa and Okumaning due to differences in the availability of free and natural wood for construction of platform. Annex 2 presents detailed cost data.

- Gross income = sales revenues from the okra harvest (scaling up to 1 ha). For one crop of okra for 500 m2, the revenue was 1765 GHC.
- Net farm income = gross income (sales revenue) minus variable costs minus depreciated fixed costs.
- Gross margin = gross income minus variable costs.

LONG-TERM FARM PROFITABILITY

Net present value (NPV) was used as the measure of the long-term profitability of using the ASPDI system on a 500 m2 vegetable plot. The NPV was calculated by developing a cash flow with a project life-span of ten years using a real discount rate *r* of 8.9% to discount the cash flows of the respective years. The real discount rate was calculated using the formula where = inflation and I = the nominal interest rate. Unforeseen events were provided for by assuming a 10% shock to the use of the technology.

Table 4 below gives the NPV calculated on the basis of data collected during its deployment in the two communities in Central and Eastern regions in 2017. The NPV is given in GHS per hectare. It can be seen that the NPV is positive in both communities, but also that there are large differences in their respective NPVs. Among the factors responsible for these differences are the proximity to a water source and the cost of accessing water for those who dug wells for water, the cost of platform construction, the cost of land, and the cost of labour for preparing the land. The geographical locations of farmers also affected the prices of some of the items that were purchased as an add-on to the installation of the system. Differences in revenue between the two farms also affect the NPV.

Scaled down to 500 m2, i.e. the size of the system, the normal NPV is GHS 3625 for Jukwa and GHS 1487 for Okumaning.

Table 4.

Net present value for one okra crop using the ASPDI system in the dry season of 2017-18. GHS per hectare.

Community	Normal NPV	NPV at 10% shock
Jukwa (Central Region)	72492	64286
Okumaning (Eastern Region)	29744	23704

Source: authors' computation from survey data (2017).

Explanation of table:

- Numbers were scaled up by a factor of twenty from 500 m2 to 1 ha.
- Decimals were rounded up or down to the nearest whole number.
- See explanation above the table for the causes of the differences in NPV between the two communities.
- It is assumed that the system will be operating for ten years with its major components intact and with only minor replacements.
- It is assumed that the interest rate remains constant for the ten-year period, taking inflation into consideration.
- It is assumed that the farmer will appropriately deploy the system and be able to fix minor problems with little or no supervision for the ten-year period.

6.1.3 VALUE OFFERING RELATED TO SPECIFIC SYSTEM FEATURES ('SELLING POINTS')

INNOVATIVE AND AFFORDABLE WATER SUPPLY SYSTEM

The innovative water-supply system (pump, solar-PV, automated water discharge) is compatible with any drip irrigation kit, including those currently sold in Ghana (section 4.51.).

Integrating a solar panel in the water-supply system creates value for small-scale farmers. With technological improvements and falling prices, solar PV water pumps have increasingly been proposed as an cost-effective and environmentally friendly approach to irrigation in SSA (Otoo et al. 2018). They not only offer an inexpensive alternative to diesel- and grid-powered pumps, they also overcome the problem of access to energy (IRENA 2015). Using solar energy-based pumps mitigates the risks of fluctuating oil prices and power surges from an unstable grid and may therefore be an attractive technology for irrigators.

The 12-volt DC pump from TOPSFLO used in the ASPDI demonstrations is cheaper than other electric (solar) pumps sold in Ghana. As already mentioned, the online retail price (in 2019) of this pump is USD 30 (GHS 175). To arrive at the retail price in Ghana, one must add freight costs, VAT, import duty, and a retailer's margin, estimated here at an additional GHS 175. The retail price in Ghana for the 50-watt solar panel used to power the pump is about GHS 250. As shown in Table 1, the total retail cost of the ASDI system is GHS 1478 (USD 255), including installation and excluding the drip kit.

6.2 CUSTOMER SEGMENTS

6.2.1 SMALL-SCALE VEGETABLE FARMERS

A study was conducted of three communities in Ghana's Eastern, Central and Volta Regions comprising small-scale vegetable farmers (Baidoo 2019; Baidoo and Ninson 2019). The total and sampled populations of farmers are shown in Table 5.

Table 5.

Number of farmers sampled in three communities

Region	Farmer population in community	Sampled population	% per region	% of total population
Eastern	216	140	64.8	44.9
Central	158	113	71.5	36.2
Volta	90	59	65.6	18.9
Total	464	312	67.2	100

Source: authors' computation from survey data (2017).

The mean household size is five and a household size of three recorded the highest frequency (22.4%). The mean duration of formal education is eight years, while 25% of these farmers have gone through ten years of formal education. The mean age of the farmers is 47.8 years.

6.3 CUSTOMER RELATIONSHIPS

Training farmers in choosing and using irrigation equipment by using contact or model farmers is imperative for a successful business model, especially in the initial stages of technology dissemination. This was emphasised by all the market actors we interviewed in Ghana. The supplier can also train local craftsmen (plumbers) or shopkeepers in how to install irrigation equipment, thereby saving their own staff time and costs.

The supplier can reach customers (farmers) in different ways:

- Direct sale to the farmer through a shop located in a major city (typically Accra, but difficult to access for smallholders)
- Direct sale to the farmer through a shop located in small rural towns (accessible for smallholders)
- Sale to the farmer through the mediation of local agents, e.g. plumbers, agronomists, shopkeepers (accessible for smallholders)
- Sale to the farmer through shops owned by third parties (located in a city or rural town)
- Leasing the equipment to the farmer (through local agents, rural shops, or shop in city)

The specific customer relationship depends on the variant of the business model chosen by the supplier. The business model variant encompasses several dimensions: type of sale channel (retail shop), type of product ownership, and product type (equipment with or without additional services), as shown in Table 6.

