Co-creation of affordable and clean pumped irrigation for smallholders: lessons from Nepal and Malawi
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ABSTRACT
Pumped irrigation is a way to intensify smallholder production. In this context, the Dutch company aQysta has developed the Barsha pump (BP), the first-ever commercial version of the spiral pumps. BPs, however, face several constraints that affect the decision-making and access of smallholders to this and other agricultural technologies, thus to their benefits. On this subject, Product Service System (PSS) is a type of business model able to potentially cope with a number of restrictions of different nature. Moreover, if co-created with the feedback of the users, and by addressing contextual tensions of different cases, these models can be substantially richer than their top-down counterparts. Six cases of use of BPs have been addressed in Nepal and Malawi. Both primary and secondary data, analyzed qualitatively under the analytic induction approach, was collected through unstructured interviews and Q-methodology. Evidence shows a wide range of (non-)technical facilitating and hampering conditions for the BP, as well as preferences of the smallholders in regard to existing and proposed business model elements. Based on the corresponding analysis, a set of opportunities for an improved BP-based business model – PSS, aiming to fulfil several (and at times opposing) needs, is ultimately proposed in the current paper.

Key words | Barsha pump, business model, co-creation, Hydro-powered pump, product-service system, smallholder, spiral pump

INTRODUCTION
Given the significant number of smallholder farms worldwide (Lowder et al. 2016), intensifying their crop production is key for food security, as well as in creating positive impacts in their livelihoods. Amongst many challenges that smallholders face, proper water management is one of the most critical elements to achieve such objective (Giordano et al. 2013). A way to improve (or enable) access to and control of irrigation water is – yet not limited to – by the use of pumping technologies to water lands that will remain otherwise (partly) unirrigated throughout the year.

Most water pumping systems, however, operate on electricity or fossil fuels, thus are (too) cost-intensive, or even inaccessible, for many smallholders due to the continuous use of these inputs (Chandel et al. 2019); moreover, they affect the environmental quality due to their gaseous emissions and noise. Comparatively, more environmentally sound technologies, and at times less expensive ones, are renewable energy (RE)-based water pumps (Gopal et al. 2015). From these, hydro-powered pumping (HPP) technologies – i.e. those hydro-mechanically driven by the water
they lift – pose even further advantages over their other RE counterparts (Fraenkel 1986).

The Dutch start-up company aQysta developed the Barsha pump (BP), the first ever commercial version of a HPP device traditionally referred to as ‘spiral pump’, firstly reported during the 18th century (Ziegler 1766) and applied after the late 1970s in a number of countries (Morgan 1984; Naegel 1998; UNEP 2015). Roughly 150 BP units have been deployed since 2014 in Nepal, and 15 units since 2018 in Malawi (aQysta, personal communication, July 26, 2019), two of the main markets for the BP. However, the pump in these countries has to deal with market inefficiencies caused by, amongst others, underdeveloped supply chains, economic constraints, lack of knowledge, amongst others, which consequently limit the access of smallholders to this as well as other agricultural technologies, thus to their benefits (Giordano et al. 2019).

Nepal and Malawi, moreover, present several characteristics that render them in flagship examples of challenges in smallholder farming in South Asia and Sub-Saharan Africa, respectively. In Nepal, the agricultural sector represents 27.6% of the GDP, and involves roughly 65% of the labor force. From the total smallholder farms, though being more than half of Nepal’s farmlands, barely 15% are irrigated (Karki et al. 2020). In the same line, Malawi holds 30% of its GDP by agriculture, which in turn comprises 64% of the working population (Chinseau et al. 2019). About 90% of the Malawian agricultural revenues come from 1.8 million smallholders, yet the irrigated farmlands reach barely up to 20% of the total farmlands (FAO 2015). Additionally, smallholders of both countries – having a substantial reliance on rainfed production – are much more vulnerable to climate change-driven effects such as erratic rainfalls, floods, and droughts (FAO 2015; Karki et al. 2020).

A business model that potentially can deal effectively with such a number of restrictions, while at the same time creating value for the involved parties, is ‘Product Service System’ (PSS) (Mont 2002). In addition, some authors state that a participatory process of co-creation/co-design (at both integrated and strategic product design levels) (Dahan et al. 2010), especially while identifying and addressing contextual tensions at an early stage – in line with the so-called Context Variation by Design (CVD) approach (Kersten et al. 2017) – will substantially enrich the outputs to meet the user’s needs. However, with exception of few authors (Corti et al. 2013; Devisscher & Mont 2008), these models have not been studied within the agricultural sector – let alone their co-created versions. None of them as well have addressed the specific case of water pumping technologies for smallholder farming.

In that perspective, Delft University of Technology and Comillas Pontificia University, as part of a larger doctoral research focused on the deployment of HPP technologies in low-income settings (Intriago et al. 2018), are exploring the co-creation and implementation of affordable and clean pumped irrigation systems for smallholders, based upon novel technologies like the aQysta BP. Within this context, the objectives of this paper are: (1) to qualitatively analyze different (and opposed) use cases of BPs in Nepal and Malawi; (2) to highlight the underlying reasons for (not) using the BP, with emphasis on the most preferred/least preferred current and proposed BP business model elements (BME); and, (3) set grounds, based on the feedback of smallholders, for the future co-design of an improved BP-based PSS.

