An Assessment of the *Tubeho Neza Public Health Program* in Rwanda

A case study on the Social Impact of investments in environmental health technologies

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The ***Tubeho Neza Public Health Program*** (the "Program") is a result of the joint efforts of a number of organizations, to which we would like to express our gratitude for making this project possible and, of course, thank each individual involved for his or her special contribution.

In-country Organizations:

Republic of Rwanda, Rwanda National Police, Rwanda Defence Force

International Organizations:

United Nations, The World Bank

Private Sector Partners:

DelAgua Health Rwanda Limited, BDO, Gold Standard, Signina Capital AG

Academic Partners:

University of Portland, University of Surrey, London School of Hygiene & Tropical Medicine

We also owe special thanks to all the community workers in Rwanda that are contributing to the project as well as ***Equipping, Restoring, and Multiplying (ERM)*** Rwanda for their on-the-field auditing services.

Furthermore, in this report, the results of the independent analysis implemented by ***WifOR Institute*** are presented. The focus of this work was on the overall socioeconomic assessment of the Program, and, for that purpose, a distinct and innovative approach was elaborated using Markov modelling and the Social Impact methodology that has been developed by ***WifOR Institute***. Moreover, we would like to express our gratitude to ***Novartis*** for its financial support.

Finally, it is worthwhile acknowledging the special role played by ***BDO*** Global and ***Signina Capital*** in providing detailed information on the project's implementation as well as ***DelAgua Health Rwanda Limited (DelAgua)*** for being charged for the collection and delivery of the Programs' data.

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Management Summary

Over the last years, the ***Tubeho Neza*** (live-well) Program has been successfully delivering cookstoves and water filters to the poorest segments of the Rwandan population. Recent population level, randomized controlled trials have shown the extent to which those interventions are effective in preventing diseases associated with poor air and water quality. Due to the use of solid fuel cookstoves and the consumption of unclean water having a high pathogen content, high prevalence of diseases such as acute respiratory infections (ARIs) and diarrhea have been the leading causes of premature mortality and diminished quality of life in Rwanda. Those diseases predominantly hit the under-five child population. Adults, nonetheless, also suffer from those diseases. The aggregate effects of those diseases on the population level significantly constrain the development of the country's welfare and, in effect, strangle its potential to prosper.

In this study, we investigated and analyzed the effects of the Program's interventions and their impacts on an aggregate macroeconomic level. We differentiated between health outcomes that are related to the use of environment-friendly cookstoves and those related to the use of water filters. We also differentiated between the effects on the under-five child population and the adult population in the working age and older.

Our analysis demonstrated that the ***Tubeho Neza*** Program yields **annual socioeconomic gains of a total of US$9.1m**, of which **US$6.4m pertain to the adult population** and **US$2.7m to wider additional gains (including US$0.9m of caregiver costs that are associated with the health of children under 5 years old).** A unique and central element of the socioeconomic impact analysis is the quantification of the caregiver impact, which demonstrates the significance of caregivers to society.

When we look at the results from an individual point of view, these showed that there was a **benefit[1] per person of US$11.75**, which can objectively be considered a strong result especially when interpreting this in the context of the country's relative wealth and development level. Alternatively, and accounting for the size of the household (a typical family of four persons was assumed), we can also conclude that the **net benefit**, or avoided cost per household, is **US$8.77**.We argue that the benefits stemming from the interventions accrue to the people living in the community. As the distribution of the gains cannot be clearly traced, we present the two alternative approaches of measuring them, both however **demonstrating a very strong impact**.

[1] the **benefit is the net avoided cost** that is derived from subtracting the intervention costs from estimated health gains

If we breakdown the benefit for the adult population, the analysis concluded that there is a benefit of **US$9.02** of avoided socioeconomic burden related to ARI and diarrhea **per adult** in Rwanda in 2014. For the child population, the benefit was estimated to be **US$1.01** of avoided socioeconomic burden related to ARI and diarrhea **per child** in Rwanda in 2014.

From a return-on-investment perspective, we can argue that **US$1 spent on the intervention resulted in US$3.1 for society** (US$11.75 benefit / US$3.74 cost).

Moreover, when compared to the average cost of cookstoves and water filters per average household, **the monetized outcomes of the *Tubeho Neza* program of US$9.1m by far offset the costs of the interventions of US$5.6m.**

Our analysis assumes that the gains in the adult population are related to **improved productivity in both paid and unpaid work activities**. Additionally, downstream value chain spill-over effects that are associated with **paid and unpaid work** were also captured and aggregated in our analysis and were shown to be relatively significant as a proportion of the total effects. For the under-five child population, cost savings related to avoided caregiving, medications, and hospitalizations were quantified and aggregated in monetary terms.

The results presented in this report support the case for investing in environmental health initiatives that demonstrate a high effectiveness on the population's health and hence on its productivity potential. Our analysis shows that the societal and economic benefits generated from investments in such initiatives reach much beyond their mere health outcomes, however important these may be, and that their monetary gains by far offset the initial investment costs. This type of analysis can be used to support policy makers when allocating budgets, especially in resource-poor settings. Most importantly, the analyses presented in this report help to (i) raise awareness and interest among stakeholders on the importance of implementing such large-scale environmental health initiatives, and (ii) gain further quantitative and qualitative insights on community health improvements and their developmental and socio-economic impacts.

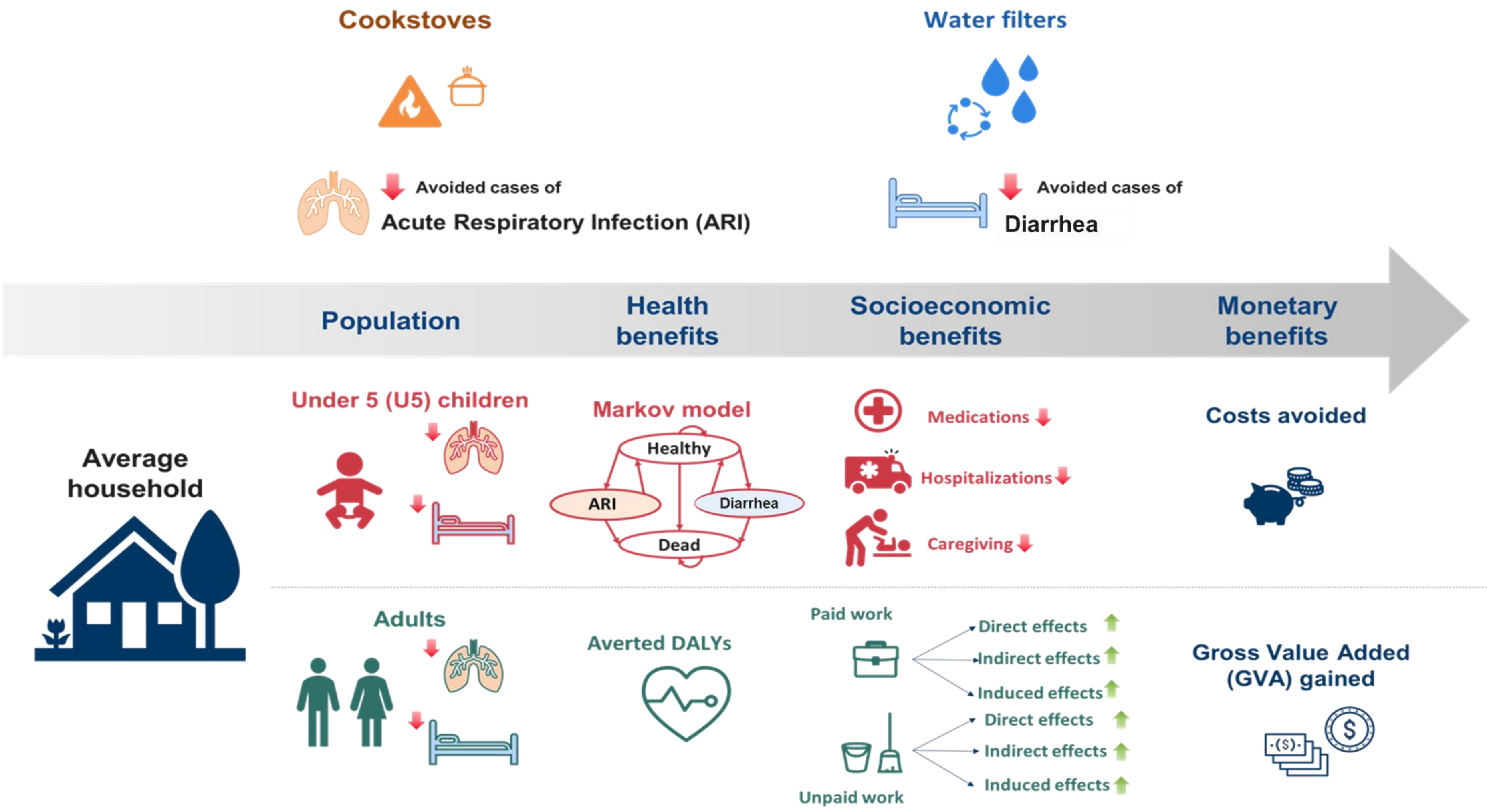

Figure 1: Overview of study needs, interventions, modelling, and outcomes

1 INTRODUCTION AND CONTEXT

In 2019, ***WifOR Institute*** was commissioned to implement an assessment of the ***Tubeho Neza*** Public Health Program in Rwanda by measuring the Social Impact of interventions with environmental health technologies. The aim is to initially conceptualize the Program's household interventions that aimed at delivering cleaner drinking water and improved indoor air quality. We also offer a calculation and analysis of the Program's Social Impact.

The idea underlying this analysis originated from the concepts developed by the ***VALUE BALANCING ALLIANCE***, a non-profit organization that addressed the need to rethink the value contribution of business as it pertains to capital. The Alliance aimed to create a standard for measuring and disclosing the environmental, human, social and financial value companies provide to society [1]. Furthermore, in 2015, the Impact Valuation Roundtable (IVR) was launched, as an informal group of over a dozen international companies, among them ***Novartis***[2] [2], and aspired in developing and operationalizing the emerging field of Impact Valuation[3]. The IVR participants considered an Impact Valuation assessment as the best approach to measure and value the effects of business activities on the health and well-being of people and the planet – in economic, environmental, and social dimensions. By taking a macro-societal perspective on the business contribution to society, the group argued that Impact Valuation could ensure long-term, successful, and sustainable value creation for all stakeholders (for further information see [3] in Bibliography)

[2] According to the *Novartis in Society Report 2018* [2], Novartis had sponsored 1000 units each of cookstoves and water filters, having an impact on approximately 5 000 people. The idea behind this contribution was to also begin to look for ways to address environmental concerns with a direct impact on global health, especially in the developing world. As an example of this intention, Novartis planned to provide cleaner burning cook stoves and water filters in 2019 within the context of the relevant project in Rwanda, in partnership with the UN Development Mechanism.