Table 6.

Dimensions of business model affecting the customer relationship

Type of sale channel	Type of product ownership	Product type
Shop in city (Accra)	End-user owns equipment (sale)	Irrigation equipment only
Shop in rural town	Supplier owns equipment (leasing)	Irrigation equipment and installation
Shop owned by third party (located in city or rural town)		Irrigation equipment, installation and after-sales service

7. BENEFITS AND COSTS FOR SOCIETY

7.1 SOCIO-ECONOMIC BENEFITS

Smallholders are known to drive most economies in sub-Saharan African countries. For example, according to the Ministry of Food and Agriculture (MOFA 2016) agriculture in Ghana is predominantly pursued by smallholders. Numerous studies have demonstrated that increases in income among smallholders in developing countries have large economic multiplier effects on the rest of the economy (Snodgrass 2014). In Chapter 6 the income benefits for smallholders in the Eastern and Central regions of adopting the ASPDI technology was demonstrated. In Northern Ghana too small-scale irrigation has had positive effects on smallholder incomes and food security. Here Balana et al. (2020) found that 'adoption of the small-scale irrigation technologies could increase the net farm profit by 154%–608% against the baseline depending on the "crop type – SSI technology" combination'. They also found that nutrition levels also improved significantly as a result of the improvements in crop yields due to irrigation and the use of additional inputs.

Further socio-economic social benefits of the ASPDI and similar small-scale technologies include more rural jobs, increased quality and availability of food for consumers, fewer food imports, and business opportunities for irrigation technology suppliers and consultants.

7.2 ENVIRONMENTAL BENEFITS

RENEWABLE ENERGY (SOLAR PV)

The use of renewable energy to generate electricity to pump water has become common worldwide. Many funders of development projects prefer photovoltaic-based pumping to fuel-based pumps because they consider them to be a clean technology free from greenhouse gas emissions.

DRIP IRRIGATION SAVES WATER AND LOWERS SOIL EROSION

Drip irrigation is a water-efficient irrigation method compared to other irrigation methods. It conveys water effectively to the immediate vicinity of crop roots and wets only a small fraction of the soil surface compared to, for example, sprinkler or hose irrigation. This ultimately reduces soil evaporation and run-off, leading to substantial savings in water resources (Oppong Danso et al. 2015; Maisiri et al. 2005; Sivanappan 1994). Another advantage of drip irrigation compared to other methods is the ease and efficiency of getting fertilizer to the crops by mixing it with the irrigation water and delivering it very close to the roots. As a result of these advantages, crops grown using drip irrigation produce higher yields of up to 100% compared to other irrigation methods (Sivanappan 1994).

7.3 SOCIO-ECONOMIC COSTS

Downstream water-users may be impacted, but the impact is considered negligible due to the small scale of the system and the high water-efficiency of the drip technology.

Foreign exchange is needed to import some of the system's components, notably the solar pump and the wafers for the solar PV panel.

However, many of the system's components are produced in Ghana, including drip lines (both main and subsidiary); 220 litre plastic containers (for reservoirs), a ten-litre plastic container for holding the pump in the water; PVC pipes (all dimensions needed for the installation); PVC glue; a fifty-watt solar PV panel; electrical wires; a polyethylene (PE) filter; and tools for assembling the system (measuring tape, drilling machine, hark saw blade).

7.4 ENVIRONMENTAL COSTS

It would have taken us beyond the scope of the study to quantify the environmental costs or impacts of the ASPDI technology; instead we present here a qualitative assessment focused on the waste management of the system's plastic and electronic components.

PLASTIC WASTE

The ASPDI system uses plastic materials with significant life-cycle environmental impacts, particularly polyvinyl chloride (PVC), which is the main material in the pipes used for the water supply (before the drip tubes). The production, use, and disposal of PVC results in the release of toxic, chlorine-based chemicals, particularly dioxin, which build up in the water, air, and food chain. Incineration of PVC emits a range of compounds that are harmful to human health and to the environment if not captured by a filter (Verma et al. 2016; Nagy 2016; Valavanidis et al. 2008). However, chlorine-free plastics are available, which could replace the use of PVC in irrigation water pipes. One option is cross-linked polyethylene (PEX) tubing, a flexible tube that requires fewer connections and fittings overall, which helps to lower costs and decreases the chances of leaks. Yet it must be protected from UV light, making it less suitable for irrigation (Rodriguez 2019). Another material used in plumbing is acrylonitrile butadiene styrene (ABS), which is an inexpensive, strong, and stiff plastic (Rogers 2015). ABS is relatively harmless as it does not contain any known carcinogens, and there are no known adverse health effects related to exposure to it (Rogers 2015).

Drip tubes, that is, the tubes that lead the water to the drippers at each plant, is a main component of the ASPDI system. Drip lines are made of high-density polyethylene (HDPE) plastic. Polyethylene is generally less toxic than PVC, but it has a shorter life span of about fifty years as opposed to a hundred years for PVC (Graham 2018). HDPE plastic can easily be recycled, which is done on a large scale in Europe (BPF 2020). The incomplete combustion of polyethylene (PE), however, as is done in open pits, can cause high concentrations of CO and noxious compounds, especially volatile organic compounds (VOCs) and semi VOCs such as olefins, paraffin, aldehydes, and light hydrocarbons (Verma et al. 2016; Valavanidis et al. 2008).

While it is technically possible to recycle both PVC and HDPE plastics, Ghana does not have the facilities or systems for doing so, nor for the environmentally safe incineration of PVC or HDPE.

