Rainwater harvesting (RWH) for resilience to climate change impact on water availability in Ghana:

Sustainability assessment of selected RWH designs

Report from Activity 1, October 2013

Photo: SNAP/CREATIVE COMMONS

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1 Introduction

1.1 Background

The project "Rainwater harvesting (RWH) for resilience to climate change impact on water availability in Ghana" is funded by the Nordic Climate Facility (NCF) of the Nordic Development Fund (NDF), and implemented through NEFCO. The aim of the project is increased resilience to climate change, by holistic sustainability assessment and implementation of RWH system designs based on standardized criteria that will offer affordable, appropriate, and cost-effective RWH solutions, including monitoring and disinfection, for safe urban water supply. The project is a collaboration between SINTEF, Norway, and the Water Research Institute (WRI) and the Science and Technology Policy Research Institute (STEPRI) of CSIR, Ghana. It runs from January 2013 to January 2015, and is centred geographically on the Greater Accra Metropolitan Area (GAMA).

This report is a deliverable from Activity 1: "Assessment of different technical alternatives for small-scale RWH, and development of standardized design criteria for appropriate and innovative model RWH systems for households and schools", as per Milestone 2, 2013-10-21**.**

1.2 Climate change and water availability in Ghana

Ghana is already affected by climate change and predicted to be a water stressed country by 2025 (Kankam-Yeboah, Amisigo and Obuobi, 2009). According to the CSIR-WRI 2000 report on climate change and water resources we will see:

- A general reduction in annual river flows in Ghana by 15-20% for the year 2020 and 30-40% for the year 2050.
- A reduction in groundwater recharge of 5-20% for 2020 and 30-40% for 2050.
- An increased irrigation water demand of 40-150% for 2020 and 150-1200% for 2050.
- A reduction in hydropower generation of 60% for 2020.
- By 2020, all river basins will be vulnerable and the whole country will face acute water shortage.

The quality of freshwater in rivers and other water bodies is also likely to be impacted negatively as the increased floods will carry pollutants into water bodies, restricting their use and putting further constraints on water availability.

According to WHO the minimum water requirement is 7.5 litres per capita per day. A quantity of about 20 litres per capita per day should be assured to take care of basic hygiene needs and basic food hygiene. Laundry/bathing might require higher amounts unless carried out at source.[1] At 20 litres the level of health concern is still "high", while at 50 litres it is "low".[2]

[1] http://www.who.int/water_sanitation_health/emergencies/qa/emergencies_qa5/en/index.html

[2] http://www.who.int/water_sanitation_health/diseases/WSH0302exsum.pdf.

The water consumption in Accra is reported to be in the range of 60 and 120 litres per capita per day (in the well served areas only) and 25 to 60 litres per capita per day when poor households buy water from vendors (Abraham et al, 2007).

While some projections (UNICEF WHO 2010) suggest that Ghana will reach its millennium development goal target of 78% for improved drinking water by 2015 this will require financial resources that cannot easily be found (Kokutse 2009). Information from the water providers also suggests that coverage is considerably lower than the most positive estimates. In the majority of Ghana's urban areas, water is rationed due to high demand and inadequate supply. In 2011, the estimated urban water coverage in Ghana as a whole was about 62%, while the un-served areas depend on secondary supplies, i.e. vendors, sachet water producers, and mostly tanker service delivery or dedicated GWCL filling points (TISDA 2011).

Climate change has made it more imperative that technology and innovation become the basis for meeting challenges in the water sector. Considering the population growth and rapid urbanization, RWH appears to be one of the most promising alternatives for supplying freshwater. However, a RWH-system can rarely be the sole source of water, but is normally supplemented by for example water from a tanker service or water supplied from other water sources.

1.3 RWH system designs

Rainwater harvesting is the collection and storage of rainwater before it reaches the aquifer. RWH can serve different purposes with respect to water use and the systems can be large or small. In this report we are mainly concerned with roof RWH systems for single households. The designs for households will be expanded for use in e.g. schools were larger systems are required.

RWH systems have various components that collect, convey and store rainwater. For simple collection of water during rains, they can be constructed in a multitude of ways. The challenge is to develop solutions that can provide water of good quality after days, weeks and months of storage required between rainy seasons, and that are environmentally, economically and socially sustainable over time. In order to identify the system(s) that will be most sustainable in the Ghanaian context, the project has developed different initial design alternatives for RWH systems, based on a compilation of components that are locally produced or easily can be made available in Accra.

The collection part of a roof RWH system consists of a catchment area, which may be a simple hard roof surface for a single household or a series of roof surfaces for communities such as residential estates, schools, hospitals and other public institutions. Conveyance components include gutters and piping to transport the water from the roof to the storage reservoir. Cleaning components may include first flush mechanisms to discard the water from first rains and filtration systems to prevent leaves, debris, soil particles and other contaminants from being carried to storage tanks or reservoirs. Disinfection systems may also be included in RWH systems, and are necessary if the collected water is to be used for potable purposes. Extraction and/or distribution systems are needed to provide a means of abstraction of the harvested water or its distribution within the house.

The combinations of the various components forming functional RWH systems are many. For example, there is a diversity of storage systems – from simple above ground earthen pots and metallic drums to fairly large below and above ground ferro-cement tanks to polyethylene (PE) tanks and very sophisticated metallic modular tank systems. Each of these storage systems come in various sizes and shapes and can be combined with collections systems of various types and sizes. Choosing an affordable, cost effective and environmentally friendly RWH system for a household or institution from the numerous alternatives can be a very daunting task.

Therefore, it is useful to select and develop system designs based on standardized criteria that will offer affordable, appropriate, and cost-effective RWH solutions, including monitoring and disinfection, for safe urban and peri-urban water supply. This report is about the initial assessment of various system designs, whereby some technical alternatives will be selected for further assessment through implementation, monitoring and evaluation of model systems for single houses and institutions (several or larger buildings).

1.4 Assessment approach

Besides efficiency in ensuring the microbiological quality of the water, the RWH system(s) should be sustainable with respect to environmental impacts, system costs, sociocultural acceptability and potential for dissemination (which also includes availability of skilled personnel able to provide repairs, availability of spare parts, or required maintenance in general). Thus, the assessment includes selection of initial design alternatives for RWH systems that are evaluated with respect to environmental, economic and social criteria/performance indicators. Results from the respective analyses are finally combined in a multivariate assessment, where the aim is to present a holistic, integrated view of the sustainability of the design alternatives.

In the discussion throughout the report, the perspective of the private household is given most weight, i.e. we focus mainly on what is a good solution and what indicators are relevant for a household given the conditions in GAMA. It should be noted, however, that different users will have different needs and interests, and the context of use may also vary greatly. Therefore, the ambition is not to identify one "best" system for all cases, but rather to show how the different designs compare along the studied dimensions, so that stakeholders promoting the technology as well as individual users may be able to make better informed and more appropriate choices.

The assessment presented in this report will be followed by a final assessment at the completion of the project, where the experiences and results from the implementation and monitoring of the 22 pilot systems will be included.

The present assessment is based on data collected in Accra in 2013. WRI and SINTEF collected information from local suppliers directly on components, including roofing materials, PVC and metallic gutters, PVC pipes, plastic tanks, and treatment components, including UV disinfection units, chlorine tablets, filtration media, and filtration vessels.
Specific data collected for each item were:

- Raw material and origin
- Transport of raw material from the production site
- Production location of the component
- Type of energy used for the production
- Transport type, transportation cost and average distance to final end-user
- Expected lifetime
- Maintenance frequency and cost
- Cost
- Transportation cost
- Installation cost
- Labour (man-hours)
- Labour mark-up

As the suitability of RWH for water supply depends on the rainfall for the given area, historical rainfall data from several measuring stations in GAMA were therefore collected. The rainfall pattern in Accra is typically as shown in Figure 1.1 with one major wet period (April to July), a minor wet period around October and dry seasons in August and from November thru February.

