Irrigation technology at the service of smallholder farmers
A sociotechnical approach to exploring sustainable business strategies

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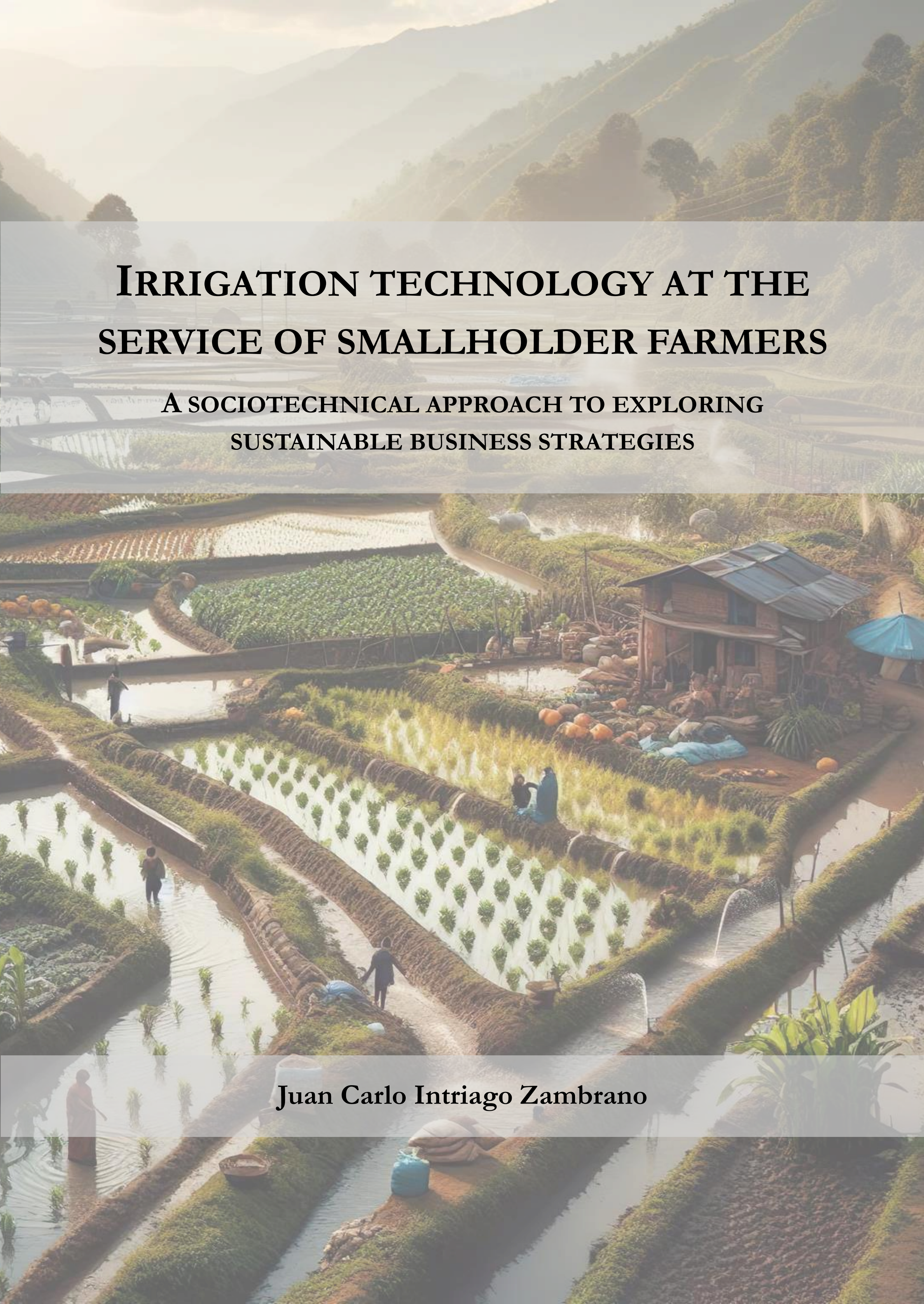

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Juan Carlo Intriago Zambrano

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Dissertation

for the purpose of obtaining the degree of doctor

at Delft University of Technology

by the authority of the Rector Magnificus prof.dr.ir. T.H.J.J. van der Hagen

chair of the Board for Doctorates

to be defended publicly on

Monday 24th of June 2024 at 15:00 o'clock

By

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This dissertation has been approved by the promotors.

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Keywords: Smallholder farming; hydro-powered pump; Barsha pump; irrigation; Q methodology; technology adoption; sustainable business model; Global South

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To *madrecita*.

The first and most important educator in my life.

I wish you were here.

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"Y sin embargo,
sin pretensiones de decir mi pena
y sin que intente convencer a nadie,
en un idioma de resignaciones
voy repitiendo que la vida es buena."

(Horacio Hidrovo Velásquez)

Background

It is not uncommon that people tend to compare pursuing a doctorate with a journey. This is particularly pronounced in PhD students, namely those human beings who, for some reason or another, decide to embark on a multiyear doctoral research project. But there are journeys and *journeys*. In the first category I would include summer holidays to an exotic destination, a road trip throughout several destinations, or visiting friends and relatives overseas. Some people, including myself, would dare to include also some more adventurous trips, like the Camino de Santiago in its many variants, the Inca trail to Machu Picchu, and any of the breathtaking multiday treks across the Himalayas.

By *journeys*, on the other hand, I refer to (really much) bigger endeavors. I will take the liberty of clustering here truly human feats or world-changing historical events. The maritime expansion enterprise by Infante Dom Henrique[1]. The first global circumnavigation by Fernão de Magalhães. The first ascent of Mount Chomolungma by Tenzing Norgay and Edmund Hillary. The deep-dive aboard the bathyscaphe Trieste by Jacques Piccard and Don Walsh. The Kon-Tiki expedition of Thor Heyerdahl across the Pacific Ocean. And the attempted trans-Antarctic expedition of captain Ernest Shackleton aboard the Endurance.

Whether pursuing a PhD degree is a journey or a *journey* is a very intimate affair. That depends on so many factors, both personal and contextual, that it will be pointless for me to attempt rationalizing the plethora of possibilities. Nonetheless, most if not all of them—journeys, *journeys*, and doctoral

[1] Owing to my strong attachment to the Portuguese culture, I intentionally refrain from recalling English forms of historical Portuguese characters like 'Prince Henry the Navigator' or 'Ferdinand Magellan'.

projects—have a rather identifiable common ground. There is a motivation behind. There are objectives to be met. There is a (sort of a) plan to be followed. There is a strategy of execution. There are resources of many kinds involved. And, not less importantly, there are difficulties to overcome, emerging decisions to be made, and improvisations to be carried out.

I will kick-off from the motivation. My (lack of) motivation. After studying with dedication 18 years in a row—primary and secondary schooling, and a bachelor's degree in architecture—I made myself a promise. I promised not to study ever again in my life. Never. I simply grew tired of studying. I felt it was time to go out, practice my profession, generate some profit, and explore the world. During eight years of professional practice, I gradually navigated from architecture and construction towards environmental management. People probably would refer to it nowadays as '*multidisciplinary background*'. By mid-2014, for potential employers in Ecuador, it meant that I was academically prepared on one field, but professionally experienced in another. I had a gap in my background. A background that did not satisfy the requirements of the job market. I was professionally staying in codfish waters[2]. Only then did I realize that my plan had not gone as expected.

Then I made a choice. One of the best choices of my life. I decided to secure a scholarship to study an MSc program abroad. I was determined to shake off the rust and step once again into the classroom. One can promptly realize that this decision was pretty much against my promise from eight years ago. But desperate times call for desperate measures. Some promises can wait. During that time, the Ecuadorian government had a strong scholarship program for talented nationals to study in the best ranked universities worldwide. I prepared myself to the best of my capacities. The effort paid off. I got the highest mark of that open call cohort for scholarships (against my own expectations, to be honest). Being myself a native from a minor city (and not from the capital or the largest cities), some media even considered such a mark a newsworthy event. After making it to some headlines in local and national newspapers—and enjoying my fifteen minutes of fame—it was time to prepare a few things.

Initially, I aimed to study an MSc program in Sweden. In a turn of events, the compass turned instead to the Netherlands. In August 2015 I was about to start the MSc Urban Environmental Management at (the then *unpronounceable*) Wageningen University. All kinds of details were taken care of. The entry visa was in my passport. Housing was arranged. Health insurance was purchased.

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[2] Literal translation to English of the Portuguese idiom '*ficar em águas de bacalhau*'. In this context, it means to be in difficulties, to go nowhere. It is rooted in Portugal's maritime past of cod fishing in Terranova (Newfoundland).

The one-way flight ticket was ready. And then *something* more or less foreseeable kicked in. Only when having boarded the airplane Guayaquil – Amsterdam, sitting next to my brother Javier, I felt the cold sweat and shivers that come with the idea of "what on earth am I doing?" I guess it was too late to regret my choices.

Frankly speaking, the MSc program was much smoother, and especially much more enjoyable than I anticipated. I rediscovered my passion for learning and expanding my knowledge. I had the opportunity to interact with so many people from different origins and backgrounds. It was wonderful to learn in such a dynamic academic environment (though many times, being 32 years old, I was the '*opa*' of the classroom). I met Dália, who in time became my beloved partner in so many adventures to come. I had a unique experience growing under the guidance of my supervisors Kasia, Francisco, and Alessandro. And, paradoxically, by deciding to study again, I finally started exploring the world. I concluded that some promises deserve to be dropped. Those promises will certainly not get offended. At least not the 'not to study ever again' one.

By October 2017, I had under my arm two key documents: an MSc diploma with *cum laude* distinction, and an Amsterdam – Guayaquil flight ticket. The first one was the expected outcome of my studies. The distinction was a beautifully unexpected reward, the *cherry on top of the cake* for what had been so far one of the best periods of my life. The second one, expected as well, had a tiny yet relevant detail: it was once more a one-way ticket. A ticket that became an entryway to more questions than answers for my future. I was to leave behind not only plenty of potentially fruitful professional opportunities. I was also bringing too many question marks to the future that Dália and I had pictured together. In any case, back then I had the wish (and the contractual obligation from my scholarship) to return to what I used to call home. I suspected it was going to be hard. I did not expect it was going to be *that hard.*

I arrived home. An extremely emotive memory marked that specific moment. After opening my suitcase, I handed over the MSc diploma to my parents with a firm but superlatively humble '*misión cumplida*' (in English, mission accomplished). They received it with the candid and beautiful expression of those who see their most treasured dreams made true in the accomplishments of their offspring. Congratulations over, and after a couple of cooling-off days, I started looking for a new job sooner rather than later. Anyhow, the urgency of solving financial issues is, give or take, an everlasting affair in Ecuador. The time elapsed pretty much in slow motion for the next five to six months. In interest of conciseness, I should state that that relatively short period brought many bitter tastes. It started with more than a couple of job rejections (some of them, ironically, due to being overqualified for the positions). It was darkened by the mistaken change of political compass in the country. It was sprinkled with fugacious working periods in two local public institutions. It was seasoned with an increasingly growing feeling of dissatisfaction. The longing for Dália and a life together was the ultimate element that cemented the decisions to come. In that moment, I thought that pursuing a doctorate—especially in Europe—was not that crazy an idea. Once more, the promise of not studying anymore would have to wait. Better said, by then that promise probably needed to be ostracized once and for all. And so, I embarked on *trying* to be admitted in a doctoral program.

Trying must be taken as a euphemism to summarize that I applied unsuccessfully for several doctoral vacancies across Europe. Many applications were sent to, and an equal number of rejections plus unanswered enquiries came from universities in Norway, Finland, Sweden, Denmark, Germany, and Switzerland. It was then, when I was in the mode of 'let's try any potential doctoral position', that I came across a doctoral vacancy at Delft University of Technology. It felt like serendipity. Or perhaps the vacancy came across me. Either way, I am convinced that it was serendipity. The job description seemed to me like those holographic stickers for the sticker albums: depending on how, where from, under which light conditions, and when you look at them, you see a somehow different image. Sometimes I was convinced that my background was highly suitable for the required profile. Other times, I felt that I was aiming very far from the target. Absolutely hesitant, when talking to Dália one day, I even told her "I will apply for that vacancy at TU Delft; however, I am convinced that the position is too technical for my profile". The rest is history. A couple of months later, and with a deep déjà vu feeling, I was once again with all kinds of details arranged: entry visa in my passport, (temporary) housing, and another one-way flight ticket. I was granted that wonderful fellowship from the TU Delft | Global Initiative.

I encountered once more that renewed spark in my soul: the joy of learning, the passion for acquiring and producing knowledge, the excitement of one of the greatest challenges of my life ahead, and, not less importantly, being hand to hand with Dália. Pursuing a doctorate. It sounds so straightforward and simple, yet it is so intricate, complex, and exciting. I recalled memories from my childhood, when my mom used to refer to PhDs almost as superheroes, as quasi superior beings that are practically omniscient. Most people involved in academics will smile, laugh, or frown upon this statement. Likely I would go for any of those reactions too. But please refrain from doing so. Please be forgiving with the oversized thoughts of a kid less than 10 years old, and his mom, for whom education was the alpha and the omega in life. This was the motivation of my *journey*.

The journey

The doctoral research turned out to be somehow different from what that small kid would have thought of more than two and a half decades before. Endless days at the office in front of the computer, reading tons of documents. Preparing research designs and plans, learning new research methods, and getting acquainted with their respective data collection instruments. Scary and intriguing meetings with my supervisors, where I left with more questions than answers, where I felt more confused than convinced. Many moments when I realized that I knew much less than I thought. Many peer review processes, when two or three faceless and nameless people (i.e., anonymous reviewers) had enough power to decide whether my work was worth seeing the light as a scientific article with a DOI.

But the process also involved myriads of beautiful moments of satisfaction. Many moments that outweighed, by far, the instants of concern or disappointment. Meeting amazing people, both within and outside academia. Learning so much about many topics (and being paid for that). Benefitting firsthand from sage people sharing their knowledge humbly and selflessly. Partaking in exciting and compelling side projects. Conducting fieldwork in breathtaking places—again, exploring more corners of the world. Growing personally and professionally while relying on great mentors and colleagues. And saturating Dália, every evening after the office or upon my return from fieldwork, by telling her about the latest advancements in my research. I bet she still remembers part of when each hydro-powered pump was developed, who invented it, and what was its fate. Or the name of each of the temples I visited in Kathmandu. Or the spicy level of the sambals I tried in each Indonesian dish I enjoyed.

Then, at a certain point of my *journey*, COVID came. The whole world upside down. I deem it needless to explain details here of a global crisis that we all suffered from in one way or another. To me, this unique, strange, and deeply odd situation brought me many setbacks and consequences at professional and personal level. Professionally, it meant that what was supposed to be an exciting plan of fieldwork, turned into a *much less* exciting online research from the comfort of my place. Instead of jeans, boots, hat, and sunscreen, I found myself more often than not wearing sweatpants, hoodies, wool socks, and fluffy slippers. Instead of participating in in-person European summer schools and conferences, I was 'enjoying' back-to-back video calls, sometimes as lectures, sometimes as virtual conferences, sometimes as graduate courses. Sometimes even as what otherwise would have been an informal coffee with a colleague in the Water Management department. But what I regret the most from the COVID crisis, at a professional level, is having lost contact with the smallholder farmers. Those farmers who were not only the core of my research, but those admirable people who always welcomed me in a selfless manner, many times with a cup of coffee, a treat, or a snack from their own produce.

At a personal level, the COVID pandemic translated into positive tests two times. Into spending long mandatory quarantine days at home, observing from a sixth floor how the world kept moving strangely forward. Into complying as strictly as possible with a set of new rules from a sort of new world, which included facemasks, physical distancing, not shaking hands, and the almost obsessive use of disinfectant hand gel. Into getting irritated by others not respecting those weird rules. Into including COVID self-tests as part of the usual groceries. But most importantly, into almost two endless and infinitely anguishing years without seeing my parents. Too long a period for someone plunged into the uncertainty of seeing or not his parents alive for the last time. For a last hug.

I guess that even in the weirdest of situations there are opportunities to tap into. The new 'online' world allowed me to partake in many more professional interactions than ever before. Perhaps too many. I had the beautiful opportunity to collaborate with project partners from geographies I never thought of before. As a fellow in a USA-based fellowship program on international development, with fellows from all over the world. As a fellow in a project with a company headquartered in Kenya, India, and Mexico. As a co-organizer in a summer school involving African and European universities. As a researcher in a project exploring the intricate relationships of digital innovation in the Global South. As a presenter in many virtual conferences focused on different fields of knowledge. As an attendee of dozens of interesting virtual academic and professional events. I am sure these virtual opportunities also contributed to taking me where I am happily standing nowadays.

As the reader may realize by now, my *journey* had (clear) objectives. I had a plan to follow in the coming years. I had a strategy of how to execute that plan in order to achieve those objectives. Certainly, there were many difficulties to overcome and decisions to make. There was even a global pandemic that forced me to somehow change my North Star for an improvised Southern Cross. But, chiefly, there were many people who contributed to this *journey*. Many who ensured that my Endurance did not sink in Antarctic waters but sailed to calm waters and safe harbor. Even when that safe harbor came two years later than planned, two years after the storm. To all those people, my undying gratitude.

Professional acknowledgements

Maurits and JC. Thank you both for your wisdom, guidance, time, hard work, and infinite patience. At the risk of this sounding like a cliché, I probably

could not have asked for a better supervisory team. Your supervisory styles still seem to me so different from one another, yet so mutually complementary in a very smooth way. I keep many beautiful memories of our trilateral meetings, when your questions, comments, suggestions, and advice were just flowing naturally like a river meandering from side to side, when my head (and my attention) was ping-ponging from one to the other of you. From all these years working together, I particularly treasure how over time you made me feel less like a graduate student, and more like a colleague. Thank you both for that immense opportunity to grow.

Maurits, you were always highly critical and constructive behind closed doors. Always pushing me to think beyond the obvious. But you were equally (if not more) supportive when sharing my research with the outside world. Thanks for that great balance between professional mentorship and warm encouragement to move forward. You were always sharp and professional while never losing the humane side, especially when things in my life were more obscure than ever. Thanks for shedding light in my path when the horizon was becoming blurry. Thanks for the subtle yet effective nudge for the last push of the *journey*, when things from my side stayed in codfish waters. Last but not least, thanks for always bearing with my extremely long sentences. Gratitude is usually an infinite resource, and I will not be sparing with it here. I fondly remember one of our first interactions back in 2018, when I thanked you after a meeting. You pointed out that I do not need to thank you, that you were only doing your job. Well, Maurits, please allow me the opportunity to thank you here one more time.

JC, you were all the time a driving force in my *journey*. Brimming with energy and creativity. Always transmitting a downpour of very enticing research ideas. Always spreading optimism and contagious smiles when the landscape was becoming dark. There was never a dull moment in a discussion with you, let alone when meeting in your office, typically bustling with creative manifestations of all kinds. From the very beginning, when during our first in-person meeting you offered me a highly lively tour through the IDE faculty, I knew this was going to be very fun. Thanks for guiding me with that mixture of such an impressive energy and sageness. Thanks for your critical eye for all kinds of details during my research. Thanks for the endless flow of options to explore, pathways to scout, and people to network with. Thanks for making me part of PBL South Asia, a project that brought me much personal and professional fulfilment, and many warmhearted friends. JC, I keep many of the A3-sized masterpieces you produced during our meetings. Allow me to consider them the silent and colorful witnesses of six years of your amazing mentorship and endless creativity.

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Personal acknowledgements

A PhD research project cannot be conducted (or at least cannot be understood) from a purely professional perspective. The 'researcher' is just one side of a coin. The other side of that indivisible coin is a human being. A person with a social and cultural background, with his/her own set of principles, morals, and values. With an emotional and spiritual component. With fears and concerns. As such, my doctoral research was also vastly supported by people who did not (directly) influence my academic and professional performance, but certainly contributed to the emotional stability required to endure the process.

Mom and dad. Since I remember you always encouraged me to grow. To become a better version of myself. To reach higher. Whenever I got tired of whatever sacrifice that growing process entailed, you just kept insisting relentlessly. When I was a kid, I did not understand that. To be honest, many times I wanted to hopelessly quit that strict upbringing at home. Now, in hindsight, I see the value of all of it. Not only that. Now, I am happy that you never let me quit. Thanks for always believing in me, even when I did not.

Mom, *madrecita*, you were always the main driving force behind my education. That elemental force of nature seeking the best for her sons. I am very thankful that for you the 'best' always was education. More and better education each time. Even when that meant letting your kids go, far across the world, in pursuit of better days. I feel at peace knowing that I continued my life far from home with your blessing. Look how far I have made it. I wish I had made the whole *journey* with you by my side. Wherever your soul might be, I am

strongly convinced that you are proud of me. Thanks for your love beyond time and space.

Dad, you are a good balance between strictness and love. You are as strict as an average Ecuadorian family requires to raise their kids amidst a not-so-friendly environment. But you are also a loving father that never stopped making sacrifices to ensure that his sons had a smooth life. A life without unnecessary luxuries but with the necessary resources to thrive in a decent, humble, and empathetic manner. Allow me to innocently recall a family story. The story collects that when I was born—and you were 40 years old—you deemed yourself too irresponsible because you were already too old. Because you would not live long enough to see your son finishing high school. I think life has been generous to you and me alike. Three academic degrees later by the end of this *journey*, and myself being as old as you were when I was born, I can tell you: look how far we have made it together.

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Gabriel García Márquez said that dying is never being again with the friends[3]. Thanks to the good friends in Ecuador, who, despite the geographical distance, have been always present in a way or another. Thanks to your presence, my life in Ecuador as I knew it has not died. *Colorado* Andrés, *Negro* Adrián, Alejo, Johanna, Cristina, Daniel, Roddy, *Doña* Leti. Thanks for being in touch now and then. Thanks for your support and for keeping tabs on how I am doing. Thanks for your patience regarding my very delayed responses. I expect my response rate to increase upon having a PhD project less from my to-do list.

Many sincere thanks to the authors of many books that accompanied me during my *journey*. Addressing so many different topics, they brought me lots of entertainment throughout the cold, rainy, and gloomy Dutch days. More often than not they were not related at all to my PhD project. I think that was more intentional than coincidental, as my mental sanity was always a priority.

Lastly, thanks to all of you who, to some extent, contributed to making this milestone in my life a reality. As six years brings a lot of interactions, moments, and circumstances, please forgive the fragility of my memory if your name or participation is not included here. I am confident that you will understand.

The way forward

It is not uncommon that PhD graduates say they would think twice before embarking on a doctorate. Or that they will never make such a choice again. Or

[3] Translation to English of the phrase "*morir es no estar nunca más con los amigos*", as written in García Márquez's *Doce Cuentos Peregrinos*.

that they advise prospective PhD students to analyze well before accepting such a long endeavor. While I do not think I will ever engage in a second doctorate (or perhaps Dália will discourage me by all means), I can say with absolute confidence that I do not regret at all having opted for this *journey*.

I did not lose my social life (whatever it means for a person like me). I have learned a big deal of many things. I met fantastic people and visited astonishing places. I grew personally and professionally. I became a much better version of myself. I enjoyed most of it from beginning to end. The balance is by large positive. As I usually say, if I had the chance to decide again whether embarking on this PhD, I would do it once more without hesitation.

But it is time to move on. I am convinced that my time in academia has come to an end. I am currently enjoying a wonderful position in the intersection of research and practice. That means that I keep enjoying learning and producing knowledge, while observing firsthand how the world of smallholder farming and agribusinesses moves in practice. Anyhow, the future can take me to different (and likely unknown) pathways. But for now, this is who I am, this is what I do. At least, I will be careful in not promising myself again not to study ever again.

Finally, I can humbly but proudly say that the product of this *journey* is not this dissertation. It is me. Thank you all for this beautiful voyage.

"Más de una mano
en lo oscuro me conforta
y más de un paso
siento marchar conmigo,
pero si no tuviera
no importa, sé que hay muertos
que alumbran los caminos."

(Silvio Rodríguez)

Table of Contents

Acknowledgements vii

Summary xxiii

Samenvatting xxvii

Resumen xxxi

Chapter 1 Introduction 1

Chapter 2 Water Lifting Water: A Comprehensive Spatiotemporal Review on the Hydro-Powered Water Pumping Technologies 25

Chapter 3 Sowing Q methodology in the Rural Global South: A Review of Challenges and Good Practices 75

Chapter 4 Q-methodology and farmers' decision-making 143

Chapter 5 Discourses on the adoption of the Barsha pump: A Q methodology study in Nepal and Indonesia 173

Chapter 6 Sustainable business models for smallholder farmers: Challenges for and lessons from the Barsha pump experience 217

Chapter 7 Discussion and Conclusions 259

List of tables 275

List of figures 276

Publications by the author 277

About the author 279

Summary

Recently, there has been a growing need for sustainable agriculture to increase food security, alleviate poverty, and contribute to climate change mitigation. Smallholder farmers (SFs) play a key role in this endeavor as they are a considerable segment of the global farming population. Despite their relevance, SFs face several challenges that hinder their productivity and compromise their livelihoods. Among the most salient challenges are limited access to (financial) resources and technology, insufficient knowledge and training, limited market access, and climate change vulnerability. Social and gender inequalities, land tenure insecurity, underdevelopment of supply chains, and lack of supportive policies further exacerbate these challenges.

Innovations of different kinds can support SFs in transforming agricultural systems towards the accomplishment of several sustainable development goals. These innovations can take the form of new technologies, new farming practices, social and collective empowerment, and systemic changes at policy and regulatory levels. In this context, and responding to the pressing issue of SFs' development, the Dutch company aQysta developed a hydro-powered water lifting device, known as the Barsha pump (BP). aQysta offers this technology as an innovative and sustainable solution to the irrigation challenges facing SFs. The BP operates solely on renewable energy, meaning that no input of fossil fuels is required to use it. aQysta argues that these features make the BP both an environmentally sound and affordable irrigation solution, with the potential of improving the livelihoods of SFs. In consonance with those claims, the BP represents a promising technological advancement that aligns well with the sustainable development of SF systems.

Technology provider companies typically resort to business models as strategic blueprints to create, deliver, and capture value. This has been largely the case of aQysta and its deployment of the BP across several SF communities. However, when it comes to technological innovations for SFs, traditional business models typically fall short in these purposes due to the several challenges of the SF target customers. By incorporating social inclusion and environmental stewardship strategies (besides legitimate profit generation), sustainable business models (SBMs) can support more robustly companies aiming to serve SFs like aQysta.

In this respect, by focusing on aQysta's technology proposition, this thesis investigates a) how innovative agricultural technologies cater for the needs of

SFs, b) how SFs decide to adopt such innovative agricultural technologies, and how SFs' contexts play a key role in that decision, and, c) how SBMs can support technology providers in delivering their value propositions to their target SFs. Through an interdisciplinary approach—with aspects of engineering, entrepreneurship, and sustainable development—this study aims to shed light on the intricate relationship between technologies, SBMs, and SF's social impact, through the following main research question:

What sustainable business model strategies stimulate the adoption of hydro-powered pumps for smallholder irrigation?

To answer this research question, I resorted to a mixed-method approach applied to five studies, which correspond to the different chapters of this thesis. These five studies compose this dissertation by analyzing the main research question from different angles: technologies, method to study SF phenomena, farmer's decision-making, SFs' technology adoption, and SBM strategies to cater for SFs' needs.

I started by reviewing the range of available hydro-powered pumping technologies over time (Chapter 2). To this end, I conducted a semi-systematic literature review of more than 800 scientific and grey documents. These documents addressed the fragmented storylines of several technologies, from their conceptualization and design to their eventual (mass) production and commercialization worldwide. I classified and plotted a total of 30 pumping technologies in space and time. Some noticeable clusters emerged in regions like Europe, South–Southeast Asia, and Eastern Africa, around 1960 – 1990. Some of the studied technologies had a global impact until contemporary times, others have been key in specific countries, and other ones had almost imperceptible lives. I found that hydro-powered pumping technologies currently face a regained momentum, hence a potentially promising future. However, manufacturers and users need to be aware of the importance that proper management systems pose for these technologies beyond their mere performance.

Then, I analyzed the potential of Q methodology (henceforth Q) as a sound participatory research method to understand SF's phenomena (Chapter 3). To reach the goal of this study, I selected and reviewed 50 Q studies applied to different forms of rural livelihoods in the Global South. In this chapter first I discuss several on-field Q limitations associated with the physical, logistical, social, and cultural constraints of such settings. Later, I drew on good practices and strategies to cope with these limitations. Beyond the limitations and strategies, I advocate building Q capacities and the gender-balanced empowerment of local researchers in the Global South. This may contribute to a better understanding of the nuances and challenges of SF's livelihoods in their respective contexts.

Through a co-authored study, I later researched farmers' decision-making strategies through the lens of Q (Chapter 4). We used Q to delve into Malawian farmers' decision to adopt certain water transport technologies for irrigation. The method was administered face-to-face to several SFs, large commercial farmers, representatives of farmer cooperatives, and experts in farming systems in Malawi. We found that SFs, typically considered a homogeneous group, did not decide in the same ways. Some SFs, in fact, may have progressive and commercial mindsets that can be hampered by lack of access to required resources. Furthermore, our results showed that decision-making has a clear gender dimension. We found Q to be a robust methodology, capable of capturing several nuances of farmers' decision-making.

Later, I focused on the specific SFs' decision (or not) to adopt the BP in its intended contexts of use (Chapter 5). By means of Q, I explored cross-cultural discourses around the adoption of BP. I administered Q to 43 (non-)farmer respondents linked to Nepali and Indonesian SF systems. I identified three relevant discourses, one of them bipolar in nature. The first one identified BP's potential early adopters. The second discourse embodied the stereotypically highly dependent SF. The last one characterized contrasting views around the BP as an enabler of potential service-oriented business models to achieve well-being. These results reflect the need for a shift of mindset toward new ways of understanding technological change in SF settings. Based on my findings, I proposed possible technology adoption pathways that may lead to the exploration of innovative business models to serve the diversity of SFs more effectively.

Lastly, I conducted a study on SBM strategies to cater better to the specific needs of SFs (Chapter 6). I used a multiple-case analysis to expand the knowledge on this incipient research area. For this analysis, I considered the cases of 10 organizations providing SF-tailored products and/or services. I conducted the cross-case analysis stage across five thematic areas relevant to SF's challenges: information and knowledge, capital and financial services, training and capacity building, rural logistics and supply chains, and market connection. Based on the results of the analyses, I drew lessons for aQysta (and similar companies) to improve BP's value proposition. I also elaborated on the implications of the study for other organizations engaging commercially with SFs.

Building on the findings of these five individual studies, I was able to identify SBM strategies to stimulate the adoption of hydro-powered pumps for SF irrigation. I present these strategies in the concluding section of this thesis

(Chapter 7) by following the five SBM thematic areas (identified in Chapter 6) across the four SFs discourses on the BP adoption (studied in Chapter 5). Proposed strategies cover SFs' issues related to: information content and delivery channels; provision of capital and financial services; approaches to deliver training and build SF capacities; approaches to build robust and sustainable last-mile networks to reach SFs; and market connection to increase SFs' commercial viability to foster technology adoption. Finally, I close my doctoral dissertation discussing the implications of my findings and proposed strategies for different actors involved in SF's technology adoption: researchers, technology developers, practitioners, and policymakers.

Samenvatting

De laatste tijd is er een groeiende behoefte aan duurzame landbouw om voedselzekerheid te vergroten, armoede te verlichten en bij te dragen aan het beperken van klimaatverandering. Kleine boeren (Smallholder Farmers, vandaar de afkorting SF in deze tekst) spelen een sleutelrol in dit streven, aangezien zij een aanzienlijk deel van de mondiale boerenbevolking vormen. Ondanks hun relevantie worden SFs geconfronteerd met verschillende uitdagingen die hun productiviteit belemmeren en hun levensonderhoud in gevaar brengen. Tot de belangrijkste uitdagingen behoren de beperkte toegang tot (financiële) middelen en technologie, onvoldoende kennis en opleiding, beperkte markttoegang en kwetsbaarheid voor klimaatverandering. Sociale en gender-gerelateerde ongelijkheid, onzekerheid over grondbezit, niet-functionerende toeleveringsketens en een gebrek aan ondersteunend beleid verergeren deze uitdagingen nog verder.

Innovaties van verschillende aard kunnen SFs ondersteunen bij het transformeren van landbouwsystemen in de richting van verschillende duurzame ontwikkelingsdoelen. Deze innovaties kunnen de vorm aannemen van nieuwe technologieën, nieuwe landbouwpraktijken, sociale en collectieve empowerment en systemische veranderingen op het niveau van beleidsregelgeving. In deze context, en als reactie op de prangende vraag naar ontwikkeling van SFs, ontwikkelde het Nederlandse bedrijf aQysta een pomp op waterkracht, bekend als de Barsha-pomp (BP). aQysta biedt deze technologie aan als een innovatieve en duurzame oplossing voor de irrigatie-uitdagingen van SFs. De BP werkt op hernieuwbare energie, wat betekent dat er geen input van fossiele brandstoffen nodig is om deze te gebruiken. aQysta stelt dat deze kenmerken de BP zowel een milieuvriendelijke als betaalbare irrigatieoplossing maken, met het potentieel om de levensstandaard van SFs te verbeteren. Op basis van deze claims vertegenwoordigt de BP een veelbelovende technologische vooruitgang die goed aansluit bij de duurzame ontwikkeling van SF-systemen.

Technologieleveranciers gebruiken doorgaans bedrijfsmodellen als strategische blauwdrukken om waarde te creëren, leveren en vastleggen. Dit is grotendeels het geval geweest voor aQysta en de inzet van de BP in verschillende SF-gemeenschappen. Als het echter om technologische innovaties voor SFs gaat, schieten traditionele bedrijfsmodellen tekort vanwege de diverse uitdagingen waarmee de SF-doelklanten te maken hebben. Door het integreren van strategieën voor sociale inclusie en milieubeheer (naast het genereren van legitieme winst), kunnen duurzame bedrijfsmodellen (SBMs) krachtiger bedrijven ondersteunen die SFs net als aQysta willen dienen.

Daarom onderzoekt dit proefschrift, door zich te concentreren op de technologische propositie van aQysta, a) hoe innovatieve landbouwtechnologieën tegemoetkomen aan de behoeften van SFs, b) hoe SFs besluiten dergelijke innovatieve landbouwtechnologieën te adopteren, en hoe de context van SFs daarin een sleutelrol speelt, en c) hoe SBMs technologieleveranciers kunnen ondersteunen bij het leveren van hun waarde-proposities aan hun doel-SFs. Via een interdisciplinaire aanpak – met aspecten van techniek, ondernemerschap en duurzame ontwikkeling – wil deze studie licht werpen op de ingewikkelde relatie tussen technologieën, SBMs (Sustainable Business Models, vandaar de afkorting SBM in deze tekst) en de sociale impact van SFs, aan de hand van de volgende hoofdonderzoeksvraag:

Welke duurzame bedrijfsmodelstrategieën stimuleren de adoptie van waterkrachtpompen voor irrigatie van kleine boeren?

Om deze onderzoeksvraag te beantwoorden, heb ik een gemengde methodebenadering gebruikt, toegepast op vijf sub-onderzoeken, die overeenkomen met de verschillende hoofdstukken van dit proefschrift. Deze vijf studies resulteren in dit proefschrift door de belangrijkste onderzoeksvraag vanuit verschillende invalshoeken te analyseren: technologieën, methode om SF-fenomenen te bestuderen, de besluitvorming van boeren, de technologie-adoptie van SFs en SBM-strategieën om in de behoeften van SFs te voorzien.

Ik begon met het beoordelen van de reeks beschikbare waterkrachtpomptechnologieën in de loop van de tijd (hoofdstuk 2). Daartoe heb ik een semi-systematisch literatuuronderzoek uitgevoerd naar ruim 800 wetenschappelijke en grijze documenten. Deze documenten gingen in op de gefragmenteerde verhaallijnen van verschillende technologieën, vanaf hun conceptualisering en ontwerp tot hun uiteindelijke (massa)productie en wereldwijde commercialisering. Ik heb in totaal 30 pomptechnologieën geclassificeerd en in kaart gebracht in ruimte en tijd. Rond 1960 – 1990 ontstonden enkele opvallende clusters in regio's als Europa, Zuidoost-Azië en Oost-Afrika. Sommige van de bestudeerde technologieën hadden tot in de huidige tijd een mondiale impact, andere zijn van cruciaal belang geweest in specifieke landen, en andere hebben een onopvallend leven gehad. Ik ontdekte dat waterkrachtpomptechnologieën momenteel een hernieuwd momentum kennen, en dus een potentieel veelbelovende toekomst. Fabrikanten en gebruikers moeten zich echter bewust zijn van belang van goede managementsystemen voor deze technologieën , naast hun prestaties.

Vervolgens analyseerde ik het potentieel van de Q-methodologie (voortaan Q) als een goede participatieve onderzoeksmethode om de omstandigheden van SFs te begrijpen (hoofdstuk 3). Ik heb 50 Q-onderzoeken geselecteerd en beoordeeld die zijn toegepast op verschillende vormen van levensonderhoud op het platteland in het Mondiale Zuiden. In dit hoofdstuk bespreek ik eerst een aantal Q-beperkingen die verband houden met de fysieke, logistieke, sociale en culturele beperkingen van dergelijke omgevingen. Later heb ik gebruik gemaakt van goede praktijken en strategieën om met deze beperkingen om te gaan. Naast de beperkingen en strategieën pleit ik voor het opbouwen van Q-capaciteiten en genderevenwichtige versterking van lokale onderzoekers in het Mondiale Zuiden. Dit kan bijdragen aan een beter begrip van de nuances en uitdagingen van het levensonderhoud van SFs in hun respectieve contexten.

Samen met een mede-auteur van een onderzoek heb ik daarna de besluitvormingsstrategieën van boeren onderzocht door de lens van Q (hoofdstuk 4). We hebben Q gebruikt om te begrijpen hoe Malawische boeren beslissen om bepaalde watertransporttechnologieën voor irrigatie te gebruiken. De Q methode werd toegepast bij verschillende SFs, grote commerciële boeren, vertegenwoordigers van boerencoöperaties en deskundigen op het gebied van landbouwsystemen in Malawi. We ontdekten dat SFs, die doorgaans als een homogene groep worden beschouwd, niet op dezelfde manier beslissingen namen. Sommige SFs hebben mogelijk een progressieve en commerciële mentaliteit die kan worden belemmerd door een gebrek aan toegang tot de benodigde middelen. Bovendien lieten onze resultaten zien dat besluitvorming een duidelijke genderdimensie heeft. We vonden dat Q een robuuste methodologie is, die in staat is om verschillende nuances van de besluitvorming van boeren vast te leggen.

Later concentreerde ik me op de beslissing van specifieke SFs om de BP te adopteren (of niet) in de beoogde gebruikscontext (hoofdstuk 5). Door middel van Q heb ik interculturele discoursen rond de adoptie van BP onderzocht. Ik heb Q toegepast in twee setting van totaal 43 (niet-) boerenrespondenten in Nepal en Indonesië. Ik identificeerde drie relevante discoursen, waarvan er één bipolair van aard was. De eerste identificeerde de potentiële vroege gebruikers van de BP. Het tweede discours belichaamde de stereotiepe sterk afhankelijke SF. De laatste kenmerkte de contrasterende opvattingen rond de BP als een katalysator voor potentiële servicegerichte bedrijfsmodellen om welzijn te bereiken. Deze resultaten weerspiegelen de noodzaak van een mentaliteitsverandering om technologische veranderingen in SF-omgevingen te begrijpen. Op basis van mijn bevindingen heb ik mogelijke trajecten voor technologie-adoptie voorgesteld die kunnen leiden tot (de verkenning van) innovatieve bedrijfsmodellen om de diversiteit van SFs effectiever te (be)dienen.

Ten slotte heb ik een onderzoek uitgevoerd naar SBM-strategieën om deze beter tegemoet laten te komen aan de specifieke behoeften van SFs (hoofdstuk 6). Ik heb een meervoudige case-analyse gebruikt om de kennis op dit beginnende onderzoeksgebied uit te breiden. Voor deze analyse heb ik tien organisaties bekeken die op maat gemaakte producten en/of diensten voor SFs leveren. Ik heb een cross-case analyse uitgevoerd op vijf thematische gebieden die relevant zijn voor de uitdagingen van SF: informatie en kennis, kapitaal en financiële diensten, training en capaciteitsopbouw, plattelandslogistiek en toeleveringsketens, en marktverbinding. Op basis van de resultaten van de analyses heb ik lessen getrokken voor aQysta (en soortgelijke bedrijven) om de waardepropositie van de BP te verbeteren. Ik ging ook dieper in op de implicaties van het onderzoek voor andere organisaties die commercieel met SFs bezig zijn.

Voortbouwend op de bevindingen van deze vijf afzonderlijke onderzoeken kon ik SBM-strategieën identificeren om de adoptie van waterkrachtpompen voor SF-irrigatie te stimuleren. Ik presenteer deze strategieën in het afsluitende deel van dit proefschrift (hoofdstuk 7) door de vijf SBM-themagebieden (geïdentificeerd in hoofdstuk 6) te volgen in de vier SF-discoursen over de adoptie van BP (bestudeerd in hoofdstuk 5). De voorgestelde strategieën hebben betrekking op de uitdagingen van SFs met betrekking tot: informatie-inhoud en leveringskanalen; verstrekking van kapitaal en financiële diensten; benaderingen om training te geven en SF-capaciteiten op te bouwen; benaderingen om robuuste en duurzame ‘last mile’-netwerken op te bouwen om SFs te bereiken; en marktconnectie om de commerciële levensvatbaarheid van SFs te vergroten en de adoptie van technologie te bevorderen. Ten slotte sluit ik mijn proefschrift af met een bespreking van de implicaties van mijn bevindingen en voorgestelde strategieën voor verschillende actoren die betrokken zijn bij de adoptie van technologie door SF: onderzoekers, technologieontwikkelaars, praktijkmensen en beleidsmakers.

Resumen

En tiempos recientes ha surgido la creciente necesidad de que la agricultura sostenible incremente la seguridad alimentaria, alivie la pobreza y contribuya a la mitigación del cambio climático. Los pequeños agricultores (Smallholder Farmers en inglés, de ahí la abreviatura SFs en este texto), al constituir un segmento significativo de la población agrícola mundial, desempeñan un papel fundamental en este esfuerzo global. Pese a su importancia, los SFs enfrentan múltiples desafíos que limitan su productividad y ponen en riesgo sus medios de subsistencia. Entre los desafíos más destacados se encuentran el acceso limitado a recursos (financieros) y tecnología, insuficientes conocimientos y capacitación, acceso limitado a los mercados, y vulnerabilidad al cambio climático. Las inequidades sociales y de género, la inseguridad en la tenencia de la tierra, el subdesarrollo de las cadenas de abastecimiento, y la falta de políticas públicas favorables exacerban aún más estos desafíos.

Diversas innovaciones pueden ayudar a los SFs en la transformación de los sistemas agrícolas y la consecución de varios objetivos de desarrollo sostenible. Estas innovaciones pueden ser nuevas tecnologías, nuevas prácticas agrícolas, empoderamiento social y colectivo, y cambios sistémicos a nivel de políticas públicas y regulaciones. En este contexto, y en respuesta a la acuciante necesidad del desarrollo socioeconómico de los SFs, la empresa neerlandesa aQysta ha desarrollado un dispositivo de bombeo hidráulico hidro-propulsado, conocido como bomba Barsha (Barsha pump en inglés, de ahí la abreviatura BP en este texto). aQysta ofrece esta tecnología como una solución innovadora y sostenible a las necesidades de riego agrícola de los SFs. La BP opera únicamente con energía renovable, lo que significa que no requiere de combustibles fósiles para operarla. aQysta sostiene que estas características hacen de la BP una solución de riego asequible y ambientalmente amigable, con el potencial de mejorar la calidad de vida de los SFs. En consonancia con tales afirmaciones, la BP supone un avance tecnológico promisorio y bien alineado con el desarrollo sostenible de los sistemas agrícolas de SFs.

Las empresas proveedoras de tecnologías suelen emplear modelos de negocio como instrumentos estratégicos para crear, ofrecer, y capturar valor. Este ha sido en gran medida el caso de aQysta y de la implementación de la BP en varias comunidades de SFs. Sin embargo, cuando se trata de innovaciones tecnológicas para SFs, los modelos de negocio tradicionales usualmente no alcanzan sus objetivos debido a los múltiples desafíos de los SFs. Al respecto, al

incorporar estrategias de inclusión social y gestión ambiental (además de la generación legítima de ganancias), los modelos de negocios sostenibles (Sustainable Business Models en inglés, de ahí la abreviatura SBMs en este texto) pueden ayudar de mejor manera a las empresas que, como aQysta, buscan servir a los SFs como potenciales clientes.

En ese sentido, al enfocarse en la propuesta tecnológica de aQysta, esta tesis investiga a) cómo las tecnologías agrícolas innovadoras satisfacen las necesidades de los SFs, b) cómo los SFs deciden adoptar dichas tecnologías agrícolas, y cómo los contextos de los SFs juegan un rol clave en esa decisión, y c) cómo los SBMs pueden ayudar a proveedores de tecnologías a ofrecer sus propuestas de valor a sus clientes SFs. A través de un enfoque interdisciplinario—con aspectos de ingeniería, emprendimiento, y desarrollo sostenible—este estudio procura elucidar la intrincada relación entre las tecnologías, los SBMs, y el impacto social para los SFs, a través de la siguiente pregunta principal de investigación:

¿Qué estrategias de modelos de negocio sostenibles estimulan la adopción de bombas hidro-propulsadas para el riego de pequeños agricultores?

Para responder a esta pregunta de investigación, recurrí a un enfoque de métodos mixtos de investigación aplicado a cinco estudios, que corresponden a los diferentes capítulos de esta tesis. Estos cinco estudios componen esta disertación al analizar la pregunta principal de investigación desde diferentes ángulos: tecnologías, método de investigación para estudiar a los SFs, la toma de decisiones de los agricultores, la adopción tecnológica de los SFs, y las estrategias de SBMs para satisfacer las necesidades de los SFs.

Comencé revisando la gama de tecnologías de bombeo hidro-propulsado disponibles a lo largo del tiempo (Capítulo 2). Para ello, realicé una revisión bibliográfica semisistemática de más de 800 documentos de literatura científica y gris. Estos documentos abordaron las historias fragmentadas de varias tecnologías, desde su conceptualización y diseño hasta su eventual producción (en masa) y comercialización a nivel mundial. Clasifiqué y ubiqué un total de 30 tecnologías de bombeo en espacio y tiempo. Algunos grupos notables surgieron en regiones como Europa, el sur y sudeste de Asia y África oriental, alrededor del periodo 1960 – 1990. Algunas de las tecnologías estudiadas tuvieron un impacto global hasta tiempos contemporáneos, otras han sido claves en países en particular, y otras tuvieron una vida casi imperceptible. Encontré que las tecnologías de bombeo hidro-propulsado gozan actualmente de buen interés y, por lo tanto, un futuro posiblemente prometedor. Sin embargo, fabricantes y usuarios deben estar conscientes de la importancia que los sistemas de gestión suponen para estas tecnologías más allá de su mero funcionamiento.

Posteriormente, analicé el potencial de la metodología Q (en adelante, Q) como un sólido método de investigación participativa para comprender los fenómenos relativos a SFs (Capítulo 3). Para alcanzar el objetivo de este estudio, seleccioné y revisé 50 investigaciones Q aplicadas a diferentes formas de medios de subsistencia rurales en el Sur Global. En este capítulo, primero analizo varias limitaciones de Q en su fase de campo, asociadas con restricciones físicas, logísticas, sociales y culturales en tales entornos. Posteriormente, extraje buenas prácticas y estrategias en la implementación de Q para hacer frente a esas limitaciones. Más allá de las limitaciones y estrategias, en la parte concluyente abogo por el desarrollo de capacidades Q y el empoderamiento con enfoque de género de investigadores locales en el Sur Global. Estas intervenciones pueden contribuir a una mejor comprensión de los matices y desafíos de los medios de subsistencia de SFs en sus respectivos contextos.

A través de un estudio en coautoría, posteriormente investigué las estrategias de decisiones de los agricultores a través de la lente de Q (Capítulo 4). Empleamos Q para estudiar la toma de decisiones de agricultores en Malaui para adoptar tecnologías de transporte de agua para el riego agrícola. El método se administró presencialmente a varios SFs, agricultores comerciales, representantes de cooperativas de agricultores, y expertos en sistemas agrícolas en Malaui. Descubrimos que los SFs, normalmente considerados un grupo homogéneo, no decidían de la misma forma. De hecho, algunos SFs presentan pensamientos progresistas y comerciales que pueden verse impedidos por la falta de acceso a los recursos necesarios. Además, nuestros resultados evidenciaron que la toma de decisiones tiene una clara dimensión de género. Encontramos que Q es una metodología sólida, capaz de capturar varios matices de las estrategias de toma de decisiones de los agricultores.

En lo posterior, me centré en la decisión (o no) de los SFs de adoptar la BP en los contextos de uso previstos por el fabricante (Capítulo 5). Por medio de Q, exploré los discursos interculturales en torno a la adopción de la BP. Administré Q a 43 participantes, agricultores y no agricultores, vinculados a los sistemas de SFs de Nepal e Indonesia. Identifiqué tres discursos relevantes, uno de ellos de naturaleza bipolar. El primer discurso personifica a los usuarios pioneros de la BP. El segundo discurso encarna el SF estereotípicamente muy dependiente de ayuda externa. El último caracteriza ópticas contrapuestas sobre la BP como facilitador de modelos de negocios basados en servicios para generar bienestar. Estos resultados reflejan la necesidad de un cambio de paradigma hacia nuevas formas de entender el cambio tecnológico de SFs. Sobre la base de mis resultados, propuse posibles vías de adopción tecnológica que contribuyan a la exploración de modelos de negocios innovadores para atender más satisfactoriamente a la diversidad de SFs.

Por último, realicé un estudio sobre estrategias de SBMs para satisfacer más efectivamente las necesidades específicas de los SFs (Capítulo 6). Utilicé un análisis de casos múltiples para ampliar el conocimiento sobre esta incipiente área de investigación. Para este análisis, consideré los casos de 10 organizaciones que ofrecen productos y/o servicios orientados a SFs. Ejecuté la etapa de análisis cruzado en cinco áreas temáticas relevantes para los desafíos de SFs: información y conocimiento, capital y servicios financieros, capacitación y desarrollo de capacidades, logística rural y cadenas de suministro, y conexión con mercados. Basándome en los resultados de los análisis, extraje lecciones que contribuyen a robustecer la propuesta de valor de la BP de aQysta (y empresas similares). Así mismo, profundicé en las implicaciones que este estudio supone para otras organizaciones que mantienen relaciones comerciales con SFs.

Basado en los resultados de estos cinco estudios individuales, identifiqué estrategias de SBMs para estimular la adopción de bombas hidro-propulsadas para riego de SFs. Estas estrategias las presento en la sección final de esta tesis (Capítulo 7) según las cinco áreas temáticas de SBMs (identificadas en el Capítulo 6) para cada uno de los cuatro discursos sobre la adopción de la BP (estudiados en el Capítulo 5). Las estrategias propuestas cubren cuestiones de los SFs relacionadas con: contenidos de información y canales de distribución; provisión de capital y servicios financieros; enfoques para impartir capacitación y desarrollar capacidades de los SFs; enfoques para redes sostenibles de entrega de última milla para SFs; y conexión con mercados para fomentar la viabilidad comercial de SFs y su capacidad de adopción tecnológica. Finalmente, concluyo mi tesis doctoral analizando las implicaciones de resultados y estrategias propuestas para diferentes actores involucrados en la adopción tecnológica de SFs: investigadores, desarrolladores de tecnología, profesionales, y formuladores de políticas públicas.

Chapter 1
Introduction

There has been a growing recognition of the need for sustainable agriculture to increase food security and mitigate climate change (Benkeblia, 2022). Smallholder farmers (SFs), who constitute a substantial portion of the global farming population (Lowder et al., 2021), play a key role in this endeavor (Fan and Rue, 2020; Giordano et al., 2019). Despite that relevance, SFs still face several challenges in accessing and securing sustainable irrigation systems, hindering their productivity and livelihoods (Giordano et al., 2019).

Responding to this pressing issue, the Dutch company aQysta developed a hydro-powered water lifting device, known as the Barsha pump (BP) (Intriago Zambrano et al., 2019). aQysta offers the BP as an innovative and sustainable solution to the irrigation challenges of SFs (aQysta, 2022, 2017). The BP operates solely on renewable energy (RE); it harnesses the power of flowing water to drive its pressure-building mechanism (Intriago Zambrano et al., 2019). This reliance on hydropower means that no input of fossil fuels is required to use the BP. The pump, therefore, operates without emitting greenhouse gases and at virtually zero running cost. Based on these features, aQysta argues that the BP is both an environmentally sound and affordable irrigation solution, with the potential of improving the livelihoods of SFs (aQysta, 2022, 2017). In line with those claims, the BP represents a promising technological advancement that aligns well with the global agenda for sustainable development.

This doctoral research has been conducted at Delft University of Technology, an academic institution known for its expertise in understanding technologies and their implications for societal advancements. In this respect, by focusing on aQysta's technology proposition, this dissertation investigates: a) how innovative agricultural technologies (intend to) cater for the needs of SFs and why oftentimes those technologies fall short in their propositions; b) how SFs decide to adopt (or not) such innovative agricultural technologies, and how SFs' contexts play a vital role in that decision; and, c) how adequately designed business models can become an effective bridge between companies' technology propositions and their target SFs. Through an interdisciplinary approach—with aspects of engineering, entrepreneurship, and sustainable development—this study aims to shed light on the intricate relationship between technology, sustainable business models (SBMs), and social impact.

Figure 1.1 depicts the relationships and interactions between the company (through its technology/product), its business model structure, and the target SFs. Companies (e.g., aQysta) may develop a single technology or product (e.g., BP) to meet certain needs of their target SFs (e.g., irrigation). Delivering a single product through traditional business models has proven to be ineffective in creating value for and capturing value from SFs (Groot et al., 2019; Long et al., 2017; Voutier, 2020). These business structures are typically unable to cope with the SF's multidimensional challenges in adopting new technologies. Among these challenges are unaffordable upfront costs of the device, no access to information and extension, limited trialability, lack of knowledge on operation and maintenance, lack of spare parts and servicing, and low return of investments due to limited market access (Bisheko and G, 2023; FAO and IPA, 2023; Kuhl, 2020; Smidt and Jokonya, 2022). By deciding not to adopt the product, neither the SF reaps the benefits that the technology promises, nor does the company generate the expected revenues.

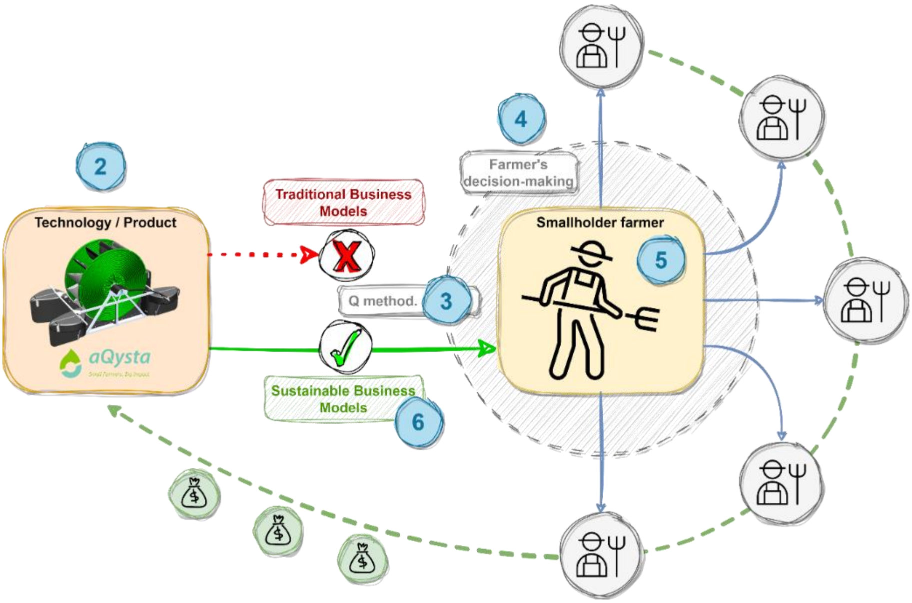

Figure 1.1. Schematic representation of the deployment and adoption of technologies among smallholder farmers.

In contrast, as **Figure 1.1** represents, SBMs can be more effective than traditional business models in delivering technologies to SFs (Amoussohoui et al., 2022; Danse et al., 2020; Gebeyehu, 2023). SBMs deliver higher value propositions by operating with complex ecosystems of partners, products, and services. For example, the initially unaffordable product can be made affordable by working with a financial institution that provides micro-credits to SFs. A local entrepreneur can provide SFs with the required spare parts and servicing for the proposed technology. In addition, an off-taker company can provide a guaranteed market to SFs through forward contracts. The participation of these other actors makes investing in the product a more attractive choice for SFs. To this purpose, the company must understand SFs' needs and decision-making considerations to tailor its SBM strategy accordingly. Once SFs decide to adopt the proposed technology, they may become agents of change in their communities by stimulating other SFs to make similar choices (i.e., to adopt the same technologies and/or practices) (right side of **Figure 1.1**). This enhanced technology diffusion means that more SFs benefit from the technology, while the company generates more margins from its SBM structure.

To accomplish the goal of this dissertation, I (co-)authored five studies, which correspond to different chapters of the thesis. This introductory chapter defines the general scope of the thesis and the structure of each of the following sections. It also presents the roles that different elements have in the transition towards a more sustainable agriculture; these elements, as depicted in **Figure 1.1**, are innovations, technologies, SFs (and their decision-making), and SBMs. In **Chapter 2** (**Figure 1.1**, encircled number 2), I provide a spatiotemporal review of the hydro-powered water pumps that were developed over time. In this chapter I explore the conditions behind their success or failure, and how these conditions influenced their adoption in different contexts of use. In **Chapter 3** (**Figure 1.1**, encircled number 3), I investigate the potential of Q methodology to understand SFs' viewpoints on adoption of innovations. This chapter also presents challenges and best practices for deploying this technique in low-resource rural settings. In **Chapter 4** (**Figure 1.1**, encircled number 4), as second author of the respective study, I co-explore farmers' decision-making strategies. I resort to Q methodology to analyze farmers' discourses to adopt (or not) certain water pumping technologies for irrigation. In **Chapter 5** (**Figure 1.1**, encircled number 5), I research SFs' viewpoints on the adoption of the BP. I use Q methodology with SF communities in Nepal and Indonesia as contexts of use for aQysta's BP. In **Chapter 6** (**Figure 1.1**, encircled number 6), I present a comparative analysis of SBM strategies to deliver products and services to SFs. This analysis can inform aQysta (and other similar companies) in their endeavors to enrich their value proposition to SFs. Ultimately, in **Chapter 7**, I discuss the findings of precedent chapters and offer concluding remarks related to the implications for relevant stakeholders. The findings of this study contribute mainly to the academic debate on the deployment and adoption process of sustainable agricultural technologies. My findings also provide suggestions for actionable insights for policymakers, practitioners, and the broader agricultural community. Ultimately, this research aspires to contribute to the transition towards more environmentally sound and commercially viable solutions for SF farming, empowering SFs, and paving the way for a more sustainable future in the agricultural sector.

1.1 The role of innovations in smallholder farming systems

SFs are vital contributors to global efforts to eradicate poverty and hunger (Fan and Rue, 2020). With the world's population projected to reach 9.7 billion by 2050 (United Nations, 2023), intensifying SF systems becomes imperative to meet the growing food demand (Fan and Rue, 2020; van Dijk et al., 2021). Moreover, in light of the challenges of climate change, environmental degradation, and limited resources, agricultural intensification must be achieved in a sustainable manner (Öborn et al., 2017). Sustainable intensification goes beyond merely increasing productivity. It focuses on achieving higher yields while minimizing negative environmental impacts and ensuring social and economic equity (Öborn et al., 2017). Innovations of different kinds are cornerstones in transforming agricultural systems towards those synergetic goals. Based on the research of different authors (Akanmu et al., 2023; Birhanu et al., 2023; Mungai et al., 2016; Öborn et al., 2017; Smith et al., 2017; Tufa et al., 2023), it can be observed that those agricultural innovations can take place at different levels, from smaller to larger scales: technology level, farm level, social level, and systemic level.

Innovations at the technology level are the most specific and tangible ones. They usually emerge in the form of improved inputs (Mungai et al., 2016), improved breeding (Marinus et al., 2023), and (digital) technologies and devices (Birhanu et al., 2023). For instance, the adoption of improved seed varieties can significantly enhance crop yields while resisting climate change effects (Cacho et al., 2020). Precision farming technologies (e.g., soil sensors, drones, and remote sensing) enable targeted and optimized management of resources such as water, fertilizers, and pesticides (Mizik, 2023). Innovations in livestock management, such as improved animal genetics, can enhance productivity while reducing environmental impacts (Mutenje et al., 2020).

At the farm level, innovations are beyond the use (or not) of specific devices or inputs. These innovations include different practices and (re)learning new farming procedures. Conservation agriculture, for example, promotes minimum soil disturbance, crop diversification, and soil cover, thereby reducing erosion and improving soil health (Tufa et al., 2023). Agroforestry systems, integrating trees with crops or livestock, enhance ecosystem services, such as nutrient cycling and carbon sequestration, while providing SFs with additional income streams (Duffy et al., 2021). Integrated pest management and organic farming practices reduce reliance on synthetic inputs and promote ecological balance within the farming system (Akanmu et al., 2023).

Innovations at the social level tackle issues related to access, knowledge, and empowerment of SFs. Farmer cooperatives and collective action facilitate access to inputs, credit, and markets, enabling smallholders to negotiate better prices and overcome market barriers (Ahmed and Mesfin, 2017; Miroro et al., 2023; Ofori et al., 2019). Capacity-building programs, farmer field schools, and knowledge-sharing platforms enhance farmers' skills and understanding of sustainable practices and technologies (Nakano et al., 2018; Pratiwi and Suzuki, 2020; Stewart et al., 2015). Interventions to empower women and marginalized SFs promote inclusive and equitable agricultural development (Adegbite and Machethe, 2020; Akter et al., 2017; Polar et al., 2017).

Innovations at the systemic level include changes in policies, institutions, and governance structures to create an enabling environment for the sustainable intensification of agriculture to take place. For example, public-private partnerships, value chain coordination, and supportive policies can foster diffusion of other innovations, technology transfer, and market access for SFs (Haughey et al., 2023; Mwamakamba et al., 2017). The integration of sustainable approaches (e.g., climate-smart farming and ecosystem-based services) into agricultural policies has the potential to promote higher value, resilience, and sustainability in SF systems (Haughey et al., 2023; Makate, 2019a).