MATERIALS AND METHODS

Criteria for selection of use cases

The BP use-cases were selected within certain Nepali and Malawian smallholder communities, during the field visits in June – July 2019—thus during the respective dry seasons to ensure a strong interaction of the farmers with the BPs – based on the following criteria: (1) at least one BP must have been posing continuous presence for ≥2 months; (2) in accordance with the CVD approach, the BP use-cases must show different characteristics (e.g. topography, water source, facilitating/hampering conditions) between each other. It is worth mentioning that this is a cross-sectional study, hence a single-point data collection from each case was conducted.

Data collection

Primary data, both quantitative and qualitative in nature, was collected during the field visit period, and triangulated mainly by: (1) unstructured interviews to BP users, other smallholders (non BP users), and experts (authorities,
NGOs) relevant to the chosen communities; and, (2) Q-methodology. Q-methodology is an increasingly popular quali-quantitative technique to study human subjectivity in regard to any phenomenon (Dziopa & Ahern 2011). It is deemed as a highly participatory method – thus relevant for the present study – in which participants acquire an active role in developing their points of view, rather than becoming mere data sources (Donner 2000; Ellingsen et al. 2009). Furthermore, this method was additionally chosen because its reliability does not depend on the sample size of respondents but rather on their diversity of opinions (ten Klooster et al. 2009), hence suitable for working under the CVD approach described above. In this particular study, Q-methodology was administered to the smallholders with statements related to the adoption and use of the BP, as well as the preferences on extra products and services to enhance its benefits.

Secondary data, which complemented the understanding of the researched phenomenon, was collected through: (1) databases administered by aQysta on the use of BPs; (2) official documents issued by the respective Nepali and Malawian authorities; and, (3) other related literature.

Data analysis

Due to the nature of the data, as well as to the size of the selected population, the collected data was analyzed qualitatively, under the analytic induction approach. Particular attention will be given to contrasting data between cases, in line with the aforementioned CVD approach.

Business models canvas

The description of business models in both Nepali and Malawian cases, the analysis of its building blocks and their interactions will be done by means of the Business Model Canvas tool, as designed by Osterwalder & Pigneur (2010).

RESULTS AND DISCUSSION

Description of current business models

The business models around the BP, both in Nepal and Malawi, are substantially product-oriented; namely, they pose a strong component in selling a product – the pump – with few or no additional services linked to it. However, their main differences lie in: (1) the channels through which the BP are delivered to smallholders; (2) the way the BP is purchased; and (3) the final cost of the BP for the end-user. Tables 1 and 2 show the business models' building blocks and their interrelations, in Nepal and Malawi, respectively, in accordance to the Business Model Canvas (Osterwalder & Pigneur 2010).

Figure 1(a) and 1(b) show schematically the BP business models in Nepal and Malawi, respectively. The Nepali model is characterized by allocating the BPs to the farmers either by means of the governments (either national, provincial, local) or retailers, being the former much more common than the latter. Through retailers, the farmers would have to pay the full upfront cost at once, whereas through the governments normally they pay 10% of the total cost due to subsidies allocated to RE-based irrigation technologies. Contrariwise, the Malawian model allocates the BPs either directly from aQysta’s national branch or through international NGOs. The former offers facilities to pay off the BP over time in periodic installments, whereas the latter considers a single upfront payment after a roughly 50% subsidy. Despite their differences, both business models in Nepal in Malawi have in common a strong focus on installation and commissioning, in detriment of a weak aftersales contact, particularly related to (periodic) maintenance and servicing of BPs as well as the timely delivery of spare parts.

There is highly limited reported information on prior experiences of business models in Nepal and Malawi around HPP-based smallholder irrigation. Moreover, very few authors have conducted studies around other RE-technologies, particularly on solar-based pumping systems. Kunen et al. (2016) elaborates on four NGO-funded cases in Nepal, where the key components were capacity building, market development activities, and long-term service, in which the pumping system is a means to improve livelihoods and not a goal on itself. Affordability is achieved by a mix of public or private subsidies and microloans payed in instalments. Closas & Rap (2007) address it from a broader and more generic perspective, and elaborate on technological and financial constraints while deploying such systems in low-income settings. More remarkably, Shrestha (1996)
Table 1 | BP business model in Nepal

| PARTNERS | ACTIVITIES | PROPOSITIONS | CUSTOMER RELATIONSHIPS | CUSTOMER SEGMENTS |
|----------|------------|--------------|------------------------|-------------------|
| aQysta Netherlands | Negotiation with NGOs to allocate public budget | Offering to smallholders a low-cost, environmentally sound hydro-powered pumping technology, able to pump 24/7 at virtually zero operation cost | Sales through retailers | Smallholders, mainly from the hilly region, lacking of secured irrigation water |
| National/Provincial governments | Installation and commissioning of BPs | | Sales through governments | |
| Retailers | | aQysta Nepal install the pumps | aQysta Nepal install the pumps | |
| | | Servicing on-demand provided by aQysta Nepal for the next two years | Aftersales limited to servicing | |
| | | | | |

| KEY RESOURCES | CHANNELS |
|---------------|----------|
| aQysta Nepal headquarters | National/Provincial governments (subsidized pumps) |
| aQysta Nepal staff | |
| BPs | Retailers |
| Transportation | |

| COST STRUCTURE | REVENUE STREAMS |
|----------------|-----------------|
| Shipping spare parts from abroad | Governmental budget (government buys pumps and allocates them subsidized later) |
| Installation and commissioning of BPs | Retailers’ upfront purchase |

