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Potential and Pitfalls of Frugal Innovation in the Water Sector: Insights from Tanzania to Global Value Chains

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Abstract: Water is perhaps the most intertwined, and basic, resource on our planet. Nevertheless, billions face water-related challenges, varying from lack of water and sanitation services to hindrances on livelihoods and socio-economic activities. The Sustainable Development Goals (SDGs) recognize the broad role that water has for development, and also call for the private sector to participate in solving these numerous development challenges. This study looks into the potential of frugal innovations as a means for the private sector to engage in water-related development challenges. Our findings, based on a case study and literature review, indicate that frugal innovations have potential in this front due to their focus on affordable, no-frills solutions. However, we also recognize pitfalls related to frugal innovations in the water sector. Although the innovations would, in principle, be sustainable, deficiencies related to scale and institutional structures may emerge. These deficiencies are linked to the importance of water in a variety of processes, both natural and manmade, as well as to the complexity of global production-consumption value chains. Increasing the innovations' sustainability impact requires broader acknowledgement of the underlying value chains and their diverse links with water. A holistic view on water can mitigate water-related business risks while increasing wellbeing on an individual level.

Keywords: water; frugal innovation; Sustainable Development Goals (SDGs); sustainability; value chain; product development; R&D

1. Introduction

Water is one of the most vital ingredients for human life, health, and wellbeing, as well as for the ecosystems and, thus, a key element for sustainable development. Yet, billions of people face water scarcity; at least 1.8 billion people use fecally-contaminated drinking water sources, 2.4 billion lack access to basic sanitation, and the majority of waste waters are discharged without proper treatment [1]. The essentiality of water and its role in a wide spectrum of activities are easily overlooked when not personally faced with these challenges. For people impacted by the water-related challenges, the implications can be numerous and may seriously hinder development and wellbeing [2,3]. In addition to individuals and the environment, water is a growing concern also for businesses throughout their value chains [4]. In 2015, The World Economic Forum ranked water crises as the number one global risk in terms of impact [5].

New solutions for these vast water challenges are needed. In addition to solving challenges on an individual level, such as access to safe water, there is a need to look further given water's intertwined role in manmade and natural systems. The solutions utilized on one side of the world can create a burden for water resources or water users on the other side of the world through the complex

value chains related to modern-day, globalized production patterns. Thus, demand for solutions, be they existing or new, are required on various levels. On the other hand, global networks and new innovations may help to turn these challenges into opportunities for business and for economic and human development more generally.

The private sector is increasingly called upon to help tackle the key development challenges, as global partnerships are emphasized and business-led solutions and technologies are called upon by the Sustainable Development Goals (SDGs) launched in 2015 [6,7]. Concurrently, circular economy and sustainable production and consumption, included in the SDGs, aim towards sustainable societies, environment, and growth. This brings more emphasis on the sustainability of the entire value chain and related processes, instead of solely the final outcome. In the water sector, this means broadening the view from mere water supply and sanitation (WSS) to broader aspects of water resources use and management.

Frugal innovations have been proposed as a potential approach for serving resource-constrained consumers in emerging and developing markets as well as in the low-growth struck Western markets [8–11] due to their notion of affordability, good (enough) quality, and no-frills structure. The objectives of SDGs resonate with these innovations, and frugal innovations are often seen to be sustainable [9,12–15]. However, existing research has largely focused on the frugal innovation outcomes, i.e., end products, and not rigorously on the sustainability implications throughout value chains.

This article looks at the potentials and pitfalls of frugal innovations as a mean for the private sector to engage and respond to water-related development challenges in a developing country context. Our case study looks at a multinational company's (Ahlstrom) frugal innovation process related to a low-cost water treatment solution in Tanzania. The case study focuses on early phase product and business development, analysing it with the help of the SWOT (strengths, weaknesses, opportunities, and threats) framework. The aim of the article is to understand the potentials and pitfalls that frugal innovations have in relation to water sector and to sustainable development, and to provide recommendations on the ways forward for both companies developing frugal innovations and other organisations (e.g., international development organisations, donors, and legislative bodies) involved in innovation processes.

The analysis is structured in the following manner: first, the water sector and the relevance of water resources for individuals, societies, businesses and development are described, followed by an introduction to the Sustainable Development Goals (SDGs), as well as the concept of frugal innovation. Following this, the three themes are brought into practice by presenting a case study from a development process of a frugal innovation in the water sector in a developing country context. Thereafter, the frugal innovation process case study is analysed with the SWOT framework. The potential pitfalls as well as opportunities for frugal innovation more generally are analysed in the discussion, together with a proposal for the way forward.

2. Materials and Methods

The aim of the literature review and case study is to look at the current status of frugal innovation field and SDGs, particularly in terms of their relation to the water sector. The literature review sets the context for the article, summarizing the pre-eminent approaches and identifying existing gaps in the emerging fields of frugal innovation, sustainable development (with focus on SDGs), and water. The case study provides a practical view for one possible path for frugal innovation development as a means for private sector contribution to water sector development and, more broadly, to sustainable development.