In the context of this doctoral research, the innovation (i.e., the BP) is placed at the technology level (**Figure 1.1**). This means that aQysta, as the manufacturer of the technology, delivers a single physical device to its target SFs, aiming to meet their irrigation needs. Even though the BP acts at the smallest scale of innovation, the SFs' decision to adopt technologies (or not) is neither straightforward nor easily predictable (Glover et al., 2019; Llewellyn and Brown, 2020; Montes de Oca Munguia and Llewellyn, 2020; Yigezu et al., 2018). A SF's decision to adopt the BP is contingent on intrinsic factors (e.g., purchasing power, farm characteristics, level of education and expertise), as well as exogenous ones that pertain to the (broader) context (e.g., applicability of the technology, market access, enabling environment, regulatory environment, etc.). This decision-making process is explored in depth in Chapter 4 and Chapter 5.

1.2 The role of renewable energy technologies in sustainable smallholder farming

Technologies are increasingly recognized as sources of innovation that can support the intensification of SF systems (Adams and Jumpah, 2021; Majeed et al., 2023). Since food and energy systems are deeply intertwined, RE technologies (RETs) hold significant potential for sustainable SF systems transformation (IRENA and FAO, 2021). RETs such as solar panels, water turbines, wind turbines, and biogas digesters, offer viable alternatives to conventional energy sources in SF systems (Agwu et al., 2023; IRENA and FAO, 2021; Lefore et al., 2021; Muteba et al., 2023; Schoeber et al., 2021). Moreover, by embedding these technologies into farm-level productive processes (e.g., milling, threshing, drying, irrigating, etc.), RETs have the potential to increase productivity, improve livelihoods, reduce environmental impact, and enhance the resilience of SFs (IRENA and FAO, 2021).

Adopting RETs can offer a number of advantages to SFs. Firstly, RETs enable greater energy independence for SFs. With reliable access to off-the-grid energy, farmers can power irrigation systems, mechanize farm operations, and utilize post-harvest processing equipment (Falchetta et al., 2022; IRENA and FAO, 2021). This increased access to alternative energy sources enhances SF productivity, reduces labor-intensive practices, and allows for greater value addition to their agricultural produce (Falchetta et al., 2022; IRENA and FAO, 2021). Secondly, RETs enable SFs to reap financial improvements and savings. By cutting the reliance on volatile and cost-intensive fossil fuels, SFs can redirect their financial capacities toward other productive investments (IRENA and FAO, 2021). These investments may include improving infrastructure, acquisition of better equipment, purchasing improved inputs, or accessing training and capacity building programs. Lastly, RETs provide SFs with access to clean and sustainable energy sources, thereby reducing the carbon footprints of farming activities (IRENA and FAO, 2021; Majeed et al., 2023).

Despite RETs' numerous advantages, SFs face several challenges in the effective adoption of these technologies. To begin with, the high upfront costs associated with RET systems pose a significant financial barrier for SFs with limited capital (IRENA and FAO, 2021; Rahman et al., 2022). Access to (public) affordable financing options and financial incentives becomes crucial to facilitate RET adoption (Rahman et al., 2022). Furthermore, limited awareness, technical knowledge and skills among SFs hinder the successful implementation and maintenance of RETs (IRENA and FAO, 2021; Rahman et al., 2022). Effective technical support, capacity building programs, and extension services are essential for SFs to bridge this gap (Nakano et al., 2018; Rahman et al., 2022). Lastly, varying availability and reliability of RE sources (i.e., sunlight, wind, water bodies) may limit the applicability of RETs in certain regions (Rahman et al., 2022). SFs located in areas with limited or inconsistent RE sources may face additional hindrances in fully benefiting from RETs. In response, customized RETs tailored to local RE conditions can be developed; however, this might result in even bigger and more unaffordable upfront costs for SFs.

Within this dissertation, the RET proposition of aQysta is the BP (**Figure 1.1**, left side). This device emerges through a regained momentum of hydro-powered pumping devices (explored further in Chapter 2). The BP is intended to serve SFs whose farmlands are in the proximity of flowing water bodies (i.e., rivers, canals), yet without access to pressurized irrigation. Moved only by the power of flowing water, the BP is alleged to offer pressurized irrigation adequate for SF production. Moreover, the BP would enable day-long irrigation, thereby not facing the limitations of other RETs (e.g., solar pumps that depend on solar radiation periods to operate). However, a limitation of the BP is its dependence on the proximity to rivers or canals. Although there are geographies with such prevalent topographic characteristics (e.g., mid-hills Nepal and Sumba Island, addressed in Chapter 5 and Chapter 6, respectively), several other regions worldwide would not comply with this site condition.

1.3 The role of smallholder farmers in sustainable development

SFs play a pivotal role in the accomplishment of sustainable development goals (SDGs), particularly in eradicating poverty (SDG 1) and hunger (SDG 2) (Fan and Rue, 2020; Giordano et al., 2019). On the first goal, small-scale agriculture is the primary source of livelihood for two to three billion rural people around the world (Diao et al., 2023). SFs thus contribute to poverty reduction by providing subsistence means in marginalized rural areas, where poverty and inequality are most severe (FAO, 2015; Mupaso et al., 2023). SFs can also aid in reducing poverty by increasing productivity and diversifying their income sources. Attaining these increases may involve SFs adopting sustainable farming practices, accessing improved markets for their products, and/or expanding into other non-farm activities. Through these strategies, SFs can increase their incomes, lower their vulnerability to poverty, and create more resilient livelihoods. Therefore, investing in and supporting SFs has a strong potential in alleviating poverty and promoting economic growth in their respective regions (Giordano et al., 2019). On the second goal, SFs are main contributors to regional and global food security (Fan and Rue, 2020; Lowder et al., 2021). About 600 million SFs worldwide produce one-third of the world's food supply (Lowder et al., 2021), and up to 80% in Asia and sub-Saharan Africa (Fan and Rue, 2020). SFs are also known to grow diverse crops, improving the resilience of local food systems and dietary diversity (Fan and Rue, 2020; Giordano et al., 2019). Moreover, by resorting to improved production means, SFs can contribute to reducing food waste, increasing the efficiency of value chains, and boosting food accessibility and affordability (Gomez y Paloma et al., 2020). At the same time, SFs' contributions extend beyond fighting against poverty and hunger. SFs bear knowledge that can support soil fertility, enhance water management, and minimize the use of synthetic inputs (Makate, 2019b). SFs contribute to rural development by creating employment opportunities, fostering community resilience, and preserving agricultural heritage (Fan and Rue, 2020; Giordano et al., 2019). Through their farming practices, SFs have become custodians of natural resources, maintaining local agrobiodiversity and protecting local ecosystems (Kozicka et al., 2020; Mburu et al., 2016).

Despite their cornerstone role, SFs face numerous challenges that hinder their potential, and thus their ability, to contribute fully to sustainable development (Fan and Rue, 2020; Giordano et al., 2019; Wiggins, 2020). Limited access to resources and technology, including high-quality seeds, fertilizers, pesticides, and modern machinery, restricts SFs' ability to engage in more productive practices (Langyintuo, 2020). Insufficient knowledge and training in modern agricultural techniques and climate-smart practices further impede their productivity (Wale and Mkuna, 2023). SFs often struggle with inadequate access to credit and financial services, hindering their capacity to invest in agricultural inputs and infrastructure (Langyintuo, 2020; Rahman and Smolak, 2014; Wiggins, 2020). Limited market access, characterized by lack of information, poor infrastructure, and unfair trade practices, poses significant barriers to SFs in selling their production at fair prices (Poole, 2017). In addition, SFs are vulnerable to the impacts of climate change, which disrupt their traditional production cycles and increase the risk of crop failures (Williams et al., 2018). Social and gender inequalities (Nchanji et al., 2020), land tenure insecurity (Murken and Gornott, 2022), underdevelopment of supply chains (Wiggins, 2020), and lack of supportive policies and institutional frameworks (Fan and Rue, 2020) further exacerbate these challenges.

Notwithstanding the abovementioned challenges, SFs can seize several opportunities to enhance their livelihoods and contribute to sustainable development (Odero-Waitituh, 2021). First, the increasing demand for sustainably produced food offers market opportunities for SFs who adopt environmentally sound and socially responsible practices (The World Bank Group, 2019). Certification schemes and fair-trade initiatives provide platforms for SFs to access higher-value markets and improve their income (Meemken, 2020; The World Bank Group, 2019). Second, empowering SFs through capacity building programs, farmer cooperatives, and inclusive governance structures can enhance their voice and agency in decision-making processes (Abdul-Rahaman and Abdulai, 2020; FAO, 2015; Ma and Abdulai, 2017; Marinus et al., 2021). By strengthening social networks and fostering collective action, SFs can address common challenges, advocate for their rights, and access resources and services more effectively (Abdul-Rahaman and Abdulai, 2020; Miroro et al., 2023). Furthermore, technological innovations present opportunities for SFs to enhance productivity (Cacho et al., 2020;

Mwamakamba et al., 2017), reduce post-harvest losses (Bisheko and G, 2023), and adopt climate-smart agricultural practices (Makate, 2019a; Yigezu et al., 2018). Access to appropriate technologies (e.g., RET systems, precision tools, climate-resilient varieties, etc.) has the potential to improve SFs' efficiency, sustainability, and commercial viability.

The SFs addressed in this doctoral research (**Figure 1.1**, right side) meet several sociodemographic characteristics. First, they are (partially) subsistence farmers, so they do not have an exclusive commercial orientation. Second, they do not have access to any market beyond the informal sales of produce in local marketplaces. Third, they represent diverse typologies of SFs: women and men, individual farmers and (in)formally organized groups, youth and experienced farmers, and different farmland conditions (captured in the contexts of use that were studied). Lastly, they are (former) users of the BP, which ensures their farms meet the technical conditions required by the technology. The characteristics of the SFs in this thesis are explored in depth in Chapter 5.

1.4 The role of sustainable business models in smallholder farming

Companies engaging with SFs may encounter difficulties rooted in the unique characteristics and needs of this target segment. SFs often experience income instability, making them less attractive to traditional businesses (Klauser and Robinson, 2020; Poole, 2017). Credit constraints, limited financial literacy, cultural differences, and geographical dispersion further complicate interactions with SFs (IDH Farmfit, 2019; Oostendorp et al., 2019). Additionally, SFs may lack the capacity to adopt best practices in agriculture and post-harvest handling, hindering formal commercial relationships with agribusinesses and off-takers (Chamberlain and Anseeuw, 2019). Lastly, SF's climate vulnerability poses high risks to production targets, possibly discouraging companies from closing forward supply deals with them. In this respect, SBMs emerge as a promising sound pathway to overcome those challenges, facilitate adoption of innovations, and deliver higher value to SFs. By aligning economic, social, and environmental objectives, these models can create value for all stakeholders involved (Dembek et al., 2018; Geissdoerfer et al., 2018; Schoneveld, 2020).

Business models serve as strategic blueprints that outline how companies and organizations create, deliver, and capture value (Osterwalder and Pigneur, 2010). These models have traditionally focused on revenue generation, but more recently concerns on social inequality and environmental degradation have prompted a shift towards the revamped concept of SBMs (Geissdoerfer et al., 2018). SBMs incorporate social inclusion and environmental stewardship alongside profit generation. This holistic approach to business operations acknowledges the importance of creating long-term value beyond mere financial gains (Geissdoerfer et al., 2018). Some examples of successful SBMs are those of bank-less mobile payment systems (M-Pesa, Paytm, Orange money), circular economy models (e.g., Patagonia, Interface), sharing economy models (e.g., Airbnb, Uber), social enterprises (e.g., TOMS shoes), and farm-to-table models (e.g., Riverford Organic Farmers).

Companies aligning their SBMs with the needs of SFs can substantially support them in their overall uplift. Through the alignment of economic, social, and environmental objectives, SBMs can unlock the potential of agricultural innovations to enhance SF productivity. First, by providing access to holistic packages of products and services, companies ensure that SFs implement integral solutions to their multifaceted issues (Adjogatse and Saab, 2022). These packages may include products like affordable and high-quality agricultural inputs (i.e., planting material, fertilizers, and pesticides), and access and use of mechanization, RETs and precision tools (Adjogatse and Saab, 2022; Bolwig et al., 2020; Fan and Rue, 2020; Gebeyehu, 2023; Klauser and Robinson, 2020). Holistic packages typically incorporate extension services, which equip SFs with the necessary skills to adopt agricultural innovations effectively (Nakano et al., 2018; Pratiwi and Suzuki, 2020). Training sessions can cover topics like modern farming techniques, climate-smart practices, sustainable land management, post-harvest handling, and marketing strategies. Furthermore, SBM strategies may offer platforms and networks where farmers can learn from each other, share best practices, and collectively address challenges (Ahmed and Mesfin, 2017; Marinus et al., 2021; Nakano et al., 2018; Ofori et al., 2019).

Second, through their SBMs, companies can also provide SFs with enhanced financial support and market opportunities. By partnering with financial service providers, companies offer access to affordable credit, microloans, and insurance products tailored to SF's needs (Klauser and Robinson, 2020; Langyintuo, 2020). This increased capital availability allows SFs to invest in agricultural innovations without being burdened by high upfront costs (Klauser and Robinson, 2020). Properly designed SBMs also create market linkages, connecting SFs to fair and transparent markets, both locally and globally (Borrella et al., 2015; Doherty and Kittipanya-Ngam, 2021; Magesa et al., 2020; Poole, 2017; Ume, 2023). These linkages improve SFs' access to profitable opportunities and may further incentivize the adoption of innovations driven by market demands (e.g., climate-smart practices, agroforestry, etc.). Moreover, SBMs' environmental and social priorities may become an additional incentive for SFs to engage in premium sustainable markets.

Thirdly, by incorporating context-sensitive strategies in their SBMs, companies can close the last-mile delivery gap typically affecting SFs

(Hernández and Blackburn, 2022; IFPRI, 2019). These gaps in the last mile emerge as poor or inadequate infrastructure (i.e., roads, railroads, storage facilities), farm remoteness, and/or geographical dispersion. Last mile gaps prevent SFs from timely accessing required products and services, while posing costlier and more complex logistics for potential buyers of their produce. SBM strategies to close last-mile gaps include partnerships with farmer groups and cooperatives (Ofori et al., 2019), intermediations through community leaders (Nakano et al., 2018), and commissioned village-based agents (IFPRI, 2019).

As shown in **Figure 1.1**, the business model is the vehicle by which the company (i.e., aQysta) delivers the technology (i.e., the BP) to its target SFs and generates profit. In this dissertation, I analyze how aQysta's traditional business model to deliver the BP faces several challenges in meeting the needs of its SF customers. As such, SFs likely see no options to adopt the technology, the impact of the BP is not delivered or replicated, and the expected profit generation in reality is limited. At the same time, I investigate how innovative SBM strategies can enrich aQysta's technology proposition, cater better for SFs' needs, and promote financial sustainability for the actors involved.

1.5 The role of farmers' decision-making over technology adoption

SFs encounter difficult choices as they pursue multiple objectives in their personal, household, and societal domains (Adolph et al., 2021). Important decisions at farm level typically include the adoption and management of technologies, the optimal use of (scarce) resources of all kinds, the management of labor, the acquisition of knowledge and information, and strategic farming choices (i.e., changes of their farming systems). Moreover, the competing nature of some of those objectives (e.g., investing in more mechanization for the farm or saving for possible household emergencies) leads SFs to deal frequently with trade-offs (Adolph et al., 2021). Amidst this complex decision-making process, the SF's decision to adopt certain technologies is a key factor to unlock the potential impact of that innovation. As shown in **Figure 1.1** (right side), once an SF decides to take up and use the proposed technology, he/she becomes an agent of change that may encourage the same decision among peers. The diffusion of the proposed technology thus might have an impact on SFs and generate more margins for the provider company.

To further investigate that decision-making process, we (myself as second author) studied the strategies of Malawian farmers on the adoption (or not) of water transport technologies for irrigation (van Dijk et al., 2022). Our study showed that farmer's decision-making is much more complex than traditional policymaking suggests. Extension services and agricultural development programs are typically based on farm size as a proxy to segment farmers. However, our findings indicated that farmers' choices involve many more intertwined variables when adopting a water transport technology. Policymakers and technology developers should consider the farmers' diverse preferences beyond their farm size and traditional labels of 'smallholder' or 'commercial' farmer. In addition, our study also revealed a gender dimension in decision-making, suggesting that female farmers may have different investment priorities focused on time-saving technologies.

Our study also underscored the significance of participatory approaches in understanding and addressing farmer constraints and preferences. In this respect, Q methodology proved a valuable tool for capturing the nuances of decision-making processes, and informing policy and technology development. By tailoring strategies to specific farmer types (beyond simplistic farm size segmentation), policymakers and development organizations can support technology adoption and agricultural development more effectively.

In relation to this specific study in Malawi (addressed in full in Chapter 4), the present dissertation has focused on understanding the different nuances of SF's decision-making. To that end, first I investigated the suitability of Q methodology as a participatory method to understand viewpoints of rural communities (presented in depth in Chapter 3). Later, I implemented it to capture the discourses of Nepali and Indonesian SF communities on the adoption of the BP (addressed in Chapter 5). On the basis of a proper understanding of SF's decision-making, the respective context-sensitive SBM strategies could be tailored more accurately (Chapter 6).

1.6 Research questions

The main research question of this doctoral dissertation is centered on understanding the SBM strategies that must be considered to stimulate the adoption of agricultural innovations for SFs. Specifically, the study seeks to investigate how different SBM strategies enhance a technology proposition (with emphasis on aQysta's BP), from the mere delivery of a device to a more holistic and sustainable solution for SFs. Moreover, by examining the contextual conditions, barriers, and outcomes of the SF's adoption of the BP, this research provides insights into the strategic implications for other relevant stakeholders. In this respect, the main research question is as follows:

What sustainable business model strategies stimulate the adoption of hydro-powered pumps for smallholder irrigation?

To the end of answering the main research questions, this doctoral dissertation has addressed several specific research questions (SRQs) per chapter (**Table 1.1**), distributed as follows:

Table 1.1. List of chapters, SRQs, and used research methods.

Chapter	SRQ	Research methods
2	What hydro-powered water pumping technologies were used over time?	Literature review
3	Which participatory research method is suitable to study the viewpoints of smallholder farmers?	Literature review
4	How does Q methodology support the understanding of farmers' decision-making?	Q methodology; semi-structured interviews
5	What are the discourses of smallholder farmers on the adoption of the Barsha pump?	Cross-cultural research approach; Q methodology; semi-structured interviews
6	What sustainable business model strategies offer higher value propositions to smallholder farmers?	Qualitative multi-case comparative approach; field observations; (online) semi-structured interviews

To answer the SRQ of Chapter 2, I conducted a comprehensive literature review of more than 800 (non)scientific documents. These documents contributed to collecting and assembling the highly fragmented stories of several hydro-powered water pumping technologies that were developed over time. Lifting water by means of hydromechanical power is a relatively obscure and uncommon principle, where only few technologies stand out in a shallow search of literature (e.g., spiral pump, coil pump, hydraulic ram pump, Chinese water turbine-pump). However, a much deeper search, through several databases and keywords, yielded 30 hydro-powered water pumping technologies that I classified in eight different groups. The high number of processed documents allowed us to plot the technologies in space (by geography) and time (by period between first and last recorded appearance). The literature review revealed noticeable clusters of activity in regions of Europe, South-Southeast Asia, and Eastern Africa, in timeframes between 1960 and 1990. Some technologies gained widespread interest until contemporary times (e.g., hydraulic ram pump, spiral/coil pump), whereas other ones became cornerstones for the development of specific countries and regions during specific periods (e.g., the Chinese water turbine-pump in China, the Garman turbine in Sudan). In contrast, other technologies had almost unnoticeable or unreported lives (e.g., hydrautomat, Lambach pump, hydropulsor). Regardless of the fate of individual technologies, our findings show that hydro-powered pumps, as a whole, face a regained momentum in recent times. Despite this promising future, researchers and developers must embrace the importance that management systems and business structures have in guaranteeing the sustained use of these technologies.

I resorted to a second literature review to answer the SRQ of Chapter 3. Stakeholders relevant to agricultural development, like policymakers and technology developers, typically consider SFs a homogeneous group (i.e., with the same challenges, needs, and possible solutions). This oversimplified definition generally leads to ineffective poverty-alleviation interventions. In response to such a commonly narrow vision, through this literature review I studied the potential of Q methodology to understand better the SFs' viewpoints and nuances. Q methodology has become a powerful participatory technique with a strong potential to reveal previously unheard discourses, like those of socially disadvantages SFs. I chose and semi-systematically reviewed 50 studies where Q methodology was used to understand the viewpoints of rural livelihoods in the Global South (with emphasis on SFs). Our study evidenced that, despite its potential, Q methodology poses several on-field limitations linked to physical, logical, social, and cultural constraints. Based on these limitations, I discuss and propose good practices and methodological strategies that can render this technique more effective when studying social phenomena in low-resource rural settings.

Following the previous chapter, in Chapter 4 we (myself as second author) empirically investigated the potential of Q methodology to understand the decision-making of farmers about agricultural innovations. To that end, we focused on the decision of Malawian farmers to adopt several water lifting technologies to support agricultural irrigation. By administering a 34-statement set to 58 respondents (including SFs, commercial farmers, and experts as proxy respondents), we identified four unique discourses on the most important decision-making elements in adopting water lifting technologies. Factor 1 represents the farmer who favors high-flowrate and high-pressure technologies, even if it implies higher investment costs. Factor 2 embodies a farmer who prefers easy-to-use and cost-effective technologies while also paying attention to costs of production and possible revenues. Factor 3 encompasses a risk-averse farmer, who is much more comfortable with proven, familiar, and understandable technologies that fit their specific needs. Factor 4 represents the resource-constrained and dependent farmer, who prefers affordable technologies with low operational costs. As such, this farmer typology is more prone to pool resources in a group to facilitate the required investments. These four factors, as well as its clustering of respondents, showed that SFs are not a homogeneous group. SFs' decision-making may differ depending on their individual preferences and contextual conditions (i.e., some SFs are actually inclined to entrepreneurial and commercial choices). In addition, our findings show that female SFs focus on time-saving technologies, suggesting they may have other investment priorities than men. By recognizing and responding to this diversity, policymakers and development organizations can better support farmers in effectively adopting relevant and effective technologies.

Supported by the inputs of Chapter 3 and Chapter 4, in Chapter 5, I offer the results of a Q methodology study specifically focused on the SF adoption of the BP. For the purpose of this study, I resorted to SF communities in Nepal (mid-hill range) and Indonesia (Sumba Island) as contexts of use of the BP. Given the natural, social, and cultural differences of these two settings, I undertook a cross-cultural research approach to the implementation of Q methodology. By offering a 38-statement set to 54 participants, I collected 43 valid sorts. The statistical analyses of these responses revealed 3 unique viewpoints on the adoption of the BP, one of them bipolar in nature. Factor 1 represents the early adopter SF, who sees in the BP a labor-saving and life-improving technology, which performs better than other water pumping technologies. Factor 2 embodies the stereotypical image of the highly dependent SF who needs financial support to afford the BP. At the same time, this factor frowns upon the BP as a technology less useful for cash cropping than other available technologies. The positive factor 3 idealizes a SF that sees the BP as an enabler of irrigation services, but which needs the provision of other goods and services to enrich its technology proposition. In contrast, the negative factor 3 represents the relatively well-off SF, who cannot only bear a possibly high upfront cost of the BP, but who also has a strong sense of ownership towards it. These discourses reflect the need for a paradigm shift on our traditional understandings of technological change in SF settings. Our findings imply that technology providers must explore innovative business models to cater for the needs of different SF segments more effectively.

In Chapter 6, through a qualitative multi-case comparative approach, I explored SBM strategies by which companies can offer higher value propositions to their target SFs customers. As crucial actors in sustainable development (particularly in poverty reduction and hunger eradication), SFs have recently gained companies' attention as potential customers and suppliers. Nonetheless, (absence of) current literature shows that SFs are generally not considered commercially viable partners in such endeavors. In this regard, SBMs can bring opportunities for companies to increase margins while improving SFs' livelihoods and addressing environmental concerns. At the same time, there is still a limited understanding of how SBMs can support organizations in their commercial engagements with SFs. In this chapter I expand this understanding by analyzing 10 business structures of products and/or services tailored to SFs (including the BP provided to Nepali and Indonesian SFs). Moreover, by conducting a cross-case analysis, I extract SBM strategies through which companies can ensure an impactful engagement with SFs. These strategies are organized across five specific dimensions relevant to

SF's challenges: 1) information and knowledge, 2) capital and financial services, 3) training and capacity building, 4) rural logistics and supply chains, and 5) connection to markets. Based on these strategies, I draw lessons for aQysta (and similar companies) from the BP experience in Nepal and Indonesia. Lastly, I discuss more broadly the implications of the findings for other organizations involved in the development of SFs' livelihoods.

Finally, the Chapter 7 comprises two subsections: first, a summary of findings of chapters 2 – 6 , and second, the implications of those findings for different stakeholders. By summarizing the findings and answering the individual SRQs, the first subsection provides the answer to the main research question of this dissertation. That answer emerges in the form of proposed SBM strategies by which aQysta (and similar companies) can enrich their value proposition to stimulate the adoption of the BP (and similar technologies) among SFs. The second subsection provides recommendations and possible actions for researchers, technology developers, practitioners, and policymakers. The recommendations aim to articulate the efforts of these stakeholders, with the ultimate goal of creating an enabling environment that allows SFs to adopt the proposed technologies more effectively (among other products and services) and thus to benefit from their desired impact more fully.

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Chapter 2

Water Lifting Water: A Comprehensive Spatiotemporal Review on the Hydro-Powered Water Pumping Technologies

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Abstract

Water pumping systems driven by renewable energies are more environmentally sound and, at times, less expensive alternatives to electric- or diesel-based ones. From these, hydro-powered pumps have further advantages. Nevertheless, these seem to be largely ignored nowadays. More than 800 scientific and nonscientific documents contributed to assemble their fragmented storylines. A total of 30 pressure-based hydro-powered pumping technologies worldwide have been classified and plotted in space and time. Although these do not present identifiable patterns, some noticeable clusters appear in regions such as Europe, South–Southeast Asia, and Eastern Africa, and in timeframes around 1960–1990, respectively. Some technologies have had a global impact and interest from their beginnings until contemporary times, others have been crucial for the development of specific countries, and other ones barely had almost imperceptible lives. All of them, nonetheless, have demonstrated to be a sound alternative to conventional pumping technologies, which can be unaffordable or inaccessible, particularly in remote and off-the-grid areas. Currently, hydro-powered pumping technologies face a regained momentum, hence a potentially promising future. However, researchers, manufacturers, and users need to be aware of the importance that management systems, as well as business models, pose for these technologies beyond their mere performance.

Keywords: hydro-powered; water-powered; water-driven; hydro-mechanical; self-reliant; water lifting; water raising; water pump

2.1 Introduction

Given the considerable number of smallholders farms worldwide [1], intensification of their crop farming is key for local and global food security [2]. However, smallholders face many uncertainties linked to weather events, crops diseases, and market fluctuations. In addition, on-farm conditions are often suboptimal because of low availability of inputs and lack of control/information to decide on their use. Although access to water is not the only factor influencing farming, improving water control for small-scale farming is a major option to secure smallholder production [3]. Pressure-based irrigation technologies, either introduced as a new choice or as the result of former gravity-based systems converted into (water-saving) drip and sprinkler irrigation, are one option. Another option is to use pumping technologies to allow water delivery to fields that used to be otherwise unirrigated.

Pumped irrigation is ruled worldwide by electricity- and diesel-based systems. They bear high operation and maintenance costs because of continuous use of electricity from the grid and expensive fuels, respectively. As a consequence, these technologies might be eventually (too) cost-intensive for most smallholders—which makes them less accessible and/or suitable for small farmers. Furthermore, they are strongly linked to air pollution due to their gaseous emissions and noise [4,5]. More environmentally sound and, at times, less expensive alternatives would be pumping systems based on renewable energy (RE) sources, i.e., solar power, wind power, biomass/biogas, and hydropower [6].

Hydro-powered pumping (HPP) technologies, namely those driven by the energy contained in the water they lift, correspond to a concept as ancient as effective [7,8]. Non-direct lifting (i.e., pressure-based) HPP devices started being envisaged by Al-Jazari in the early 13th century [9], and later on by Taqi Al-Din [7,10], Agricola [11], Ramelli [12], and other authors [13] during the 16th century. These pumping systems pose further advantages over their other RE-based counterparts: (i) Their energy source is generally available 24 hours a day, seven days a week, relatively concentrated and more predictable; (ii) they have a higher power-to-size ratio, thus are more cost-effective; (iii) they are mechanically simpler and more robust, hence less maintenance-demanding and long-lasting; and (iv) they are typically more efficient (up to 85%) [14].

Nevertheless, and despite their advantages and long history in water lifting, HPP systems seem to be largely disregarded nowadays. On one hand, there are some contemporary studies [15–21] and literature reviews [4–6,22,23] on RE-based water pumping systems. However, none of them address hydropower as a sound source of energy. On the other hand, there are several old publications [14,24–31] that considered it to a bigger or lesser extent, though completely overlooking many other then-contemporary HPP technologies that were relevant—and, in some cases, even predominant—for other (non-Western) contexts. Therefore, and considering such knowledge fragmentation and consequent gap, this review constitutes the first worldwide-scale depiction of the past and present trends on the documented research, development, application, and commercialization of the HPP technologies. In turn, such information provides a general yet solid basis for scholars, (industry) researchers, managers, manufacturers, and users, with respect to the future uses these technologies (as well as new ones derived from them) might have under different sets of physical and social conditions.

It is so that two universities, namely Delft University of Technology and Comillas Pontifical University, from The Netherlands and Spain, respectively, are currently carrying out the DARE-TU (Developing Agriculture and Renewable Energy with the TUrbine pump) project. It aims to research the cocreation and implementation of affordable clean irrigation systems, based upon novel HPP technologies [32] developed in collaboration with the Dutch start-up company aQysta. Within this context, the objectives of the present article are:

1. To summarize and classify the HPP technologies researched, applied, and eventually commercialized globally over time;
2. To define their state-of-the-art by synthesizing their respective storylines and highlighting the highest level of their developments;
3. To identify global spatial and temporal patterns on the (re)invention, application, and spread of HPP technologies.

2.2 Methods

2.2.1 Selection Criteria for HPP Technologies

Relevant HPP technologies, within the context of the present review, fulfilled the following criteria:

1. Exclusively driven by the kinetic and/or potential energy of water;
2. Rely exclusively on hydro-mechanical energy, hence not relying whatsoever on electro/electrochemical conversion processes;
3. Work by building up pressure (i.e., must not be a direct lift technology);
4. Pose any form of actual or potential use for supplying water, preferably to agricultural activities and human consumption, thus must ensure a relatively constant and reliable flow. As a consequence, devices such as the superhydrophobic pump [33] were neglected;
5. Operate with the same (fresh) water to be supplied, therefore technologies such as ocean-driven turbines, firefighter ejector

turbo-pumps [34,35], water-driven foam pumps, or the hydraulic turbocharger™ [36] were not taken into account.

2.2.2 Sources of Information

To look for relevant data, the following literature and sources of information were considered:

1. Peer-reviewed literature, from online academic databases through Google Scholar search engine (https://scholar.google.com/) and Google Books digital library service (https://books.google.com/);
2. Peer-reviewed and grey literature (i.e., non-peer-reviewed), retrieved from online databases, accessed through Google search engine (https://www.google.com/);
3. Documents bibliographically referenced in the two previous sources (particularly old ones)—yet not indexed in the previous search engines—from different academic databases and libraries worldwide (through TU Delft library services);
4. Personal communication from other authors.

Initial search iterations made evident that, unlike other RE-based pumping technologies, there is a considerable lack of scientific literature regarding HPP. This was the main driver to expand the screening process toward grey literature, thereby filling information gaps that could not have been considered otherwise, hence increasing information bias [37]. Furthermore, a triangulation of sources/databases was performed (i.e., not using a single source), in order to overcome implicit accuracy limitations that the Google search engines pose regarding systematic reviews [38].

2.2.3 Literature Screening

2.2.3.1 Keywords and Terms

The complete set of keywords used in the search engines was gradually enlarged as the iterative search process took place. To produce more accurate results based on generic and broad terms, these were combined with the words "water", "irrigation", and "pump". In some iterations, terms were expressed as exact phrases by making use of quotation marks.

The final set of terms was: "hydro-powered", "water-powered", "water wheel", "water-driven", "turbine-driven", "hydro-mechanical", "hydraulic ram", "hydram", "impulse", "spiral", "coil", "manometric", "Wirtz", "Plata", "Chinese turbine-pump", "water-turbine", "sling", "HyPump", "Barsha", "no power", "self-powered", "self-propelled", "river-current turbine", "hydrokinetic turbine", "fuel-less", "powerless", "Glockemann", "High lifter", "pump as turbine", "Hydrobine", "PowerSpout PHP", "Filardo", "Markovic self-propelled", "zero-energy", "PAPA", "Garman turbine", "river turbine", "water-current turbine", "Tyson turbine", "Mangal turbine", "Bunyip", "Linear turbine", "Tuapeka turbine", "tidal turbine", "Cherepnov water lifter", "hydropulsor", "hydrautomat", and "pulser".

To ensure higher accuracy of results from the search engines, some words were intentionally and explicitly ruled out during the search. These terms were gradually set depending on the initial results of each iteration. For instance, searching only with the term "water-turbine pump" returned too many inaccurate results linked to a technology out of the scope of this paper. However, when excluding the terms "-vertical" and "-deep well", the accuracy eventually became higher. The ruled out terms were: "desalination", "solar", "vertical", "deep well", "wind", "sump", "ocean", "generator", and "coronary" (linked to the Filardo surname within the cardiology field).

Although the main screening of literature was conducted in English, it was necessary to perform iterations with terms in other languages to look for other HPP technologies otherwise absolutely overlooked. In Spanish: "*bomba de río*", "*río-bomba*", "*turbo bomba*", "*turbo bombeo*", "*bomba funcionando como turbina*", and "*ariete multipulsor*"; in Italian: *"elevatore idraulico*" and "*elevatore di Cigliano*"; in Portuguese: "*roda d'água*"; in Romanian: "*transformatorul hidraulic*", "*turbotransformatorul hidraulic*"; in Russian: "*Черепнов водоподъемник*", "*водоподъемник токаря Черепнова*", "*Автономных водоподъемников*", and "*Аэрогидравлического водоподъемника*"; in German "*Brunnhäuser*" and "*Lambachpumpe*"; in Mandarin: "*水轮泵*", "*水锤泵*"; in Vietnamese: "*bơm thủy luân*"; in Indonesian: "*pompa air tenaga hidro*"; in Thai "*เครื่องสูบน้ำกังหันน้ำแบบ*". It is worth mentioning that the technologies screened and analyzed here might not be limited to the aforementioned languages. Nevertheless, true to the authors' knowledge, these were the ones whose keywords provided consistent results within the scope of the present review.

2.2.3.2 Selection of Results

The first search iterations depicted several temporal gaps in the literature, i.e., not all the relevant technologies, in accordance with the selection criteria, could be found around the same period but in heterogeneous time frames (decades, centuries) throughout the history. Therefore, to increase the likelihood of gathering valuable data, the process of search and subsequent selection of information was not restricted to any specific time range (e.g., only 20th and 21st centuries), but from the present until the origin of the first-ever recorded HPP technologies.

Results of search engines, for both peer-reviewed and grey literature, were taken into consideration as long as they provided any of these aspects: (i)

Technical information and applicability of the technologies; (ii) the description of a particular case study and/or its uniqueness worldwide; (iii) the development of an innovative design; and/or (iv) unique facts that contribute in understanding the storyline of evolution, success or failure of the technologies.

Literature from search engines was selected by consecutive sampling, i.e., all the relevant subjects were considered. In consequence, each search iteration was explored thoroughly until its outcomes became out of scope of the selection criteria, usually beyond the first 40 results. Notwithstanding the previous technique, snowball-sampling (through bibliographic references and hyperlinks) was also used in the case of technologies whose documents were not indexed in any database or did not respond to the set of keywords.

2.2.3.3 Data Classification and Processing

Results of iterative searches showed a wide diversity of HPP devices in terms of shapes, sizes, prime movers, pumping principles, prime mover—pumping device integration, working conditions, benefits, and applicability. Due to this heterogeneity, HPP technologies were grouped and classified not based on a single criterion, but on the combination of a series of properties related to their morphological/mechanical characteristics.

In line with the proposed classification, two datasets were built from the selected documents, namely bibliography and application cases, respectively (see Appendix A in Supplementary Materials) [39]. The bibliography dataset grouped and quantified documents according to their nature (scientific or grey literature), type of document, year of publication, and language, among other bibliographic information. Furthermore, scientific literature consisted of: Articles published in high- and low-impact factor journals, books and books sections, conference proceedings, and encyclopedias. Grey literature involved: Working papers, research newsletters, theses, magazine articles, reports, research bulletins, brochures, websites, information in social networks, presentations, patents, newspaper articles, videos, and others. The application cases dataset, on the other hand, was built from all the instances found in the bibliography where HPP devices have been reported under any kind of actual use (e.g., agricultural irrigation, water supply, research, others) within the selection criteria. It encompassed year of implementation, country, and type of end-use. It must be noticed, nevertheless, that there is not any quantitative relation between the number of documents and number of reported cases, i.e., a single article might report thousands of HPP devices in use, whereas some documents could triangulate few application cases in a specific context.

Some assumptions were made while building the datasets. Regarding the literature, certain documents were recorded as many times as different technologies they addressed. On the application cases, whenever it was not possible to determine the number of devices (i.e., literature refers to "some" or "few") either/or their year of application, a number of two and/or the year of the corresponding document were allocated, respectively. Manufacturers of technologies have been assigned only as one case, whereas neither retailers nor distributors were considered. Repowered and renovated cases were accounted for again, as long as they posed an upgrade or change in the technology.

Statistical analyses of the datasets were performed with Microsoft® Excel® 2016. Due to considerable differences between reported cases of HPP technologies (order of magnitude of six), these were plotted in space and time on the basis of a customized logarithmic scale.

2.3 Main Findings

2.3.1 HPP Technologies

In total, 30 technologies were identified and grouped into eight classes: (i) Manometric pumps, (ii) hydro-pneumatic water lifters; (iii) hybrid turbine-pumps; (iv) water turbine pumps; (v) tubular multi-propeller turbines; (vi) water current turbines; (vii) generic integrations; and (viii) other devices. **Figure 2.1** shows the classification of HPP technologies. Their timeframe and presence worldwide, as well as some of their technical properties, are summarized in **Table 2.1**. The narrative on the origins, evolution, and fate of each technology is contained in Appendix B (see Supplementary Materials).

2.3.1.1 Manometric Pumps

These devices consist of any kind of semi-submerged curved pipes winding around a fixed central point or axis, which rotates continuously, thereby alternatively taking in both water and air packets through an open end in each revolution. The other extreme (i.e., the outlet), which matches the center/axis, is connected to a water-tight rotary fitting joined to a fixed pipe [40]. They are named after their resemblance to a wounded cascading manometer, thus operating on its principle, where the series of loops of the pipe act as manometers separated from one another by the trapped air columns [41–44]. The total lifting head at the outlet results from the addition of the manometric head difference in each loop. Several authors have thoroughly studied the hydraulics of this water lifting principle [40,41,45–49].

The shape of the curved pipe can be either planar [50], convolved in a three-dimensional cylindrical surface [51], or in a conical one [49]. Besides, regarding the water stream, the axis of the pipe can be cross-flow or axial-flow. These different shapes give rise to manometric pumps that acquire several names throughout the literature, sometimes being used interchangeably or even as synonyms. For convention of the present work however, cross-flow planar, cross-flow non-planar, and axial-flow non-planar pipes will be referred as hydro-powered spiral pump (HSP), hydro-powered coil pump (HCP), and hydro-powered helix pump (HHP), respectively. **Figure 2.2** depicts different types of manometric pumps.

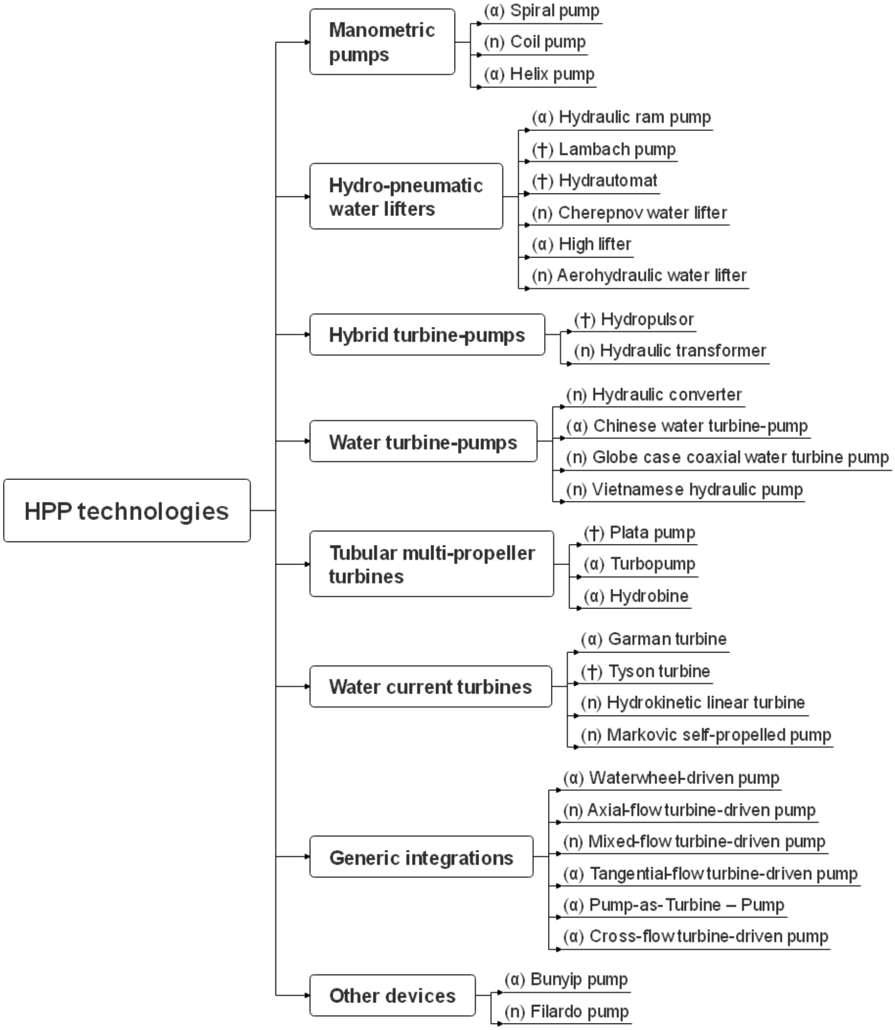


Figure 2.1. Classification of HPP technologies and their latest development/production stage. The symbols (α), (†), and (n) stand for commercially available, commercially extinct, and noncommercial technologies, respectively.

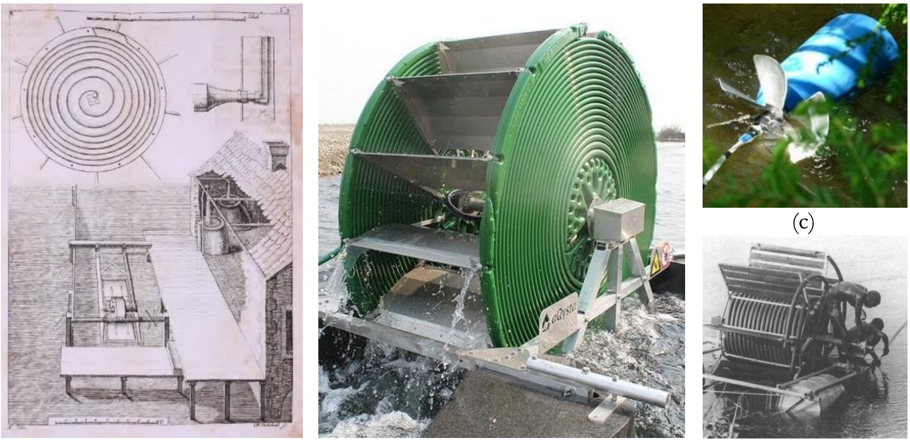
Table 2.1. Summary of HPP technologies.

Class	Technology	First Record	Last Record	Reported Devices	Nr. of Countries	Prime Mover	Pumping Device	Pumping Principle	Integration	Required Head	Location in Water
Manometric pumps	Spiral pump	1746	2018	192	19	Waterwheel	Spiral pipe	PD	DA, CS	ZH	SS
	Coil pump	1778	1997	14	8	Waterwheel	Coil pipe	PD	DA	ZH	SS
	Helix pump	1987	2017	27	12	Axial-flow propeller	Helix pipe	PD	DA	ZH	SS
Hydro-pneumatic water lifters	Hydraulic ram pump	1796	2017	~6840	42	Compressed air	HT, SARP	PD	VS, Diaphragm	LH	OS, SS, SU
	Lambach pump	1880s	1961	35	3	Compressed air	SARP, DARP	PD	PS	LH	OS
	Hydrautomat	1920s	2013	13	6	Compressed air	HT	PD	VS	LH	SU
	Cherepnov water lifter	1960	1996	6	5	Compressed air	HT	PD	VS	LH	OS
	High lifter	1984	2016	4	1	Compressed air	SARP	PD	PS	LH	OS
	Aerohydraulic water lifter	1998	1998	4	1	Compressed air	HT	PD	VS	LH	SS
Hybrid turbine-pumps	Hydropulsor	1909	1912	5	2	Turbine-pump impeller	Turbine-pump impeller	VH	Integrated impeller	LH	OS
	Hydraulic transformer	1940	1999	12	1	Turbine-pump impeller	Turbine-pump impeller	VH	Integrated impeller	LH	OS
Water turbine-pumps	Hydraulic converter	1921	1921	1	1	Axial turbine	CP	VH	CS	LH	SU
	Chinese water turbine-pump	1954	2007	~81500	15	Kaplan turbine	CP	VH	CS, TS	LH, MH	SU
	Globe case coaxial water turbine pump	1999	2014	4	1	Kaplan turbine	CP	VH	CS	LH	OS
	Vietnamese	2009	2014	9	1	Kaplan turbine	CP	VH	CS	LH	SU

Class	Technology	First Record	Last Record	Reported Devices	Nr. of Countries	Prime Mover	Pumping Device	Pumping Principle	Integration	Required Head	Location in Water
	hydraulic pump										
Tubular multi-propeller turbines	Plata pump	1972	1990	17	8	Multi-propeller turbine	SARP	PD	TS	ULH	SS
	Turbopump	1983	1992	~300	1	Multi-propeller turbine	SARP	PD	TS	ULH	SS
	Hydrobine	1998	2014	7	4	Multi-propeller turbine	SARP	PD	TS	ULH	SS
Water current turbines	Garman turbine	1976	2018	69	6	3-bladed propeller turbine	CP	VH	TS	ZH	SS
	Tyson turbine	1982	2009	28	9	7-bladed turbine	DARP	PD	TS	ZH	SS
	Hydrokinetic linear turbine	1984	2017	13	4	Linear turbine	SARP	PD	Slider-crank	ZH	SS
	Markovic self-propelled pump	1993	2009	3	1	Mixed flow propeller turbine	SARP	PD	Slider-crank	ZH	SU
Generic integrations	Waterwheel-driven pump	1528	2018	139	19	Waterwheel	SARP, DARP, DP, CP	PD, VH	TS	ZH, LH	OS, SS
	Axial-flow turbine-driven pump	1851	2011	88	9	Axial-flow turbines (Kaplan, Tubular, Bulb, S-shape, Jonval, Girard)	DARP, CP, DP	PD, VH	CS, TS	LH	SS, SU
	Mixed-flow turbine-driven pump	1897	2005	18	4	Mixed-flow turbines (Francis, Samson, S.	CP, DARP	PD, VH	CS, TS	LH	SS

Class	Technology	First Record	Last Record	Reported Devices	Nr. of Countries	Prime Mover	Pumping Device	Pumping Principle	Integration	Required Head	Location in Water
						Morgan Smith, Leffel)					
	Tangential-flow turbine-driven pump	1900	2018	17	7	Tengential-flow turbines (Pelton, Turgo, Ghatta)	CP, Plunger pump, Progressive cavity pump, DP, SARP, DARP	PD, VH	CS, TS	HH	OS
	Pump-as-Turbine - Pump	1952	2018	47	10	Pump working in reverse	CP, DP	PD, VH	CS, TS	LH	OS
	Cross-flow turbine-driven pump	1979	2018	26	10	Cross-flow turbine (Michell – Banki, Ossberger, BYS)	CP, DP	PD, VH	CS, TS	LH	OS
Other devices	Bunyip pump	2006	2018	6	1	Rubber tire	SARP	PD	DA	LH	OS
	Filardo pump	2012	2013	5	1	Ribbon frond mechanism	Peristaltic pumping pipes	PD	DA	ZH	SU

On pumping devices: HT, SARP, DARP, CP, and DP stand for hydraulic tank, single-acting reciprocating pump, double-acting reciprocating pump, centrifugal pump, and diaphragm pump, respectively. On pumping principles: PD and VH stand for positive displacement and velocity head, respectively. On integration: DA, CS, VS, PS, and TS stand for direct attachment, coaxial shaft, valve system, piston system, and transmission system, respectively. On required head: ZH, LH, MH, ULH, and HH stand for zero-head, low-head, medium-head, ultra-low-head, and high-head, respectively. On location regarding water: SS, OS, and SU stand for semi-submerged, on-surface, and submerged, respectively.



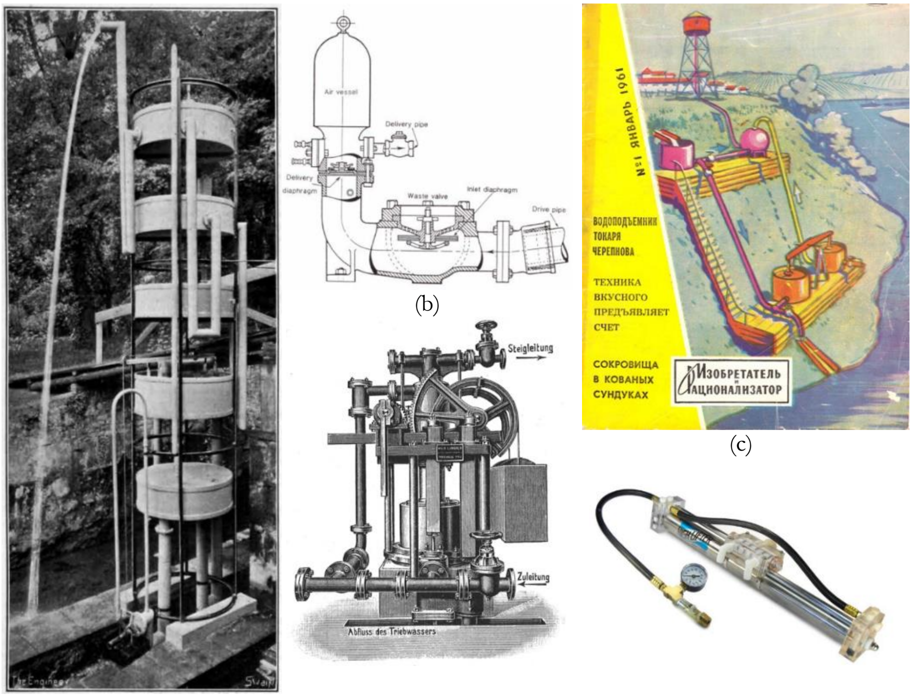
(a) (b) (c) (d)

Figure 2.2. Different types of manometric pumps: (**a**) First ever known hydro-powered spiral pump (HSP) from 1746 in Zurich [52]. CC BY-NC 3.0; (**b**) Modern HSP—aQysta's Barsha pump [53]. © USAID (https://securingwaterforfood.org/innovator-news/hydro-powered-pump-offers-eco-friendly-irrigation-solution). Cropped from the original; (**c**) Hydro-powered helix pump (HHP) [54]. Reproduced with permission from Rife Hydraulic. © Rife Hydraulic Engine Manufacturing Company (https://www.riferam.com/pumps.html); (**d**) Hydro-powered coil pump (HCP) [51]. Reproduced with permission from Practical Action Publishing Ltd. © Otto Clemensen (https://doi.org/10.3362/0262-8104.1985.030).

The HSP, HCP, and HHP generally harness the required energy by means of waterwheels (frequently stream shot ones), radial paddles, or axial-flow propellers, respectively. Therefore, these devices do not usually rely on the water potential head but on the velocity of the water stream (i.e., kinetic head). Both the curved pipe and prime mover can be joined either by attaching them together [55,56] or either by transmitting the rotational movement from one to another through a shaft or transmission system. More than one curved pipe can be assembled to the whole device [57,58].

2.3.1.2 Hydro-Pneumatic Water Lifters

These HPP devices lift water at the expense of potential energy from falling water and pneumatic compression [59,60]. They are usually self-oscillatory, thus relying on automatic draining components (e.g., valves, floating devices, magnetic switches, counterweights) that allow the lifting cycles to recommence [61–65]. However, other less common variants operate without any moving component [66–68]. Hydro-pneumatic water lifters can be built in the form of compact machines [69–74] or very large and complex systems [61,67,75,76]. Technologies within this class are the hydraulic ram pump (HRP) and its many variants (e.g., multipulser, Platypus, Dingo™, Glockemann, PAPA, Venturo), Lambach pump (LP), hydrautomat, Cherepnov water lifter (CWL), High Lifter, and aerohydraulic water lifter. From these, the most common and widely applied is the HRP. Several types of hydro-pneumatic water lifters are shown in **Figure 2.3**.



(a) (d) (e)

Figure 2.3. Different types of hydro-pneumatic water lifters: (**a**) Hydrautomat [77]. © Grace's Guide Ltd. (https://www.gracesguide.co.uk/The_Engineer_1922/07/07). CC BY-SA 4.0; (**b**) Scheme of an hydraulic ram pump (HRP) [78]. Reproduced with permission from Jeremy Milln. © The National Trust (https://industrial-archaeology.org/wp-content/uploads/2016/04/AIA-News-93-Summer- 1995.pdf); (**c**) Illustration of the Cherepnov water lifter (CWL) installed at the former Gorky Oblast, Russia [75,79]. Reproduced with permission from "Inventor and Innovator" magazine. © Изобретатель и рационализатор (http://i-r.ru/article/2254/); (**d**) Early model of Lambach pump (LP) [62]. © Hauptverein Deutscher Ingenieure in der Tschechoslowakischen Republik; (**e**) High lifter [80]. Reproduced with permission from Humboldt Solar Water Pump. © Humboldt Solar Water Pump (http://www.humboldtsolarwaterpump.com/high-lifter-gravity-water-pump-for-your-off-grid-water-system/).

2.3.1.3 Hybrid Turbine-Pumps

Hybrid turbine-pumps, unlike many other HPP technologies, do not join two different machines (i.e., prime mover and pump), but they physically integrate both of them in a single, different hydraulic device. Therefore, they must be understood as the hybridization of a type of water turbine and a centrifugal pump, hence fulfilling both functions at the same time [81]. Hybrid turbine-pumps are usually compact devices [82,83], though they have been also implemented in large-scale versions, able to reach lifting heads of even hundreds of meters, for waterworks and irrigation systems [84,85]. These machines are very versatile [85–88], though require complementary civil works to operate properly [83]. The Hydropulsor and the hydraulic transformer (HT) are in this group. **Figure 2.4** illustrates the different types of hybrid turbine-pumps.

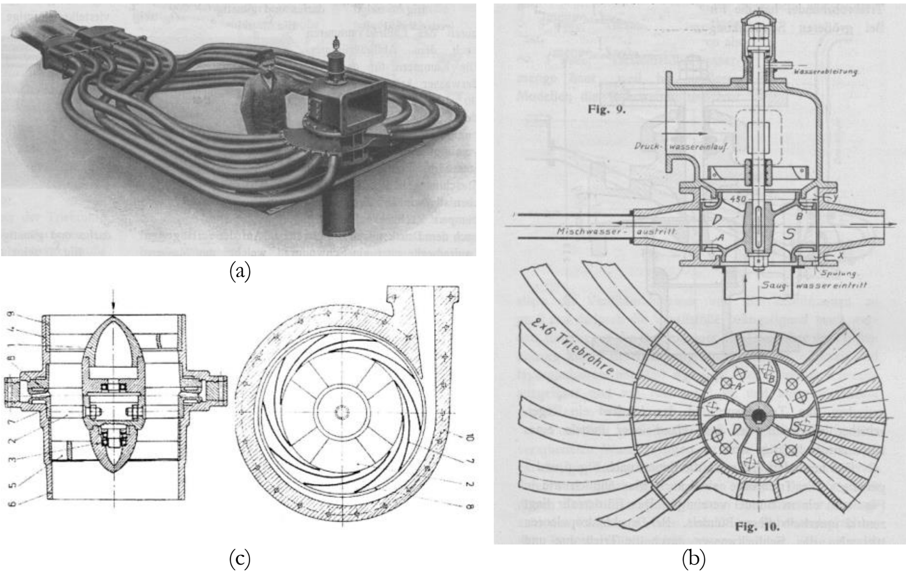


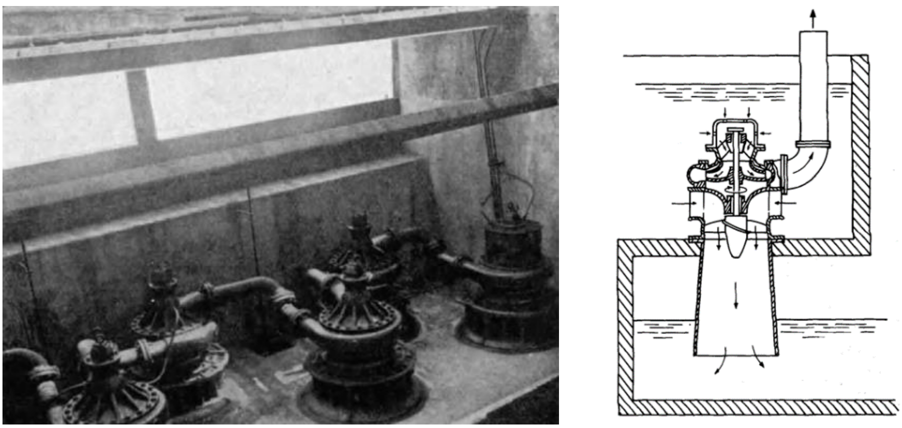
Figure 2.4. Different types of hybrid turbine-pumps: (**a**) Hydropulsor installed at Dretzel, Germany [85]. © Digitalisierung des Polytechnische Journal (http://dingler.culture.hu-berlin.de/article/pj327/ar327220). CC BY-NC-SA 3.0; (**b**) Impeller/runner of the Hydropulsor installed at Dretzel, Germany [85]. © Digitalisierung des Polytechnische Journal (http://dingler.culture.hu-berlin.de/article/pj327/ar327220). CC BY-NC-SA 3.0; (**c**) Longitudinal and transversal section of an hydraulic transformer (HT) [89]. (http://www.afst.valahia.ro/images/documente/2010/issue2/2010-2-4-3-Man-Eugen-Teodor.pdf). CC BY.

2.3.1.4 Water Turbine-Pumps

The water turbine-pump (WTP), largely referred to the literature as a machine unique to China, results from embodying in a single case, and coaxially joining–through a single shaft [90–95] or transmission system [96,97]-an axial-flow turbine (usually a Kaplan type) and a centrifugal pump. Both components are usually fully submerged, hence operating with the same water body, though some models [98,99] operate on surface, by means of water-tight pipes. The head difference in the water drives the turbine, whose vanes and blades can be either fixed or adjustable, and which in turn transmits its rotational mechanical energy directly to the pump [26,100]. Due to this characteristic, some authors consider WTPs highly efficient machines [25,93,94,96]. The WTP group encompasses the hydraulic converter, Chinese water turbine-pump (CWTP), Globe case coaxial water turbine pump, and Vietnamese hydraulic pump.

WTPs are quite modular, thus prone to be installed in a wide variety of setups [91,93,101,102], fulfilling different requirements: Stand-alone or in batteries (pump stations); with single-stage or multistage pumping configurations [97,103,104]; placed either horizontally, vertically, or mixed; in parallel and/or in series; as single-purpose devices, only for lifting water, or multi-purpose ones [94,97,105–107], combined with electricity generation and other machinery [14,90,91,93,96,97,108]; installed in dams, canal drops, and excavated diversion canals [107,109]; and in both low-land tidal rivers and mountainous areas [93,97,108,110]. Although they are generally better suited for low-head conditions [14,90,111–114], there are few reported cases that make use of medium- and high-working heads [99,113]. Furthermore, WTPs cover a broad range of models able to lift water from a few up to hundreds of meters [14,28,90,94,99]. Commercially, WTPs are classified in regard to the diameter of the turbine runner (given in cm) and the head ratio (pumping head : working head) [90,93]. A 40-6 model, for instance, will have a 40 cm-diameter runner and a 6:1 head ratio. Devices of 10-160 cm diameter, from 4:1 to 20:1 head ratio, and maximum efficiencies of 70%, exemplify the wide variety of solutions [93,96,115].

Unlike other ready-to-use HPP devices, WTPs are highly demanding in complementary civil works [93,107]. They frequently require dams, weirs and/or gates to create artificial drops, thus augmenting the working head, as well as pits to hold the machine. Additionally, a draft tube is also built to amplify the effect of the hydrostatic head [95]. As stated by some authors [14,26,50], albeit the WTP by itself bears relatively low production costs, investments of complementary constructions [96,107,110] largely outpace them. Several WTPs and their installations can be seen in **Figure 2.5**.



(a) (b)

(c)

(d)

(e)

Figure 2.5. Different types of water turbine-pumps (WTPs): (**a**) Hydraulic converters installed in in the Muffatwehr at the Isar River in Munich [81]. Reproduced with permission from Springer Nature. © Springer Nature (https://doi.org/10.1007/978-3-642-50802-8_18); (**b**) Schematic view of the typical installation of a WTP [14]. Reproduced with permission from Food and Agriculture Organization of the United Nations © FAO (http://www.fao.org/3/ah810e/AH810E12.htm#12.1). A from the original; (**c**) Mass production of Chinese water turbine-pump (CWTP). Reproduced with permission from Gejing Jiang. © 有　金华天阳电子有限公司 (http://www.jiaxiangwang.com/cn/guizhou.htm); (**d**) Multi-stage Vietnamese hydraulic pump [116]. © Viện Khoa học Thủy lợi Việt Nam (http://www.vawr.org.vn/index.aspx?aac=CLICK&aid=ARTICLE_DETAIL&ari=2314&lang=1&menu=&mid=-138&pid=1&title=cong-nghe-bom-thuy-luan-bom-nuoc-tu-dong-phuc-vu-nong-nghiep-mien-nui-va-trung-du); (**e**) Globe case coaxial water turbine pumps commissioned in the Mae Phum Reservoir, Phayao province, Thailand [117]. © Royal Irrigation Department. CC BY-NC-SA 3.0. Cropped from the original.