[3] Impact Valuation can be defined as the application of welfare economics to determine the positive and negative value contribution of business activities to society in monetary terms.

Based on these premises, ***Novartis*** has adopted the Financial, Environmental and Social (FES) impact valuation approach, of which the Social Impact is a key element. The main idea behind this approach is that measuring the social and environmental impact that business activities have on society, in addition to economic value, offers a more holistic view of the real impact of a business activity.

The current analysis presented in this report focuses only on the Social Impact dimension, where the impact of the Program's health interventions viewed as improvements in the longevity and quality of life of specific age groups (children under 5 and adults), is quantified and valued in terms Gross Value Added – GVA. Figure 2 presents the Health Value that is reflected in survival and longevity benefits, the Population value in terms of quality-of-life improvements, the Productivity Impact to society that refers to improved productivity effects for both paid and unpaid activities, and the Benefits to the Health System that is measured by the decreased burden on the health system, e.g. fewer hospitalizations.

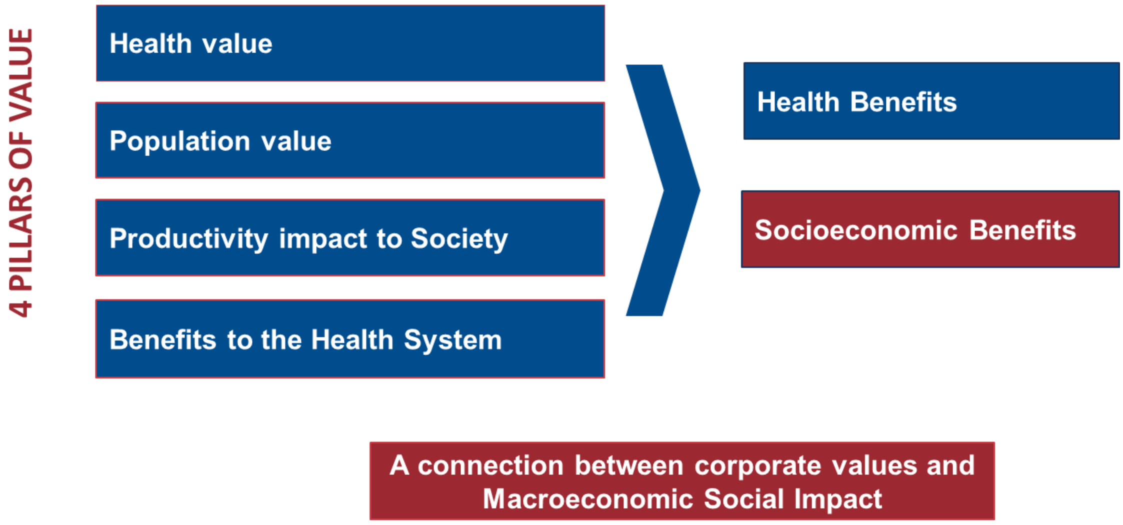

Figure 2: Theoretical framework of the Social Impact study

In this context, expenditure related to health interventions could be viewed and valued as investments that yield improved population health outcomes. The Social Impact Analysis measures the societal impact that these investments bring by improved productivity that is a result of averted disease-related disabilities and productivity losses. Hence, Social Impact Analysis is considered the meeting point between value delivery to the society and the scientific methodology to capture this value in a country-specific, macro-economic context. Furthermore, efficient spending in health-related interventions is increasingly being recognized as a direct predictor of better health outcomes and national wealth [4]. In this respect, national public spending or even corporate responsibility spending in health- related causes is conditionally bound to bringing about better quality of life and wellbeing upon the respective populations, and such spending could be considered as a form of investment with measurable effects.

Measuring health-related quality of life precisely and reliably has been, nonetheless, a longstanding challenge in public health. Capturing and quantifying a universal unit of increase or decrease in quality of life on the individual and collective patient levels could enable economists to monetize such unit into an economically comprehensible monetary outcome that is compatible with traditional validated economic research techniques. Significant strides in the last few decades were taken to address the conceptual and ethical challenges in this regard, resulting in an increase in the quantity and quality of the body of evidence being published.

The main objective of this report is to analyze and measure the Social Impact of the health interventions implemented in the context of the ***Tubeho Neza*** project. Through the Social Impact analysis methodology developed by ***WifOR institute***, this report is aiming to present the quantifiable societal value of the ***Tubeho Neza*** activity. Our aim is to present a more complete picture on the Program's overall impact including financial, environmental, and social aspects.

Overall, interventions that aim to advance the population's health status contribute to the increase of the Gross Domestic Product (GDP) as they help a country to maintain a healthy (and, in ***WifOR's*** view, a more productive) workforce. Additionally, such interventions contribute to the economy via educational activities and employment, mainly through the implementation of educational and training programs [5].

On the environmental effects of the ***Tubeho Neza*** project, a study assesses the impact of stoves on fine Particular Matter ($PM_{2.5}$). Their findings indicated a 48% reduction of 24-h $PM_{2.5}$ concentrations in the cooking area. Specifically, the decline was 37% for those cooking indoors and 73% for those cooking outdoors [6]. It is evident that high efficiency cookstoves lead to a 73% reduction in household air pollution and a 28% reduction in cookstove emission exposure among children [5].

Furthermore, it is estimated that approximately 120,000 tons of annual woodfuel savings in the Western Province of Rwanda can be attributed to the project, decreasing to 102,000 tons in 2024. These measurements suggest that this project might compensate for the government-projected deficit in woodfuel of 106,000 tons per year by 2020. This reduction can also be translated in a decline of 48 days per year in collection of fuelwood for the Rwandan families [7].

It is estimated that 55% and 19% of Rwandan households in rural and urban areas respectively, take 30 minutes on average to obtain drinking water [8]. The water contamination is a widespread phenomenon during water transportation from the source to the households [9]. Thus, the use of water filters is required to advance the quality of drinking water.

1.1 The Project's need and Rationale

Worldwide, approximately 1.8 million people have no access to safe drinking water. Furthermore, almost one third of water consumed is contaminated. Additionally, in low-income countries, 3 billion people use biomass fuels (i.e. wood) when cooking. Drinking untreated, mostly contaminated water and using solid fuels lead to a wide range of adverse health impacts, especially in children [10]. Household water treatment, for instance filtering, could reduce the risk of enteric infections and diarrhea, while improvements in household ventilation could contribute to better respiratory health [10]. With almost 80% of Rwandan people relying on firewood for cooking and over 40% using boiling water as a treatment before drinking, interventions such as water filters and efficient cookstoves could help reduce the consumption of firewood by decreasing its demand and, therefore, address the problem of its shortage in availability [11].

The humanitarian ***Tubeho Neza*** (Live Well) program provided the rural population of Rwanda with the means to combat two major causes, Diarrhea and Acute Respiratory Infections (ARI), of infantile mortality (7% and 11%, respectively) in children under 5 years of age [7].

These two interventions consisted in offering water filters and cookstoves to provide clean water and improved air conditions. The motivation of this analysis is to highlight the combined impact of these two interventions. This could inform future similar activities and provide evidence-based insights on future actions.

This study is not limited to the analysis of the avoided morbidity and premature mortality rates. It also intends to raise further considerations on the broader impact such interventions bring about in simple socioeconomic terms.

In Rwanda, 22,000 children under the age of 5 died in a year [6] before the intervention started. The idea of this analysis is to calculate the incremental Social Impact brought about by the introduction and implementation of the ***Tubeho Neza*** intervention in Rwanda. In this way, the intervention can be viewed as a health investment that has a measurable return to the society.

Furthermore, ***DelAgua*** has sponsored an independent evaluation of the health impacts of this program, run by the ***London School of Hygiene and Tropical Medicine, Emory University, Oregon Health Science University, and Portland State University***. The research team involved in that evaluation had undertaken a cluster-randomized trial to evaluate the intervention in terms of coverage, use, exposure, and health. In the current analysis conducted by ***WifOR Institute***, various data sources and other information have been used, including data from the above-mentioned independent evaluation.

1.2 An overview of the Program

The ***Tubeho Neza*** Public Health Program (thereof referred to as the ***Tubeho Neza*** Program or Program) is a large-scale public health program in Rwanda. The Program is a partnership between the ***Ministry of Health of the Republic of Rwanda*** and the social enterprise ***DelAgua.*** Its objective is to deliver environmental health technologies to the poorest segment in Rwanda. ***DelAgua*** is a social enterprise that partnered with the ***Ministry of Health of the Republic of Rwanda*** in 2012, in order to launch a project for the distribution of water filters and improved cookstoves to the poorest 25% of families in Rwanda (socioeconomic Ubudehe levels 1 and 2) [12] . More than 100,000 low-income households in 72 out of 96 randomly selected sectors of the Western Province received improved cookstoves and advanced water filters in the fall of 2014.

The program has, thus far, reached over 1.5 million people with household interventions aiming at delivering cleaner drinking water and improved indoor air quality [5]. Those interventions are presumed to directly result in improved health outcomes. This has been demonstrated by the program evaluations showing reduced disease burden in the targeted population over time measured in averted disability-adjusted life years (ADALYs)[4] [13]. The assessment project assigned to ***WifOR Institute*** measured the Social Impact of the Program in Rwanda. The results of the Analysis, among other outcomes, can potentially serve ***DelAgua*** as a social enterprise, in complementing the triple bottom line approach, when reporting the holistic impact of the program in Rwanda. ***WifOR Institute***, in close cooperation with ***Novartis***, has developed a statistical model that measures the Social Impact of health interventions using a quality-adjusted-life-year (QALY) -based approach. Owing to the conceptual compatibility of QALYs and ADALYs, this project aimed at updating the Social Impact model to account for the ADALYs generated and measured by the Program in Rwanda. Therefore, and as a starting point,

[4] Averted disability-adjusted life years (ADALYs) have been used as a performance indicator to measure the burden of disease averted due to environmental health interventions

this analysis measured the socioeconomic impact of the health interventions in the context of the Program in monetary terms.