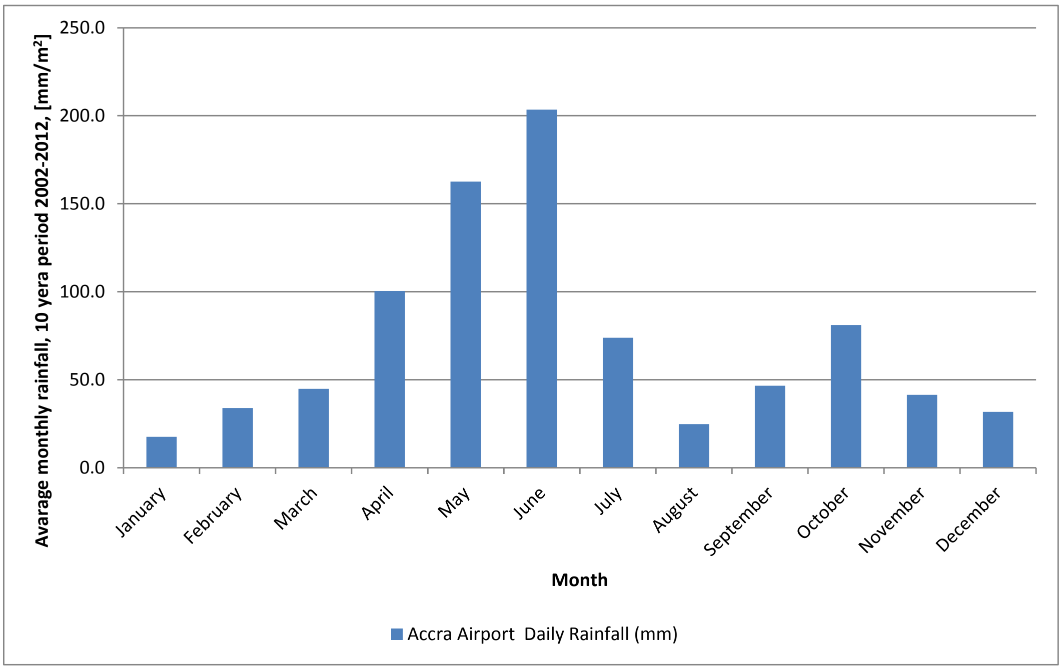

Figure 1.1: Monthly average precipitation for Accra (source: WRI).

The results of the study presented in this report are based on daily rainfall data for the 10 year period 2002-01-01 – 2011-12-31 from the meteorological station at Kotoka International Airport in Accra, which were found to be the most reliable and relevant for the areas targeted in the project. The assessment results are therefore specific for Accra, but extensions to the general case have been made when relevant.

Initially a baseline survey (chapter 2) was carried out, among 54 households in parts of the GAMA where there is difficulty in accessing water from the national water distribution network. The rationale was to assess the conditions prevalent in target areas before selecting the initial designs, and get an updated local empirical basis for the selection of criteria and indicators for the sustainability analyses. Topic areas in the survey included:

- General information about the household
- Current water situation
- Level of satisfaction
- Views on water alternatives
- Consumer choices
- Relations in the household
- Environmental consciousness
- Home environment and aesthetics
- Community relations
- Health and hygiene
- Subsistence

As a basis for the sustainability assessment, 36 initial design alternatives of RWH systems (chapter 3) were prepared to cover the range available to households. The initial designs were made to cover a range of water consumptions, roof sizes, storage tank volumes and water treatment alternatives, and were grouped in three main categories depending on complexity and cost: Basic, intermediate and advanced designs.

In the main analysis, the assessment of environmental sustainability (chapter 4) is based life cycle assessment (LCA). LCA investigates the environmental impacts of a product over its entire life, from raw material acquisition, through construction, transportation, use, to disposal. In the present study it aims at evaluating two scenarios, the first (noted scenario 0) corresponds to the scenarios where the water is supplied only by tanker service and the second corresponds to the scenario where RWH is combined with water tankers to meet the household water demand.

The social 'pillar' of sustainability is vaguely defined, and so far no consensus has emerged on what are adequate criteria for social sustainability (Murphy 2012). The tendency is that each project derives its own set of indicators and criteria specific to the intervention or research question analysed (Omann and Spangenberg 2002). For some purposes, the most relevant perspective is to consider social sustainability in a global context, with a focus on welfare, equity and distribution among larger populations. In other cases, one may choose to focus on the up-keep and development of specific industries and value chains, be it at an international, regional or local level. In the evaluation of specific aid and development projects, emphasis is often placed on how interventions are appropriated at the community level, and the barriers and potential for maintaining and developing new practices after the project has been completed. In our case, all these perspectives are relevant. Climate change is a global challenge, and increased resilience on a larger scale is the ultimate objective of this project. Local business development is both a means to this objective, and an end in itself. Making RWH a lasting and sustainable practice at the household level is a prerequisite for the development of a local market for such solutions, and thus the most basic aim we want to achieve. The criteria selected for social sustainability assessment (chapter 5), therefore, turn mainly around impacts at the household level. However, they also include social capital, acceptance, and scope for entrepreneurship in wider social networks, and the empowerment of vulnerable citizens in an increasingly global economy.

On the economic side, the analysis and assessment includes both benefits and costs. As there are multiple options regarding use, services supplied, water management, etc., cost considerations are inadequate for ranking and decision-making at system level. Hence both costs and benefits need to be taken into account. The assessment of economic sustainability (chapter 6) covered both a general method to determine the economically optimal size of the storage tank and an economic assessment of the 36 initial design alternatives.

The holistic sustainability assessment (chapter 7) is based on the preceding sustainability assessments of the different RWH systems from an environmental, social and economic perspective. When selecting alternatives to be included in a set of standard designs and also when modifying these to fit the particular layout and conditions of a given house, all these perspectives should be taken into account in a simple and transparent way. The different assessments therefore need to be compared and the pros and cons of each need to be weighted against each other in what may be termed a multi criteria analysis. In daily life we all do this in many situations with more or less well grounded reasoning and analysis to arrive at a conclusion. The aim of the discussion in the final chapter of this report is to present a methodology for combining the different assessments from the environmental, social and economic pillars of sustainability, and discuss how the dimensions/criteria impact on the sustainability of the solutions when a holistic perspective is taken.

2 Baseline study

2.1 Sample and method

The target areas for the baseline study included Ashongman, Pokuasi, Kwabenya, Ashaley Botwe, and Adenta, all parts of the GAMA where there is difficulty in accessing water from the national water distribution network. The target population was made up of all the households in the target areas. Random sampling was used to sample 54 households for the survey. Purposive sampling was used to select household's heads in the various households. This was considered the most appropriate technique since the household heads had valuable knowledge and information on the data needed for the survey. Combined methods of data collection were used so that all possible information would be available to make a comprehensive analysis and to examine recommendations for future project implementation. The methods of data collection adopted for this study were:

- Structured questionnaire (face to face interview)
- Non participant observation at the project sight

The data collected were edited, coded, processed and analysed using computer software applications such as MS Excel and SPSS. Simple descriptive statistics frequency tables and percentages were used in analysing the quantitative data.

2.2 Key results

2.2.1 Socioeconomic characteristics of households

There were considerably more males (76 per cent) than females (22 per cent) in the surveyed population. This is an indication that only 22 per cent of the households sampled were headed by females. The other household socioeconomic characteristics are summarized in Table 2.1. The minimum household size was one member and maximum was ten members with a mean size of about five persons. This included all members who lived together in a house. In the case of age, the minimum age was one year and maximum was eighty four years with a mean age of about twenty nine years. The survey results indicate that, a majority (74.1 per cent) of the household heads had tertiary education. About 17 per cent had Secondary/Technical education. Almost 4 per cent had Junior High School/Middle School Leaving Certificate and 4 per cent had Primary education. About 2 per cent had no formal education (Table 2.1). Thus most of the household heads surveyed had some level of formal education.

Table 2.1: Socioeconomic characteristics of households.

	Household Size	Age
Minimum	1	1
Maximum	10	84
Mean	5.4	29.3
Educational Status		
Educational Status	**Frequency**	**Percentage**
Non	1	1.9
Primary	2	3.7
JHS/MSLC	2	3.7
Secondary/Technical	9	16.7
Tertiary	40	74.1
Total	**54**	**100.0**
Income Level		
Income level (GH¢)	**Frequency**	**Percentage**
Below 1 000	23	42.6
1 000 – 2 000	16	29.6
2 001 – 3 000	6	11.1
3 001 – 4 000	4	7.4
4 001 – 5 000	2	3.7
No Response	3	5.6
Total	**54**	**100.0**

The income levels per month of the household heads also indicated that, about 43 per cent received incomes below GH¢1 000.00. About 30 per cent received incomes between GH¢1 000.00 and GH¢ 2 000.00 and the remaining 27 per cent received incomes between GH¢ 2 001.00 and GH¢ 5 000.00. The household heads were mainly salaried workers with a few owning businesses and living on remittances. However, 39 per cent of the respondents were considering more income options, mainly trade and investing in farming and sale of water. This depicts a sense of entrepreneurship.

2.2.2 Physical structures of households

The households surveyed were mainly four to five bedroom houses. According to Figure 2.1, the roof type of most of the households was aluminium, which is most suited for the implementation of RWH systems. Apart from asbestos which constituted only 3.7 per cent, the remaining roof types which constituted about 9 per cent, could also well be used for RWH.