ELECTRONIC WASTE

The ASPDI system has two electronic components: a solar pump and a solar panel. Electronic waste, including so-called solar e-waste, is a growing problem, particularly in developing countries with less developed recycling and waste-management systems (Hansen, Nygaard, and Dal Maso 2020). In Ghana, the collection of e-waste at landfills, such as the Agbogbloshie dump in Accra, causes serious health problems for thousands of workers, including burns and infected wounds, as well as respiratory problems, chronic nausea, and headaches (Yeung 2019). The short life span of the TOPSFLO solar pump makes responsible waste management particularly important in this context. At approximately 25 years, the life of the solar panel is much longer, but it must still be carefully disposed of at the end of its life. Relevant for improved e-waste management could be SGS Renovo Ghana, a programme for the control, management, and disposal of electrical and electronic equipment waste (WEEE) and tires (SGS 2020). SGS Ghana is being implemented by the Swiss company SGS (*www.sgs.com*).

8. DISCUSSION AND CONCLUSION

8.1 EVALUATION OF APPROACH

Based on a review of the sustainable business model literature, in this working paper we have described a framework for designing a sustainable business model (SBM) for a small-scale irrigation system. The framework was designed to consider both economic and environmental sustainability, as well as the social dimension in the sense of ensuring the inclusion of small producers. Our sustainable business model (SBM) framework is an extension of existing frameworks and approaches, particularly those proposed by Richardson (2008), Osterwalder and Pigneur (2010), Bocken (2015), Bocken et al. (2018), Yunus, Moingeon, and Lehmann-Ortega (2010), and Sabatier et al. (2017). In particularly, the framework is composed of three main parts (i.e., value creation and delivery, value capture, and value proposition), which are all assessed in terms of the economic, social, and environmental costs and benefits generated for society at large.

The SBM framework was applied to the case of small-scale irrigation in sub-Saharan Africa, specifically to a low-cost, automated solar-powered drip-irrigation technology developed for small-scale vegetable farming in Ghana, the ASPDI system. A proto-type of the technology was developed in a research and innovation project, and its performance and impacts were evaluated on-station and on-farm over several years. The on-farm evaluation included testing of the system by demonstration farmers, feedback from farmers at field days, and willingness-to-pay surveys. Analyses of the value chains for vegetables and for irrigation technologies in Ghana were also performed. Lastly, potential suppliers (technology providers) of the technology provided feedback on the system at meetings in Accra. This research enabled a comprehensive ex-ante sustainability evaluation to be made of the technology and its associated business model in respect of its provision, thus covering the perspectives of technology providers, farmers, and society.

The results of the evaluation presented in this paper highlight important issues related to the development, market diffusion, and farmer adoption of new small-scale irrigation technologies.

8.2 VALUE CREATION AND DELIVERY

We found that all the necessary factors for **value creation** are present in Ghana today, including the ASPDI technology itself, the necessary resources and capabilities, and the stakeholders. An important exception to the resources needed appears to be (poor) access to finance for the main customer segment (smallholders), suggesting that up-scaling this SBM will to some extent depend on existing or new projects and programmes that can help mitigate this credit constraint. Another weak factor is the low use and demand for the type of pump used in the ASPDI system, which increases the retail cost of this critical component due to the transport and import costs (unless the system is sold at a speed and scale allowing it to be shipped by container).

One option for increasing value creation is to bundle technology provision with the delivery of auxiliary services to customers, including agronomic advice, equipment maintenance etc. A challenge here may be the small profit margins in the smallholder segment. Though the small-scale segment has great market potential in terms of the number of potential customers, earning substantial profits will require high sales volumes. Bundling services with technology provision may increase the costs, for example, additional staff and transportation costs, and reduce profit margins. Consequently, partnerships with farmers' associations, donors, and government agencies regarding the delivery of technologies and services through schemes and projects may be an effective strategy due to the achievement of economies of scale.

Value delivery is a particularly weak link in the diffusion of the ASPDI technology, and of all other small-scale irrigation technologies for that matter. None of the irrigation technology providers in Ghana seems to have a sales and distribution network suitable for selling low-cost equipment to many smallholders, and none of them have experience in selling such equipment in large quantities to individual farmers, only through donor projects. The complexity of irrigation products requires sales staff with specific knowledge, and local hardware and agricultural input shops do not have such staff. One way forward may be to train local extension agents, craftsmen or farmers in the installation and operation of small-scale irrigation systems, as one technology provider recently did for its drip kit. Achieving this sort of local skills development on a large scale is expensive and seems unlikely to happen without government or project support. Altogether, we estimate that selling the ASPDI technology to smallholders in large quantities will require the technology provider to make additional, dedicated investments in sales and marketing. Again, targeting schemes and projects could help reduce sales and marketing costs per unit of product.

8.3 VALUE CAPTURE

The study has estimated the **cost of supplying the ASPDI system to farmers in Ghana** in terms of the pure equipment cost (GHS 2126), the cost when installed and ready to use on the farm (GHS 2439), and the cost after one year of use, including maintenance (GHS 2683). Ghanaian retail prices were used in computing these costs, as wholesale prices were not available. See Annex 2 for a detailed breakdown of costs. Two cost issues are highlighted here that need special attention from the supplier of the ASPDI system: the costs of importing the solar pump, which is not already available in the market, and sales and marketing costs associated with reaching smallholders in rural areas. The former was assumed to be 100% of the online retail price, while the latter was not included in the cost computation due to a lack of data. A third issue is the cost of assembling and packaging the different components of the system.

We estimated the **supplier's revenue per unit of product** based on the pure equipment cost plus an assumed 15% additional cost of sales and marketing, and adding a 10% retailers' margin, resulting in a retail price of GHS 2690. If the suppler sells 1000 units at this price, the total profit is GHS 245,000, and with 10,000 units it is GHS 2,450,000. Possible losses due to, for example, faulty equipment, cancellation of orders, unsold stock, theft, etc. are not considered here, nor is the cost of credit. The possible gains from procuring the equipment at wholesale prices are also not considered.