Table 2 | BP business model in Malawi

| PARTNERS | ACTIVITIES | PROPOSITIONS | CUSTOMER RELATIONSHIPS | CUSTOMER SEGMENTS |
|----------|------------|--------------|------------------------|-------------------|
| aQysta Netherlands | Negotiation with NGOs to allocate public budget | Offering to smallholders a low-cost, environmentally sound hydro-powered pumping technology, able to pump 24/7 at virtually zero operation cost | Sales through NGOs | Smallholders lacking of secured irrigation water |
| NGOs | Approach to agricultural extension agencies, to inform about the pump | | aQysta Malawi install the pumps | |
| Agricultural extension agencies | Installation and commissioning of BPs | | Servicing on-demand provided by aQysta Malawi for the next two years | |
| | | | Aftersales limited to servicing | |
| | | | | |

| KEY RESOURCES | CHANNELS |
|---------------|----------|
| aQysta Malawi headquarters | aQysta Malawi |
| aQysta Malawi staff | NGOs |
| BPs | |
| Transportation | |

| COST STRUCTURE | REVENUE STREAMS |
|----------------|-----------------|
| Shipping spare parts from abroad | NGO’s budgets for pumps allocation |
| Installation and commissioning of BPs | Installments from smallholders to pay off the pump |
Figure 1 | Schemes of BP business models and their respective legend. Sections A and B correspond to the business models in Nepal and Malawi, respectively.
identified – already more than two decades ago – key problems and required conditions for optimum implementation of these systems; however, it seems paradoxical that even nowadays those remain somehow the same in the cases analyzed in this study.

**Brief description of cases**

On the basis of the criteria pointed out above, the selected communities were, in Nepal: (1) Sokhu Besi neighborhood in the Jhangajholi Ratamata village, Sindhuli district, (2) Manthali municipality, Ramechhap district, and (3) Lele village, Lalitpur district; and, in Malawi: (4) Michiru, near Blantyre, (5) Tedzani, near Zalewa, and (6) Kachere cooperative, near Ntchisi. These BP use cases show a wide range of codified categories/attributes, as summarized in Table 3.

Relying on six cases, three per each country, might seem non-optimal for drawing generalized conclusions with respect to co-creating a business model. However, and particularly strengthened by the nature of Q-methodology (ten Klooster et al. 2008; Ellingsen et al. 2010), it certainly enables to study the phenomenon of the BP in detail, with richer qualitative information than any quantitative approach would offer (Miles et al. 2015).

**Case 1: Sokhu Besi.** The farmer is the sole owner of the BP, obtained by means of a subsidy (~90%) from the local government. The water supplied by the BP supports both crop – mainly vegetables sold to local markets – and livestock farming. The unit has been operative yet with two broken waterwheel paddles, thus working less efficiently. The farmer counts on basic complementary infrastructure for pumped water management: two plastic reservoirs and one plastic-lined open-air excavated pond, both at farmground level. The BP shares space with other two community-owned diesel water pumps on the riverside, which are used by the neighboring farmers to irrigate their respective farms. The latter require fuel input, resulting in operation costs 600 NPR (~€4.80) per hour per farmer. Nevertheless, in general those neighboring farmers prefer the diesel pumps over the BP due to its higher pressure and flowrate, and (perceived) faster spinning speed.

**Case 2: Manthali.** The farmer has two BPs, one owned – subsidized ~90% by the government – and one lent quadrangular prototype (intended to reach twice the pumped flow). His farm consists of several plots, some of them rented from neighboring farmers, to produce vegetables for sale at the local market. Albeit in operational conditions, none of the BPs was in use at the time of the field visit. The farmer argued this was due to the forthcoming rains, hence potential floods that could wash away the pumps; however, this might also be occurring due to the preferential use of groundwater sources within his lands. According to other interviewees, the farmer receives more revenues from selling groundwater to neighbors than the agricultural produce itself. This coincides with the fact that some plots remain barren, although he could ensure higher water volumes by additionally using the two BPs.

**Case 3: Lele.** The current farmers took over the farm on rental basis three months before the field visit. An infrastructure was already established, i.e. open plastic greenhouses and drip irrigation system, though the latter was removed by the farmers. The breast-shot BP, lent along with the farm, stopped functioning after a flood damaged the ~0.50 m weir four months before. The farmers do not know how the BP operates. As a consequence, they bought an electric pump right away to supply their farm’s need of water. This pump feeds an in-farm plastic-lined excavated reservoir, as well as a sprinkler irrigation system. They grow a number of vegetables that are sold locally.