Key literature on frugal innovation, focusing on peer-reviewed articles, and main publications and documentation on the SDGs and the water sector were scrutinized in the literature review. Part of the review of the SDGs and the state of water resources is based on databases and assessments conducted by international organisations, such as the United Nations.

The case study material is based on an experimental product and business development process, which began in the fall of 2015 as a joint effort of Aalto University and Ahlstrom [16]. The case focuses on the development of a frugal water innovation—a new kind of water filter—that aims to reach consumers in the low income context of Tanzania.

The case study builds on an explorative case study research design and its qualitative analysis. Such an approach was chosen for three reasons: due to the relatively vaguely defined concept and development process of frugal innovations; due to the highly explorative nature of the whole project; and due to the complexities arising from the context of a developing country, including unavailability of reliable data [17,18]. The action research tradition is utilized as a framework for the case, as it enables dialogue between the practitioners (case company) and researchers, as well as active involvement of researchers in the product and business model development conducted in the new market area [19].

The research methods utilized within the case study included literature review, meetings and interviews, observations, and key-informant interviews. Households, entrepreneurs, companies, public sector actors, donor organisations, and students were amongst the interviewees during the field research period in Tanzania. Key informants included local people, entrepreneurs, and company representatives, as well as selected officials and experts. Observations were conducted in communities, local homes, and on commercial activities in Tanzania. Workshops with Tanzanian university students were also utilized to gather, structure, and analyse data. Research was conducted by an interdisciplinary research team, guided by the first author. Key points from each interview, meeting, workshop and observation were written down by the research team and compiled at the end of the field research period.

3. Setting the Context: Water, SDGs, and Frugal Innovations

3.1. Water Sector

Water circulates continuously on Earth through the hydrological cycle, which ensures several important services for humankind, ranging from freshwater and food, to ecosystem functions and recreational facilities. The temporal and spatial variability in the cycle are enormous, as are the differences and variations in water quality.

Economic growth combined with growing population, rapid urbanization, industrialisation, and the soaring middle class have translated into a greater demand of goods and services, including basic necessities such as housing, energy, food and water. These drivers also increase the demand for domestic and industrial water, particularly in developing countries [20]. At the same time, one third of the global population (2.3 billion) live under high physical water scarcity (available water resources are insufficient to meet all demand) [21], while another 1.7 billion people live under moderate water scarcity [22]. Further, 1.6 billion live in areas under economic water scarcity (human, institutional, and financial capital limit access to water e.g., due to lack of infrastructure) [23]. By and large these areas are located in Africa and Asia, where the majority of the low and lower middle income countries are also located (Figure 1).

Recent estimates indicate that 4 billion people face severe physical (blue) water scarcity at least one month of the year [24]. For the rural poor in Asia and Africa, increasing water scarcity is also expected to become a limiting factor in food production and livelihoods generation [20]. Due to the interdependencies of water and value chains of various processes in different sectors, water-related challenges are expected to affect various sectors and geographical areas [5,25].

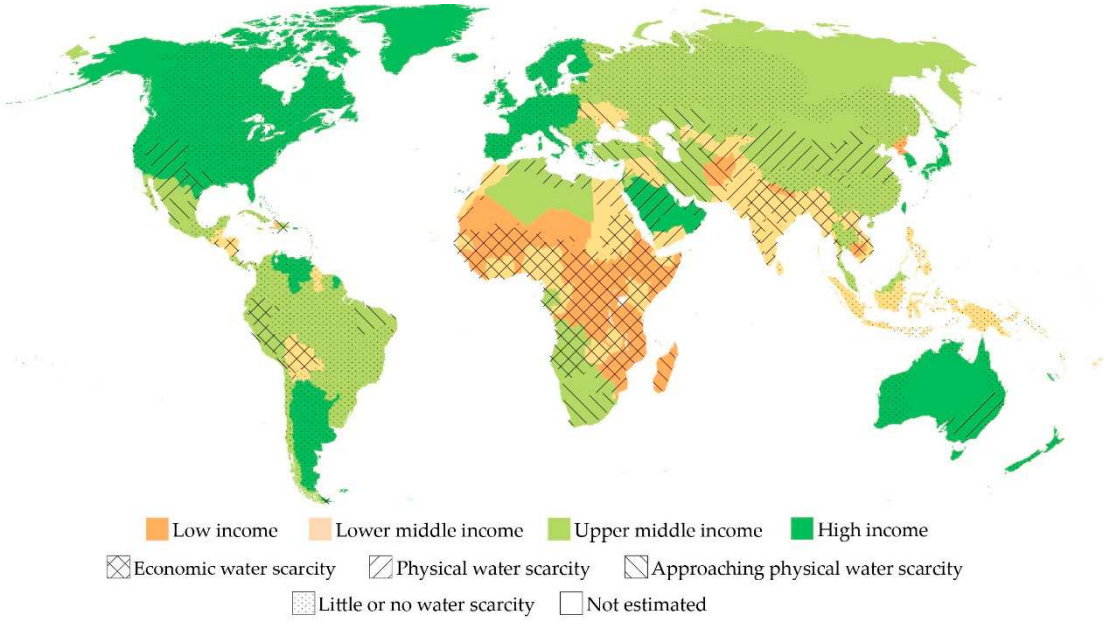

Figure 1. Water scarcity and countries by income class (income data from [26], water scarcity map modified from [23]).