2.3.1.5 Tubular Multi-Propeller Turbines

The tubular multi-propeller turbines (TMPT), which include the Plata pump, Turbopump, and Hydrobine, as shown in **Figure 2.6**, are semi-submerged, axial-flow, ultra-low head (0.25–1.0 m) pumping devices [14,24,118] encased in a cylindrical body made out of metal [118] or fiberglass [29,119]. They consist of a series of coaxial propeller turbine rotors joined through a single shaft, coupled to one/two single-action reciprocating water pumps by means of a slider-crank mechanism [14,27,119]. TMPTs are meant to be installed laying on a slight slope angle to make water flow through the cylinder, thereby usually requiring basic site preparation [14,24,27]. Furthermore, TMPTs are able to be installed either in parallel or in series [27]. Their maximum power is developed when the turbine works about half full of water, but it can operate well in a range of three-quarters full to almost empty [14,27]. Additionally, modern versions [120,121] of these devices are designed for both water pumping and electricity generation.

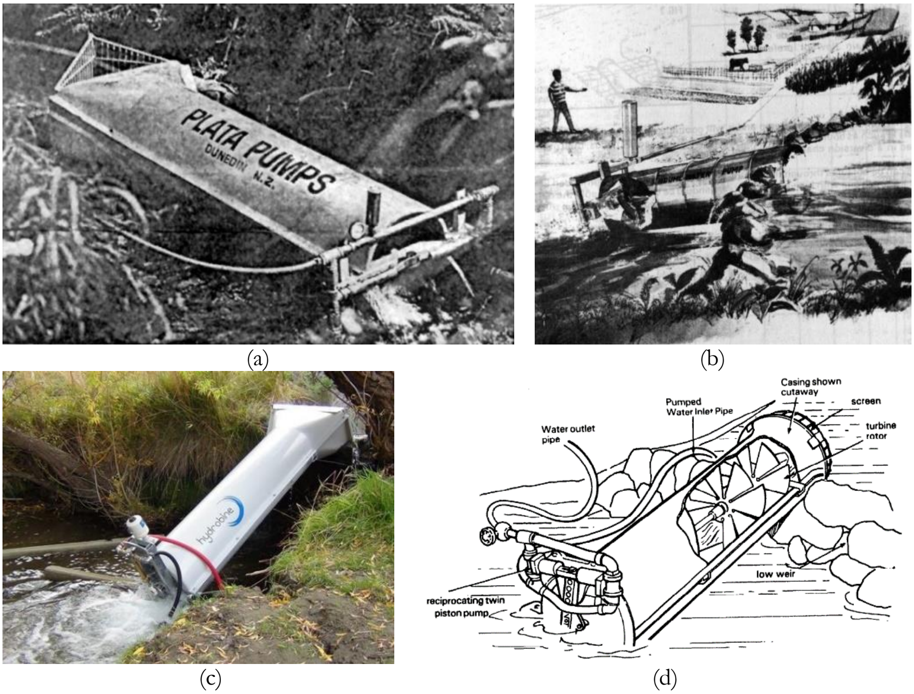


Figure 2.6. Different types of tubular multi-propeller turbines (TMPTs): (**a**) Plata pump [119]. Reproduced with permission from Alternative Technology Association Inc. © The Alternative Technology Association (https://www.jstor.org/stable/softtechaltetech.13.18); (**b**) Illustration of a Turbopump in operation [122]. © S.C. White (http://www.wossac.com/search/wossac_detail.cfm?ID=2076); (**c**) Hydrobine in operation [123]. Reproduced with permission from Wayne Perkins. © EB Engineering Solutions (https://www.facebook.com/Hydrobine/photos/pcb.789312184518066/789311851184766/?type=3&theater). Cropped from the original; (**d**) Schematic view of a TMPT [14]. Reproduced with permission from Food and Agriculture Organization of the United Nations © FAO (http://www.fao.org/3/ah810e/AH810E12.htm#12.1).

The operation of TMPTs can raise some issues due to particles and floating debris. A grid before the turbine intake will prevent them, though it might require daily clearance. Frequent silting can contribute to undesired changes in the working head of the structures, thereby requiring periodic removal of deposits [27,118,122].

The performance and benefits of TMPTs are a point of disagreement. Whereas some literature mentions excellent lifts [29,119] of even hundreds of meters [118], other authors [14,27,42,111,122] point them out as relatively expensive, less robust, and less efficient machines compared to other HPP technologies.

2.3.1.6 Water Current Turbines

Water current turbines (WCTs) lift water by harnessing kinetic energy from free-flowing streams [124–127]. WCTs, comprising the Garman turbine (GT), Tyson turbine (TT), Hydrokinetic linear turbine, and Markovic self-propelled pump, consist of a fully submerged turbine, coupled to a centrifugal or reciprocating water pump by a transmission system. These devices are frequently moored in nontidal (unidirectional flow) rivers, though tidal ones are considered as well [128,129], particularly in locations where damming water is impractical due to economic or engineering reasons [124,127]. Less common WCTs incorporate piston pumps by employing crankshaft-and-connecting rod systems, as well as vertical Darrieus-type water turbines [24]. **Figure 2.7** shows several types of WCTs.

(a) (c) (d) (b) (e)

Figure 2.7. Different types of water current turbines (WCTs): (**a**) Construction of a Garman turbine (GT). © Thropton Energy Services. Courtesy of Dr. Barbara Sexon; (**b**) Two GTs in operation. © Thropton Energy Services. Courtesy of Dr. Barbara Sexon. Cropped from the original; (**c**) Tyson turbine (TT) in operation. Reproduced with permission from Museum of the Riverina. © Wagga Wagga City Council. Courtesy of Mr. Luke Grealy; (**d**) Hydrokinetic linear turbine operating [129]. Reproduced with permission from John Service. © Tuapeka Turbines (http://tuapeka-turbines.com/blog/mini-linear-turbine-test-whakatane-river-new-zealand-14-march-2014/). Cropped from the original; (**e**) Markovic self-propelled pump [130]. Reproduced with permission from Nataša Markovič. © Vladimir Markovič (http://izumi.si/doc/ENERGY_AS_ENEMY.pdf).

WCTs are relatively simple to build with readily available materials, yet are sturdy and long lasting. Besides, they do not require additional civil works, thereby reducing costs and favoring their versatility [124,126,127,131–133]. However, WCTs present problems and interferences with weed (e.g., water hyacinth) and floating debris [134–139], which in turn determine their maintenance frequency, though this largely depends on the type of river [140].

There are cases of turbines cleaned several times a day [124], and other ones only every few days or weeks [140,141]. In this respect, some efforts have been done in improving the design to counteract this issue [134–136].

WCTs are used for water pumping and/or electro-generation. Nonetheless, current research on these devices focuses mainly on the latter [135,136,142–146], whereas the pumping purpose is barely addressed by few authors [147].

2.3.1.7 Generic Integrations

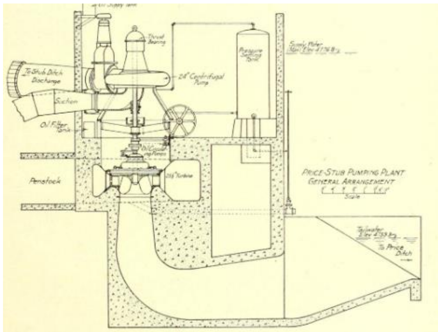
Besides the specific HPP technologies previously addressed, there are cases in which generically coupling a prime mover and a pumping device works effectively. Moreover, these arrangements are usually more flexible for a number of conditions compared to specific devices. Due to their generic nature, however, it is not possible to trace back the origin or evolution of each of these inventions.

Among the prime movers used for these purposes are: Waterwheels, the most primitive form of water turbine, hence more used in the remote past; axial-flow turbines; mixed-flow turbines; tangential-flow turbines; pumps working in reverse, often known as pump-as-turbines; and cross-flow turbines. On the other hand, a wide variety of pumping devices can be coupled: Single and multistage centrifugal pumps, plunger pumps, progressive cavity pumps, and single and double action piston pump, among others. Both off-the-shelf [148–152] as well as tailor-made [153–156] setups are used for these purposes, and usually their implementation requires extra infrastructure to work properly [150,155,157–160].

In regard to the type of prime mover, these generic integrations are waterwheel-driven pump (WDP), axial-flow turbine-driven pump (ADP), mixed-flow turbine-driven pump (MDP), tangential-flow turbine-driven pump (TDP), pump-as-turbine-pump (PAT-P), and cross-flow turbine-driven pump (CDP). **Figure 2.8** depicts different types of these generic integrations.

(a) (b)


(c)


(d)

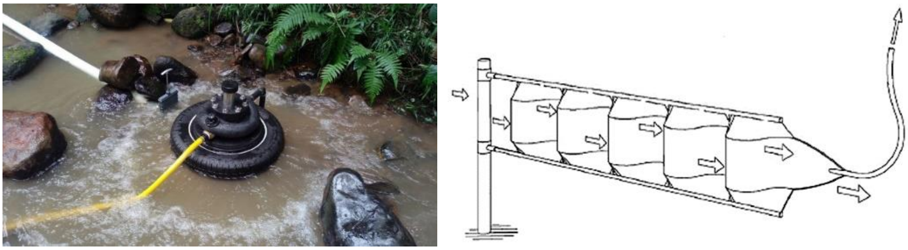
(e)


(f)

Figure 2.8. Different types of generic integrations of HPPs: (**a**) Waterwheel-driven pump (WDP) system in Brazil [161]. Reproduced with permission from Agropress. © AGROTEC (https://dl.uc.pt/bitstream/10316.2/29970/1/Agrotec7_artigo35.pdf). Cropped from the original; (**b**) WDP type "Mangal Turbine" [162]. Reproduced with permission from Bharat Dogra. © Bharat Dogra, as authorized by the author Mangal Singh (https://thewire.in/agriculture/mangal-singh-bundelkhand-turbine). Cropped from the original; (**c**) Cross-flow turbine-driven pump (CDP) system in Indonesia [163]. Reproduced with permission of the author. © Isnugroho (https://publikasiilmiah.ums.ac.id/xmlui/handle/11617/4447). Cropped from the original; (**d**) Mixed-flow turbine-driven pump (MDP) in the Price-Stub pumping plant, Grand Valley Project, Colorado [155]. Document under public domain (https://archive.org/details/reclamationrecor11unit/page/308); (**e**) Off-the-shelf tangential-flow turbine-driven pump (TDP) unit. © ZM Bombas (http://zmbombas.com.br/turbobomba). Reproduced with permission of the author. (**f**) PAT-P system in an underground karst cave system in Gua Bribin, Indonesia [164]. © Franz Nestmann et al. (https://doi.org/10.1016/j.proeng.2013.03.006). CC BY-NC-ND 3.0.

2.3.1.8 Other Devices

This group comprises two HPP devices that, due to their mechanical characteristics and energy harnessing method, do not fit in any of the other groups. These, which are the Bunyip pump and the Filardo pump, are characterized for being relatively novel inventions, though their commercial and research status are mutually opposite to each other. The former results from the integration of a conventional rubber tire (which provides elastic potential energy) and a piston pump, while the latter harnesses kinetic energy from running water by means of a so-called ribbon frond mechanism, which acts as a linear peristaltic pump. Both devices can be seen in **Figure 2.9**.



(a) (b)

Figure 2.9. Other HPP devices: (**a**) Bunyip pump [165]. Reproduced with permission of the author. © Brett Porta (https://www.facebook.com/portasaffordablepumps/photos/a.835289806627751/1033397573483639/?type=3&theater). Cropped from the original; (**b**) Concept of Filardo pump [166]. Reproduced with permission of Elsevier. © Elsevier (https://doi.org/10.1016/j.renene.2016.01.089). Cropped from the original.

2.3.2 Literature Analysis

A total of 854 documents of different nature, in 17 languages, either as a whole or sections of them, were selected and classified. From these, 418 and 436 correspond to scientific and grey literature, of which 156 and 125 are non-English documents, respectively. As represented in **Figure 2.10**, the number and distribution of these documents per HPP technology are neither homogeneous nor follow any identifiable pattern.

Although roughly half of the total selected documents belong to scientific literature, this is mostly concentrated in only three technologies, namely the CWTP, HRP, and WDP (18%, 17%, and 11%, respectively). In relative terms, however, the Hydraulic converter, CWTP, CWL, and Hydropulsor are the largest holders of these sources (100%, 76%, 72%, and 71%, respectively). On the opposite side, the HRP and WDP are the main bearers of grey literature (14% and 11%, respectively), though its biggest relative concentration relies on the HHP, High lifter, Vietnamese hydraulic pump, Hydrobine, Markovic self-propelled pump, and Bunyip pump. In point of fact, the five latter only exist in that domain of information, i.e., they are not reported at all in scientific documentation.

Notably, documents from sources usually neglected in scientific research (e.g., low-impact factor journals, commercial literature, nonscientific websites, social media) offered large fragments of information not found otherwise. Such is the case of the HHP, LP, High lifter, Vietnamese hydraulic pump, Hydrobine, Markovic self-propelled pump, and Bunyip pump. Furthermore, the mapping of certain case studies and/or research worldwide (section 2.3.3) was only possible due to those sources.

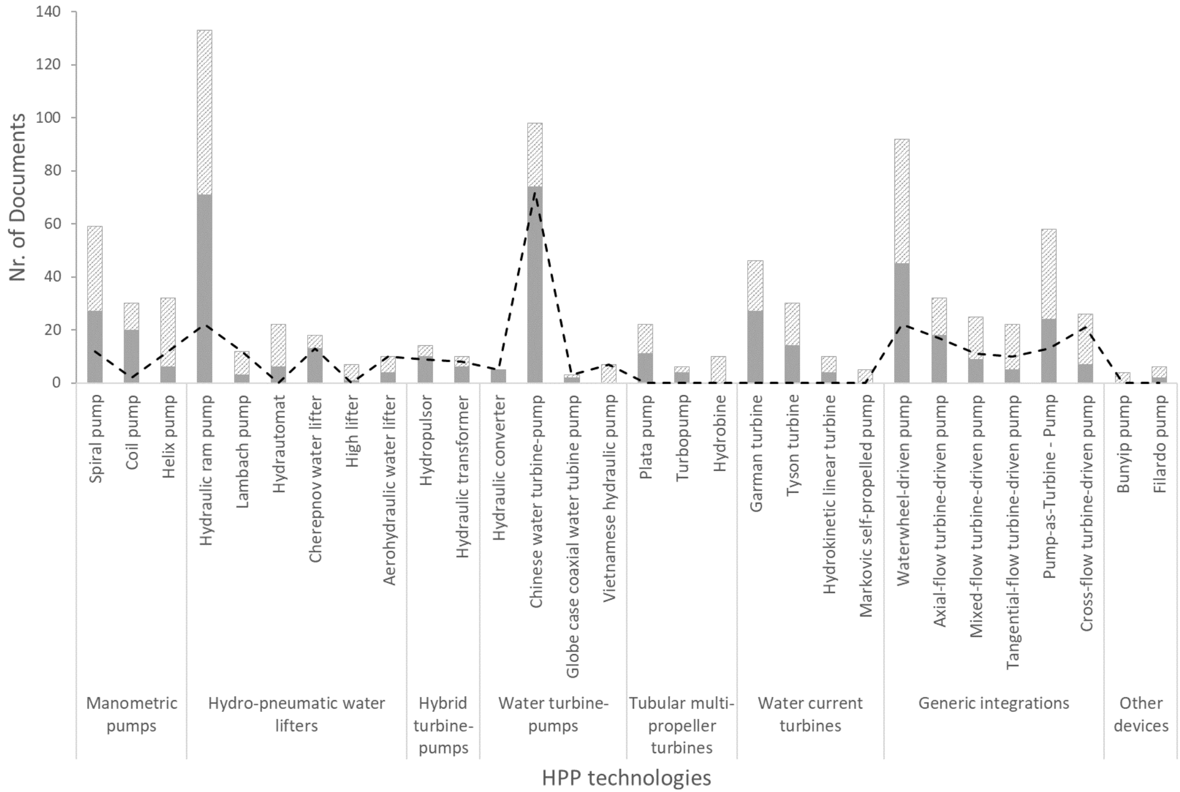


Figure 2.10. Number of selected documents per HPP technology. The grey solid bars, grey diagonal pattern bars, and black dashed line correspond to scientific literature, grey literature, and non-English literature (both scientific and grey), respectively.

One-third of the total documents corresponds to non-English literature, thus cannot be considered negligible. Out of that quantity, 26% belongs only to CWTP, whereas roughly 23% is evenly distributed between the HRP, WDP, and CDP. Albeit five technologies (i.e., LP, Aerohydraulic water lifter, Hydraulic converter, Globe case coaxial water pump, and Vietnamese hydraulic pump) contribute to barely 13% of the total, those pose the particularity of being exclusively reported in non-English documents. Other technologies with a high relative non-English representation are the CDP, HT, CWTP, CWL, and Hydropulsor (81%, 80%, 74%, 72%, and 64%, respectively).

All these documents, which belong to the 30 HPP technologies and their respective categories, have been published in different years throughout history. However, as seen in **Figure 2.11** and **Figure 2.12**, there are certain periods in which noticeable boosts of literature took place. The hydro-pneumatic water lifters, though showing a steady increase over time, have two particular moments: The former around the early 1920s and the latter since the early 1980s, due to the punctual and momentary interest of the Hydrautomat and the sustained production on the HRP, respectively. Documents addressing technologies such as the HSP, WDP, and PAT-P gained a particular rebound during the 21st century (though the two former existed since few centuries ago), thus providing an evident increase to their respective categories, i.e., manometric pumps and generic integrations. The WTPs, thanks to the CWTP, present a remarkable peak in their literary production during the late 1970s and 1980s which, during the present century, has flattened drastically. The documentation on WCTs, mainly linked to the records on the GT, presents the particularity of increasing during the last decade, despite those technologies having been actively researched/applied during the 1980s and 1990s.

These numbers, as well as their distributions amongst the different HPP technologies, offer solid evidence in understanding: (i) How scientific production has (historically) focused in certain–to the detriment and neglect of other ones–regardless their development stage and benefits; (ii) how some HPP technologies (e.g., High Lifter, Hydrobine, Bunyip pump) exist, scale out, and thrive commercially, unnoticed by the written scientific sphere; and (iii) how, despite the long history of HPP systems, room still exists for further scientific studies focusing on old, as well as relatively new, HPP technologies.

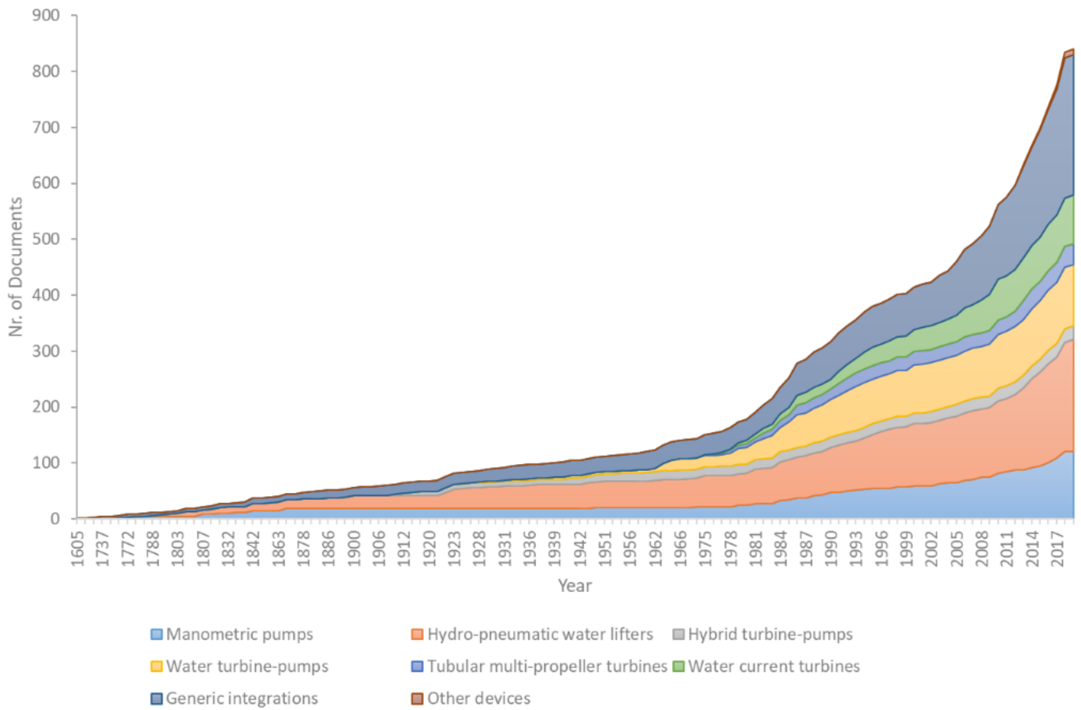


Figure 2.11. Cumulative number of selected documents published over time. The different colored areas depict the running total of documents produced per category of technology per year.

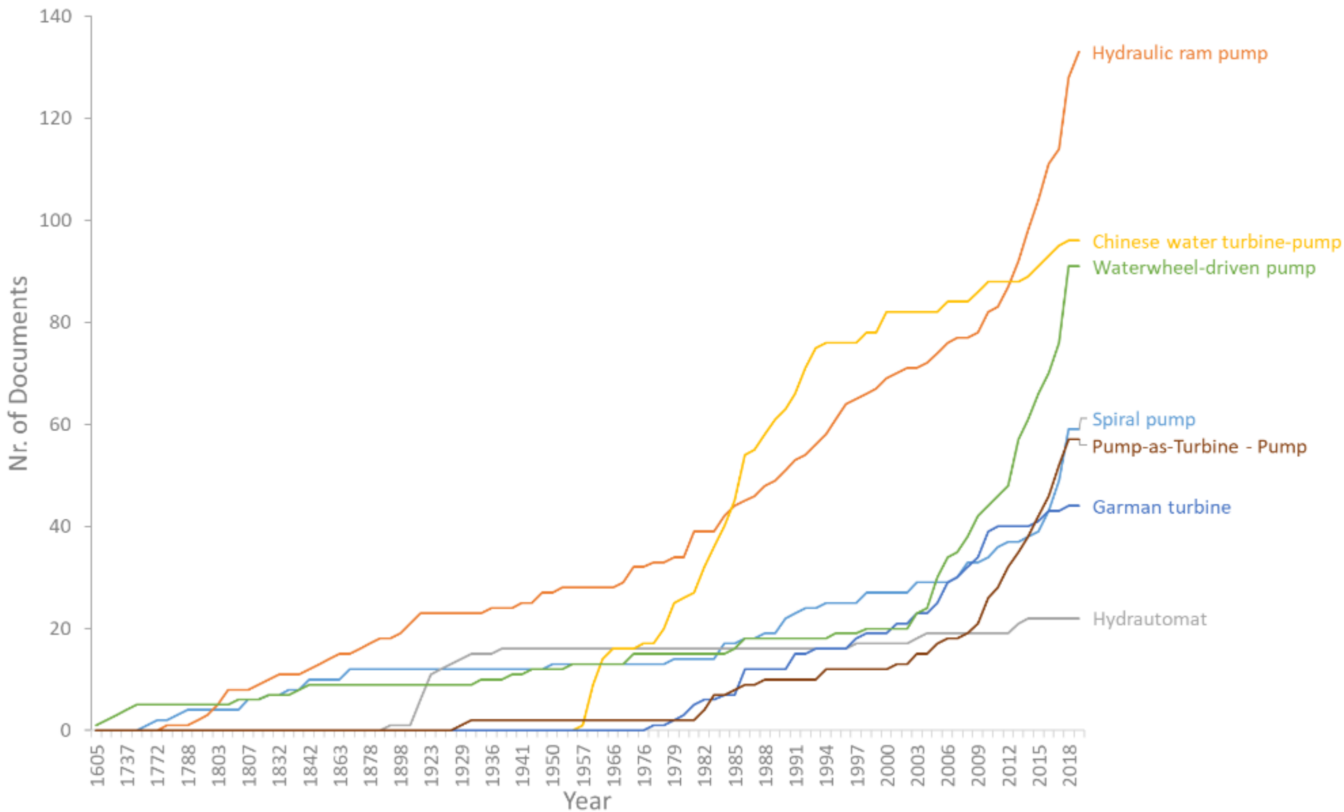


Figure 2.12. Noncumulative number of selected documents published over time. The different colored lines depict the running total of documents produced per technology per year. Only the most noticeable ones are represented.

2.3.3 Spatial Analysis

The worldwide spread of HPP technologies, as can be seen in **Figure 2.13**, has not been followed any recognizable spatial pattern. On the contrary, literature shows their places of origin, density of application, end-use, and propagation, are as heterogeneous (and, at times, even contradicting one another) as diverse are the technologies themselves. Moreover, they have faced different fates in both very high and high-human development index (H-HDI) and medium and low-human development index (L-HDI) countries, under a number of contrasting conditions.

At a continental and subcontinental level, there are noticeable agglomerations of HPP technologies. The three main global clusters take place in Europe, South–Southeast Asia, and Eastern Africa. None of them are in coincidence with areas in which other RE-based pumping systems (e.g., solar-powered) have been installed [4]. The first one depicts an even distribution, mainly in western European countries such as the United Kingdom, Germany, The Netherlands, France, and Spain, which group a number of developers, manufacturers, and research centers linked to HPP technologies. On the other hand, the Asian and African clusters seem to be associated to areas of intensive traditional agriculture (i.e., southeast China, Indo-Gangetic plain, Indochinese peninsula), and to main transboundary river basins (e.g., Nile, Jubba, Zambezi), respectively. From these three groups, as presented in **Figure 2.14**, the Asian group is the only one with a consistent predominance of the agricultural irrigation as main end-use, whereas the European and African groups present a mix of water supply–agricultural irrigation uses.

With respect to a country scale, both quantitative and qualitative concentrations of technologies can be distinguished, i.e., number of reported cases and distinct technologies, respectively. The number of installed units per country is amply dominated by the CWTP in China and the HRP in the United States, both H-HDI countries, as shown in **Figure 2.13** and **Table 2.2**. Nevertheless, as seen in **Figure 2.14**, these technologies predominantly fulfilled two different end-uses, i.e., agricultural irrigation and water supply, respectively. The former resulted from an immense undertaking of the Chinese government, whereas the latter was a product of the proliferation of American manufacturers and the consequent popularization of the HRP. Other technologies that show a high nationwide density are the Turbopump and HSP in Kenya and Nepal, respectively, both serving agricultural irrigation, and the HRP in Philippines, mainly used to supply water in rural villages. These three cases, all within L-HDI countries, are the sole result of the efforts of their respective manufacturers.

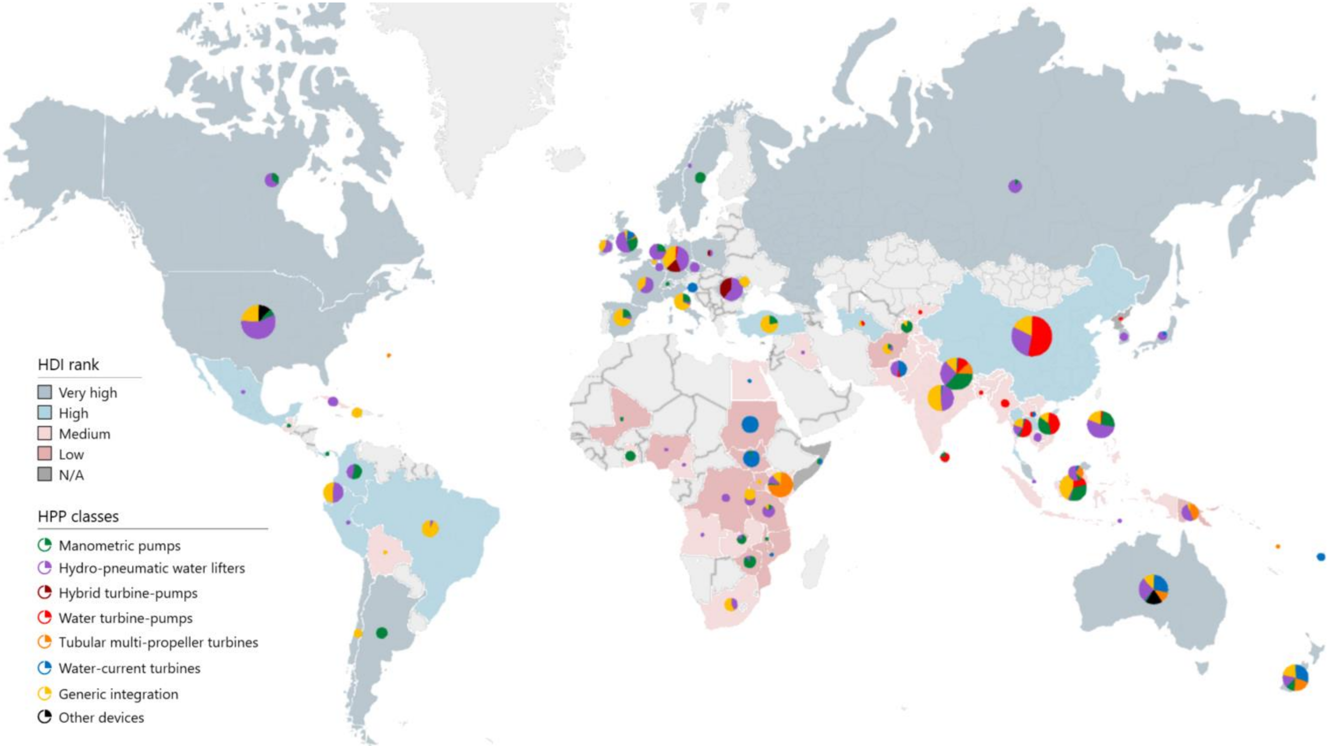


Figure 2.13. Worldwide mapping of HPP technologies per country. The size of each circle and the arc length of each colored slice represent, proportionally based on a logarithmic scale, the total number of reported devices and the number of reported devices per HPP classes, respectively. The background color of each country depicts its rank regarding the Human Development Index (HDI).

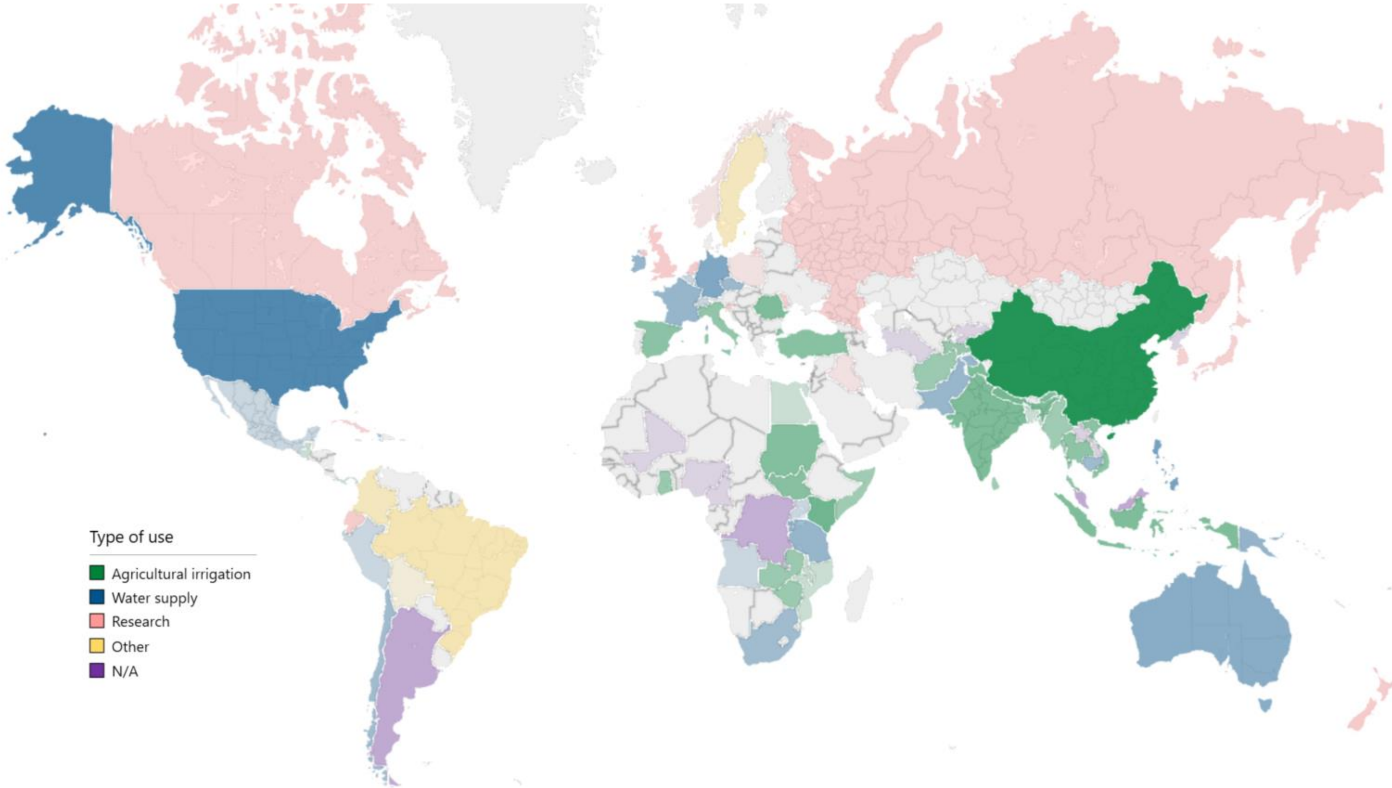


Figure 2.14. Worldwide mapping of predominant HPP technologies end-uses per country. The intensity of the colors represents, proportionally based on a logarithmic scale, the total number of reported HPP devices serving that end-use. The category "Other" groups the presence of manufacturers, as well as other less-common reported uses: Livestock water supply, aquaculture, land drainage, sewage pumping, landscape irrigation.

Table 2.2. Top-five ranking of countries in regard to different categories.

Ranking	Density of Technologies	Concentration of Diverse Technologies	Nr. of Manufacturers
1	China (CWTP)	USA (11)	UK (8)
2	USA (HRP)	Australia (9)	China, USA (7)
3	Kenya (Turbopump)	New Zealand (8)	Brazil, New Zealand (6)
4	Nepal (HSP)	Indonesia, Nepal, Thailand (7)	Australia (5)
5	Philippines (HRP)	Germany, Kenya, UK (6)	Colombia, Nepal (4)

The top-five ranking of countries are ordered from highest (1) to lowest (5). The density of technologies, concentration of diverse technologies, and number of manufacturers, are expressed regarding the predominant technology, number of distinct technologies, and number of distinct manufacturers, respectively.

On the other hand, both H-HDI and L-HDI countries have been fertile land for the application and coexistence of many diverse HPP technologies, as depicted in **Figure 2.13** and **Table 2.2**. With 11 different technologies the USA is the country bearing the highest diversity. However, the Australasian and South-Southeast Asian regions hold other important contenders: Australia, New Zealand, Indonesia, Nepal, and Thailand. In contrast, the concentration of manufacturers of HPP technologies is led by UK, USA, China, New Zealand, and Brazil, i.e., mainly H-HDI countries. Nevertheless, technologies such as the GT, Vietnamese hydraulic pump, Turbopump, and HRP are flagships of effective local production in L-HDI countries (e.g., Nepal, Philippines, Afghanistan, Kenya, Vietnam).

A number of technologies have been able to move across political boundaries, though with different destinies: The HRP, whose presence is reported in 42 countries, became the most cosmopolitan, ubiquitous a nd diversified HPP technology. The expansion of the CWTP, nonetheless, is unique amongst HPP devices: Although it bears the biggest number of reported applied cases ever, vastly outpacing any other technology, it just moved discreetly to other 14 countries (besides China), where it did not flourish at all. Other technologies that show certain degree of global presence are the HSP, WDP, HHP, CDP, and PAT-P. In contrast, the Plata pump (turning into the Kenyan Turbopump) and the GT quickly moved from their original H-HDI countries to L-HDI ones, modestly thriving within their new limits, possibly thanks to effective transfer of knowledge.

Technologies such as the HHP, the TT, and the Hydrobine, for example, arose completely within H-HDI countries (Sweden, Australia, and New Zealand, respectively), whereas other devices like many HSPs, HCPs and CDPs found their way in L-HDI ones. Interestingly, the HT, Bunyip Pump, Globe case coaxial water turbine pump, and the High Lifter on one hand, and the MT and Vietnamese hydraulic pump on the other hand, are technologies that have virtually remained within their original boundaries in H-HDI and L-HDI countries, respectively, without having experienced any further expansion.

2.3.4 Temporal Analysis

Unlike what occurs with their worldwide spread, evolution of HPP technologies over time follows noticeable patterns of peaks and depressions, as depicted in **Figure 2.15**. During the 16th and 17th centuries, the earliest HPP technologies (e.g., WDP, HSP, HCP) consisted mainly of large-scale waterworks for urban settings (e.g., Paris, London, Philadelphia, Munich) or for nobility buildings (e.g., Toledo, Versailles, Modave, Arkhangelskoye). Their number was very limited, mainly due to their complexity in construction and the high investment costs involved. During the 18th and 19th centuries, however, the invention of the HRP provided a considerable boost to HPP systems by fulfilling the function of a small-scale, affordable pumping technology that contributed in changing the lifestyle of many European and American households [167].

This first peak was gradually overshadowed during the first half of the 20th century by the rise of forms of readily available energy (e.g., steam, electric) different from hydraulic. Nevertheless, its second half was the most prolific period for HPP technologies, when many of them arose as a direct response to either scarce, unaffordable, or inaccessible fossil-based energy [168–170], in which high global oil prices due to critical events (e.g., oil embargos, Iran/Iraq War, Gulf War) seemed to be a main game-changer [171]. The main contributor to this unequalled peak in history was the aggressive spread of the CWTP over China during two continuous decades [114], though the rebound of the HRP [167] and the quick, yet focalized rising of the Turbopump [118] became non-negligible additions as well. This period is also characterized by the emergence of many other technologies such as the GT, PAT-P, TT, CDP, HT, and HCP, among others.

During the 2000s, however, HPP technologies faced a slump apparently linked to the drop of international oil prices [171], hence to more affordable fossil-origin energy, which in turn partially dragged down the interest for RE-based technologies [172]. Nowadays, there has been a regained HPP momentum, which could be the indirect result not only of fossil-fuel trends, but also of an increasing environmental awareness and more affordable RE-based technologies [172,173]. Although no other technology has ever reached the numbers of the CWTP, many of them altogether provide this current impulse: HSP, HRP, ADP, CDP, PAT-P. Nonetheless, the fluctuation of international oil prices can jeopardize the progress of RE [172], thus HPP along with it.

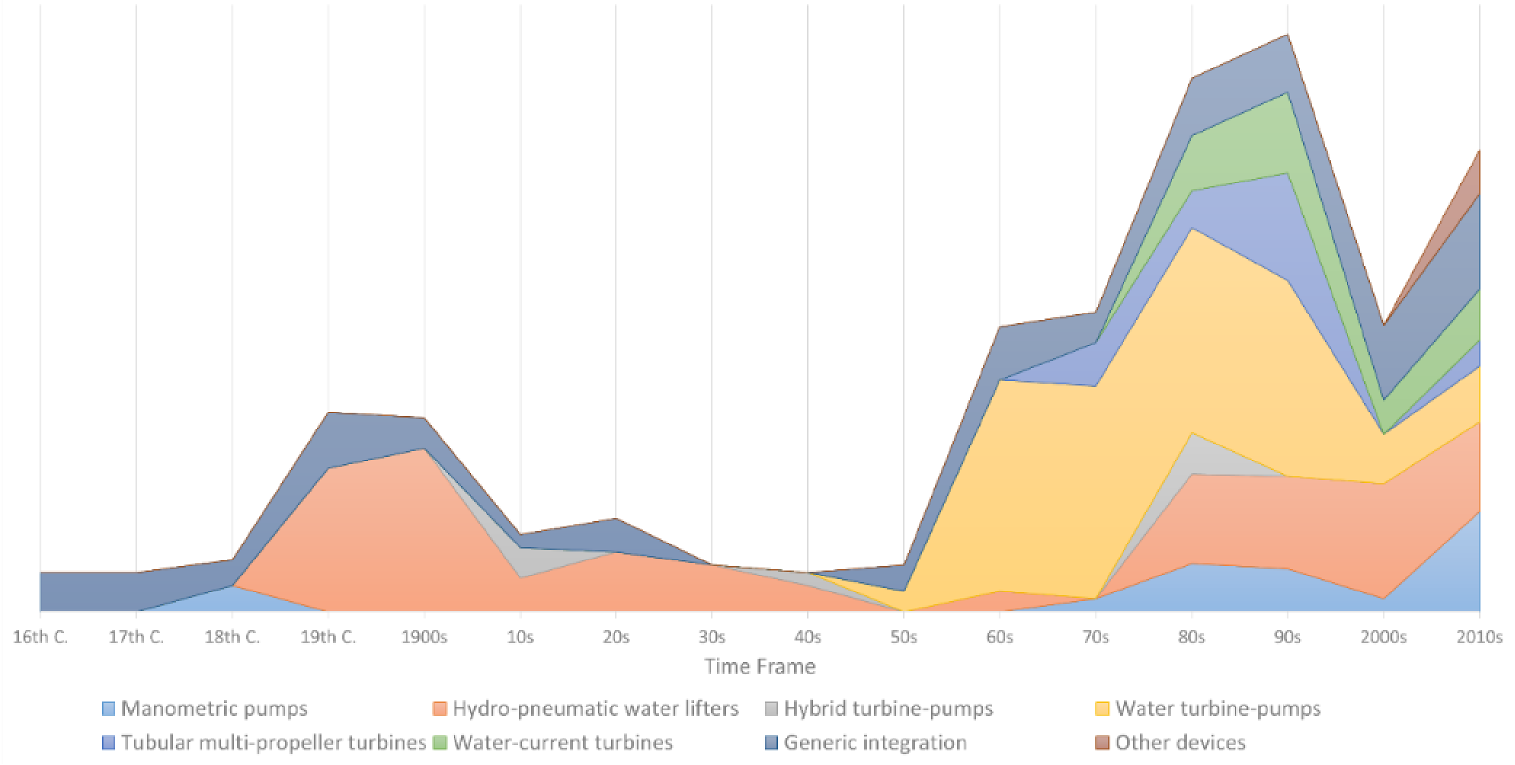


Figure 2.15. Number of reported cases of HPP technologies over time, depicted proportionally based on a logarithmic scale. The different colored areas represent each of the HPP classes.

At an individual level, HPP technologies present very dissimilar storylines in regard to their survival, growth, application, and fate. The LP, Hydrautomat, Hydropulsor and Plata pump declined despite their benefits, good reception, and commercial status. Moreover, devices such as the Platypus HRP and the Plata pump left the stage almost without any traceable information. Some technologies became marketable only after long research and prototyping processes (e.g., HSP, HRP, CWTP, GT), whereas other ones went commercial almost without research and development phase (e.g., HHP, Plata pump, Turbopump, High Lifter, Bunyip pump, Hydrobine). On the other hand, another group of technologies has not aroused any apparent commercial interest, thus being relegated to the research realm: CWL, HT, hydrokinetic linear turbine, hydraulic converter. Furthermore, a last group corresponds to potentially promising technologies incipiently researched in contemporary times: Filardo pump, aerohydraulic water lifter.

Some technologies thrived despite adversities, while other ones sunk even while counting on favorable conditions. Inherent properties, like simplicity of manufacturing, robustness, and sound functioning, have been key for the worldwide spread and persistence of the HRP over time, whose principle has remained virtually unchanged for more than two centuries. In the same line, a globally ubiquitous, well-developed market and affordable off-the-shelf units have been a solid ground for the more recent expansion of PAT-P throughout the second half of the 20th century. By contrast, complexity, uniqueness, and highly concentrated expertise of the LP resulted in crucial weaknesses when facing threats like world wars and market collapses.

Factors belonging to the management systems of HPP technologies have been also gravitating. Seemingly proper business models for the HHP seem a sound reason for its discreet, yet sustained use, especially in H-HDI countries (e.g., USA, Canada, Sweden). Contrariwise, mismanagement issues such as stakeholders' misalignments, weak supply chains, lack of spare parts, and stagnation in development were deadly for the Plata pump and for the once-acclaimed and officially supported CWTP. Moreover, the firm will of the people involved has led to push forward some causes against odds. Peter Garman, for instance, practically devoted his life to develop and spread the GT in L-HDI countries in Africa, despite civil wars, discontinuation of the research program, and local-manufacturing issues. Mangal Singh and Auke Idzenga are other examples of standing against many sociopolitical constraints, though the expansion of their Mangal Turbine WDP and HRP have found opposite destinies in India and Philippines, respectively. On the other hand, the constancy and endeavoring of Warren Tyson was eventually not enough for the TT to cope with world market crashes that led to an eventual commercial crumbling.

The appropriate technology movement and many of its related research centers and agencies (e.g., ITDG–Practical Action, VITA, SKAT, CICAT, GIZ) largely contributed to the expansion and implementation of some HPP technologies during the 1970s, 1980s, and 1990s. Several cases of HCPs, HRPs, GTs, and CDTs are direct products of their undertakings. In most of these instances, there was a strong component on expertise transfer, local manufacturing, and technology empowerment, aiming to create more resilient technologies rather than profit from patented ones [51,74,124,173–178].

2.4 Conclusions

HPP technologies have a long history, though having experienced different levels of prominence. More than 800 documents, different in nature and content, have been thoroughly reviewed to shape their role in space and time. Some of these technologies, such as the HRP and the WDP, have had global impact and interest since their origins until contemporary times, whereas other ones, like the Hydraulic converter, Hydropulsor, and HT, have had short and almost imperceptible lives. On the other hand, the CWTP, albeit with a relatively short lifespan, was one of the backbones of rural development in China, and a unique case worldwide. To a bigger or lesser extent, all of them have demonstrated to be a sound alternative to conventional water pumping systems, which can be unaffordable or even inaccessible, particularly in remote and off-the-grid areas.

In this sense, and in accordance with the objectives previously raised in the present document, three main following concluding remarks can be drawn:

1. The concept of pumping water by only relying in hydro-mechanical power–at least due to the amount of readily available "westernized" literature–is something seemingly reserved for few well-known technologies like the HRP, WDP, CWTP, GT, and HSP. Nevertheless, after an exhaustive and systematic search process, up to 30 HPP technologies were screened and analyzed. However, due to the wide range of features and applicability, their classification became eventually a main challenge for the present study. It is so that eight classes were defined, not based on one single property on the technologies, but on the combination of several of them (i.e., working principle, pumping principle, prime mover, pumping device, integration of the parts).
2. HPP technologies are not currently the main protagonists globally in water lifting. Some of them, however, mainly off-the-shelf devices within the class of generic integrations (i.e., CDP, PAT-P, TDP, WDP) applied in low-income countries, keep being the standard-bearers of their development, commercialization, and application. Moreover, and

despite their more than two century-long existence, both HRP and HSP pose a sustained interest from manufacturers and researchers, who persistently find in them low-cost, robust, and environmentally sound means of delivering water to new heights.

3. Individual HPP technologies do not present any apparent global spatial and temporal patterns. However, their aggregated analysis does say much more, not only on what has been done before, but on the current, as well as possible future, directions of research, application, and commercialization. For instance, nowadays, many South American countries show an incipient, yet growing interest in working with these technologies in both academia and industry. On the other hand, Sub-Saharan Africa remains a region where HPPs have the potential to create a higher social impact by improving livelihoods through sustained water supply. Last, yet not least, the baggage of expertise on design and manufacturing, as well as a higher capacity of adoption and use of HPPs in other regions (i.e., Europe, South and Southeast Asia), will be always a valuable capital for academics and manufacturers while exploring new insights in their respective domains.

HPP technologies still have a potentially promising future to keep supplying water in different contexts, particularly due to their current regained momentum. However, researchers, manufacturers, and users need to be aware of the importance that management systems, as well as business models, pose for these technologies beyond their mere performance. Their adequate implementation can represent higher resilience and adaptability capacities, while their lack or an open mismanagement could turn into their weakest point. The synthesis presented in this document serves as a reference starting point for other researchers in fields such as hydraulics engineering, water and irrigation management, and industrial archaeology, as well as others interested in the world of HPP systems.

Supplementary Materials

Datasets related to this article can be found at https://hdl.handle.net/10411/5RSELQ, an open-source online data repository hosted at DataverseNL [39].

Author Contributions

Conceptualization, J.C.I.Z. and M.W.E.; methodology, J.C.I.Z. and M.W.E.; formal analysis, J.C.I.Z., investigation, J.C.I.Z., J.M. and E.A.P., writing—original draft preparation, J.C.I.Z.; writing—review and editing, J.M., E.A.P., J.C.D. and M.W.E.; visualization, J.C.I.Z.; supervision, J.C.D. and M.W.E.

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Conflicts of Interest

One of the authors belongs to aQysta B.V., manufacturer of the Barsha Pump, one of the HPP technologies addressed in the present document.

Acronyms

RE	Renewable energy
HPP	Hydro-powered pumping
HSP	Hydro-powered spiral pump
HCP	Hydro-powered coil pump
HHP	Hydro-powered helix pump
HRP	Hydraulic ram pump
LP	Lambach pump
CWL	Cherepnov water lifter
HT	Hydraulic transformer
WTP	Water turbine pump
CWTP	Chinese water turbine pump
TMPT	Tubular multi-propeller turbine
WCT	Water current turbine
GT	Garman turbine
TT	Tyson turbine
WDP	Waterwheel-driven pump
ADP	Axial-flow turbine-driven pump
MDP	Mixed-flow turbine-driven pump
TDP	Tangential-flow turbine-driven pump
PAT-P	Pump-as-Turbine – Pump
CDP	Cross-flow turbine-driven pump
H-HDI	Very High and High-human development index
L-LDI	Medium and Low-human development index

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Chapter 3

Sowing Q methodology in the Rural Global South: A Review of Challenges and Good Practices

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Abstract

Poverty reduction is a priority on the global agenda. Several causes lead to diverse and complex forms of poverty, mostly concentrated in the Rural Global South (RGS). However, many poverty-alleviation policies keep (over)simplifying poverty to income levels, leading to flawed interventions. Adequate strategies to cope with RGS poverty require a much deeper understanding of its various forms and causes. Q methodology (Q) is a powerful participatory research technique that enables the study of different and consistent discourses of a phenomenon. Moreover, it has the potential to identify and reveal previously unheard narratives, thus allowing us to question the traditional meaning of RGS poverty. Yet, as a time- and assistance-intensive technique, its implementation faces methodological challenges that are currently overlooked and ought to be considered. We selected and reviewed 50 Q studies applied to different forms of RGS livelihoods. First, we discuss several on-field Q limitations associated with the physical, logistical, social, and cultural constraints. Second, we draw on good practices and strategies to cope with these limitations. Notwithstanding the limitations and strategies, we advocate building Q capacities and the gender-balanced empowerment of local researchers. This may contribute to a better understanding of the nuances and challenges of RGS livelihoods.

Keywords: Q methodology; Global South; rural poverty; methodological challenges

3.1 Introduction

The reduction of poverty and its ultimate eradication are key goals of the global agenda [Sustainable Development Goal (SDG) 1] (1). The conditions that lead to (extreme) poverty, mainly rooted in the Rural Global South[4] (RGS) (2,3), are very different across human groups or even individuals within the same community (4). Given that poverty is related to the deprivation of several resources and services (e.g., decent work, health, sanitation, drinking water, education) and a low capacity for self-determination (5), it acquires diverse, multidimensional forms (4). Still, there is a generalized unified conceptualization of poverty in poverty-alleviation policies, which relies primarily on income thresholds [e.g., World Bank's International Poverty Line (4,6)] as their compass (7). Such definitions and metrics overshadow the underlying context-dependent complexities: gender dimensions, urban/rural divide, societal power relationships, and local economic dynamics (8). In addition, facilitators of poverty alleviation programs are usually outsiders who imprint their own priorities, which is often related to a number of substantial biases (8–10). These limited approaches have led to distorted comprehension of the problem and ineffective interventions (7).

Smallholder agriculture is a good example of how an inadequate understanding of RGS dynamics has resulted in many failures (11,12). On one hand, this sector represents the most prominent livelihood in RGS economies. It is the main occupation of 70% of the RGS poor, supplies up to 80% of the food consumed in Asia and sub-Saharan Africa, and is the main activity of approximately 50% of RGS women in several countries (13). Investing in smallholder farming is therefore a crucial strategy in boosting RGS economies, securing and increasing incomes (SDG 1), providing decent and inclusive work (SDG 8), and supporting food security (SDG 2) (13–16). Unfortunately, many policies and interventions have not addressed farmers' actual needs and expectations (14) and have resulted in failures, such as biases in agricultural mechanization and technology adoption (17,18), lack of empowerment of female farmers (19–21), and high rates of rural youth disengagement and unemployment (22,23).

Adequate strategies to cope with RGS poverty require a much deeper understanding of its various forms and causes (4,8). Numerous research methods to unravel the complexities of RGS poverty have arisen in response to this need (8,24). Among these methods, Q methodology (henceforth referred to as Q) has emerged as a powerful participatory research technique that enables the study of different discourses in various contexts. It allows

[4] In this document, the Global South comprises low- and middle-income countries, as classified by the United Nations (147).

researchers to shift from single (and perhaps oversimplified) definitions around a particular phenomenon (e.g., RGS poverty) to the analysis of the perspectives of respondents about it (25). Simultaneously, Q embraces this diversity while maintaining a reductionist approach. This results in consistently clustered viewpoints that represent the spectrum of individual perceptions. Moreover, by systematically encompassing grassroots voices, Q may allow us to question the traditional meanings of RGS poverty by identifying and revealing previously unheard narratives.

Despite this potential and its effective implementation across several disciplines (26,27), Q is seldom engaged with a focus on the rurality of the Global South (28). Even in such cases, the on-field points of attention are seemingly underreported. Hardly any study has critically elaborated on its methodological implications in these contexts, let alone those whose livelihoods depend on any form of (smallholder) agriculture. Considering the challenges of conducting fieldwork in the RGS (29–33), and as part of a larger Q-led doctoral project conducted at Delft University of Technology (34), we aim to analyze and discuss: 1) methodological challenges of the implementation of Q in RGS settings that ought to be considered; and 2) the best (reported) practices to cope with these challenges, with emphasis on on-field deployment. Before discussing our review approach and its results, we provide background information on Q methodology.

3.2 Background on Q

Q is a semi-qualitative method developed in the 1930s by Stephenson (35) to scientifically understand human subjectivity within the field of psychology (27,36,37). In fundamental terms, it is considered an adaptation of Spearman's factor analysis, hence also referred to as an inverted factor technique (38). Q is performed by providing participants with a set of stimuli (usually, yet not limited to written statements), known as the Q-set, which must be sorted across an 'agree'/'disagree' (or equivalent) ranking scale, typically following a forced quasi-normal distribution sorting grid. The final sorting, frequently referred to as the Q-sort, is performed according to each participant's point of view, thereby reflecting the underlying subjectivity (39). Further processing of the collected data allows the identification of common unique viewpoints—normally referred to as factors—across respondents.

Q is considered a bottom-up research method, strongly characterized by promoting participation (40) and letting respondents express their own voices rather than confirming previously defined research hypotheses (36,39,40). Q has several substantial advantages, as follows:

- It combines the strengths of qualitative and quantitative methods by allowing subjective themes to emerge from collected data.
- It enables the researcher to identify similarities and dissents of participants' viewpoints regarding controversial topics.
- It provides participants with the control of defining the issue relevant to them.
- It is a highly adaptable method that allows to assess different dimensions of subjectivity.

On the downside, Q also presents limitations (28,36,40), as follows:

- It can be time-consuming for both researchers and respondents, thus discouraging active participation.
- Q participants may feel 'forced' in sorting the provided statements across a predefined grid.
- Sampling of respondents, selection and accuracy of statements, and interpretation of results can be strongly biased by the researcher.
- It demands constant facilitation; it requires large and adequate workspaces.

The Q technique obviously follows through the four typical methodological stages: 1) research design, 2) data collection, 3) analysis and results, and 4) interpretation (Figure 3.1). Next to the first stage, focusing on the scope and goal of the study and the research question, Q focuses on concourse development, selection of the Q-set, design of the sorting grid, and definition of the study population P-set. The second stage comprises the administration of the Q instruments to the P-set and, consequently, the respondents producing the respective sorts. The third stage involves statistical analyses of the dataset (after compiling the sorts), usually through dedicated computer software (36), resulting in extracted factors (groups). Finally, the fourth step is the process by which factors become meaningful through a narrative that combines an inspection of the ranked elements and rich, qualitative complementary data provided by the participants (e.g., reasoning on sorting choices, sociodemographic data, general opinion on the topic, and general opinion of the method) (37).

Given the diverse use of terminology across several Q studies (39), we provide some terms used throughout this review.

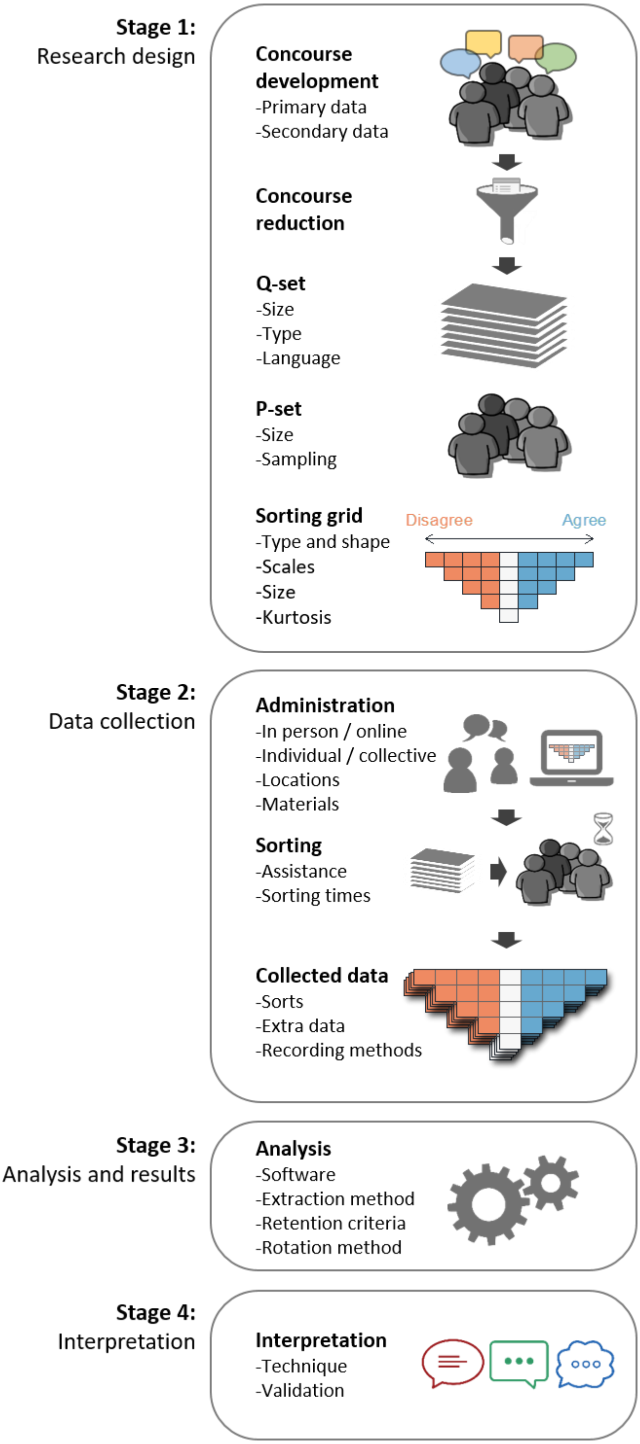

Figure 3.1. Stages and steps of Q, adapted from (28)

Concourse. This is a hypothetical infinite pool of positions, opinions, or perspectives on a certain topic. It is developed by collecting potentially relevant voices (27) from the primary and/or secondary data. The former is related to first-hand information gathered through interviews and observations with intervening actors. The latter is obtained through both scientific and gray literature of any kind that is relevant to the topic under study.

Q-set. This set of stimuli is a subset drawn from the general concourse. It is usually provided to participants in the form of written statements, although it can also be presented through pictures, drawings, sounds, videos, or even odors (25,39). There are no specific rules for defining the number of items that comprise the Q-set. The literature suggests a broad range, from as few as 10 to as extensive as 140 (36,39). Since it is a reduced form of the concourse, it must be large enough to be representative and small enough to be manageable for the participants.

P-set. This is the group of people that participate in the Q study. There is no consensus on the number of individuals to participate. The relevance of a Q is not given by the size of the P-set, as the representativeness of the different viewpoints on the topic under study is at least as important (36). The objective of Q is, first and foremost, to define typical viewpoints rather than their proportions across the total population (36,37).

Sort. This is the answer of a single individual after sorting (also referred to as distribution or ranking by other authors) satisfactorily all the items of the Q-set over the provided (un)forced sorting grid (36).

3.3 Methodology

We employed a semi-systematic approach in this review. As (41) argues, this is an appropriate strategy to review mixed qualitative/quantitative information and identify knowledge gaps in the literature. Our approach enabled us to synthesize state-of-the-art knowledge on the application of Q in RGS settings, its intrinsic methodological issues, and best practices.

3.3.1 Sources of information

We chose database search as the preferred technique to search for references. Because this review focuses on the application of Q across different fields instead of discipline-specific studies, we opted for two multidisciplinary scientific databases, namely Scopus and Web of Science. Complementarily, we triangulated these databases using Google Scholar to prevent location bias. In addition to the database search, we also used snowball sampling (through bibliographic references and hyperlinks) to identify additional documents that did not appear in the iterative searches.

3.3.2 Search criteria

To search for the literature in the respective scientific databases, we used the terms “Q methodology” and “Q-methodology”, in combination with any/some of the following terms: “rural”, “farm”, “farmer”, “farming”, “smallholder”, “agriculture”, “irrigation”, “water”, “forest”, “forestry”. We acknowledge the possible biases in the review as a consequence of screening literature using terms exclusively in the English language. We believe that our results provide sufficient details and discussion to accept this language-based restriction in our review.

We searched for references between April and August 2020, and within the publishing period of 2010 – 2020. Through iterative searches, it became apparent that prior to that period, very few studies fit within the scope of this review.