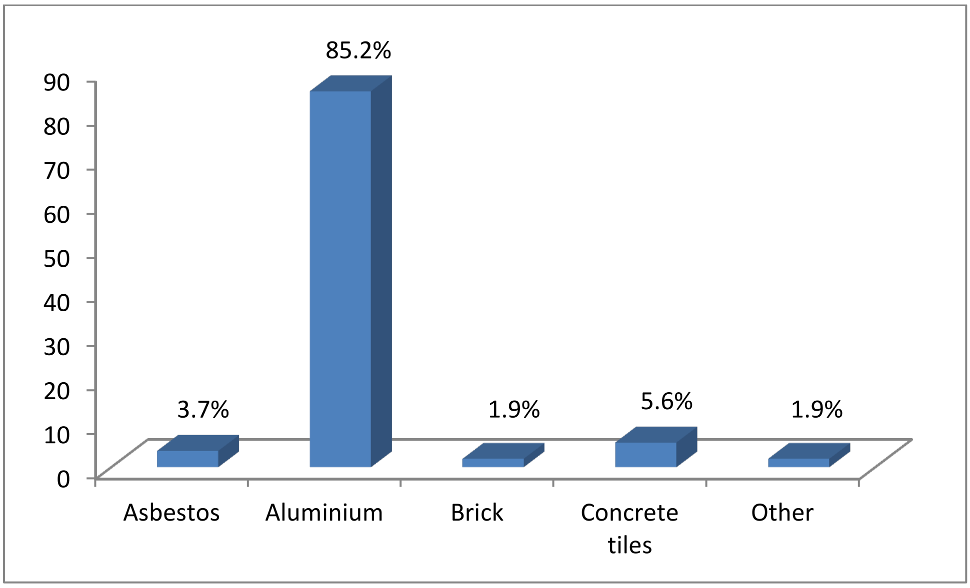

Figure 2.1: Roof types of households.

Most of the households had water storage tanks with filtration and boiling as the main means of water treatment. This clearly indicates that respondents had difficulty accessing water and also underscores the level of water quality consciousness of respondents, suggesting that RWH would be beneficial if implemented.

2.2.3 Sources of water and water use

The major sources of water in the different survey areas included sachet water, commercial water tanker, well water, borehole water, pipe borne water and rain water (Table 2.2). For most of the water sources identified, the households used it for the purpose of drinking, cooking and for other domestic use. The choice of water source depended on quality, reliability and convenience, as much as cost.

Table 2.2: Sources of water and water use.

Source of Water	**Water Use**					
	Drinking		**Cooking**		**Other Domestic Use**	
	Frequency	**Percentage**	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Sachet Water	47	87.0	5	9.2	2	3.7
Commercial Tanker	4	7.4	28	51.8	24	44.4
Well water	1	1.9	10	18.5	14	15.9
Borehole	2	3.7	6	11.1	6	11.1
Pipe borne	0	0	3	5.6	2	3.7
Rain Water	0	0	1	1.9	3	5.6
No response	0	0	1	1.9	3	5.6
Total	**54**	**100.0**	**54**	**100.0**	**54**	**100.0**

The results from Table 2.2 show that a majority (87 per cent) of the households used sachet water as their main source of drinking water. About half (52 per cent) and 44 per cent of the households used water from commercial water tankers for cooking and other domestic use respectively. The cost of buying water from the commercial water tankers according to the average household, was about GH¢200.00/month. None of the households surveyed used rain water as their source of drinking water. Only 2 per cent used it for cooking and about 6 per cent used it for other domestic purposes. Pipe borne water, which many believed to be a good source of water, was rarely mentioned as an option. About 6 per cent reported that they used pipe borne water for cooking and 4 per cent used it for other domestic purposes. This indicates its non-existence or unreliability in the target areas because of the non-availability or poor accessibility from the national water distribution network.

2.2.4 Consumer choices

The survey sought to identify whether households had made any substantial investment in recent times and the results showed that, some households have invested in buying of lands, shops and other household items such as cars and television sets. From the results it was also identified that, about 85.2 per cent of the respondents were willing to make investments in order to improve their water supply whiles 5.6 per cent were not willing to do so (Figure 2.2).

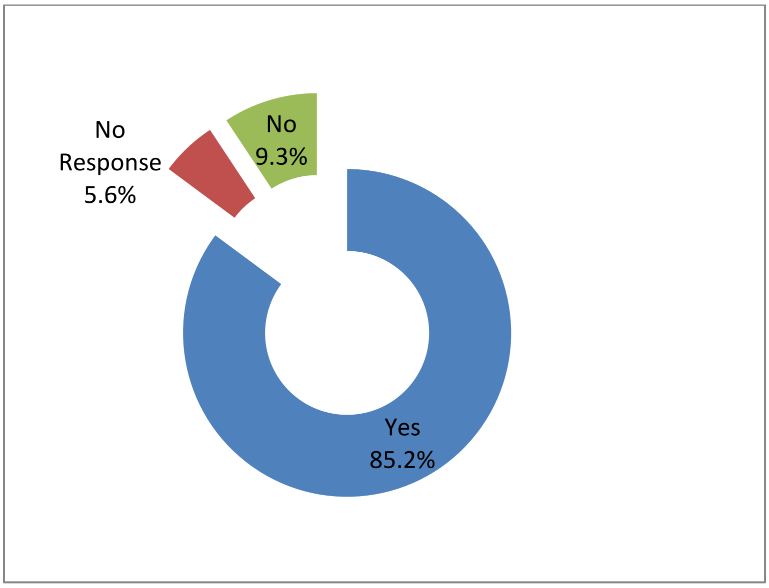

Figure 2.2: Households' willingness to invest to improve water supply.

The survey also revealed that even if interest rates are high in Ghana, some households had taken loans and others would consider taking loans, mainly for business and education. If borehole was an option for good quality water, most would prefer that, but many would also consider modern RWH systems. There was quite a strong scepticism towards Chinese products. Products from Europe or the US were associated with more quality, while attitudes towards Ghanaian products were mixed, with some being sceptical about quality and many wanting to support local products to strengthen local development. Some would prefer PE storage tanks, which are well known and widely used in Ghana already, while others said they would prefer storage tanks made from cement, because of their durability. In all, this depicts households' willingness to invest and the need to consider different attitudes and preferences in the selection of designs and implementation of RWH systems.

2.2.5 Relations in the households

In Ghana, women and children are usually responsible for fetching water. In most cases, women also regulate the use of water in households. In the present survey, this was so in 43% of the cases, but the majority of the respondents said this responsibility was shared by man and wife together. Getting water would in some cases involve travelling and incurring transportation costs, but because many relied on tanker water or had their own wells, they did not report spending a lot of time getting water to the house. Still, water was among the regular conflict issues in the households, along with other common home conflict issues as seen in Figure 2.4. This underscores that water is a scarce commodity, whose administration can involve social challenges. If a household's water situation is improved, it may remove or reduce a set of actual or potential tensions in the home and improve quality of life also at this level.

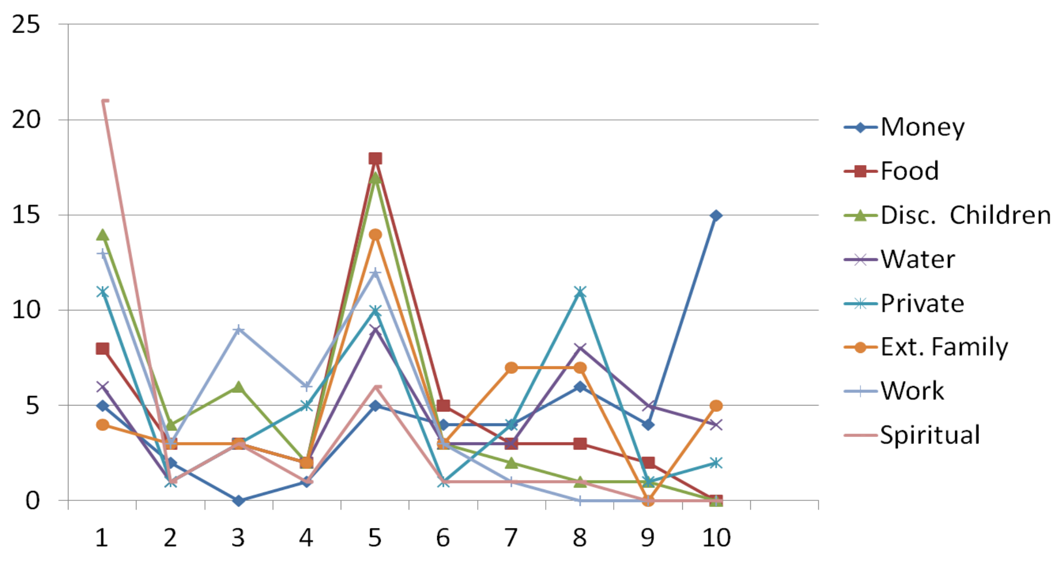

Figure 2.3: Home conflict issues.