More specifically, the Program of Activity involved the distribution of *Vestergaard Frandsen LifeStraw®* Family 2,0 units[5] and *EcoZoom Dura high efficiency* cook stoves to households in Rwanda. *The Vestergaard Frandsen LifeStraw* Family 2.0 is a point-of-use microbial water treatment system intended for routine use in low-income settings. The system is a table-top unit where the user pours untreated water through a 20-micron pre-filter into a six-liter influent water tank. Water is then gravity-filtered through a 0.20-micron hollow-fiber ultrafiltration membrane into a 5.5-liter safe storage container. Water can be dispensed from the safe storage container through a plastic tap, limiting recontamination. The filter is backwashed by squeezing a plastic bulb located on the opposite side of the tap. The membrane can filter up to 18,000 liters of water, enough to supply a family of five with microbiologically clean drinking water for three to five years. The EcoZoom Dura, is based on the rocket-stove concept that is designed to concentrate the combustion process while channelling air flow to create a more complete burn. A complete burn of carbon rich material will also result in little to no smoke [14]. Each household received a stove and a filter in the initial distribution drive held between 15 September and 12 December 2014 (Phase 2 households) and in a second distribution drive held throughout 2016, each household received a stove (Phase 3 households). There was a pilot phase (Phase 1) of the project in 2012.

The distributions were coordinated and managed by ***DelAgua Health Rwanda Limited (DelAgua)*** in collaboration with the ***Ministry of Health of the Republic of Rwanda.*** (see map in Figure 3).

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[5] LifeStraw® Family 2.0 is a high-volume point-of-use water filter produced by *Vestergaard*. It converts microbiologically contaminated water into clean, safe drinking water, filtering up to 30,000 liters of EPA-quality water, enough to supply a family of five with clean drinking water for three to five years. We can therefore presume that the estimated lifetime of the product, for all practical purposes, is at least 5 years.

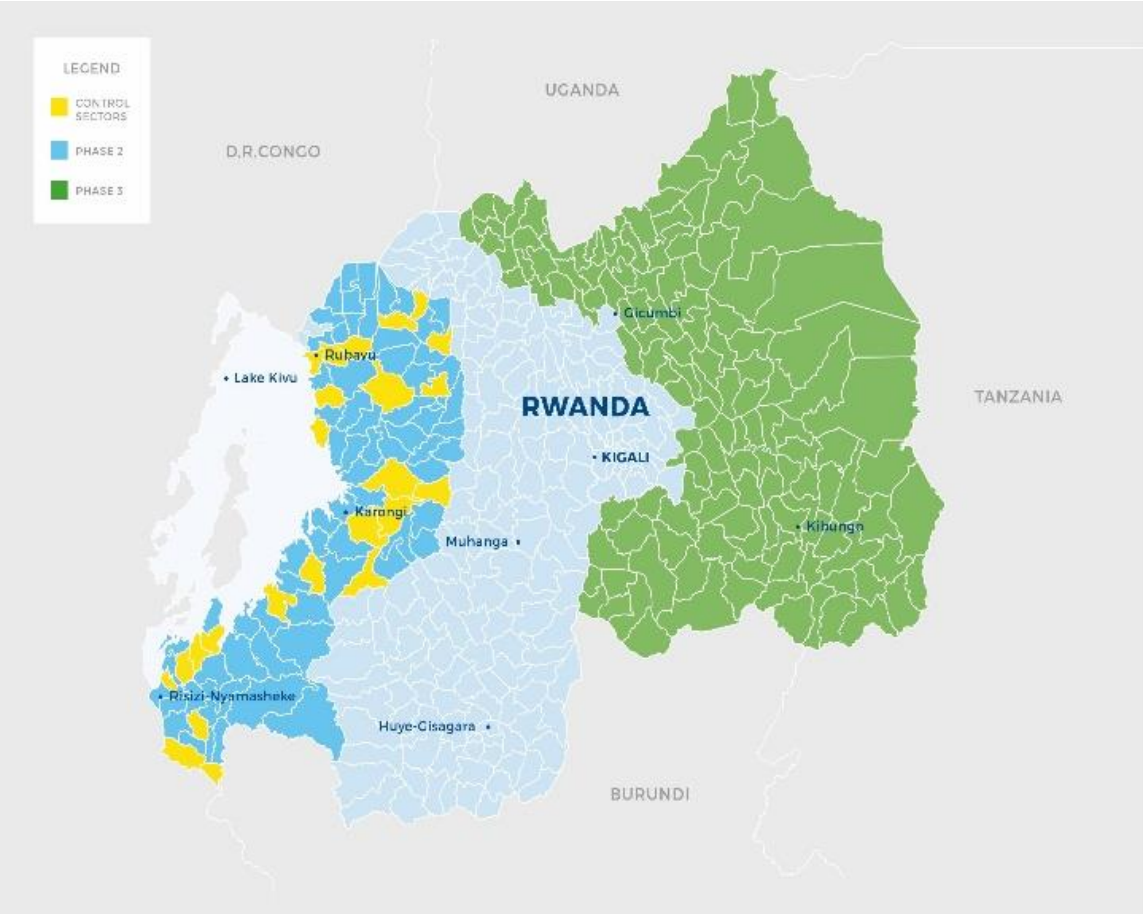

Figure 3: Sectors in Rwanda showing control areas, phase 2, and phase 3

1.3 Academic Valuation of the relation of the Program's activity to health benefits

In a recent paper of Kirby et al, 2019 [10] there is a thorough analysis of the effects of large-scale distribution of water filters and cookstoves on peoples' health, and especially with regards to diarrhea and acute respiratory infections. This study was focused on the Western Province of Rwanda, based on the ***DelAgua*** relevant activity and the abovementioned sponsored research of ***Portland State University*** and of the ***London School of Hygiene and Tropical Medicine***. The paper attempted to present evidence on the health effects that programmatic distribution of water filters and cookstoves at scale have on the population. The key findings indicate that the intervention improved household drinking water quality and reduced caregiver-reported diarrhea among children less than 5 years of age. It also further concluded that there was reduced caregiver reported acute respiratory infection (though there was no evidence of improved air quality). Given that unsafe drinking water and household air pollution are leading health risks, especially for young children in low-income countries, diarrhea and acute respiratory infections are leading causes of child mortality and major burdens on healthcare systems. The results of the study suggest that the program was effective in reaching a vulnerable population and improving drinking water quality and therefore reducing risk of diarrhea and acute respiratory infections among children under 5.

Furthermore, in an earlier paper of 2017, an analysis was undertaken for only the household water filters distribution in rural Rwanda [15]. The study was based on the same premises arguing that unsafe drinking water and household air pollution are two significant health risks that contribute to child diarrhea and pneumonia, both being major causes of death of children under 5 years old [16] [17] [18]. As in the previous and most recent study discussed above [10], this analysis supported the argument that the intervention water filters were significantly effective in reducing the risks, and hence there is a potential for such interventions to improve household water quality and child death at scale.

In a cost-benefit analysis [11], the estimated investment costs of the interventions were stated to be US$35 per stove and US$40 per water filter, with a recurring annual costs of US$7 per device per household. The overall estimated cost of the program in a 5-year period was around US$11.63 million, with an estimated cost per household of approximately US$114. The same study indicated that the intervention adaptation was high, that is 92.8% and 95.4% for the cookstoves and the water filters respectively. Regarding time savings, 93.1% reported a reduction in the required time for collecting fuelwoods [11].

This program has clearly started as an environmental program that was mainly set-up as a Program of Activity under the CDM-UN framework [19]. Following its implementation for several years since its launch in 2012, a clear health impact has been recognized by several studies. More specifically, the effects of a large-scale distribution of water filters and natural draft rocket-style cookstoves on diarrhea and acute respiratory infection were studied [10]. The health, livelihood, and environmental impacts of the distribution of a carbon-credit-financed, large-scale water filter and improved cookstove programme in Rwanda was assessed [7] and the health impact of the household filters use from a microbiological standpoint was evaluated [15].

2 THE SITUATION IN RWANDA

2.1 Socioeconomic and Demographic Profile of Rwanda

Rwanda is a small landlocked country located in East-Central Africa with a surface area of 26,338 sq.km and is densely populated - with density among the highest in Africa - and a population of 12,759,814, of which approximately 52% are women. The population is young and predominantly rural. Rwanda's demographic profile is characterized by rapid population growth that has resulted from a long period of high and slowly declining fertility rates, amidst steadily declining death rates. Rwanda is also characterized by a youthful age structure and a rapidly growing urban population that accounted only for the 17.3% of total population in 2019. Moreover, with a high annual urbanization rate of 5.9% (exceeds by far the world average of 2.1%), the urban population is projected to grow by 30% in 2032, The largest parts of the population are concentrated in the central regions of the country and along the shore of Lake Kivu, in the west [20] [21].

The country's health profile is dominated by communicable diseases, and significant health challenges, including high maternal mortality rates, as well as the HIV/AIDS epidemic. Furthermore, a very high degree of health risk is attributable to major infectious diseases such as food or waterborne diseases - bacterial diarrhea, hepatitis A, typhoid fever, vector borne diseases - malaria and dengue fever, and animal contact diseases – rabies [22].

It's worth noting though that Rwanda has made tremendous progress in many areas of social welfare, being one of the most noted global and continental examples of fast economic growth and successful post-war reconstruction. Recent surveys indicate that the percentage of people living under poverty has significantly dropped by 5.8 percentage points, from 44.9% in 2011, to 39.1% in 2014**.** Rwanda's economy is also increasingly experiencing the predominance of the service sector as it gained importance relative to agriculture over the recent years [20].

2.2 The patient population and the targeted diseases

Environmental contamination at the household level is a major cause of death and disease, particularly among rural populations in low-income countries. Household air pollution (HAP) contributes to acute lower respiratory infection (ALRI [23]) and is the leading cause of death in children under 5 years. Among adults, HAP is a risk factor for diseases such as ischaemic heart disease, stroke, hypertension, chronic obstructive pulmonary disease, lung cancer, trachea, bronchus, cerebrovascular disease and cataracts [24], [25], [26].