3.3.3 Selection criteria

Within the scope of the present study, we employed the following inclusion criteria to determine the relevance of selected documents:

1. Application of Q as (one of the) main research technique(s);
2. Addressing topics around RGS livelihoods, with particular emphasis on any form of (smallholder) agriculture;
3. Direct involvement of RGS dwellers during the methodological cycle of Q, with a specific emphasis on smallholder farmers; and,
4. Given the incipient and unfamiliar use of Q in RGS settings, peer-reviewed scientific article, published in a SCImago-indexed journal, with emphasis on Q1/Q2 impact factor quartiles.

Notwithstanding the above inclusion criteria, the final selection of studies was made based on our judgement. In our discussion below, we left aside five studies that, although fulfilled the set of criteria, showed a lack of (Q) methodological clarity (42–44), or considered RGS livelihoods from the perspective of non-rural actors (i.e., extension officers) (45,46).

3.3.4 Analytical methods and abstracted data

We analyzed the selected documents through a content analysis. Using this technique, we abstracted two types of information: descriptive information and the effects and findings of each study (41). The former comprised general characteristics of studies, that is, subject of study, category of Q study, (non) open access, and geographical foci of both study areas and researchers’ affiliations. This information contributed to revealing possible underlying Q research gaps between Global South and Global North. The latter consisted of Q methodological choices and their consequent findings, in accordance with the four methodological stages of Q pointed out above (**Figure 3.1**), with special emphasis on fieldwork, that is, research design and data collection.

3.4 Main findings

We selected in total 50 studies based on the above selection criteria. **Table 3.1** summarizes the data extracted from these studies. The complete dataset with qualitative and quantitative information obtained during the semi-systematic review process can be found in the Supplementary Material.

3.4.1 Characteristics of studies

The selected studies were mainly across the subjects[5] of environmental studies (n=15), conservation (n=7), forest and forestry (n=5), agriculture (n=4), and international development (n=4) (**Figure 3.2**a). Rural studies have traditionally focused on these subjects (33,97), leaving aside other relevant yet still neglected (Q) research themes in the RGS, including subjects such as rural health, women empowerment, food safety, environmental justice, responsible mechanization, and education. Furthermore, we categorized the 50 selected studies according to the Q themes proposed in (28). Most of these studies are within the category of management alternatives (n=36), with two other categories worth mentioning being conflict resolutions (n=4) and policy appraisals (n=10) (**Figure 3.2**b).

Only 16% (n=8) of the selected papers were published as open-access (54,57,69,81,83,85,87,88) (**Figure 3.2**a). Given the financial, legal, and technical restrictions faced by low- and middle-income countries, open access to scientific knowledge and data is crucial in the development of their research (98–101). It seems paradoxical that, to a large extent, the selected studies, which can directly benefit (Q) researchers in Global South countries, are not (easily) accessible to these scholars.

[5] According to the classifications of journals of Ulrichsweb™ Global Serials Directory (http://ulrichsweb.serialssolutions.com/); in cases of journals bearing more than one discipline, the more representative was assigned to the respective document.

Table 3.1. Data extracted from the 50 selected studies.

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
1 (47)	Laos: Savannakhet and Champasak provinces	To identify drivers and constraints affecting smallholder farmers' decision-making when considering introduced technologies	PD: NE-UN / SD: GL-UN	EJ	16	SS	T: 35 F: 16 M: 19 RD: 100%	Not important to Very important	-3 to +3 (7p)	T: Face-to-face L: N/A A: By-step guidance; clarification of statements	~1 h	S: PQMethod E: PCA R: Varimax	NF: 2 VE: 40%	Z-score table	Long societal scenarios	Semi-literacy of respondents
2 (48)	Ecuador: Tabuga village (Manabí province)	To identify and categorize barriers to teaching environmental education	SD: SL-GL	EJ	25	PS, CS	T: 25 F: 7 M: 18 RD: N/A	Very unimportant barriers to Very important barriers	-4 to +4 (9p)	T: Face-to-face L: Schools A: Pre-sort instructions	~35 m	S: PQMethod E: N/A R: N/A	NF: 3 VE: 44%	Factor table	Explanatory labels	N/A
3 (49)	Indonesia: South Sumatra, Riau and West Kalimantan provinces	To analyze discourses around the Indonesian Sustainable Palm Oil policy	PD: EX-PR / SD: SL-GL	DD, MM, SW	54	N/A	T: 27 F: N/A M: N/A RD: 0%	Most disagree to Most agree	-5 to +5 (11p)	T: Face-to-face L: N/A A: Clarification of statements	N/A	S: PQMethod E: PCA R: Varimax	NF: 5 VE: 48%	Factor table	Long societal scenarios	N/A
4 (50)	Brazil: Lagoa Grande village (Mato Grosso do Sul state)	To identify rural women's viewpoint about the elements that would facilitate them to eventually take over the family farm	SD: SL-GL	CD	30	CS, SS	T: 28 F: 28 M: 0 RD: 39%	Strong disagreement to Strong agreement	-4 to +4 (9p)	T: Face-to-face, individually L: N/A A: N/A	N/A	S: PQMethod E: PCA R: Varimax	NF: 5 VE: 64%	Factor table	Societal scenarios	Time restrictions did not allow to conduct post-sorting interviews
5 (51)	Brazil: Far west of Bahía state	To analyze discourses regarding environmental governance held amongst key actors in a region of expanding high-	PD: EX-PR	CT	26	PS, SS	T: 21 F: 4 M: 17 RD: 24%	Most disagree with my views to Most agree with my views	-4 to +4 (9p)	T: N/A L: N/A A: N/A	~25 m	S: PQMethod E: N/A R: Varimax	NF: 4 VE: 67%	Z-score table	Societal scenarios	Anguishing of respondents after some difficult choices in sorting

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
		input, high-output agriculture														
6 (52)	Thailand: Ping river basin (Chiang Mai province)	To explore perspectives of environmental best practices in Thai agriculture	PD: EX-OR / SD: UN	MM	36	PS	T: 72 F: N/A M: N/A RD: 100%	Disagree to Agree (not clear)	-4 to +4 (9p)	T: Face-to-face L: N/A A: By-step guidance	N/A	S: PQMethod E: PCA R: Varimax	NF: 4 VE: N/A	Factor table	Behavioral adjectives	N/A
7 (53)	Brazil: Paragominas municipality	To explore smallholders' perceptions of fire use, fire control, and firefighting in a post-frontier region of the eastern Amazon, and how these relate to fire risk perceptions and governance preferences	PD: NE-PR / SD: UN	MM	17	SS	T: 51 F: N/A M: N/A RD: 100%	Strongly disagrees to Strongly agrees	-2 to +2 (5p)	T: Face-to-face, individually L: Farmers' houses A: By-step guidance; reading of statements	~1/2 h	S: N/A E: PCA R: Varimax	NF: 4 VE: 55%	Modified Z-score table	Long societal scenarios	Low literacy levels of respondents
8 (54)	Indonesia: Riau province	To illustrate the diverse stakeholders' perceptions of peat fires and fire management interventions across sectors and scales of governance	PD: EX-PR / SD: SL-GL	IR	70	PS	T: 219 F: N/A M: N/A RD: 80%	Least important to Most important / Least effective to Most effective	-3 to +3 (8p)	T: N/A L: N/A A: On-demand reading of statements	N/A	S: qmethod for R E: PCA R: Varimax	NF: 9 (4 / 5) VE: 47% / 39%	Factor table and Z-score diagram	Long societal scenarios	N/A
9 (55)	Iran: Marvdasht county	To study stakeholders' perceptions toward agricultural water poverty	PD: EX-PR / SD: UN	MM	54	PS	T: 75 F: N/A M: N/A RD: 67%	Strongly disagree to Strongly agree	-2 to +2 (5p)	T: Face-to-face, individually L: N/A A: N/A	N/A	S: PQMethod E: CFA R: Varimax	NF: 7 (4 – farmers / 3 – specialists) VE: 42% / 45%	Z-score table	Long behavioral adjectives	N/A
10	Brazil:	To determine	PD:	EJ	26	PS	T: 26	Most agree	+4 to -4	T: Face-to-face	~40 m	S: PQMethod	NF: 4	Combined Z-	Long	N/A

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
(56)	Andalucía village (Nioaque municipality, Mato Grosso do Sul state)	empirically social perspectives regarding ethanol-agrarian reform conflicts, focusing specifically on food security and safety	EX-PR				F: N/A M: N/A RD: N/A	with my views to Most disagree with my views	(9p)	L: N/A A: By-step guidance	(sorting); ~55 m (interview)	E: N/A R: N/A	VE: 63%	score and factor table	societal scenarios	
11 (57)	Brazil: Mato Grosso state	To identify viewpoints of sellers and buyers of an emerging forest certificate trading scheme	PD: EX-UN / SD: SL-GL	CD	39	PS, SS	T: 59 F: N/A M: N/A RD: 100%	Strongly disagree to Strongly agree	-4 to +4 (9p)	T: Face-to-face L: N/A A: Pre-sort instructions	~1 h	S: qmethod for R E: PCA R: Varimax	NF: 6 (3 / 3) VE: 44% / 46%	Factor table	Behavioral adjectives	Remote and nonaffiliated farmers were likely undersampled
12 (58)	Niger: N'dounga, Namaro and Bitinkodji communes	To examine the viewpoints of stakeholders in the management and conservation of farm animal biodiversity in Niger	PD: EX-NR / SD: SL-GL	N/A	48	PS	T: 20 F: N/A M: N/A RD: 35%	I totally disagree to I fully agree	-3 to +3 (7p)	T: Face-to-face L: N/A A: Pre-sort instructions	N/A	S: qmethod for R E: PCA R: Varimax	NF: 3 VE: 61%	Factor table	Behavioral adjectives	Low educational level of several respondents
13 (59)	Nepal: Beldangi I refugee camp (Damak municipality)	To explore the mutual imaging of aid workers and refugees in humanitarian crisis contexts	PD: EX-PR / SD: UN	N/A	47	SRS	T: 28 F: N/A M: N/A RD: N/A	Strongly disagree to Strongly agree	N/A (11p)	T: Face-to-face L: N/A A: N/A	N/A	S: PQMethod E: N/A R: N/A	NF: 4 VE: N/A	N/A	Generic labels	N/A
14 (60)	China: Rizhao, Tai'an, Xuzhou, Lu'an, Xinyang, Zhumadian, Fuyang, Shangqiu and Luoyang cities	To evaluate the attitudes of Chinese farmers in the period of agricultural supply-side structural reform	N/A	N/A	33	N/A	T: 61 F: 27 M: 35 RD: 100%	Strong disagreement to Strong agreement	-4 to +4 (9p)	T: Face-to-face L: N/A A: N/A	30 m - 3 h	S: PQMethod E: PCA R: Varimax	NF: 3 VE: 44%	Combined Z-score and factor table	Behavioral adjectives	N/A
15 (61)	Argentina: Salta province	To identify and describe social	SD: SL-GL	CT	68	PS	T: 60 F: N/A	Less agreement to	-5 to +5 (11p)	T: Face-to-face / Online (POETQ)	N/A	S: PQMethod E: PCA	NF: 4 VE: 54%	Z-score table	Societal scenarios	N/A

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
		perspectives on deforestation, land use change and economic development					M: N/A RD: 17%	More agreement		L: N/A A: N/A / Software-led		R: Varimax				
16 (62)	Malaysia: Mangrove Forest Reserve, Perak state	To identify perspectives on the management of Matang Mangrove Forest Reserve	PD: EX-NR / SD: SL-GL	CT	48	SS	T: 29 F: N/A M: N/A RD: 31%	Least agreement to Strongest agreement	-3 to +3 (7p)	T: Face-to-face L: N/A A: N/A	N/A	S: PQMethod E: CFA R: Varimax	NF: 3 VE: 41%	Factor arrays	Long societal scenarios	Participants had difficulties at times while sorting Q was difficult or impossible to administer to some rural dwellers, due to social, educational and cultural barriers Some respondents tended to please researchers rather than answering authentically
17 (63)	Indonesia: West Lombok district	To analyze diverse perspectives on the certification of a payment for watershed services scheme	PD: EX-NR / SD: SL	N/A	48	PS, SS	T: 19 F: N/A M: N/A RD: 21%	Most disagreed to Most agreed	-6 to +6 (13p)	T: Face-to-face L: N/A A: By-step guidance	N/A	S: PQMethod E: PCA R: Varimax	NF: 3 VE: 51%	Factor table	Long societal scenarios	N/A
18 (64)	Ethiopia: Southwestern Ethopia (Jimma zone)	To examine alternative approaches to food security and biodiversity conservation	PD: EX-NR / SD: SL-GL	CT	32	PS	T: 50 F: N/A M: N/A RD: 2%	Most important to Least important	+4 to -4 (vertical) (9p)	T: Face-to-face, individually L: N/A A: Pre-sort instructions	N/A	S: qmethod for R E: PCA R: Varimax	NF: 4 VE: 48%	Z-score table	Societal scenarios	N/A
19 (65)	Ukraine: Kyiv, Kherson, Ternopil, Lviv and Chernihiv municipalities	To reveal barriers to crop rotation	PD: EX-PR	N/A	27	PS, SS	T: 10 F: N/A M: N/A RD: 20%	Strongly agree to Strongly disagree	+3 to -3 (7p)	T: Online (Q sortware) L: N/A A: Software-led	N/A	S: qmethod for R 32.2 E: N/A R: Varimax	NF: 3 VE: 53%	Factor table and Z-score diagram	Societal scenarios	Respondents were difficult to reach

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
20 (66)	Laos: Leng, Lé, Xay, Nadou villages (Kham district, Xieng Khouang province)	To understand farmers' perceptions of soil fertility	PD: NE-UN	N/A	47	N/A	T: 19 F: N/A M: N/A RD: 100%	Disagree to Agree	-5 to +5 (11p)	T: Face-to-face L: Respondents' houses A: By-step guidance; reading of statements; on-demand clarification	N/A	S: PQMethod E: CFA R: Varimax	NF: 3 VE: N/A	Factor table	Mixed (scenarios and adjectives)	N/A
21 (67)	Costa Rica: Talamanca region	To examine perspectives about baseline constructions of land-use change, and the potential role of offsets in an indigenous community	PD: EX-PR / SD: SL-GL	CT	30	PS	T: 15 F: 4 M: 11 RD: 67%	Most disagree to Most agree	-4 to +4 (9p)	T: Face-to-face L: N/A A: N/A	N/A	S: PQMethod E: N/A R: Varimax	NF: 3 VE: 46%	Factor table	Behavioral adjectives	N/A
22 (68)	Brazil: Santa Catarina region	To analyze the perception of farmers on the landscape and its dynamics	SD: SL-GL	N/A	16	SS	T: 90 F: 45 M: 45 RD: 100%	Higher agreement to Less agreement	+3 to -3 (7p)	T: Face-to-face L: N/A A: N/A	N/A	S: PQMethod E: PCA R: Varimax	NF: 3 VE: 48%	Factor table	Societal scenarios	N/A
23 (69)	Mexico: La Preciosita Sangre de Cristo village (Puebla state)	To understand young farmers' views of a community-based ecotourism project	PD: EX-OR	CA	36	PS	T: 16 F: 5 M: 11 RD: 100%	I don't identify with to I identify with	-5 to +5 (11p)	T: Face-to-face, collectively L: N/A A: N/A	N/A	S: PQMethod E: PCA R: Varimax	NF: 3 VE: N/A	Z-score table, factor arrays and factor table	Societal scenarios	N/A
24 (70)	Colombia: Bogotá, Cali, Buenaventura, Medellín municipalities	To explore the discourses that underpin Payment for Ecosystem Services debates and practice in Colombia	SD: SL-GL	CD, CT, EJ	36	PS, SS	T: 41 F: N/A M: N/A RD: N/A	Strongly disagree to Strongly agree	-4 to +4 (9p)	T: Face-to-face L: N/A A: Pre-sort instructions; by-step guidance; on-demand clarification	~1 h	S: qmethod for R E: PCA R: Varimax	NF: 3 VE: 59%	Combined Z-score and factor table	Societal scenarios	N/A
25 (71)	Vietnam: Phuoc Duc and Tam Lanh	To examine community perceptions	SD: UN	N/A	25	SS	T: 137 F: 49 M: 88	Least important to Most	-4 to +4 (9p)	T: Face-to-face, individually L: N/A	N/A	S: N/A E: PCA R: Varimax	NF: 8 (5 / 3) VE:	Factor table	Generic labels	N/A

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
	communes (Quang Nam province)	concerning the impact of gold mining					RD: 88%	important		A: Pre-sort instructions			51.23% / 43%			
26 (72)	Cambodia: Oddar Meanchey province	To assess the perceptions of local stakeholders towards the quality of governance of the first REDD+ pilot project in Cambodia	SD: SL-GL	CD	40	PS	T: 52 F: N/A M: N/A RD: 100%	Most strongly disagree to Most strongly agree	-4 to +4 (9p)	T: Face-to-face, individually L: Respondents' houses A: Pre-sort instructions; by-step guidance	N/A	S: PQMethod E: PCA R: Varimax	NF: 4 VE: 35%	Z-score table	Societal scenarios	N/A
27 (73)	Cambodia: Oddar Meanchey province	To investigate the views of local experts on the sustainability of community-based forestry management	SD: SL-GL	EJ	43	SS	T: 52 F: 8 M: 44 RD: 100%	I Most Disagree to I Most Agree	-5 to +5 (11p)	T: Face-to-face, individually L: N/A T: By-step guidance	~50 m	S: PQMethod E: PCA R: Varimax	NF: 4 VE: 37%	Modified Z-score table	Societal scenarios	N/A
28 (74)	Papua New Guinea: Eastern Highlands and Morobe provinces	To examine the motivations for growing diverse crops amongst semi-subsistence rural farmers in Papua New Guinea	PD: NE-PR	CD	31	RS, SS	T: 92 F: 50 M: 42 RD: 100%	Don't agree at all to Agree very much	-3 to +3 (7p)	T: Face-to-face L: N/A A: By-step guidance; reading of statements	N/A	S: PQMethod E: PCA R: Varimax	NF: 5 VE: N/A	Factor table	Behavioral adjectives	Low literacy level of respondents
29 (75)	Brazil: Mato Grosso do Sul state	To assess the diversity of values and goals amongst Brazilian commercial-scale progressive beef farmers	SD: UN	N/A	49	PS, SRS	T: 26 F: 0 M: 26 RD: 100%	Strong disagreement to Strong agreement	-4 to +4 (9p)	T: Face-to-face L: N/A A: N/A	~1.5 h	S: PQMethod E: PCA R: Varimax	NF: 4 VE: 62%	Factor table	Behavioral adjectives	Respondents were all male; they were the main decision makers, although some women were the legal owners of the farms
30 (76)	Indonesia: East Kalimantan province	To study the general perceptions of rural populations	PD: NE-PR	EJ	30	SRS	T: 31 F: 12 M: 19 RD: 100%	Most disagree with to Most agree with	-3 to +3 (8p)	T: Face-to-face, three-person rounds L: N/A	20 m - 1 h	S: PQMethod E: PCA R: Varimax	NF: 3 VE: N/A	Factor arrays and factor table	Mixed (scenarios and adjectives)	Respondents had different levels of fluency in Indonesian

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
		toward industrial plantations								A: Pre-sort instructions; on-demand clarification						
31 (77)	Indonesia: Getas village (Blora district), Pitu village (Ngawi district)	To explore stakeholder perceptions of the effects of agroforestry and mono-cropping systems on water use	SD: SL-GL	N/A	17	N/A	T: 33 F: N/A M: N/A RD: N/A	Fully agree to Fully disagree	+2 to -2 (5p)	T: Face-to-face; individual and collective L: N/A A: N/A	N/A	S: qmethod for R E: N/A R: N/A	NF: 3 VE: N/A	Z-score diagram	Generic labels	N/A
32 (78)	Mexico: La Preciosita Sangre de Cristo village (Puebla state)	To identify perspectives on sustainable management of a community-owned forest reserve	PD: EX-OR	CT	36	N/A	T: 20 F: 9 M: 1 RD: 100%	Unlike me to Like me	-4 to +4 (9p)	T: N/A L: N/A A: N/A	N/A	S: PQMethod E: PCA R: Varimax	NF: 3 VE: 65%	Z-score and factor tables	Societal scenarios	N/A
33 (79)	Colombia: Cimitarra, Magangué, Guapi, Pasto and Tuluá municipalities	To understand stakeholders' values about Colombian forest legislation and its implications for legal timber trade	PD: EX-UN	EJ, SW	34	PS	T: 27 F: 5 M: 22 RD: 19%	Less affect me to Most affect me	-4 to +4 (9p)	T: Face-to-face, individually L: N/A A: N/A	N/A	S: PQMethod E: PCA R: Varimax	NF: 4 VE: 52%	Z-score table	Long societal scenarios	N/A
34 (80)	Mexico: La Preciosita Sangre de Cristo village (Puebla state)	To examine perceptions of small forest owners to build infrastructure in their forest as part of their community-based ecotourism project, and, to explore their underlying reasons to retain the forest for	PD: EX-OR / SD: SL-GL	CA	32	PS	T: 14 F: 7 M: 7 RD: 100%	Unlike me to Like me	-4 to +4 (9p)	T: Face-to-face L: Respondents' houses A: N/A	N/A	S: PQMethod E: PCA R: Varimax	NF: 3 VE: 56%	Z-score table	Long societal scenarios	N/A

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
		ecotourism														
35 (81)	Namibia	To investigate whether a diverse range of stakeholders could agree on how to mitigate conflict between carnivores and livestock farmers in Namibia	PD: EX-PR / SD: GL	CD	36	PS, SS	T: 35 F: N/A M: N/A RD: 40%	Strongly disagree to Strongly agree	-3 to +3 (7p)	T: Online (SurveyMonkey) L: N/A A: Software-led	N/A	S: PQMethod E: PCA R: Varimax	NF: 2 (2 in each of three rounds) VE: 51% / 45% / 57%	Z-score table	Generic labels	N/A
36 (82)	Brazil: São Felix do Xingu (Pará state)	To study small-scale farmers' needs to end deforestation	PD: NE-UN	N/A	29	SS	T: 14 F: 0 M: 14 RD: 100%	Strongly disapproves to Strongly approves	-2 to +2 (5p)	T: Face-to-face L: Farmers' villages A: N/A	~30 m	S: N/A E: PCA R: Varimax	NF: 3 VE: N/A	Z-score table	Behavioral adjectives	Due to remoteness researchers had to rely on an organization to reach participants Communications difficulties hampered higher participation rates Some women farmer refused to participate due to shyness Some participants found difficult to make sorting choices
37 (83)	South Africa: Jouberton and Ikageng communities, Ventersdorp municipality	To study the influence of religious beliefs on the understanding and experience of climate change adaptation	PD: EX-OR	N/A	40	PS, SS	T: 25 F: N/A M: N/A RD: N/A	Strongly agree to Strongly disagree	+3 to -3 (7p)	T: Face-to-face L: N/A A: Pre-sort instructions	N/A	S: PQMethod E: PCA R: N/A	NF: 5 VE: 58%	Factor table	Mixed (scenarios and adjectives)	N/A
38 (84)	Madagascar: Alaotra-Mangoro and Analanjirofo	To gain a better understanding of farmers' definitions and	PD: EX-OR	N/A	52	SS	T: 30 F: N/A M: N/A RD: 100%	Most disagree to Most agree	1 to 11 (11p)	T: Face-to-face, individually L: N/A A: N/A	N/A	S: PQMethod E: N/A R: Varimax	NF: 5 VE: 38%	Combined Z-score and factor table	Societal scenarios	Possible dissimilarities in terms translated between languages

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
	regions	experiences of change														and local dialects
39 (85)	Ghana: Tepa (Ashanti region), Savelugu (Northern region)	To understand young people's attitudes towards farming; and, to understand what should be done about rural young people and farming	PD: NE-UN / SD: SL-GL	N/A	32	SS	T: 38 F: 20 M: 18 RD: 100%	Most disagree to Most agree	-3 to +3 (7p)	T: Face-to-face L: N/A A: Pre-sort instructions; by-step guidance; on-demand clarification	N/A	S: PQMethod E: PCA R: Varimax	NF: 8 (4 / 4) VE: N/A	Factor table	Long societal scenarios	N/A
40 (86)	Iran: Khuzestan province	To understand how farmers perceive the impact of dust phenomenon on agricultural production activities	PD: EX-PR / SD: GL	CT, EJ	48	PS, SS	T: 60 F: 0 M: 60 RD: 100%	Strongly disagree to Strongly agree	-2 to +2 (5p)	T: Face-to-face L: N/A A: N/A	N/A	S: PQMethod E: CFA R: Varimax	NF: 3 VE: 54%	N/A	Behavioral adjectives	N/A
41 (87)	Vietnam: Long An and Tay Ninh provinces	To explore farmers' perceptions of foot-and-mouth disease vaccination	PD: EX-OR	N/A	46	STS	T: 46 F: 13 M: 29 RD: 100%	Strongly in disagreement to Strongly in agreement	-3 to +3 (7p)	T: Face-to-face, individually L: Usually farmers' houses A: Pre-sort instructions	>1 h	S: qmethod for R E: PCA R: Varimax	NF: 3 VE: 57%	Factor arrays and Z-score table	Societal scenarios	Low degree of farmer participation Some participants did not follow instructions Too short post-sorting answers due to tiredness after long sorting times Possible response bias due to pre-sorting discussions Some participants complained about unclear or complicated statements
42 (88)	Vietnam: Dong Thap province	To identify poultry farmers' drivers to	PD: EX-PR	CT	46	RS, SS	T: 54 F: 6	Extremely disagree to	-3 to +3 (7p)	T: Face-to-face L: Usually	~1 h	S: R E: PCA	NF: 7 (4 / 3)	Factor arrays and factor	Societal scenarios	Sampled target population changed

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
	(Mekong delta)	use high amounts of antimicrobials					M: 48 RD: 52%	Extremely agree		farmers' houses A: Pre-sort instructions		R: N/A	VE: 55% / 50%	table		due to unpredictable field constraints Some participants misunderstood instructions or were not willing to complete the sorting Husbands were usually the respondents, although wives were the ones conducting the farm work
43 (89)	Ghana: Tarkwa-Nsuaem municipality	To understands areas of agreements and disagreements amongst critical stakeholders as a way to improve environmental policy development and implementation	PD: EX-PR / SD: SL-GL	CD	31	PS	T: 15 F: N/A M: N/A RD: N/A	Least effective to Most effective	-3 to +3 (7p)	T: Face-to-face L: N/A A: By-step guidance	N/A	S: R E: N/A R: Varimax	NF: 3 VE: 46%	Factor table and factor arrays	Societal scenarios	N/A
44 (90)	Colombia: Luruaco and Santa Catalina municipalities	To explore the understanding of the conservation-development relationship by a rural community in Colombia	PD: EX-UN	CT	40	RS, PS	T: 38 F: 20 M: 16 RD: 100%	Disagree most to Agree most	-4 to +4 (9p)	T: Face-to-face, collectively L: N/A A: N/A	N/A	S: PQMethod E: PCA R: Varimax	NF: 4 VE: 51%	Crib sheets	Societal scenarios	N/A
45 (91)	Ecuador: Quito municipality; Tundayme and Los Encuentros	To assess subjective perceptions of key stakeholders	SD: UN	N/A	30	SS	T: 47 F: N/A M: N/A RD: N/A	Agree the most to Disagree the most	N/A	T: N/A L: N/A A: Pre-sort instructions	N/A	S: PQMethod E: CFA R: Varimax / Judgmental	NF: 4 VE: 62%	Factor table	Societal scenarios	N/A

Nr. (Ref.)	Location	Aim	Concourse Sources	Concourse RT	Q-set size	P-set ST	P-set Size	Sorting grid Criteria	Sorting grid Scale	Administration	Sorting time	Analysis	Factors Results	Factors Presentation	Factors Labelling	Salient reported difficulties
	parishes (Zamora Chinchipe province); San Juan Bosco municipality (Morona Santiago province)	regarding mining projects														
46 (92)	Rwanda: Murambi and Masoro communities (Rulindo district)	To quantitatively analyze qualitative perspectives regarding impacts of mining-led development at a district level in Rwanda	PD: EX-PR / SD: GL	CT	46	PS, SS	T: 49 F: 15 M: 34 RD: 71%	Fully Disagree to Fully Agree	-6 to +6 (13p)	T: Face-to-face L: Communities, offices A: Pre-sort instructions	N/A	S: PQMethod E: PCA R: Varimax	NF: 3 VE: 41%	Factor arrays and factor table	Long societal scenarios	Some respondents sorted out of the distribution grid; at times they were unable to prioritize statements Some respondents criticized the forced distribution
47 (93)	Indonesia: North Luwu, Bondowoso and Pelalawan districts	To identify sustainability perspectives in agriculture	PD: EX-PR / SD: SL-GL	CT, CD	37	PS	T: 64 F: 13 M: 51 RD: 52%	Strongly disagree to Strongly agree	-4 to +4 (9p)	T: Face-to-face L: N/A A: Pre-sort instructions; by-step guidance; reading of statements; on-demand clarification	N/A	S: PQMethod E: PCA R: Varimax	NF: 2 VE: 33%	Modified Z-score table	Behavioral adjectives	Gender diversity was hard to accomplish in the field due to cultural constraints
48 (94)	Ghana: Tepa (Ashanti region), Savelugu (Northern region)	To explore perspectives of job desirability	PD: NE-UN / SD: SL-GL	N/A	59	SS	T: 72 F: 29 M: 43 RD: 100%	Most disagree to Most Agree	-4 to +4 (9p)	T: Face-to-face L: N/A A: Pre-sort instructions; by-step guidance; on-demand clarification	65 m (students); 50 m (parents)	S: PQMethod E: PCA R: Varimax	NF: 19 (8 / 11) VE: N/A	Factor summary table	Long societal scenarios	The initial aim was to interview students and their parents; because some parents could not or were unwilling to participate, the authors resorted to parents of non-participant students

Nr. (Ref.)	Location	Aim	Concourse		Q-set size	P-set		Sorting grid		Administration	Sorting time	Analysis	Factors			Salient reported difficulties
			Sources	RT		ST	Size	Criteria	Scale				Results	Presentation	Labelling	
49 (95)	Mexico: Chiapas state	To identify smallholders' views with regard to silvopastoral practices in a community in the forest frontier in Chiapas	PD: EX-PR / SD: UN	CT	26	PS	T: 32 F: 0 M: 32 RD: 100%	Most disagree to Most agree	-3 to +3 (7p)	T: Face-to-face L: N/A A: N/A	N/A	S: qmethod for R E: PCA R: Varimax	NF: 3 VE: N/A	Z-score diagram	Behavioral adjectives	Lack of female respondents because male head of household is the decision maker
50 (96)	Iran: Hamidiyeh district	To investigate and understand farmers' perceptions regarding climate change	PD: EX-PR / SD: SL-GL	MM	42	PS, SS	T: 46 F: N/A M: N/A RD: 100%	Most disagree to Most agree	-2 to +2 (5p)	T: Face-to-face, individually L: Extension offices, homes, farms A: By-step guidance	~80 m	S: PQMethod E: CFA R: Varimax	NF: 3 VE: 56%	Factor table	Mixed (scenarios and adjectives)	N/A

List of acronyms in the table:
In Concourse – Sources column: primary data (PD); not-exclusive for the study (NE); exclusive for the study (EX); unspecified sources (UN); partially rural dwellers sources (PR); only rural dweller sources (OR); no rural dweller sources (NR); secondary data (SD); grey literature (GL); scientific literature (SL)
In Concourse – Reduction Technique (RT) column: expert judgement (EJ); division in discourses (DD); matrix method (MM); software (SW); categorization (CT); iterative refinement (IR); combination and deletion of similar statements (CD); content analysis (CA)
In P-set – Sampling Technique (ST) column: snowball sampling (SS); purposive sampling (PS); convenience sampling (CS); random sampling (RS); stratified random sampling (SRS); structured sampling (STS)
In P-set – Size column: total (T); female (F); male (M); percentage of rural dwellers (RD)
In Sorting grid – Scale column: sorting points (p)
In Administration column: administration technique (T), location (L), assistance (A)
In Analysis column: software (S); factor extraction method (E); factor rotation method (R); Principal Component Analysis (PCA); Centroid Factor Analysis (CFA)
In Factors – Results column: number of retained factors (NF); total variance explained (VE)

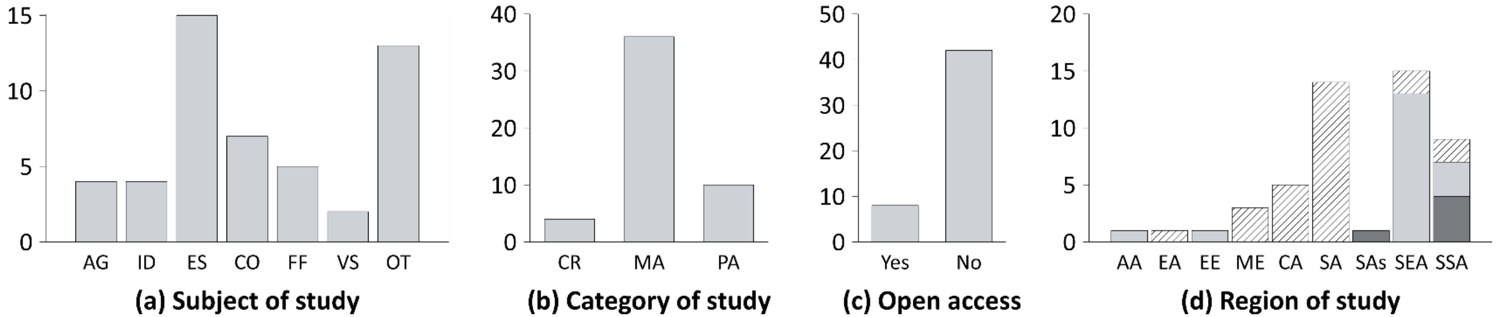

Figure 3.2. Characteristics of the selected studies.
(a) Number of studies across disciplines of agriculture (AG), international development (ID), environmental studies (ES), conservation (CO), forests and forestry (FF), veterinary sciences (VS), and others (OT).
(b) Number of studies per category of Q study [as defined by (28)] as conflict resolution (CR), management alternatives (MA) and policy appraisal (PA).
(c) Number of studies published as (non)open-access documents.
(d) Number of studies per geographical region, across Australasia (AA), East Asia (EA), Eastern Europe (EE), Middle East (ME), Central America (CA), South America (SA), South Asia (SAs), Southeast Asia (SEA) and sub-Saharan Africa (SSA); solid dark gray, solid light gray and diagonal-line patterns on each bar represent the proportions of low-, lower-middle- and upper-middle-income countries, respectively.

3.4.2 Geographical foci

Despite their strong focus on RGS populations, only two publications (83,88) were authored by researchers exclusively affiliated with institutions in their respective target countries. As illustrated on the world map in **Figure 3.3**, most studies were conducted by (main) authors exclusively (n=25) or partially affiliated (n=6) with organizations located in countries of the Global North. The selected studies showed a strong emphasis on Southeast Asia (n=15), South America (n=14), and sub-Saharan Africa (n=9) (**Figure 3.2**d and **Figure 3.3**). As represented in **Figure 3.2**d, only 10% of the studies (n=5) (58,59,64,84,92) aimed specifically at low-income countries, which bear the weakest economic category, where the livelihoods of RGS dwellers face more profound subsistence challenges. Moreover, none of the studies that focused on low-income countries were (exclusively) carried out by researchers and institutions within their national boundaries, nor from any other Global South country (**Figure 3.3**). This might reflect the access and equality issues that researchers from these geographical areas have to confront[6]. This clear decoupling between the places where the study has been envisaged and carried out, and where the data have been collected, could pose even further constraints for the (still limited) research capacities in the Global South. According to (102), research capacity building should be a long-term, explicit process that must go beyond the temporal scope of a single project or grant, whereas (103) advocates the international co-production of knowledge between a number of (non)academic actors whose outputs must be more accessible and understandable for wider audiences. In addition, this detachment, which leads to sporadic, spatially biased contacts, could play against robust relationships and trust between researchers and communities, which are key requirements in rural studies (8,9).

[6] We do realize that our own research endeavors can be labelled in similar terms. In itself, we would argue that involvement of researchers from the GN in itself is not necessarily to be avoided – but we do argue that the balance of research power between GN and GS is in need of correction, including the labelling of GN and GS itself.

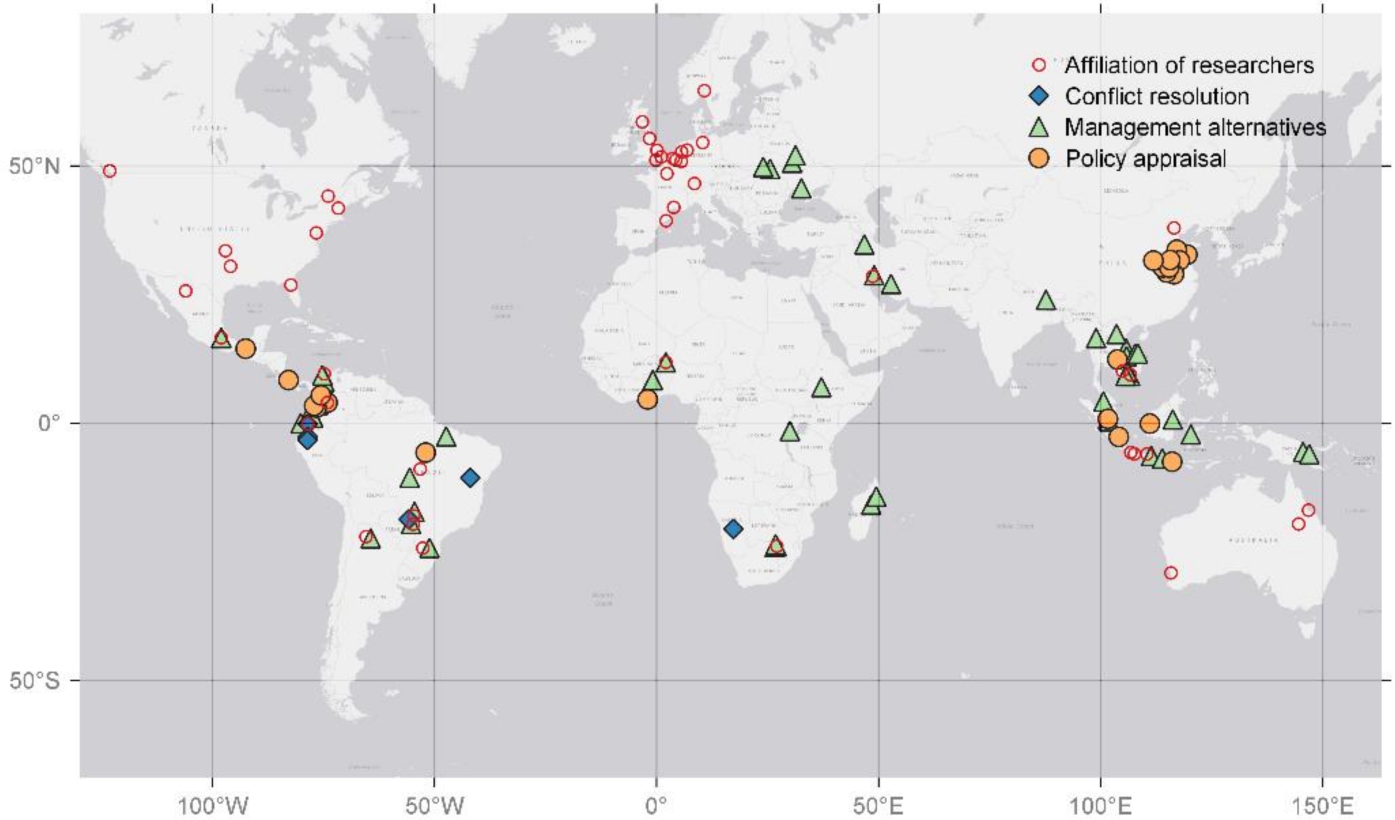

Figure 3.3. Geographic location of main authors' affiliations and studies per theme of Q study [as defined by (28)].

3.4.3 Research design

3.4.3.1 Concourse development

A minority (n=15) of the selected studies relied purely on primary data for the development of their concourse, either exclusively for their respective studies (51,56,65,69,78,79,83,84,87,88,90) or as part of a larger umbrella project (66,74,76,82). Moreover, only five of these studies relied solely on RGS dwellers (69,78,83,84,87). Approximately half of the studies (n=23) employed a mixed primary/secondary data approach (47,49,52–55,57–59,62–64,67,80,81,85,86,89,92–96), whereas 11 studies used only secondary data (48,50,61,68,70–73,75,77,91) (**Figure 3.4**a). The concourses varied in size from as small as 42 (51) to as large as 419 statements (52) (**Figure 3.4**b).

The development of the concourse requires time and rigor to ensure that the eventual Q-set represents an acceptable range of voices involved in the topic under study (26,36). Although the concourse can be built purely from secondary data (40), it makes sense to incorporate primary data to guarantee proper representation of the range of discourses (36). When addressing understudied topics, geographic areas, and/or human groups, primary data collection for concourse development from RGS dwellers might become the only (or at least main) option. Seven studies (74,78,79,83,84,87,88) are remarkable examples of such cases, especially because of their exhaustive primary data sources. In certain cases, however, RGS dwellers may be located in too remote—or ultimately almost unreachable—areas, or their political-cultural values or legal status could hide potential participants (e.g., lower-caste individuals, refugees and displaced groups, women of particular societies, individuals involved in illegal activities). Moreover, purely primary data collection for the concourse is not always applicable nor is perhaps the best approach when (financial) resources are a main limiting factor (50,82) or when it is difficult to (re)visit participants (57,65,82,88,94).

Considering these possible limitations, three strategies for concourse development should be considered. First, (partially) resort to reliable secondary data, mainly if produced around the same study area or population. Second, reuse primary data from previous fieldwork activities, especially when they were part of a larger research program, as applied by (47,53,82). Third, as reported in (49,58,64,65,76,81,86,88,93), to build the concourse based on proxies' discourses (i.e., experts, advisors, scholars, etc.), although researchers must be aware of its potential compromise in the accuracy and representativeness of the viewpoints (104).

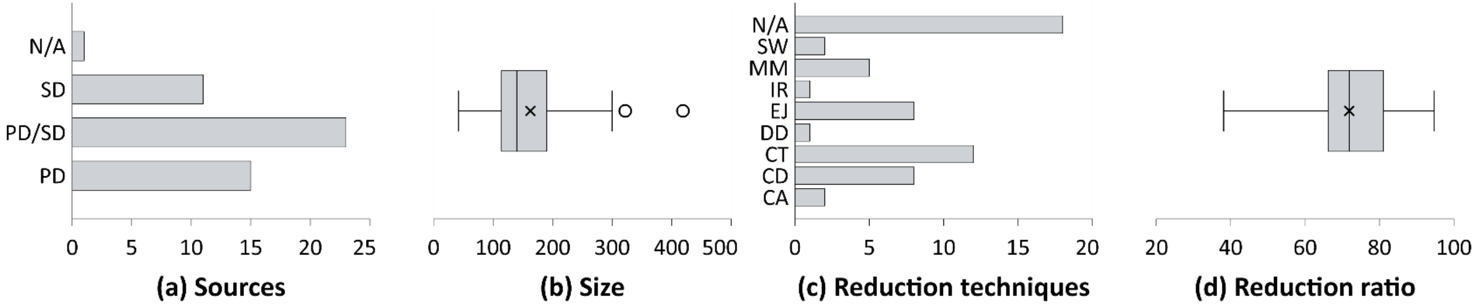

Figure 3.4. Characteristics of the concourse.
(a) Number of studies per source for concourse construction, based on primary data (PD), secondary data (SD) and mixed sources (PD/SD).
(b) Size of the constructed concourse in number of statements across studies.
(c) Number of studies per concourse reduction technique, comprising software (SW), matrix method (MM), iterative refinement (IR), expert judgement (EJ), division in discourses (DD), categorization (CT), combination and deletion of similar statements (CD), content analysis (CA).
(d) Concourse reduction ratio across studies, expressed as the decreasing percentage between the concourse and the Q-set.

3.4.3.2 Concourse reduction

There is no specific recipe or fixed methodology on how to reduce the collected concourse to statements, let alone the number of statements required by the study. An appropriate approach is to consider the coverage and balance of the statements in such a way that they become as equally representative and balanced as possible across the different discourses (26,28). The reduction process should not eliminate any relevant statement of certain discourse(s), given that it will provoke further biases in the later sorts. Here, it may be good to remind ourselves that the Q set aims to create possible combinations between statements as expressions of diverse perspectives; as such, individual statements should represent sufficient diversity themselves but would not need to cover every possible perspective as such.

Most of the selected studies (51,61,62,64,67,78,88,90,92,95) relied on a reductionist technique of categorization, that is, classification into different categories within the found discourses, to filter statements out of the general concourse. Other studies (50,57,73,74,81,89) applied a basic method of combining similar statements and deleting duplicates, redundant, and/or unclear ones. Other less frequent methods for selection of statements were purely expert judgement (47,48,56,73,76,79), matrix method (49,52,53,55,96), content analysis (69,80), division of statements according to found discourses (49), and funnel-like iterative refinement (54). Other authors (70,86,93) have employed combinations of these techniques. Moreover, (49) and (79) were the only studies that used specific qualitative data analysis software (Nvivo 11 and ATLAS.ti 7.5.9, respectively) to make a systematic selection of statements (**Figure 3.4**c).

Q studies dealing with conflict resolution may produce an unbalanced representation of discourses, typically in favor of the most powerful voices, while reducing the concourse. This could be more exacerbated when involving less-empowered RGS individuals compared to other stronger actors (91,92). Here, the matrix method becomes interesting, as it aims to capture several dimensions of both discourses and categories of statements, thereby ensuring representativeness across viewpoints. Three studies (49,55,96) enriched this technique using political discourse theory, as explained by (105).

There is no ideal concourse reduction percentage; it largely depends on the concourse type, number of sources, and amount of information extracted into the initial statements. As such, this percentage has been found to be not uniform across the selected studies. Of the 23 studies that provided sufficient information to calculate this reduction, two (48,51), 13 (55,57,62,67,72,73,75,81,86,89,90,95,96), six (50,56,70,78,79,93), and two

(52,68) reported reductions of <50%, 50% – 75%, 75% – 90% and even up to >90%, respectively (**Figure 3.4**d).

3.4.3.3 Q-set (size)

The size of the Q-set across studies ranged from 16 to 70, although most were around 30 – 50 (Figure 3.5a). The decision on the Q-set size should not be underestimated, nor should it be considered as a mere output of the concourse reduction process. Some authors have reported ideal sizes as high as 40 – 80, ≥40, ≥60 and 60 – 90 (26). Large Q-sets enlarge the (already time-consuming) sorting process, thereby possibly discouraging respondents and eventually increasing the dropout rate (25,36,106). In light of these two antagonistic positions and considering RGS-related constraints for Q (e.g., illiteracy, improper site conditions, exposure to elements), researchers may be inclined to keep a highly reduced number of statements (47,53,74,85), without compromising the representativeness of the discourses.

3.4.3.4 Q-set (presentation of statements)

The vast majority of the selected studies (n=47) presented statements solely in written form. Exceptions to this are (54), which also included images (though not specified) next to written statements; (50), which would suggest the use of illustrations along with the wording; and (47), which was the only one conducted with a photo-based Q-set supported by proxy statements. The latter was intentionally chosen, along with just 16 statements, to reduce the complexity of engaging semi-literate Laotian farmers. Researchers may encounter other potential limitations besides illiteracy. For instance, participants with visual conditions (e.g., visual impairment and color blindness) would require visual items to be carefully implemented. Some authors have employed high-contrast designs and even statements written in Braille (107,108), whereas others advocate for non-conventional audiovisual-based Q-sets (109). It is noteworthy that the latter are usually attached to digital tools and software such as VQMethod (110), whose availability and/or applicability could be compromised in RGS contexts.

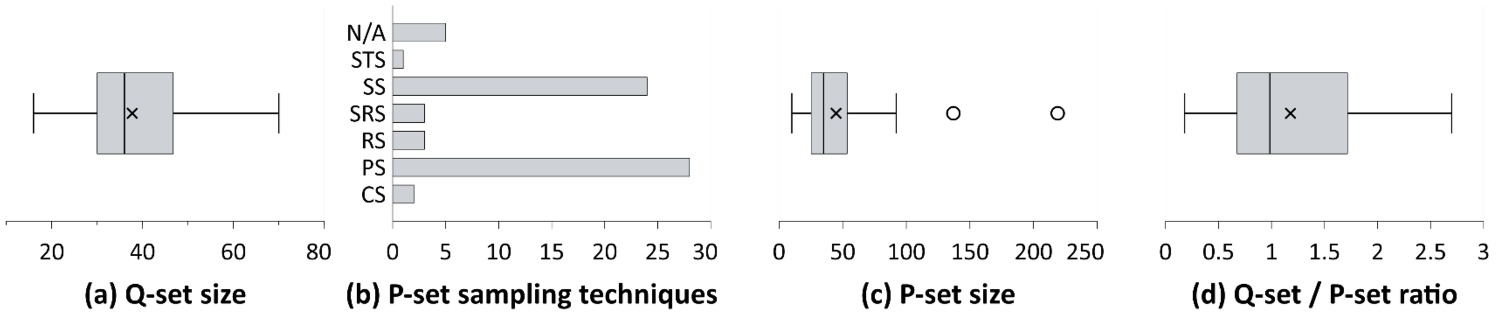

Figure 3.5. Characteristics of research design.
(a) Q-set size in number of statements across studies.
(b) Number of studies per P-set sampling techniques, including convenience sampling (CS), purposive sampling (PS), random sampling (RS), stratified random sampling (SRS), snowball sampling (SS) and structured sampling (STS).
(c) P-set size in number of participants across studies.
(d) Q-set/P-set ratio across studies.

Most of the selected studies (n=36) presented their statements written in a Latin script language (Afaan Oromo, English, French, Malagasy, Malay, Indonesian, Kinyarwanda, Portuguese, Spanish, Tok Pisin, Tswana, and Afrikaans). From these, (49) and (62) worked with a combination of Indonesian/English and Malay/English, respectively, whereas (84) presented a unique successive translation of French, Malagasy, Sihanaka dialect, and Betsimisaraka dialect. In contrast, 14 studies (47,52,55,59,60,65,66,71–73,86–88,96) were conducted in non-Latin script languages (Khmer, Lao, Mandarin, Nepali, Persian, Thai, and Ukrainian). Although the latter does not seem to pose any inconvenience for the administration of hand-written Q-sets, it certainly might bear further limitations for researchers willing to rely on digital/electronic platforms and tools (110–113). For example, current popular software has limited use (or none at all) of certain non-Latin script languages, which tend to belong to Global South cultures. For some Asian languages, complex and rare characters are not even defined for digital systems (114). Trivial operations, such as operating files of written statements across several platforms and throughout different software products (word processing, spreadsheets, design, CAD, etc.), might create spontaneous modifications in non-Latin characters, thus possibly rendering statements in rather meaningless wording. This digital constraint might further limit the applicability of the aforementioned inclusive audiovisual tools.

The sole use of a national/official language and/or lingua franca, even among native speakers, does not entail immediate accuracy and/or bias reduction. (76) highlighted that language could be an issue across several ethnic groups in the study area, and, although relying on a lingua franca (Bahasa Indonesia, in this case) as a solution, respondents still presented different levels of fluency. Other authors (83,84), who had to deal with successive translations throughout a series of languages and dialects, resorted to the committee approach [as defined in (115)], in which discussions between researchers and translators aimed to use the most suitable terms for each statement, thereby reducing the likelihood of misinterpretation. Although (50) and (95) conducted studies in Brazil and Mexico with purely native Portuguese and Spanish speaker research teams, respectively, special care was given to adapting the statements to local terms through extensive iterative piloting with on-site experts and community members.

3.4.3.5 P-set (sampling techniques)

The P-sets were mainly sampled through purposive sampling (n=15) (52,54–56,58,61,64,67,69,72,79,80,89,93,95), snowball sampling (n=11) (47,53,62,68,71,73,82,84,85,91,94), and a dual-method approach, which is usually a combination of the first two (n=10) (51,57,63,65,70,81,83,86,92,96) or in combination with convenience sampling (48,50), random sampling (74,88,90) and stratified random sampling (75). (59,76) and (87) are the only ones that rely solely on an exclusive approach of stratified random sampling and structured sampling, respectively (**Figure 3.5**b).

Both purposive and snowball sampling have become practical methods to recruit potential Q respondents. The selected studies applied these techniques relying on contacts of governmental representatives (47,55,71), (local) organizations (48,53,57,64,68,73,82), local experts (63), local community leaders (47,53,55,62,71,72,74,84), and recruited respondents themselves (50,62,83,91). Their main shortcoming is that researchers may end up with undesirably homogeneous P-sets (26,87,116) associated with the prevalence of existing networks (117,118). This homogeneity can ultimately leave hard-to-reach RGS respondents aside (119), possibly biasing the analyzed viewpoints. For instance, although (75,88) aimed at a gender-balanced P-set, their snowball sampling resulted only in male respondents due to a lack of engagement with/of women. (82) acknowledged potential biases in the respondents because of their closeness to a local farmers' aid organization. (84) reported that snowballing through village heads was a matter of cultural etiquette, which could lead to other types of unforeseen cultural interactions. (87) remarked that sampling through key local informants resulted in a limited representation of certain perspectives, thereby hampering their interpretation. Variations in snowball sampling could be suitable for reducing these biases; for instance, turning initial key informants from selectors to legitimators of the spread voice (117), or increasing the trust of the desired networks by emphasizing the integrity, transparency, and sensitivity of (local) researchers (118).

3.4.3.6 P-set (size)

Q does not rely on large P-sets but on their diversity of viewpoints (26,36,37). Hence, there is not an ideal minimum number of participants. According to (26), some authors advocate for ranges of 40 – 60 participants; others favor Q-set/P-set ratios higher than 1, with the number of respondents being lower than the number of statements. P-set sizes across the selected studies ranged from 10 to 219, although the majority were concentrated around 30 – 50 (Figure 3.5c). The Q-set/P-set ratios varied from 0.18 to 2.70, with most of them being around 1.0 – 1.5 (Figure 3.5d). From the selected studies, only two of them antagonistically elaborated on it: (63) appealed to the <1 ratio as an indicator of ideal P-set size, whereas (93) pointed out that a ratio larger than <1 would have increased the likelihood of finding a correlation between loaded respondents.

3.4.3.7 P-set (gender)

Gender representativeness, particularly concerning women's participation, did not prove to be an active P-set criterion across the selected studies (Figure

3.6a). The aggregated female/male ratios[7] of the selected studies (**Figure 3.6**b) revealed that female participants were typically about half of their male counterparts. Honorable exceptions are (50), whose focus was exclusively on a female phenomenon, and (68,69,80), which considered a strong gender dimension in conducting their studies and interpreting viewpoints. In addition, only two studies (84,90) were explicit about gender balance, whereas (76,85,89,92–94) aimed towards proper gender diversity and women representation.

Four studies (75,82,86,95) relied exclusively on male participants (**Figure 3.6**a). These numbers should not be taken exclusively as unawareness from the researchers but also as a result of potential political and cultural ideas. For instance, (75,88) pointed out that although some women had stronger (legal) attachment to their farms, they gave up responding in favor of their husbands. (82,93) indicated that women were too shy to talk or faced cultural constraints, ultimately declining their participation. Contrarily, (90) highlighted the higher number of female participants, though not offering any plausible explanation, whereas (74) argued that men usually being absent from the village/farm resulted in slightly skewed female participation. Taking into account the particular challenges RGS women must face in accessing resources (13,14), gender imbalance can cause further biases and/or incompleteness of the topic that researchers expect to understand. Therefore, it is key for Q researchers in RGS settings to adopt cross-cutting, gender-sensitive approaches in their studies, primarily when dealing with male-dominated societies.

3.4.3.8 Sorting grid

There are no rules to ascertain the sorting grid in which the Q-set must be sorted. Typical shapes include quasi-normal (pyramid) and inverted quasi-normal (inverted pyramid) forced-sorting grids. In this regard, 17 and 20 selected studies provided the former and the latter, respectively (**Figure 3.7**). In contrast, (64) used a unique, double-pyramid or diamond shape. This matrix, unlike typical grids, bears a principle of inverted axes. The ranking is performed across a vertical scale, whereas the rows, distributed symmetrically, hold for statements with the same value. A non-forced grid was used in (77) (not depicted), although the authors did not explain the reason for its use (nor its subsequent analytical process). (67) piloted a non-forced distribution that was discarded in favor of a forced grid; the authors argued that the forced approach led participants to reflect more while sorting. In contrast, (62) allowed its respondents to deviate from the forced distribution as a way to cope with decision issues while sorting.

[7] (50) was not accounted due to its exclusivity of female participants.

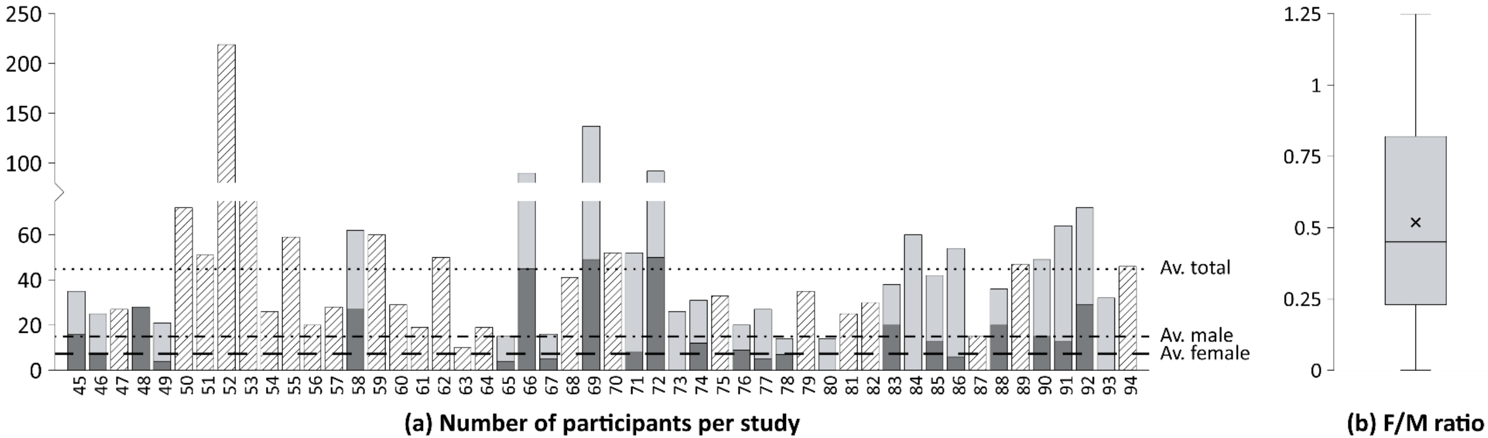

Figure 3.6. P-set size and genders.
(a) Number and gender of participants per each of the 50 studies. Numbers on the X-axis correspond to the references. Solid dark gray, solid light gray and diagonal-line patterns on each bar represent the proportions of female participants, male participants, and gender-unspecified participants, respectively. Dashed line, dotted-dashed line and dotted line represent the average of female, male and total participants across studies, respectively.
(b) Female/Male ratio across the selected studies. (50) considered female participants only, thus is not represented here.

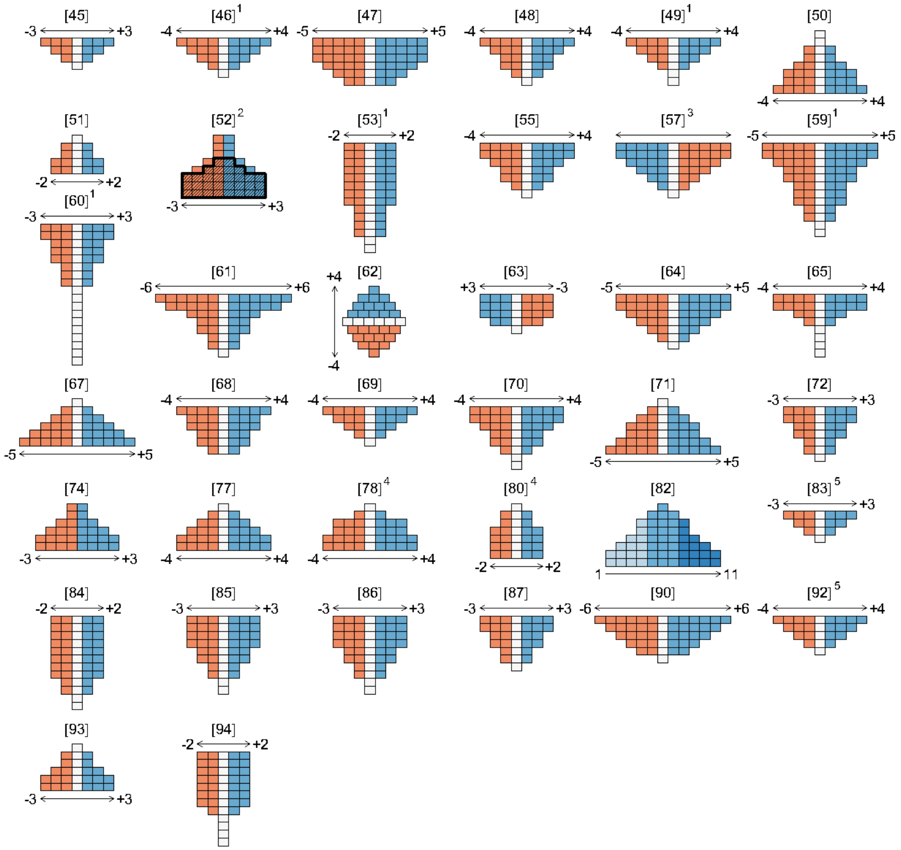

Figure 3.7. Sorting grids of the selected studies.

[1] (48,51,55,61,62) did not report the orientation of their grids. They were assumed as inverted distributions.

[2] The shaded area with thicker border represents the second grid used in (54).

[3] (59) did not use a quantitative scale; instead, its authors reported graphical hints (happy/sad faces).

[4] Reported grids of (80,82) did not match with their respective number of statements.

[5] (85,94) resorted to two grids; only information of one of them was provided.

The shape of the sorting grid does not influence the reliability of the method. The forced distribution should be considered as a mere device to encourage respondents to perform a systematic analysis of each item (26,120). However, unless properly designed and explained, the (inverted) pyramidal shape, with the strongest load of statements in the central column, might transmit to the participant the impression of importance, in which the apex of the pyramid should match the most critical statement(s). From this perspective, the diamond grid used by (64) would offer a more natural, easy-to-read, top-to-bottom hierarchy, which can be further underpinned by providing graphical hints or ideograms (e.g., sad/happy faces) depicting the degrees of agreement along with the ranking scale (53,59,82).