2.2.6 Health and hygiene

All respondents indicated that they had enough water to have daily baths, without seasonal variation, so at this level they could afford to have their needs covered. They reported using tanker, well, or sachet water for washing vegetables and fruits. Most would also use tanker or well water for doing dishes, without boiling it first. 65% reported that they flushed the toilet after every use, while others would try and minimize flushing to save water. 6 respondents (11%) reported that they or other members of the household had suffered some kind of water borne disease the last two weeks. The Ghana Living Standards Survey (2008a) reported that in Accra generally, 14 per cent of persons were sick in the two weeks preceding the survey. A recent study on urban water supply in Northern Ghana (Osumanu 2013) shows that diarrhoea incidence in children is associated with the source of water supply for households. Water from unprotected wells and water vendors was associated with the highest risk, but people who relied on tanker service and/or sachet water for drinking also reported higher incidence that those with access to piped water (ibid.) This indicates that there is a good potential for improving health and hygiene conditions if RWH systems with proper disinfection units and procedures are introduced.

2.2.7 Community relations

Most of the respondents owned their houses and said they will remain in their communities for very long periods, even though some had houses elsewhere. This is very important since it would make for maintenance and use of RWH in a long-term perspective. Most respondents were also willing to share water in case of shortage. While many said it is common to invest jointly in additional water sources, many also said they would avoid sharing water sources, due to the conflict potential this would involve. Figure 2.4 shows the various levels of conflict issues amongst members in a neighbourhood to which limited water availability is a key issue. Others include waste handling, flooding, power shortage/blackouts, safety/crime, high conflict level and traffic and related pollution. According to the respondents, there were no clearly identified community leaders and conflict resolution was mainly handled by themselves and the police especially in crime cases. On the issue of water availability, respondents thought RWH could reduce the problems and impact positively on their status.

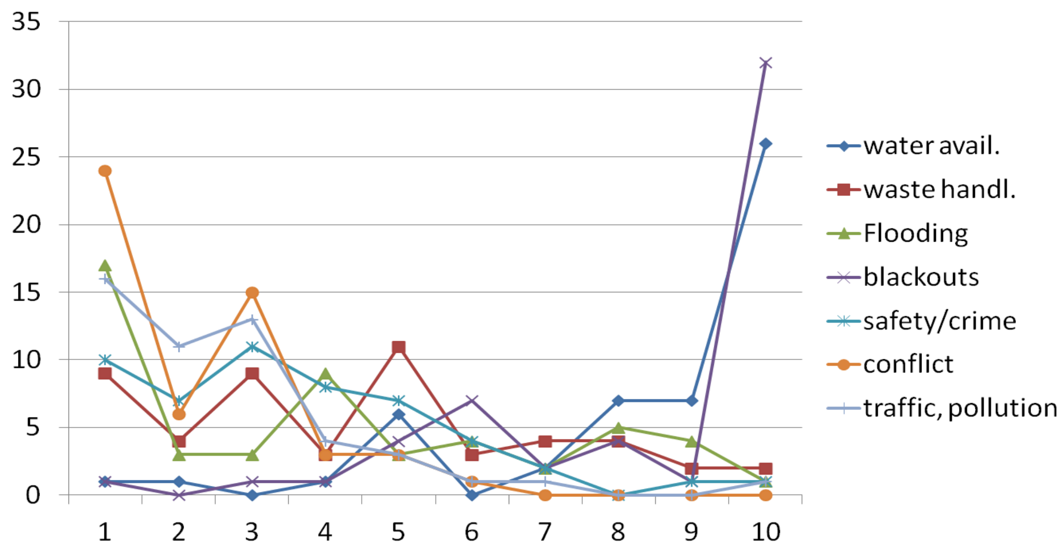

Figure 2.4: Community conflict issues.

2.2.8 Environmental Consciousness

For economic reasons, the respondents were very conscious about saving fuel and power/electricity. According to their views, Ghana has environmental issues mainly in waste handling and sanitation. About 87 per cent thought these challenges could impact on water availability where they live, while 5.6 per cent thought otherwise. While two referred to flooding and two mentioned limited water availability, however, none mentioned climate change as an environmental challenge of concern to them. This indicates that there is the need for more awareness creation on climate change.

2.2.9 Knowledge on Rain Water Harvesting and its importance

All the respondents indicated awareness of RWH as an alternative water source. Most respondents (59 per cent) claimed that RWH is done in simple form in their communities, and the vast majority was positive about modern RWH systems. Most felt that rainwater mainly is good for washing, but some said they would use rainwater as all purpose water, also for cooking and drinking. There is, in other words, an existing rain water collection practice and basic knowledge of it in most target areas surveyed. This basic knowledge and practice of rain water collection may enhance the implementation of RWH systems. Respondents were of the view that RWH systems would save costs, reduce stress, and save time and energy for other domestic purposes. Some other benefits respondents expressed were for income, gardening/farming and sharing with others in need as well as reducing difficulty in water accessibility in the target communities.

3 RWH system designs

3.1 Design procedure

The performance of a RWH system depends on rainfall, both quantity (mm) and the rainfall pattern over the year (wet and dry periods). If it rains only in one short period of the year a large tank is needed in order to store and supply the required quantity of water throughout the year. With frequent and evenly distributed rainfalls, a much smaller tank will do. The roof size will also influence the tank size decision. For an existing building the roof size is fixed and will enter the assessment as a constant parameter. However, in some cases only parts of the roof will be utilised for rainwater harvesting. The kind of roofing is also important – steel or aluminium sheets are far more suitable than thatch. In addition gutters and piping must have adequate capacity and be installed so water doesn't spill. Further information and descriptions can be found in "Roofwater Harvesting – a Handbook for Practioners" (T.H. Thomas and D.B. Martinson, 2007).

The runoff coefficient used in this study was 0.8, which gives an annual run-off (ARO) of 80% of roof area times the annual rainfall in mm. Thomas and Martinson, 2007 use a run-off coefficient of 0.85. For steel sheets even 0.95 is possible. However, considering that old roofs will have lower run-off coefficients than new roofs, a run-off coefficient of 0.8 was considered conservative. Water consumption can not be higher than annual run-off. If the sum of daily demand over the year approaches annual run-off, the necessary tank size typically grows disproportional. Hence, as a rule of thumb, it is recommended (Thomas and Martinson, 2007) that daily demand should be less or equal to 80 % of annual run-off.

The required quantity of water supplied by the system is crucial for design. In the assessments a fixed quantity per day – dependent on the size of the household - has been assumed. Abraham et al. (2007), reported water consumption per capita per day (lpcd) in Accra to be in the range 25 litres (buying water by the bucket) to 120 litres (connected to the water utility). The Water Sector Strategic Development Plan (WSSDP, 2011) terms the 50 lpcd supply level as the intermediate supply service and points out that as at 2008 only 40% of the urban population in Ghana received this service. For the designs in this study, daily per capita abstraction rates of 20, 40 and 60 litres all year round were chosen. An adaption to distinct rainfall and draught periods will be to increase consumption in wet periods or when the tank is almost full and water usually is lost do to overflow, and reduce consumption in dry periods or when water tank level is below a certain limit, but this has not been entered into the performance calculations for the different design alternatives in this study.

To select and finalize designs of model systems for single houses and institutions (several of larger buildings), standardized design criteria were used, incorporating modular designs to facilitate widespread use over a range of situations with respect to capacity and cost. A selection of designed RWH systems was evaluated with respect to environmental, economic and social criteria, to compare the different alternatives in a transparent and objective manner. The results from the analyses will later be compared to define target values that describe an optimal sustainable RWH system from an environmental, economic and social point of view, respectively. The target values will be defined in collaboration with local stakeholders.

In order to identify the system(s) that will be most sustainable in the Ghanaian context, different alternatives for RWH systems were developed. This included the choice of materials, design configurations, first flush diverters (interceptor, splitter or pit), filtration systems to remove debris such as leaves, grit, moss and soil from the collected rainwater prior to its entry into the storage tank, water transport systems (pump or gravity), and finally, water treatment/disinfection systems among which many alternatives, to be used alone or in combination, are available.