Similarly to the hydrological cycle, water is flowing through the value chains of human-made processes. Water is present and used throughout these value chains, from the extraction of raw materials, to the production and utilization of products and services, and all the way to their disposal or reuse. To illustrate the intertwined nature of water and these activities, the diagram below shows the connections and embeddedness of the hydrological cycle and key value chains (Figure 2).

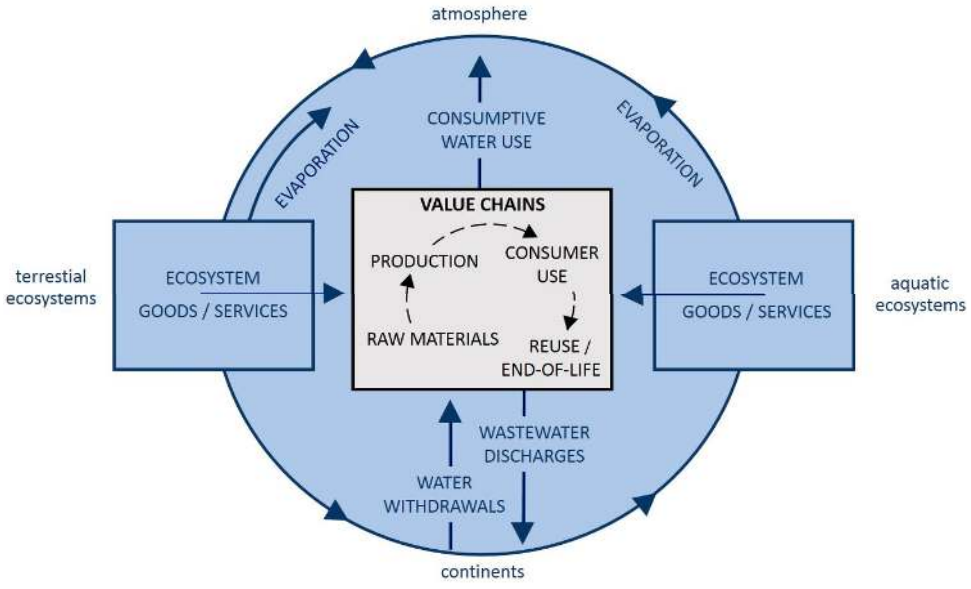

Figure 2. Hydrological cycle (blue areas; modified from [27]) and its linkage to industrial value chains (grey box; adapted from [28,29]).

In terms of social and economic development, the most critical water-intensive value chain is linked to agriculture-based food production. Its impacts to water use are equally critical, with agricultural activities accounting for an estimated 70% of global freshwater withdrawals and 90% of consumptive water use [30]. In addition to actual cultivation of crops for food and feed, water is needed in various

other parts of the value chain as, for instance, agricultural inputs (e.g., seeds and fertilizers), as well as agricultural processing and manufacturing all require large amounts of water. Water is also important in other value chains, with industrial processes and energy generation requiring water for extraction and processing of raw materials, production processes, and finalization of products. Together, these activities make up approximately 20% of global freshwater withdrawals [31,32].

Domestic water use, accounting for approximately 10% of global water withdrawals, typically links most directly to individual's health and wellbeing. To make domestic water available, water needs to be abstracted from surface or ground water supplies, analysed and treated when possible, then distributed and, ideally, collected for treatment before releasing it back to the nature. However, the actual processes differ greatly and, for example, in many parts of Africa, water quality is rarely analytically assessed or appropriately treated [33–35]. There is, thus, a need for industrial processes to e.g., deliver safe water to people, as different equipment and technologies are required. While in many of these activities, water is consumed locally, it is at the same time often flowing virtually around the world through various commodities, playing a key role along the value chains of different sectors and products [36].

3.2. Sustainable Development Goals (SDGs)

The year 2015 was the target year of the Millennium Development Goals (MDGs), as well as the launch of the new Sustainable Development Goals (SDGs). SDGs are set to reach the whole world: governments, private sector, civil society, as well as international organisations; and global partnership is required for their implementation. SDGs aim to respond to global challenges, such as growing resource scarcity, poverty, inequality, population growth, economic and social challenges, as well as environmental and health threats [6].