The sorting grids in Q are structured through two ordinal scales: qualitative and quantitative. The former typically comprises a wording-based scale to measure the level of agreement. The latter, matching with the qualitative one, generally makes use of odd symmetric scales [(54,76) become rare even-scale exceptions] with negative and positive sides and several sorting points, whose center corresponds to the neutral position, also referred to as 'distensive zero' (26). Most of the selected studies (n=39) employed qualitative scales, with (a variation in) the typical disagree/agree scale. Others resorted to (variations of) importance (47,48,54,64,71), effectiveness (54,89), (dis)approval (82), affection (79), and self-identification (69,78,80). The latter group employed highly personal approaches (I don't identify with/I identify with, Unlike me/Like me), even though they studied perceptions of external phenomena (i.e., sustainable management of a community-owned forest reserve and related tourism infrastructure) rather than deeply intrinsic subject-wise affairs. In these cases, sorting impersonal statements like 'Agriculture is not profitable' (69), 'The reserve should have more wild animals' (78) or 'Ecotourism is a way to preserve the forest' (80), could become sources of confusions. Researchers should pay close attention to the possible mismatches between the wording of statements and the grid's qualitative scales to prevent respondents from being biased by a false sense of doubt or neutrality.

The quantitative scales of the selected studies ranged from five to 13 points, although most of them were concentrated on seven (n=13) and nine (n=19). Although the number of sorting points enlarges/shortens the continuum through which respondents make ranking decisions on a given Q-set (26), little is mentioned about their impact on the difficulty level of the sorting process. It is logical to think that the more sorting points are offered, the more time the respondent will take to position every single statement, and consequently, the more burdensome the process could become. In turn, this can negatively impact the in-sorting motivation, possibly decreasing the number of well-thought responses, as well as participation and completion rates.

Most of the selected studies (n=41) employed a negative-to-positive order of the quantitative scales. Exceptions are studies with absolute (84) and positive-to-negative (56,65,68,77,83) [and its vertical variation (64)] scales. Absolute scales are used to prevent discomfort in the participants due to seemingly forced positive/negative choices while sorting; for example, participants do not necessarily have to feel disagreement, but a lower level of agreement in a negatively ranked statement (26). Positive-to-negative scales could entail confusion in participants from sociolinguistic contexts with right-to-left reading languages (e.g., Persian, Arabic, Hebrew, Urdu, etc.), where the direction of the scale can enter into conflict with the respondents' approach to reading and thus understanding (121).

The range of these scales, in combination with the different Q-set sizes, resulted in a wide diversity of sorting grids of both size and shape. These can be categorized according to the number of statements and kurtosis (**Table 3.2**). Most of the selected studies used mesokurtic sorting grids (n=26), consistent with the traditional shapes depicted in introductory studies to Q (26); 10% (n=5) and 16% (n=8) employed less common platykurtic (flat) and leptokurtic (steep) shapes, respectively (**Figure 3.7**).

Table 3.2. Characteristics of sorting grids with regard to their size and kurtosis.

Q-set	Platykurtic (flat)	Mesokurtic	Leptokurtic (steep)
10-30	(65)	(47,48,50,51,53,67,71,76,95)	(82)
31-50	(70,92)	(52,57,59,63,64,66,69,72–74,79,80,85,89)†	(62,86–88,96)
51-70	(49,54)*†	(61,84,94)†	(54,55)*†

*(54) was the only study that offered two sorting grids from two different kurtosis categories.
†(54,85,94) provided two Q-sets to the participants; the table registers the sum of their statements.

According to (26), targeting the correct size and kurtosis of the sorting grid is key to making participants feel comfortable during the sorting process. Two complementary factors that should lead the choices are the complexity or specialized nature of the topic and the related level of knowledge of participants. Steeper grids allow for larger neutrality and less decision making. By contrast, flatter ones are suitable for participants and/or topics that require more fine-grained decisions. Most of the selected studies seemingly made arbitrary choices of sorting grids; scarcely, three offered justifications for their grid choices. (49) implemented platykurtic grids owing to the knowledgeability of the respondents [consistent with (26)]. (54) preferred a platykurtic shape (one of the two grids) to enable subtle discrimination throughout many agreed statements. (74) opted for a mesokurtic grid to diminish low-literacy cognitive barriers by allowing for more neutral positions. In addition, although (58) did not depict the sorting grid, its authors argued its simplicity was chosen because of the low educational level of the respondents.

3.4.4 Data collection

3.4.4.1 Location and materials

Q is typically a space-demanding technique that requires controlled environments and large flat workspaces. The use of appropriate, robust, and resistant materials can cause a substantial difference during their administration (26,40). Only 20% of the studies (n=10) reported their respective locations where sorting occurred. Most of these (53,66,72,80,87,88,96) mentioned respondents' houses or farms, whereas others pointed out generically each village or community (82,92), offices of stakeholders (92,96), and schools (48). In RGS contexts, particularly in remote and scattered areas where it is not feasible to gather participants at specific locations, ideal site conditions cannot be easily met and controlled. If the sorting location is the main workplace of the dweller, exposure to the elements (i.e., sun, wind, rain, and moisture) will certainly imply further constraints for researchers (122). Lack of proper furniture (e.g., large tables and chairs for participants) is another point of concern that must not be overlooked, as it can hamper the engagement of participants. Probably due to the unavailability of these facilities, some of the selected studies were sorted directly on the floor (53,66).

Although 30 of the selected studies indicated certain use of materials, most of these referred only to generic instruments such as 'cards' and 'boards'. Others provided further specifications, such as paper (61,72,73,80,85,94), (thin) paper/cardboard (50,53,66,82), laminated cards and board (64), magnetic cards and board (83), and a combination of paper, pencil, and eraser (without cards and sorting board) (92). Three studies (61,65,81) did not (partially) use any of these kinds of materials because of the use of online platforms. Materials such as mere paper and/or cardboard can result in damaged instruments if sorting is conducted outdoors during drizzling periods, and too lightweight materials could be compromised in the case of winds, becoming an additional burden to the respondent. The selection of adequate materials can help researchers cope with these unforeseen conditions; thus, these logistical issues should not be underestimated. (64) and (83) are good examples of the proper management of materials that facilitate interaction between researchers and respondents. The former used laminated cards, thereby becoming waterproof and highly durable throughout the field journeys. Furthermore, it implemented a system of hook and loop fasteners, hence being windproof and rendering it prone to be used vertically (coping with lack of flat horizontal space). Finally, the board was designed in a foldable layout, thus becoming more portable, in a (seemingly) waterproof material. The latter provided similar benefits through magnetic materials, although these could be more costly and scarce in certain (rural) settings.

3.4.4.2 Administration technique

Most of the selected studies were conducted face to face. Of these, 15 were done individually with each respondent (48,50,53,55,60,64,71–73,77,79,84,87,95,96), thereby being more time-consuming for the research teams. For this reason, studies (74), (71), and (54), with 92, 137, and 219 effective respondents, respectively, became impressive cases of collected sorts for this type of study. In contrast, studies (69), (76), and (90) were collectively conducted during a 16-person community meeting, in rounds of three people simultaneously, and in a 39-person deliberative workshop, respectively. Considering that (90) poses an exceptional setup for RGS contexts, it would have been interesting to understand how it was executed; unfortunately, the authors did not provide any details on the process or locations. In addition, it is worth recalling whether Q is administered individually or collectively can influence the results (115). Since it is intended to capture personal viewpoints, undesired group opinions —especially when involving dominant individuals and/or in collectivistic cultures—could steer some respondents' own perspectives (106).

Online-administered Q is an acceptable alternative to its face-to-face version (26). Some authors (123–127) have successfully conducted online-administered Q sorts, although this is still a rare choice nowadays. From the selected studies, only three (61,65,81) were (partially) conducted by means of online tools, namely Partnership Online Evaluation Tool with Q methodology – POETQ (111,128), Qsortware (113) and SurveyMonkey (112); none of them took place in a low-income country. Online administration at times might be the only feasible technique, for instance, when addressing an international community (129)[8] or in view of exceptional yet plausible limited-access scenarios, such as the COVID-19 global pandemic crisis (130). In RGS settings, the online administration of Q is certainly restricted by much more than merely the researcher's willingness to use it. RGS dwellers worldwide face a serious lack of access to the Internet (131), deeply limited access to equipment and electricity (132), and (technological) illiteracy (133).

On one hand, the (digital) gap between researchers and RGS populations demands building and/or reinforcing local (Q) research capacities. On the other hand, circumstances like those of the ongoing pandemic may pose a sudden and unforeseen turn towards remote research (130) that renders that gap more acute and critical than ever. The way forward during the latter should not be limited to relying on local networks (e.g., NGOs, cooperatives, village development centers, extension officers) as a way to bridge the gap. The crisis must foster the development of innovative, open-source tools to make Q more accessible and with fewer shortcomings, especially under the light of an increasing access to and use of mobile phones in the Global South (134).

3.4.4.3 Assistance and facilitation

Q is an assistance-intensive technique; therefore, for RGS dwellers who might bear further cultural- and literacy-related constraints (135), appropriate facilitation is crucial. Most of the selected studies relied on pre-sort instructions (i.e., explanation of the purpose and whole process) (48,57,58,64,70–

[8] The author gave up the option of Q due to lack of feasible web-based alternatives.

72,76,83,85,87,88,91–94), normally accompanied by step-by-step oral guidance (47,52,53,56,63,66,70,72–74,85,89,93,94,96). Other complementary, more time-consuming activities were reading of (almost) every statement by the research team (53,54,66,74,93), especially because of low levels of literacy and on-demand iterative clarification of statements (47,49,66,70,76,85,93,94). In-depth explanations and interactions may smoothen the sorting process and reduce the risk of participants misunderstanding instructions and misinterpreting statements; however, this may also increase sorting times and interviewer bias, which can seriously affect the respondents' engagement and validity of the findings. Moreover, the status of the researchers (i.e., origin, gender, age, etc.) may provoke unexpected behavior from participants; in these cases, proper selection, training, and supervision of (local) assistants is highly advisable (115).

When researchers are not (native) speakers of the P-set language(s), as it occurred with 20% (n=10) of the selected studies (48,51,52,59,62,65,67,71,74,78)[9], they will likely rely on translators and interpreters. In this case, particular emphasis should be placed on biases beyond the mere accuracy of the terms in statements. Interpreters and assistants must first thoroughly understand the dynamics of the methodology and the topic under investigation, so they can provide a more accurate explanation to participants (122). Similarly, they must be aware of not influencing the respondents' sorts with their own opinions while facilitating. This potential limitation again links to discussing the need to build (Q) research capacities in the local contexts of the Global South. By intensively involving local scholars, universities, and institutes, these studies could be conducted by relying on native speakers and will also empower those who can better understand the demands of their local realities.

Online-administered studies (61,65,81) do not allow—nor should require—face-to-face facilitation. Their respective platforms give the participant the chance to read written instructions as many times as needed to understand the required dynamics. Three main downsides are that they require participants to have access to the required equipment, demand a certain degree of (ICT) literacy, and entirely rely on each respondent's interpretation of the provided statements.

Sorting a set of statements holistically through a (relatively) large grid can be a daunting and cumbersome process, especially if respondents are not vastly knowledgeable on the topic under study. The so-called three-pile technique is a popular way among researchers to cope with this burden (26). It consists of a

[9] Assumed after the authors' countries of affiliations and language employed during the studies.

primary rough sorting in which the participant distributes all statements based on three criteria: agree, neutral, and disagree. This preliminary rough sort is thereafter refined by positioning the statements to the sorting grid. From the selected studies, 48% (n=24) (47,49,50,53,55,58,63–66,70,72–74,79,84,85,87–89,93–96) resorted to this technique. (63) implemented an interesting two-step modification, where participants sequentially sorted into three and nine sub-piles (three per each first pile), thus enabling a smoother transition to the final grid distribution.

3.4.4.4 Sorting times

Required sorting times across the selected studies were reported to be as low as 25 minutes (51), and as high as 1.5 hours (56,75) and (up to) 3.0 hours (60) (**Figure 3.8**a). Considering that these times are highly interrelated with the Q-set size, we can define a sorting time ratio expressed in seconds (s) per statement (st). These ratios varied from approximately 58 s st^{-1} (51) to 225 s st^{-1} (47), although most ratios were concentrated around 100 s st^{-1} (**Figure 3.8**b). A third variable that influences the time required for sorting, which is usually overlooked in Q studies, is the number of sorting points throughout the grid. Larger Q-sets, distributed over a wider range of sorting choices, naturally take respondents longer times than otherwise. Accounting for this third variable, we define another ratio as the required time in seconds (s) per statement (st) per sorting point (sp). Most of the selected studies were within ratios of <10 s st^{-1} sp^{-1} (48,51,73) and 10 – 20 s st^{-1} sp^{-1}. (57,70,75,76,82,87,88,94) (**Figure 3.8**c); others had higher ratios of >20 s st^{-1} sp^{-1} (53,56,60,96), and even an exceptionally high ratio of 32 s st^{-1} sp^{-1} (47).

Only (87) elaborated on the consequences of (too) long sorting times hampering the Q process. Regarding the high ratios of (47,53), they found their origins in the reported illiteracy conditions of their respective respondents. Other unexplained yet salient time-related facts from certain studies are worth remarking. Although (47) presented the smallest Q-set, presented in the form of pictures instead of written statements, it counterintuitively resulted in the highest sorting time ratios. Its images could facilitate the sorting flow yet could also turn into subjective instruments that perhaps demanded more extended interpretation and discussion times. In contrast, although (73) had a large Q-set that had to be additionally sorted vertically (concerning the strength of feeling of each statement within a given sorting point), it turned into barely 6 s st^{-1} sp^{-1}, the lowest reported ratio.

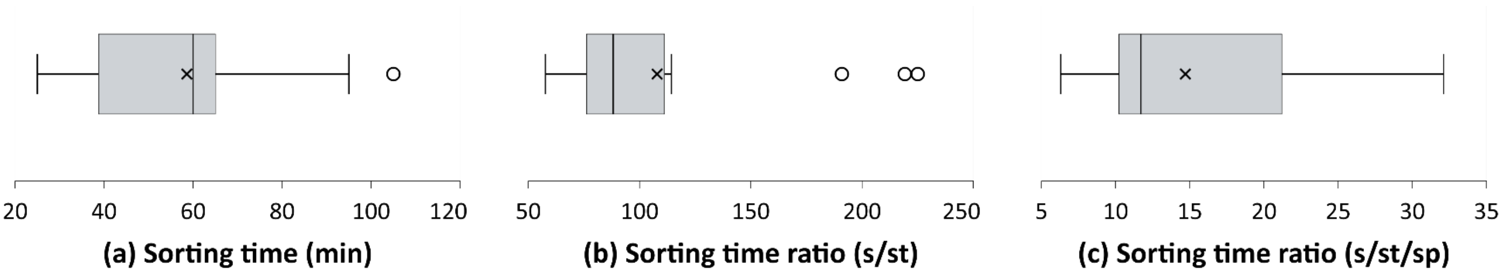

Figure 3.8. Sorting times across the selected studies.
(a) Absolute sorting time in minutes.
(b) Sorting time ratio, expressed in seconds per statement.
(c) Sorting time ratio, expressed in seconds per statement per sorting points.

Except for (94), none of the studies with the largest Q-sets (>50 statements) (49,54,55,61,84) indicated sorting times. From these, two particularly interesting cases to analyze would have been (61), which presented 68 lengthy written statements, and (54), which asked each respondent to sort two 30- and 40-statement Q-sets in a single sitting.

3.4.4.5 Complementary information

To provide Q studies with an accurate and holistic interpretation of viewpoints, authors normally collect qualitatively rich complementary information (e.g., sociodemographic data, reasoning on sorting, etc.) (26,28). The most commonly used technique is the post-sorting interview about the placement of the (most extreme) elements and related topics (47,48,50–59,61–66,68–82,84–94), as well as its collective variant in the form of focus group discussions (92,93). Other less common techniques include in-sorting interviews (about clarifying and sorting statements) (49,60,71), pre-sorting interviews (57,82), sociodemographic surveys (85,96), and secondary information from prior interviews (83). It is worth noting that according to (87), (too) long sorting times led participants to provide poor-quality complementary information during exit interviews.

3.4.4.6 Data recording

Q studies require adequate data recording of both the sort itself and any other information that contributes to the interpretation (26). Less than half of the selected studies (n=19) provided relevant information. Most of them used any form of (audio) recording for interviews (47,48,53,57,60,64,75,83,88,91), answer sheets for recording the sorts (52,72,73,92,96), and written notes (53,64,85,94). Less reported techniques include photos of sorts (47), structured questionnaires (72), and even a unique approach of collecting notes written by the participants themselves (79). Regarding web-based Q studies (61,65,81), their respective platforms offered their own data-recording methods. Moreover, these studies did not limit the application of other online methods such as email-based follow-up interviews (65).

Means of recording could be more restricted, in both quality and quantity, in RGS settings. Although none of the studies pointed out any related limitations, it makes sense to resort to methods that fulfil certain context-friendly properties: portable and lightweight, particularly for journeys between remote areas with low accessibility; elements-resistant, so rain, dust, heat, and humidity do not compromise recorded data; off-the-grid operation, either through long-life batteries for electronic equipment and/or by using non-electronic media. Moreover, a good strategy for reducing the risk of on-field data loss is to rely on several complementary and redundant recording methods.

3.4.5 Analysis and results

3.4.5.1 Analytical software

The current norm for Q data analysis is the use of dedicated software (26). All the selected studies opted for open-source options. Most of them (n=36) used (any version of) PQMethod (136), whereas a minority (n=11) (54,57,58,64,65,70,77,87–89,95) relied on the 'qmethod' package for R (137) (Figure 3.9a).

3.4.5.2 Factor extraction methods

Modern computer-based factor extraction methods involve Principal Component Analysis (PCA) and Centroid Factor Analysis (CFA). Both methods offer similar results in practice, although PCA provides the mathematically soundest solution, whereas CFA enables Q methodologists a less fixed, more exploratory approach (26). Many authors (n=35) chose the former, whereas only six resorted to the latter (55,66,68,86,91,96) (**Figure 3.9**b). The few justifications provided were, for PCA, the popularity and best mathematical solution it provides (47) and the identification of commonalities and distinctions between sorts (64,71), whereas for CFA, the most permissive data exploration (62).

3.4.5.3 Factor retention criteria

Q theoretically allows the extraction and retention of as many factors as are deemed convenient or significant. Researchers may rely on a pool of several (statistical) criteria during this process (26), from which the most frequently used in the selected studies were the (combination of) Kaiser-Guttman criterion (eigenvalue threshold) (n=22) (48–50,53,55,62–64,67–70,72,75,81,82,84,86,87,90,93,96), sorts loadings' thresholds (n=16) (48–50,53,55,62,63,70,73–75,85,86,88,92,96), total variance explained (n=8) (48,54,69,70,87,88,90,92), and interpretability of factors (n=7) (54,56,58,61,64,76,87) (**Figure 3.9**c). Other less common (complementary) criteria included the scree test (54,57,64,71), standard error thresholds (85,91), expert judgement (47), distinguishing statements thresholds (53), low correlation of factors (54), Horst' centroid method (60), parallel analysis (71), and sensitivity analysis (95). The authors mostly decided on the number of factors to retain either through a single- (47,56–58,60,61,67,68,72–74,76,81,82,84,91,93,95) or dual-criteria approach (49,50,55,62,63,69,71,75,85,86,88,90,92,96), although additional criteria may be adopted complementarily (48,53,54,64,70,87).

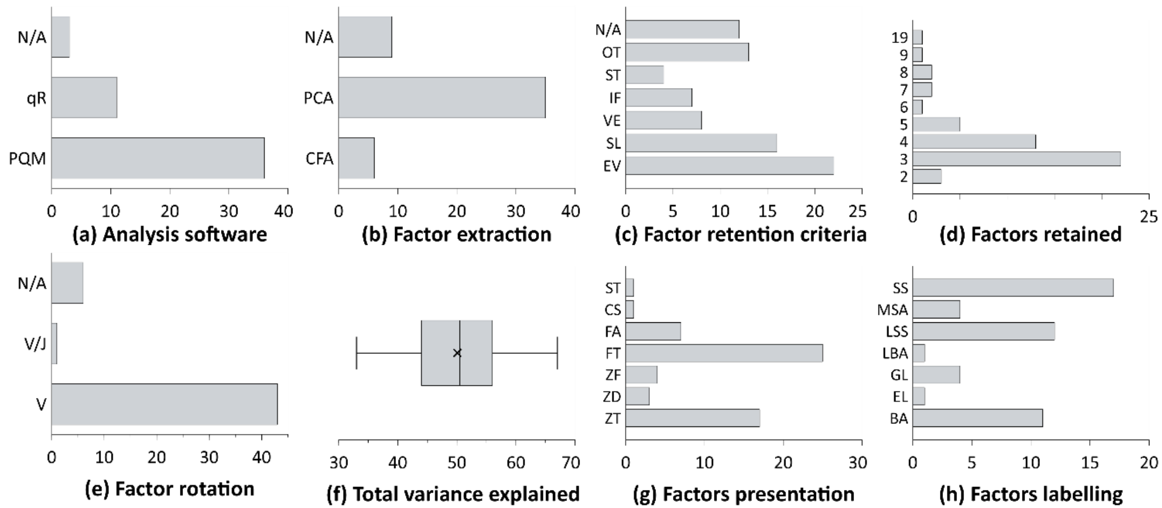

Figure 3.9. Characteristics of Q analysis and interpretation.
(a) Number of studies per software for Q analysis, either PQMethod (PQM) or qmethod for R (qR).
(b) Number of studies per factor extraction method, either Centroid Factor Analysis (CFA) or Principal Component Analysis (PCA).
(c) Number of studies per factor retention criteria, as eigenvalue threshold (EV), sorts loading threshold (SL), total variance explained (VE), interpretability of factors (IF), scree test (ST), and others (OT).
(d) Number of studies per number of factors retained.
(e) Number of studies per factor rotation method, either Varimax (V) or mixed Varimax/Judgmental (V/J).
(f) Percentage of total variance explained across studies.
(g) Number of studies per factors presentation technique, as Z-score table (ZT), Z-score diagram (ZD), combined Z-score and factor table (ZF), factor table (FT), factor array (FA), crib sheet (CS), and summary table (ST).
(h) Number of studies per factor labelling approach, as behavioral adjectives (BA), explanatory labels (EL), generic labels (GL), long behavioral adjectives (LBA), long societal scenarios (LSS), mixed behavioral adjectives and societal scenarios (MSA), and societal scenarios (SS).

The majority of the studies retained three (n=22) (48,58,60,62,63,65–70,76–78,80,82,86,87,89,92,95,96) and four (n=13) factors (51–53,56,59,61,64,72,73,75,79,90,91), whereas fewer authors presented two-(47,81,93) and five-factor (49,50,74,83,84) solutions (Figure 3.9d). It is worth noting that some studies resulted in larger sets of six (57), seven (55,88), eight (71,85), nine (54), and even 19 factors (94) after relying on multiple P-sets and/or Q-sets.

3.4.5.4 Factor rotation methods

Another integral part of Q analysis is the factor rotation. This is conducted by means of automatic or manual processes, namely Varimax and Judgmental rotation. None of these two methods is considered superior to the other. Their application depends on the nature of the data and the objectives of the researchers; in some cases, it is considered better to combine them (26). Virtually all the selected studies (n=41) reported the use of Varimax (**Figure 3.9**e); very few justified their choice based on reliability (47,93) and maximization of variance (61,65,81,87,92). Only (91) conducted a complementary manual rotation of factors, with the aim of finding a meaningful explanation of the data.

3.4.5.5 Total variance

The total explained variance was statistically consistent across the selected studies. Most of the studies reported a total variance of 45% – 55% (n=22) and >55% (n=12), whereas a minority did so with <45% (n=17) (**Figure 3.9**f). On the contrary, (93) was the only study whose total variance explained (33%) was below the usually accepted threshold of 35% – 45% (26), which can be a result of the low Q-set/P-set ratio, as explained by (138).

3.4.5.6 Factor presentation

Adequate visualization of retained factors is key to conveying to the reader what makes them unique and thus different from one another. The most preferred techniques across the selected studies were factor tables (n=25) (48–50,52,54,57,58,63,65–69,71,74–76,78,83,85,88,89,91,92,96), (modified) Z-score tables (n=17) (47,51,53,55,61,64,69,72,73,77–82,87,93), or their combined variant (n=4) (56,60,70,84) (**Figure 3.9**g). Few studies presented their factors using less common factor arrays (62,69,76,87–89,92), crib sheets (90), and factor summary table (94).

3.4.6 Interpretation

Given the subjectivity that interpreting viewpoints entails, and the particularities of each of the selected studies, the contents of the interpretations themselves were not considered within the scope of this review. Nevertheless, some commonalities can be identified regarding the labelling and framing of the interpreted factors. Although labelling is not a mandatory step in Q, it is certainly a common practice among Q methodologists. These labels are intended to deliver, in a nutshell, what characterizes each viewpoint and makes it unique compared to one another (26,36,40). Because these labels depend mostly on the creativity of the researchers, there are virtually endless options to define them; however, some approaches are recognizable. Some labels assign behavioral characteristics to respondents, whereas others focus on defining a given situation or even providing a short explanation of certain positions.

Most of the selected studies relied on labels for societal scenarios, either in their compact (n=17) (50,51,61,64,65,68–70,72,73,78,84,87–91) or longer forms (n=12) (47,49,53,54,56,62,63,79,80,85,92,94), behavioral adjectives (n=11) (52,57,58,60,67,74,75,82,86,93,95), or their combinations (n=4) (66,76,83,96). Few authors resorted to longer, descriptive versions of behavioral adjectives (n=1) (55) and explanatory labels (n=1) (48). Other studies (n=4) (59,71,77,81) reported the use of generic nameless labels, distinguished by the use of numbers or letters (**Figure 3.9**h).

Interpreted factors should ideally be validated through ulterior interaction with respondents. By iteratively providing participants with draft interpretations, they can offer further feedback that contributes to refining the narratives (139,140). This appears to have been amply overlooked (or underreported) in Q studies. Of the selected studies, only four (51,65,67,83) mentioned that they had resorted to this technique. Regarding RGS settings, where even one-time (sorting) contact with respondents could already be limited, validation seems to become a less likely choice. Under such circumstances, an alternative could be to validate the narratives with at least the highest loaded respondents for each factor (65,67).

3.4.7 Challenges and the way forward

The deployment of Q is a planning-, time-, and facilitation-intensive process (25,36,106,141). The first two stages, namely research design and data collection, are the ones requiring researcher–(RGS) participant interactions; hence, the ones that concentrate most of the identified methodological challenges (**Table 3.3**). As such, during its implementation in the RGS—particularly in low-income settings—along with its (non)human-dependent constraints, it will almost certainly result in limitations and improvisations. Paradoxically, most of the Q scientific literature keeps looping on the portion that has already been exhaustively reported: analysis and interpretation (27,38,39). From the selected studies, only four (62,82,87,92) critically elaborated on on-field methodological issues. An unawareness of these challenges could undermine the successful implementation of Q with RGS dwellers.

Most challenges across the selected studies were related to the difficulty in reaching (female) respondents, thereby possibly underrepresenting viewpoints (48,51,57,65,75,81,82,88,93–95). This was not exclusively limited to physical/geographical unreachability, but also to social and cultural barriers that excluded at times female and other less socially connected participants. In addition, some research teams faced particular constraints due to their dependency on local third parties (e.g., NGOs, farmer associations), and thus lack of on-field autonomy, to reach the desired P-set (82).

Other authors (47,53,58,62,74) reported illiteracy, semi-literacy, and low education as limiting factors in conducting sorting sessions more successfully. Such limitations likely lead to (too) long sorting interactions, which in turn could lead to a number of challenges. These include post-sorting time restrictions for researchers (50), thereby compromising the quality of collected complementary data (87); response biases due to short, not-well-thought sorts (63,87); decrease in the level of engagement of respondents (51,82,87,88); and even ultimately drop-out problems (53,90,95). These potential limitations become much more salient when focusing on sub-Saharan Africa and South Asia, the regions with the highest illiteracy rates among adults worldwide (142,143).

Another identified issue was the lack of methodological clarity of the administered Q, which evolved towards inaccurate or invalid responses. For instance, (87,88) pointed out that some participants could not follow sorting instructions and at times found statements too complicated or contradictory, whereas (62,92) reported that some respondents who were uncomfortable with the forced distribution tended to sort out of the grid. Perhaps these difficulties become more understandable if Q is compared with other more familiar, more economical, and easier-to-administer attitudinal measuring instruments, such as the Likert scale (141,144). Linguistic problems, such as different degrees of fluency in both researchers and participants (76), as well as mismatches and misunderstandings in provided terms and wordings (84), might aggravate this methodological obscurity.

Table 3.3. Summary of discussed challenges due to the implementation of Q in RGS settings and respective good practices

Stage	Aspect	Challenge	Good practices
Q stage 1: Research design	Concourse development and reduction	*Inaccessibility to RGS dwellers as primary data sources	Resort to reliable secondary data
			Reuse of primary data from larger research program
			Rely on proxies' discourses
		*Unbalanced representation of discourses, in detriment of less-empowered individuals	Apply matrix reduction method
	Q-set	Too large Q-sets might discourage participation	Keep small number of statements without compromising representativeness
		*Illiteracy of participants	Use other (visual) techniques (e.g. pictures / illustrations)
		Incompatibility of non-Latin script languages of Global South cultures with certain electronic platforms	Use of hand-written material, which can be ultimately digitalized
			Development and definition of non-Latin script languages
		Multiple languages or dialects involved	Apply a reliable translation method (115)
			Iterative piloting of statements in the local context
	P-set	*Too homogeneous P-set due to biased snowball/purposive sampling	Use variations of snowball sampling (117,118)
		Underrepresentation of female respondents	Adoption of cross-cutting gender-sensitive approaches in the research process
	Sorting grid	Confusion due to mismatches between qualitative scale and wording of statements	Make sure both elements hold to one another consistently

Stage	Aspect	Challenge	Good practices
		Burden caused by (too) many sorting points in quantitative scale	Limit the number of sorting points depending on the topic under study and characteristics of respondents
		Mismatch between direction of quantitative scale and the sociolinguistic context of participants	Define a qualitative scale sensitive to the linguistic context
		Inappropriate shape of sorting grids	Define the shape of sorting grids based on nature of topic and level of knowledge of participants
Q stage 2: Data collection	Location and materials	*Inappropriate locations and unavailability of adequate furniture	Use of right materials for boards (sorting grid) and cards (statements)
	Administration technique	Data collection is too time consuming for researchers	Administer sorts simultaneously to small groups of (3 – 4) respondents
		Undesired interactions between respondents in collective sorts	Consider small groups of (3 – 4) respondents, preventing their interaction
		*(Digital) gap between researchers and studied populations	Long-term Q capacity building in the Global South
		*Limited use of online-administered Q	Development of open-source, mobile-friendly Q platforms
	Assistance and facilitation	Biases in responses due to prolonged assistance	Provide concise pre-sort instructions and clear (short) statements
			Limit assistance to the sorting mechanism rather than interpretation of statements
			Use the three-pile technique (or its nine-pile variant) as auxiliary sorting method
		Biases due to status of researchers	Training and empowerment of local researchers and/or assistants

Stage	Aspect	Challenge	Good practices
		Biases due to translation and interpretation	Proper training of interpreters about both the method and the topic
			Long-term Q capacity building in the Global South
	Sorting times	Too long sorting times affecting response rates and validity	Control number and type of statements, as well as the number of sorting points
	Complementary information	Poor quality of collected information	Use structured instruments (surveys, forms) to reduce total interaction times and burden of respondents
	Data recording	Possible loss of data	Use of context-sensitive recording means
			Rely on mutually complementary and redundant recording methods
Q stage 4: Interpretation	Validation	*Impossibility of validation due to remoteness	(Remote) validation with at least the highest loaded respondent per factor
Post-Q: Knowledge production	Access to knowledge	Q studies with limited access to Global South researchers	Open-access publishing
		*Socio-geographical decoupling of researchers and studied populations	Long-term Q capacity building in the Global South

*Challenges that may be more profoundly present in RGS settings

Based on the selected documents, we also identified and discussed several good practices that could help in coping with the issues mentioned above (Table 3.3). Researchers can immediately adopt and implement these practices. For example, the design of an appropriate sorting grid is a costless and quicker process with substantial positive impacts. Other measures, however, demand longer participation and commitment of many more actors (e.g., Q capacity building in the Global South and development of more compatible Q electronic platforms). Moreover, the implementation of identified good practices must sometimes undergo trade-off decisions; for instance, complex translations and piloting of statements are not ideal when time and financial restrictions condition the study.

Beyond the discussed challenges, it is worth noting that (74,82) argued that their participants found Q an original and engaging technique. This is consistent with (106,144), whose (non RGS) P-set enjoyed sorting, and even deemed Q 'a welcome change to the usual research practices'. Other selected studies (50,53,59,87) framed it to their respondents, perhaps intentionally, as a game rather than a survey method. Perhaps these perceptions and strategies are yet to be exploited to reduce the burden on participants.

Finally, although no single study reported any ethical conflicts of Q with cultural values, it also appears as an overlooked topic among researchers. Only (65,68,84,87,88) scantily touched upon the clearance and compliance with ethical standards. Nonetheless, this might represent just the tip of a much more complex (cross-)cultural iceberg [for example, the multi-cultural mining conflicts in the Ecuadorian Amazon reported in (91)]. This could be the result of a (still) too Eurocentric, culture-insensitive way of conducting Q research (106). For example, it should call our attention when (145) points out that they gave up on using Q in northeast Madagascar after some villagers perceived it as a form of sorcery. Perhaps more subtle forms of cultural conflict occur in the RGS, and the research community is simply not aware of it (or does not document it). Another instance is the rising and mismanagement of RGS dwellers' (monetary) expectations, especially after exposing them to recurrent and sustained interventions by (non)academic organizations (122). Unfortunately, the data gathered here has not allowed us to elaborate much more in-depth on these topics, yet certainly is a way worth exploring.

3.5 Concluding remarks

Q can be considered as a flexible, innovative, and powerful technique for assessing differences in values across groups. It has strong potential to better understand the dynamics of the RGS beyond oversimplified and stereotypical narratives of poverty. Hence, it can become a valuable tool to support context-sensitive and sustainable development interventions. At the same time, conducting Q studies in RGS settings may pose particular onsite methodological challenges and limitations. These, unless properly addressed in the planning and execution, may hamper Q's effectiveness in revealing RGS discourses that are faithful to respondents' perceptions and opinions. Such inaccurate and distorted discourses may eventually lead to flawed decisions and actions. As a response, we have highlighted good Q methodological practices whereby researchers could cope with those challenges and limitations, thereby ensuring a better accuracy and comprehension of the discourses emerging from the studied phenomenon (e.g., RGS poverty). We encourage Q researchers, particularly those engaging with RGS studies, to implement the strategies presented here.

Notwithstanding limitations and good practices, we advocate the construction of robust Q capacities and the gender-balanced empowerment of local researchers, along with the indispensable provision/production of open access and inclusive scientific knowledge, data, and tools. These efforts may contribute to closing geographical, social, and cultural gaps, such as the ones we have analyzed throughout the present work. presented here.

Supplementary Material

The dataset related to this study can be found at https://doi.org/10.34894/K252KB, an open-source online data repository hosted at DataverseNL (146).

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Author contribution statement

Author	Statement
Juan Carlo Intriago Zambrano	-Conception and design of the work; acquisition, analysis, and interpretation of data -Drafting of the work -Final approval of the version to be published -Agreement to be accountable for all aspects of the work
Jan-Carel Diehl	-Interpretation of data -Critical review for important intellectual content -Final approval of the version to be published -Agreement to be accountable for all aspects of the work
Maurits W. Ertsen	-Interpretation of data -Critical review for important intellectual content -Final approval of the version to be published -Agreement to be accountable for all aspects of the work

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Conflicts of interest

We report there are no competing interests to declare.

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Chapter 4

Q-methodology and farmers' decision-making

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Abstract

Despite extensive research on farmers' constraints and decisions, technology developers, policymakers and development organizations still encounter difficulties in relating policies to farmers' strategies. Often, the concept of 'smallholders' is applied as explaining and predicting farmers' decisions—suggesting that specific strategies of farmers can be meaningfully related to their farm size. Our study into farmers' decision-making concerning water transport technologies in Malawi suggests that this way of grouping farmers in policy and development programs does not match actual decision strategies. Using Q-methodology (Q) as a method allowed us to find decision-making patterns without predefining variables that would influence decision-making. We found that farmers within a predefined smallholder group did not decide in the same ways. Furthermore, our results show that decision-making has a clear gender dimension. We argue that Q is able to capture the nuances of farmers' decision-making processes. As such, the methodology potentially provides a useful feed for policy and technology development.

Keywords: farmer decision-making, farmer typology, Q-methodology, water transport, technology adoption

4.1 Introduction

Malawi is a landlocked country between Mozambique, Zambia and Tanzania, facing high climate variability and many agricultural challenges. Its economy predominantly depends on agriculture, with the sector contributing over a third of the Gross Domestic Product on average (SMEC, 2015). Occasionally it is even higher (e.g., 40% in 2013 according to Harrison and Chiroro, 2016). Agriculture covers about 90% of the total domestic exports (OEC, 2020). As such, the agricultural sector supports over three quarters of the population (SMEC, 2015; Harrison and Chiroro, 2016)—or about 14 million people. Unfortunately, production increases have failed to keep up with population growth, resulting in food shortages in times of poor rainfall (FEWS NET, 2012). With this in mind, the Malawi government has developed an active policy to stimulate agricultural production in the country. Strengthening access to water to secure crop growth is a major pillar of this policy, with subsidies and other arrangements in place to facilitate farmers' uptake of new technologies.

When developing and applying policy measures, it is quite reasonable that policymakers and technology developers standardize target farmer groups to a certain extent, in terms of preferences and decision-making. This standardization can be based on the available (extensive) research on farming typologies and the complexity of farmers' adoption of technologies (Tittonell et al., 2010; Wigboldus et al., 2016; Kuehne et al., 2017; Alvarez et al., 2018; Hammond et al., 2020; Llewellyn and Brown, 2020; Montes de Oca Munguia and Llewellyn, 2020; Saengavut and Jirasatthumb, 2021; Sarker et al., 2021). Nonetheless, various agricultural policies still rely on one explanatory factor, land size ownership, to relate to farmers' conditions and decision-making. Examples of this are European payment schemes (European Commission, 2021; Toma et al., 2021), agricultural transformation policies (Fan et al., 2013), agrarian reforms (Cousins, 2013; Scoones et al., 2019), subsidy programs (Mason and Jayne, 2013; Sharma et al., 2015), and credit allocation (Isaga, 2018). Even one of the more famous current policy criteria, the global food security target (SDG2, target 2.3) (Gil et al., 2019; United Nations, 2020), builds on land ownership. Using land size (ownership) to explain farmers' preferences is based on the assumption that farmers owning relatively small or large pieces of land are supposed to make decisions in specific, different ways. Larger farmers are typically perceived as decision makers with commercial interest, whereas smallholders are automatically taken as the opposite.

Imposing unrepresentative labels on a continuum of characteristics, using a single variable to categorize the complex realities of farmers, may actually fail to stimulate take-up of agricultural technologies. Within this frame of reference, we conducted field research to study how Malawian farmers make decisions concerning water transport technologies (WTTs) for agricultural irrigation (van Dijk, 2020)—with our study including gravity irrigation system, watering can, petrol pump, treadle pump, solar pump and the Barsha pump (the latter being a recent innovation, see Intriago Zambrano et al., 2019). Our results, as reported in van Dijk (2020), suggest that land size does not explain or predict how farmers make decisions and cannot represent the diversity of strategies that farmers employ. We found that many Malawian smallholders actually think in a commercial way. Rather than their mindset, their options to act on that decision-making strategy are less. Limited land ownership may constrain concrete options to improve farming, but not necessarily explain how farmers reason about farming.

With these considerations in mind, the objective of this paper is to discuss the spectrum of decision-making strategies that Malawian farmers employ in the adoption of WTT in agriculture. After a brief historical background on farming categorization and typologies, we explain our data collection and analysis strategy in some detail, as we think that the Q-methodology (henceforth Q) is especially promising to bring forward the spectrum of decision-making—or other relevant topics for that matter. Once we have analyzed the qualitative and quantitative data related to decision-making strategies of our respondents, we contrast our findings with the land-ownership labels we criticized above and we explore differences between male and female farmers. After a discussion and brief conclusion on our field study, we suggest how our findings matter for actors in the larger field of agricultural development.

4.2 Historical background

In the last 50 years, many governments, national and international development organizations and NGO's have invested heavily in agricultural development (African Development Fund, 2006). To ensure investments resulted in effective policy formation, numerous efforts have been made to describe farmers and their properties (Collinson, 2000). Categorization (and simplification) of farmers made policies manageable, enabling streamlining and targeting aid initiatives and technological interventions in the agricultural sector. Farm(er)s were classified by land property size to provide a picture of the agricultural resources and their optimal utilization (USDA, 2020). In the 1960s, many studies described resource allocation patterns and productivity, mainly among resource-limited farmers in the "Global South" (Norman, 2002). However, technological recommendations were rarely adopted because they were poorly designed or irrelevant, especially when contrasted against criteria relevant to farmers (Collinson, 2000). The farmer-data extraction approach of these contrasted sharply with later participatory approaches that involve farmers in technological design and development (Norman, 2002).

From the mid to late 1970s, the attempt to understand farming phenomena evolved to more inclusive farming systems research (Norman, 2002). A related research methods evolved around the concept of farming styles and typologies (van der Ploeg, 1985, 1994) in the late 1980s, with the more specific aim to understand diversity in farming communities. A farming style encompasses the complex but integrated set of variables, norms, knowledge elements, experiences, etc., that describe the way farming decisions are made. Studying farming styles provides (simplified) representations of community diversity through relatively homogeneous groups of farm types (Alvarez et al., 2018). Despite the evolution in understanding farming systems, and the complexity of its many variables, research findings have largely not been translated into adequate policies, programs and projects. The single variable of farm size is still the dominant variable to classify farmers, mainly because of its relative ease to measure and availability of (access to) data. Farm size is considered to explain differences in technical efficiency, land productivity and income, and a major influence on decision-making behavior (Katongo, 1986; Lund and Price, 1998; Lowder et al., 2016; Rose et al., 2018).

The most common definition (Thapa and Gaiha, 2014; Rapsomanikis, 2015), also used in the World Bank's Rural Development Strategy (World Bank, 2003), defines smallholders as farmers "*with a low asset base and operating in <2 hectares of cropland.*" What a small or big farm size is, however, is relative to its context. Across different countries, the distribution of farm sizes depends on a number of agro-ecological and demographic conditions, as well as economic and technological factors (FAO, 2015). This contextual influence is nowadays embraced (to certain extent) by FAO's middle-sized farm threshold per country (Rapsomanikis, 2015). In accordance to this threshold, expressed in hectares, smallholders and large farmers are defined as those managing a farm smaller (or equal to) and bigger than that area, respectively. However, as we discuss further below, land size did not explain reasoning on decision-making of any of these farmers. First, we move to the methodology that allowed us to reach that conclusion.

4.3 Methods: Q-methodology

We relied on Q as the research method for this study. The methodology clusters participants according to their ranking of value- and goal-related stimuli (frequently written statements) and thereby creates typologies that encapsulate the diversity of the participants (Pereira et al., 2016). In short, Q groups participants that sort statements in roughly the same way, which results in groups that show similar viewpoints and considerations. As such, Q provides insight into unique viewpoints or perspectives through systematic examination and understanding of an individual's subjectivity. We opted for Q for two reasons. First, it has the ability to capture qualitative aspects of the topic under study, while offering at the same time a robust statistical approach, thereby combining the strengths of qualitative and quantitative methods (Simons, 2013). Second, as a participatory method, Q enables a stronger farmer participation due to its bottom-up construction of what subjectively matters in the adoption of WTTs (Donner, 2001). To clarify the methodological deployment of Q in our study, we describe how we developed its four steps: (1) Research design, (2) Data collection (administration), (3) Analysis (and consequent results), and (4) Interpretation (as described in Zabala et al., 2018).

4.3.1 Research design

4.3.1.1 Concourse development

In order to conduct a Q study successfully, one needs a representative image of the voices and positions around the issue under consideration—or the "concourse." The content of the concourse determines the quality and reliability of the findings and the identification of the resulting viewpoints. The better the resources from which the concourse is developed, the better it is able to provide a representation of options related to an individuals' subjectivity. We built the concourse on farmers' adoption of WTTs resorting to a two-step approach. First, an initial list of statements was drawn from secondary data sources, i.e., (non)academic literature. Later, in June 2019, we performed semi-structured, tape-recorded on-site interviews with 13 farmers and seven agricultural experts in Malawi. We sampled both farmers and experts through convenience and purposive sampling techniques, based on the network of contacts of the first author, and aiming to cover diverse geographic areas in Malawi. With these interviews, we could validate the initial list, but also gather additional contextualized statements related to the topics within the concourse. Particular attention was paid to understand how the subjectivities surrounding different variables (finances, management, ownership, technology characteristics, etc.) ultimately shape decisions on uptake (or not) of WTTs.

4.3.1.2 Q-set

Our initial set of topics in the concourse was reduced through further categorization, deletion and combination of duplicates—using categories of farmer-related, technology-related and contextual variables (Montes de Oca Munguia and Llewellyn, 2020). Our final Q-set counted 34 statements related to farmers' decision-making on WTT uptake, with the set of statements balancing out between categories. This number of statement in a Q-set is within typically accepted ranges (Watts and Stenner, 2012). The statements were initially written in English; they were translated to Chichewa (local Malawian language) by native speakers [Appendix A in Supplementary material (van Dijk and Intriago Zambrano, 2020)].

4.3.1.3 Sorting grid

The 34 statements fitted with a mesokurtic, 9-point, forced inverted quasi-normal distribution sorting grid—consisting of a -4 to +4, "strongly disagree" to "strongly agree" scale (**Table 4.1**). We considered this grid as most useful for two reasons. First, farmers and extensions officers are not necessarily equally knowledgeable on the topic (if they would have been, a platykurtic shape would have been useful). Second, we are not exploring a phenomenon that is fully unfamiliar to our target audience (which would have suggested a leptokurtic shape) (Watts and Stenner, 2012). We provided two positions on each extreme, thus allowing a few elements in the category of most (dis)agreement, as this offered more explanatory information for the later interpretation of factors.

Table 4.1. Features of the sorting grid.

Sorting criteria	Strongly disagree								Strongly agree
Sorting point	-4	-3	-2	-1	0	+1	+2	+3	+4
Nr. statements	2	3	4	5	6	5	4	3	2

4.3.1.4 P-set sampling techniques

We sampled both farming communities and respondents by means of a purposive sampling technique (Watts and Stenner, 2012). Communities were selected in agricultural areas with several WTTs. Respondents were farmers offering a suitable diversity for three criteria: land size, types of farming (individual or cooperative), and WTTs being used. We reached both communities and respondents through a network of agricultural experts operating in Malawian farming systems. These agricultural experts themselves participated as proxy-respondents on behalf of farmers in their respective districts. This additional participation allowed further study how farmers and experts compare with respect to WTT uptake. Details of the 58-respondent P-set, including category, specific role, gender location and WTTs used, can be found in Appendix B in Supplementary material (van Dijk and Intriago Zambrano, 2020).

4.3.1.5 Data collection (administration)

We administered Q exclusively through the face-to-face technique. With farmers, Q was usually conducted right next to their respective houses or farms, whereas for experts Q was mostly conducted in their respective offices. We allowed both individual and collective sorting sessions with farmers. The (few) collective Qs were performed with farming cooperatives, in which several members had group discussions that resulted in a single sort deemed representative of their organization and its internal dynamics. As far as we can see, these different sorts can be compared. We will return to these different Q sorts in the results section.

Sorting sessions were either in English or Chichewa, depending on the preferred language of the respondent—with Chichewa users usually using a fellow farmer or a local extension officer to translate between the user and the researcher. We made sure as best we could that this extra involvement did not influence the sorting itself. When sorting, respondents were asked the umbrella question: What are the most important decision making elements for me as a farmer in adopting water transport technology for irrigation? We offered a four-stage assistance to the participants: (1) pre-sort instructions in English and Chichewa (i.e., researchers, study goal, sorting dynamics), both written and verbally (mandatory in the case of illiterate participants); (2) preliminary sorting with the optional three-pile technique (i.e., conducting a first rough distribution by disagree, neutral, agree criteria), although participants frequently skipped this step, thus engaging directly with the full 9-point sorting grid (as indicated in **Table 4.1**); (3) by-step sorting guidance; (4) on-demand clarification and support. Each participant sorted on the sorting grid, drawn on a cardboard, with the 34 statements that were printed and glued on cardboard chips (890 mm × 890 mm) with a randomly assigned number behind. Participants could shuffle the chips on the go around the grid according to their own judgment. We recorded the final distribution, after which we conducted tape-recorded interviews with participants, where they explained their respective choices and reasoning.

4.3.1.6 Analysis

We analyzed the dataset of collected sorts with KADE (Ken-Q Analysis Desktop Edition) v1.2.0 (Banasick, 2019), which has the benefit of a non-proprietary GNU General Public License, user-friendly graphical user interface, and cross-platform availability. As factor extraction method, we employed the Principal Component Analysis technique, which we preferred to Centroid Factor Analysis method, due to its single, mathematically-best solution (Watts and Stenner, 2012). We opted to explore different factor-number solutions with respect to the Kaiser-Guttman criterion [Eigenvalue (EV) threshold; EV>1.0] (Watts and Stenner, 2012), composite reliability ($r_f \geq 0.94$) (Ghazali et al., 2018), representativeness criterion (≥50% P-set loaded) (Hylton et al., 2018), and distinguishing statements (≥5 distinguishing statements at statistical significance $p<0.01$) (Cammelli et al., 2019). Retained factors were rotated with the Varimax technique, given its maximum variance solution and fit for a holistic analysis trajectory. We required the majority of common variance to automatically load significant sorts ($p<0.05$), resulting in confounded sorts not being taken into account.

4.3.1.7 Interpretation

We interpreted the retained factors by means of the holistic technique of crib sheets (Watts and Stenner, 2012), which focuses on the examination of factor scores in relation to other statements within the factor, as well as on its comparison with other factors. Crib sheets ensure that the interpretation considers the relative positions of statements within each factor, not just the individual statements in isolation.

4.4 Results and discussion

4.4.1 Collected sorts

We managed to collect a total of 58 valid sorts [Appendix C in Supplementary material (van Dijk and Intriago Zambrano, 2020)], which usually took 20 – 40 min each after initial instructions. The sorts came from 49 farmers (either individuals or cooperatives' representatives) and 9 experts. Farmer respondents ranged from poorly-educated farmers operating on ~0.1 ha farms, to well-educated farmers farming on areas up to 5 ha. **Table 4.2** contains details on respondent. Most of the farmers that were initially interviewed during the concourse development were revisited for the sorting and data collection. As such, the extensive qualitative insights collected during the interviews could help explaining their sorting decisions. Besides, many interviewees had expressed an interest in knowing how their input had been translated by us into the puzzle-like Q exercise.

Table 4.2. Total collected sorts, with respect to type of participant and gender.

Participant	Gender			Total
	Female	Male	Mixed F/M*	
Individual smallholder farmer	3	6	--	9
Cooperative smallholder farmers	6	5	18	29
Individual large farmer	2	6	--	8
Cooperative large farmers	0	2	1	3
Expert(s)	1	7	1	9

*This category pertains to groups that comprised both female and male participants.

Our data collection created a P-set/Q-set ratio of 1.71; although this ratio is higher than typically, in practice this does not pose further statistical issues (Watts and Stenner, 2012). Given that female farmers usually bear poorer access to resources of all kinds (Poole, 2017; Giordano et al., 2019), we acknowledge that the male-skewed P-set could mean certain form of underrepresentation of the topic under study.

4.4.2 Statistical analyses

Our exploration of possible analysis trajectories that met the criteria mentioned in section Analysis (**Table 4.3**) suggests how different decision-making styles interact with each other and that, depending on the chosen factor solution, respondents can be understood representing views with multiple aspects— which are stressed depending on the factor selected. This is illustrated in the Q maps of the three- and four-factor solutions (**Figure 4.1**A and **Figure 4.1**B, respectively) (see Yoshizawa et al., 2016) for details on this aspect. Q maps are based on two axes, with in our case the horizontal axis relating to the theme "support," and the vertical one the theme "risk." We aim to show among the "support axis" whether respondents value being "independent" or whether they value "support" (including advice) from others. The "risk axis" spreads from "risk averse" to "risk taker," depending on how much value participants attached to familiarity and understandability in selecting WTTs. The plotted values are the average scores of those loading in a factor, specifically for the statements related to support and risk. Another theme we explored, but do not depict here, is the cost-effectiveness orientation of the respondents. Details of themes, calculations of scores and plotting of Q maps can be found in Appendix D in Supplementary material (van Dijk and Intriago Zambrano, 2020).

Table 4.3. Factor retention criteria, description, and results.

Criterion	Description	Nr. Factors
Kaiser-Guttman	Retain factors with EV≥1	8
Composite reliability	Retain factors with r_f≥0.94	5
Representativeness	Retain factors when ≥50% P-set loaded	8
Distinguishing statements	Retain factors with ≥5 distinguishing statements at statistical significance p<0.01	5

The Q maps show the dynamic clustering and (possible) shared viewpoints of the loaders, specifically depending on the analysis trajectories that the researcher(s) aim to select. The bubble around the respective plotted loaders captures the perspectives of each factor, with a factor being a group of respondents that share a similar sorting—even with finding variance within a factor, with some participants even plotting outside the core factor bubble. Furthermore, as factor bubbles overlap, we must also assume that participants of different factors can share similar perspectives on certain decision- making theme. Q maps are to be understood as exploratory tools, with their construction being the choice of the researchers. Q maps do help in rapidly observing factors' distribution and identifying associated discourses.

We concluded that both the three- and four-factor solutions gave enough distinguishing statements for analysis. The "perfect fit" does not exist, but we did consider the four-factor solution as the most interesting fit for the data and field observations [KADE analysis log in

Appendix E in Supplementary material (van Dijk and Intriago Zambrano, 2020)]. It offered us the best trade-off between the maximum variance—its embracement of variety and subjectivity—and the interpretability potential to make meaningful ontologies out of each of the factors (Pereira et al., 2016). The four factors represent 43 of the 58 participants (74% of the sample) and account for 55% of the total variance. Characteristics of factors and factor scores are given in **Table 4.4** and

Table 4.5, respectively. The remaining 15 participants loaded insignificantly on any or significantly on more than one factor. These confounded loaders are not analyzed further in this text, but it is useful to keep in mind that the variation we report among respondents may be even higher.

Table 4.4. Factors characteristics.

Characteristic	Factor			
	1	2	3	4
No. of SL sorts	12	11	9	11
Composite reliability	0.980	0.978	0.973	0.978
SE of factor Z-scores	0.141	0.148	0.164	0.148
% unrotated variance	38	6	5	5
% rotated variance	15	13	12	15

SL, Significantly loaded; SE, Standard error.

Table 4.5. Raw factor scores.

Nr.	Statement	Factor			
		1	2	3	4
1	I prefer paying through installments over time.	0	0	2*	3*
2	I want overall affordable costs.	1	4*	2	2
3	I don't mind paying fuel to keep the technology working.	2*	-4	-1	-2
4	I am happy with my current pumping method. I don't want to invest.	-1	-1	-2	-2
5	I prefer to wait for someone to give me an irrigation technology.	-2	-2	-1	-1
6	It is too expensive. I don't want to invest.	-3	-3	-4	-3
7	I have other farming limitations. I don't want to invest.	-3	-3	-2	-2
8	I prefer to use and pay for a technology with a group of farmers instead of individually.	2	0	0	2
9	I prefer to adopt a more expensive technology but safe on running cost.	1	1	0	-1*
10	I find easy individual operation important.	1	3	1	0
11	I find easy maneuverability important.	-2*	0	0	2*
12	I find it important that the technology is hard to vandalize or steal.	0	-1	4*	1*

Nr.	Statement	Factor			
		1	2	3	4
13	I want to be able to maintain the technology myself.	3	2	2	1
14	I want it to be cheap to maintain the technology.	0	4*	1	0
15	I want my irrigation technology to give me a better status in my community.	-1	-2	-1	-1
16	I prefer a technology that works automatically without human power.	-1	2*	-1	-3
17	I prefer a technology that can give me a high volume of water.	4*	1	0	0
18	I prefer a technology that can give me a high pressure.	3*	1	-3*	-1
19	I want the technology to enable me to grow crops that I can sell at the market.	4*	3	3	3
20	I want the technology to enable me to grow crops that I can eat.	2	2	1	4
21	I prefer a technology that uses water efficiently.	-1	3*	0	1
22	I don't mind watering the crops myself without the use of a technology.	-3	-3	-3	-4
23	My water availability and water source determine my technology choice.	0	1	4*	2
24	I want support from my community and family.	-2	-1	-2	-3
25	I don't own the land on which I farm. I don't want to invest.	-4	-4	-4	-4
26	I can't expand my farm. I don't want to invest.	-2	-2	-3	-2
27	I prefer a technology that has been advocated by the extension officers.	3	2	0*	3
28	I need external support after implementation.	0	0	-1*	4*
29	I prefer if the company representatives are Malawian.	-4*	-1	-2	-1
30	I want to hear about the technology before I adopt it.	2	0*	3	1*
31	I want to have seen the technology before I adopt it.	1	-2*	2	0
32	I want to try out the technology before I adopt it.	-1	-1	1	0
33	I want a technology that other farmers have used successfully before I adopt it.	0	1	1	0
34	I prefer technology that I can understand.	1	0*	3	1

* Distinguishing statement at $p<0.01$

4.4.3 Factors interpretation

Each of the four factors can be considered as a synthetic representative farmer according to key sorting behavior. As such, we did create brief participant typologies to synthesize our findings (**Table 4.6**), in line with a common practice in Q methodology (see Fairweather and Keating, 1994; Walter, 1997; Brodt et al., 2006; Burton and Wilson, 2006; Pereira et al., 2016). Actually, it is quite common to assign labels to factors according to key characteristics. The wording of these labels matter. The main risk of using labels is that one could fall back into certain prejudices. This may result in a traditional way of thinking in which certain characteristics are forced upon an individual or group. Such an approach in essence undermines the goal of Q to consider the gathered data in terms of the participants' own (patterns of) responses. Predefined grouping would mean looking for predefined patterns among people, whereas Q builds on the claim that "*people and not tests that are the variables*" (Coogan and Herrington, 2011, p. 24).

Table 4.6. A brief summary of the four factors.

Factor 1	**Characteristics**: water volume seeker, team player, advice follower Loaders prefer high-flowrate and high-pressure WTTs that can be shared with a group. Investing in relatively more expensive technologies is an acceptable consequence. External advice and sourcing is highly appreciated, perhaps because of lack of knowledge about WTTs.
Factor 2	**Characteristics**: cost-effective decision maker, long-term thinker, individual risk taker Loaders appear to have profit maximization and farm expansion as primary objective. They are looking for WTTs that are affordable and labor saving, but also offer low running costs. Loaders pay special attention to gross margin and cost of production. Since these farmers often operate individually, it is important that the technology is easy to individually operate.
Factor 3	**Characteristics**: context aware, risk averse, individual and independent farmer Loaders aim to minimize risk. Therefore, they have a strong preference for proven, familiar, understandable technologies that are hard to vandalize or steal. Assessment of available water resources for irrigation are taken into account to make sure the WTT fits their specific situation.
Factor 4	**Characteristics**: dependent, resource constrained, team player Loaders prefer affordable WTTs, with low running costs, for a group. External support or advice is hugely appreciated. Paying for technologies by installments and pooling it in a group helps to invest in technology options. Easy maneuverability helps to share the technology with other farmers in the group.

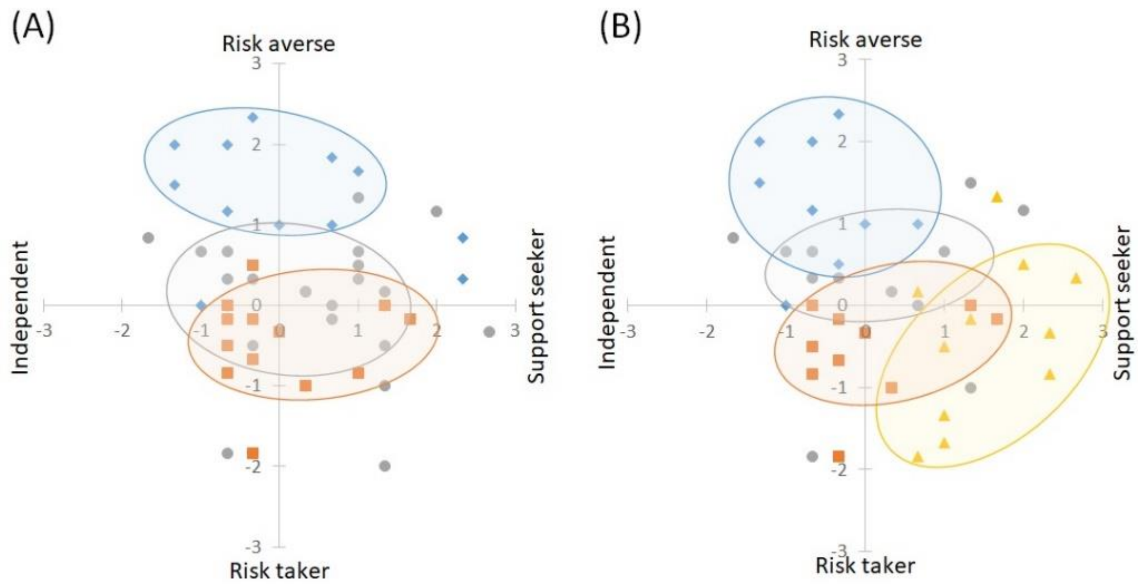

Figure 4.1. Q maps of (A) three-factor and (B) four-factor solutions. Gray circles, red squares, blue diamonds and yellow triangles represent factors 1, 2, 3, and 4 (for four-factor solution), respectively. Bubbles with the same colors reflect the clustering of the corresponding loaders regarding the support and risk thematic axes.

Many complexities are reflected in the clustering of the P-set, and these should therefore be interpreted with caution. The interpretation with specific terms might be distorted by bias, affecting the validity and reliability of findings. Factors' multidimensional character, inherent to the concourse and the resulting statements, should not be summarized into one single orientation. To avoid such occurrences, we did not give names to our four factors—but we did provide a set of terms that seem to cover the different considerations reflected in the sorting. These were composed by examining the sorting of statements in relation to other statements within each factor and between factors [crib sheets of Appendix F in Supplementary material (van Dijk and Intriago Zambrano, 2020)]. The detailed interpretations of the factors are shared in the subsections, using the notation of number of statement and factor score. As an example (29: -4) means that statement 29 was scored -4 (in line with the scores of

Table 4.5).