Collectively, pneumonia and diarrhea are responsible for an estimated 6.9 million deaths annually [27]. In Rwanda, almost all households (99.0% of rural householders) use biomass for cooking. Strikingly so, only 10% of the rural population have water on their premises [8].

Despite clear evidence that HAP and unsafe drinking water are important risk factors, there is limited evidence of the health impact of improved cookstoves that can be deployed at scale among vulnerable populations [28]. Trials are currently underway to explore the effectiveness of locally-made low-tech rocket stoves [29], improved biomass stoves [30], imported Philips® gasifier stove [29], biomass stoves with chimney [31], LPG stoves [30],[31] and ethanol stoves. Significantly, however, all these efforts are implemented at a limited scale, hence with very limited efficacy information.

The case for drinking water is similar. Although household water filters have been in more than a dozen efficacy trials, evidence of their effectiveness is still limited [6]. The up-front cost of household water filters and stoves has limited the extent to which they have been scaled up, particularly in rural settings. Carbon credit financing came as a solution and offers the potential to provide these technologies to poor and vulnerable populations and to encourage their actual adoption and use on a long-term basis [32].

Household water treatment (HWT) interventions may play an important role in protecting public health [33]. This also could provide a basis for informing the development or revision of national or international technology performance evaluation programmes. It is underpinned by concepts established in the World Health Organization's (WHO) Guidelines for drinking-water quality (GDWQ), and the laboratory methods described are meant to be relevant in resource-limited settings.

Based on the initial results, the ***Ministry of Health of the Republic of Rwanda*** and ***DelAgua*** decided to scale up the intervention to cover the poorest third of the population (categorization of poverty based on Ubudehe 1 and 2 [12]) throughout all of Western

Province (Phase 2). The implementation plan called for delivery to 72 of the 96 sectors (groups of villages that also correspond with catchment areas for primary care clinics), with the balance to be covered approximately one year later. The ***Ministry of Health*** and ***DelAgua*** agreed to select the initial round randomly to ensure equity. As a result, a sector-level, cluster-randomized controlled trial was conducted to assess the impact of the intervention on health outcomes, using records maintained by the clinics and CHWs (the “clinic-level RCT”). Concurrently, 87 villages were randomly selected from each arm of the sector-level RCT for a nested village-level RCT where coverage could be assessed along with uptake (use), exposure, and other measures of health outcomes (reported, CHW recorded, instrumented and potential blood-based biomarkers) (the “village-level RCT”)[10]. The implementer delivered the intervention to approximately 100,000 eligible households within the 72 intervention sectors (during the period of September through December 2014) [10]. The novelty of this analysis is that it offers an interpretation of the impact of the health intervention in macroeconomic terms. Typically, studies measure health effects and present them as such. With our analysis, we have moved a step forward, and translate health effects (that are micro in nature) at a macro level, by calculating the actual impact in terms of Gross Value Added (GVA). Through this analysis, comparisons among different interventions are made, and impacts are defined in a country-specific context by taking in account national socioeconomic parameters.

3 METHODOLOGICAL APPROACH

3.1 The Study Population

The main aim of this work was to design an approach that could reliably measure and monetize productivity improvements of a healthier population due to the Program, including improvements that are related to the decrease of children caregiver burden. Furthermore, the biggest challenge was to identify available data that could be used to support the Social Impact Analysis, and where data was not available, we estimated benefits by calculating the avoided costs. We adopted two different approaches, one for the impact of the intervention on children and their caregivers, and one for the impact on the adult population (the overall model is described in more detail in the following parts).

The model we developed analyzed a population of 1,000,000 children in Rwanda, under the age of five that are at risk of having diarrhea, acute respiratory infection (ARI) or were at risk of dying. Furthermore, the model accounted for the impacts of the child population that became ill from those two conditions on the adult caregivers, in terms of productivity reduction. The adult population, men and women, that was accounted for was 500,000 people[6].

For our analytical purposes, two scenarios were analyzed. The first scenario, that served as a baseline, showed the development of the population over one year, without the intervention. The second scenario included the effects and the costs related to the intervention.

Our methodological approach included two aspects that were used to estimate the broader impact of the interventions in socioeconomic terms. The first aspect considered the gains that are related to the avoided costs related to children under 5 years old, that do not get sick due to the improvements brought through the intervention. The other aspect relates to the gains of the adult healthier population, both in terms of the

[6] From the data base of the 400,000 households that is available to us, we have the following breakdowns [6] :

- 1 million children (there is no indication by gender of the children)
- 270,000 women
- 230,000 men
- The age distribution of the adults (above 16 is) 85% up to 60 and 15% above 60

calculated paid and unpaid benefits. Hence, our model required to identify or produce available data from the literature to quantify the monetary benefits due to the decreased medication costs, the lower hospitalization rates, and the reduction of the caregiver burden (averted wage loss) that was attributed to a healthier children population (for children of 5 years old and under). Furthermore, we used reported data to calculate the societal impact due to improved productivity of the adult population based on Averted Disability-Adjusted Life Years (ADALYs). The data we used were from various sources on file from ***Signina Capital***, the Kirby (2019) study [10], and further insights derived through the UN CDM program 9626.

As an additional note, while reviewing the data related to the intervention, we noticed that the following information was not available:

- The incidence of ARI and diarrhea for the population that the intervention was applied at (instead we used age- and disease-specific incidence for Rwanda).
- Rwanda-specific data on costs for the following:
    - Medicine for ARI (instead we reverted to data for low- and middle-income countries).
    - Hospitalization for ARI and diarrhea (instead we used proxy data, e.g. from Bangladesh)
    - Caregiver for ARI (instead we used data for low- and middle-income countries).

This analysis followed a two-step approach that is described in the following section.

3.2 Quantifying the avoided costs due to a healthier children population under 5 years of age: A Markov state-transition model

This model was developed to estimate the effects (health outcomes and costs) of the ***Tubeho Neza*** program over a period of one year. The model simulated the transition among different discrete health states of the average child patient. The cycle length that set for this model was one week because of the average duration of the disease. Two scenarios were analyzed, that of the situation with "no intervention" and that with the intervention.

The model is structured based on the existence of four discrete health states: Healthy state, Diarrhea state, ARI state, and Dead state. The model presumes that all patients at baseline are at the healthy state. The transitions across health states along the four conditions is determined by the transition probabilities (TPs) and are adjusted by the effects due to the intervention. In other words, these effects indicate the reduction of the disease incidence (Diarrhea and ARI) when the intervention is available. Patients remain healthy or can move among the various conditions, except for the state of being dead, where, by definition, this is an absorbing state. Figure 4 portrays the model design and the various health states.

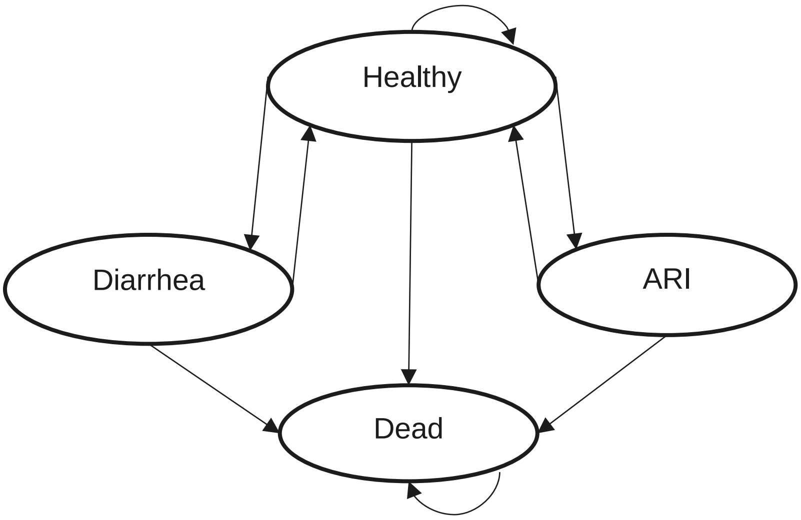

Figure 4: The four discrete health states and the movements among them

The model also estimated the three major cost elements that are associated with the diseases, that of expenditures of medication and hospitalization and the loss of wages of caregivers due to the child's hospitalization. These costs were estimated from the societal perspective, which in actual terms reflected a full range of social opportunity costs**,** associated with the intervention activity. Therefore, the benefits of the Program's interventions are expressed by the gains or avoided cost differences, for both diseases, with and without the intervention. In *Annex 1* the Markov model inputs parameters and their estimations are listed, along with further details on how these were estimated. Also, following the input information, the model outputs, that are the health outcomes (calculated in DALYs) are presented and details on how these were derived are outlined.

Due to the short time horizon of the analysis, no discount rate was used.

3.3 Valuing the ADALYs in the Adult population

For the adult population, the Averted Disability Adjusted Life Years (ADALYs) was analyzed, in combination with socioeconomic parameters, in order to quantify the Social Impact. The total population (men and women) was 500,000 adults, and the time horizon was for one year, the year 2014.

Through collaborative scientific efforts, ***Tubeho Neza*** program has been able to collect systematic data for the purposes of program monitoring and evaluation [12],[25]. Further syntheses of the collected data have given rise to health metrics on the reduction of the disease burden in the targeted population, in comparison to control groups. The scientific methods used to validate the health metric used, ADALY, are elaborated in sufficient detail in Anenberg et al. [34].

In relevance to the model developed by WifOR, the ADALYs , being the mathematical complement of QALYs, i.e. both metrics are aggregate measures corresponding to one year lived in perfect health [35]. The health outcome of an intervention can be quantitatively measured as averted loss of DALYs, or as the direct gain in QALYs. On the other hand, the Social Impact Analysis captures the macroeconomic impact of a healthier population due to higher productivity and decreased incidence of Acute Respiratory Infections (ARI) and diarrhea. Furthermore, with regards to the adult population, the associated effects on adult population, distinctly, and strictly in their capacity as caregivers, was also estimated. This was accounted for in the calculation of avoided costs, due to better health of children, and is considered to indicate a specific gain associated to a healthier children population. Given the wide coverage of the program in Rwanda, this effect is regarded as relatively important.

Input parameters for the model were obtained from extended literature review and other online databases [36]–[39]. The methodology developed by WifOR Institute for measuring Social Impact was used and the outcome was presented in Gross Value Added for paid work and for unpaid activities.