**Case 4: Michiru.** This farm is a BP demonstration site in the Blantyre District. Since the farmer is aware of global warming effect, he sees the BP as an ideal technology. The unit has been in his possession for three months without any charge, after which he will have to start paying it off. The BP has been working so far irregularly due to water level fluctuations. Consequently river management – done through sandbags – will remain a reoccurring activity. The water supplied is used to irrigate several types of vegetables. Moreover, the farmer constructed a reservoir, which acts both as water storage and fish pond, to further manage the pumped water. After filling it, the water quickly seeped away; aQysta has offered to supply with a plastic lining to tackle this issue. Though this lining is not provided as part of any BP-marketed package, the company is interested in reaching a high performance for this demonstration site, hence the offer.

**Case 5: Tedzani.** This farm is an experimental site, intended to test the BP feasibility in the Shire River. Its
| Attributes of the selected BP use cases in farming communities in Nepal and Malawi |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
|                                 | Nepal                            | Malawi                          | Nepal                            | Malawi                          | Nepal                            | Malawi                          |
|                                 | Sokhu Besi                       | Manthali                        | Lele                             | Michiru                         | Tedzani                          | Kachere cooperative             |
| Distance from aQysta            | 88 km                            | 129 km                          | 16 km                            | 3 km                            | 60 km                            | 396 km                          |
| Travelling time                 | ~ 3.5 h                          | ~ 5 h                           | ~ 1 h                            | 15 min                          | ~ 2 h                            | ~ 6.5 h                          |
| Topography                      | River bottom valley              | River bottom valley             | Sub-valley                       | River bottom valley             | River bottom valley              | Shire river basin                |
| Accessibility                   | Next to national highway         | Next to regional road           | Next to district road             | Next to district road            | Next to footpath                 | Next to dirt road                |
| Main water source               | Sun Koshi river                  | Tamakoshi river                 | Unnamed river                    | Likhubula river                 | Shire river                      | Chafumbi river                   |
| Farm size                       | 0.4 ha                           | 1 ha                            | 0.2 ha                           | ~ 1 ha                          | 4 ha (partly cultivated)         | ~ 1.5 ha                         |
| BP presence time                | ~ 3 y                            | ~ 2 y                           | ~ 1.5 y                          | ~ 3 m                           | ~ 2 m                            | ~ 3 m                            |
| Facilitating conditions for BP  | Closeness to river (~170 m)      | Closeness to river (~80 m)      | Closeness to river (~105 m)      | Closeness to river (~30 m)      | Closeness to river (~80 m)       | Closeness to river (~120 m)      |
|                                 | Stream speed                     | Groundwater sources             | - Stream speed                    | - Stream speed                   | - Stream speed                    | - Stream speed                   |
|                                 |                                  |                                  | - Need of a weir                  | - Need of a weir                 | - Floating weed                   | - Lack of irrigation equipment   |
|                                 |                                  |                                  | - River floods                    |                                  | - Changing water depth            |                                  |
|                                 |                                  |                                  |                                  |                                  | - Changing water depth            |                                  |
| Hampering conditions for BP     | Presence of diesel water pumps   | Groundwater sources             | - Stream speed                    | - Stream speed                   | - Stream speed                    | - Lack of irrigation equipment   |
|                                 |                                  |                                  | - Need of a weir                  | - Need of a weir                 | - Floating weed                   |                                  |
|                                 |                                  |                                  | - River floods                    |                                  | - Changing water depth            |                                  |
|                                 |                                  |                                  |                                  |                                  | - Changing water depth            |                                  |
| BP ownership                    | 1 private                        | 1 private/ ~ 1 lent              | ~ 1 lent                          | 1 lent (demonstration)           | 1 lent (for testing)              | 1 private                        |
| BP conditions                   | Partially functional and operative | Fully functional yet not operative | Fully functional yet inoperative | Partially functional and operative | Partially functional and inoperative | Fully functional and operative |
| Farmer attitude on BP           | Willing to keep using it         | BP less useful than other water pumps | BP does not provide any benefit | Willing to keep using it         | Willing to keep using it          | Willing to keep using it         |
| Impact of the BP                | The farm relies on the BP        | None (BPs not in use)            | None (BPs not in use)             | The farm relies on the BP        | None (BP not in use)              | The farm relies on the BP        |
| Most preferred existing BME     | Subsidies                        | Subsidies                       | Clean energy                      | Flexible payment methods         | Flexible payment methods          | Flexible payment methods         |
|                                 | Clean energy                     | Zero operation costs            | Easy to install and use           | Zero operation costs             | Zero operation costs              | Zero operation costs             |
|                                 |                                  | - Subsidies                     | - Clean energy                    | - Clean energy                   | - Clean energy                    | - No human labor                 |
|                                 |                                  |                                  | - Easy to install and use         | - No human labor                 | - Clean energy                    |                                  |
| Most preferred proposed BME     | Extra services                   | Extra services                  | Nothing                           | Extra services (reservoirs)      | Nothing                           | Nothing                          |
|                                 | Entrepreneurial training         | Creation of jobs                |                                  | - Provision of (basic) infrastructure |                                  |                                  |

(continued)
conditions however, are challenging: too deep to anchor the BP, too low water speed next to the banks, rapidly fluctuant water level, and houses crocodiles. If this installation turns successful, the farmer will pay the BP off in instalments – a key driver for her choice – after which she is willing to buy another one. The main reason to adopt a BP was to cut down on fuel costs of the pumps that are currently used for irrigation. The BP was in the water but not operating due to low water speed.