The SDGs can be seen to not only bring pressure but also novel opportunities for the water sector. When compared to the MDGs, the SDGs take a broader view on water. The SDGs pursue a more integrated approach on water, and recognize water's role and importance beyond water supply and sanitation by taking into account, e.g., water resources management and connections to water-related disasters and ecosystems [37]. Although, water is explicitly mentioned in only one of the goals and in a few SDG targets, it is implicitly included in almost all of the goals due to its interlinked nature and role in various sectors and value chains.

The SDGs also encourage the private sector to join the pursuit for sustainable development, new innovations, and enabling technologies, as well as sustainable production and consumption, together with a circular economy are pleaded for [6]. The greatest demand is in the developing countries, where the public sector is often unable to fully respond to the growing needs of people [38]. Hence, affordable and inclusive water-related technologies and innovations, involvement of private sector, together with an integrated view on water and related value chains, are needed to achieve the SDGs by 2030. At the same time, given the critical role of water for wellbeing and livelihoods, supportive local and global level governance is required to ensure the sustainability of private sector involvement [39,40].

3.3. Frugal Innovations

Recognition of the market potential of resource-constrained consumers and the rising competition over these markets have impelled the discourse of frugal innovations. These innovations have emerged in various sectors varying from healthcare instruments to energy solutions and household appliances, and have raised attention amongst academia, practitioners as well as policy-makers [8–12,14,41,42]. Frugal innovations aim to provide affordable, no-frills, good (enough) quality products and services for resource-constrained consumers [9,10,14,43]. Given that a great majority of frugal innovations are private sector driven, they also serve as one potential entry point for the private sector to engage in promoting (sustainable) development.

These innovations are usually targeted to meet relatively basic needs at a lower cost than their counterparts and, hence, provide high value [8–10]. Multinational corporations (MNCs), as well as smaller companies, have successfully developed frugal innovations and tapped into these low income markets. A shift in mind-sets, strategies, R&D, product development, organisational structures, and business models, are necessitated from the new entrants in the field [8,10,11,14].

Frugal innovations are usually novel solutions, from both market and technology perspective [11]. However, as a rather young concept, the actual implementation of frugal innovation processes is still varied: some of the solutions are developed from scratch, while others are built on existing technologies [8–10]. In both cases, the solutions need to respond to the specific needs in their target environments. Thus, understanding the local circumstances, as well as the requirements, desires and behaviour of end users, are vital for their success [8,10]. Low-cost manufacturing and low-cost of materials and design, combined with simplicity, basic functionality, and minimal feature sets are argued to be prerequisites for achieving affordability and necessary qualities for the solutions [10].

In order to understand and translate local needs into the end products, reach cost goals and gain direct market access, several MNCs—including Tata, Haier, General Electric, Mettler Toledo, and Siemens—have used their local subsidiaries, with varying degrees of autonomy, for the development of frugal innovation applications [8,10,11]. The demands of the resource-constrained consumers are, therefore, spread throughout the value chains of the companies, from raw materials to production and end-of-life, in the quest of affordability and value.

Sustainability of frugal innovations is claimed to arise mainly from no-frills design and simplicity of the frugal solutions, i.e., outcomes [9,12,13]. These qualities of the outcomes are argued to lead to lower resource consumption and, therefore, increased sustainability [9,13,44]. Yet, it is not properly studied whether the entire frugal innovation process, covering value chains from procurement of raw materials to production, distribution and end-of-life, is actually sustainable.

In the water sector, the most well-known frugal innovations have focused on providing safe water to consumers. Tata's Swach and Hindustan Unilever's Pureit are examples of these [42]; both are point-of-use water treatment devices for household use. While these outcomes have potential in enhancing sustainable development, a broader view of the water sector (from WSS to water resources management), makes the contributions for sustainable development a more complex question [42].

4. Case—Development of a Frugal Water Treatment Solution for Low Income Market

4.1. Background—Research and Development Process and Its Outcome

Our case study provides insights to the research and development process of frugal water treatment innovation, which was conducted in collaboration between a multinational corporation, Ahlstrom, and Aalto University. Ahlstrom is a Finland-based, globally-operating business-to-business company producing fiber-based materials for various uses, ranging from filters to medical fabrics and food packaging. The company has around 3300 employees in 22 different countries and its net sales in 2015 were EUR 1.1 billion [45]. The objective of the joint project between Ahlstrom and Aalto University was to develop a new application of an existing high-tech material of Ahlstrom, for a new market area in a developing country context in Tanzania [11].

Sources of water and means for treatment are characterized by diversity and inconsistent quality in Tanzania [16,46,47]. In addition to piped water from water utilities, households get water, for instance, from boreholes, shallow wells, rivers and streams, as well as from a variety of informal water vendors. Household water treatment methods include boiling, filtration through a cloth, purification tablets, and ceramic filters, as well as more sophisticated treatment technologies. As a result, the cost for both water abstraction and treatment also varies greatly. At the same time, there are also several households that do not receive safe water nor treat their water appropriately. In addition, microbial contamination, as well as fluoride and salinity, are amongst the water quality challenges in Tanzania [46,48–50].