The societal impact, in other words the socioeconomic benefits, that is represented by the activity gains associated with improved health, were quantified from a macroeconomic perspective. This was achieved through linking ADALYs with a measure of patient's paid and unpaid work activities. Country specific parameters from macroeconomic databases were used. To estimate a measure of paid work for individuals in the working age, ADALYs were valuated against the average annual labor productivity, i.e. the country specific gross value added (GVA) per employee. Thus, it was assumed that all adults who are younger than 60 years of age are economically active (either on full or part time basis). To quantify the activity gains beyond employment, information on the average time use in hours per day was used as a basis to attach a monetary value for unpaid work to each ADALY. In addition, the wider economic indirect and induced effects, initiated by an increase in economic activity, were also considered, by using country-specific value-added multipliers [38].

In conclusion, benefits were generated for the adults by both the incremental gains associated to the child population's caregivers and also the monetized social impact for the adult population, due to health improvements that followed the Project's interventions. These were then aggregated and translated into activity gains measured in terms of extra time of activity and were comprised of both paid and unpaid work. The Socioeconomic Benefits, as monetary contributions to the national GDP, were calculated and expressed in US dollars. Figure 5 and 6 below present the methodological process that this analysis has applied to measure the Socioeconomic Benefits, as well as the factors considered for measuring the Socioeconomic Footprint of a health intervention.

3.4 Socioeconomic Benefits Analysis

Once the health benefits are collated, as explained in the previous section, the activity gains associated with improved health for the adult population are quantified from a macroeconomic perspective. This was achieved through ***WifOR's*** methodology for linking ADALYs gains with a measure of patient's paid and unpaid work activities. Country specific parameters from macroeconomic databases by the United Nations (UN) or the World Bank are used. In the graph below (Figure 5*),* the scope of the Social Impact approach is graphically represented, where the total impact also includes spillover effects (indirect and induced) that are added to the direct effects in order to derive the total Social Impact of a health intervention.[7]

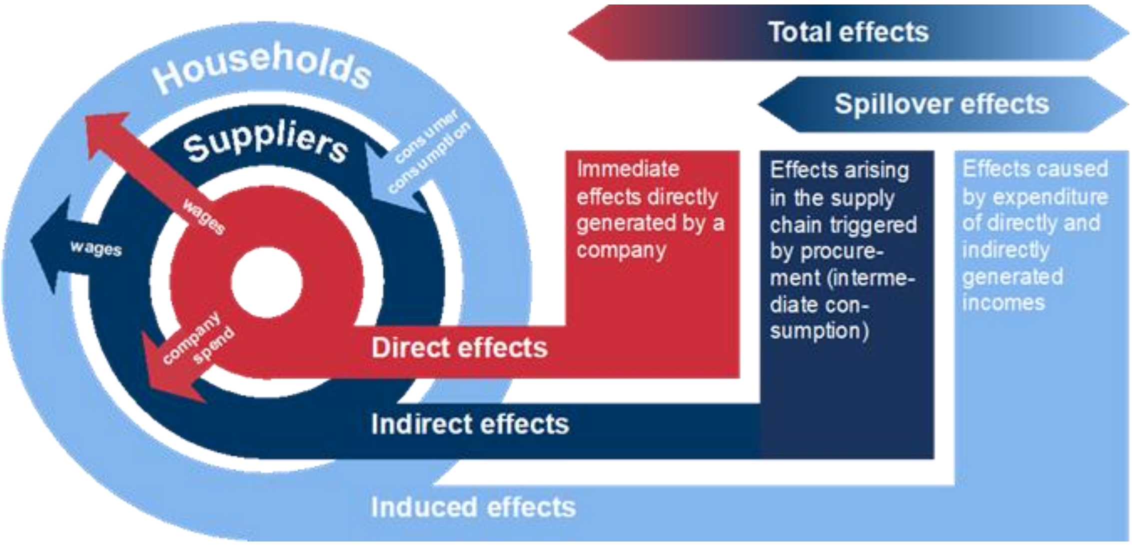

Figure 5: Scope of the Social Impact approach – Direct, indirect, and induced effects. WifOR Institute illustration

To estimate a measure of paid work for individuals in the working age, gained ADALYs were valuated against the average annual labor productivity, i.e. the country specific

[7] By direct effects we refer to the immediate economic impact – measured by Gross Value Added – which is generated by a person's activity or an intervention. The indirect effects arise along the process intermediate consumption of goods and services from suppliers. The induced effects are ones that are captured through the impact of further spending of the income related to the direct and indirect effects. Direct, along with the indirect and induced effects (spillover effects) sum up to the overall effect.

Gross Value Added (GVA) per employee [36], [38]. Thus, it was assumed that the population under 60 years of age are economically active (either on full or part time basis), and children were excluded from the analysis (we treated the health intervention benefit associated to the children population separately, as a distinct benefit generated by the interventions, as described in the chapter before).

To quantify the activity gains beyond employment, information on the average time use in hours per day [37], was used as a basis to attach a monetary value for unpaid work to each ADALY. Data on unpaid work activities was only available in highly aggregated form. On this account, the amount of unpaid work in terms of GDP contributions was approximated in two steps. First, built on the assumption that GDP per capita [36] reflects the amount of paid work per capita, the measure was multiplied by the ratio of time use for paid and unpaid work per capita. The ratio can be interpreted as people spending a factor of the amount of time for paid work additionally on unpaid work (e.g. housework, informal care or voluntary work) [40]. In a second step, the resulting figure was multiplied by an estimated factor, which was intended to reflect that unpaid work activities have a lower labour productivity than average across all sectors of the economy (

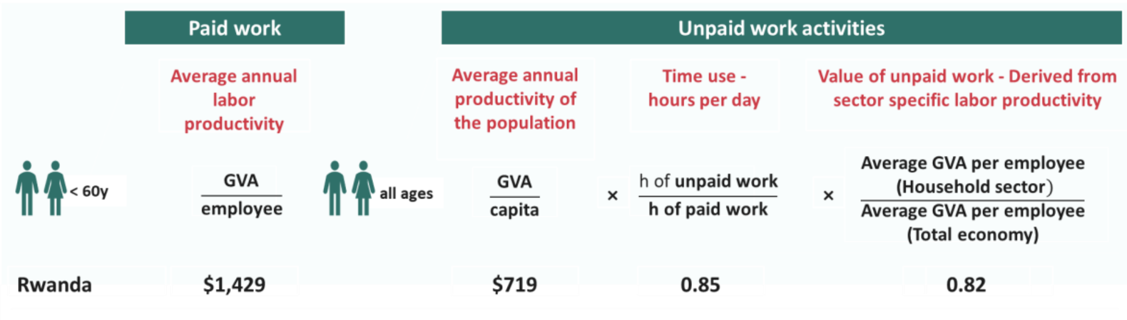

Figure 6).

In addition, the wider economic indirect and induced effects initiated by an increase in economic activity were taken into account by using country-specific value-added multipliers.

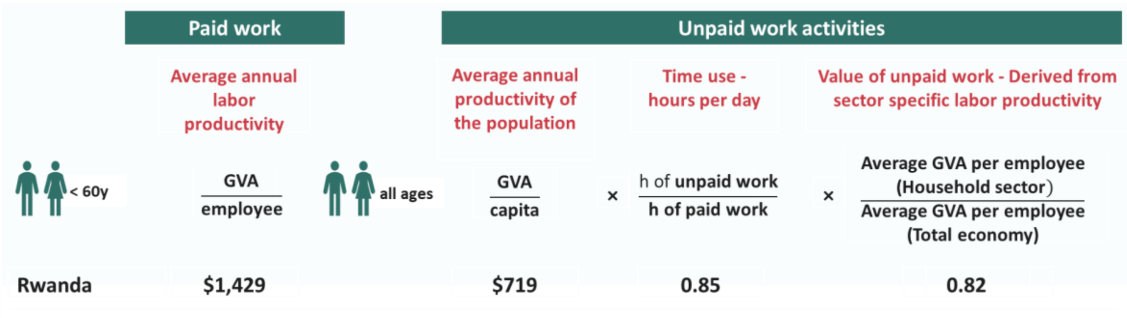

Figure 6: Parameters used in deriving the Socioeconomic Benefits

For Rwanda, due to data limitations, a few adjustments had to be made during implementation. There was no data on time use available from the United Nations time use portal or any other source. Therefore, it was necessary to identify a country whose values could be used as best proxy. We used Ethiopia as proxy country for time use statistics (hours worked paid and unpaid [36], [37]) and sector distribution of employment [36], [38] and GVA for the purposes of the Social Impact Analysis. Ethiopia was chosen as proxy country based on geographical distance, economic development (GDP per capita) and level of human development (Human Development Index) [36], [39].

4 THE RESULTS

The results will be presented at two levels following the rationale of the approach that was developed (see 3.1 and 3.2): a. In terms of the socioeconomic gains that are associated with the children under 5 years of age population and b. In terms of the socioeconomic gains for the adult population.

The socioeconomic gains that were associated with the children population under 5 years of age amounted to US$ 2.7 million. This is the benefit generated for one year as a result of the ***Tubeho Neza*** program when accounting for the avoided costs of children medication, hospitalization, and their caregivers' gained wages, for both diarrhea and ARI (the detailed outcomes of the Markov model can be found in the table in *Annex 2*). As to the socioeconomic gains as a result of the program for the adult population, on a yearly basis, the monetized social impact benefit that was calculated was a GVA of approx. US$ 6.4 million[8] (***WifOR*** Social Impact model calculations), including the direct, indirect, and induced impact, for both paid and unpaid activities. The analysis within the adult population was based on published ADALYs for the year 2014: 593 ADALYs for diarrhea and 965 for ARI - generated by the adult population of 500,000 people (women and men). Figure 7 illustrates the breakdown of the benefits that are associated with the adult population.

Figure 7: The social impact benefit in GVA

On the next page in Figure 8, the overall results are presented in two distinct socioeconomic benefits of the total population. Our approach adopted a two-level estimation for measuring the socioeconomic benefit, one in averted cost gains in US$ and the other in GVA gains in

[8] The Social Impact included both paid work (US$ 4,633,811) and unpaid activities (US$ 1,739,804), that sums up to a GVA of US$ 6.37 million.

US$, with the overall annual benefit for Rwanda related to the ***Tubeho Neza*** program, estimated to be at US$ 9.1 million.