Finally, in assessing value capture, it is important to differentiate between the costs and revenues of the automated water-supply system (a new product) and those pertaining to the drip kit (an existing product). Arguably, the former product adds value to the latter by providing a stable water supply to the drip lines at a relatively low cost compared to alternative low-pressure water-supply technologies (see section 8.4 on value proposition below). Hence, the automated water-supply technology would be especially interesting to a producer of drip kits such as Interplast.

8.4 VALUE PROPOSITION

Because irrigation systems consist of several interrelated components or technologies, the performance of a new technology (or invention) depends strongly on its links with other technologies in the system. It can also be difficult to separate the effects of the new technology from those of these other technologies. In the present case, the new technology covers the *water supply* (water extraction and storage – electric pump, solar panel, and automated water discharge), which is connected to an existing technology for *water distribution* (i.e. drip lines).

The value proposition of the ASPDI system therefore has two parts:

The **performance and cost of the ASPDI water-supply technology**, both in its own right, and compared to alternative water-supply technologies. We found that the system supplies adequate water to a 500 m2 vegetable plot irrigated by drip lines when using a near-surface water source (using a head of 2.4 met during tests). The system's automated flush mechanism (siphon apparatus) installed in an elevated tank works well and saves farm labour and managerial attention. However, there are already alternative small-scale solar pumps on the market. The main differences between the ASPDI and these technologies are:

- The lower cost of the ASPDI (USD 255 vs. 466 for the least expensive alternative) makes it more affordable for smallholders.
- The ASPDI can be assembled with minimum training using components available in many hardware shops. The exception is the pump, which has to be imported.
- The ASPDI (as a proto-type) is not packaged as a single unit or piece of kit, which may disadvantage it compared to the alternatives.
- The ASPDI has an automated flushing mechanism (siphon apparatus), which the others do not. The siphon apparatus works reliably and consistently by automatically and intermittently discharging water from the elevated tank to pressurize the drip irrigation laterals, thus being able to irrigate while largely unattended (Danso et al. 2018).
- The ASPDI is designed for smaller plots (500 m2, compared to 2500 m2 for the Future Pump SF1).
- The combination of affordability, simple technology, and smaller scale suggests a different customer segment:
  - Resource-poor farmers (in terms of cash, labour, or land)
  - Farmers in the early stage of commercial vegetable-farming or producing for their own consumption
  - Part-time or backyard farmers

The **benefits and costs for farmers of the system as a whole** (water supply and distribution). We found that farmers generally profit from using the ASPDI system. The short-term profitability, measured as net-farm income, in two communities was, respectively, GHS 1260 and 757 for a 500 m2 plot cultivating okra in the dry season. The corresponding long-term profitability, measured as net-present value, was GHS 3625 and GHS 1487. The cost of acquiring, installing and maintaining (for one year) the system was GHS 2683. While this is a low investment cost compared to the alternative systems, financing it is still likely to be a constraint for many smallholders.

8.5 BENEFITS AND COSTS FOR SOCIETY

We identified important environmental and socio-economic benefits for society as a whole from the large-scale adoption of the ASPDI system. Drip irrigation saves water compared to sprinkler irrigation, while the use of a solar pump reduces GHGs compared to grid and diesel-powered pumps. Several socio-economic benefits were identified: improved nutrition and food security among adopting households, increased income and employment in rural communities, improved access to better-quality vegetables for poor consumers, increased employment in the irrigation sector, and reduced imports of high-quality vegetables. We have not been able to quantify these socio-economic benefits, which would also apply to other small-scale irrigation technologies.

There were also social costs associated with the system, mainly in terms of the life-cycle environmental impacts of the materials used in the equipment, especially given the current level of waste management in Ghana. It may also be argued that the diffusion of the ASPDI system (or any other small-scale irrigation technology) will increase the extent of vegetable farming by making it more profitable. This in turn will increase the use of weedicides and insecticides, which can have harmful health and environmental impacts. On the other hand, if drip irrigation replaces sprinkler irrigation, this will reduce water consumption and the need for weedicides. This suggests the need for a comprehensive approach in which responsible farming practices are promoted alongside responsible irrigation.

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ANNEX 1. LIST OF STAKEHOLDER INTERVIEWS

Table A1.

List of interviewees and interviews

Interviewee	Position	Stakeholder type	Organization	Format	Date
March 2020					
Kwame Boate and Joe Gyapong	Country Director and Senior Program Manager	NGO	Technoserve Ghana	Semi-structured interview and meeting	02-03-2020
Dominique Kofi Ampong	Deputy Director	Government agency	Ghana Irrigation Development Authority (GIDA),	Semi-structured interview	03-03-2020
Sara Hatoum and Emmanuel Techie-Menson	NA and Business Dev. Executive	Retailer	Hatoum Trading Company Ghana	Meeting	03-03-2020
Sara Hatoum	NA	Retailer	Hatoum Trading Company Ghana	Semi-structured interview	05-03-2020
Catherine Fabbi and Haidar Malhas	Business Development-Irrigation and Irrigation-Manager	Manufacturer	Interplast (Irrigation Department)	Semi-structured interview and meeting	03-03-2020
Roland Tudzi and 6 male farmers, aged 28 to 40 years	President of Anloga farmer association and vegetable farmers	Farmer	Main farmer association in Anloga for vegetable farming	Semi-structured group interview	04-03-2020
Anna Samake Tenemba and Mr Evans	Owner of MBC Africa and owner of BEIT (Be It)	SME/Non-profit	MBC: SME and membership organisation. BEIT: Non-profit SME	Semi-structured interview with two stakeholders	05-03-2020
Samuel Abbey	Department Manager	Retailer	Dizengoff Ghana, Irrigation and Greenhouse Department	Semi-structured interview	05-03-2020
Waldo Boshoff	General Manager	Retailer	Dizengoff Agric. Divison	Short meeting	05-03-2020
Edward Sabi	Professor	Researcher	University of Ghana, Department Agricultural Engineering	Semi-structured interview	06-03-2020
November 2019					
Mr. Awotwi	WEBSOC contact famer in Nkontrodo (Cape Coast)	Farmer		Semi-structured interview and farm visit	09-09-2019
Michael Tetteh	WEBSOC contact famer in Jukwa-Watreso	Farmer		Semi-structured interview and farm visit	09-09-2019
Fred, Ebenezer and Matthew	WEBSOC contact famers in Antado	Farmer		Semi-structured group interview and farm visit	09-09-2019
Sara Hatoum	NA	Retailer	Hatoum Trading Company Ghana	Semi-structured interview and shop visit	11-09-2019