Standardization included selection and specification of the sizes and quality of the materials, rain collectors, down pipes and other piping components, storage tanks, disinfection methods and materials and water abstraction or distribution components. The aim was to sift through the various RWH components currently available in the market in Ghana, examine their quality, prices and suitability, and recommend components that would provide cost effective, functional and good quality RWH models. The standardization also includes a water quality monitoring regime to assure the quality of harvested water.

The amount of rainfall that can be harvested depends on the available rainfall, the roof type and the roof area. Accra has a double rainfall regime and at least an annual rainfall amount of more than 700 mm/m^2. This means that given a certain suitable roof type the main restrictions to the amount of harvestable water are the roof areas and affordable storage.

3.2 Initial designs

The model systems have been developed and standardized for three main systems for individual houses. These are the Basic (≤ 4 000 €), Intermediate (≤ 5 800 €) and Advanced (≤ 6 500 €) systems. In the Basic system the emphasis is on suitability at low cost; the Intermediate system could be more sustainable and have a higher appeal, with a mid-range price, inclusion of a filtration unit and materials of the highest quality; the Advanced one is a more advanced system, which includes state-of-the-art systems for disinfection and monitoring/quality control.

The criteria used for this classification included:

- Roof area (number of bedrooms),
- Number of persons in the household – 2 per bedroom (6 for the Basic and Intermediate systems and 8 for the Advanced systems),
- Storage tank size and type (plastic or ferro-cement),
- Per capita consumption for all year round use,
- Disinfection system (filters (sand, membranes, etc.), filters with pumps, SODIS batch reactors, UV systems, chlorine)
- Distribution system – mode of access to stored water
- Monitoring system (manual with log-book, automatic unit, etc.).

All systems have been designed to include first flush. More detailed descriptions of each of the 3 systems are given below.

3.2.1 Basic system

The basic system is based on a design with simple components, but including essential features such as self cleaning screens in the down spouts and a first flush diverter (Figure 3.1 and Table 3.1). The first flush diverter requires manual operation. The system does not require electricity.

3.2.2 Intermediate system

The intermediate system (Figure 3.2 and Table 3.2) is based on a design with robust components and includes essential features such as self cleaning screens in the down spouts and a first flush diverter. The first flush diverter is automatic and closes after wasting a pre-defined volume of water. The intermediate system also has a simple supply system with a basic water treatment to deliver tap water indoors. The system consists of a pump, a filter and a small tank placed on an elevated platform to give the required water pressure in the supply pipe to the house. The exact placement and layout can be adjusted in each case. The systems will have a manually operated electric pump installed and so requires electricity. Alternatively, the electric pump may be changed with a manual pump to avoid the dependency on electricity.

3.2.3 Advanced system

The advanced system (Figure 3.3 and Table 3.3) includes essential features such as self cleaning screens in the down spouts and a first flush diverter, but has a more advanced water treatment and supply sub-system than the intermediate system. The first flush diverter is automatic and closes after wasting a pre-defined volume of water. The water supply system is automated and includes UV-disinfection to deliver tap water indoors. The system consists of a pump, pressure tank, filter and a UV-disinfection unit. The water supply sub-system can be placed by the house wall or in another convenient place. The exact placement and layout can be adjusted in each case. The system requires a constant electricity supply.

Depending on the roof size and storage tank different performances are obtained within each system category.

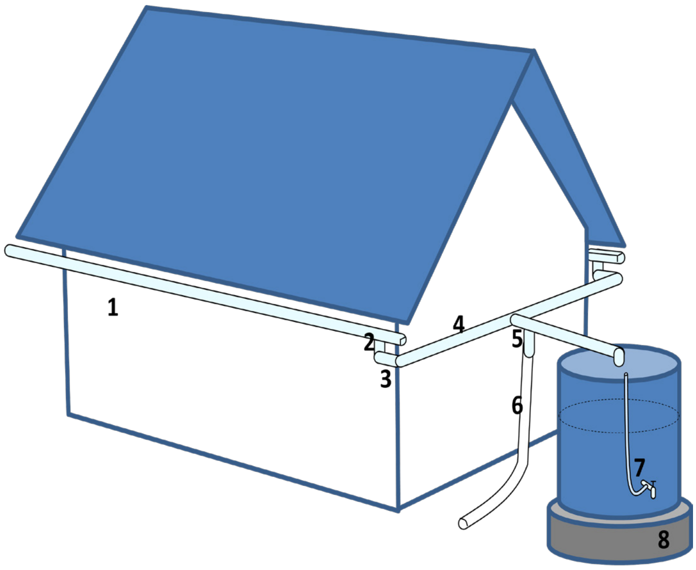

Figure 3.1: The Basic RWH System

Table 3.1: The Basic RWH System

#	System components	Quantity
1	Gutters on front and back roof mounted with 2° downward fall towards the downspouts.	Length of gutters will be determined by the house size.
2	Downspouts fitted with self cleaning screens for leaves and debris.	2 (for rectangular house with front and back roof)
3	90° bends to turn the house corners and enter the storage tank.	5 (for rectangular house with front and back roof)
4	Piping from downspouts to storage tank. All piping must be fitted with downward fall towards the tank to avoid stagnant water pools inside.	Length of piping will be determined by the house size.
5	T-connections to join the piping from each side of the house and fit the first flush diverter.	2
6	First flush diverter made from flexible hose that can be folded double and tied off for closing.	1
7	Tank with water tap and level indicator made from flexible clear hose. When installing prefabricated plastic tanks, tank volumes can be selected from standard sizes from 1.8 m^3 up to 10 m^3 assuming a 3 m height from the ground to the gutters. Larger volumes may require building a ferro cement tank on-site.	1 Additional tanks for increased storage volume and/or pressure head may be installed.
8	Tank foundation.	1 (for each tank)

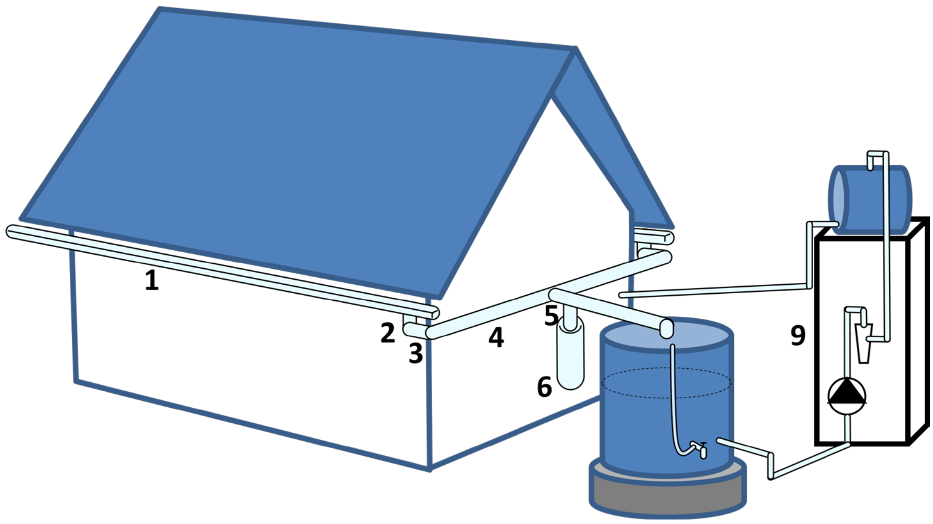

Figure 3.2: The Intermediate RWH System

Table 3.2: The Intermediate RWH System

#	System components	Quantity
1	Gutters on front and back roof mounted with 2^{o} downward fall towards the downspouts.	Length of gutters will be determined by the house size.
2	Downspouts fitted with self cleaning screens for leaves and debris.	2 (for rectangular house with front and back roof)
3	90^{o} bends to turn the house corners and enter the storage tank.	5 (for rectangular house with front and back roof)
4	Piping from downspouts to storage tank. All piping must be fitted with downward fall towards the tank to avoid stagnant water pools inside.	Length of piping will be determined by the house size.
5	T-connections to join the piping from each side of the house and fit the first flush diverter.	2
6	Automated first flush diverter.	1
7	Tank with water tap and level indicator made from flexible clear hose. When installing prefabricated plastic tanks, tank volumes can be selected from standard sizes from 1.8 m^3 up to 10 m^3 assuming a 3 m height from the ground to the gutters. Larger volumes may require building a ferro cement tank on-site.	1 Additional tanks for increased storage volume and/or pressure head may be installed.
8	Tank foundation.	1 (for each tank)
9	Water supply sub-system with pump, cartridge filter and head-tank mounted on an elevated platform.	1 (complete sub-system, piping from head-tank to house will come in addition)