4.4.3.1 Factor 1

Factor 1 (F1) has an EV 22.00 and explains 15% of the total rotated variance; 12 participants load significantly in this factor, with the vast majority (n=10) being smallholders, along with one larger farmer and one expert. Most WTTs used in this group are gravity irrigation and watering can, alongside a single loader using a petrol pump.

The idealized loader of F1 expresses a strong focus on WTTs offering high water flowrates (17: +4) and pressure (18: +3)— in contrast to the lower importance given to efficient water use (21: -1), and even ignoring the limitations that specific water sources may pose (23: 0). This farmer has a deep willingness to invest in (25: -4; 7: -3) and seek for a WTT (5: -2), particularly on one that enables the production of cash crops to increase revenues (19: +4). In fact, the ideal F1 respondent would prefer to invest upfront (1: 0) in a more expensive WTT, as long as it is easy to service (13: +3) despite its maintenance cost (14: 0), can be sourced/pooled with other farmers (8: +2) and has low operation costs (9: +1). For this farmer, WTT maneuverability (11: -2), testability (32: -1) and familiarity (33: 0) are less important. These characteristics may perhaps suggest that the F1 farmer is after a solar pump, were it not that the ideal loader expresses the preference to pay for fuel to keep running the WTT (3: +2)—which resembles a petrol pump. This could relate to the observation that most loaders rely on gravity irrigation systems, and may have limited access to sources of information about other available WTTs. This potential conflict in making a choice also shows up in terms of external support. The F1 farmer carefully follows advice provided by local extension officers (27: +3), but also prefers to rely on foreign WTT suppliers (28: -4).

4.4.3.2 Factor 2

Factor 2 (F2) has an EV of 3.74 and explains 13% of the total rotated variance; 11 farmer participants load significantly in this factor, with eight corresponding to smallholders. It is worth noting that F2 did not load any of the experts. Most WTTs used by respondents correspond to automatic devices such as the petrol, solar and Barsha pumps—even though we also find one user of gravity irrigation, two loaders using watering cans and one case of a treadle pump.

The F2 ideal farmer values WTT cost-effectiveness. In the decision-making process, this farmer is strongly willing to invest (25: -4; 7: -3) and seek for a WTT (5: -2), either individually or in-group (8: 0), paying special attention to the general affordability of the (initial) investment (2: +4; 21: +3), and long-term maintenance (14: +4) and running costs (9: +1; 3: -4) of the WTT. Paying in installments, however, is not of considerable importance for this farmer (1: 0). This could suggest she has enough financial resources to pay for the technology. Another important variable of the cost-effectiveness is the individual ease of use and labor saving ability of the WTT (10: +3). Its capacity to operate automatically is therefore strongly preferred (16: +2). Unlike watering cans—which require substantial human power—the WTT should require little human effort or attention when pumping water. This enables the farmer to focus on other activities such as working on the crops or expanding the farm. F2 farmer attaches relatively low value to familiarity (31: -2; 32: -1; 30: 0; 33: +1), understandability (34: 0), safety (12: -1), or status (15: -2). She is confident enough to adopt the technology, as long as it satisfies the criteria mentioned above. This reasoning can be in close relation with the types of automatic water pumps that many of the loaders are already using.

4.4.3.3 Factor 3

Factor 3 (F3) has an EV of 3.23 and explains 12% of the total rotated variance; 9 participants load significantly in this factor, with one smallholder, four large farmers and four agricultural experts. The loaded farmers use mechanized WTTs: petrol, pump and Barsha pumps.

The idealized farmer of F3 considers that different biophysical farm conditions influence the appropriateness of a WTT. She is inclined to find the best technology fit (23: +4), which is not necessarily determined by high pressure (18: -3) or flowrate (17: 0). Consequently, the F3 farmer is willing to invest in a more optimal WTT (25: -4; 26: -3; 4: -2), despite high investment costs (6: -4). To cope with possible upfront costs, this farmer prefers to pay in installments (1: +2), either individually or in-group (8: 0). This reduces risks associated to high initial investments and opens up a wider range of technology options. This farmer is also rather risk-averse, expressed in the relatively high value given to familiarity (30: +3; 31: +2; 33: +1), understandability (34: +3) and testability (32: +1) of the WTT, but also in the preference for technologies that are hard to vandalize or steal (12: +4). Moreover, F3 farmers manifest a low attachment to external support (27: 0; 28: -1). This could be a reflection of well-informed farmers, which may fit with their current use of automatic water pumps.

4.4.3.4 Factor 4

Factor 4 (F4) has an EV of 2.70 and explains 15% of the total rotated variance; 11 participants load significantly in this factor. It is worth remarking that this was the only factor consisting exclusively of smallholders, as it did not load any large farmer or agricultural expert. Gravity irrigation is the prevalent WTT used, followed by a smaller representation of watering can, petrol pump and Barsha pump.

The ideal F4 farmer appears to be influenced by variables involving external support. This support can encompass finances and help with farming inputs, but also knowledge about irrigation management, local markets or different WTT options (28: +4). The decision-making process, for instance, seems to be strongly steered by professional advice given by governmental extension officers (27: +3), and not by community peers or relatives (24: -3). There is the strong willingness to invest in a WTT to irrigate better (25: -4; 22: -4; 4: -2); perhaps this is related to the prevalent use of gravity irrigation among the loaders. However, financial restrictions may limit the availability of choices. Paying for technologies in installments (1: +3)—and even more if pooling financial resources with a group (8: +2)—thus helps in opening a wider range of technology alternatives. Easy maneuverability of the technology (11: +2) may become an enabler in sharing a WTT with a fellow farmers, hence further facilitating in sharing the investment. In contrast, less important decision factors are the ease of operations (10: 0), maintenance costs (14: 0), familiarity (33: 0) and pumping performance (17: 0). Moreover, the use of an automatic (or less human-power demanding) WTT is not considered important (16: -3), possibly due to its linkage with expensive fuels (3: -2) and high upfront costs of the device (9: -1). This farmer seems to value both self-consumption (20: +4) and commercialization (19: +3).

4.4.4 Farming discourses vs. land size

With the four factors in mind, we compared our four-factor categorization of farmers to the 0.91 ha middle-sized farm threshold in Malawi (FAO, 2017). According to this threshold, Malawian smallholder farmers operate farms ≤0.91 ha, whereas large farmers operate >0.91 ha. In **Table 4.7**, the participants are labeled according to these definitions and compared to the factors. We can clearly observe that the predefined groups of smallholder farmers, large farmers (and experts) do not sort in one characteristic way for their labels or roles. The group showing the greatest variety in sorting behavior is the smallholder farmer group, as its members loaded in all four different factors—with several of them highly correlating to factors with commercial mindsets and independent objectives. Large farmers also sorted in different ways, with a more specific focus on either F2, with its focus on cost-effectiveness and labor saving ability, or F3 where participants expressed a focus on risk aversion, independency and context-awareness. Interestingly, about half of the experts ended up in the unloaded group, meaning they loaded insignificantly on one single factor or shared significant sorting behaviors with multiple factors. We can speculate about a possible underlying mismatch between farmers' decision-making rationales compared to the experts' understanding, but a definite claim in this respect is out of the scope of our current work.

Table 4.7. Overview of the factors' composition with respect to the predetermined labeling of respondents.

Label/role	Loaded sorts				Unloaded sorts
	F1	**F2**	**F3**	**F4**	
Smallholder	10	8	1	11	11
Large farmer	1	3	4	0	0
Expert	1	0	4	0	4

What we think we can claim is that farmer decision-making on WTT in Malawi is not rooted in the variable of land size, which is so dominant in policymaking and implementation. This stresses the observation we already made above: with factors representing different possible grouping patterns—compared to typical ways of labeling—we need to be careful with how we (pre)define people. Literature and policies, for instance, tend to illustrate that Malawian smallholder farmers are stagnant and destined to decline, as they do not (yet) think commercially. In contrast, our results show smallholders that show that type of decision-making. We suggest these farmers are willing to move into commercial farming, but may simply not have the means to do so. As such, farm size might have an influence on what farmers (can) do, but would not be the single variable to explain farmer's decision-making.

4.4.5 Female and male farmers

Women often hold completely different investment priorities than men, with female farmers often value timesaving technologies and male farmers more likely to value technologies that increase productivity (Byanyima, 2015). To explore this gendered decision making, we present the gender distribution in the four respective factors in **Table 4.8**—with sorts performed in mixed groups of male and female indicated as well. The table presents the number and percentage of male, female and mixed groups in their respective factors, and the normalized percentages relative to sample size distribution. We encounter male and female farmers in every factor (or decision-making preference), with a high normalized female percentage in F1 (characterized by water volume and group-based WTTs) and F2 (characterized by cost-effective and labor saving technologies). Less females loaded on F3, characterized by independent and risk averse decision-making. While this research is not focused on the impact of gender aspects on farmer decision-making, we should clearly not assume that men and women farmers have the same investment preferences (see van Koppen et al., 2013), nor that all women farmers have the same preference. Understanding the variables that distinguish decision-making between and for different genders, possibly under different conditions, could be very valuable to study in future (Q) research.

Table 4.8. Gender distribution across the four factors.

Factor	Loaded sorts [nr. (%)]			Normalized values (%)		
	Male	Female	Mixed	Male	Female	Mixed F/M
F1	4 (33)	4 (33)	4 (33)	22	49	29
F2	7 (64)	4 (36)	0 (0)	45	55	0
F3	8 (89)	1 (11)	0 (0)	79	21	0
F4	3 (27)	1 (9)	7 (64)	21	15	64

4.5 Conclusions from our field study

Our findings suggest that the decision-making variables surrounding the adoption of WTTs in Malawi is highly diverse. Our Q approach allows us to suggest that regarding these WTTs, it makes sense to distinguish between four participant types, characterized by different distinguishing variables. We do not suggest in any way that these four types to be written in stone, but we do claim that our four factors show that there is considerable diversity with the groups of smallholders, large farmers and experts concerning decision-making on WTT adoption in Malawi. The notion of farming decision making is therefore not exclusively rooted in the variable of land size. We have also suggested that the strategies of female and male farmers may be different in terms of how many male and female farmers are represented in different factors. Our findings are in line with other studies that identified different farmer types as relatively homogeneous groups (Brodt et al., 2006; Pereira et al., 2016; Vander Vennet et al., 2016). Although further background variables were beyond the scope of this work, it would be a valuable addition for further research to explore underpinning reasons, other than land size, why some farmers sorted differently than others.

Again, we do not claim that the four factors that we presented are the perfect—let alone only—representation of participants' subjectivity concerning the adoption of WTTs. We acknowledge that it is challenging, if not impossible, to fully capture the diversity of farming systems in any study, as it is inevitable that the rich set of considerations of actual decision makers is simplified and standardized. With that in mind, we argue that current land-based categorizations of farmers do not support the development of effective policies for agricultural development. When using this definition, one can be labeled as a "smallholder farmer" and yet have (contradictorily) similar decision-making patterns as a "commercial farmer" or an "expert." As such, land size has to be considered a poor measure to predict farmer decision-making.

A more representative categorization of farmers can be achieved through bottom-up approaches, giving the diversity of decision makers a clearer voice through participatory methods. We argue that Q is particularly suited to explore this representative diversity, as Q allows going beyond a single-variable threshold (i.e., land size) without predefining too strict what the unknown diversity would entail. Whereas, the actual design of the Q sort itself obviously does already reduce the complexity that can be encountered, the analysis promotes a richness in results. Depending on the analysis trajectory the researcher selects, individuals can be "transformed" from one group to another, and how different decision-making styles interact with each other. This suggests that farmer technology decision-making is part of a social dynamic system that is influenced by a wider range of variables, including the perspective of the researcher(s)!

This explicit acknowledgment of social dynamics in itself is in contrast with more traditional top-down thinking of straight-lined technological transfer from governments, development organizations and technology sellers, that was, and often still is, apparent in low-income countries. In this approach, the (smallholder) farmer is still the end-user, a passive actor, a receiver of whatever is done before. Moreover, while other possible variables of influence in decision-making (e.g., uncertainty, capital, costs, performance, etc.) are abundantly recognized and discussed in literature, they are rarely translated into policies.

4.6 Policy implications of our findings

Once we know that being a smallholder does not mean at all that one is only caring to provide food for one's household, it must mean that smallholders are not to be understood as "those poor farmers who need to be made aware of commercial strategies." Our results suggest that many Malawian smallholder farmers want to develop themselves to be competitive in the (local) market. In our study, we did discuss with smallholders (or their cooperatives) who have organized themselves, created large and meaningful entities for the local market, and become commercially competitive. However, it often might be the case that smallholders do not have the immediate opportunities to develop those commercially attractive farming strategies— which may partially be the result of not being recognized as capable decision makers within policy programs.

Whereas, we cannot claim that every situation will be similar to what was found for Malawi, we do think that our findings do have a wider relevance for the scholarly and policy communities involved in agricultural development. Smallholder farmers can become the nursery from which successful commercial farmers can develop—and should be valued as such (Aliber and Hall, 2012). Hence, the definition of "smallholder farmer" used in policy should be avoid the strict focus on farm size. Smallholders are not a homogeneous group, but rather a diverse set of farmers with varying characteristics, as Llewellyn and Brown (2020) firmly stress as well. As other studies suggest, there could be alternative underpinning reasons for differences in decision-making (Matshe and Young, 2004; Pannell et al., 2006; Doss et al., 2014; Doss and Meinzen-Dick, 2015; Mutenje et al., 2016; Wheeler et al., 2017). Compressing the meaning of a farmer down into one category that in practice represents multiple characteristics of farmers, hides the importance of the question (who decides) which characteristics are to be included anyway. This is especially relevant when these definitions take center stage in policies, technologies and development programs.

Proper understanding with the aim to alleviate specific constraints of farmers promises to produce higher benefits compared to implementing and promoting blanket, universal strategies and technologies. Instead of a convenient standardized one-size-fits-all imposing approach—in which it is predefined what farmers need and want based on unrepresentative criteria—policies, investments, innovations and technologies would need to adapt concretely to the different farmer types that are found in their working areas. Adapting measures to country's contexts and respective farmers, can play a critical role in bringing down barriers for farmers to efficiently uptake WTT for irrigation—and possibly allow replacing the metaphor "technology transfer", often used in policies and development programs, with "technology translation" (Garb and Friedlander, 2014)— or even co-creation. Policies and technology packages do not have to be tailor-made on individual scale, but should recognize multiple, relevant types of farmers who make decisions based on different variables. Recognizing this diversity—which can be fruitfully brought forward by Q—and translating it into contextualized support and technology packages, can encourage sustainable and effective farmer development.

Data availability statement

The datasets generated/analyzed for this study can be found in the DataverseNL (https://doi.org/10.34894/ZUY803) (van Dijk and Intriago Zambrano, 2020).

Ethics statement

The studies involving human participants were reviewed and approved by Human Research Ethics Committee of Delft University of Technology. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

RvD: conceptualization, methodology, investigation, formal analysis, writing—original draft, visualization, and project administration. JI: writing—reviewing and editing, data curation, visualization, and supervision. JD and ME: methodology, writing—reviewing and editing, supervision, and funding acquisition. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.954934/full#supplementary-material

Abbreviations

WTT, water transport technology; Q, Q-methodology; EV, Eigenvalue; F1, Factor 1; F2, Factor 2; F3, Factor 3; F4, Factor 4.

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Chapter 5

Discourses on the adoption of the Barsha pump: A Q methodology study in Nepal and Indonesia

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Abstract

Improved water management is an important strategy to support smallholder farming, and thus to foster food security and improved livelihoods. Within this strategy, technologies like water pumps, especially those operating on renewable energies, are key, as they are more environmentally sound and affordable alternatives. Their successful and sustained uptake is a complex process—largely dependent on the adopter and its surrounding context—usually overlooked by traditional linear technology-transfer approaches. By means of Q methodology, we explored cross-cultural discourses around the adoption of the Barsha pump (BP), a self-reliant hydro-mechanical device that does not require any external input than flowing water to operate. We administered the method to 43 (non-)farmer respondents linked to Nepali and Indonesian smallholder farming systems. We identified three relevant discourses, one of them bipolar in nature. These three groups accounted for 39, 36, and 28% of the total explained variance of our study. The first one identified BP's potential early adopters. The second discourse embodied the (stereotypical) highly dependent smallholder. The last one characterized (contrasting) views around the BP as an enabler of potential service-oriented business models to achieve wellbeing. These results reflect the need for a shift of mindset toward new ways of understanding technological change in smallholder settings. On the one side, simplistic one-size-fits-all models cannot connect to the diversity of issues and opinions as we found. On the other side, it is virtually impossible to produce tailored solutions to satisfy each of those individual realities. We propose possible adoption pathways that may lead to the exploration of innovative and adaptable business models that serve the diversity of smallholder farming needs more effectively.

Keywords: water management, smallholder farming, Barsha pump, hydro-powered pump, Q methodology, Nepal, Indonesia

5.1 Introduction

Eradication of hunger and malnourishment is a main goal on the global agenda [Sustainable Development Goal (SDG) 2: Zero Hunger] (United Nations, 2020a; Villarreal, 2022). Achievement of this target would require the global food production to increase roughly by 50% within the next 30 years (FAO, 2017). Such a substantial growth will largely stand on the shoulders of smallholder farmers (SF) (Giordano et al., 2019), who are mostly clustered in South and Southeast Asia, and to a lesser extent in sub-Saharan Africa (Samberg et al., 2016). Appropriate interventions in this sector would not just contribute to global food security, but also (in)directly to poverty alleviation by boosting local economies (SDG 1), reduction of gender inequalities by empowering female smallholder farmers (SDG 5), and protection and promotion of farming systems biodiversity (SDG 15) (Poole, 2017; Giordano et al., 2019).

Given that limited water access is one of the main challenges that SFs face, investing in water management technologies is a cornerstone strategy in the accomplishment of these SDGs (Giordano et al., 2019). In this respect, small private irrigation through diesel- and electric-pump sets is an already dominating strategy across Asia, and a steadily increasing one in sub- Saharan Africa (de Fraiture and Giordano, 2014). Spread of these conventional technologies can lead to negative environmental impacts associated with water over-abstraction and polluting emissions. Additionally, unaffordable and even inaccessible fuels and grid-electricity might render these water pumps cost-prohibitive—or ultimately inapplicable—for the poorest and most remote SF (de Fraiture and Giordano, 2014). Water pumps operating on renewable energy (e.g., solar, wind, and hydro) appear as more environmentally sound, more financially affordable, and as such more appropriate alternatives for remote, off-the-grid locations (Gopal et al., 2013). Within this category, hydro-powered pumps (HPPs) have a number of additional advantages compared to other water pumps. Hydro-powered pumps use a concentrated, widely available and predictable energy source, are more cost-effective, are mechanically less complex and more robust, and as a result are typically more efficient (Fraenkel and Thake, 2006). Still, HPPs have been largely neglected, seemingly due to the development of other forms of readily available energy (e.g., electricity, fossil fuels). Nevertheless, hydro-powered devices have regained an interesting momentum in recent times (Intriago Zambrano et al., 2019).

Many authors have studied adoption patterns and constraints of conventional water pumps in SF settings (Burney and Naylor, 2012; Getacher et al., 2013; de Fraiture and Giordano, 2014; Gebregziabher et al., 2014; Namara et al., 2014; Ali et al., 2016; Mottaleb et al., 2016; Chuchird et al., 2017; Abebe and Shewa, 2018; Mottaleb, 2018; Theis et al., 2018). Only a few have explored the adoption of renewable energy-pumps, typically scoped on solar-driven systems (Burney and Naylor, 2012; Nederstigt and Bom, 2014; Ali et al., 2016; Zhou and Abdullah, 2017; Shah et al., 2018; Theis et al., 2018; Gupta, 2019; Wong, 2019; Bastakoti et al., 2020). Similar to any other agricultural innovation, adoption of (non)conventional water pumping technologies is a complex process that largely depends on the receiver and the surrounding context (Alexander et al., 2020; Llewellyn and Brown, 2020; Olum et al., 2020). The highly heterogeneous (social and biophysical) nature of smallholder agriculture, which complicates this relationship between farmer and context further (Ruben and Pender, 2004), must be first understood in order to implement effective strategies adapted to local realities (Vanlauwe et al., 2014). Traditional technology- push approaches have generally overlooked a broader range of smallholders' decision-making variables and contextual conditions, thus resulting in discouragingly low and slow adoption rates (Röling, 2009; Giordano et al., 2019; Alexander et al., 2020; Olum et al., 2020). In general, adoption literature has widely disregarded farmers' perceptions as a crucial influencing variable in the technology uptake process (Foguesatto et al., 2020), which is the research gap we tackle in this study.

The Dutch startup company aQysta has developed a novel waterwheel-powered HPP—commercially known as the Barsha pump (BP)—which it markets as a sustainable water pumping solution for SF (aQysta, 2022). This company, headquartered in a high-income setting, has gradually introduced the pump to the Nepali and Indonesian (Sumba Island) markets through a technology-push approach (technology and contexts are explained in section 5.3). This market approach has resulted in a device that is not necessarily familiar for SFs nor exactly aligned with their respective values. Potential disagreements of viewpoints may thus emerge between the manufacturer/provider and the end-users during this technology provision process.

This study, as part of a larger doctoral research at Delft University of Technology on sustainable smallholder irrigation (Intriago et al., 2018), investigates cross-cultural discourses and perceptions on the adoption of the BP—and their possible (dis)agreements—, thereby addressing the research gap mentioned above. In this respect, the key novelty of this work is the systematic analysis of SFs' perceptions from different contexts on the adoption/delivery of a novel renewable energy technology for irrigation (i.e., BP), and its implications for relevant stakeholders (e.g., manufacturers, technology providers, practitioners, researchers).

For the purpose of our study, we leveraged on the etic[10] cross-cultural research approach (Buil et al., 2012; Stone et al., 2017). Through this approach, we sought to compare systematically the discourses of stakeholders linked to different regions/contexts. The etic approach requires using the same instrument to measure the phenomenon (i.e., adoption of the BP) from outside their context, thereby facilitating a comparative analysis between Nepali and Sumbanese SFs. Moreover, through the participatory nature of Q methodology (explained in detail in section 5.2), we analyzed the diversity of emerging viewpoints and discussed their areas of (possible) consensus and disagreements (results and discussion, sections 0 and 5.5). Lastly, based on those discourses, we drew possible adoption strategies that may be relevant for both manufacturers and policymakers (section 5.6). Our findings would be relevant for aQysta and enrich the policy and academic debates on HPP technologies and their uptake by (smallholder) farmers.

5.2 Materials and methods

Q methodology (henceforth Q) is a technique developed by William Stephenson in the 1930s to study human subjectivity (Stephenson, 1935). Q is employed to explore the different viewpoints people may have with regard to a (complex) phenomenon. It is considered a simple yet innovative adaptation of Spearman's factor analysis method. Q has a mixed qualitative-quantitative nature, hence it is sometimes referred to as a semi-quantitative method (Stenner and Rogers, 2004; Watts and Stenner, 2005a). Though initially envisaged for the field of psychology, Q has been effectively applied across a number of other disciplines such as management, nursing, human geography, tourism, and rural research (Watts and Stenner, 2012). Due to its bottom-up, culture-sensitive participatory nature, Q has been successfully applied within cross-cultural studies (Ahmed et al., 2012; Stone et al., 2017). Therefore, we deemed it suitable for our study to explore both contrasting and convergent culture-influenced perspectives on the adoption of the novel BP.

Q is executed by asking participants (P-set) to distribute a set of stimuli (Q-set)—typically, yet not limited to, written statements—across an 'agree/disagree' (or similar) ranking scale, usually within a forced quasi-normal distribution grid (i.e., sort). The completed sort is done in accordance with each participant's perspective, therefore capturing the subjectivity regarding the topic under study. Ultimately, the processing of collected sorts allows the identification of discourses or perspectives across the P-set, commonly referred

[10] The 'etic' and 'emic' are the two predominant research approaches in cross-cultural research. Whereas the etic approach studies the phenomenon from outside its context, thus focusing on universal constructs and theories, the emic one does it within the specific context.

to in Q as factors (Watts and Stenner, 2012). Therefore, every time we use the term 'factors' throughout this work, we refer to the unique discourses/viewpoints that emerge from the collected data.

5.2.1 Research method

Q is better understood through the four typical methodological stages, namely (1) Research design, (2) Data collection, (3) Analysis, and (4) Interpretation. The first stage relates to the definition of the research question, concourse, Q-set, P-set, and sorting grid. The second one refers to the administration of the instruments (i.e., statements, sorting grid, surveys) to the participants and subsequent collection of sorts. The third one corresponds to the analysis of collected sorts and production of factors, usually through dedicated software. The last stage implies the construction of meaningful narratives for each of the identified factors, typically by complementing rich qualitative complementary data.

5.2.2 Research design

5.2.2.1 Concourse development

We constructed the concourse based on primary and secondary data sources. The primary sources were a focus group discussion with experts from different disciplines, as well as semi-structured interviews with key local informants in each of the target study areas, both conducted in March 2019. The secondary sources consisted of documents from a literature review about the development of hydro-powered pumping technologies over time, conducted between June 2018 and June 2019 (Intriago Zambrano et al., 2019).

We processed and synthesized the concourse by the methods of categorization, thereby deleting or combining similar statements. For this process, we considered two sets of categories for statements: (1) variables that influence the adoption of water pumping technologies for smallholder irrigation (affordability; technical performance; environmental soundness; ease and convenience of installation, operation and maintenance; extension and access to information; observability and trialability; legal and institutional framework), and (2) building blocks that may shape business models around the BP (additional products and services (technical assistance, infrastructure, agricultural inputs); ownership; entrepreneurship and job-enabling conditions; involvement of external parties).

5.2.2.2 Q-set construction

As a result, we selected 38 written statements (in the English language) about elements that might influence SF adoption of the BP. This number ensured sufficient coverage of different themes of concern, yet provided a manageable amount of items. The Q-set fits within methodologically acceptable ranges (Watts and Stenner, 2012). The 38 statements were translated into the Nepali and Indonesian languages [Appendix A in Supplementary material (Intriago Zambrano, 2020)] by a parallel translation technique (Buil et al., 2012). To ensure cross-cultural calibration equivalence, we customized the data collection instruments considering elements unique to each context (Buil et al., 2012). This considered currency (Nepali rupee or Indonesian rupiah), land size (Ropani or Hectare), and local types of land tenure.

5.2.2.3 Sorting grid design

We selected a slightly leptokurtic, 9-sorting point, forced inverted quasi-normal distribution as sorting grid. It was designed with a -4 to +4, "strongly disagree" to "strongly agree" scale (**Table 5.1**). Given the exploratory nature of this research, the leptokurtic shape allowed more (nearly) neutral positions to provide more space for indifference, neutrality or doubtfulness amongst participants (Watts and Stenner, 2012).

Table 5.1. Features of the sorting grid.

Sorting criteria	Strongly disagree								Strongly agree
Sorting point	-4	-3	-2	-1	0	+1	+2	+3	+4
Nr. statements	2	3	4	6	8	6	4	3	2

5.2.2.4 P-set sampling techniques

We sampled two groups of participants: (1) SF and (2) other relevant non-farmer (NF) stakeholders linked to smallholder farming systems [i.e., technology developers, non-profit organizations (NGOs), experts, governmental authorities. We asked NFs to sort as if they were farmers themselves. By collecting insights on how NFs perceive SFs, through the lens of their own discipline, we aimed to explore possible (mis)alignments of viewpoints.

We identified SF participants from selected communities by purposive sampling. Participants were selected based on two criteria: (a) bearing certain degree of familiarity with the BP (i.e., owning, using, having used, or having seen), and (b) posing sociodemographic diversity (e.g., gender, income, distance to main urban centers, farm conditions, etc.). We identified them with the assistance of aQysta (Nepal) and the local NGO Yayasan Komunitas Radio Max Waingapu (YKRMW) (Indonesia).

We sampled NF participants by purposive and snowball sampling, based on their degree of familiarity with the BP and Nepali/Sumbanese smallholder farming systems. We identified them by personal references, iterative internet searches, and authorship of related (non)academic literature.

5.2.3 Administration (data collection)

We resorted to face-to-face sorting for SF participants. It was conducted on-farm, at the respondent's household, or village (outdoors) meeting point. Lack of proper furniture and exposure to elements was occasionally challenging. The places were usually close to each other within selected farming communities. SF sorting sessions took place either collectively or individually, depending on the circumstances of each site and the number of available participants. Staff of aQysta Nepal and YKRMW, as native Nepali and Indonesian speakers, facilitated the sorting sessions. Facilitators offered four-stage assistance to participants: (1) pre-sort instructions (i.e., introduction to researchers, study aim, sorting mechanism); (2) preliminary rough sorting with the three-pile technique; (3) step-by-step sorting guidance; and, (4) on-demand clarification of instructions and statements. Each SF participant was provided with a sorting sheet (with written instructions) and the 38 printed statements alongside supporting illustrations. We offered the statements in shuffled and randomly numbered laminated paper cards (40 × 50 mm). We allowed SF participants to reallocate the cards over the distribution until they were satisfied.

We also collected two sets of complementary data to be able to further analyze sorting choices: (1) sociodemographic and farm data, through a structured survey, and (2) the reasoning about the ranking of statements and trade-offs, through an unstructured post-sort interview. The interview frequently resulted in short answers due to post-sort fatigue from the respondents. We relied on sort sheets, survey sheets and written notes to record the collected data. We took pictures of those documents, which were ultimately synchronized with an encrypted cloud storage service. Complementarily, we recorded on-site physical and social observations for triangulation purposes.

We administered Q to NF participants by the online platform Easy HtmlQ[11] (Banasick, 2020). This technique allowed reaching out to an international NF audience, and could cope with the limitations of the COVID-19 global pandemic crisis (Omary et al., 2020). The platform contained the required sorting instructions and step-by-step guidance. Unlike its face-to-face counterpart, the online version relied purely on the original English-written statements. We collected complementary sociodemographic information and sorting reasoning through the platform itself.

[11] The versions of this platform used for this study are available for some time at: https://barshapump-nepal.netlify.app and https://barshapump-indonesia.netlify.app.

5.2.4 Analysis

We analyzed the dataset of collected sorts with KADE v1.2.0 (Banasick, 2019), which was preferred over other analytical software because of its nonproprietary GNU General Public License, simple and easy-to-use graphical user interface, and cross-platform availability. Due to the exploratory nature of the study, we conducted several iterative analyses, considering three different P-set segmentations, namely SF, NF, and a SF+NF combination (SF-NF). Considering that country is usually a poor cultural proxy (Buil et al., 2012; Taras et al., 2016), we neglected per-country segmentations of the dataset, thereby allowing the factors to emerge by themselves according to the analytical methods that we describe below.

5.2.4.1 Factor extraction method

Centroid Factor Analysis (CFA) and Principal Component Analysis (PCA) usually provide roughly similar results. Their main difference lies in PCA providing the mathematically best solution, thus the one that should be numerically accepted. In contrast, because our aim is to explore the data through a judgmental, investigatory approach, we preferred CFA as the technique to extract factors in our study. PCA was still used iteratively to conduct the scree test as one of the factor retention criteria (Watts and Stenner, 2012).

5.2.4.2 Factor retention criteria

To define the number of retained factors, we explored several decision-making statistical criteria: (a) Kaiser-Guttman criterion [Eigenvalue (EV) threshold], (b) Significantly loaded sorts, (c) Humphrey's rule, (d) PCA-based scree test (Watts and Stenner, 2012), (e) Horst Centroid Factors (Hu et al., 2018), and f) Distinct statements threshold (Cammelli et al., 2019). We underpinned these criteria by looking at the highest number of significantly loaded sorts ($p<0.05$) in each factor and the most distinctive sorts grouping in the respective Q maps (Yoshizawa et al., 2016). It is worth remarking that there are no "best" criteria to retain factors (Watts and Stenner, 2012): each factor selection needs to be explained specifically, as we will do below in sections 0 and 5.5.

5.2.4.3 Factor rotation method

We resorted to Varimax as factor rotation method. This technique was preferred over by-hand rotation, because it maximizes the total variance explained—hence the identification of salient factors—in line with the inductive, bottom-up exploratory essence of this study (Watts and Stenner, 2012). We required the majority of common variance to load significant sorts ($p<0.05$) automatically. As a result, confounded sorts were excluded from the analysis.

5.2.5 Interpretation and validation

We interpreted retained factors, namely respondents' viewpoints, using the holistic method of crib sheets system, as described in Watts and Stenner (2012). We split and interpreted bipolar factors whenever the respective Q maps showed a clearly opposite placing of their significantly loaded sorts (Watts and Stenner, 2012). We validated the interpretation by asking iterative feedback to the highest NF loaders of each factor via e-mail (Robbins, 2005). Though desirable, we could not validate with the highest SF loaders due to the COVID-19 pandemic mobility restrictions.

5.3 The settings of technology choice

5.3.1 The Barsha pump

The BP, named after "rain" in Nepali language (वर्षा), is a waterwheel-driven manometric HPP that relies on twin planar spiral pipes to build pressure (Intriago Zambrano et al., 2019). This pump constitutes the commercial version of a device invented back in the mid-16th century (Ziegler, 1766), usually referred to as spiral or Wirtz pump (Intriago Zambrano et al., 2019). Currently, aQysta's main markets are Nepal, Malawi and Indonesia (aQysta, 2018a).

The latest version of the BP is offered in three variants, suitable for both riverine and canal settings of different depths and widths. The BP needs a mooring or anchoring mechanism to avoid the pump to be swept away. At times, it might also need some basic site preparation, such as water funneling through improvised, on-site made structures (**Figure 5.1**a). To operate, it requires a minimum input flow rate of 300 L s^{-1} and water speed of 1 m s^{-1}. Depending on specific contextual conditions, the BP is capable to pump a maximum[12] of 20 – 80 m^3 d^{-1} (0.23 – 0.93 L s^{-1}) up to 20 m of head and 1 km far, and is suitable to irrigate up to 2 ha of land. Its size is roughly 1.5 m in diameter and it weighs about 90 kg (**Figure 5.1**b) (aQysta, 2018b).

As any other HPP of its kind, the BP works solely on the kinetic energy of the water (Intriago Zambrano et al., 2019), hence virtually posing costless operation. Its foreseen maintenance is limited to basic cleanup of the waterwheel from entangled objects, (re)adequacy of the installation site to ensure proper operation, and replacement of any damaged part.

[12] Maximum pumping specifications are traded-off, i.e., it is not possible to meet them all simultaneously.

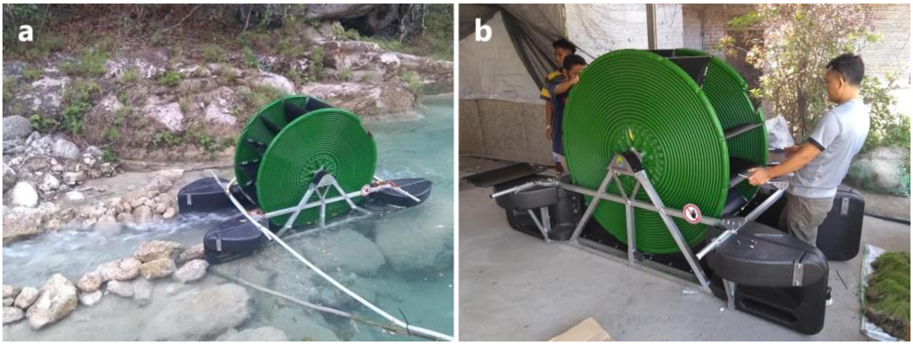

Figure 5.1. The Barsha Pump. (a) Commissioned and operating in the Mbatakapidu River, Eastern Sumba. (b) Assembly before its installation.

5.3.2 Study areas

South and Southeast Asia are two of the most (densely) populated regions in the world (Roser et al., 2013). Despite being the largest staple producers (Ritchie and Roser, 2020) and having the largest SF share (Samberg et al., 2016), these regions also are highly food-insecure (FAO, 2019) and undernourished (Roser and Ritchie, 2013). Within this challenging setting, the BP is slowly penetrating the agricultural markets of two of the poorest and least developed SF areas in these regions: the mid-hills in Nepal (United Nations, 2020b) and the island of Sumba in Indonesia (Vel and Makambombu, 2010).

5.3.2.1 Mid-hill Nepal

Agriculture in the mid-hills region of Nepal deals with conditions that are notably complex. Albeit this region holds the vast majority of Nepali SF, Roka (2017), GC and Hall (2020), it receives much less agricultural investment than the more fertile Terai flatlands (Devkota et al., 2020; GC and Hall, 2020). The challenging topography of the mid-hills region with its associated remoteness exacerbates its SF poverty. Many farmers cultivate less than 0.50 ha, and many are actually (nearly) landless (GC and Hall, 2020). Furthermore, due to social, legal and political constraints, women SF are particularly more disadvantaged despite their substantial agricultural participation (Roka, 2017).

aQysta offers the BP in Nepal through a typically product-oriented delivery model: the farmer pays to become the owner of a BP. Nepali SFs are able to reach the technology through direct contact with aQysta Nepal or via third parties (e.g., retailers, governments, NGOs). SF usually opt for the latter, given that financial aids—installments, subsidies, micro-credits—are frequently part of the technology provision schemes.

5.3.2.2 Sumba Island

One of Indonesia's most remote islands, Sumba does have potentially profitable paddy-suitable valleys across its geography; however, these are only available to wealthier and more influential inhabitants, thereby relegating the poorest SF to dry, humble-yield hillside farmlands (Vel, 2008; Vel and Makambombu, 2009). This issue is more exacerbated in Eastern Sumba, with its predominant subsistence farming (Vel, 2008). SF, particularly from the so-called *tani*-class[13] have the weakest access to resources throughout the island (Vel and Makambombu, 2009, 2010). From these, women, youth and ethnic minorities are the most disadvantaged (Vel and Makambombu, 2009, 2010; Nugrohowardhani, 2014).

aQysta's national Indonesian office is in Jakarta; the main BP provider in Sumba is YKRMW. The BP is offered through a service-oriented delivery model. Instead of selling the device to the farmers, the organization provides a BP-based irrigation service. YKRMW not only owns, installs, operates and maintains the BP, but also provides additional irrigation infrastructure (e.g., piping, sprinklers) to ensure that irrigation water arrives on time at the farms. Additionally, the organization offers training and technical assistance to improve farming practices. In exchange, SF pay for the service with part of the sales revenues, under the so-called pay-per-harvest business model of the EASI-Pay project (NWO, 2020).

5.3.2.3 Selected farming communities

We selected three farming communities in mid-hill Nepal (Ratamata, Manthali and Lele) and four in Sumba Island (Kalu, Mbatakapidu, Mondu Lambi and Lai Pandak). We chose them (1) because these communities are using/have used at least one BP (hence SF are exposed to the technology), and (2) accessibility for the study (e.g., distance, traveling time, remoteness) from the urban centers in mid-hill Nepal (Lalitpur) and eastern Sumba (Waingapu). Details of the selected locations are presented in **Figure 5.2** and **Table 5.2**.

Table 5.2. Characteristics of selected farming communities.

	Nepal			Indonesia			
District	**Sindhuli**	**Ramechhap**	**Lalitpur**	**East Sumba**			
Community	**Ratamata**	**Manthali**	**Lele**	**Kalu**	**Mbatakapidu**	**Mondu Lambi**	**Lai Pandak**
Distance[1] (km)	88	129	16	2	9	86	128
Travelling time[2] (h)	3.5	5	1	0.1	0.5	2.3	2.2

[1] Rough distance measured from each operative urban center in mid-hill Nepal (Kathmandu) and eastern Sumba (Waingapu)
[2] Rough travelling time by car

[13] Emic term that refers to the lowest societal layer, which includes both farmers and unemployed/incomeless people (Vel and Makambombu, 2010).

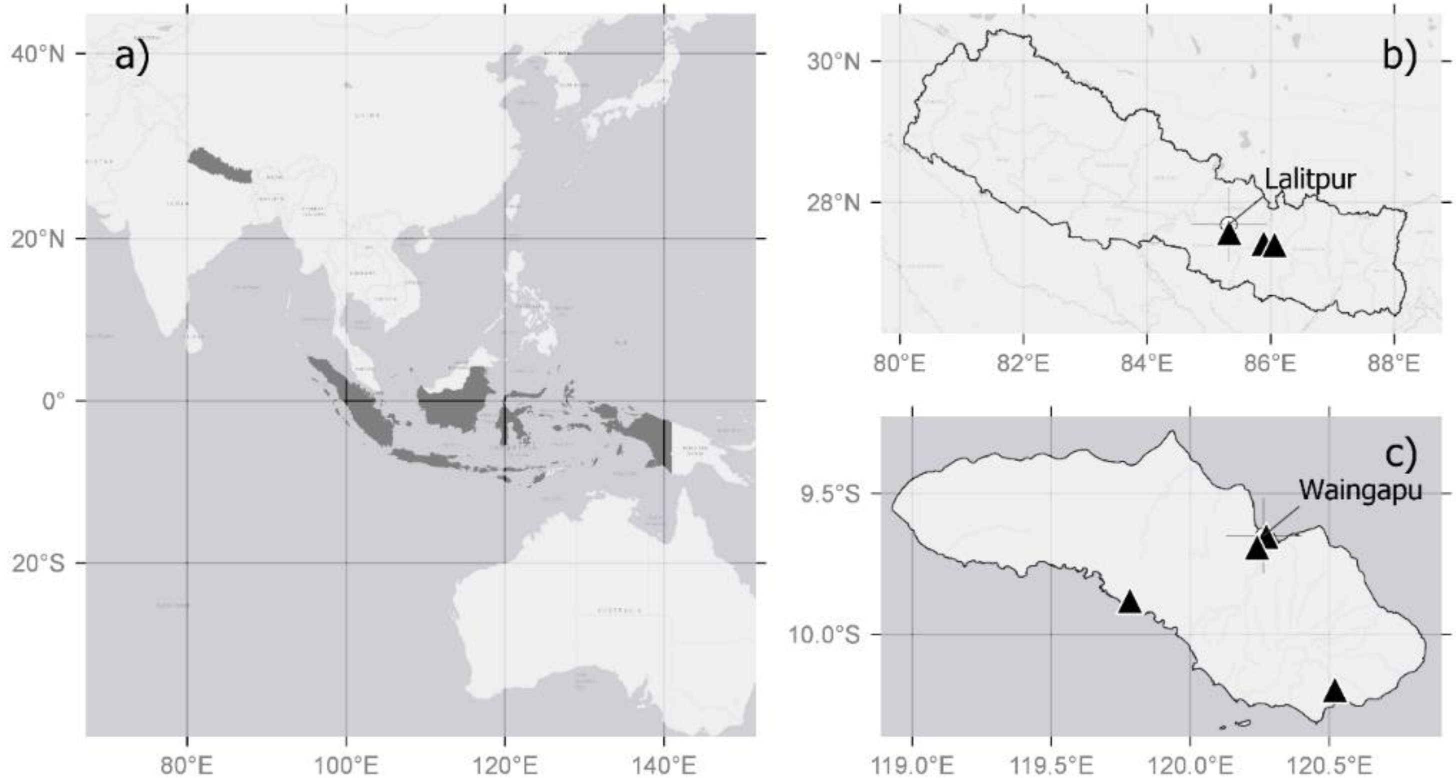

Figure 5.2. Geographical locations of study sites. (a) Countries of study (dark shade): Nepal and Indonesia. Black triangles and crosshairs mark studied farming communities and main urban centers in (b) Nepal and (c) Indonesia (Sumba island), respectively.

5.4 Results

5.4.1 Data collection

We invited 30 SF participants, 18 from Nepal and 12 from Indonesia, which resulted in 7 and 12 valid collected sorts respectively (**Table 5.3**). Each sorting took roughly 40 minutes to complete. Sortings with illiterate participants, who required sustained assistance, took longer times. Reasons for dropout were: participants declining to participate (n=3), producing unsuccessful sorts (e.g., sorting out of the grid, unfinished sorting) (n=7), and producing invalid sorts (e.g., nonthought sorting due to inebriation) (n=1).

Table 5.3. Characteristics of sampled SF P-set.

	Nepal			Indonesia			
District	Sindhuli	Ramechhap	Lalitpur	East Sumba			
Location	Ratamata	Manthali	Lele	Kalu	Mbatakapidu	Mondu Lambi	Lai Pandak
Administration	CW	IN	IN	3-person round			
Place	CMP	HH	Farm	HH	CMP	HH	Farm
Facilitator	aQysta Nepal			YKRMW			
Valid sorts[1] (F)	0 (2)	0 (0)	1 (1)	0 (0)	3 (3)	1 (1)	1 (1)
Valid sorts[1] (M)	5 (13)	1 (1)	0 (1)	3 (3)	0 (0)	2 (2)	2 (2)

[1] Total (both valid and non-valid) number of participants in brackets
CW, collective workshop; IN, individually; CMP, community meeting point; HH, household; F, Female; M, male.

Although gender balance was a P-set sampling criterion, it was not always possible to fulfill this in the field due to composition of and interaction within each farming community.

We invited 73 NF participants through e-mails, websites (contact forms), and social networks. 24 respondents produced valid sorts (**Table 5.4**). The response rate was influence by respondents not answering at all (n=42), declining due to disagreement with the topic or the methodology (n=2), or not answering after first contact (n=5). It is worth noticing that none of the invited governmental representatives decided to take part in the study.

The total valid sorts [Appendix B in Supplementary material (Intriago Zambrano, 2020)] produced P-set sizes of 19 (SF), 24 (NF) and 43 (SF+NF), which in turn resulted in P-set/Q-set ratios of 0.50, 0.63 and 1.13. Both sizes and ratios are within ranges accepted by Q methodologists (Watts and Stenner, 2012). The female/male ratios of valid sorts were 0.46 (SF), 0.50 (NF) and 0.48 (SF+NF). Female farmers generally face a more limited access to resources

(Poole, 2017; Giordano et al., 2019); thus, we acknowledge these slightly male-skewed ratios might pose biases and/or incompleteness of the topic under study.

Table 5.4. Characteristics of sampled NF P-set.

	Nepal				Indonesia				Total
Role	**TD**	**NGO**	**EXP**	**GR**	**TD**	**NGO**	**EXP**	**GR**	
Invited participants	9	18	31	4	1	3	7	0	73
Valid sorts (F)	3	3	0	0	1	1	0	0	8
Valid sorts (M)	6	4	3	0	0	1	2	0	16

TD, technology developers; NGO, non-profit organizations representatives; EXP, expert; GR, government representatives; F, female; M, male.

5.4.2 Analysis

Using the factor retention criteria as shown in Table 5.5, we decided to retain three factors for both SF, NF, and SF-NF segments [Appendices C, D and E in Supplementary material, respectively (Intriago Zambrano, 2020)]. This choice aligns well with the retention criteria related to number of loaded sorts and Q maps (see Table 5.5). However, it is worth stressing that we did not rely on those criteria because of any form of superiority over others; rather, we took them as a compass that matched our experience from the respective field observations (Watts and Stenner, 2012). Our iteratively exploration of correlations between factor- and Z-scores of those segments (also accounting two- and three-factor solutions), produced only secondary insights that we decided to leave out in the analysis [Appendix F in Supplementary material (Intriago Zambrano, 2020)]. We could identify the third factor of each segment as bipolar (Figure 5.3), as it expressed two opposed, mirror-image perspectives across loaded sorts (Watts and Stenner, 2005b). Our three factors accounted for 39% (SF), 36% (NF) and 28% (SF-NF) of the total explained variance. The SF-NF variance might be perceived as relatively low, especially in light of the frequently accepted range of 35–40% (Watts and Stenner, 2012). A low variance is not necessarily problematic, however (Cuppen, 2010; Watts and Stenner, 2012). Although an SF-NF four-factor solution would actually have offered a higher total explained variance, we selected the three-factor one for its clearer and more consistent factor clustering (Figure 5.3C). Characteristics of the three factors (i.e., 1, 2, 3+ , 3-) are indicated in Table 5.6; their raw scores can be found in Table 5.7.

Table 5.5. Factor retention criteria, description and results.

Criterion	Description	Factors		
		SF	NF	SF-NF
Kaiser-Guttman	Retain factors with EV ≥1	4	3	8
Significant sorts	Retain factors with ≥2 SL sorts at statistical significance p<0.01 SL=2.58 √(Q-set)	2	5	6
Humphrey's rule	Retain factors if cross-product of the two highest loadings >2SE or >SE (less strict rule) SE=1/√(Q-set)	1 (>2SE) 5 (>SE)	2 (>2SE) 5 (>SE)	1 (>2SE) 8 (>SE)
Scree test	Based on the EVs scree plot, retain factors before the straightened section of the curve	2	4	2
Hors Centroid Factors	Algorithm self-limits factors (on 30 iterations at 1 10^{-4} cutoff threshold)	3	3	4
Distinct statements threshold	Retain factors with ≥5 distinct statements at statistical significance p<0.01 to ensure interpretability	4	3	4
Number of loaded sorts	Maximum amount of SL sorts between analyzed N-factor solutions	3	3	3
Q maps	Highest graphical variance between factors	3	3	3

EV, eigenvalues; SL, significantly loaded; SE, standard error.

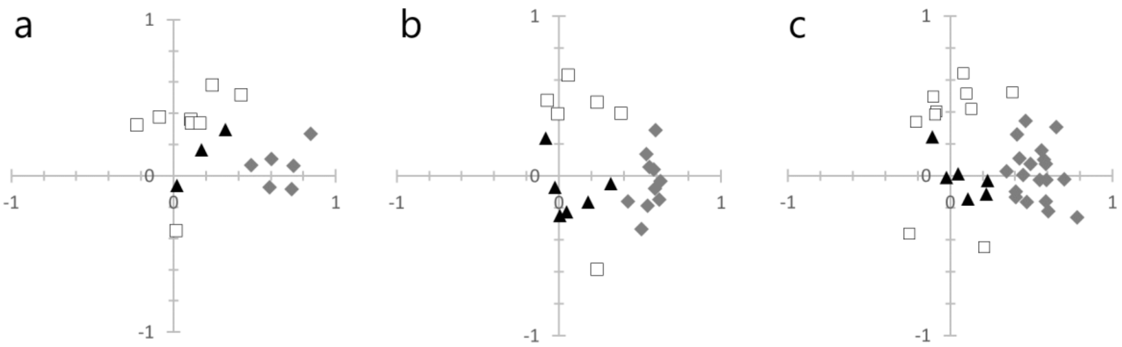

Figure 5.3. Q maps of (**A**) SF, (**B**) NF, (**C**) SF-NF. Gray diamonds, black triangles and white squares represent significantly loaded sorts of factors 1, 2, and (bipolar) 3, respectively.

Table 5.6. Factors characteristics.

	SF				NF				SF-NF			
	1	**2**	**3+**	**3-**	**1**	**2**	**3+**	**3-**	**1**	**2**	**3+**	**3-**
No. of SL sorts	6	3	7	1	10	6	5	1	19	6	8	2
Composite reliability	0.960	0.923	0.966	0.800	0.976	0.960	0.952	0.80	0.987	0.960	0.970	0.889
SE of factor Z-scores	0.200	0.277	0.184	0.447	0.155	0.200	0.219	0.447	0.114	0.200	0.173	0.333
% explained variance	22	10	7		14	13	9		14	9	5	

1, 2, 3+ and 3- relates to the (bipolar) factors of each segment
SL, significantly loaded; SE, standard error.

Table 5.7. Raw factor scores of SF, NF and SF-NF.

Nr.	Statement	SF				NF				SF-NF			
		1	**2**	**3+**	**3-**	**1**	**2**	**3+**	**3-**	**1**	**2**	**3+**	**3-**
1	I need financial aid from an external organisation or person to deal with the installation and commissioning costs required by the Barsha pump	1*	-3	4*	-3	2*	4	4	-1*	1	4*	3	2
2	I need financial aid from an external organisation or person to deal with the operation costs required by the Barsha pump	1	-1	1	1	-1	3*	0	-1	0*	3*	1*	-3*
3	The savings on the operation of the Barsha pump –because it does not need electricity or diesel– is worth the (relatively) high upfront cost	3	0	3	2	3	-1	1	4	2	-2*	2	2
4	I prefer to pay more to have extra optional infrastructure in my farm (e.g. sprinklers, drippers), so I can make better use of the water provided by the Barsha pump	0	-2	0	-3	1	0	1	0	-1	2	1	-2
5	I prefer to pay more to have additional technical assistance (e.g. irrigation advices, growing advices) beyond just irrigation water provided by the Barsha pump	-2	-3	0*	4*	0	-3*	1	0	-1	1*	-2	3*
6	It is more convenient for me to make use of the Barsha pump without being the owner	-1	0	2*	-4*	-1*	1	-4*	4	-2	-3	4*	-4*
7	The natural landscape does not require considerable modifications to install the Barsha pump	-1	0	-2	-1	-1	-4	-1	-3	0	-1	-1	-1
8	The water bodies do not require considerable modifications to install the Barsha pump	-1	0	-3	-1	-1*	-3	1*	-4	-1	-4*	-1	1*
9	The existing irrigation infrastructure (e.g. canals, gates) does not require considerable modifications and adaptations to install the Barsha pump	-1	0	-2*	0	-2	-4	0	-4	0*	-4	-4	3*
10	An external organisation or person must be in charge of installing and commissioning the Barsha pump	-2	3	-1	4	-3*	2	3	2	-3*	1	1	4*
11	Some members of the community could have job positions by being involved in the installation and commissioning of the Barsha pump	-2	2	-3	2	1	1	-2*	3	-1	-2	0	0
12	An external organisation or person must be in charge of operating the Barsha pump	-4	-4	-1*	2*	-4	1	-3	0	-4*	-1	0	-1

Nr.	Statement	SF				NF				SF-NF			
		1	**2**	**3+**	**3-**	**1**	**2**	**3+**	**3-**	**1**	**2**	**3+**	**3-**
13	Some members of the community could have job positions by being involved in the operation of the Barsha pump	0	-2	-1	0	0	0	-3*	3*	-2	0	-1	-3
14	I prefer to use the Barsha pump over electricity- or diesel-based water pumps because it operates on clean energy	4*	-1*	1	1	2	4	-3*	2	3	-1	4	0
15	An external organisation or person must assist me in how to irrigate with the water provided by the Barsha pump	-3*	0	4*	0	-2	3*	-2	-2	-3	1*	3*	-2
16	An external organisation or person must assist me in how to grow more efficiently with the water provided by the Barsha pump	-2	-2	3*	-1	-2	2	2	0	-3*	4	3	0*
17	An external organisation or person must be in charge of maintaining the Barsha pump	-3	-4	-1	0	-4*	2*	-1	-1	-4*	3	1	-2*
18	Some members of the community could have job positions by being involved in the maintenance of the Barsha pump	-1	1	-2	-1	1	1	-4*	3	-1	-3	0*	-4
19	I think my farm facilitates the installation and commissioning of the Barsha pump	2	0	1	0	0	0	0	0	1	1	0	-1
20	I think the Barsha pump can be installed straightforward in my farm without much expertise	-3*	4*	1	0	0	-2	-1	-2	0	-2	-1	0
21	I think my farm facilitates operating the Barsha pump	0	1	2	0	1	-1	0	0	2	0	-1	0
22	I think the Barsha pump can be operated straightforward in my farm without much expertise	3	2	1	0	1	0	-2	1	3*	0	0	-1
23	I think that a person without much expertise can provide maintenance to the Barsha pump	2	3	0	-1	0	-1	1	-1	1	1	-3*	0
24	I think the Barsha pump can provide enough volume of water to my farm for producing year-round	0	1	0	-1	3*	-3	0	-2	2	-2	-3	1
25	I think the Barsha pump can provide enough water pressure to my farm for producing year-round	2	1	0	-2	1	-2	-1	0	2*	-1	-2	-1

Nr.	Statement	SF				NF				SF-NF			
		1	2	3+	3-	1	2	3+	3-	1	2	3+	3-
26	The Barsha pump helps me more than other water pumps in increasing my agricultural production	1	-1	2	1	-2	-2	0	-1	0	-3*	0	1
27	The Barsha pump helps me more than other water pumps in growing new cash crops	2	2	-1	1	-1	1	-1	-1	1	-1	1	0
28	The Barsha pump improves my quality of life	4*	-1	2	1	2	0	0	1	4*	0	2	2
29	The use of the Barsha pump in my farm saves me labour	3	-1	3	-2	4	0	-2	2	4*	-1	1*	-3
30	I would recommend other farmers to use the Barsha pump as well	1	2	0	1	2	0	2	1	1	0	0	1
31	I would prefer a person from my own country to provide me with the Barsha pump	-1	1*	-4	-2	0	-1	1	1	-1	1	-2	1
32	I prefer to see another person using the Barsha pump before using it myself	-4	0*	-3	-2	3	1	2	-3*	0	3*	-1	-1
33	I think the Barsha pump would be more valuable if seeds are provided along with it	1	1	0	-3*	-1	2	2	1	0	0	2*	0
34	I would like to have entrepreneurial training on the Barsha pump, so I can start my own business	1	3	1	-4*	4	3	3	1	3	2	2	-2*
35	The laws of my country facilitates me to have access to the Barsha pump	0	-2	-1	3	0	-2	4*	-2	0*	2*	-4*	3*
36	The national government facilitates me to have access to the Barsha pump	0	-1	-4	3	-3	-1	-1	-3	-2	0	-3*	1
37	The local government facilitates me to have access to the Barsha pump	0	-3	-2	3	-3*	-1	3	0	-2	2*	-2	4*
38	NGOs operating in the area of my community facilitate me to have access to the Barsha pump	0	4	0	2	0	0	0	2	1	0	0	2

* Distinguishing statement at p<0.01
1, 2, 3+ and 3- relates to the (bipolar) factors for each P-set segment

5.4.3 Factors interpretation

In this section, we provide the interpretations of the three SF-NF factors, based on the analysis of factor scores (**Table 5.7**) and crib sheets [Appendix G in Supplementary material (Intriago Zambrano, 2020)], as described in Watts and Stenner (2012). Each factor's interpretation contains a first paragraph with a summary of relevant statistical and demographic information (i.e., participants who compose the group); this gives the reader a quick overview of how and who has been included in that factor. The second paragraph (and third in case of our bipolar factor 3) offers the narrative of the factor, building on the information contained in each of the crib sheets. That narrative should be understood as how an 'ideal' respondent of certain factor would think based on those scores. Additionally, to underpin the interpretative narrative regarding the Q-set stimuli, we share the number of a statement and its factor score; i.e., (28: +4) would mean that statement number 28 was scored +4 (in accordance to **Table 5.7**).

We focused on interpreting the combined SF-NF P-set segment as it includes the total universe of respondents (both SFs and NFs), hence offering a higher diversity of potential viewpoints. Furthermore, the combination allows exploring how SF and NF hold to one another, regardless their categories of countries, roles and genders (**Figure 5.4** and **Figure 5.5**), thereby facilitating a cross-context comparison. **Figure 5.4** shows a Sankey diagram with the cumulative distribution of respondents across factors, regarding their country (Nepal/Indonesia), roles (SF/NF) and gender (female/male). One would perhaps initially assume that actors from the same country (left extreme of the figure) may think in a similar manner, meaning that they will (mostly) group in the same factor. However, as **Figure 5.4** shows, actual factors' composition (right extreme of the figure) is rather heterogeneous. F1, for instance, includes (non)farmer female and male actors from both Nepal and Indonesia. Similarly, as another example, though in a much smaller group, F3+ includes participants from almost all categories.

Whereas labeling of factors is common practice among Q researchers, we refrained from assigning descriptive names to the three factors. We believe that Q enables us to embrace richness and diversity of voices, thus oversimplifying that diversity in labels may actually be counterproductive to that potential of Q.

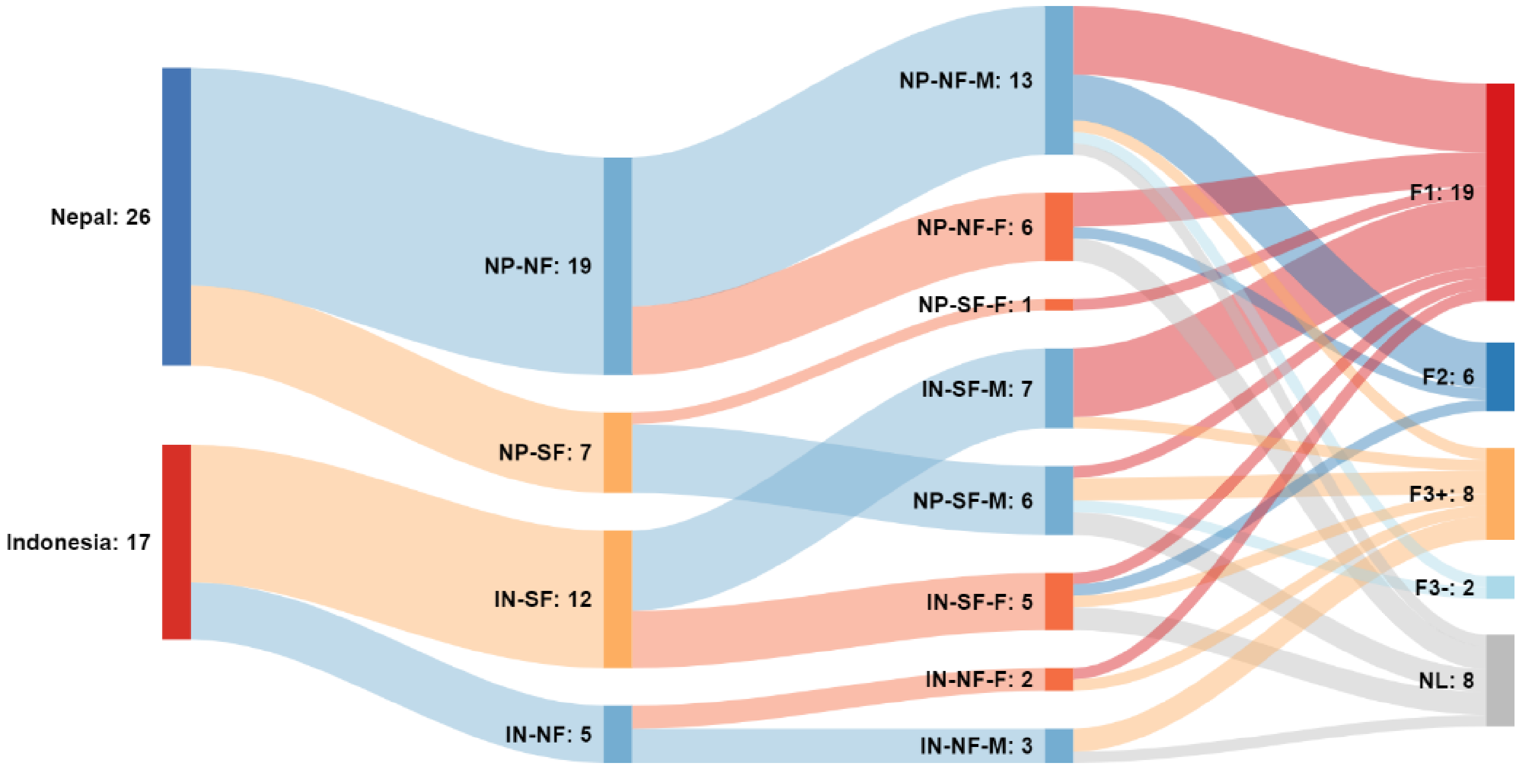

Figure 5.4. Cumulative distribution of respondents of SF-NF segment across factors (F1, F2, F3+, F3-) with respect to their countries, roles and gender. Acronyms: Nepal (NP), Indonesia (IN), female (F), male (M), non-loaded respondents (NL).