ANNEX 1. LIST OF STAKEHOLDER INTERVIEWS

Table A1.

List of interviewees and interviews

Interviewee	Position	Stakeholder type	Organization	Format	Date
March 2019					
Fred	WEBSOC contact famer in Antado	Farmer		Interview and farm visit	04-03-2019
Farmers attending WEBSOC field day in Antado	Potential adopters of ASPDI system	Farmer		Questionnaire and semi-structured interviews	05-03-2019
Dr. Collison	Researcher at FOHCREC research station in Kade	Researcher	FOHREC / University of Ghana	Meeting	07-03-2019
Mr. Martinson	Director of crops	Government agency	MOFA extension office in Kade	Meeting	07-03-2019
Mr Koklo	WEBSOC contact famer in Subi (Kade)	Farmer		Farm visit	07-03-2019
Mr Mensa	WEBSOC contact famer in Kumaning (Kade)	Farmer		Farm visit	07-03-2019
September 2018					
Kwame Boate and Joe Gyapong	Country Director and Senior Program Manager	NGO	Technoserve Ghana	Meting	11-09-2018
Soren Robenhagen	Commercial Attaché	Donor	Danish Embassy	Meeting	11-09-2018
Richard	Sales representative	Retailer	Dizengoff	Interview and shop visit	11-09-2018
Ebenezer Asante	Sales representative	Retailer	Agrimat	Interview and shop visit	11-09-2018
Charles Nyaaba	Head of Programmes	NGO	Peasant Farmers Association of Ghana	Interview	11-09-2081
Madam Tina	Shopkeeper	SME retailer	Tina's Farmer Shop	Interview and shop visit	12-09-2018
Ebenezer	WEBSOC contact famer in Antado	Farmer		Interview and farm visit	12-09-2018
Michael Tetteh	WEBSOC contact famer in Jukwa-Watreso	Farmer		Interview and farm visit	13-09-2018
Kwadjo Dick and Richard	District director and Extension agent	Government agency	KEEA MoFA office in Cape Coast	Meeting	13-09-2018
January 2018					
Fred	WEBSOC contact famer in Antado	Farmer		Interview and farm visit	29-01-2018
Nicholas	WEBSOC contact famer in Elmina	Farmer		Interview and farm visit	29-01-2018
Michael	WEBSOC contact famer in Kade	Farmer		Interview and farm visit	30-01-2018

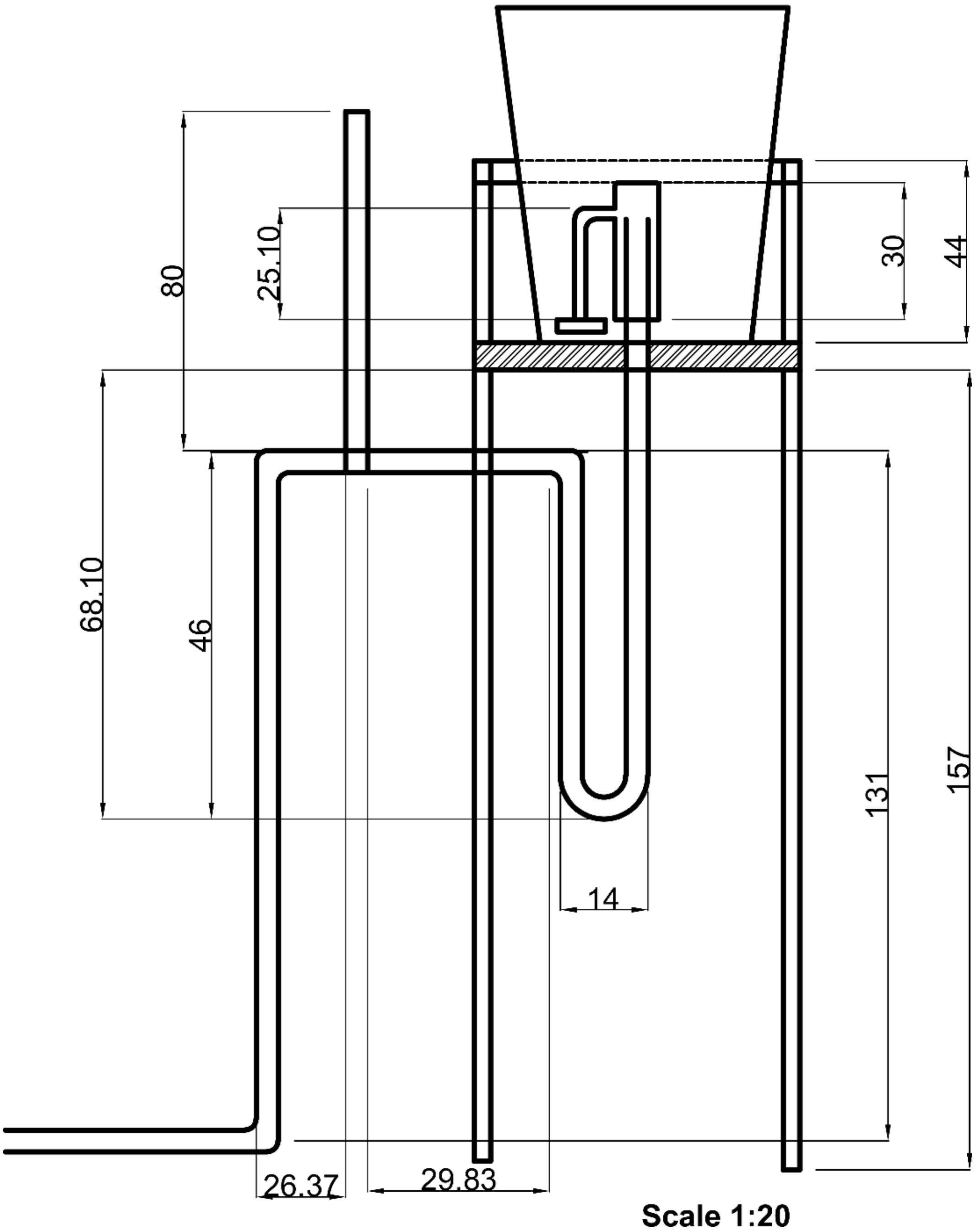
ANNEX 2. COMPONENTS AND COST OF THE ASPDI SYSTEM