A multidisciplinary research team from Aalto University, including graduate students with various backgrounds and led by the first author, was responsible for conducting research and developing the frugal innovation and business model in collaboration with local partners [16]. The team had a high degree of freedom to perform the task, with Ahlstrom holding a largely supportive role, giving access to required data and materials. The project focused on the early phases of product and business model development, and led to the establishment of a prototype. The developed prototype was a water filter that is utilizable at the household level and comes with a replaceable filter cartridge, which utilizes Ahlstrom's technology. Further product and business model development is still continuing at the time of writing, and testing in the focus market is planned to take place in the near future by an external venture, not Ahlstrom itself.

The design parameters for the frugal water treatment innovation, namely the water filter, were determined at the beginning: it had to be frugal, market-based (profitable), and create value for the involved parties. Low competitive cost, good quality and functionality in, and suitability to, the local environment [8–10] were key parameters for the product design and development. Sustainability of the water filter, in all its aspects, was to be considered. The size, scale, outlook, as well as the form of application, were for the team to define, but they had to meet the needs of low-income consumers.

Based on the conducted research, which took place both in Finland and in Tanzania, a decision on positioning was made based on recognized opportunities and potential impact and effectiveness. Research activities were conducted in parallel with idea and concept generation, and in collaboration with various partners. Ideas and concepts were developed rapidly and their evaluation was based on the 4A's (affordability, accessibility, availability, awareness) (see e.g., [51]), SWOT analysis and the above-mentioned design parameters, instead of the stage-gates process normally used by Ahlstrom. The assessment criteria evolved especially during the field research period, and the key findings were reflected in the assessment of concepts and in further prototypes. The developed prototypes were evaluated using a similar process as well as tested in laboratory conditions, guiding the decision on the final prototype.

The research and development activities were characterised by a lower level of formality and standardisation in comparison to traditional innovation projects of Ahlstrom. At the same time, the traditional steps of the innovation process (see e.g., [52,53]) were generally followed. The process was rather user-centred in order to understand the local context and operating environment, and participatory methods were utilized to capture the needs and, in particular, desires of the end users. The team worked in an agile and flexible manner, responding and adjusting to the emerged findings, limitation and opportunities. Principles of design thinking were applied to balance business (viability), people (desirability), and technology (feasibility) in the processes [54].

4.2. Strengths, Weaknesses, Opportunities, and Threats of the Frugal Innovation Process

In this section, we apply a SWOT analysis (see e.g., [55]) to look at the key strengths and weaknesses (internal to Ahlstrom and this process), as well as opportunities and threats (external i.e., derived from the operating environment) related to this frugal innovation process.

Smart positioning and the mode of application in the water supply chain, together with low production and operational costs, are among the key strengths of the water filter. Initial estimates in Dar es Salaam showed that the operating cost of the filter is up to seven times less than that of traditional household-scale water treatment by boiling water with charcoal [16]. This positioning enables the provision of safe water at a lower cost, while generating earnings for the company. The filter is a plugin accessory to existing utensils commonly found in the households in Tanzania, does not require electricity, and is smaller in size than comparable point-of-use water filtration solutions (e.g., Tata Swach and Unilever Pureit). The embedded technology is inexpensive at the utilized scale and the manufacturing costs for the product are low, leaving a margin for the producer and partners. The plan for piggybacking on existing distribution networks through local partners makes reaching the end users and target market segments easier.

Prior to embarking with the project, Ahlstrom's technology was identified to have potential in resource-constrained environments due to its low cost and potential for removing bacteria and viruses from water without electricity. However, there was lack of knowledge on how to apply the water treatment technology successfully and efficiently in such a context. Agility and proximity to the envisioned end users in the research and development process enabled identification of an effective and fit positioning for the filter in the target market and an in-depth understanding of the environment and local desires and needs.

However, the filter has its weaknesses and is likely to be out of reach for the poorest of the poor if not subsidized, as it is an additional cost on top of purchased water and the initial investment is relatively high for people in the poorest segments of society. As the product solely focuses on treatment of water at the household level, it relies on the processes of water extraction and supply, which are presumed to be both existing and functioning. Economies of scale, in terms of safe water, can be regarded to be harder to reach with such household devices than e.g., with centralized larger scale solutions. As a consumer product, with replaceable parts, the innovation generates waste. This can become a challenge in the study area, and also other developing countries, where waste management and recycling systems are often insufficient and run by a mix of formal and informal actors [56,57]. The innovation contains e.g., plastic and alumina nanofibers, which can cause harm to the environment if disposed of inadequately. To limit these potential negative environmental impacts, which can have further socio-economic impacts, a return scheme for the replaceable parts is being planned to ensure adequate recycling and disposal.