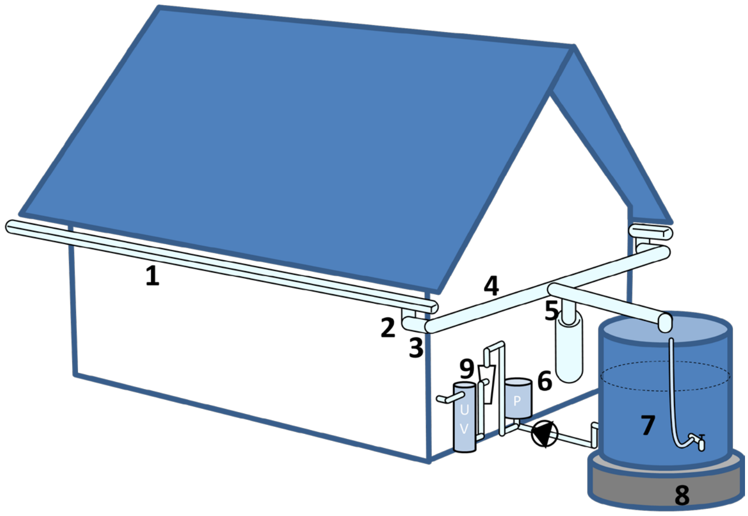

Figure 3.3: The Advanced RWH System

Table 3.3: The Advanced RWH System

#	System components	Quantity
1	Gutters on front and back roof mounted with 2° downward fall towards the downspouts.	Length of gutters will be determined by the house size.
2	Downspouts fitted with self cleaning screens for leaves and debris.	2 (for rectangular house with front and back roof)
3	90° bends to turn the house corners and enter the storage tank.	5 (for rectangular house with front and back roof)
4	Piping from downspouts to storage tank. All piping must be fitted with downward fall towards the tank to avoid stagnant water pools inside.	Length of piping will be determined by the house size.
5	T-connections to join the piping from each side of the house and fit the first flush diverter.	2
6	First flush diverter made from flexible hose that can be folded double and tied off for closing.	1
7	Tank with water tap and level indicator made from flexible clear hose. When installing prefabricated plastic tanks, tank volumes can be selected from standard sizes from 1.8 m^3 up to 10 m^3 assuming a 3 m height from the ground to the gutters. Larger volumes may require building a ferro cement tank on-site.	1 Additional tanks for increased storage volume and/or pressure head may be installed.
8	Tank foundation.	1 (for each tank)
9	Water supply sub-system with pump, pressure tank, cartridge filter and UV-disinfection that automatically maintains a set pressure in the supply line.	1 (complete sub-system, layout can be adjusted to the site.)

3.3 Expected performance

System performance is evaluated based on the following:

- All designs include essential features e.g. self cleaning screens and first flush diverters.
- Three levels of complexity regarding components, treatment and supply system:
- Basic: Manual operation, no post treatment, no supply system.
- Intermediate: Manual operation but has an electric pump, manual disinfection, head tank for water supply.
- Advanced: Fully automated treatment and supply system.
- Assumptions regarding house and system:
    - One story rectangular house, length to width ratio: 2.
    - Wall height 3 m.
    - Assumed increasing water consumption and system size Basic < Intermediate < advanced, but overlap in ranges.
    - Daily water consumptions: 80 – 480 l/day (4-8 persons, 20-60 lpcd).
    - Roof areas: 50 – 300 m2.
    - Storage tanks: 1.8 – 35 m3.
    - Delivery performance calculated based on 10 year daily rainfall data collected at the Kotoka International Airport, Accra.

The criteria used to assess the performance of a system as regards to optimal tank size are given in Table 3.4. Thus, tanks are not necessarily sized to collect all the available roof runoff (100% efficiency) but also to satisfy various levels of the other criteria. The working levels for these criteria will be selected with stakeholders.

Table 3.4: Performance criteria for selected RWH systems

Criterion	Definition
Reliability	% of time tank is not empty within a year
Satisfaction	% annual water demand met by the system
Efficiency	% of available annual roof runoff collected

Twelve sub-systems have been developed in each of the 3 main systems described above for functionality and economic, environmental and social sustainability analysis. The results with respect to performance are given in Appendix I.

4 Environmental sustainability assessment

4.1 Methodology

Splitting up the RWH system into its sub-systems and analysing each of these enables one to understand the contributions of the different sub-systems to the various environmental impacts. It is essential however to define the system boundaries. The system boundaries defined for the systems studied in the case of this assessment are presented in Figure 4.1 and Figure 4.2.

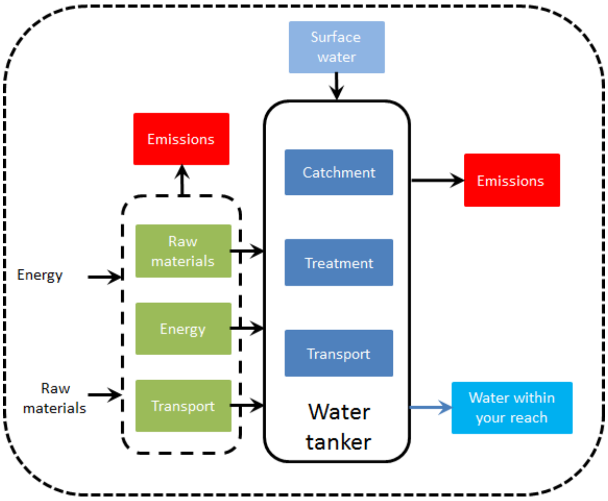

Figure 4.1: System boundaries for the production and transport of $1m^3$ delivered by the tanker services

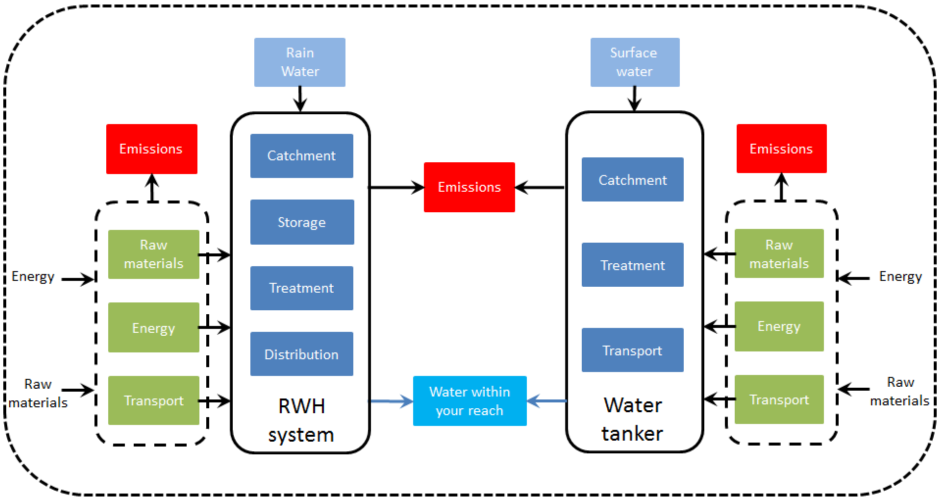

Figure 4.2: System boundaries for the supply by the RWH and water tanker of $1m^3$ to the household.

The environmental assessment was performed using the LCA, which is an international standard methodology ISO14040 and ISO14044 whose phases are shown in Figure 4.3. The ILCD Handbook (2010) is a general guide for performing an LCA.

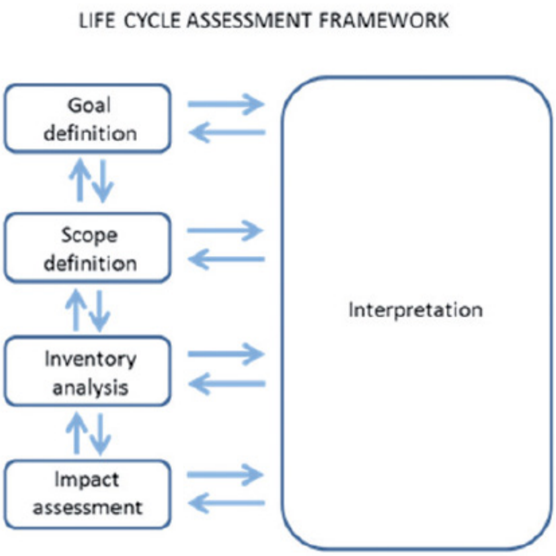

Figure 4.3: Life cycle assessment framework according to the ILCD Handbook (2010)

This LCA evaluates environmental impacts of the systems from cradle to grave as shown in Figure 4.4.