Table A2.

Components and costs of the automated solar power drip irrigation (ASPDI) system

#	Item	Price (GHS)	Cost per category	Category
1	50-watt solar panel	250		
2	10 metres of 1.5 mm electrical cable	50		
3	electric switch	20		
4	timber stand for solar panel	30	350	Solar panel and accessories
5	12 V solar pump (TOPSFLO brand) (online price)	175	175	Solar pump online
6	solar pump import (freight, import duty, taxes, etc.)	175	175	Pump import cost
7	mesh for water intake	10		
8	10L plastic container	5		
9	100 metres of 3/4 hose pipe	150	165	Solar pump accessories
10	220 litre barrel / reservoir	100		
11	timber stand for barrel	60	160	Water tank & platform
12	6 metres of 1-inch PVC pipe	38		
13	6 metres 3/4 PVC pipe	30	68	12 m PVC pipes
14	Metal weight to fix bell in tank	20		
15	3 inches of PVC pipe (for bell)	24		
16	3/4 air PVC valve	14		
17	3/4 PVC elbow (4 pieces)	10		
18	1 inch x 32mm screen filter	12		
19	1 inch PVC elbow (4 pieces)	8		
20	1 inch PVC tee	1		
21	1 inch faucet socket	5		
22	1 inch valve socket	10		
23	1 inch x 32 mm female adaptor	15		
24	2 inch end cup	5		
25	Teflon tape (PVC thread type)	1		
26	1 inch air valve	15		
27	PVC glue	15		
28	Glue (epoxy/aradite)	8		
29	Wooden peg to support driplines	10		
30	Wooden peg to support driplines	10	183	Other pipes, fittings, accessories
Total cost of automated water supply system		**1276**	**1276**	
31	500 m2 drip kit (ready to use), Ingreen brand from Interplast. Including 17.5% taxes (VAT 12.5%, NHIL 2.5%, GETFUND 2.5%).		850	
Total cost of equipment			**2126**	
32	Packaging and transport to farm		100	Estimated
33	Installation (labour costs)		213	Est. as 10% of equipment cost
Total cost of equipment 'on farm'			**2439**	
34	Maintenance cost (per year)		244	Est. as 10% of 'on-farm' cost
Grand total, 1st year			**2683**	Sum of 'on-farm' cost and 1 year of maintenance cost

ANNEX 3. THE SIPHON SYSTEM OF THE ASPDI PLACED WITHIN AN ELEVATED TANK



Source: (Danso et al. 2018).

ANNEX 4. IRRIGATION EQUIPMENT SUPPLIERS IN GHANA

An annotated list of the suppliers of irrigation equipment in Ghana, which are deemed to be the most likely adopters of the ASPDI business model proposed in this paper. The suppliers consist of five firms trading in agricultural or water equipment (Agri-Mat, Dizengoff Ghana, HTC Ghana, PumpTech Ghana, DENG Ltd) and one manufacturer (Interplast) of plastic pipes and recently also drip kits. Finally, an example of a rural agricultural input supplier (Tina's farmer's shop) is presented.

AGRIMAT

Agricultural Material Ltd (*www.agrimatghana.com*) is a Ghanaian-owned agricultural input and equipment trading company with a shop and head office in Accra. One of its several divisions, AgriMat Engineering, focuses on irrigation equipment and accessories. The shop stocks a wide range of irrigation technologies with a focus on sprinkler irrigation. Their experience is that farmers mainly demand sprinklers because they are cheaper than drip kits; most of these customers are vegetable farmers. Because of the limited demand, their stock of drip kits and drip lines is relatively limited. AgriMat also provides technical assistance to clients and can provide them with spare parts when needed, having a large stock. It also offers borehole-drilling. Occasionally AgriMat demonstrates irrigation products on farmers' fields. It sells water pumps with a wide range of capacities, which can pump water from dams, streams, rivers, and boreholes. Its products are imported from Taiwan and Japan, among other countries.

DIZENGOFF GHANA

Dizengoff Ghana (*www.dizengoffgh.com*) is an agricultural trading company that has been operating in Ghana since 1957. Once Israeli-owned, it is now a subsidiary of Balton CP Ltd, the UK. It operates as a group of eight subsidiary companies from nineteen locations in Africa, with procurement and logistics functions in the UK and Israel. In agriculture, Balton CP sells a range of products, including fertilizers, agro-chemicals, seeds, farm machinery, greenhouses, systems for water management and irrigation, and related agricultural services and advice (*www.baltoncp.com*).