On a global, regional, as well as national level, the key opportunities arise largely from megatrends, prevailing physical and economic challenges, and the poor state of WSS services, leading to demand for water treatment and service solutions. Household-level water treatment solutions offer an alternative to traditional centralized systems, which in rapidly growing and urbanizing areas are not always able to fulfill the needs of these growing populations. It also provides a solution for households outside these centralized systems. Regardless of the fast growing GDPs in many African and Asian countries [58], financial capital is still scarce and the relative affordability of the developed water filter is thus an advantage. The specific context of our study, Tanzania, is ranked amongst the top 10 countries with the greatest number of people living without access to safe drinking water, indicating a major need and potential for affordable water treatment solutions [59]. The SDGs bring further pressure to enhance water supply and sanitation, and are likely to bring additional investments in the sector.

On a local level, key threats include competition and counterfeits, corruption, as well as challenges related to entering the market. In Tanzania it was observed that, especially in the consumer markets, big companies with their powerful brands tend to rule the market, making entrance challenging for new players. Institutional challenges regarding WSS, and more broadly water resources management, together with insufficient investments in other water-dependent sectors, make the development of, and investments in, the water sector unreliable. Furthermore, legal and political risks, lack of infrastructure and human resources, are commonly listed amongst the challenges in such markets.

Looking beyond frugal innovation into the global-level value chains, other types of sustainability related threats can be seen. The components of the innovation are sourced globally, as is commonly the case in present day business operations. Thus, in regards to water, it is challenging to track e.g., practices and quantities of water consumption and use (water footprint) or potential risks caused to waters, environment, and humans along the whole value chain.

5. Discussion

5.1. Potentials

The case study helped us to recognize two key potentials of frugal innovations in terms of sustainable development and water sector: (i) a broader view of water and the related challenges can increase opportunities for business and expand the field of operations; and (ii) a frugal innovation

mind-set can serve as a medium for companies to find new ways to organise products and business development (i.e., innovation processes), and to respond to water-related challenges of the less affluent.

Firstly, *realizing the opportunities in the water sector beyond the organisations' traditional field of operation opens larger markets*. In our case study, Ahlstrom recognized opportunities for their technology beyond the industrial processes (where its products are traditionally applied), and aimed, with the help of partners, in researching these opportunities, and developing new applications to a new market area and for completely new market segment. Especially in low-income settings, which are often faced with a range of development challenges, affordable solutions are needed. The potential of business-led solutions in solving the sustainable development challenges has also been recognized by prominent umbrella organisations promoting sustainable business, e.g., [7]. In this growing water market, the advantage of frugal innovation is intertwined in its characteristics; low-cost, quality, and suitability to its environment.

Secondly, frugal innovation processes often require—due to their emphasis on affordability—a complete re-think of current operating practises. Success of frugal innovations commonly depends on understanding the local context, as they simultaneously focus on achieving a radical cost goal and ensuring suitability for the local environment [8,10]. In this way, *frugal innovations can encourage companies to find new ways of working* within their product development and design processes, and even shift organisational mind-sets and change existing operating structures.

In our case study, such new ways included novel forms of collaboration with new partners, as well as freedom to work largely outside the established corporate structures and processes. In terms of product development, Ahlstrom utilised an agile model where it worked mainly through new partnerships that also utilized local knowledge, instead of large investments in their own R&D infrastructure. This also led to lower upfront investments costs and hence lower financial risks for the company. In some other cases, frugal innovation processes have led, for example, in establishment of new, locally-based R&D centres and subsidiaries [10].

Furthermore, as shown by the case study and reviewed literature, *the strength of frugal innovations is in the provision of good (enough) quality solutions, affordably enough, to the end users, even in low income classes*. Given that many such innovations also contribute to wellbeing and livelihood development, these new solutions can advance sustainable development particularly on an individual and household level. An additional contribution to sustainability comes when these new innovations replace undesirable or inefficient practices or are environmentally, socially, or economically better than the old solutions [42]. In our case study, the frugal innovation solution replaces the use of charcoal or firewood for boiling water, thus decreasing greenhouse gas emissions, as well as deforestation and possible adverse health effects.

5.2. Pitfalls

Our analysis also recognised potential pitfalls in using frugal innovations to contribute to water sector solutions and to sustainable development. We group these pitfalls into two main categories: (i) *sustainability deficiencies*, exemplifying the challenges linked to the different aspects of sustainable development; and (ii) *institutional deficiencies*, representing the pitfalls related to institutional roles and responsibilities.

Sustainability deficiencies are closely linked to issues with the frugal innovation value chains, which—like any industrial value chain—involve several stages from extraction of raw materials to production, and from the actual use (consumption) to end-of-life and possible re-use. As frugal innovations are commonly targeted directly to consumers, focus is strongly set on the qualities of the end products, which may lead to neglect of social, environmental, and economic implications in other parts of the value chain.

While frugal innovations emphasise the importance of local context and needs, their actual production often takes place in global value chains. These value chains are commonly complex and include a number of actors in different geographical locations with various qualities and characteristics.