**Case 6: Kachere cooperative.** This is a group of smallholders that has received support from several organizations; they shifted from watering cans to treadle pumps, and later on to diverting the river and gravity irrigation. None of these methods worked to their satisfaction, as such they inquired a BP, which was provided after paying a deposit. Yet, they find the pumped flow rate insufficient compared to other (conventional) water pumps. This occurs due to the mismatch in the irrigation water supply and demand, associated with lack of efficient irrigation systems (e.g. dripers, sprinklers) and buffer storage infrastructure (e.g. tanks, reservoirs). In consequence, water surplus continuously pumped through the night is not stored but simply flows off. Moreover, even though farmers are aware that they could pay in instalments, affordability is still a concern.

### Facilitating and hampering conditions for the BP

It was observed, in line with findings on other HPP devices (Garman 1986; Weng 1994; Naegel 1998), that a sound technical performance of the technology does not guarantee its sustained use. In Manthali and Lele, the BPs were simply neglected despite optimal working conditions. In Sokhu Besi and Kachere cooperative, similarly to other studies on RE-technologies (Bhattacharyya 2006; UNCTAD 2010), (non)existence of external elements (e.g. reservoirs, centrifugal pumps) affected the perceived usefulness of the BP. Though not part of any of the aforementioned visited cases, in accordance to aQysta there is another Nepali community in which the BP was deemed as undesirable since it might impede the provision of a subsidized diesel water pump (aQysta, personal communication, June 11, 2019). By contrast, the Michiru and Tedzani cases depict the willingness of the farmers to use the BP, even though site conditions were unfavorable.
These conditions, particularly for newly adopted technologies, are negatively boosted by weak supply chains (Weng 1994; Johan 2015; Giordano et al. 2019). In both Nepal and Malawi, aQysta rely only on a centralized office; as a consequence, all the site-dependent after-sale services (e.g. repairs, maintenance) are decreased in efficiency (Dahan et al. 2010). In both countries, due to their topography and road conditions, extended travelling times deepen the remoteness of certain locations, thereby worsening the already limited logistic networks (UNDP 2018).

Preferences on existing and proposed BME

Most preferred existing BME

Some existing BMEs could cause undesirable side effects if not well managed. Subsidies can steer practices and behaviors, hence are capable to cope with several barriers (e.g. unaffordability, promotion of use, gender inequity) (Fisher & Kandiwa 2014; Bista et al. 2018; Rai et al. 2019). Nevertheless, if not considered as temporary elements of change, linked to obligations from the counterpart, they can turn into permanent ‘crutches’ for smallholders (Clay 2013), even posing eventual decreases in productivity (Paudel & Rago 2017) and substantial market distortions (Closas & Rap 2017). Moreover, the technology is prone to be deemed as a mere handout due to the lack of empowerment. In some cases, subsidies can be out of the reach of many smallholders due to remoteness or institutional barriers (Gauchan & Shrestha 2017; Paudel & Rago 2017). Unlike Nepali BPs, which are largely subsidized by the local governments, the Malawian ones do not rely on such mechanisms (although they were previously subsidized by UNDP), hence their unaffordability is worsened in the latter. Therefore, flexible payment methods, e.g. instalments, is a preferred BME in Malawi. Although zero-operation costs and no human labor required are strengths of the BP, they could be misinterpreted as zero-maintenance due to a lack of understanding of the technology (Surendra et al. 2011). If proper maintenance is not given to the BP, its lifetime will be severely compromised. Likewise many other newly introduced (RE) technologies, the BP was observed to require substantial follow-up support and maintenance assistance, as well as transfer of know-how (Gewali & Bhandari 2005; Johnson & Lybecker 2009).

Despite being a clean energy-based technology, and notwithstanding its advantages, the BP faces some challenges that might hamper its implementation: policy barriers, lack of awareness, and financial barriers (Surendra et al. 2011).