Dizengoff Ghana has customers across Ghana and West Africa. Its head office is in Accra, and it has shops in Kumasi, Tamale, and Takoradi. Dizengoff wholesales agricultural inputs through local retailers, but not equipment due to the expertise needed to advise farmers in its use. Dizengoff employs ten field agronomists to advice customers on agricultural practices and the availability of inputs and equipment.

Dizengoff has an irrigation department with seven staff in Accra. It sells drip, sprinkler, and centre pivot systems. It sells drip kits for 250m2, 500m2, 1 acre and 1 ha farm sizes, of the brand Netafim (*www.netafim.com*). Drip-line sizes include 16mm and 12mm and with punctures. The emitters have filters for sieving out foreign materials when using the system especially for fertigation (injection of water-soluble fertiliser into the irrigation system). The shop also stocks main pipes ranging from 25mm to 100mm sizes. Since 2020, Dizengoff has also sold Ingreen drip lines produced by Interplast, and it also sells solar pumps from the Italian pump manufacturer DAB (*www.dabpumps.com*).

Around 90% of the revenue of Dizengoff's irrigation department comes from the supply of equipment and services to projects, including some funded by the World Bank, African Development Bank (ADB), Malaysian Investment Development Authority (MIDA), and FICA (Ivory Coast). These projects mainly require drip irrigation technology and rarely sprinkler technology. Direct sales of irrigation equipment are mainly to medium-sized farmers (five hectares or more). Dizengoff sold a centre pivot system in two instances, to private farms.

In respect of vegetable growing, Dizengoff sells an evaporative cooling system for vegetables and different types of shade nets.

HTC GHANA

HTC Ghana (*www.facebook.com/HTCGHANA*) is a Ghanaian-owned company founded in 2008 in Tamale. Its primary focus is on building materials, construction equipment, and power tools. During its first years its focus was on northern Ghana, but in 2017 it expanded to a further three regions and established a fifth branch office and head office in Accra. Today, HTC has shops in Accra, Ho, Tamale, Bolgatanga, Tarkwa, and Wa, with a recent addition in Takoradi. The company employs thirty local staff and eight expats. In agriculture, HTC deals in irrigation equipment, solar panels, solar inverters, pumps, inverters, and filters, among others. The pumps include solar pumps, surface water pumps, submersible water pumps, submersible motors, pressure booster pumps, and solar-powered water pumps.

To develop its irrigation business, in 2015 HTC set up a subsidiary called 'Irrigation' with five or six staff. The HTC shop in Accra now exhibits a wide selection of irrigation equipment. In the area of drip irrigation, HTC sells equipment made by the Indian producer Jain, specifically its DripTech brand, to ensure high quality and that all components fit together. HTC is the sole distributer of DripTech products in Ghana and can draw on the expertise of Jain engineers. A feature of DripTech drip lines is that the holes are cut by laser to increase durability. The drip technology is sold mainly as pre-assembled drip kits, in sizes from 500 m2 to 1 acre, as HTC believes that farmers need equipment that is ready to use.

For use with the one-acre drip system, HTC sells the FuturePump solar pump (*www.futurepump.com*), produced in India, which has been designed for

smallholder conditions. HTC also sells pumps made by the Indian producer Shakti Pumps (*www.shaktipumps.com*), which produces a range of pumps, including a series of DC solar pumps.

HTC emphasizes that it sells a solution, not just a product, and the company has employed technicians to service farmers. It also runs two solar-power irrigation demonstration plots in northern Ghana. They observe that selling irrigation solutions requires careful pre-sale analyses of the specific needs and conditions of the customer and his/her farm.

Around 30-40% of drip kits are sold directly to farmers and the remainder to projects. HTC does not wholesale its irrigation products to other retailers due in part to the training needs.

INTERPLAST

Interplast (*www.interplast.com*) is a Ghanaian-owned manufacturer of plastic pipes for water and sewage, established in 1970. It is West Africa's leading producer in this area, producing a variety of pipes catering for both large infrastructural projects and small-scale operations. Interplast has more than 500 distributors in Ghana and exports to 21 countries.

In 2012, Ingreen was established as the irrigation department within Interplast. Ingreen was initially a landscape irrigation department, but it has subsequently expanded into the agricultural sector. As Ingreen intends to be a one-stop shop, it stocks a variety of irrigation products, including pumps, pipes, sprinklers, and fittings. Ingreen caters for both small- and large-scale farmers. It has no street-facing shops, but sells its products from its head office located at the factory site in Accra.

Since August 2019, Ingreen has been producing its own drip lines and drip tape, with a capacity of 200 meters of pipe per minute. The production equipment is the same as that used by the Indian drip-irrigation equipment manufacturer, Jain. The drip lines are designed to be assembled with in-line drippers produced by Jain. In December 2019, Ingreen released its first 'plug-and-play' drip kits for sale. The kits range in coverage from 500 m2 to 1 ha and retail at USD 130 (GHS 720 ex. tax, and GHS 850 incl. tax) for 500 m2 and USD 2080 (GHS 11,429 ex. tax, and GHS 13,500 incl. tax) for 1 ha[1]. Ingreen observes that its kits are at the lower price end compared to other drip kits on the Ghanaian market. By using Jain machinery to produce drip lines in-house, Ingreen claims to be able to keep the price low without comprising quality.

Ingreen makes use of Interplast's large distributor network to reach farmers across Ghana through participation in exhibitions, and by procuring irrigation projects, where Ingreen provides equipment, conducts farmer training, and performs system maintenance. Noting that selling irrigation equipment is about selling "know-how", Ingreen also offer consultation, installation, maintenance, and other support services.