In such a global value chain, the urge for affordable end products can easily materialize as a demand for low-cost suppliers, producers and materials. The drive for cheap production is not always congruent with the triple bottom line of sustainable development, but quite the opposite: there are examples of well-established companies that have struggled with environmental and social norms in low-cost manufacturing countries [60–63]. For instance China, one sourcing country also in our case study, is well-known for low-cost manufacturing, but also for social and environmental problems related to rapid industrialisation and weak enforcement of social and environmental regulations [64–66]. Similar challenges are related to raw material extraction, as well as end-of-life solutions. For example, extraction of raw materials is often water intensive and takes place in already water scarce areas. Thus, a frugal innovation product's potential advantage of using less resources [9,13] may be partly lost when analysing the innovations at a larger scale and earlier in their value chain. In our case study, for example, one could argue that it would be more sustainable to develop a well-functioning centralized water treatment solution instead of focusing on providing individual households with in-house devices produced within a global value chain.

Institutional deficiencies relate to the roles and responsibilities that all actors—including the private sector—should have in the water sector. Contrary to some other frugal innovation sectors such as IT, the water sector is characterized by a high degree of public sector involvement in, and responsibility, for the regulation and, in many cases, also for the provision of the water services. At the same time, frugal innovations developed by the private sector commonly focus on only a certain, specific aspect related to the water sector, for example, in our case study on providing good quality drinking water on household level. While such single innovations may be useful, particularly in the shorter term, they also need to consider the broader institutional context within which they are embedded in: otherwise they may actually not contribute to the establishment of more comprehensive, often public sector-driven solutions. As institutional environment in emerging markets is often challenging, such consideration also helps in understanding potential institutional voids and the ways private sector can acknowledge and respond to those [41,67].

5.3. Way Forward: Envisioning a Broader View for Water-Related Frugal Innovations

Our findings, based on literature and the case study, imply that there is a need to understand and take into account the bigger picture of water-related frugal innovations, especially if they are to be aligned with the goals set for sustainable development. In order to facilitate discussion on this, we developed a diagram that aims to visualise the connections between frugal innovation value chains, water, and sustainability (Figure 3).

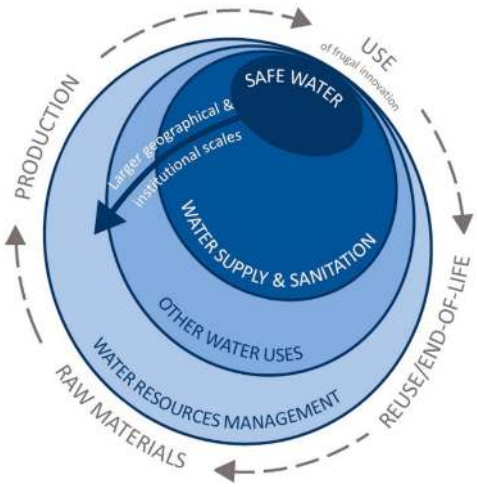

Figure 3. Diagram for scaling-up sustainability impact of frugal innovations in the water sector, combining water sector (spheres) with the frugal innovation value chain (dashed arrows).

Our visualisation includes two main issues; water and frugal innovation value chains. The diagram emphasises the need to take a broader view in both these dimensions, including geographical and institutional scales from local towards global scale. Our message from the diagram is that the *sustainability impact of frugal innovations should be considered throughout the value chains in which they are created*. Instead of focusing solely on the end product and its sustainability, a frugal innovation process should also ensure that the end-of-life of these products is considered, meaning adequate re-use, recycling and, if required, disposal, takes place. Similar emphasis should be put on the sustainability of production, including that of raw materials.

Acknowledging the complexities related to today's global supply chains, we do note that such a task is often difficult. Hence, we see that such a process would most likely evolve in a step-wise manner, starting from those phases and scales that the frugal innovation actor has direct influence on. In our case study, this would first include better consideration of the end-of-life of the products, and then increasing the sustainability of production and, further, raw materials.

The diagram also seeks to capture the diversity related to water use and management. While the focus of many development interventions (and that of the MDGs) is on water supply and sanitation or safe water (darker spheres in Figure 3), water is also crucially linked to other sectors of our society, from food and energy production to industries (as noted by the SDGs). This increases the geographical and institutional scales related to water, and emphasises the need to move (at least) one scale up in the "water spheres". In terms of our case study, consideration of the broader water supply and sanitation situation, instead of just provision of safe water, could link the frugal innovation better to other water sector actors and even yield a higher sustainability impact in terms of outreach or covered WSS needs.

Both of these dimensions have close linkages to *geographical and institutional scales*. Both the number of actors and scales usually increase when looking at multiple different phases of frugal innovation value chains: raw material extraction, production, and end-of-life solutions may all engage a set of different actors and may take place in an altogether different country than the actual product use. Similarly, the number of sectors and actors increases when moving up across the water axis, increasing the institutional diversity. While the actual frugal innovation processes are commonly run by companies, the actual innovation process also usually relates to several other actors from public sector, civil society, and academia. Although the aims of public and private sector involvement in water sector may be rather different, their ways of working and expertise can be strongly complementary. Making the most of this, however, requires, clarity on the roles and responsibilities between different actors. For example, the private sector can—possibly in collaboration with universities and research institutes—provide new types of technologies, products and services, while the public sector can create an enabling environment for these new innovations and ensure that the new services contribute to the broader aims of the sector and are accessible to everyone.