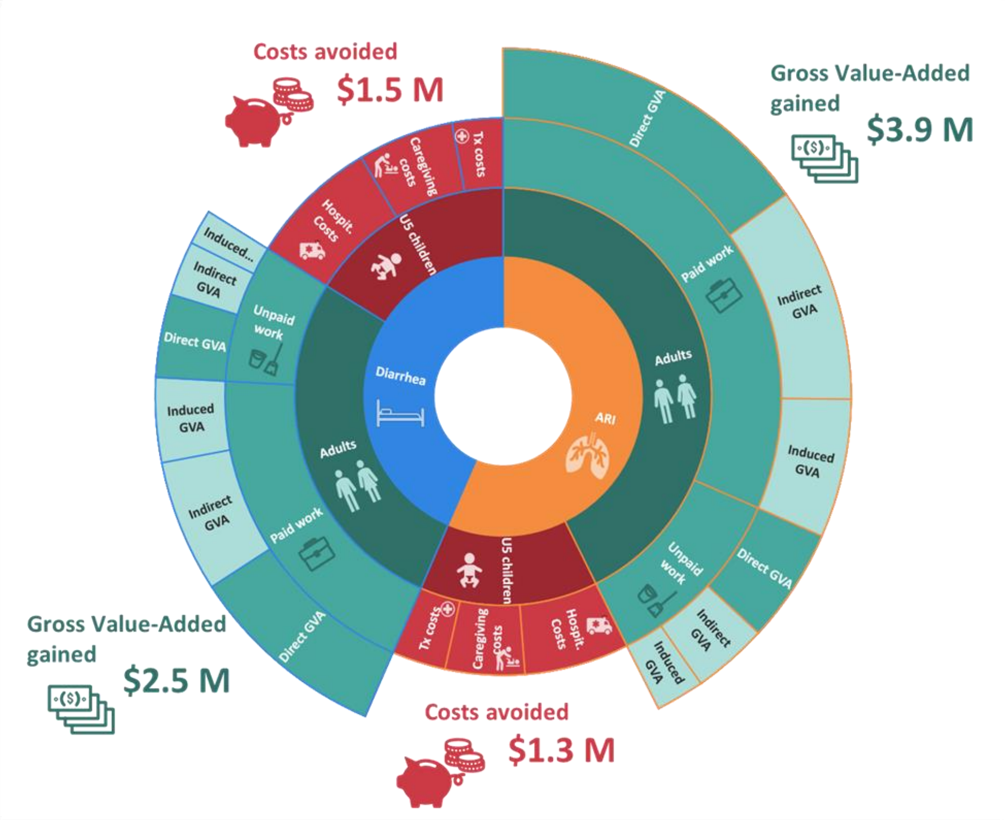

Figure 8: Overall socioeconomic benefit - Tubeho Neza yields annual socioeconomic gains of US$6.4m in adults and additional benefits of US$2.7m for children under 5

Viewing the gains of the ***Tubeho Neza*** program from a different angle, the cost analysis on the total population of 1.5 million people (1 million children and 0.5 million adults), over one year demonstrated an overall incremental cost of US$-3.96 million for diarrhea and US$-5.14 million for ARI, adding to a total of socioeconomic gain and additional benefits sum of US$9.1 million (US$2.7 avoided cost of illness added to the US$6.4 of GVA of socioeconomic gain). Therefore, this socioeconomic benefit offsets by far the total cost of the intervention (water filters and cookstoves) of US$5.6 million**.**

For the adult population, for the year 2014, the averted DALYs (or ADALYs) were 0.0031 and the avoided socioeconomic burden of diarrhea and ARI was US$-9.02 per adult (see Figure 9).

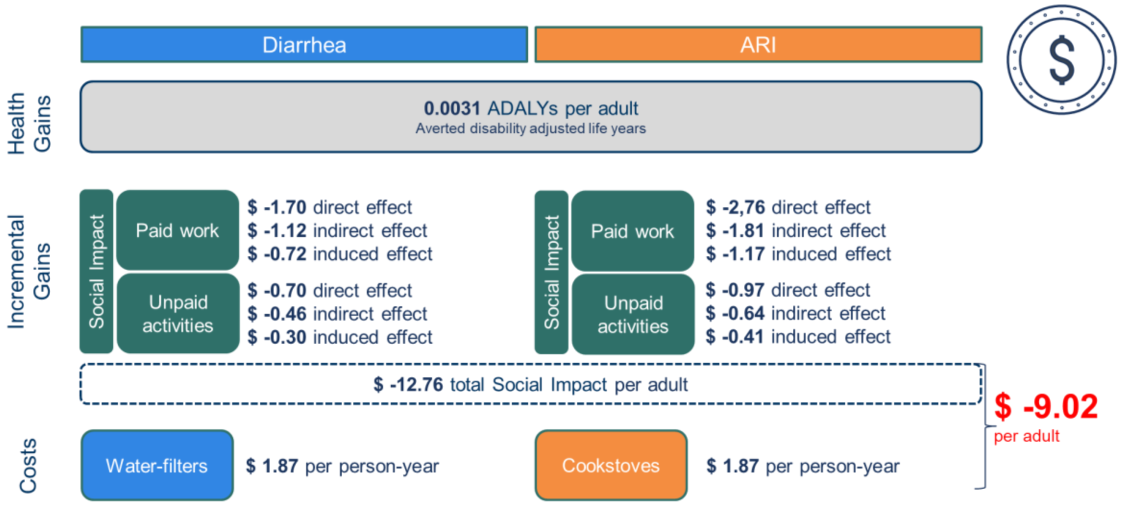

Figure 9: Overall benefits for the adult population - Averted DALYs (ADALYs) and avoided socioeconomic burden of Diarrhea and ARI per adult person in Rwanda in 2014

For the child population, the averted DALYs (ADALYs) were 0.0026 and the net costs of the intervention after subtracting the benefits due to avoided cost of illness of diarrhea and ARI, for the year 2014, were estimated at US$1.01 per child (see Figure 10*).*

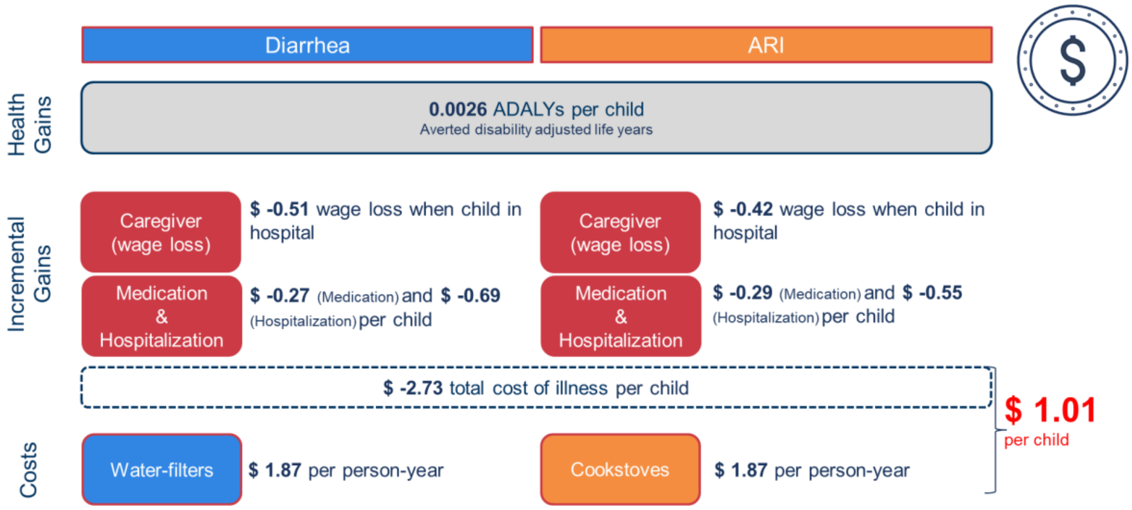

Figure 10: Overall benefits for the child population - Averted DALYs (ADALYs) and avoided cost of illness of Diarrhea and ARI per child in Rwanda in 2014

In summary, the ***Tubeho Neza*** program yielded a net monetary benefit per person of US$ 11.75 (a total incremental gain of US$12.76 + US$2.73 - US$3.74 intervention cost of water filters & cookstoves) per person-year. This result corresponded to an overall monetized health gain of US$0.0057 (0.0031 ADALYs per adult + 0.0026 ADALYs per child) of averted DALYs for the year 2014). See Figure 11 for an illustration of these results.

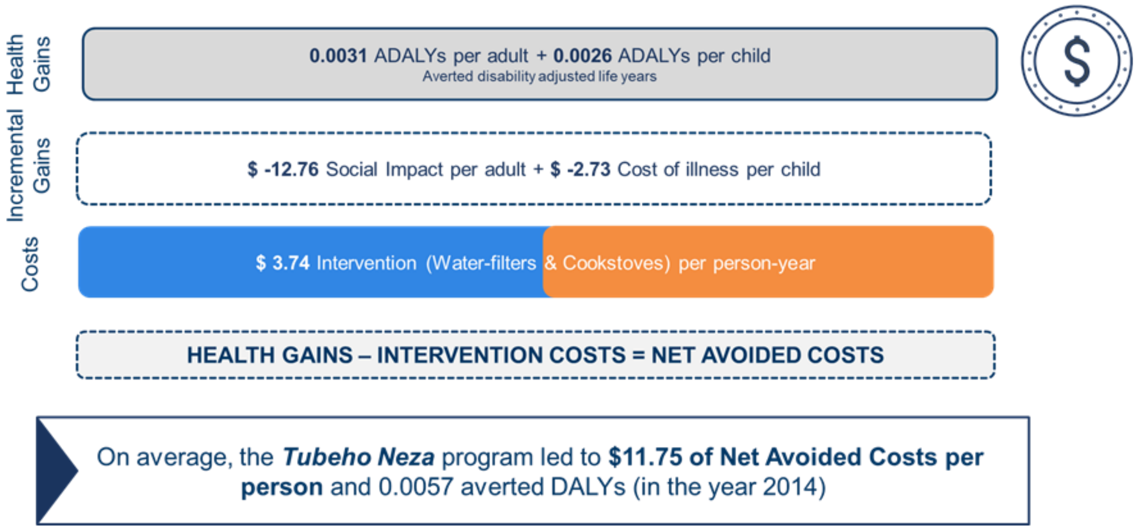

Figure 11: Overall avoided cost per person of the Tubeho Neza program - Per person health and incremental gains and costs of the Tubeho Neza program in Rwanda

As to the residents per household, we assumed that the average household comprises of 3.75 persons. This is derived by dividing the overall population considered of 1,500,000 people by 400,000 households that were analyzed, that gives us a result of 3.75 person per household (this is based on data from various sources on file from Signina Capital, Kirby (2019) [10], and further insights derived through the UN CDM program [19]. Please note, however, that the information on the number of people in the mean household varies across various sources (e.g. Barstow et al. [27] reported 4.5 and Kirby et al. [10] reported 5.2 person per household).