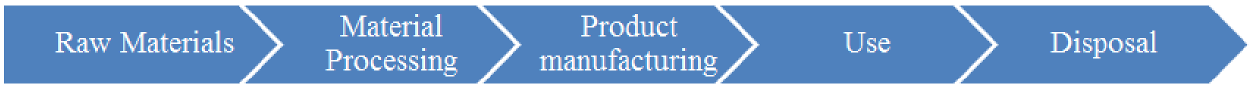

Figure 4.4: Life stage included in this study

The functional unit used in the LCA was 1 m^3 of water supplied to the household either by water tanker services, by the RWH system alone, or by the RWH system in combination with the tanker services.

4.2 Life Cycle Inventory

The inventory analysis includes both materials and processes grouped into life cycle stages (i.e. raw materials extraction and processing, transportation, construction, use and final disposal) and into subsystems (catchment, storage, and distribution).

There are three basic ways to obtain data for a life cycle assessment. The first way is to get field data, which accurately reflect the characteristics of a system and is thereby preferred. If field data are not available, relevant data from previous similar studies can be used. Lastly, data can be obtained from many commercial programs, such as SimaPro. In this study, real data were collected from various suppliers and from the literature. Also data from databases included in SIMAPRO, with some modifications when needed, were used. For example energy resources included in Eco-invent database were replaced by local energy resources (Electricity mix in Ghana is composed by 81.7% hydropower and 18.3% thermal using natural gas (W. Ahiataku-Togobo and K. Amankwa, 2005)) depending on the location of the manufacturer of the product. Transportation distances of materials and consumables found in the Eco-invent database, were replaced to better fit the reality. Table 4.1 gives a short overview of the inventory analysis used in this study, but a more detailed inventory analysis per functional unit is given in Appendix II. Ferro-cement tank construction materials were defined using the document from the Water Brigades Ghana (2012) as a basis.

All input and output data collected in the inventory phase were normalised to the functional unit. Input and output data included the use of materials and energy, and releases to air, land and water associated with the processes.

4.3 Impact assessments

The software SIMAPRO 7.1.5 was used with the method Eco Indicator 99. The latter was developed with the aim to simplify the interpretation and weighting of results. One of the intended applications was the calculation of single-point eco-indicator scores that can be used by designers in day to day decision making. An eco-indicator is a value that expresses the environmental impact of a product, a process, or a service in a single number. The environmental effects of each of the impact categories are normalised relative to a reference. The reference used to obtain the normalisation factors for each of the impact categories is related to the environmental impacts in each of the impact categories that an average European person causes in one year. This results in impact scores for each of the categories which in turn are multiplied by weight factors to get impact scores or eco-points for each impact category. The impact scores of all impact categories can be aggregated to get one single score or eco-point for each unit process and product. The higher the eco-point, the more negative is the environmental impact.

The method CML 2001 was used to evaluate the global warming potential over a time interval of 100 years. Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years.

As mentioned in the introduction, the environmental assessment in this study aims at evaluating two scenarios, the first (noted scenario 0) corresponds to the scenario where the water is supplied only by the water tanker services and the second corresponds to the scenario where RWH is combined with water tankers to meet the household water demand. For the latter, the calculation of each alternative of scenario 1 is done by evaluating first the production of 1 m^3 of water by the considered RWH design alternative, and then by calculating the impact of 1 m^3 delivered to the household, which corresponds to a fraction of the impact of the 1m^3 produced by the RWH system and a fraction of the impact of 1m^3 delivered by the tanker services.

Table 4.1: Inventory analysis of studied systems

	Components	Material	Origin	Processes considered	Life time (years)
Catchment	Gutter	PVC	• UK (7100 km)	• PVC resin production (Ecoinvent, Simapro) • Steel hot roiled production (ELCD, Simapro) • PVC extrusion: 0.38 kwh/kg (Howard, 2009) • PVC injection moulding: 3.14 kwh/kg (Plastics Energy Best Practice Guidebook, 2006) • Transport by truck and container (Ecoinvent, Simapro) • Steel forming: 1.2 kwh/tonne (Carbon trust, 2011)	15
		Galvanized steel	• Australia (13800 km)		25
	Pipe	PVC	• Origin of resin: Germany (7100 km) and processing in Accra		15
Storage	PE tank	LLDPE	• Origin of resin: China (19900 km) and processing in Accra	• LLDPE resin (Industry data, Simapro) • Rotational moulding 5 kwh/kg (Plastics Energy Best Practice Guidebook, 2006) • Transport by truck and container (Ecoinvent, Simapro)	15
	Ferro-cement tank	Cement, sand, Lime, bricks, rubble stones, crushed stones, water, and steel	• Accra (50 km) and South Africa for the steel (5 150 km)	• Cement mortar, limestone, bricks, and gravel (Ecoinvent, Simapro) • Sand (ELCD, Simapro) • Transport by truck and container (Ecoinvent, Simapro)	50
Treatment & Distribution	Pump	Steel	• China (19900 km)	• Steel (ELCD, Simapro) • Transport by truck and container (Ecoinvent, Simapro)	10
	UV reactor	Steel	• China (19900 km)	• Transport by truck and container (Ecoinvent, Simapro)	15
	Cartridge filters	Polypropylene	• China (19900 km)	• Polypropylene and injection moulding (Industry data, Simapro) • Transport by truck and container (Ecoinvent, Simapro)	0.1
	Chemical disinfection	Sodium hypochlorite	• UK (7100 km)	• Production (Ecoinvent, Simapro)	--

4.4 Scenario 0: Water supply by Tanker service

Scenario 0 is the base case where the water used by the household is produced at the water treatment plant and then transported to the household using trucks. The assumed size of truck is 3.5 to 16 tones and the assumed distance from the waterworks to the household is 30 km. The water supplied by the water tanker was assumed to be produced by a conventional waterworks of which data are available in SIMAPRO. The modelled waterworks uses surface water as raw water and following steps for the treatment: Coagulation/Flocculation – Water softening (decarbonisation) – Disinfection with ozone – Filtration – Chlorination. The storage was assumed to be a 1.8m^3 plastic tank made of linear low density polyethylene (LLDPE) placed on a concrete foundation, and these items were included in the LCA calculations. Figure 4.5 displays the impacts for the scenario 0 with respect to various impact categories of which the meaning is presented in Table 4.2.

Table 4.2: Overview of the environmental impacts of the urban water system (M. El-Sayed Mohamed Mahgoub et al., 2010)

Impact category	General description	Relation to the urban water system
Carcinogens	The damage to human health from carcinogenic substances.	Heavy metals in effluents may cause carcinogenic effects in humans.
Climate change	Indirect impact of climate change to human health due to the anticipated increase in temperature, sea level rise and other impacts.	The air emissions that results from water or wastewater treatment produce green house gases (CO_2, NH_4, N_2O).
Ecotoxicity	Damage to ecosystem quality (air, water and soil) caused by ecotoxic substances.	Sludge generated from treatment of water or wastewater, wastewater and effluents may contain toxic substances.
Minerals	Damage to resources caused by minerals depletion.	Indirectly, the treatment process of water and wastewater causes depletion of minerals through the use of the chemicals.
Respiratory organics	Respiratory effects from organic pollutants emitted to the air.	Some substances that are used in water treatment (such as ozone) have respiratory effects.
Radiation	The damage to human health related to the routine releases of radioactive material to the environment.	No relation (the results of the research showed zero impact in this category).
Eutrophication and acidification	Damage to ecosystem quality caused by acidification and eutrophication due to deposition of inorganic substances.	Nutrients (Sulphates, nitrates, and phosphates) in wastewater (raw wastewater, or wastewater subjected to primary or secondary treatment only) cause eutrophication and acidification, in addition air-borne emissions can cause acidification.
Fossil fuels	Damage to resources caused by depletion of fossil fuels.	The energy used in treatment and pumping is mostly generated from fossil fuel, so urban water systems cause depletion of fossil fuel.
Respiratory inorganics	Respiratory effects from inorganic pollutants emitted to the air.	Wastewater treatment may produce air emissions (such as NH_3, NO_2, CO) that have respiratory effects.
Ozone layer	Damage to human health due to depletion of ozone layer (ultraviolet radiation impact).	Chlorine containing substances used in water treatment have a negative effect on the ozone layer.
Land use	Impacts of land cover changes on ecosystem quality.	The infrastructure of the urban water system changes land use.

Note: The relation to the urban water system mentioned in the table is the direct relation, furthermore, there is an indirect relation such as the air emissions during the manufacturing of the chemicals used in water or wastewater treatment (respiratory effects and climate change categories), the emissions during electricity generation (respiratory effects and climate change categories), etc.