Least preferred existing BME

In Sokhu Besi, where the BP was in operation within their applicability ranges, its pumped pressure and flowrate were considered insufficient. In Michiru, it was seen as a useful yet cumbersome device that could be stolen or vandalized. As pointed out by Surendra et al. (2011), this might be linked to a lack of awareness of the technology and its benefits. This was aggravated by the presence of other (traditional) water pumps; and, by the absence of theft and vandalism prevention measures (e.g. locks, chains, fences) and water management infrastructure that reduces its usefulness, respectively. In the Nepali cases, despite the BP’s virtual zero operation costs, its savings are not perceived as compensating the high upfront cost. Therefore, it becomes imperative to increase its affordability as well as the understandings of the farmers of the technology (Surendra et al. 2011). The maintenance of the BP, though not specialized, is seen as complex by the Sokhu Besi and Lele farmers. This perception might be exacerbated by the lack of know-how that would enable local partners and/or owners to perform it (Johnson & Lybecker 2009); i.e. even small repairs must be conducted by the company headquarters. In the Lele case, its maintenance by an external organization is deemed as undesired.

Most preferred proposed BME

Both extra services – e.g. assistance, infrastructure, inputs – and creation of new jobs, fit under a product-oriented PSS (Mont 2002; Tukker 2004; Beuren et al. 2013). While not having to be all managed but coordinated by the company, the extra services would enable potential job opportunities and their benefits (Mont 2002; Beuren et al. 2013).
Least preferred proposed BME

Paying for extra services was one of the least preferred options. Though contradictory with the preference for counting on them, it is obvious that the BP would be much less affordable with extra costs, particularly if paid upfront in economically depressed areas (Surendra et al. 2011). In addition, using the BP without being the owner was not considered desirable by the Manthali farmer, thus posing potential barriers to other payment schemes (Tukker 2004).

Co-creating along with smallholders

In accordance to Casali et al. (2018) the involvement of several stakeholders is a main requisite to cope with the complexities of business models, as it happens usually with technological deployments in low-income settings. Such is the case of the agricultural technology supply chains in Nepal and Malawi, whose weaknesses easily jeopardize the successful adoption and sustained use of a water pumping technology. However, engagement with BP-smallholders, as vulnerable stakeholders whose voices might not be considered legitimate enough to be heard (Derry 2012), is a long process that requires trust, constant capacity building and empowerment (Mena et al. 2010; Candelo et al. 2018). Nevertheless, this study must be understood as a first attempt to enable those commonly unheard smallholders – by means of a participatory methodology – to contribute with their share of (indigenous) knowledge in a smoother transfer of (water pumping) technology.

Opportunities for an improved business model – PSS

Based on the pitfalls and challenges of the current business models analyzed above, which in accordance to past studies (Shrestha 1996; Kunen et al. 2016; Closas & Rap 2017) remain in the same order of restrictions, an improved, BP-based PSS can be built upon these specific opportunities:

• To offer water pumping systems rather than mere pumping devices; i.e. to give BP-based packages with customized (outsourced) services such as irrigation and water management infrastructure, thereby increasing the usefulness of the BP under a wider range of scenarios. Whenever required, additional civil infrastructure that ensures optimal operation of BPs (weirs, dams, funnels) should be considered as an integral part of these systems. Nevertheless, the technical – financial feasibility of these components, due to their potential complexity, is worth a separate study.
• To operate with financial aids (e.g. subsidies, microloans), which support the BP affordability, along with co-payment conditions from the end-users. Moreover, extra services offered along with the BP could be attached to these payment methods as well.
• To identify and partner with existing actors to strengthen the supply chains. In Nepal and Malawi, both Collection and Distribution Centers (Rai et al. 2019) and Agricultural Extension Officers (Fisher & Kandiwa 2014), respectively, act as two-way middlemen that provide technical assistance and agricultural inputs to smallholders. This would reduce service times, create local job opportunities, and increase contact times.
• To partner with NGOs to conduct awareness raising and know-how transfer programs, hence to increase the understanding of the BP as a RE-based technology (Surendra et al. 2011).
• To ensure optimal working conditions whenever required, by the commissioning of additional infrastructure (weirs, diversion canals, gates) that can be outsourced. This will require, however, further assessment of financing and pay-off methods. Otherwise, BP underperformance could ultimately affect its perceived usefulness amongst farmers.

CONCLUSIONS

Hundreds of BPs are in use in several countries. From these, six cases from Nepal and Malawi were selected and analyzed due to their noticeable differences. In line with the wide range of conditions, the BP owners/users, as well as their neighboring farmers, showed different attitudes on the technical performance of the device and its respective BMEs. Nevertheless, and in line with the CVD approach, instead of aiming to a tailor-made top-down solution for
specific situations, the present paper shows how embracing such a diversity could enable co-created richer – yet not perfect – solutions to fulfil several (and at times opposed) needs while coping with different restrictions. Notwithstanding the participatory capabilities of the employed methods, this study has become just a first attempt to hearing unheard smallholders, aiming towards the co-creation of knowledge on improved BP-based business models.

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REFERENCES

Beuren, F. H., Gomes Ferreira, M. G. & Cauchick Miguel, P. A. 2015 Product-service systems: a literature review on integrated products and services. J. Clean. Prod. 47, 222−231. https://doi.org/10.1016/j.jclepro.2012.12.028.

Bhattacharyya, S. C. 2006 Renewable energies and the poor: niche or nexus? Energy Policy 34, 659−665. https://doi.org/10.1016/j.enpol.2004.08.009.