Given the key role that the public sector—from the community level to the central government and international level—holds in the water sector, it seems evident that private sectors actors should recognise this role, and engage with relevant public sector actors from the very beginning of their frugal innovation process. While the public sector is not free of its own institutional challenges [38,68], we see that it should still have the main role for general water sector development, as the private sector actors often do not have the mandate, comprehensive expertise, and willingness to fill the governance gap beyond their immediate sphere of operation [69].

All in all, taking a broadened view on water and frugal innovation value chains is not without challenges. Yet, we believe that it is still worth pursuing as it can increase both the sustainability impact and business opportunities of frugal innovations by reaching more people and providing solutions across the entire value chains and water spheres (Figure 3). One example of a company that has used such business opportunity is Grundfos, which has started to widen its field of business by taking a broader view on challenges it aims to solve, expanding its operations from water pump manufacturing into supplying water kiosks, including new kinds of payment systems and remote monitoring services [70,71].

5.4. Limitations

As the case study presented in this article is based on an experimental and early stage product and business development process, the findings should be considered as an indication of tentative opportunities and pitfalls, setting directions for future studies and actions. Overall, the entire concept of frugal innovation is still developing and related definitions are still in flux.

The selected case study context also brings its challenges for the applicability of quantitative data and analysis methods. As a result, only explorative case study design and qualitative analysis methods were applied. Complementary quantitative analysis would naturally improve and deepen the analysis.

The key methodological recommendation for future research is therefore to conduct such a detailed quantitative analysis of the case study context. This could include, e.g., detailed value chain analysis, further cost comparison between different treatment options and market size, and survey data from consumer preferences. At a more conceptual level, we recommend more detailed studies on the sustainability of the value chains beyond frugal innovations and related water resources in order to further clarify their contribution to sustainability potentials and pitfalls highlighted in this article.

6. Conclusions

This article looked at potentials and pitfalls of frugal innovations in the context of water and sustainable development. Frugal innovations were selected as a medium as they have been affiliated with serving resource-constrained consumers, enhancing sustainability, and having potential for generating profits for the companies involved. The circular nature of water and its contribution to a variety of socio-economic activities urged the expansion of the scale of analysis from frugal innovation products, i.e., outcomes, to entire frugal innovation processes. Global value chains related to the production of modern-day goods added another layer of complexity to the analysis. A frugal water innovation case study and a literature review clarified the sustainability related strengths, weaknesses, opportunities, and threats, as well as the potentials and pitfalls of frugal innovations in the water sector.

Our results indicate that a frugal innovation approach can enable organisations to find new opportunities for innovation and impact as well as obtain new mind-sets and offset for product development for new market segments. This process is also likely to highlight the importance of understanding the local context and prevailing constraints as well as the needs and desires in these environments. Furthermore, these innovations have a clear potential to contribute towards sustainable development.

Sustainability deficiencies, such as unsustainable low-cost manufacturing and generation of waste, were observed to arise largely from the quest for (extreme) affordability, disregard of underlying value chains of frugal innovations, and the characteristics of the resource-constrained usage environments (e.g., lack of infrastructure). Our results also indicated that the estimated resource intensity of frugal innovations is linked to the scale and context in which they are analysed. In addition, we identified potential institutional deficiencies, rising from the lack of clear roles between the public and private actors in the water sector.

These kinds of findings call for dialogue and collaboration between different actors and, ultimately, also for general guidelines on tackling frugality and sustainability in relation to innovation processes. Such guidelines can be discussed through different forums, ranging from the multinational UN system and the SDG process to business platforms and research networks. We believe that the guidelines could be most efficiently established as part of already existing forums—such as the World Business Council for Sustainable Development or the UN Global Compact—that also actively engage private sector actors in its work.

We also introduced a diagram that looks at the connections between value chains of frugal innovations and water resources. The diagram emphasised the need to take a broader view in both these dimensions, including geographical and institutional scales. In terms of frugal innovation processes, such a view would entail considering sustainability, including water use, in all phases of the

value chains, from the extraction of raw materials to the end-of-life of the solutions. In terms of water, such a view should include recognition of various uses and users of water. Importantly, we see that such a broader view on water sector and frugal innovation process would enhance both the business opportunities and sustainability impact of frugal innovations by reaching more people and providing solutions across the value chain.

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Abbreviations

The following abbreviations are used in this manuscript:

B2B	Business-to-Business
GDP	Gross Domestic Product
MDG	Millennium Development Goals
MNC	Multinational Corporation
R&D	Research and Development
SDG	Sustainable Development Goal
SWOT	Strengths, weaknesses, opportunities, and threats
WSS	Water Supply and Sanitation

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