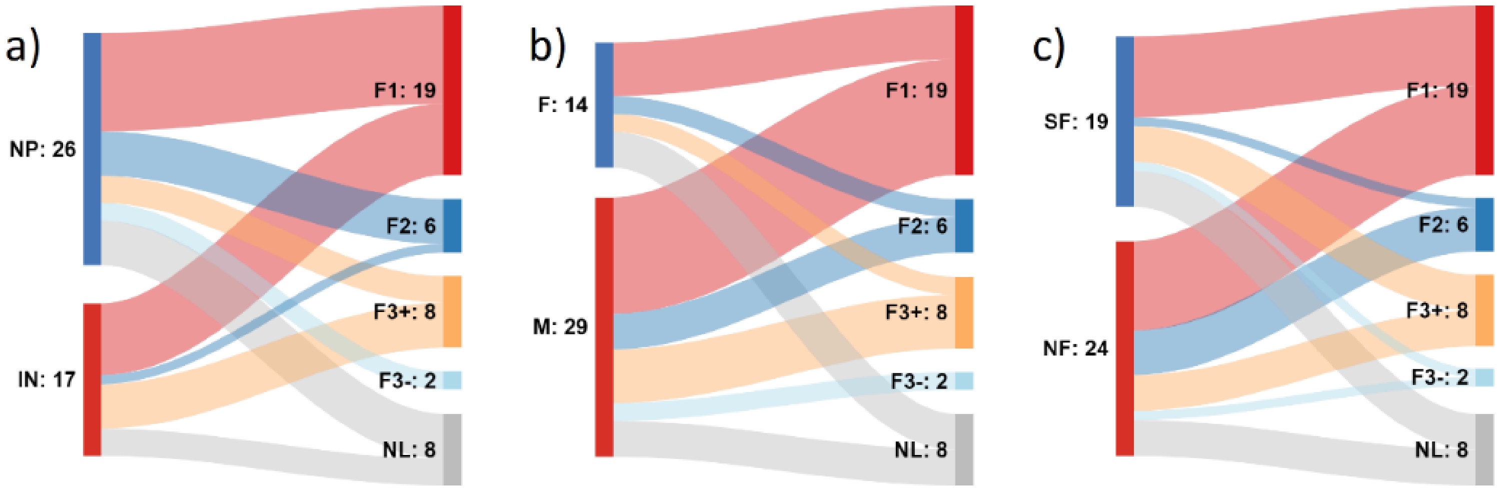

Figure 5.5. Noncumulative distribution of respondents of SF-NF segment across factors (F1, F2, F3+, F3-) regarding (A) country, (B) gender, (C) role. Acronyms: Nepal (NP), Indonesia (IN), female (F), male (M), non-loaded respondents (NL).

5.4.3.1 Factor 1

Factor 1 (F1) has an EV of 6.20 and explains 14% of the total variance; 19 participants are significantly loaded in this factor (nine SFs and 10 NFs) (**Figure 5.5**C). The SFs in factor 1, predominantly males of Sumbanese origin (**Figure 5.4**, **Figure 5.5**B) form a heterogeneous group in terms of experience, age and education. Most of them belong to small households (≤4 people) and perceive themselves as economically poor, with farming being their only source of income. These SFs do not own BPs (the majority rent them) and work part-time with a commercial orientation in rented plots. The NFs of F1, most of them highly acquainted with the BP, are mainly (n=6) technology developers, and further include three NGOs managers and one expert.

F1 symbolizes a consistent BP early adopter who think such adoption improves quality of life (28: +4) by saving farming labor (29: +4) and offering better overall performance than conventional water pumps (27: +1). The main strengths of the BP appear in its virtually costless operation (3: +2) and its relatively sufficient provided flow rate (24: +2) and pressure (25: +2). Although the BP might require on-site adaptations (7: 0), its (simplicity of) design would allow becoming empowered and independent actors (22: +3; 15: -3; 16: -3) who do not demand (intensive) assistance to install (10: -3; 19: +1; 20: 0), operate (12: -4; 21: +2) and maintain the BP (17: -4; 23: +1). In fact, its user-friendly features might encourage becoming BP-entrepreneurs (e.g., service providers in communities) (34: +3). Despite all these perceived advantages, however, F1 members may refrain from strongly advocating and recommending the BP (30: +1). Perhaps due to poor economic status and/or strong sense of independence, they feel skeptical about acquiring additional goods (e.g., seeds) (33: 0). They do not see local governments as enablers to access the BP (33: 0).

5.4.3.2 Factor 2

Factor 2 (F2) has an EV of 3.84 and explains 9% of the total variance. Six participants loaded significantly in this factor: one Sumbanese SF and five NFs (**Figure 5.5**A, **Figure 5.5**C). The only loaded SF is a young adult, highly educated woman with low farming experience (<1 year), who belongs to a small household (≤4 people). She farms with rented land and BP, and work part-time with a commercial orientation; she perceives herself as being economically poor. NFs encompass two highly BP-experienced technology developers, one NGO representative and two experts.

Ideal loaders of F2 reflect highly dependent SFs, who need external (financial) assistance to not only install (1: +4; 20: -2), operate (2: +3) and maintain the BP (17: +3), but also to grow more efficiently with it (16: +4). They see the BP as a device that does not easily integrate with natural (8: -4; 7: -1) and built environments (9: -4). This results in lower perceived BP benefits;

for instance, its advantageous costless operation would not outpace its relatively high upfront cost (3: -2). They also consider the BP as less useful for profitable farming than conventional pumps (26: -3; 14: -1; 27: -1), which may also explain their interest in additional irrigation infrastructure to enhance BP benefits (4: +2). It is obvious that they would not advocate the BP (30: 0), nor would consider that it improves their quality of life (28: 0). They do not see BP-related jobs and entrepreneurship (13: 0; 11: -2) in the local communities as an attractive option, despite the BP's relative straightforwardness in commissioning and maintaining (23: +1; 19: +1). On the contrary, they would rather see another person first farming with the BP before adopting it (32: +3), preferably provided by a local actor (31: +1).

5.4.3.3 Factor 3

Factor 3 has an EV of 2.30 and explains 5% of the total variance. Ten participants loaded significantly in this bipolar factor, eight in a positive pole (F3+) and two in a negative one (F3-) (**Figure 5.3**C, **Figure 5.4**). Both roles see the BP as extremely interesting, but in highly different modes: F3+ members prefer to use the pump as a service, whereas F3- members aim to own the pump to use it.

F3+ includes one highly educated, inexperienced (< 1 year) young-adult Sumbanese SF, and three lowly educated, well experienced (> 10 years) mid-age SFs (two Nepali and one Sumbanese) (Figures 4, **Figure 5.5**C). The young Sumbanese SF farms with commercial orientation on rented land, and considers himself as economically poor. The mid-age SFs practice subsistence farming on their own plots, and consider themselves as economically average. None of them is owner of any BP. F3+ also comprises three NGO representatives and one expert (**Figure 5.4**, **Figure 5.5**C), all well acquainted with BP operation in SF contexts.

F3- consists of a mid-educated, mid-age male Nepali SF (**Figure 5.4**, **Figure 5.5**) with extensive farming experience (> 10 years), who belongs to a large household (≥ 10 people). He farms full-time with a strong commercial orientation in many contiguous, rented plots, which he irrigates with his own two BPs and with groundwater. He considers himself as economically average. F3- also includes one male NF who is a highly BP-experienced technology developer (**Figure 5.4**, **Figure 5.5**).

Ideal respondents of F3+ emerge as potential users of a BP-based irrigation service rather than owners of a product (6: +4), underpinned by the preference of external actors providing goods (e.g., seeds) (33: +2) and services (e.g., irrigation technical assistance, BP operation) (15: +3; 12:0) beyond the mere sale of the BP—although they might also be reluctant to incur in associated additional expenses (5: -2). Given a perceived simplicity of installation (9: -4; 7: -1) and maintenance (23: -3), F3+ members also believe to a certain extent that other community members can benefit from BP-related employments (18: 0; 11: 0). There is a general distrust in local actors (e.g., governments, NGOs) (36: -3; 37: -2; 38: 0) and laws (35: -4) as facilitators of the BP; in fact, foreign stakeholders should ensure BP access (31: -2) according to F3+ members. They have opposing views about the technical performance of the BP. On the one hand, they acknowledge the advantages of the BP regarding its clean (14: +4) and costless operation (3: +2), which can turn into better profits (25: +1) compared to conventional water pumps. On the other hand, they also perceive lower water pressure (25: -2) and flow rate (24: -3) as main downsides of the BP. These views may explain that they would not require seeing other people farming first with the BP (32: -1) and that they would be cautious in recommending others its use (30: 0).

Opposed to the positive pole, idealized loaders of F3- arise as financially independent actors (2: -3) with a strong sense of ownership toward the BP (6: -4). This could be related to the BP's limited outputs, generally just enough for a single household, hence the reluctance to pool/share the BP. Their skepticism about the BP's easiness of installation (9: +3; 8: +1; 20: 0; 19: -1; 7: -1) and operation (22: -1) may lead them to prefer an external stakeholder to commission it (10: +4). They are unwilling to pay for additional goods besides the BP (4: -2), though they consider desirable to afford some services such as farming technical assistance (5: +3). These farmers appear to be interested to secure what they have instead of investing, and thus risking, in new means of production. This may explain why they do not consider local BP-related job positions (18: -4; 13: -3; 11: 0) and/or entrepreneurship (34: -2) as suitable choices. They see local (non)governmental actors (37: +4; 38: +2; 36: +1) and laws (35: +3) as enablers to access the BP; logically, they are therefore inclined to receive it through a local person (31: +1). Likely, these local actors have a budget allocated for yearly agricultural programs, which farmers may see as an opportunity to benefit from. They recognize the virtually costless operation (3: +2) of the BP compared to conventional water pumps (26: +1), although they do not see any farming-labor savings by using it (29: -3). Nevertheless, they could adopt the BP without seeing it elsewhere first (32: -1), and might recommend others to use it as well (30: +1).

5.5 Discussion

Our etic cross-cultural research approach allows comparing viewpoints of different actors linked to Nepali and Sumbanese farming settings. The comparison reveals that perceived adoption of the BP is highly heterogeneous. In fact, results did not show any significantly recognizable consensus statements between the three factors. Ideas on adoption, moreover, do not consistently relate to social constructs like 'country', 'gender role' and 'farming role', but are rather mixed (**Figure 5.4**, **Figure 5.5**). This is noticeable, for instance, in the disaggregation of male Nepali SF (F1, F3+ and F3-) and female Indonesian SF (F1, F2, F3+), groups which may be otherwise thought of as 'homogeneous' types of farmer. The discourses did not correlate either to education level, land tenure or age of the SF. None of those variables seems to explain the way participants grouped, which holds well with observations that SFs agricultural innovation is a complex process not explainable in terms of simple adoption-diffusion models (Glover et al., 2019). Indeed, SFs' discourses may actually involve even more—and more diverse— drivers than industrial farming (Paudel et al., 2019a,b, 2020; Alexander et al., 2020; Llewellyn and Brown, 2020). The results also show SFs are not a homogeneous group, but rather a category encompassing a wide range of farm and household characteristics (Fan et al., 2013; Fan and Rue, 2020). Without suggesting that cultural identities of individuals are meaningless, we would rather suggest that our results show that BP provision models cannot be simply identified as one delivery model for Nepal and another one for Sumba, for example. On the contrary, country/context, gender and roles heterogeneities may trigger the which innovative and flexible BP provision models can better satisfy the (farming) needs of those diverse backgrounds.

5.5.1 Factor 1

F1 brings a strong discourse similarity between (mainly) male Sumbanese SFs and Nepali NFs (both male and female). These seemingly dissimilar groups show a complementary interest in the BP as an innovative, affordable and easy to operate game changer in low-resource farming settings. Within the Nepali context, however, the NF ideas on options for using a BP is not precisely consonant with the expectation of Nepali farmers. The counterintuitive convergence between NFs from Nepal and SFs from Sumba may be explained by misalignments between technology (alongside its delivery models) and the actual aspirations of SFs in Nepal (Glover et al., 2019).

F1 groups SFs who perceive themselves as economically poor and that do not have any other sources of income than farming. Most of them are Sumbanese SFs who, unlike their Nepali counterparts—who may have more access to technologies and agents of all kinds (Paudel et al., 2019a)—do not have much presence nor choices of agricultural equipment. As such, the evident male SF majority in F1 can reflect the low empowerment position that Indonesian women still face in agricultural decision-making (Akter et al., 2017; Indrayanti and Mochtar, 2021).The pay-per-harvest business model present in Sumba directly reduces the financial and technical burden for a SF to use the BP, making the technology more accessible and affordable, and even an enabler of rural entrepreneurship (Van Loon et al., 2020). Direct and constant intervention of YKRMW as service provider would have supported BP use and likely triggered SFs in F1 to act as early adopters (Llewellyn and Brown, 2020). Nevertheless, we must keep in mind that a pilot project-driven adoption is far from being a steady and sustained BP uptake over time, which would demand a broader synergy between many other actors and processes (Woltering et al., 2019; Devkota et al., 2020; Van Loon et al., 2020).

NF loaders in F1 might see the BP as an agent of appropriate mechanization to boost agricultural production in small and fragmented farms (Sims and Kienzle, 2017; Devkota et al., 2020; Van Loon et al., 2020). Despite NF and SF loaders sharing a similar viewpoint in this factor, during our fieldwork we could not observe a particularly close contact between farmers and BP manufacturer; in Sumba, actually, we could not detect any contact whatsoever. In the Sumbanese case, the service provider seemed to take over that gap successfully—thereby developing SF into actual users of the technology—whereas in Nepal that gap turned their respective F1 loaders into mere aspiring BP users.

5.5.2 Factor 2

F2 is the least heterogeneous cluster, mainly loaded with Nepali, male NFs. The overarching NF ideas appear to build on the (inaccurate, as our results show) stereotypically impoverished, aid-reliant, subsistence-oriented SF (Fan and Rue, 2020; de Brauw and Bulte, 2021). Indeed, F2 members stress the limited access to resources of all kinds that has traditionally characterized SFs (Poole, 2017), and thus the inability to afford and eventually adopt the BP. As such, SFs become actors that (should) largely rely on the external aid of multiple stakeholders. Unlike F1, where limited technological choices increase the desirability of BP, F2 emerges from settings where both BP and SFs are subjected to other interactions between human and technological agents.

We observed those interactions in Nepali farming communities, in which the BP was usually ignored in favor of other pumping choices. In line with what Llewellyn and Brown (2020) suggest, these settings trigger two unfavorable conditions for F2 to adopt the BP: 1) higher upfront costs and comparatively lower performances of the BP in a market already flooded by more affordable and accessible Chinese and Indian technologies (Paudel et al., 2019a; Devkota et al., 2020), and 2) a strongly technocratic, product-oriented approach, alongside weak supply chains of spare parts and expertise (Devkota et al., 2020). Merely selling an artifact, without a proper training nor timely servicing, may severely compromise SF empowerment and education concerning the BP (Van Loon et al., 2020). In view of increasingly feminized farming settings, like Nepal, where gender-insensitive technology reinforces patriarchal roles of mechanized farming (Devkota et al., 2020; Paudel et al., 2020; Sudgen et al., 2020), the BP may even be more compromised.

The allocation of public subsidies to sustainable agricultural machinery (Poudyal et al., 2019), including the BP, may (partially) cope with higher investment required for a BP. However, given the complexity of technology adoption, this is not enough to guarantee sustained uptake, especially when certain institutional arrangements have resulted at times in misuse and ultimate ineffectiveness of subsidies (Gurung et al., 2013; Khatiwada, 2020).

5.5.3 Factor 3

F3, in both its positive and negative poles, is an interestingly rich group with roughly evenly distributed proportions of stakeholders in terms of gender, role and country. This diversity may be related to the opposite positions that an innovation like the BP may bring to existing farming practices and values (Curry et al., 2021).

Where F1 and F2 seem to be related to access/use (or not) of the BP through a linear technology-transfer model, F3 opens up diverging perspectives on innovative BP delivery models (Röling, 2009), including its barriers (Annarelli et al., 2016). Whereas F3+ loaders embrace the BP as an enabler of potential service-oriented business models to achieve wellbeing, F3- poses the rejection of a service-model with its focus on BP ownership. As such, F3 builds on a possible shift of paradigm from the traditional understanding of (agricultural) technology as a 'black-box'—a troubleshooter package deployable at any site— toward the conception of a technology-centered reorganizer of farming practices, as Glover et al. (2017) discuss.

A key concern with respect to innovative business models, such as the service-based F3+ preference, is the resistance to cultural shifts of both technology producers and users (Annarelli et al., 2016), which can be exacerbated in light of possible risk-averse behavior of SFs (Senapati, 2020). These business models would also require financial and organizational arrangements beyond the mere seller-buyer relation (e.g., including policy makers, nonprofit organizations, governmental authorities, etc.) (Röling, 2009; Agrawal and Jain, 2019; Van Loon et al., 2020). Members of F3-, in contrast, show a strong sense of ownership and full exercise of property rights (i.e., use, benefit, modification, transferring) (Cherry and Pidgeon, 2018) over BP and related irrigation water. BP ownership almost became a cultural manifestation, especially for wealthier and more empowered actors, as we could gather from our field observations. This (still dominant) mode of consumption (Demyttenaere et al., 2016) does bring implicit risks and responsibilities — usually referred to as the 'burdens of ownership' (Cherry and Pidgeon, 2018). For the BP, users may end up purchasing a device unsuitable for farm and/or (distance to) water source, as well as the responsibility of BP maintenance and repair.

5.6 Implications: Beyond adoption discourses

Each individual respondent in our Q sort represents by her/himself a unique perception on how the adoption of the BP should (not) look like. SF participants responded based on their diverse experiences and expectations. NF participants expressed their vision on what an SF is, and how she/he would (not) react toward the introduction of the BP in her/his community. It is virtually impossible for technology adoption and business models to cater for all those numberless individual realities, wickedly dependent on the interaction of both technology, adopter, and context (Montes de Oca Munguia and Llewellyn, 2020; Olum et al., 2020). With Q allowing us to identify consistent clusters of shared viewpoints, we would argue that potentially attractive one-size-fits-all models cannot satisfy each of these clusters either. There is a need to respond to this diversity, probably with a set of flexible, innovative and adaptable business models that could help in delivering a range of BP-based products and services. The range would not only satisfy (irrigation) needs, but also fulfill personal desires and culture-bound expectations. If properly designed, such wider models for the BP can become inspiration for processes of sustainable agricultural mechanization (Paudel et al., 2019a; Devkota et al., 2020), gender empowerment in increasingly feminized farming settings (Slavchevska et al., 2019; Rola-Rubzen et al., 2020; Sudgen et al., 2020), and potential reduction of inequalities through inclusive positive rural transformation (Chamberlain and Anseeuw, 2019; German et al., 2020; Kyriakarakos et al., 2020; Van Loon et al., 2020).

Designing business models that cover SF needs is beyond the scope of this paper. Nonetheless, given the discourses around the BP adoption that we discussed, we can propose possible pathways/strategies worth exploring. Using the conceptual framework of Glover et al. (2019) about technological change in SF settings, we suggest for each factor propositions and encounters from BP providers, as well as expected dispositions and responses from the prospective SF users (**Table 5.8**). These suggestions should be seen as a first outline of new ways to understand adoption of agricultural innovations, as triggers for possible novel business models required for sustainable changes in smallholder agricultural systems (Woltering et al., 2019; Kyriakarakos et al., 2020).

In order to develop different perspectives that still allow to be meaningfully clustered, we would argue that Q is a highly useful method. Q being a powerful technique to study human subjectivity does obviously not mean that its application in rural—and at times remote—smallholder communities is without its issues. Q has to deal as well with a number of general biases that Chambers (2017) coined as the 'rural poverty unseen'. We acknowledge limitations of our own study with respect to spatial (farthest locations were not visited due to time constraints), personal (gender balance was difficult to achieve in some places) and seasonal (our fieldwork took place in dry seasons) biases (Chambers, 2017). Future studies, scoping toward those unexplored conditions, will surely contribute to expand our findings and discussions, thus possibly finding new, undetected discourses around SFs' technological innovation.

Table 5.8. Suggested pathways to provide the BP with respect to each factor, based on the conceptual framework of Glover et al. (2019).

	Propositions	Encounters	Dispositions	Responses
F1	Burden-less water pump with cost-less operation that converts water in (any form of) well-being	Direct, risk-free contact with the BP, by seeing/trying it and/or witnessing its results	Aspirational hopes towards a device that enables a better quality of life	BP would act as a trigger for SF to access new farming horizons in quality and/or quantity
F2	Affordable, accessible and easy-to-use device, appropriate for remote farming niches with high land fragmentation, where (potential) farmers are not served by other technologies	Direct and sustained contact with the BP, perhaps first through a well-known local early adopter	Openness towards a well-tested device whose benefits have become tangible	Appropriate mechanization in fragmented land contexts, which would demand more robust supply chains to become sustainable
F3+	Burden-free provision of affordable, timely and consistent irrigation water, along with other possible goods and services	Both formal (deliberately organized) and informal (spontaneous) spread of message of an innovative water management system rather than a mere water pumping device	Interest on new farming directions, in which an innovative system aims to provide user satisfaction	Implementation of new BP-based business models would demand bidirectional and more complex interactions of more stakeholders
F3-	Sale of an innovative water pump with emphasis on its comparative advantages	Formal and planned transmission of the advantages of the BP compared to other existing water pumps	Interest on a product that offers comparative advantages in managing irrigation water	Strong post-sale support with accurate troubleshooting that ensures owner satisfaction

Researchers, let alone rural dwellers, are not highly familiarized with Q (ten Klooster et al., 2008). Q can bring curiosity and interest (Schneider et al., 2015; Nordhagen et al., 2017), but also confusion, doubts or even discomfort and stress (Hugé et al., 2016; Weldegiorgis and Ali, 2016; Truong et al., 2017, 2019). In that respect, we observed differences in the responses of Nepali and Sumbanese farmers toward Q. The former seemed more hesitant in translating their thoughts on the sort, whereas the latter showed higher engagement and usually took the initiative to sort by themselves. Either case, the required sorting times frequently ended in tiredness of the respondents. This fatigue may pose an additional source of biases due to the respondent's desire to finish the Q exercise. In these cases, collected answers could be unauthentic (e.g., random, non-thought sorting), or too short and (perhaps) eventually meaningless (e.g., during the post-sort interview), as reported in Truong et al. (2017).

Lastly, low levels of education (and occasional illiteracy) of some smallholders may directly impact the smooth administration of Q, which usually relies on written statements. Assistance and translation becomes crucial in such cases, but could lead to biased responses due to permanent intervention, long sorting times, and possibly disengagement of participants (Truong et al., 2017, 2019; Vargas et al., 2019). Although we did our best to keep these undesired effects to a minimum, we do acknowledge potentially biased responses due to the mentioned reasons. We therefore advocate a gender-balanced empowerment of local researchers regarding Q, so they become—as the ones closer to the local realities and needs of SFs—main actors in the co-production of knowledge and interventions for development.

5.7 Conclusion

By means of Q, we have explored discourses on the adoption of the BP in the different smallholder settings of mid-hill Nepal and Sumba Island, Indonesia. Inviting NFs as respondents allowed us to include the understanding of other parties regarding smallholder adoption of technology. Three unique factors—one of them bipolar—emerged from our reductionist analysis and interpretations. None of these perspectives responded directly to the country/community of respondents, nor even to variables usually addressed in literature on agricultural technology adoption (e.g., gender, age, education, land tenure). The factors we identified were highly heterogeneous in nature, concerning both discourses and composition. Some factors revealed alignments of viewpoint between apparently unrelated groups, whereas individuals from certain single groups could also split across factors.

That heterogeneity shows the complexity of smallholders' technological change. This is likely related to the wicked interaction between the (would-be) adopter, her/his context and the characteristics of the technology itself. In light of that complexity, strategies for technological adoption should not be conceived through a one-size-fits-all approach intended for a single "smallholder" category. On the other side, it would be impossible to provide countless tailor-made solutions to cater for every set of individual needs, let alone considering the diversity in smallholder farming. Systematic identification of adoption viewpoints, possibly by employing Q, offers a balanced and sensitive approach to operate on middle grounds in this respect. Q allows discovering diversities in smallholder communities while at the same time providing manageable blocks to draw possible (BP) adoption strategies.

Amongst those strategies, innovative and inclusive business models could be powerful tools to deliver technologies more effectively. These models would be able to create value for manufacturers, while better satisfying the (farming) needs of diverse SFs. Manufacturers and providers should consider that these models also require dynamic synergies between human and technological agents, beyond the traditional and shortsighted producer-user linear relationship. If properly designed, they can stimulate positive and inclusive technological agricultural transformation.

Data availability statement

The datasets generated/analyzed for this study can be found in the DataverseNL (https://doi.org/10.34894/AURC5E) (Intriago Zambrano, 2020).

Ethics statement

The studies involving human participants were reviewed and approved by human research Ethics Committee of Delft University of Technology. The patients/participants provided their written informed consent to participate in this study.

Author contributions

JI: conceptualization, methodology, investigation, formal analysis, writing—original draft, and visualization. J-CD: writing—reviewing and editing, supervision, and funding acquisition. ME: methodology, writing—reviewing and editing, supervision, funding acquisition, and project administration. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The supplementary material of this study can be found in the DataverseNL (https://doi.org/10.34894/AURC5E) (Intriago Zambrano, 2020).

Abbreviations

BP, Barsha pump; SDG, Sustainable Development Goal; SF, Smallholder farmer; HPP, Hydro-powered pump. Q, Q methodology; NF, non-farmer; NGO, Non-profit organization; YKRMW, Yayasan Komunitas Radio Max Waingapu; CFA, Centroid Factor Analysis; PCA, Principal Component Analysis; EV, Eigenvalue; F1, Factor 1; F2, Factor 2; F3+, Factor 3 (positive pole); F3-, Factor 3 (negative pole).

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Chapter 6

Sustainable business models for smallholder farmers: Challenges for and lessons from the Barsha pump experience

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Abstract

Smallholder farmers (SFs) are cornerstone actors in eradicating poverty and hunger. Companies have recently focused on SFs as potential customers and suppliers. Several hindrances yet prevent SFs to be commercially viable actors. In this respect, sustainable business models (SBMs) bring opportunities for companies to increase profit, improve SFs' livelihoods, and promote environmental sustainability. Recognizing these opportunities, the Dutch company aQysta provides the Barsha pump (BP) as a sustainable irrigation solution for SFs. The challenges for BP adoption that remain for SFs illustrate that there is still limited understanding of how SBMs can support companies in engaging with SFs. To expand this understanding, we conducted a multiple-case analysis of 10 organizations providing SF-tailored products and/or services. Based on this analysis, we have drawn lessons for aQysta (and similar companies) to improve the BP's value proposition and we elaborate on the implications of this study for other organizations engaging commercially with SFs.

Keywords: Barsha pump, hydro-powered pump, irrigation, product-service systems, smallholder farming, sustainable business models

6.1 Introduction

Eradicating poverty and hunger are main priorities on the global development agenda (Sustainable Development Goals [SDGs] 1: No Poverty, and 2: Zero Hunger). In the next three decades, about 685 million people must move above the deep poverty line (The World Bank, 2022), and global food production must increase by with about 50% (FAO, 2017). Smallholder farmers (SFs), comprising 70% of the global poor (Giordano et al., 2019), are key yet usually neglected actors in coping with these two challenges (Gomez y Paloma et al., 2020; Nwanze & Fan, 2016). First, interventions in the SF sector are up to eleven times more effective in poverty alleviation than in other fields (Giordano et al., 2019). Second, SFs are responsible for a significant global production of staple crops (e.g., 64% of rice, 50% of groundnut, 23% of wheat) (Giordano et al., 2019; Gomez y Paloma et al., 2020). In addition, SFs can contribute to other development areas: gender equality (SDG 5), decent and inclusive work (SDG 8), and protection of biodiversity (SDG 15) (Giordano et al., 2019; Gomez y Paloma et al., 2020; Poole, 2017; Terlau et al., 2019).

In recent years, private companies have seen in SFs a source of untapped opportunities for their businesses (TechnoServe, 2021). SFs are both a source of produce for agri-processors, and an attractive market for providers of products and services (Franz et al., 2014; TechnoServe, 2021). Adequate business strategies have thus the potential to generate both social impact for underserved SFs and revenues for companies. However, several hindrances prevent SFs from becoming commercially viable partners in the agrifood value chains. A prevalent challenge is SFs' limited access to products (e.g., farming inputs, machinery and other technologies) and services (e.g., extension, finance, mechanization, market linkages) required to be more productive (Gomez y Paloma et al., 2020). Other challenges affecting SFs are the vulnerability to climate change (particularly in rainfed systems), land insecurity, limited access to irrigation and energy, inadequate regulatory environment, informal markets, and volatility of prices (Giordano et al., 2019; Gomez y Paloma et al., 2020).

Through properly designed business models (BMs), companies can improve their commercial engagements with SFs (Geissdoerfer et al., 2018; Groot et al., 2019; IDH, 2019; Long et al., 2017; TechnoServe, 2021). Furthermore, by innovating towards sustainable BMs (SBMs), these companies have not only the potential to bolster their long-term profitability, but also to include SFs in the agrifood value chains (and create higher value for their communities) while promoting environmental and social sustainability (Michelson, 2020; Schoneveld, 2020; Sulle et al., 2014; TechnoServe, 2021; Vorley et al., 2009). To reach that potential, companies typically require support in deploying a fully-fledged SBM structure (Adjogatse & Saab, 2022). That support demands the coordinated interaction of public and private actors (e.g., governments, financial institutions, retailers, and research institutes) in an adequate business ecosystem (Adjogatse & Saab, 2022; TechnoServe, 2021). By implementing SBM strategies, companies can ensure the effective provision of their products and services, and stimulate continuous participation of SFs in better markets (TechnoServe, 2021).

Recognizing these pressing issues, the Dutch company aQysta developed a BM focused on irrigation solutions for SFs. Investing in irrigation is a key intervention to improve SFs' productivity and livelihoods (Giordano et al., 2019). With secured irrigation, SFs create opportunities to farm year-round, diversify crop production, improve yields and quality, increase profits, and respond to erratic rainfall patterns (Izzi et al., 2021). In this context, aQysta has developed the Barsha pump (BP), designed to cater to SF's irrigation needs. The BP is a hydro-powered device that builds pressure through two spiral pipes driven by a waterwheel. It is installed in rivers or canals (**Figure 6.1**a) with a flow rate of at least 300 $L\ s^{-1}$ and a water velocity of about 1 $m\ s^{-1}$. It has a diameter of about 1.5 m (**Figure 6.1**b) and weighs around 90 kg. In ideal conditions, the BP pumps a maximum of 20 – 80 $m^{-3}\ d^{-1}$ (0.23 – 0.93 $L\ s^{-1}$) up to 20 m head (or 1 km in horizontal distance)[14]. According to aQysta (2018a), the BP can irrigate up to 2 ha. The BP is currently used in several countries, with its principal markets being Nepal, Indonesia, Malawi and India (aQysta, 2018b). For a comprehensive description of the BP and its context of use, please refer to Intriago Zambrano et al. (2019) and Intriago Zambrano et al. (2022).

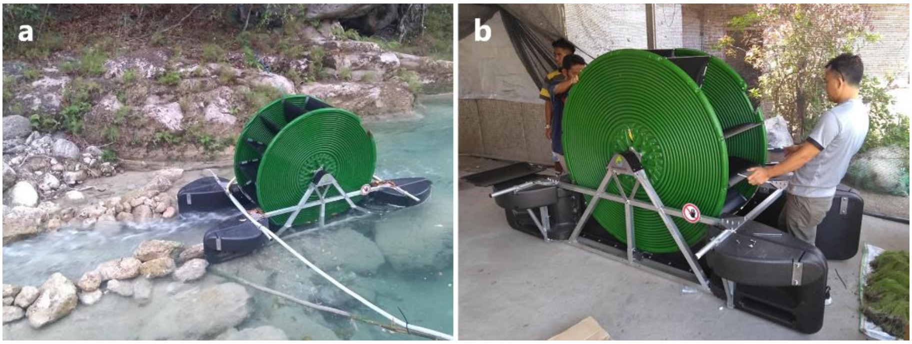

Figure 6.1. The Barsha pump. (a) Installed and operating in a river. (b) Being assembled before its installation.

aQysta claims that the BP is a better solution for SFs than diesel-powered irrigation (aQysta, 2019). The BP is said to be more affordable and

[14] Maximum pumping specifications are traded-off, that is, it is not possible to meet them all simultaneously.

cost-effective for SFs. The BP bears virtually zero operation costs by not operating on fossil fuels. The BP allegedly creates more impact among SFs, especially the most disadvantaged ones. By not relying on fuels' supply chains or electricity networks, the BP delivers higher value in remote, off-the-grid, and probably more marginalized agricultural areas. The BP is claimed to bear a simple and robust design that facilitates its operation and maintenance. By using only mechanical parts, and not electric or electronic components, its maintenance is limited to cleaning the waterwheel, (re)adequate the installation site, and repair/replace any damaged part. Lastly, the BP is said to be a more environmentally sound technology. By not emitting combustion gases, and not relying on fossil fuels, irrigating with the BP poses a negligible environmental footprint.

Notwithstanding aQysta's claims, and despite the BP's advantages, its adoption[15] among SFs remains challenging. According to some authors (Ali et al., 2016; Bastakoti et al., 2020; Intriago Zambrano et al., 2019; Kiprono & Ibáñez Llario, 2020; Kumar et al., 2020), multiple barriers prevent SFs to adopt these technologies, and thus to unlock SFs' potential through controlled irrigation. Among these are high upfront costs and associated cumbersome access to capital, site-specific limitations, unavailability in local markets, absence of local expertise, limited access to information, and poor training and capacity building.

This paper aims to connect aQysta's BP-related experience to other studies on these limitations within SF contexts. Several researchers have studied BM frameworks to deliver value more effectively to SFs (CGIAR, 2017), the creation of business cases for SFs through BM innovation (Bolwig et al., 2020; Gebrezgabher et al., 2021; Otoo et al., 2018), and the SBM structures of companies engaging commercially with SFs (Doherty & Kittipanya-Ngam, 2021). These results are extremely valuable, but specific knowledge on the relationship between companies' SBM strategies and the value they deliver to SFs remains rather limited. To further understand how companies' SBM strategies can deliver higher value to SFs, while generating profit and promoting environmental protection, we present a qualitative multiple-case analysis of 10 SBM cases. Our study aims to: (1) understand how companies contribute to SFs' development by delivering higher value through SBM strategies, and (2)

[15] We acknowledge the shortcomings of the 'technology adoption' concept. This term, as Glover et al. (2019, p. 169) state, "simplifies and mischaracterises what happens during processes of technological change", a claim even more relevant when considering other aspects such as sustained/continued adoption over time (Theis et al., 2018). As our focus in this text is not on the adoption concept, however, we do use the term 'adoption' as 'the decision of an SF to make use of certain product/service'.

draw lessons on SBM innovations for companies that engage with SFs, using aQysta/BP as an example.

The structure of this paper is as follows. Section 6.2 describes the multiple-case study research method, the sampling techniques and case selection criteria, and the data collection and analysis methods. Section 6.3 presents the synopsis and description of the selected case studies. In section 6.4, we elaborate and discuss the thematic patterns of SBM strategies. Both the synopses and the thematic strategies are of interest to non-profit organizations (NGOs), practitioners, and policymakers focused on SBM innovations. Section 6.5 discusses lessons for aQysta's BP and its value proposition. In section 6.6, we elaborate on the implications of these findings for similar providers of products/ services aiming to SFs as customer segments. Lastly, we present our conclusions in section 6.7.

6.2 Methodology

6.2.1 Research method: Multiple-case study

The study of SBMs to deliver value for SFs, as an incipient research domain, presents three key characteristics mentioned by Yin (2018). First, it aligns with the need of answering the 'how' between SBMs and delivery of value to SFs. Second, it provides the researchers no (or quite little) control over these societal events (both at SBM and SF level). Third, it is not a historical but rather a contemporary phenomenon, whose theory has not been comprehensively built.

Based on those three characteristics, we opted for the case study research method to explore the relationship between SBMs and the value delivery to SFs. Moreover, we decided to undertake a multiple-case research design to: (1) increase the reliability and robustness of the study; (2) allow independent analytic conclusions to emerge from each case, through within-case analyses; and (3) deliberately select contrasting situations across cases, through cross-case analyses (Eisenhardt, 1989; Yin, 2018). Through the within-case analyses, we generate case-based theoretical notions from the SBM strategies of each firm/organization. In the cross-case analysis, we look at evidence through multiple lenses to identify thematic areas of interventions for businesses to innovate towards SBMs.

6.2.2 Case study structure: Sustainable business model canvas

BM definitions are subject of debates among researchers (Bocken et al., 2014; DaSilva & Trkman, 2014). For practical reasons, in this research we resort to a value-centered definition: a BM is a strategic blueprint that "describes the rationale of how an organization creates, delivers, and captures value" (Osterwalder & Pigneur, 2010, p. 14). In recent years, and strongly driven by the global development agenda, this definition has shifted towards inclusive growth and environmental sustainability. This change challenges the traditional income-oriented growth discourse by incorporating social and environmental justice principles (Schoneveld, 2020). In this regard, SBMs have emerged as dynamic instruments with a strong potential of creating synergies between the well-being to communities, environmental benefits, and economic profit to firms (Dembek et al., 2018; Evans et al., 2017). In this research, therefore, we structure the selected case studies according to the SBM canvas, its four overarching value-categories, and its 11 building blocks, as proposed by Bocken et al. (2018). This structure can be seen in **Figure 6.2**.

6.2.3 Selection of case studies

6.2.3.1 Sampling techniques

We selected 10 case studies through purposive and convenience sampling techniques, based on two approaches: (1) maximum variation sampling, which "aims at capturing and describing the central themes that cut across a great deal of variation" (Patton, 2015, p. 428), and (2) the theoretical (i.e., not random) sampling principle, which "(f)ocuses efforts on theoretically useful cases — that is, those that replicate or extend theory by filling conceptual categories" (Eisenhardt, 1989, p. 533). We opted for the combination of these approaches to enrich the theory of SBM strategies to deliver value to SFs. In addition, we aim to inform specific audiences (i.e., policymakers, NGOs, companies, and practitioners) about the spectrum of opportunities within this field of knowledge.

6.2.3.2 Selection criteria

For our study, the selected cases must comply with three criteria:

- A possible maximum degree of variation across SBM structures (i.e., product-oriented to service-oriented), geographies (i.e., continents and countries), involved actors (e.g., public, private, NGO, civil society) and size of organization/SBM structure. This variation allowed us to identify themes and patterns of SBM strategies across the heterogeneity of cases.
- The (main) customer segments are SFs located in the Global South[16].

[16] The Global South – North divide has been criticized as a controversial concept (Sajed, 2020), similarly to other ones like 'developing-developed countries', 'majority-minority world', or 'third world countries'. Given that many leading scholars in development studies advocate the Global South – North dichotomy (Berger, 2021; Clarke, 2018; Dirlik, 2007), we did opt for the term. Moreover, we do not elaborate on its drawbacks since epistemological discussions on the concept are out of the scope of the present work.

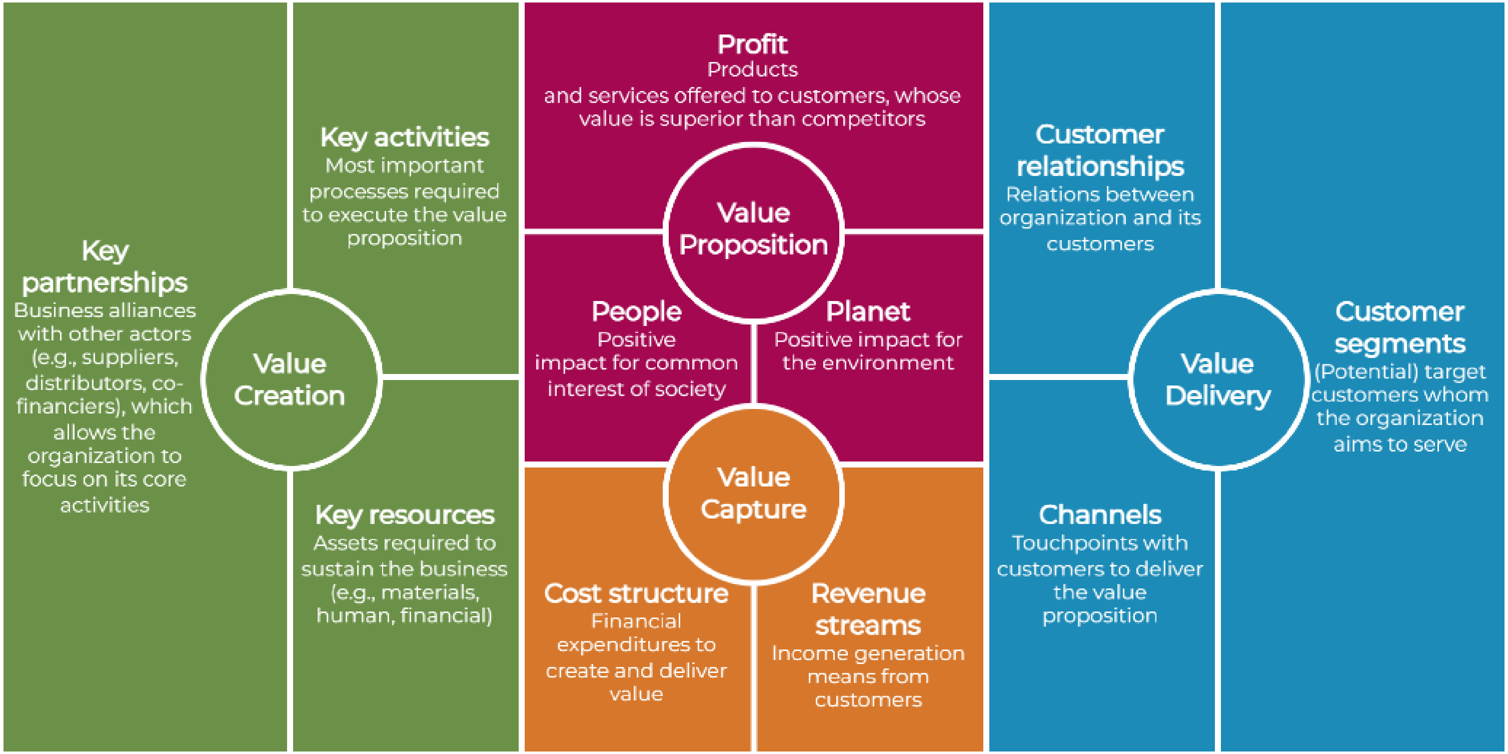

Figure 6.2. Structure of the sustainable model canvas (adapted from Bocken et al., 2018).

- To enrich the analysis of business strategies, the SBMs' value propositions pose an innovation in their structures beyond the traditional selling-buying model (i.e., upfront purchase).

6.2.4 Data collection

The dataset of the 10 case studies comprised both primary and secondary data. Primary data, collected between June 2019 and August 2021, consisted mainly of online semi-structured interviews. Our interview guide follows the eleven building blocks of the SBMs canvas (as proposed by Bocken et al., 2018), can be found in the Appendix A of Supplementary Materials (Intriago Zambrano, 2022). In addition, the aQysta-related cases included field observations and extensive face-to-face discussions as well. We interviewed key actors in different case studies, such as CEOs, managers, experts, and representatives of the organizations involved in the SBM structures. The interviews usually lasted 60 min and were recorded and transcribed upon prior agreement of the interviewees. All the case studies were complemented by secondary data, which consisted of (non)scientific articles and reports, marketing material and corporate online information.

6.2.5 Within-case analysis

We conducted the within-case data analysis using "detailed case study write-ups for each (case). These write-ups are often simply pure descriptions, but they are central to the generation of insight" (Eisenhardt, 1989, p. 540). Each write-up focused on understanding the SBM strategies within a single case and its respective products/ services delivered to SFs. These individual analyses provide a synopsis of how the respective organizations create, deliver and capture value regarding their SF customer segment.

6.2.6 Cross-case analysis

From the three tactics for cross-case analyses described by Eisenhardt (1989), we chose "to select categories or dimensions, and then to look for within-group similarities coupled with intergroup differences" (Eisenhardt, 1989, p. 540). We focused on five consecutive dimensions/themes[17], which range from the SF's access to certain product/service, to the profit that the SF makes based on the use of that product/service. The dimensions of this 'access-to-profit' cycle, and their clustered SBM strategies, are as follows:

1. *Information and knowledge*: strategies to make SFs aware and informed about available products/services.

[17] Given the lack of standardized themes in the extant literature, we chose the five dimensions based on the clusters that emerged from the collected data, as suggested by Eisenhardt (1989).

2. *Capital and financial services*: strategies to make products/services affordable for SFs.
3. *Training and capacity building*: strategies to empower SFs on how to use products/services effectively.
4. *Rural logistics and supply chains*: strategies to ensure that products/services are delivered to SFs over time (e.g., inputs, spare parts, servicing, etc.).
5. *Connection to markets*: strategies to ensure SFs make profit based on using the products/services.

The cross-case analysis is particularly relevant to build theory on how SBMs stimulate the SF adoption of products/services, while generating profits, and promoting environmental protection. This analysis allowed us — through the use of structured lenses (Eisenhardt, 1989) — to identify common patterns emerging from the diversity (Patton, 2015) of SBM strategies.

6.2.7 Lessons-drawing

To draw lessons, we resorted to a framework adapted from Rose (2002, 1991). First, the results of both within-case and cross-case analyses were the source for SBM strategies. Second, based on that empirical evidence, we formulated SBM innovations that companies can implement. This formulation followed the 'synthesis' lesson-drawing (Rose, 1991), whereby the proposal combines recognizable elements from different SBM structures into a distinctive whole. Third, we discuss the gains the proposed interventions may bring to aQysta/BP.

6.3 Synopses of cases

Based on the selection criteria, we chose cases of 10 organizations, with offices in several countries, offering a range of agricultural products/services to SFs. **Table 6.1** shows an overview of the cases, specifying the organization's name, type of product/service offered, locations of both provider organization and SF target customers, (types of) actors involved, and details of collected primary and secondary data.

In consonance with the theoretical and maximum variation sampling approaches, we selected the cases to ensure SBM diversity across categories. These categories covered the complexity of the network of actors (and its capacity to co-create value); provision of products/services or bundles; types of actors (see also column 4 of **Table 6.1**); and, relative size of leading organizations. In addition, by mapping these categories across network size and provision of product/service (**Figure 6.3**), we can cluster the cases in:

a. Single actor – product: aQysta (Nepal), Futurepump
b. Single actor – product/service bundle: aQysta (Indonesia), Sesi Technologies

c. Single actor – service: ADBL
d. Tandem of actors – product: MORINGA
e. Tandem of actors – product/service bundle: (B)energy, Organization X
f. Tandem of actors – service: Dimitra, MetKasekor

Table 6.2 shows the SBM structures of the selected cases. These structures reflect how each organization contributes to development by proposing, creating, delivering, and capturing value in its engagement with SFs. These value dimensions encompass the SBM building blocks (Bocken et al., 2018). To align with those building blocks, we split the value proposition into people, planet, and profit.

To increase our understanding of the 10 cases, we elaborate on the description and SBM innovations of each case. The innovations can be of different nature, for example technological (hydro-powered pumping, digital platform), financial (tailored microcredits, flexible payment schemes), logistical (multi-tier distribution), or strategic (key partnerships, product/service bundles). The description of the cases can be found in Appendix B of Supplementary Materials (Intriago Zambrano, 2022).

6.4 A cross-case analysis of business strategies

The case analyses offers the basis for the cross-case analysis, emphasizing similarities and differences between cases (Eisenhardt, 1989; Yin, 2018). We conducted the cross-case analysis across the five proposed dimensions of the 'access-to-profit' cycle, namely: (1) information and knowledge, (2) capital and financial services, (3) training and capacity building, (4) rural logistics and supply chains, and (5) connection to markets.

6.4.1 Information and knowledge

Access to information is a key resource for SFs. Availability of relevant, accurate and timely knowledge is an enabler to make informed decisions. With that information, SFs can decide whether to use certain machinery or input, or where and how to request a microcredit (Ndimbwa et al., 2021; Poole, 2017). However, proper access to information and advisory services remains challenging for most SFs worldwide (FAO, 2020). According to the FAO (2020), there is a substantial disconnection between SFs and information suppliers (i.e., governments, companies, researchers). Suppliers tend to generate potentially irrelevant information that sometimes is inaccessible to SFs. In addition, SFs are rarely involved in the co-creation of that knowledge.

Table 6.1. Selected case studies and details of collected data.

CASE[a]	LOCATIONS		ACTORS INVOLVED	COLLECTED DATA	
	ORGANIZATION	SFs		PRIMARY[b]	SECONDARY
aQysta (Nepal) Hydro-powered water pump	Netherlands, Nepal	Nepal	**Private**: aQysta **Public**: National government; provincial governments	-Field observations in 3 SF communities -3 interviews with representatives of aQysta Nepal -3 Interviews with SFs **DoC**: June 2019	Grey literature
aQysta (Indonesia) Hydro-powered irrigation service	Netherlands, Indonesia	Indonesia	**Private**: aQysta **Non-profit**: Yayasan Komunitas Radio Max Waingapu (YKRMW)	-Field observations in 6 SF communities -1 interview with representative of aQysta Indonesia -2 interviews with representatives of YKRMW -4 interviews with SFs **DoC**: July 2019	Scientific and grey literature
Futurepump Solar pump	UK, India	Ethiopia, Kenya	**Private**: Futurepump; national distributors; Kijani testing (field testing service) **Public**: National governments **Non-profit**: PRACTICA (research and innovation)	-1 interview with representative of Futurepump -1 interview with representative of PRACTICA **DoC**: March 2021	Grey literature
Sesi Technologies Grain post-harvest products and services	Ghana	Ghana	**Private**: Sesi Technologies; partner companies (providers of specific products/services)	-1 interview with representative of Sesi Technologies **DoC**: August 2021	Grey literature
(B)energy Biogas systems	Germany	Rwanda	**Private**: (B)energy; national distributors	-1 interview with representative of (B)energy **DoC**: June 2021	Grey literature
Dimitra	USA	Uganda,	**Private**: Dimitra; farmer associations	-1 interview with representative	Grey literature

CASE[a]	LOCATIONS		ACTORS INVOLVED	COLLECTED DATA	
	ORGANIZATION	SFs		PRIMARY[b]	SECONDARY
Farm management platform		Nigeria	**Public**: National governments **Non-profit**: Agricultural NGOs	of Dimitra **DoC**: August 2021	
Agricultural Development Bank Limited (ADBL) Agricultural microcredit	Nepal	Nepal	**Public**: ADBL; national government	-1 interview with representative of ADBL **DoC**: June 2021	Grey literature
Organization X[c] Micro-insurance against extreme weather events	Zambia	Zambia	**Private**: Organization X; partner companies (providers of specific products/services) **Non-profit**: NGO (advisor) §	-1 interview with representative of NGO **DoC**: April 2021	Scientific and grey literature[d]¶
MetKasekor Technologies for conservation agriculture	Cambodia	Cambodia	**Private**: Technology manufacturers and local entrepreneurs (providers of specific products/services) **Public**: National government; provincial governments **Non-profit**: Swisscontact (convener and promotor)	-1 interview with representative of Swisscontact **DoC**: April 2021	Grey literature
MORINGA Agricultural inputs and services	Indonesia	Indonesia	**Private**: Multinational companies (providers of inputs); local agribusinesses (providers of specific products/services) **Non-profit**: World Vision | Wahana Visi Indonesia (convener and promotor)	-1 interview with representatives of World Vision | Wahana Visi Indonesia **DoC**: May 2021	Grey literature

Abbreviation: DoC, date of collection
[a] The case comprises information about the organization (in bold letters) and the type of product/service offered.
[b] Due to privacy concerns, specific positions of interviewees are intentionally kept anonymous.
[c] The interviewee of this case asked for complete anonymity of the case.
[d] Due to requested complete anonymity, these secondary sources are not listed in the references.

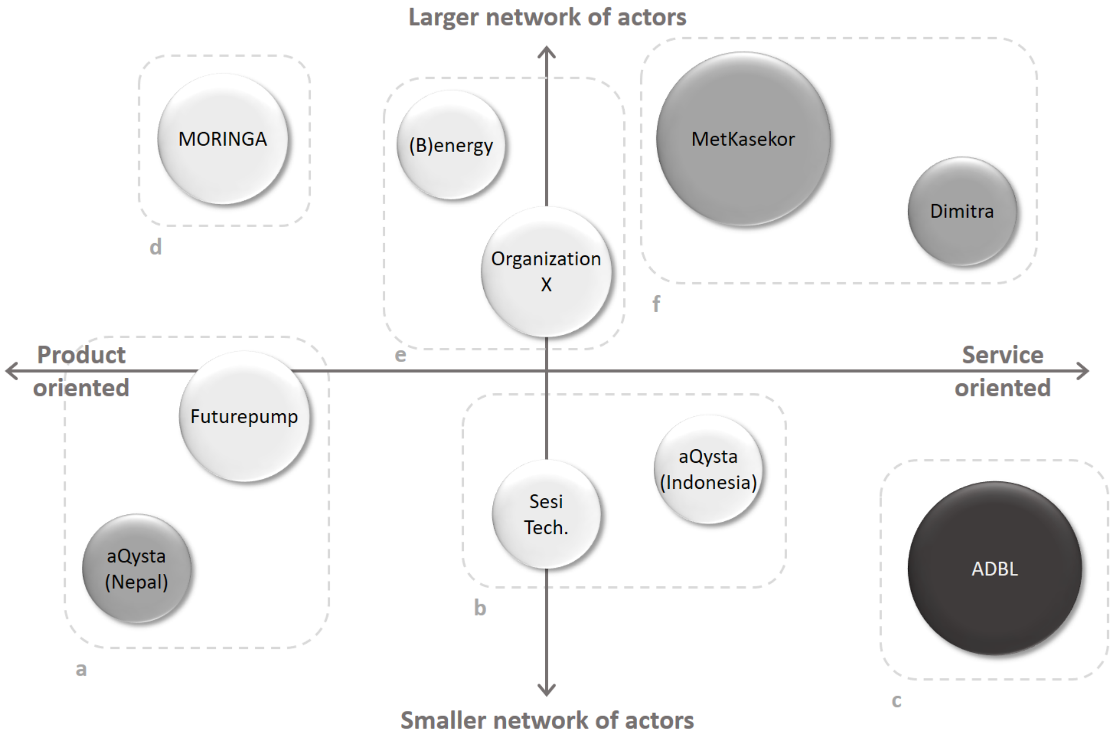

Figure 6.3. Conceptual classification of case studies across axes of product/service-oriented models and complexity/size of network of actors. The relative size of the bubbles is an indication of the size of the organization(s) involved. Light gray, medium gray, and dark gray colors of the bubbles represent the majority participation of private, public-private, and public actors, respectively. Dotted-line rectangles and letters (a, b, c, d, e, f) represent clusters of cases across the axes.

Table 6.2. Overview of business model structure of cases, regarding their value proposition, creation, delivery, and capture.

CASE	VALUE			
	PROPOSITION	**CREATION**	**DELIVERY**	**CAPTURE**
aQysta (Nepal) Hydro-powered water pump	**PE**: Low-cost pressurized irrigation to enable higher productivity **PL**: Carbon-free water pumping technology **PR**: Robust, ready-to-use water pump	**KA**: BP demonstrations, installation, and servicing **KR**: Staff, own capital, spare parts, vehicles, and tools **KP**: Governments, retailers	**CS**: SFs in hilly areas close to water streams **CR**: Direct delivery of BP to SFs; servicing for a 2-year period **CH**: Direct communication between SFs and aQysta office, retailers, and/or governments	**CO**: Rent, salaries, BP importing, in-country transportation **RS**: BP sales
aQysta (Indonesia) Hydro-powered irrigation service	**PE**: Enabler of cash cropping to improve livelihoods **PL**: Sustainable agricultural practices **PR**: Bundle of agricultural irrigation products and services	**KA**: Installation and servicing of BP and irrigation system; delivery of inputs; capacity building **KR**: Staff, donors' capital, BP, irrigation infrastructure, inputs, vehicles, and tools **KP**: YKRMW, donors, Dutch and Indonesian universities	**CS**: SFs in hilly areas close to water streams **CR**: Frequent contact between YKRMW and SFs **CH**: Direct communication between SFs and YKRMW	**CO**: Rent, salaries, BP importing, in-country transportation, sourcing of inputs and parts **RS**: Project donations, fraction of SD harvest sale
Futurepump Solar pump	**PE**: Low-cost pressurized irrigation tailored to improve SF's productivity **PL**: Carbon-free water pumping **PR**: Robust, ready-to-use water pump	**KA**: Marketing, manufacturing, and shipping of solar pumps to distributors; continuous research and innovation of solar pumps; training to distributors **KR**: Staff, own capital, venture capital, (spare) parts of solar pumping systems **KP**: National distributors, local retailers, Kijani testing (field testing service), PRACTICA (R&D NGO),	**CS**: SFs operating ≤2 acres (~0.80 ha) **CR**: Delivery of pumps to distributors, governments, or NGOs; these provide solar pumps to SFs **CH**: Direct communication between SFs and distributors, governments, or NGOs; social media; agricultural fairs	**CO**: Rents, salaries, production and shipping of solar pumps and parts, stock keeping, marketing **RS**: Sales of solar pumps to distributors, governments, and NGOs; grants; SF payments in projects (usually in-kind)

CASE	VALUE			
	PROPOSITION	**CREATION**	**DELIVERY**	**CAPTURE**
		governments, NGOs		
Sesi Technologies Grain post-harvest products and services	**PE**: Increase of competitiveness and income of SFs by improving postharvest handling of grains **PL**: Reduction of food losses by increasing the quality and lifetime of grains **PR**: Delivery of a customizable bundle of grains' postharvest products and services (i.e., Farmer Pack)	**KA**: Timely mobilization of machinery (thresher, dryer) to SF communities, timely availability of staff, informing SFs about the availability of resources **KR**: Investment capital, staff, machinery, vehicles **KP**: Suppliers of machinery and inputs, financial institutions, donors	**CS**: Grain SFs, with certain degree of sensitization about the benefits of the Farmer Pack **CR**: Direct relation with the SFs; Sesi Technologies goes directly to the communities (37 so far) **CH**: Direct communication between Sesi Technologies SFs (on-site) and suppliers; word-of-mouth through local leaders and farmer networks	**CO**: Investment and maintenance in machinery and vehicles, salaries, and purchase of other products included in the bundle **RS**: SF payments (either in cash or in grain, flexibly)
(B)energy Biogas systems	**PE**: Improvement of quality of life of farmers and community members by stimulation of local entrepreneurship and provision of clean cooking **PL**: Reduction of organic waste by transforming it into biogas and organic fertilizer **PR**: Commercial biogas systems	**KA**: Manufacturing and sourcing of biogas systems, shipping to target countries, recruitment of national distributors, marketing, and events **KR**: Capital, staff, and material resources to produce the technologies **KP**: African Energy Chamber (investor), European suppliers and manufacturers, volunteers [i.e., (B)Angels], other biogas companies (coordination in the sector)	**CS**: SFs willing and capable to invest in a biogas system, and villagers willing to cook with biogas **CR**: (B)energy has direct contact with national distributors, installers, and end-users (during training); remote contact with the different user levels through app **CH**: Main contact points are done through a multi-tier scheme, where each actor connects with the following; (B)energy app to convey information to all the user levels; demos in villages	**CO**: Production costs, rents, salaries, utilities, administrative costs, international shipping **RS**: Sale of biogas products (biodigesters, gas backpacks, stoves), events (training, speeches, etc.), training for installers
Dimitra	**PE**: Increase of SFs	**KA**: Design and technical delivery of	**CS**: SFs operating ≤4 ha, with interest	**CO**: Rent, salaries, labour,

CASE	VALUE			
	PROPOSITION	**CREATION**	**DELIVERY**	**CAPTURE**
Farm management platform	performance and competitiveness, by enabling them to manage their operations and best practices in a more efficient manner **PL**: N/A **PR**: Provision of a platform for SF operations management	the system, technical support and training, development of new technologies, refinement of current designs, marketing to organizations **KR**: Own capital, staff (developers, sales, marketing), tools and resources, ICTs **KP**: Organizations, farmer associations, governments, developer companies, financial groups	in applying technology to manage and improve their operations **CR**: Constant SF feedback collection through the platform; improvement of the systems and rollout of new versions **CH**: Dimitra has direct contact with organizations, farmer associations, governments, and financial groups. The contact with SFs is through the middle organizations	ICTs, and equipment **RS**: Through farmer associations, organizations, or governments (SFs access the services paying periodic fees, on-demand, or charity)
ADBL Agricultural microcredit	**PE**: Increased SF access to affordable and tailored capital that enhances investment capacity **PL**: N/A **PR**: Agricultural microcredit for SFs	**KA**: Training of staff in SF assistance; processing of documentation to qualify credits; marketing through different channels **KR**: Own capital; staff; physical assets in offices; ICT equipment; office branding material **KP**: International donors; international development banks; reinsurance providers	**CS**: SFs (<0.5 ha farm and <2500 NPR income) **CR**: SFs go directly to ADBL branches to request assistance, request credits, and do the repayments **CH**: Traditional media (TV and local FM radio, in both national and local languages), written material, social media, merchandising, official website, events at provincial and local levels	**CO**: Rent, salaries, operation costs (loan monitoring, supervision, and collection), ICTs, energy (diesel generators) **RS**: Interest rates of ~3-3.5% (actual rate is ~8.5%, government subsidizes ~5%)
Organization X Micro-insurance against extreme weather events	**PE**: Increased SF resilience by providing financial protection against extreme weather events **PL**: N/A **PR**: Bundle sales of individual micro-insurance (alongside other agricultural products and	**KA**: Establishment of the contract farming scheme; 100% upfront pre-financing of insurance premium; delivery of bundle to SFs; claiming and distribution of payouts; settling of payments by the end of season **KR**: Staff, own capital, loans capital,	**CS**: Marginalized cotton SFs **CR**: SFs are aggregated under a contract farming scheme; close contact between SFs and agribusiness **CH**: Direct, on-field communication between SFs and agribusiness	**CO**: Rent, salaries, sourcing of insurance and inputs **RS**: Cotton sales by the end of season

CASE	VALUE			
	PROPOSITION	CREATION	DELIVERY	CAPTURE
	services)	inputs; vehicles **KP**: Insurance provider; inputs providers; brokers (iNGOs); banks		
MetKasekor Technologies for conservation agriculture	**PE**: Improved SF farm productivity by accessing to affordable agricultural services and capacity building **PL**: Sustainable intensification of agriculture **PR**: Creation of market for six agricultural technologies and other related products and services	**KA**: Training to provincial governments, and from these to service providers; networking with private suppliers of agricultural products and services **KR**: (Training) staff, public budget, agricultural technologies, and inputs **KP**: Provincial governments, private suppliers, service providers (early adopters)	**CS**: SFs close to service providers **CR**: SFs receive products and services from service providers, who are early adopter SFs **CH**: Periodic evaluation meetings between national and provincial governments; training sessions from provincial governments and private companies to service providers; contact between service providers and SFs at local level	**CO**: Salaries, mobilization, and training, meetings, and workshops **RS**: Public funds (national annual budget); SFs pay to local service providers (flexible dealings between these actors)
MORINGA Agricultural inputs and services	**PE**: Improved SF incomes and livelihoods by building capacities on better agricultural practices and linkage to agricultural value chains **PL**: N/A **PR**: Increased demand for specific agricultural inputs	**KA**: Identification of intermediate service provider; funding of demo plots; networking with buyers **KR**: Staff, own capital, agricultural inputs, agricultural technologies, and inputs **KP**: Broker (iNGO), national retailers, intermediate service provider (local agri-shop), local social and religious leaders	**CS**: SFs close to service providers **CR**: SFs receive products and services from service providers, who are existing agri-shops at local levels **CH**: Meetings and workshops for SFs; marketing through service provider; word-of-mouth through local leaders	**CO**: Salaries, mobilization and training, meetings and workshops, transport of inputs, setting of demo plots **RS**: Sales of inputs to service providers; SFs pay to them on flexible basis (upfront, credit, in harvest)

Abbreviations: CH, channels; CO, cost structure; CR, customer relationships; CS, customer segments; KA, key activities; KP, key partnerships; KR, Key resources; PE, People; PL, planet; PR, profit; RS, revenue streams.