Bista, D. R., Dhuneg, S. & Adhikari, S. 2018 Status of fertilizer and seed subsidy in Nepal: review and recommendation. J. Agric. Environ. 17, 1−10. https://doi.org/10.3126/aje.v17i0.19854.

Candelo, E., Casalegno, C., Civera, C. & Mosca, F. 2018 Turning farmers into business partners through value co-creation projects. Insights from the coffee supply chain. Sustainability 10, 1018. https://doi.org/10.3390/su10041018.

Casali, G., Perano, M., Moretta Tartaglione, A. & Zolin, R. 2018 How business idea fit affects sustainability and creates opportunities for value co-creation in nascent firms. Sustainability 10, 189. https://doi.org/10.3390/su10010189.

Chandel, S., Nagaraju Naik, M. & Chandel, R. 2015 Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. Renew. Sustain. Energy Rev. 49, 1084−1099. https://doi.org/10.1016/j.rser.2015.04.083.

Chinseau, E., Dougill, A. & Stringer, L. 2019 Why do smallholder farmers dis-adopt conservation agriculture? Insights From Malawi. L. Degrad. Dev. 30, 533−543. https://doi.org/10.1002/ldr.3190.

Clay, J. 2015 Are Agricultural Subsidies Causing More Harm Than Good? Guard.

Closas, A. & Rap, E. 2017 Solar-based groundwater pumping for irrigation: sustainability, policies, and limitations. Energy Policy 104, 33−37. https://doi.org/10.1016/j.enpol.2017.01.035.

Corti, D., Granados, M. H., Macchi, M. & Canetta, L. 2013 Service-oriented business models for agricultural machinery manufacturers: Looking forward to improving sustainability. In: 2013 International Conference on Engineering, Technology and Innovation (ICE) & IEEE International Technology Management Conference. IEEE, pp. 1−8. https://doi.org/10.1109/ITMC.2013.7352612.

Dahan, N. M., Doh, J. P., Oetzel, J. & Yaziji, M. 2010 Corporate-NGO collaboration: co-creating new business models for developing markets. Long Range Plann. 43, 326−342. https://doi.org/10.1016/j.lrp.2009.11.003.

Derry, R. 2012 Reclaiming marginalized stakeholders. J. Bus. Ethics 111, 253−264. https://doi.org/10.1007/s11551-012-1205-x.

Devischer, T. & Mont, O. 2008 An analysis of a product service system in Bolivia: coffee in Yungas. Int. J. Innov. Sustain. Dev. 3, 262. https://doi.org/10.1504/IJISD.2008.022229.

Donner, J. C. 2001 Using Q-Sorts in Participatory Processes: An Introduction to the Methodology. In: Social Analysis: Selected Tools and Techniques. Social Development Family of the World Bank, Washington D.C, USA, pp. 24−49.

Dziopa, F. & Ahern, K. 2011 A systematic literature review of the applications of Q-technique and its methodology. Methodology 7, 39−55. https://doi.org/10.1027/1614-2241/a000021.

Ellingsen, I. T., Storksen, I. & Stephens, P. 2010 Q methodology in social work research. Int. J. Soc. Res. Methodol. 13, 395−409. https://doi.org/10.1080/13645570903368286.

FAO 2015 National Investment Profile. Water for Agriculture and Energy, Malawi. Lilongwe/Rome.

Fisher, M. & Kandiwa, V. 2014 Can agricultural input subsidies reduce the gender gap in modern maize adoption? Evidence from Malawi. Food Policy 45, 101−111. https://doi.org/10.1016/j.foodpol.2014.01.007.

Fraenkel, P. 1986 Water Pumping Devices: A Handbook for Users and Choosers. Intermediate Technology Publications, London, UK.

Garman, P. 1986 Water Current Turbines: A Fieldworker’s Guide. Practical Action Publishing, Warwickshire, UK.

Gauchan, D. & Shrestha, S. 2017 Agricultural and rural mechanisation in Nepal: Status, issues and options for future. In: Rural Mechanisation: A Driver in Agricultural Change and Rural Development (S. M. A. Mandal, S. D. Biggs & S. E. Justice eds). Institute for Inclusive Finance and Development, Dhaka, Bangladesh, pp. 97−118.

Gewali, M. B. & Bhandari, R. 2005 Renewable energy technologies and infrastructure in Nepal: Status, issues and options for future. In: Renewable energy technologies and infrastructure in Nepal: Status, issues and options for future. World Rev. Sci. Technol. Sustain. Dev. 2, 92. https://doi.org/10.1504/WRSTSD.2005.006730.

Giordano, M., Barron, J. & Ünver, O. 2019 Water Scarcity and Challenges for Smallholder Agriculture. In: Sustainable Food and Agriculture. Elsevier, pp. 75−94. https://doi.org/10.1016/B978-0-12-812134-4.00005-4.
Gopal, C., Mohanraj, M., Chandramohan, P. & Chandrasekar, P. 2015 Renewable energy source water pumping systems – A literature review. Renew. Sustain. Energy Rev. 25, 351–370. https://doi.org/10.1016/j.rser.2013.04.012.