Alternatively, and accounting for the presumed size of the household as we stated, we can say that the net benefit, or avoided cost per household, is US$8.77.[9] The benefits that stem from the interventions accrue to the people living in the community, and since the way that these gains are distributed cannot clearly be traced, we present the two alternative approaches of measuring them, both demonstrating a very strong impact.

[9] This is derived as follows: 2.5* $2.73+1.25*$12.76 = US$ 22.77 minus the cost per intervention of US$ 14 per household, that results to an average benefit per household of US$ 8.77. We have assumed that the numbers of children and adults per household is 2.5 and 1.25, respectively, and weighted the net avoided costs of US$2.73 and US$ 12.76 (for children and adults respectively) due to the intervention.

5 FINAL REMARKS AND LIMITATIONS

The current report arguably delivers an innovative, ground-breaking impact analysis that provides insights and quantified visibility on value aspects for investments in health interventions. Although the scale of the project is confined to specific rural areas of Rwanda, the insights provided by the analysis offer quantitative evidence of the societal value of interventions as the ones analyzed, which can set the ground for designing new governmental policies, private-public partnerships, and corporate social responsibility programs. The Social Impact Analysis approach, as a way of valuation, is also suggesting a new approach for the assessment of health investments, one where the socioeconomic benefits of a health intervention, viewed as returns to an investment, can be quantified and compared with other investments. Measuring these returns in Gross Value Added – GVA allows various public and private interventions to be compared. Due to the paucity of relevant data, we chose a hybrid approach in this analysis, presenting values in terms of GVA for the impact on the adult population where data was available. For the case of the impact associated with a healthier child population, we estimated values in terms of gains in averted costs and wage losses of caregivers that are associated with children being ill. We contended that the benefit for the children is even better captured when combining both the immediate health benefits (drop of mortality or incidence of diseases) and the gains in terms of averted costs. Results for both categories were expressed in US$, and conceptually, although not the same, the sum could offer a quantified order of magnitude of the benefit associated with the ***Tubeho Neza*** program within a specific time period (a year in our case - 2014).

Having said that, however, in this section we list the main set of assumptions that we could expect to compromise, to some extent, the certainty of our estimates. For the most part, however, we believe that the uncertainty brought about by the assumptions made is acceptable given the scope of this study's analysis, that is to primarily deliver insights on the societal returns of large-scale health interventions and give further food for thought, in an explorative way, for the design, the prioritization, and the need for implementation of such projects in similar setups around the world.

As more project-specific experience and knowledge accumulates, ***WifOR Institute***, along with the commissioning parties and other key partners, is committed to continuously improve and refine the methodologies and assumptions made for future implementations of similar analysis.

The underlying assumptions, in the context of the analysis that is presented in this report, are elaborated in the following points:

1.The health gains reported for a studied population in the literature did not always coincide absolutely with the target population of the intervention in question. The latter is characterized by age (younger than five years) and caregiver reported diarrhea and ARI in the past seven days (before survey). The studied population in the literature however, diagnosed by healthcare professionals, was defined in terms of in or outpatient treatment. The degree of precision depends on the extent to which the studied population's characteristics are similar with the target population, something that, in the absence of formally recorded data or information, could be a factor with questionable reliability (e.g. the data on the sickness of children was based on reported information by caregivers).

2. While ADALY is an aggregate metric of survival and quality of life, we assumed that one ADALY is equivalent to one person-year of full capability of performing paid and unpaid activities.

3. No discount rate was used in the model since the time horizons defined were small. Although, strictly speaking, values shall be all converted into present values to be comparable, the study assumed that these differences are insignificant and would not affect the results.

4. Details on the differences on the adult populations' characteristics were not considered. It was assumed that an average person has the same economic profile with the population's average person, e.g. the amount of time spent working.

5. The child population under 5 years of age that was analyzed, is assumed to all have two major health burdens, related to diarrhea and ARI, and all the adult population is assumed to be providing caregiver services to children. Due to the importance of these two diseases in terms of the morbidity and mortality of the child population, we considered that this is a reasonable assumption to make. Also, the model was designed so that a child could either suffer from diarrhea or ARI. It does not cover the possibility to have both diseases at the same point in time. No differences in severity of diseases

were made in terms of different health states in the Markov model. However, we differentiated between moderate and severe forms for the calculations of hospital costs and wage losses of the caregivers.

6. Expressing the Social Impact in US$ (not the national currency) neutralizes the inherent association that exists between the monetary gains and the living costs in the country (or the region of the country in our case) that is analyzed.

7. Since Rwanda is a developing country, it is expected that the informal economic sector plays an important role. Not taking the informal sector into account in our calculations might have biased our estimates when calculating the GVA generated due to unpaid work.

8. As far as our data sources allowed for, Rwanda-specific data was used in the Markov model. When no specific data was available, e.g. costs for hospitalization or costs for medicine for ARI, we applied data from proxy countries such as Bangladesh or low and middle-income countries (LMIC).

6 FUTURE EXTENSIONS

The effects of improved health on the population as well as the strong Social Impact results and societal gains from a healthier child population support the idea of pursuing the current Program and implementing other similar programs.

In what concerns this Program, although the health benefits alone for both the child and adult population are a strong reason for expanding the reach of the program, an increased coverage would also bring significant economic value, and hence economic development, to the regions that the program was implemented. Moreover, when leveraged with the Social Impact results, from the macroeconomic perspective of the country, then an even more compelling case is made for investing in such health interventions. Society and the economy both benefit from improved health conditions, which is demonstrated by a positive, and relatively high per person net gain of US$11.75 (or alternatively viewed, when considering the household, that is a similarly high benefit per household of US$8.77) for the population where the ***Tubeho Neza*** program was implemented.

In further developments of our analysis, ***WifOR Institute*** will be willing to explore other areas of potential impact of the ***Tubeho Neza*** program, e.g. decreased time in pregnancies due to reductions in mortalities for ages under 5 years, decreased care giver burden, and the associated impacts on the gains in productive time spent on paid and unpaid work, and the like. Moreover, some further analysis on the various dependencies that relate to the root cause of environmental and health problems could shed more light on the interrelations of the various factors that have an impact on both the environment and hence on peoples' health (for example, the use of batteries is one such factor that, if substituted with alternative technologies, could limit the negative effects and improve environmental health conditions).

It is also worthwhile noting that several plans are under consideration for future corporate sponsorship programs that will aim to tackle the supressed demands[10]. For instance,

[10] Suppressed demands (such as inadequate levels of education, low income, poor infrastructure) is the situation where the required Minimum Service Levels (MSL), for the human development are unavailable or inadequate[41]. Suppressed demands place a challenge in the implementation

MAJI Holding refers to the idea of delivering simple items to the poorest communities as a way of overcoming barriers of suppressed demand [4]. This idea aims to support the funding of this multi-faceted initiative, catalyzing change across Africa, and possibly in other poor regions, with actions that will be focusing on providing clean water and safer or healthier air. Such a sponsorship initiative offers an opportunity to procure full spectrum health and clean climate change solutions to African communities, powered by the private sector financing.

Given the additional expertise developed through this program, ***WifOR Institute*** would be ready to partner with supporters of similar projects aiming to demonstrate the extended impact deriving of humanitarian initiatives. The measurement of this impact would allow to optimally finetune the structure and reach in order to have the maximum benefit.

Finally, there are plans for a retail program that will help to deal with suppressed demand.

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and the effectiveness of new interventions in poor communities, as their real demands are not properly reflected [42]

7 CONCLUSIONS

The socioeconomic impact analysis that was conducted for the ***Tubeho Neza Public Health Program in Rwanda*** has resulted in the development of an innovative approach combing the **Social Impact Analysis** methodology, developed and applied by ***WifOR Institute*** to calculate the macroeconomic value outcome of a health intervention, with that of a **Markov decision process**[11] approach. The integration of these two approaches allowed us to quantify the societal impact of the investments associated with this large-scale, environmental health intervention and to present a novel way of addressing the impact analysis of such initiatives.

Our analysis demonstrated that the ***Tubeho Neza*** Program yields **annual socioeconomic gains of a total of US$9.1 million**, of which **US$6.4m pertain to the adult population and US$2.7m to wider additional gainsincluding US$0.9m of caregiver costs that are associated with the health of children under 5 years old).** A unique and central element of the socioeconomic impact analysis is the quantification of the caregiver impact, which demonstrates the significance of caregivers to society.

When we look at the results from an individual point of view, these showed that there was a **benefit**[12] **per person of US$11.75**, which can objectively be considered a strong result especially when interpreting this in the context of the country's relative wealth and development level. Alternatively, and accounting for the size of the household (a typical family of four persons was assumed), we can also conclude that the **net benefit**, or avoided cost per household, is **US$8.77**. We argue that the benefits stemming from the interventions accrue to the people living in the community. As the distribution of the gains cannot be clearly traced, we present the two alternative approaches of measuring them, both however **demonstrating a very strong impact**.

If we breakdown the benefit for the adult population, the analysis concluded that there is a benefit of **US$9.02** of avoided socioeconomic burden related to ARI and diarrhea **per adult** in Rwanda in 2014. For the child population, the benefit was estimated to be

[11] a Markov decision process is a discrete time stochastic control process

[12] the **benefit is the net avoided cost** that is derived from subtracting the intervention costs from estimated health gains

US$1.01 of avoided socioeconomic burden related to ARI and diarrhea **per child** in Rwanda in 2014.

From a return-on-investment perspective, we can argue that **US$1 spent on the intervention resulted in US$3.1 for society** (US$11.75 benefit / US$3.74 cost).