Some of our cases rely on traditional information channels, including direct branding and advertisement through local branches. This strategy is prevailing in the BP in Nepal, Futurepump through its national distributors, and the ADBL. For this strategy to be effective, the brand/product must be linked to a long-standing actor that SFs can recognize more easily. Futurepump leverages on the prestige and leading presence of Davis & Shirtliff in East Africa (Davis & Shirtliff, 2022). ADBL builds on its background as a predominant stakeholder in the agrarian history of the country (ADB/Nepal, 1982; Banskota, 1985). Direct advertising does not guarantee outreach and awareness among SFs (Phiri et al., 2019), especially in 'media dark' areas (Prahalad, 2005). This may explain why both cases also bring information closer to SFs through local agricultural fairs and events. Both firms use social media platforms too. The effectiveness of platforms, however, largely depends upon rural internet penetration rates, digital literacy of SFs and accessibility to related equipment (Phiri et al., 2019).

Local networks and word-of-mouth may be more effective ways to make information accessible to SFs (Ndimbwa et al., 2021; Phiri et al., 2019). Actors from these networks are geographically closer to SFs and usually represent more trustable faces too. Cases that apply these strategies to reach users are the BP in Indonesia, Sesi Technologies, (B)energy, Organization X, MetKasekor and MORINGA. The work of Sesi Technologies in some communities made neighboring leaders request similar services in their villages. The multitier model of (B)energy operates through local networks: national distributors look for producers, whereas producers and installers identify end-users. Organization X informs SFs directly through its own field staff about the micro-insurances. Both MetKasekor and MORINGA operate through awareness campaigns and intermediate service providers located close to the SFs. According to Poole (2017), there is the risk of local retailers acting on their own interest. They can be more interested in selling their own stock rather than becoming a source of information for SFs.

SFs oftentimes prefer 'seeing is believing' to make decisions (Hansen & Roll, 2016; Kondylis et al., 2017; Ndimbwa et al., 2021; TechnoServe, 2017). This approach works through demo plots or agricultural shows. This is an effective and popular way to demonstrate the effects of products or services. Moreover, it does not involve any financial risk for the SFs (Ndimbwa et al., 2021; Yigezu et al., 2018). Futurepump, (B)energy, MetKasekor and MORINGA use demonstration plots to showcase their products and services. (B)energy has installed systems in local markets and villages for SFs to see how it works. MORINGA sets demo plots by pooling funds from a private company, land from the community, and labor from the intermediate service provider.

Learning through early adopters is a particular case of on-site demonstrations. Its main advantage is that early adopters are likely the closest and most familiar actors to SFs. On the downside, its effectiveness may be affected by other intervening variables (e.g., farm characteristics, soil types, level of education, etc.). These demonstrations also may transmit not only the benefits but also the disadvantages and risks of certain innovations (Chavas & Nauges, 2020; Conley & Udry, 2010; Maertens, 2017). Futurepump has spearheaded its pumps in some communities through local leaders. MetKasekor's early adopters showcase the technologies on their own farmlands. MORINGA identifies existing local retailers that become early adopters within their existing business.

6.4.2 Capital and financial services

Access to capital is a key enabling factor for SFs to unlock their potential (Rahman & Smolak, 2014). Meeting certain financial capacity guarantees SFs access to appropriate agricultural technology, high-quality inputs, and better markets. Securing financial resources for SFs has a direct impact on increasing their productivity and revenues, and consequently in the dynamics of the local economy (Isaga, 2018; Shepherd, 2007). Limited access to capital, however, remains one of the most ubiquitous and evident challenges for SFs (Isaga, 2018; Langyintuo, 2020). Financial institutions usually consider SFs not creditworthy clients. These institutions thus seldom offer financial products tailored to SF's needs. This exclusion is rooted in too high transaction costs due to remoteness and dispersion, too long return-of-investment periods, underdeveloped infrastructures, and high risks linked to extreme weather events, volatility of prices, lack of access to inputs, and underdeveloped value chains (Isaga, 2018; Langyintuo, 2020; Rahman & Smolak, 2014). Due to this exclusion, which is more exacerbated in women (Marks, 2019), SFs tend to rely on informal credit sources like friends and relatives, remittances or even loan sharks (Isaga, 2018; Tchewafei et al., 2020). To bridge that gap in the traditional banking systems, some authors (Chen et al., 2015; Fan et al., 2013; Langyintuo, 2020; Miranda et al., 2019; Yi et al., 2021) have explored and proposed innovative options such as credit guarantee schemes, value chain financing (e.g., contract farming), and warehouse receipt financing.

Products and services are typically offered to SFs on upfront payments. Cases that operate under this scheme are the BP in Nepal, Futurepump, Sesi Technologies, (B)energy, MetKasekor and MORINGA. This model assumes that SFs belong to a customer segment with higher purchasing power and/or access to formal credit (Prahalad, 2005). In contrast, the payment capacity of many SFs shows much more limited out-of-pocket money. Their cash availability fluctuates seasonally, usually linked to agricultural production and sales of produce (Langyintuo, 2020; Oluwatayo, 2019). Due to that cash fluctuation, some providers opt to offer their products or services on (micro)credit basis. The most evident is the case of ADBL's SF-tailored microcredits. The repayment plans are sensitive to the intermittent cash flow of the clients. Futurepump's distributor in Kenya cooperates with Equity Bank Kenya to offer its products with these payment facilities. Dimitra offers SFs to pay monthly/annual fees, or on-demand (in specific trading points over time), whereas the middle organization bears the bulk upfront payment. MetKasekor and MORINGA consider the options of flexible arrangements, which may involve the participation of microfinance mechanisms.

Microfinance institutions may cater to specific needs of SFs, but those have limitations. They usually bear limited capital, smaller outreach, and high-interest rates. They can be unreachable to SFs if located in urban areas. Their repayment schedules do not always match with the seasonality of SFs' cash flows (Dossou et al., 2020; Langyintuo, 2020; Shepherd, 2007). Microfinancing through farmer associations at times copes with these limitations. These associations are locally present, involved in the farming businesses, and can provide their SFs with on-credit products and services (Bizikova et al., 2020). In addition, associations have stronger capacities than individual SFs to negotiate better prices of products and services (Bizikova et al., 2020). At the same time, associations may experience difficulties in enforcing loan repayment among their associates (Shepherd, 2007).

Subsidies make products and services more affordable for SFs. These can come as public subsidies (as defined in a public policy) or through private, donor-driven projects. ADBL and the BP in Nepal leverage on subsidies provided by the Government of Nepal. These instruments subsidize roughly 5% of ADBL's microcredits for SFs, and up to ~90% of the BP. Futurepump (in Ethiopia) (GIZ, 2020), Sesi Technologies (Siemens Stiftung, 2020), Dimitra and the BP in Indonesia reach SFs through donor-driven subsidies. In Futurepump in Ethiopia, SFs additionally contribute in-kind (e.g., land, labor, maintenance, showcase). Subsidies are not free of pitfalls. Mismanaged subsidies can compromise the financial sustainability of local economies. That mismanagement can result in market distortions, unrealistic costs of products and services, asymmetric competition with local entrepreneurs, and misuse of external funds ((B)energy, 2021a; Gurung et al., 2013; Khatiwada, 2020; Shepherd, 2007).

Pay-with-harvest has recently emerged as a financing mechanism for SFs (Tibbo et al., 2020). In this model, SFs pay with (a fraction of) their harvest to access products and services. The model can be combined with traditional cash payments and/or microcredits. The payment can be agreed upon as a percentage of the total production (rather than a fixed amount of produce), mitigating the SF's financial after a harvest failure (Tibbo et al., 2020). The BP in Indonesia, MetKasekor and Sesi Technologies offer these payment options. The latter offers the most flexibility to the users: the SF chooses the percentages of cash/harvest payment, and the type of services that will be paid for. Operating through a contract farming scheme (Ruml et al., 2022), Organization X settles the cost of the bundle of products and services — including the micro-insurance — when collecting the produce from its SFs. This is done at the end of the season, so SFs do not make any payments upfront. Side-selling (i.e., sales to other non-committed buyers) is one of the most prominent challenges in pay-with-harvest models, and is even more sensitive when contracts are mediating (Casaburi & Willis, 2017; Tibbo et al., 2020). By side-selling, SFs may not meet pre-agreed harvest volumes, which can turn into financial losses for products/services providers.

6.4.3 Training and capacity building

The SFs' decision to adopt agricultural practices is largely influenced by their knowledge and skills (Stewart et al., 2015). Training is a means to strengthen SFs' capacities, which facilitates the uptake of new products and services (Pratiwi & Suzuki, 2020). Training takes various forms depending on their content, duration, participation level, and type of training provider (Pratiwi & Suzuki, 2020; Stewart et al., 2015). The combination of those factors results in different training approaches. Examples of those approaches are the typical 'train and visit' governmental extension services, and the more participatory farmer field schools (Stewart et al., 2015). Moreover, in recent times several context-sensitive training approaches have emerged, as De Janvry et al. (2017) report. The effectiveness of these interventions varies depending on the target SF, the community (De Janvry et al., 2017), and the training location itself (Nakano et al., 2018; Pratiwi & Suzuki, 2020).

Sesi Technologies and Organization X train their SF users directly. Sesi Technologies makes it possible due to its decentralized structure of services, which are delivered as closely as required to the SFs. Organization X trains SFs through its own field staff in frequent touch points throughout the season. These interactions are largely used to inform and train SFs on the micro-insurance and other products and services included in the contractual arrangements. Additionally, given the immaturity of the micro-insurance market, Organization X also counts on development aid organizations to build capacities of insurance providers, agribusinesses, and SFs.

Most firms studied here do not provide direct training to SFs. Training them directly would bear costs that likely neither companies nor SFs can afford (Nakano et al., 2018). These companies rather upskill intermediary actors, who then cascade down knowledge to SFs through further interactions. aQysta trains its staff at the national branch in Nepal. Based on training from aQysta, the service provider of the BP in Indonesia took over the operation of its pumps. Futurepump offers training to their national distributors, like David & Shirtliff in Kenya (Davies, 2018), to support SFs. Futurepump has trained extension officers in Ethiopia through NGOs (GIZ, 2020). (B)energy offers direct capacity building to its national distributors, installers, and end-users ((B)energy, 2021b, 2021c). Dimitra trains the middle organizations that acquire their services and make them available to SFs (Dimitra, 2021). ADBL ensures an equal level of preparation in all its branches throughout the country. MetKasekor and MORINGA train their respective local service providers (who at times are SFs), which is reported as a more effective local capacity building mechanism (Nakano et al., 2018).

Futurepump and (B)energy provide remote training to cope with their users' geographical distance, dispersion, and/or remoteness. Futurepump has a comprehensive set of videos about its products' installation, operation, and maintenance. (B)energy administers a proprietary application and online training (videos with subtitles) for installers, and online training for SFs. The installers can receive direct troubleshooting from the distributor through the application. Moreover, if required, distributors can contact (B)energy headquarters in Germany for further assistance. The use of digital platforms and applications is an effective and affordable way to massively roll out new information to the users. However, the digital divide due to limited internet penetration (Villapol et al., 2018), limited access to ICT equipment and electricity (Armey & Hosman, 2016), and/or (digital) illiteracy (Jere et al., 2013), can pose a substantial challenge to implement these strategies.

6.4.4 Rural logistics and supply chains

A large extent of literature focuses on how to connect SFs to well-developed markets (addressed in the following subsection) (Akter et al., 2021; KC et al., 2020; Poole, 2017; Sher et al., 2020; Tessema et al., 2019). However, much less of it studies the importance of rural logistics and strong supply chains in delivering key products and services to SFs. Logistics implies much more than just a one-time delivery of a physical product in SF communities. It must consider the continuous flow and timely availability of inputs, technologies and equipment (including spare parts and tools), and information and knowledge (ADB, 2017).

Provider companies deal with several challenges in delivering their products and services to SFs (Fowler & White, 2015). First, they may be less encouraged to supply capital-constrained SFs, as compared to larger, riskless users (e.g., governments, agribusinesses, farmer cooperatives, and large farmers). Second, they may see SFs as an unattractive market due to dispersed demand, deficient road infrastructure, and costly transportation. Third, they may refrain from engaging commercially with local retailers showing marketing mismanagement (e.g., failing in bookkeeping and managing inventory). Furthermore, cash limitations may restrict their investment efforts in outreach activities (e.g., promotional activities, stocking inventory, opening local stores). Lastly, lack of mutual trust between providers and SFs may hinder an otherwise beneficial long-term, strong relationship.

Our cases use different strategies to (partially) cope with the challenges above. aQysta delivers the BP in Nepal through its national branch. Due to using its own staff and logistics, however, aQysta faces the constant issue of remoteness and extended traveling times in Nepal. Futurepump relies on well-positioned national distributors and/or their regional branches. (B)energy counts on active installers, who market the technology locally. Futurepump and (B)energy also train local actors (i.e., extension workers, and technicians), so SFs can access their knowledge as closely as possible. ADBL delivers its services through hundreds of branches throughout Nepal (ADBL, 2022). MetKasekor and MORINGA train early adopters and local retailers, respectively, so these can act as sub-district- or village-level service providers. In a similar line, the BP in Indonesia is made accessible to SFs through a local service provider; however, its supply chain from the Netherlands is not formally established and thus relatively fragile. Sesi Technologies, on the other hand, is the only case that provides its FarmerPack directly at village level, without the intervention of intermediate actors. In fact, due to its bundle of products and services, Sesi Technologies can be considered as the intermediary of many other suppliers of machinery and inputs.

6.4.5 Connection to markets

Pure subsistence farming barely exists nowadays. Even the most marginalized SFs are linked to agricultural markets. They participate with their cash flows, purchase products and services, and contribute to the supply of foodstuffs (Poole, 2017). This linkage, and the growing global demand for their diversity of produce, bring them opportunities to improve their incomes. At the same time, many market challenges, prevent SFs from being competitive and from seizing those opportunities (Markelova et al., 2009; Odero-Waitituh, 2021; Wiggins, 2020). Lack of pricing information oftentimes place SFs at a disadvantage regarding intermediaries and other third parties. Too costly procedures may leave SFs out of some niche markets (e.g., certifications for organic or fair trade). Poor road networks limit the acquisition of inputs and transportability of produce while increasing postharvest losses. The volatile rural market environment usually involves high marketing costs, and prices subjected to fluctuant supply and demand dynamics. Lastly, weak institutional and policy frameworks may exacerbate all these distortions.

Private businesses, especially smaller ones, may have extremely limited influence on the macro factors that condition agricultural markets. These companies usually cannot invest in improved public road infrastructure. They cannot steer international prices of agri-commodities. Their business advocacy to steer agricultural policies is rather limited. Nonetheless, companies can implement strategies to adapt better to those market conditions, or even to cope with those restrictions. The local provider of the BP in in Indonesia guarantees SFs a market for their produce. Organization X provides its SFs with off-take contracts that set buying prices at the start of the season. MORINGA maximizes SF profits by identifying agri-commodities with the highest commercial potential, and by connecting producers with potential premium buyers. Sesi Technologies and Dimitra provide information about prices and buyers through their respective channels. These two organizations also promote higher, more competitive produce quality that enables SFs reaching higher selling prices. Sesi Technologies accomplishes that goal by providing a bundle of value-adding postharvest services (i.e., drying, threshing, storing), whereas Dimitra facilitates SFs in managing the traceability of products to meet certain standards (e.g., to export livestock). Lastly, (B)energy, MetKasekor and MORINGA directly stimulate the local economic dynamics by providing entrepreneurial support to intermediate providers.

6.5 Lessons for the Barsha Pump

Both aQysta and its BP are newcomers in the world of water pumping (aQysta, 2022a). Neither of them is common knowledge among SF communities. The company resorts to three ***information and knowledge*** strategies: web-based channels, on-site demonstrations (targeting mainly sectional governments), and showcasing at agricultural events. However, ICT divides and physical remoteness of SFs may result in information not reaching them. Information on the BP could be made more easily available to SF communities through intermediate actors (e.g., local agribusinesses, farmer groups, NGOs) and/or local early adopters. These actors ensure more effective outreach through word-of-mouth and 'seeing is believing'.

SFs stressed the BP's virtually-zero operation costs as one of its most salient features. This characteristic is more relevant when compared to cost-demanding fuels required by petrol pumps. However, this feature is overshadowed by its relatively high upfront costs. The BP's floating variant (installed on-site) costs about 1300 EUR in Nepal and 1800 EUR in Indonesia[18], with equivalent petrol pumps costing roughly 200 EUR and 370

[18] These are installed costs of the highest-priced version of the BP (floating variant). Other variants (e.g., standing, canal), which dispend with some components, may pose lower costs.

EUR, respectively. This means that, without adequate access to ***capital and financial services***, the BP can be quite unaffordable for SFs despite its 2-year break-even point (aQysta, 2019). Although aQysta leverages on subsidies to make the BP more affordable, these instruments tend to favor other renewable energy technologies [e.g., solar pumps in the Eastern Gangetic Plains (Bastakoti et al., 2020) and Ethiopia (GIZ, 2020)]. Additionally, diesel and solar pumps – more compact and transportable than the BP – enable more easily mobile (i.e., on bikes and motorbikes) and affordable pay-as-you-go SF irrigation services. Examples of such initiatives are JOHAR (Nitnaware, 2021; Singh et al., 2020), SunCulture's Pay-As-You-Grow (ARE, 2021), PAY-N-PUMP (PAY-N-PUMP, 2021) and Agriworks Uganda (Agriworks Uganda, 2022). Consequently, the BP must compete in markets with more affordable and better-positioned pumping technologies. The BP could find financial support in microfinance institutions, and/or in microcredits facilitated by agribusinesses through contract farming schemes. However, the main challenge of this strategy is that such actors may be reluctant to operate with an unfamiliar technology.

The BP bears a straightforward pumping principle, a simple and robust design, and a few-component construction. Despite that simplicity, without proper ***training and capacity building***, SF users might not easily relate to BP's installation, operation, and servicing. Unless local actors are properly trained, the BP operation in SF communities can turn logistically complex. This complexity can be further exacerbated if the required knowledge is based in urban centers far from SFs (e.g., Kathmandu in Nepal). aQysta could train intermediate, village-based actors as local BP servicing providers. These actors can be existing retailers and/or SFs with required technical predispositions and skills. Nonetheless, aQysta still needs to meet a minimum density of BPs per area to justify the investment in training of these local actors.

The BP's value proposition is higher in remote, off-the-grid locations. Under such conditions, diesel pumps fall behind as competitors due to weak or inexistent fuel supply chains. In lack of robust ***rural logistics and supply chains***, this advantage turns into a paradox: the more valuable the BP is, the more burdensome its servicing may become. Two strategies can improve BP's servicing in remote areas. The first one is to produce spare parts as locally as possible. Some components (e.g., the waterwheel paddles) can be manufactured with local, low-cost methods. This strategy can be supported by using market-standard components (e.g., screws, aluminum, bolts and nuts) available in local markets. Off-the-shelf components from local stores can replace unique parts (e.g., standard diaphragm pumps and gearboxes, instead of spiral pipes), though this requires additional redesign efforts. This strategy shortens required supply chains, ensures availability of parts, and potentially stimulates local jobs. The second strategy is to leverage on existing supply chains of other actors. By collaborating with stakeholders that already operate with robust logistic networks (e.g., agribusinesses, NGOs, farmer cooperatives), aQysta can boost the timely availability of expertise and components.

The BP can be an ideal irrigation device under certain farm conditions (i.e., size, crops, distance from water source). However, as it occurs with any other water pump, its sole use is not enough to close logistic, financial, and information gaps that SFs usually face in their ***connection to markets*** (Lee et al., 2012; Markelova & Mwangi, 2010; Poole, 2017). This is a common shortcoming of technology transfer models whereby the device is seen as a trouble-shooting black box supposed to work in every context (Glover et al., 2017; Glover et al., 2019; Röling, 2009). In this respect, the BP should become less central within the value proposition of aQysta. The BP could be more in line with other products and services equally important for SFs, for example, inputs, machinery, knowledge, produce off-taking, and so forth. Provided that aQysta cannot become a holistic provider, this paradigm shift demands the coordinated intervention of many more actors in the value chain (Adjogatse & Saab, 2022). We can find examples of such synergies in cases described here like Sesi Technologies, Organization X, MetKasekor, MORINGA.

Recently, aQysta started shifting its business scope from a developer of hydro-powered pumps to a provider of SF farming services. Through the Grown Farm Incubator business model (aQysta, 2022b), aQysta provides SFs with on-credit agricultural inputs, technologies, services (e.g., certifications, training, advice, market connections), and even land if required. To ensure a timely cash flow for SFs, aQysta gives them advances of the predicted harvest, with costs being settled at the end of the season. SFs do not repay the advanced money in case of harvest losses due to natural disasters and climate risks. Although this model resembles that of contract farming (Ruml et al., 2022), it differs mainly in the advanced payment schemes, the share of profits between aQysta and SFs based on transparent prices, and the financing of irrigation technology (aQysta, personal communication, October 17, 2022). This new business approach has started with 50 farmers in Malawi, India and Nepal (aQysta, 2022a). A more comprehensive analysis of the Grown model could not be part of this text, but a first assessment for Malawi is available in Van Engelenhoven (2022).

6.6 Implications for companies and development

Companies providing a single product or service may address one specific need of SFs (e.g., an irrigation pump to enable SF irrigation). However, such a narrow business strategy typically fails to address the SF's multifaceted challenges (Adams & Jumpah, 2021; Akzar et al., 2023). By not reaching a higher value proposition, SFs may ultimately disregard the offered product or service. In addition, these products and services are often inaccessible or unaffordable to SFs due to various obstacles. As a result of this pernicious loop, the company struggles in generating profit, and the impact created at SF level is practically negligible.

Innovating towards SBMs may offer companies new business opportunities and a better financial resilience. At the same time, it involves the complexity of enhancing the value proposition towards the threefold goal of (1) attaining revenues, (2) improving SF's well-being, and (3) contributing to preserving the environment (Geissdoerfer et al., 2018). First, profit considerations need to recognize that SFs differ from wealthier population segments (e.g., large-scale commercial farmers). SFs typically cannot afford more expensive products and services. When engaging with SFs, prioritizing small margins from a broader SF base is more advantageous than seeking larger margins from a smaller segment (Prahalad, 2005). Companies should enrich their value proposition by offering additional products and services that improve SFs' productivity. Through this improvement, both SF and companies have more access to premium markets, better prices, and bigger margins.

Agri-processors can strengthen their engagement with SFs by providing bundles of products and services. Companies can act as a holistic provider or in coalition with other actors (Adjogatse & Saab, 2022). Partnerships with other providers (i.e., providers of inputs, mechanization, finance, etc.) is key for agri-processors to deliver higher value to SFs while focusing on their core business (Adjogatse & Saab, 2022; IDH, 2019; USAID, 2019). Furthermore, a good offer of products and services keeps SF's loyalty to the company, thus ensuring a steady supply of produce (Van der Velden et al., 2017). Lastly, companies should identify profitable products and services (e.g., mechanization, spraying, and high-quality inputs), which are generally easier to monetize compared to training or advisory services. An adequate balance between profitable versus less-lucrative products and services may ensure higher SF value while generating margins for the provider.

Second, when focusing on the impact on SFs, it is essential to tailor the offer to their unique needs. Examples of this offer are seed varieties resistant to specific climate conditions (Cacho et al., 2020), micro-loans with flexible repayment schedules (Dossou et al., 2020), and context-sensitive machinery (Paudel et al., 2023). By understanding those needs, companies can offer products and services that create a longer-lasting SF impact. Besides, companies must emphasize efforts on last-mile delivery strategies. No matter how impactful the products or services are if SFs cannot have timely access to them. Examples of such strategies include village-based agents (Scheer & Okelai, 2019), cascading through farmer cooperatives (Miroro et al., 2023; Sugden et al., 2021), and lead farmers liaising with SFs (Ragasa, 2020). Offering products and services comprehensible to SFs is pivotal to stimulate their uptake. Using context-sensitive communication channels (e.g., radio broadcasts, intermediaries like farmer groups or village-based retailers), can inform SFs more effectively about the availability of products and services.

Providing financial support to SFs is crucial for them to access products and services (Colina et al., 2023; Leyson & Morgan, 2022; Zook, 2014). Financial support strategies are forward contracts with SFs (including the on-credit provision of products and services) (Tabe-Ojong & Abay, 2023), and tri-partite agreements that involve financial service providers (IDH, 2023). Collaborating with grassroots structures like farmer cooperatives (Ma et al., 2022; Miroro et al., 2023; Shen et al., 2022) or village loan and savings associations (Seidu, 2017; Solidaridad, 2021) can facilitate this financial objective. Moreover, partnering with agribusinesses that source produce from SFs can secure market access and improve their long-term commercial viability (TechnoServe, 2023).

Third, to address environmental concerns, it is imperative for companies to provide sustainable products and services. For example, companies can shift towards lower environmental footprint solutions like renewable energy-powered irrigation (Lefore et al., 2021). Providers can also focus their offer to sustainably intensify SF agriculture. Among these are as high-yield and climate-resistant seeds (Cacho et al., 2020), no-till machinery (Sims & Kienzle, 2017), and practices like conservation agriculture (Lee & Gambiza, 2022). Furthermore, companies can offer products and services that favor the regeneration of agricultural ecosystems, like organic fertilizers (Muluneh et al., 2022), agroforestry practices (Duffy et al., 2021), and integrated soil fertility management (Kwadzo & Quayson, 2021).

6.7 Conclusion

SFs are key actors in approaches aiming at reducing poverty and increasing global food production, both by public and private actors. For private actors like companies, SBMs can be appropriate instruments to bridge the many gaps that SFs face in accessing required products and services. The lack of SFs' access to information, capital, training, logistics, and market linkages affects the whole agricultural value chain. By exploring 10 cases of SBMs, we have identified several strategies that providers apply to make products and services accessible, affordable, profitable, and sustainable to/for farmers. These strategies range from leveraging on public subsidies and new channels of (digital) information to complex multi-stakeholder business ecosystems.

Using these cases and strategies, we observed the opportunities ahead for the BP as a product and for aQysta (and other similar companies) as a business. The pump can leverage on the robustness of long-standing actors to transmit timely information about its benefits. Due to its comparatively high cost, coupling the pump with access to (micro)financial services to achieve affordability is recommendable. Training on commissioning and servicing the BP can be achieved through existing intermediate actors closer to SFs. Proper supply of parts and knowledge to sustain the use of the pump can build on existing logistics and market-standard components. To ensure better SFs' connection to markets, the BP as a product may need to become one of the components of a more robust SBM.

The lessons from the cross-case analysis can be connected to other products and services intended to reach SFs. We have elaborated on the implications that the strategies may have in the BMs of other companies engaging with SFs. These companies must consider several business strategies in pursuing the threefold enhancement of their SBM's value proposition. More research on innovations in SBMs is necessary to measure the impact that the implementation of strategies may have in improving the livelihoods of SFs, while promoting environmental protection, and ensuring long-term financial profitability of product/service providers.

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Supporting information

Additional supporting information can be found online in the Supporting Information section at the end of this article (https://doi.org/10.1002/bsd2.271).

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Chapter 7
Discussion and Conclusions

In this concluding chapter, I discuss and reflect on the outcomes of the chapters that make this dissertation. First, it includes a summary of findings from the literature and field studies (chapter 2 – 6), as well as a proposal of SBM strategies based on the SFs' discourses on BP adoption as identified in Chapter 5 and the cross-case analyses of different SBM models from Chapter 6. Second, it discusses the implications of those findings for several actors (i.e., researchers, technology developers, practitioners, and policymakers).

7.1 Summary of findings

The overarching goal of my doctoral research was to identify SBM strategies to stimulate the adoption of hydro-powered pumps for SF irrigation. With the multidimensional challenges that SF face, SBM strategies must play a critical role in helping SF adopt new technologies and practices. Adequate SBM strategies can deal with SFs' financial constraints, lack of information and knowledge, risk aversion, and weak supply chains, among others. When investigating the role of SBMs in SF's uplift, it became evident that this is still an incipient research area, particularly when focusing on potential SBM strategies.

The main research question of this thesis was: What sustainable business model strategies stimulate the adoption of hydro-powered pumps for smallholder irrigation? To answer this question, I conducted several studies using a mixed-method approach (i.e., literature review, Q methodology, semi-structured interviews, field observations, cross-cultural research approach, qualitative multi-case comparative approach). In Chapter 2, I presented the contextual conditions of success (or failure) of hydro-powered pumping technologies developed over time. Chapter 3 explored Q methodology as a suitable technique to understand the viewpoints of rural communities in low-income countries. Chapter 4 engaged with Q methodology to reveal farmers' decision making on the adoption of water pumps for irrigation. In Chapter 5, by means of Q methodology, I focused specifically on understanding the SF's discourses of idealized farmers on the adoption of the BP. Lastly, building on the previous chapters, Chapter 6 presented SBM strategies that can stimulate the uptake of agricultural goods and services (including the BP) by enriching the companies' value propositions to SFs. Answering the SRQs, **Table 7.1** presents the summary of findings per study and chapter. I conclude this dissertation by offering a set of SBM strategies that can cater better for the needs of the idealized farmers represented in the discourses on the adoption of the BP (**Table 7.2**).

7.2 Implications for different stakeholders

Throughout my doctoral research I closely observed the relationships between aQysta, the BP, and its target SFs in different contexts. These observations became the main basis of the findings, conclusions, and implications presented in this dissertation. Nonetheless, supported by my current position as Innovation Manager at IDH Intelligence (FarmFit Intelligence, 2023a; IDH, 2023a) that started in mid-2022, I enriched my knowledge of the interactions that occur between companies, innovations, and SFs. Through this experience I have come in close contact with commercial engagements between small- and medium-size agribusinesses and SFs in Sub-Saharan Africa (particularly in Uganda, Nigeria, Tanzania, Kenya, and Ghana). I have also gained a deeper understanding on the role that SBM innovations play in making that commercial engagement more socially inclusive, economically impactful, and environmentally sustainable. Examples of these innovations are commissioned-based agent networks in Uganda to deliver SF services (FarmFit Intelligence, 2023b, 2023c), mobile aggregation centers to source grains from SFs in Kenya (FarmFit Intelligence, 2023d; IDH Transforming Markets, 2022), and block farms of SFs to promote sustainable value chains of cassava and rice in Nigeria (Fabusoro and Ogundijo, 2020; FarmFit Intelligence, 2023e). Strengthened by this broader knowledge acquired after my doctoral research, below I elaborate on the implications of my findings for stakeholders involved in SBM innovations for SFs.

7.2.1 Researchers

Researchers should consider participatory research approaches, such as farmer-centered or co-design methodologies (e.g., Q methodology used in this work to study the implementation of the BP). These approaches require actively involving SFs in the research process, including problem identification, technology design, and evaluation. By working closely with farmers, researchers can gain a much deeper understanding of their needs, preferences, and priorities. This type of research may be complemented with other participatory techniques, such as focus group discussions and workshops, which provide spaces for interactive discussion and sharing experiences among SFs. Such participatory approaches are certainly time-consuming as it was my experience with the deployment of Q methodology. However, an accurate representation of voices is indispensable in the pursuit of a faithful depiction of SF challenges and opportunities. Adequate planning and resource allocation in the research design phase is therefore of utmost importance prior to engaging SFs in the field.

Table 7.1. Summary of findings per chapter.

Chapter and SRQ	Main findings
Chapter 2: What hydro-powered water pumping technologies were used over time?	• Hydro-powered pumps are not the main RET technologies for agricultural irrigation, yet have regained momentum among technology developers and researchers in the last two decades. • The most used hydro-powered pumps for agricultural irrigation are generic integrations of off-the-shelf prime movers and pumping devices. In addition, hydraulic ram pumps and spiral pumps (like the BP) keep attracting the interest of manufacturers and researchers. • Factors that stimulate the uptake of hydro-powered pumping are: a) the pursue of low-cost and robust small-scale RETs, b) harnessing small-scale hydropower as an untapped source of renewable energy, c) the availability of new manufacturing design and manufacturing methods, as it has occurred with the BP. • Main barriers that hydro-powered pumps encounter are: a) site-specific technical limitations, b) high upfront costs of devices and/or additional infrastructure, c) weak supply chains for spare parts and servicing, d) mismanagement of after-sales services.
Chapter 3: Which participatory research method is suitable to study the viewpoints of smallholder farmers?	• Q methodology is an appropriate participatory technique to study the dynamics of rural communities in the Global South in general, and those of SF communities in particular. • As a time- and facilitation-intensive technique, its implementation in low-resource, rural settings brings a number of methodological challenges. These are related to physical, logistical, social and cultural constraints that need to be considered. • At the same time, several studies report good practices in the implementation of Q methodology that help overcoming the identified challenges.
Chapter 4: How does Q methodology support the understanding of farmers' decision-making?	• Farmers' decision making is more complex than typical segmentations (i.e., SF, commercial farmer) suggest. • The decision to adopt (or not) certain water pumping technology for irrigation depends on many more intertwined variables than just land size. • Land size is an inadequate proxy to tailor agricultural policies and strategies (e.g., development interventions, agricultural extension). • Farmers' decision-making has a gender dimension, whereby women farmers may prioritize time-saving technologies. • Q methodology proved a valuable participatory technique to reveal nuances of the decision-making process that might otherwise be overlooked.
Chapter 5:	• By means of Q methodology I found three unique factors (one bipolar) that reflect how diverse SFs would prefer the delivery

Chapter and SRQ	Main findings
What are the discourses of smallholder farmers on the adoption of the Barsha pump?	of the BP. • Factor 1 (F1) prioritizes cost-less irrigation water to improve livelihoods. Factor 2 (F2) aims for an easy-to-operate device in remote settings. Positive Factor 3 (F3+) seeks the availability of irrigation water alongside a bundle of other goods and services. Negative Factor 3 (F3-) focuses on the comparative advantages of an innovative water pump. • The adoption of the BP cannot be predicted by variables usually addressed in literature on agricultural technology adoption (e.g., gender, age, education, land tenure), and not even by social constructs like community or country. • Whereas a one-size-fits-all strategy of technology delivery for a single 'SF' category is ineffective, it would be impossible to provide infinite solutions to cater for every set of individual needs. Nonetheless, the identified discourses become a north star to the design of business pathways and strategies.
Chapter 6: What sustainable business model strategies offer higher value propositions to smallholder farmers?	• To enrich the value proposition to SFs, companies typically engage with more complex business ecosystems: more actors and partners, more goods and services. • To provide SFs with access to information and knowledge companies have a wide array of strategies, including: traditional information channels, direct branding, social media platforms, local networks, and intermediate service providers. At times these are complemented with demonstration events. • To provide access to capital and financial services, usual strategies are contracts involving guarantee schemes, forward contracting, and warehouse receipt financing. Some products and services are offered on (micro)credit or supported on subsidies, and may involve tri-partite (micro) financing. Some other goods and services are offered on demand, or after harvesting the agricultural produce. • Training and capacity building is offered directly by some companies with their own staff. Other companies upskill intermediary actors to cascade down the knowledge, thereby engaging in training-of-trainer schemes. Another set of companies may opt to use platforms, applications, and videos to offer asynchronous training. • To strengthen rural logistics and supply chains, some providers may operate through national and local distributors, as opposed to using their own staff. Other organizations rely on a wide structure of branches throughout the area of operations. Another group resorts to building capacities of already existing local retailers at village level. • To provide SFs with connection to markets, some companies may work with forward contracts that establish target produce volumes. Other organizations also connect SFs with premium buyers who require certain premium qualities; these also provide SFs with the required skills and training to reach those qualities. Some other companies may offer information about prices and buyers through their own platforms.

Table 7.2. Proposed SBM strategies linked to each SFs' discourses on the adoption of the BP.

	F1	F2	F3+	F3-
Information and knowledge	-Delivery of information through intermediate service providers -Delivered information should emphasize the benefits of the BP in saving labor, possibly with on-site demonstrations	-Delivered information should strongly emphasize the benefits of the BP over other available water pumping technologies -The BP should be demonstrated, and tried if possible, to showcase those benefits. Ideally, lead farmers and early adopters should provide access to this knowledge -The BP should be enriched with value-adding products and services (e.g., inputs, irrigation infrastructure)	-The information provided should go on irrigation services and not on the BP as a product -The irrigation service provider should be the actor delivering this information to SFs. It can be done directly through own staff, or by the mediation of well-trained intermediate actors at village-level	-Information on the BP can be offered directly through traditional information channels -Provided information should go around the BP and some farming technical assistance, but no about extra goods and services -The SF from this factor may act as early adopter that may help informing other SFs in their communities
Capital and financial services	-The BP should be delivered through subsidies, (micro)credits, and/or on a pay-as-you-go basis to reduce its financial burden	-The BP should be delivered through on-credit schemes whereby SF's pay for it over time after produce aggregation periods. Subsidies can support this process	-Since this factor might be reluctant to incur additional expenses that enrich the BP, a bundle of products of services should be financed through other means than mere upfront payments. Pay-per-use, on-credit, and (micro)loans may support these process	-Due to the better financial position of this factor, financial services is optional
Training and capacity building	-The intermediate service providers should train and empower SFs on the BP's installation and servicing	-The capacity building must focus on how to grow better with the BP, not on how to use the BP. As such, the BP would work under a irrigation service scheme	-Training should be offered by well-trained intermediate actors -Trainings ideally should involve demonstration plots, through which SFs can see by themselves the advantages of the BP	-Training is not a key element for this factor. The typology of this SF prefers to pay for commissioning and servicing the BP as required

	F1	F2	F3+	F3-
Rural logistics and supply chains	-The intermediate service providers should close the last-mile delivery gap, including availability of spare parts and (advanced) servicing	-It is crucial to strengthen supply chains to sustain the operation and competitiveness of the BP over time. This can be achieved through intermediate providers, local entrepreneurs, village agents, and/or own branches of the company	-Supply chains must be strengthened through local entrepreneurs at village level to provide required parts and servicing. However, to project confidence to SFs, these actors must be ideally backed up by the prestigious image of a solid company	-Servicing and spare parts must be ensured, either through own staff or intermediate local actors
Connection to markets	-Provision of the BP should go along produce off-take to prove its benefit. This off-take can be done through partnerships with agro-processors and/or through the intermediate providers (acting as last-mile agent network) -Partnering with the intermediate service providers (e.g., villages entrepreneurs) would boost local economies	-Forward contracts (either from aQysta or from third parties) should be provided to the SFs alongside the BP. Otherwise, as a standing-alone technology, it would not compete against other water pumps in consolidated agricultural areas	-The bundle of goods and services offered alongside the BP to SFs should include off-taking and aggregation services (either through forward contracts or aggregation through third parties). Given that this factor does not perceive much comparative value from the BP, enriching its offer by market connections is a key element	-Given the financial independence of this factor, market connection can be considered a secondary service that might (not) be considered

SF is a label that typically encompasses subsistence and/or non-commercial farmers in the Global South. However, their diversity, heterogeneity and complexity go beyond a label and farmland size (i.e., the typical threshold of farming under 2 Ha), and frequently even beyond social constructs like countries or regions. Through my professional experience, I have learned how companies segment their SFs based on different characteristics relevant to their engagement (e.g., farm size, services received, type of contracting, crops cultivated, geographical scope). In this respect, researchers studying the heterogeneity of SF systems should engage in in-depth field observations that include daily activities, intra-household decision-making, agricultural practices, and water and energy usage patterns. Ethnographic studies allow researchers to immerse themselves in the SFs' contexts, understand their cultural and social dynamics, and gain insights into their needs and preferences regarding adoption of agricultural innovations in general, and RETs in particular. The outcomes of such studies will inform other actors better about the diversity SFs and their preferences.

To produce actionable insights that can be taken up and tested in different contexts (e.g., new interventions and innovations in the SBMs), researchers must focus on time-efficient methods and tools to collect and analyze data. Q methodology proved an interesting technique to capture the nuances of groups regarding specific topics; however, its time-consuming nature makes it less attractive for research designs requiring several touchpoints over time with the research subjects. In response to this need, and as a part of a short-term project next to this doctoral dissertation, we prepared a minimum viable product called "Renewable Energy for Smallholder Irrigation: A Technology Adoption Toolkit" (Belting et al., 2021), provided as an annex of this chapter. This toolkit aims to provide a semi-structured space for discussion between stakeholders involved in the deployment and adoption of RE-powered water pumps. During my professional practice I have observed that some companies resort to dedicated farm information management systems [see (Henriyadi et al., 2022; IDH and Intellecap, 2020) as reference] to collect data, generate aggregated analyses, and make data-driven decisions tailored to the needs of their SFs.

Researchers should establish an active engagement and feedback loop with SFs and other relevant stakeholders (e.g., technology developers, practitioners, policymakers) throughout the research process. These more frequent touchpoints must involve scholars of the respective studied regions. The engagement may include regular communication, follow-up visits, and iterative co-design of interventions. By incorporating SFs' feedback more actively, researchers can ensure that the developed SBMs and technologies align better with the farmers' context, needs, and preferences. Furthermore, the feedback loop, especially towards the research subjects, becomes also a much more ethical response to the traditional extractive research approach (i.e., outsiders gathering data from the communities and never returning results afterwards). In this respect, I must acknowledge that I fell short in delivering my research findings to SFs and many other actors who contributed to it. Although the dissemination of results to SFs was considered in the initial planning, the consequences of the COVID-19 pandemic that stretched until 2022 prevented me from reaching that desired stage of co-creation. Therefore, the stakeholder engagement was limited to occasional online interactions and sharing of scientific publications.

Researchers should conduct comprehensive techno-economic assessments of agricultural innovations in the context of SFs. This involves evaluating the costs, benefits, and potential returns on investment associated with different technology choices. These assessments can help identify economically viable solutions and provide insights into the financial feasibility of deploying certain technologies in SF systems. Researchers should assess the environmental and socio-economic impacts of implementing certain technologies of interest in SF contexts. This includes evaluating the potential reduction in greenhouse gas emissions, the impact on local ecosystems, the creation of employment opportunities, and the overall socio-economic benefits for SFs. Such assessments can guide the development of SBMs that align with broader sustainability goals. At IDH, for example, the Business Analytics group (formerly Service Delivery Model group) focuses on studying the economic performance, expected returns of investments, impact case on SFs, environmental performance, among other business aspects, of certain innovations under a range of scenarios (IDH, 2023b). These business model analyses have guided several companies in their investments. In some cases, these analyses have even helped agribusinesses in securing impact funds to transition to SBMs.

Having transitioned from my doctoral research to my current position, I observed a substantial gap between academic production and the actual commercial engagements with SFs. By working with different agribusinesses, I have experienced a much more solid and dynamic interaction between companies, their SBMs, and SFs. These companies are implementing a wide range of innovations to make their businesses more sustainable, inclusive, empowering, and impactful. However, this kind of commercial undertaking seems to be overlooked and/or underreported by researchers. In this sense, researchers interested in SF systems can focus their efforts on studying and learning from those business experiences as a vehicle for development in the agricultural sector of the Global South.

7.2.2 Technology developers

Developers need to focus on tailoring and adapting their technologies (e.g., RE-powered water pumps) to suit the specific site requirements, small scale, and limitations typical of SF contexts (e.g., small-scale irrigation at affordable costs). This involves designing innovations that are suitable for and easy to operate in remote or resource-constrained areas. In this respect, in accordance with my findings, aQysta designed the BP as a small-scale irrigation device. However, its main drawback is that its transportability was limited by its size and weight (especially if compared to equivalent solar- and diesel-pumps). Agribusinesses related to my professional practice also find difficulties in offering certain technological choices to their SFs in some regions. Due to the unprofitable scale of their farmers, some companies refrained from investing in agricultural machinery and value-adding post-harvest equipment. A company in Uganda, for example, dropped the plan of investing in tractors for land preparation because the operational costs would be unaffordable to its SFs. As a result of this constraint, SFs must keep preparing their fields with conventional human labor. The same company offers some post-harvest services to its farmers in a semi-centralized scheme. The equipment is deployed in satellite storage facilities, but the farmers still need to transport their produce to access this service. These examples illustrate the outstanding gap between the small scale of SFs and the expected operational scale through which agricultural technologies are designed.

Technology developers should prioritize the affordability and accessibility of their technologies intended to serve SFs. This may involve producing low-cost designs or exploring innovative financing models such as pay-as-you-go systems, microfinance, leasing, or tri-partite financing options. Ensuring affordability and accessibility enables more farmers to adopt technologies, leading to broader market penetration of the innovations. The deployment of the BP in Indonesia posed an interesting example of these mechanisms. Through a pay-as-you-go scheme, SFs could access the technology at affordable rates. Such a system, unfortunately, was not the main value capture strategy of aQysta, and hence was not implemented throughout other contexts of use. Other interesting cases of innovative financing for technologies for SFs in Nigeria are the ubiquitous point-of-sale network and the emergence of fintech companies. These actors bring several low-cost financial services to SFs in their own communities, circumventing the strict requirements of traditional formal banks. Leveraging on these systems, some Nigerian companies (linked to my professional portfolio) bring a range of affordable technological options to their SFs (e.g., harvesters, tractors, sprayers, irrigation).

SFs often operate in challenging environments with limited infrastructure and fluctuating environmental conditions. Therefore, technology developers must ensure that their products are reliable and robust, capable of withstanding harsh environmental conditions and frequent power fluctuations and/or unavailability. Developing technologies that require minimal or basic maintenance and can function efficiently under diverse circumstances is crucial for long-term viability. In addition, technology developers should invest in training and capacity-building initiatives to empower SFs on their agricultural technologies. This includes providing training programs, workshops, and user manuals and procedures to ensure SFs have the necessary knowledge and skills to effectively utilize the technologies. Building the capacity of farmers strengthens their ownership over adopted technologies and enhances the financial sustainability of the business structures. Several companies I have observed through my professional practice offer training programs to their SFs and other relevant actors (e.g., community-based agents, community champions, lead farmers). Part of those training programs focus on increasing digital literacy, managing digital devices platforms, and the use of certain agricultural equipment. Although this represents costs for the companies, it ensures a more adequate uptake of technologies that can directly influence the turnover of the business.

Developers should consider integrating their technologies with existing agricultural equipment and practices. For example, coupling water pumps with irrigation infrastructure, or coupling RETs with post-harvest processing facilities can enhance the overall productivity and efficiency of SFs. This integration enables SFs to adopt technologies more easily and derive maximum benefits from the proposed technologies. Moreover, developers should aim for scalability and replicability of their solutions across different SF contexts. This involves designing technologies that can be easily adapted and deployed in various regions and communities. Standardization, modular design, and streamlined installation processes can facilitate the scaling up and replication of technologies, ultimately favoring SF adoption and margins generation. Additionally, technology developers need to stay abreast of technological advancements and continuously innovate to improve the performance, efficiency, and affordability of their technologies. A key pitfall of the scalability of the BP is its hydraulic principle. Its spiral pipes cannot be simply enlarged nor multiplied to increase its pressure or flowrate. Engaging in such a design will turn the pump too heavy to rotate at an adequate speed, decreasing the required pressure, and too burdensome to be moved and placed around. In contrast, technologies like solar pumps are much more modular and scalable. PV panels can be added or removed as per the energy requirements. Off-the-shelf water pumps of different sizes can be integrated according to the pumping needs and site conditions. They can operate under a much broader range of surface and underground water bodies. This flexibility will enable a business to diversify its SF target customers without having to reinvest in new expertise.

7.2.3 Practitioners

Practitioners, including NGOs, farming cooperatives, and SFs' providers, should adopt market-based approaches to deliver products and services to SFs. This involves developing SBMs that consider market dynamics, pricing mechanisms, and revenue generation strategies. By leveraging market-based approaches, practitioners can catalyze viable and self-sustaining systems that provide affordable and accessible products and services to SFs. As an example, from my observations on the BP, the delivery model applied in Indonesia allowed SFs to benefit from affordable irrigation while providing a guaranteed local market for their produce. In contrast, Nepali SFs struggled in dealing with unaffordable upfront costs of the BP, next to the uncertainty of marketing (or not) their crops. In this respect, practitioners should explore innovative financing models to overcome the financial barriers typically faced by SFs. This includes pay-as-you-go models, tri-partite financing, microfinance, or cooperative financing. By operating through flexible and affordable payment options, practitioners can enable SFs to access and benefit from several agricultural innovations without incurring significant upfront costs. Within my professional experience, I have seen companies offering several financing options: agreements with banks, partnerships with fintechs, in-kind repayment of loans at harvest time, long-term repayment of land clearing, among others.

Practitioners are usually responsible for the distribution and deployment of agricultural innovations. They should establish efficient supply chains, ensure the availability of high-quality components, and offer installation and maintenance services tailored to the specific needs of SFs. Reliable distribution networks and skilled servicing teams contribute to the successful implementation of SBMs and their related products and services. As I have shown in my findings, this aspect proved to be an unsurmountable challenge for the BP in both Nepal and Indonesia. The lack of robust supply chains and timely servicing led to many after-sale problems that limited the diffusion of this technology across their contexts of use. It is worth remarking, however, that the efficiency of the supply chains is largely contingent on the condition of the current infrastructure, which is generally out of the practitioners' control and falls already in policymakers' domains. Nonetheless, through the implementation of adequate SBM strategies, practitioners should provide SFs with training programs, technical assistance, and after-sales services on the implemented technologies. By building the SFs' capacity to operate and maintain the technologies, practitioners enhance the longevity and effectiveness of the provided technologies. Implementing companies related to my current professional practice typically offer extensive and multifaceted training to their SFs. Through their capacity building programs, these companies ensure that the offered innovations (whether technologies or practices) and services can be effectively internalized and sustained over time. Depending on the farming system and business strategy, other companies opt to partner with technology providers to ensure that longevity. For instance, Nigerian rice processors operating block farms take advantage of economies of scale to close long-term leasing agreements with providers of agricultural machinery to serve their SFs.

Active engagement and involvement of SFs should accompany the practitioners' technological deployment. This can include tailored consultation, conducting needs assessments, and involving SFs in co-designing solutions. SF participation fosters a sense of ownership and ensures that the technologies align with their local context, preferences, and specific needs. This engagement should also inform practitioners on the additional value-adding products and services that enrich their value propositions to SFs. In contrast, the BP became a technology envisioned, designed, and produced in the Netherlands, too distant a setting—socially, economically, and geographically—to the SF's expected contexts of use. This multidimensional detachment ultimately placed the BP in a seemingly uncomfortable position regarding its target SFs. Taking a different approach, some companies from my professional portfolio focus on keeping a close and strong relationship with their SFs. The strategies that each of these companies apply are largely tailored to the farming systems and contextual conditions of their commercial engagements. These strategies include networks of community-based agents; training-of-trainers approaches; formal farmer groups that cascade goods, services, and information; and community champions that liaise with SFs on the field.

Finally, practitioners should establish monitoring and evaluation mechanisms to assess the impact and effectiveness of their SBMs. This involves tracking productivity gains, economic outcomes, and environmental benefits resulting from the adoption of the provided agricultural technologies and innovations. Monitoring and evaluation data helps practitioners generate intelligence and make informed decisions, refine their approaches, and demonstrate the value of their interventions. However, small and medium enterprises focused on SFs, however, may face a severe lack of in-house expertise for monitoring and evaluation purposes. Mainly focused on selling BPs, aQysta barely collected and processed any customer data that supports its after-sale interventions. In addition, despite their efforts, companies related to my current professional position typically find difficulties in implementing monitoring and evaluation systems in their work. These difficulties are related to underfunding, lack of qualified staff, and unaffordable management information systems, among others.

7.2.4 Policymakers

Policymakers must establish supportive policy frameworks that incentivize and facilitate the deployment of agricultural technologies suitable for SF contexts. This includes developing adoption targets, providing financial incentives (e.g., subsidies or tax benefits), and streamlining regulatory processes to reduce barriers to entry of innovations. Supportive policies have the potential to create an enabling environment that encourages investment, innovation, and market development. Policymakers also must establish clear and consistent regulatory frameworks that govern the deployment of technologies in SF agriculture. These frameworks should address areas such as pricing, quality standards, and environmental sustainability. Clear regulations provide certainty for investors and technology developers, facilitating the deployment of SBMs and the expansion of the technologies among SFs. My experience throughout both my doctoral research and the IDH Intelligence portfolio, indicates that unfortunately this is not usually the case. Agribusinesses and technology developers aiming to engage SFs have to deal with typically discouraging policy environments. Some of the challenges in this respect include trade and importing barriers, volatile national currencies, lack of research and development funds, and unclear and unharmonized regional standards.

Policymakers should invest in public extension programs aiming at knowledge dissemination, education, and capacity building. Such programs must prioritize the enhancement of knowledge and skills of SFs and other actors involved in SF systems. These extension programs should complement (and not overlap or compete) with the capacity building offered by private actors. However, public extension programs are usually insufficient for effective and more profitable commercial engagements with SFs. In my current professional practice, I have observed companies that have to invest (most of the time without generating margins) to train and capacitate their farmers to compensate for deficient public capacity building interventions. Policymakers can foster public-private partnerships to leverage resources, expertise, and infrastructure for the deployment of technologies in SF agriculture. By promoting complex business ecosystems, collaboration between the public and private sectors enables knowledge sharing, technological innovation, and market development for SFs. These partnerships can also enhance the financial viability and scalability of SBMs. Nevertheless, similarly to the shortfall in extension, effective public-private partnerships are yet to be fully realized in many geographies of the Global South.

Policymakers have the potential to engage in international cooperation and regional integration efforts. Through these engagements, policymakers may facilitate accessing international funding, technical expertise, and best agricultural practices relevant to their respective SF contexts. Collaboration with international partners allows policymakers to learn from successful experiences with agricultural technologies in other regions, access global knowledge networks, and leverage resources for the development and implementation of SBMs in their respective countries and/or regions. Different regional integration efforts exist in the Global South. Examples of these efforts are the South Asian Association for Regional Cooperation, the Association of Southeast Asian Nations, the East African Community, the Southern African Development Community. However, a main issue is the seeming disconnection between the political agenda and priorities of these international communities, and the unmet needs of the private sector in fulfilling robust commercial engagements with their SFs.

Finally, adequate policies can allocate funding for research and development initiatives focused on SF-sensitive technologies. By supporting research efforts, policymakers enable the generation of knowledge, technological advancements, and evidence-based policy recommendations. Research funding helps bridge the gap between academia and practical applications, contributing to the development of SBMs to serve SFs. Nevertheless, a substantial fraction of that funding keeps flowing from high-income economies towards the Global South in the form of development aid and Global North – South cooperation programs. This approach unavoidably leads to responding to the agendas of the funders, potentially creating a dissociation with the priorities of the countries of implementation. Research and impact investments should ideally be made and managed in the local and regional contexts, so the interventions will be more sensitive to the aspirations of local researchers, businesses, and SFs.

Appendix

The appendix of this chapter corresponds to the conference article titled 'Renewable Energy for Smallholder Irrigation: A Technology Adoption Toolkit'. This article has been peer reviewed and published open access in MDPI Environmental Sciences Proceedings under Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/) as:

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List of tables

Table 1.1. List of chapters, SRQs, and used research methods 13
Table 2.1. Summary of HPP technologies 36
Table 2.2. Top-five ranking of countries 56
Table 3.1. Data extracted from the 50 selected studies 86
Table 3.2. Characteristics of sorting grids 112
Table 3.3. Summary of discussed challenges 124
Table 4.1. Features of the sorting grid 151
Table 4.2. Total collected sorts 153
Table 4.3. Factor retention criteria, description, and results 154
Table 4.4. Factors characteristics 155
Table 4.5. Raw factor scores 155
Table 4.6. A brief summary of the four factors 157
Table 4.7. Overview of the factors' composition 162
Table 4.8. Gender distribution across the four factors 163
Table 5.1. Features of the sorting grid 181
Table 5.2. Characteristics of selected farming communities 186
Table 5.3. Characteristics of sampled SF P-set 188
Table 5.4. Characteristics of sampled NF P-set 189
Table 5.5. Factor retention criteria, description and results 190
Table 5.6. Factors characteristics 191
Table 5.7. Raw factor scores 192
Table 5.8. Suggested pathways to provide the BP 205
Table 6.1. Selected case studies and details of collected data 230
Table 6.2. Overview of business model structure of cases 233
Table 7.1. Summary of findings per chapter 261
Table 7.2. Proposed SBM strategies 263

List of figures

Figure 1.1. Schematic representation of the deployment and adoption of technologies among smallholder farmers 2
Figure 2.1. Classification of HPP technologies 35
Figure 2.2. Different types of manometric pumps 39
Figure 2.3. Different types of hydro-pneumatic water lifters 40
Figure 2.4. Different types of hybrid turbine-pumps 41
Figure 2.5. Different types of water turbine-pumps 43
Figure 2.6. Different types of tubular multi-propeller turbines 44
Figure 2.7. Different types of water current turbines 45
Figure 2.8. Different types of generic integrations of HPPs 47
Figure 2.9. Other HPP devices 48
Figure 2.10. Number of selected documents 49
Figure 2.11. Cumulative number of selected documents 51
Figure 2.12. Noncumulative number of selected documents 52
Figure 2.13. Worldwide mapping of HPP technologies per country 54
Figure 2.14. Worldwide mapping of predominant HPP technologies 55
Figure 2.15. Number of reported cases of HPP technologies 58
Figure 3.1. Stages and steps of Q 82
Figure 3.2. Characteristics of the selected studies 98
Figure 3.3. Geographic location of main authors' affiliations 100
Figure 3.4. Characteristics of the concourse 102
Figure 3.5. Characteristics of research design 105
Figure 3.6. P-set size and genders 109
Figure 3.7. Sorting grids of the selected studies 110
Figure 3.8. Sorting times across the selected studies 117
Figure 3.9. Characteristics of Q analysis and interpretation 120
Figure 4.1. Q maps of (A) three-factor and (B) four-factor solutions 158
Figure 5.1. The Barsha Pump 185
Figure 5.2. Geographical locations of study sites 187
Figure 5.3. Q maps 191
Figure 5.4. Cumulative distribution of respondents 196
Figure 5.5. Noncumulative distribution of respondents 197
Figure 6.1. The Barsha pump 222
Figure 6.2. Structure of the sustainable model canvas 226
Figure 6.3. Conceptual classification of case studies 232

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About the author

Juan Carlo (or JC, in short) was born in 1983 in Portoviejo, capital of the coastal province of Manabí (Ecuador). His parents, Zayda and Bienvenido, never hesitated to invest in his education as much as a middle-class Ecuadorian household allowed during the late 1980s – 2000s. During his primary and secondary schooling, JC became increasingly passionate about learning and expanding his knowledge.

In 2006, JC obtained his BArch degree from *Universidad San Gregorio de Portoviejo* with the highest distinction. He then worked three years in private architectural practices, four years in the Ministry of Environment of Ecuador, and one year in a transnational Brazilian construction company. By late 2014, JC was struggling with unemployment, mostly owing to seemingly divorced disciplines in his background: architecture and environmental management. As JC was dealing with alarmingly dwindling savings and an unpromising job future, he took one of the best decisions of his life: applying for a scholarship from the Ecuadorian government to study a MSc abroad. That became a relief valve for an unsustainable professional and financial situation.

'Abroad' initially meant Sweden for JC. In a turn of events, it eventually became the Netherlands. Aiming to bridge the gap in his background, in 2015 JC pursued a MSc degree in Urban Environmental Management at Wageningen University. He successfully graduated *cum laude* in 2017. Instead of bridging the gap, the MSc introduced JC to a whole new world of academic and professional interests. These included renewable energy technologies, smallholder farming, and use of nonconventional water resources in agriculture.

After a seven-month interval back in Portoviejo –and fugacious work periods in two public institutions– JC made it once again to the Netherlands. Having received a fellowship from TU Delft | Global Initiative, in 2018 he embarked on a PhD in Water Management at Delft University of Technology. During quite an enjoyable (and hopefully fruitful) doctoral journey, JC travelled to wonderful places, met fantastic people, went lost in translation, read a big deal of many topics, discovered new personal and professional interests, made a thousand mistakes, got married in a frugal ceremony, survived a global pandemic, went through deep sorrow moments, found a wonderful job, grew myriad of white hairs, and perhaps –*only perhaps*– became a little bit wiser.

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