Intriago, J. C., Ertsen, M., Diehl, J.-C., Michavila, J. & Arenas, E. 2018 Co-creation of affordable irrigation technology: The DARE-TU project. In: International Conference Water Science for Impact, Wageningen, The Netherlands, pp. 1.

Johan, S. 2015 Value Chains, Agricultural Markets and Food Security: The State of Agricultural Commodity Markets 2015–16 IN DEPTH, Rome, Italy.

Johnson, D. K. N. & Lybecker, K. M. 2009 Challenges to technology transfer: a literature review of the constraints on environmental technology dissemination. SSRN Electron. J. 42. https://doi.org/10.2139/ssrn.1456222.

Karki, S., Burton, P. & Mackey, B. 2020 Climate change adaptation by subsistence and smallholder farmers: insights from three agro-ecological regions of Nepal. Cogent Soc. Sci. 6. https://doi.org/10.1080/23311886.2020.1720555.

Kersten, W. C., Diehl, J. C. & Crul, M. R. M. 2015 Influence of context variation on quality of solutions: experiences with gasifier stoves. Procedia Manuf. 8, 487–494. https://doi.org/10.1016/j.promfg.2017.02.062.

Kunen, E., Pandey, B., Foster, R., Holthaus, J., Shrestha, B. & Ngetich, B. 2016 Solar Water Pumping: Kenya and Nepal Market Acceleration. In: Proceedings of the ISES Solar World Congress 2015. International Solar Energy Society, Freiburg, Germany, pp. 1–12. https://doi.org/10.18086/swc.2015.03.04.

Lowder, S. K., Skoet, J. & Raney, T. 2016 The number, size, and distribution of farms, smallholder farms, and family farms worldwide. World Dev. 87, 16–29. https://doi.org/10.1016/j.worlddev.2015.10.041.

Mena, S., de Leece, M., Baumann, D., Black, N., Lindeman, S. & McShane, L. 2010 Advancing the business and human rights agenda: dialogue, empowerment, and constructive engagement. J. Bus. Ethics 95, 161–188. https://doi.org/10.1007/s10551-009-0188-8.

Miles, M. B., Huberman, A. M. & Saldana, J. 2013 Qualitative Data Analysis: A Methods Sourcebook, 3rd edn. SAGE Publications Ltd.

Mont, O. 2002 Clarifying the concept of product – service system. J. Clean. Prod. 10, 237–245. https://doi.org/10.1016/S0959-6526(01)00039-7.

Morgan, P. 1984 A spiral tube water wheel pump. Blair Res. Bull.

Naegel, L. C. A. 1998 The Hydrostatic Spiral Pump: Design, Construction and Field Tests of Locally-Developed Spiral Pumps. Jaspers Verslag, Munich, Germany.

Osterwalder, A. & Pigneur, Y. 2010 Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers. Wiley, Hoboken, New Jersey.

Paudel, J. & Rago, C. L. 2017 Subsidy and Agricultural Productivity in Nepal. In: Agricultural & Applied Economics Association Annual Meeting, p. 12.

Rai, M., Paudel, B., Zhang, Y., Khanal, N., Nepal, P. & Koirala, H. 2019 Vegetable farming and farmers’ livelihood: insights from Kathmandu Valley, Nepal. Sustainability 11, 889. https://doi.org/10.3390/su11030889.

Shrestha, J. N. 1996 Solar PV water pumping system for rural development in Nepal: problems and prospects. In: IECEC 96. Proceedings of the 31st Intern Society Energy Conversion Engineering Conference. IEEE, pp. 1657–1662. https://doi.org/10.1109/IECEC.1996.553350.

Surendra, K. C., Khanal, S. K., Shrestha, P. & Lamsal, B. 2011 Current status of renewable energy in Nepal: opportunities and challenges. Renew. Sustain. Energy Rev. 15, 4107–4117. https://doi.org/10.1016/j.rser.2011.07.022.

Tukker, A. 2004 Eight types of product–service system: eight ways to sustainability? Experiences From SusProNet. Bus. Strateg. Environ. 13, 246–260. https://doi.org/10.1002/bse.414.

UNCTAD 2010 Renewable Energy Technologies for Rural Development Renewable Energy Technologies for Rural Development (No. UNCTAD/DTL/STICT/2009/4). Science, Technology and Innovation – Current Studies, New York & Geneva.

UNDP 2018 Value Chain Development of Fruit and Vegetables in Nepal. Kathmandu, Nepal.

UNEP 2015 Environmental Dispatches: Reflections on Challenges, Innovation and Resilience in Asia-Pacific. Nairobi, Kenya.

Weng, A. 1994 水轮泵的技术发展 [Technical development of the water turbine pump]. 水轮泵 [Water-Turbine Pump] 1–7.

Ziegler, J. H. 1766 Vorläufige Anzeige eines neuen Schöpfrades [Preliminary display of a new bucket wheel]. In: Abhandlungen Der Naturforschenden Gesellschaft in Zürich [Treatises of the Nature Research Society in Zurich]. Zurich, Switzerland, pp. 431–463.

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