Ingreen therefore currently operates as both a manufacturer and a retailer. It does not sell irrigation equipment to local retailers because they do not have the necessary know-how about irrigation, risking Ingreen's reputation. The exception is Dizengoff, which since 2020 has been selling Ingreen drip products. Over time, Ingreen's strategy is to operate solely as a distributor and manufacturer of irrigation equipment, leaving all the services involved to its network of distributors.

PUMPTECH GHANA

PumpTech Ghana (*www.pumptechgh.com*) specializes in the sale of water pumps, with a focus on high-end pumps imported from Germany (Lorentz) and Denmark (Grundfos). It also supplies agricultural irrigation solutions, but its high-end products seem of little relevance to smallholders.

DENG LIMITED

Incorporated in 1988, DENG (Danish Engineering) Limited (*www.dengltd.com*) is an engineering company and equipment supplier established in 1988. It lists eight areas of expertise, one of which is water filtration and irrigation, another renewable energy. DENG sells water pumps from Lorentz (Germany) and Lowara/Xylem (UK), and solar energy systems from Solaropti (Denmark) and DC/AC inverters from Studer (Switzerland). DENG's main office is in Accra, and it is currently expanding into other West African countries.

TINA'S FARMER SHOP

Tina opened her shop in Cape Coast about 27 years ago. She had lost her job with the Ministry of Food and Agriculture (MOFA), but had learnt many things about agricultural inputs whilst she was with MOFA, which made it was easier for her to set up the shop. She also has secondary education in agriculture. She sells different farm inputs, including some sprinkler irrigation materials. The customers mostly buy agrochemicals. Of the irrigation materials, she sells two or three sprinklers per month. She bags up vegetable seeds and sells them, some of which include green pepper and cabbage. There are similar shops like hers in the neighbourhood. She is mostly a retailer, but sometimes sells on a wholesale basis. She occasionally sells to her customers on credit, but repayment can be a problem. She has a storeroom in her house where she keeps her stock.

1 *The tax element is 17.5% in total, composed of VAT 12.5%, NHIL 2.5%, and GETFUND 2.5%, which are all manda-tory for all Ghanaians, including farmers and anyone purchasing the products for use in Ghana. Customers out-side Ghana are exempted from these taxes (and pay the USD prices), but some documentation must be pre-sented to get these tax exemptions.*

ANNEX 5. ALTERNATIVES TO THE ASPDI SYSTEM

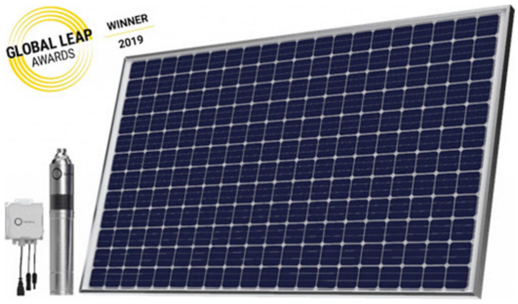
FUTUREPUMP SF1 SOLAR PUMP

The best known solar pump for small-scale drip irrigation in SSA is probably the FuturePump SF1 (*www.Futurepump.com*). The SF1 is designed for a 0.25 ha plot, i.e. five times the size of the ASPDI system, and so has a much greater capacity of 1600 litres/hour at 6 m or 2500 litres/hour at 10 m, a maximum lift/head of 10 m, and a maximum distance from the water source of 100 m with minimal loss of flow. The life expectancy of the pump is 15 years and for the solar panel 25 years.

The SF1 is integrated within a portable frame and consists of three main parts: an 80-watt PV panel (in two connected parts), a 30-V (4 A) motor that turns a flywheel, and a pump to draw water out of a well, river or lake. The pump is not submersible but is built into the frame, in contrast to the pump used in the ASPDI system. The SF1 pump can run at two speeds so that low speed (12 V, solar panels in parallel) can be used in less sunlight and high speed (24 V, panels in series) in bright sunlight, using a manual switch.

The FuturePump SF1 (including the 80-watt solar panel) is sold in Ghana by Hatoum Trading Company (HTC) for a price of GHS 3700 (USD 650).

SUNCULTURE RAINMAKER2 SOLAR PUMP



The RainMaker2 with ClimateSmart DirectTM is produced by SunCulture in Kenya (*www.sunculture.com*). It is a high-end solar-powered irrigation system using a submersible pump directly powered by a 310 W roof-mounted solar panel. It can pump up to 1100 litres/hour (0.30 m head) or 700 litres/hour (27 meters head), making it suitable for deep wells. The life expectancy of the solar pump's motor is ten years. In Kenya, SunCulture retails RainMaker2 ClimateSmart DirectTM for KSH 49,999 (USD 466).

ENNOS SUNLIGHT PUMP

The Swiss company Ennos (www.ennos.ch) produces a 0.5HP (375W) solar-power pump that operates from multiple panel configurations from 100 to 400W. Like the SF1, the pump and the other components (except the solar panel) are placed in a metal frame and are not submersible. The maximum flow rate is 45 litres/minute, the maximum head 40 meters. In the 'application example 1', the performance is as follows: total head: 25m, solar power: 300W, maximum water flow: 34 litre/minute, full load hours: 6 hours, total water output per day: 12,240 litres (Ennos, n.d.). Ennos has distributors in several countries in East and southern Africa but only one in West Africa (Burkina Faso). One online retailer in Germany sells the pump for EURO 769 (USD 837 or GHS 4831), without a solar panel, making it the most expensive of the alternatives presented here.

UNEP DTU PARTNERSHIP

DESIGNING A SUSTAINABLE BUSINESS MODEL FOR AUTOMATED SOLAR-PV DRIP IRRIGATION FOR SMALLHOLDERS IN GHANA

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