Moreover, when compared to the average cost of cookstoves and water filters per average household, **the monetized outcomes of the *Tubeho Neza* program of US$9.1m by far offset the costs of the interventions of US$5.6m.**

Our analysis assumes that the gains in the adult population are related to **improved productivity in both paid and unpaid work activities**. Additionally, downstream value chain spill-over effects that are associated with **paid and unpaid work** were also captured and aggregated in our analysis and were shown to be relatively significant as a proportion of the total effects. For the under-five child population, cost savings related to avoided caregiving, medications, and hospitalizations were quantified and aggregated in monetary terms.

From an analytical standpoint, we have demonstrated through this analysis that there is an **emerging alignment between health impacts** (as expressed by ADALYs) **and monetized benefits** (that are associated with the ADALYs calculated). This means that the two main intervention parameters that were studied, providing water filters and cookstoves, proved to be pivotal in improving health states. Hence, this result, as a combined effect, brought wealth to the society in Rwanda. As an overall conclusive note, we claim that the effects of healthcare interventions can be measured beyond their mere medical results. Additionally, we conclude that our approach could offer important policy insights and evidence-based information for maintaining and further supporting such initiatives.

Taking a different perspective, we can make an argument that simple and low-cost interventions, such as the ones that were analyzed, not only have a dramatic lifesaving and quality of life impact but also a profound socioeconomic effect. In addition, in terms of the type of intervention and the way it was implemented, we can highlight the importance of partnering between various stakeholders to meet specific health ends – in this case the improvement of a population's well-being by decreasing the effects of two major causes of illness, mortality and poor health.

Lastly, the multi-parameter analysis developed for this case study, and its demonstrated impact, may serve as a pilot case offering a guide to future similar projects that aim to improve the environment and health and thus contribute to overall welfare and economic development.

Annex 1

Input Parameter	**Description**	**Value**	**Reference**
Transition Probability			
Healthy to Diarrhea	Weekly probability of moving from Healthy state to Diarrhea state	0.005	[43]
Health to ARI	Weekly probability of moving from Healthy state to ARI state	0.004	[43]
Mortality probability			
Dying from Diarrhea	Weekly probability of dying from Diarrhea	0.00028	[44]
Dying from ARI	Weekly probability of dying from ARI	0.00033	[44]
All-cause mortality	Weekly probability of dying from all other causes	0.00021	[44]
Effect of intervention			
Water filters	Reduction of Diarrhea prevalence reported by caregivers[13]	0.71	[10]
Cookstoves	Reduction of ARI prevalence reported by caregivers	0.75	[10]
Costs			
Intervention	Weekly costs for water filters and cookstoves per person	$ 0.08	[11]
Medicine Diarrhea	Weekly costs per child for Diarrhea-specific medication	$ 1.42	[45]

[13] This is the prevalence ratio as reported in Kirby et al 2019 [10]. The prevalence of Diarrhea is reduced by 29%, and therefore the prevalence ratio (PR) is 0.71.

Medicine ARI	Weekly costs per child for ARI-specific medication[14]	$ 1.86	[46]
Hospitalization Diarrhea	Weekly costs per child for Diarrhea-specific hospitalization[15]	$ 5.45	[47]
Hospitalization ARI	Weekly costs per child for ARI-specific hospitalization[16]	$ 5.82	[47]
Caregiver Diarrhea	Weekly wage loss due to Diarrhea-specific hospitalization	$ 4.02	[45]
Caregiver ARI	Weekly wage loss due to ARI-specific hospitalization	$ 4.40	[45], [48]
Share of hospitalization Diarrhea	Children who need hospitalization due to illness and cannot be treated as an outpatient	0.66	[49]
Share of hospitalization ARI	Children who need hospitalization due to illness and cannot be treated as an outpatient	0.62	[50]
Disability weights (DALYs)			
Diarrhea		0.22694	[43]
ARI		0.27626	[43]

Annex 1: Inputs used in the model

[14] Value based on low and middle-income countries (year of assessment is 2001)

[15] Due to the fact that there were no data available on the cost of hospitalization for both diseases for the age group of children under 5 years old in Rwanda, we used Bangladesh as a proxy country, given that it has a similar country profile to Rwanda, and hence we used data of the year 2007 from a study from Bangladesh.

[16] Due to the fact that there were no data available on the cost of hospitalization for both diseases for the age group of children under 5 years old in Rwanda, we used Bangladesh as a proxy country, given that it has a similar country profile to Rwanda, and hence we used data of the year 2007 from a study from Bangladesh.

Model inputs

The input parameters were obtained from the following literature and calculations. The parameters in the category "effect of intervention" indicate a lower TP from the Healthy state to the state of Diarrhea or to the state of ARI in the "Intervention" scenario. These parameters correspond to the prevalence ratios (PR) that are published in Kirby et al. [10]. The weekly TPs from Healthy to Diarrhea or to ARI were obtained from age specific incidence for Rwanda [43]. The TPs that relate to dying from diarrhea or ARI were obtained from the age-specific rate of deaths for Rwanda, while the TP that relate to dying from other causes (background mortality) was taken from the age- and country-specific death rate from GBD [43] [44]. The annual rates were divided by 52 (weeks per year) to yield the weekly probabilities. Given these parameters, the TPs for remaining in or transition to the Healthy state and probabilities of recovering from diarrhea or ARI were calculated (see

Figure 12 below).

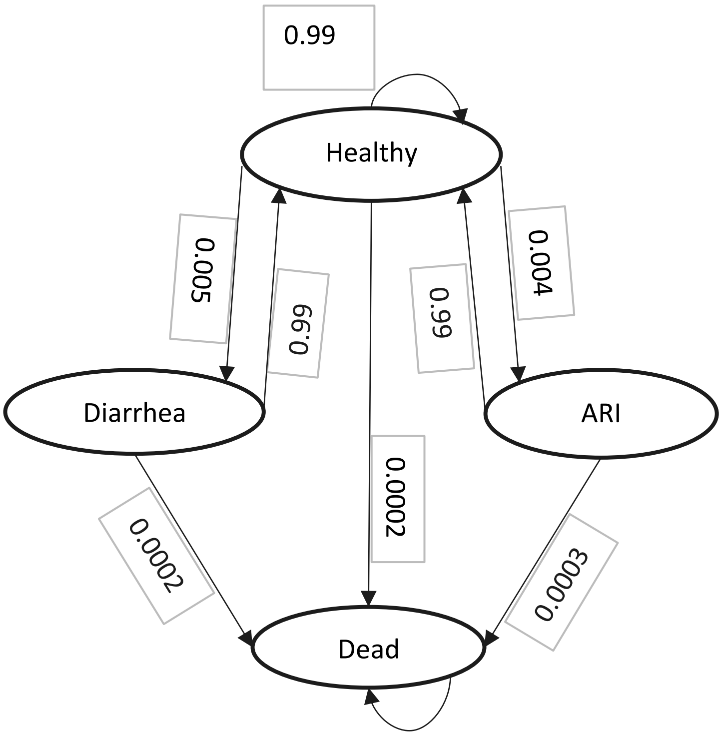

Figure 12: The four discrete health states and the TPs estimates among them

Finally, the costs of the intervention (water filters and cookstoves) were obtained from a published economic evaluation of the interventions. These costs are reported as recurring annual costs per device per household [11].

Model outputs

The health outcome was presented in disability adjusted life years (DALYs). DALYs are the sum of years of life lost and years lived with disability:

DALY = YLL + YLD

Where:
YLL: Years of Life lost
YLD: Years lived with Disability

YLL represents the premature death and combines disease-specific deaths with age-specific life expectancy in Rwanda [44]. YLD is the product of the prevalence and disease-specific disability weights (DWs), provided by the Global Burden of Disease study 2017 [43].
The DWs are specific for moderate and severe form of illness. We assumed that all hospitalized children would have severe DW and if treated as outpatients they would have a moderate DW. With the given shares of those treatment options, we weighted the DWs and obtained a weighted average DW for diarrhea and for ARI [43] [49] [50]. DALYs were modelled for both scenarios.

Costs were estimated from the societal perspective, which included medical costs (medication and hospitalization) and non-medical costs (wage loss of caregiver). This data was obtained from literature and increased to the year 2014 (if reported for e.g. 2001 or 2007). Using the Consumer Price Index (CPI), which allows to calculate how much higher the prices were in 2014 as compared to 2001 or 2007, the CPI-ratio of 2014 and 2001/ 2007 was multiplied by the nominal value. Medication costs for diarrhea were taken from Ngabo et al. who reported average costs per episode for the year 2014 [45]. It is evident that a child is suffering an average of five episodes per year, hence the costs were calculated in yearly costs and then were translated in weekly costs [51]. Same cost component for ARI were taken from Simoes et al., who published data per episode for 2001. The calculation was conducted accordingly for the diarrhea costs and similarly increased to the year 2014 [46] [51]. Costs of hospital stay for both diseases were obtained from Halder et al. [47]. The average costs per episode for 2007 were converted in costs per week and adjusted for the year 2014. The non-medical costs in this model are the caregiver costs in terms of wage loss per day. Ngabo et al. reported Rwanda-specific average household lost income due to child`s length of stay in the hospital [45].The length of an episode for diarrhea was estimated to be 5.3 days while for ARI 5.8 days and these figures were included in the calculations [45], [48].

Annex 2

		No intervention	Intervention	Incremental Costs (Intervention minus No intervention)
		Total per year per 1,000,000		
Diarrhoea	Medication	$ 382,888.80	$ 111,711.14	$ -271,117.66
	Hospitalization	$ 969,008.61	$ 282,868.55	$ -686,140,05
	Caregiver	$ 713,866.27	$ 208,388.57	$ -505,477,70
ARI	Medication	$ 382,675.92	$ 96,300.86	$ -286,375.05
	Hospitalization	$ 740,486.12	$ 186,344.24	$ -554,141.88
	Caregiver	$ 559,666.80	$ 140,840,83	$ -418,825.97

Annex 2: The breakdown of the incremental costs that were calculated with the Markov model

The cost analysis was implemented over one year for 1 million children for the diseases diarrhea and ARI. These demonstrated incremental gains of **US$1.46 million for diarrhea and US$1.25 million for ARI**. These gains break down in costs for caregivers due to wage loss (US$505,447 diarrhea/ US$418,825 ARI), hospitalization (US$686,140 diarrhea/ US$554,142 ARI) and medication (US$ 271,118 diarrhea/ US$286,375 ARI).

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