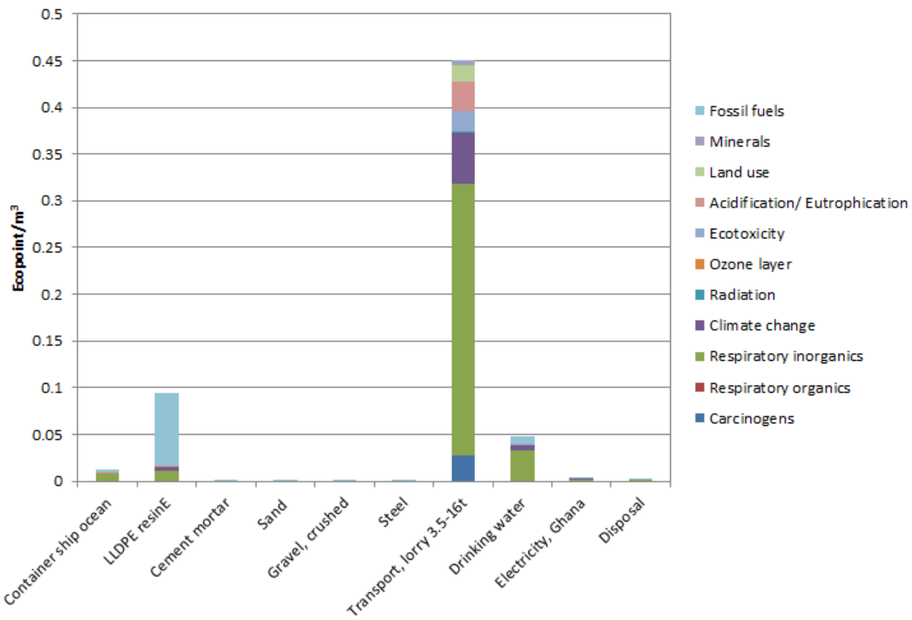

Figure 4.5: Environmental impacts of each sub-component obtained for the scenario 0.

The assessment results for scenario 0 showed that the transport of water counts for more than 75% of the total impact, the plastic tank for the storage counts for 14%, while the water production counts only for 8%. The high impact associated with the transport is mainly due to the transport by truck which uses a high amount of fuel for small amount of delivered water. This means of transportation also has a high impact on people's health, as it increases the emission of inorganic particles and contributes to the climate change due to emissions of greenhouse gases. This evaluation also shows that the most important component after the transport is the LLDPE used for the production of the PE tank. Indeed, the manufacture of such resin requires a large amount of fossil fuels used as raw material and for the production of energy, which also results in high emission of respiratory inorganics and high impact on the global warming due to emission of greenhouse gases.

4.5 Scenario 1: RWH supplemented with tanker service

Figure 4.6 displays the results obtained for the alternative 1 without extra water supplied by the tanker services. Apart from the truck transport and the drinking water production, alternative 1 presents the same impacts as scenario 0. The most important component was the LLDPE that is used for the production of PE tanks due to the reasons mentioned above. The second largest impact is from the transportation overseas of raw material by container using fossil fuels and producing respiratory inorganics.

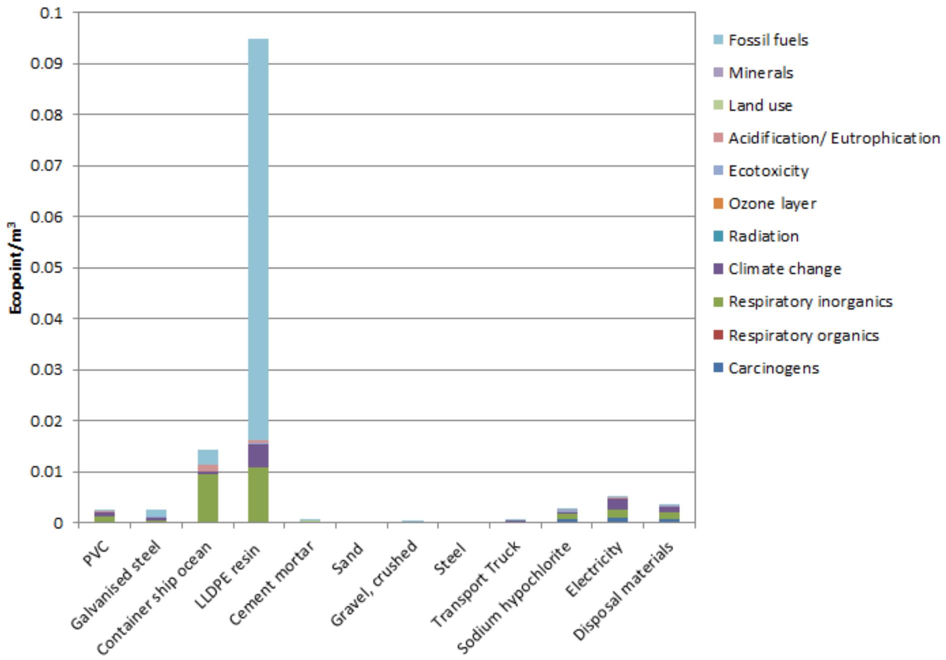

Figure 4.6: Environmental impacts of each sub-component obtained for the alternative 1 without water tanker supply.

Figure 4.7, Figure 4.8 and Figure 4.9 display results obtained for the different alternatives of scenario 1 with respect to different impact categories. The sum of each impact category gives the total calculated Eco-points obtained for each alternative. Scenario 0 presents the highest environmental impact due to the transport by trucks, as explained earlier. The results shows that in any case using rainwater harvesting systems is beneficial to the environment when compared to the situation where the whole water is bought from tankers.

All the scenarios using PE tanks have higher fossil fuel depletion due to the production of LLDPE compared to the ferro-cement alternatives. In general, scenarios which include ferro-cement tanks show smaller impact – mainly due to emission of inorganic particles compared to PE tanks. Indeed in the case of ferro-cement tanks the life time is much longer (50 years) compared to PE tanks (15 years), and therefore the amount of water harvested is much higher, resulting in smaller impact per m^3 harvested. When looking at the overall environmental impacts, it seems obvious that with respect to environmental criteria the best choice is to use ferro-cement tanks. However, the results are based on some assumptions and are therefor not necessarily valid under different conditions.

When comparing the alternative 1 with and without water tanker services (data not shown), the results show that the transport of the water bought from tankers to fulfil the demand from household results in an increase of emissions of respiratory inorganics, fossil fuel depletion, greenhouse gases and climate change. Among the different alternatives, one may note by observing the respiratory inorganics indicator that for some alternatives (1, 5, 6, 10, 11, 13, 17, 21, 22, 23, 25, 26, 29, 30, 31, 33, 34, and 35) the contribution from the transport of water is more important, as the amount of water needed to supplement to the harvested water is more important. This contribution seems to affect the intermediate and advanced alternatives to a larger extent. However, for the alternatives where the tank is sufficiently large to harvest the demanded water, the tank has a larger contribution to the total impact, as shown by the larger contribution to fossil fuel depletion.

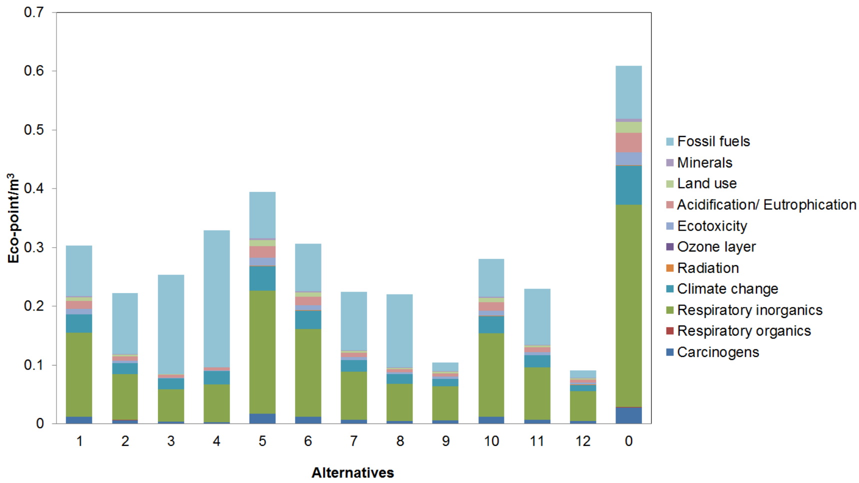

Figure 4.7: Environmental impacts by impact categories for scenario 0 compared to a) alternatives 1 to 12 (basic systems) of scenario 1.

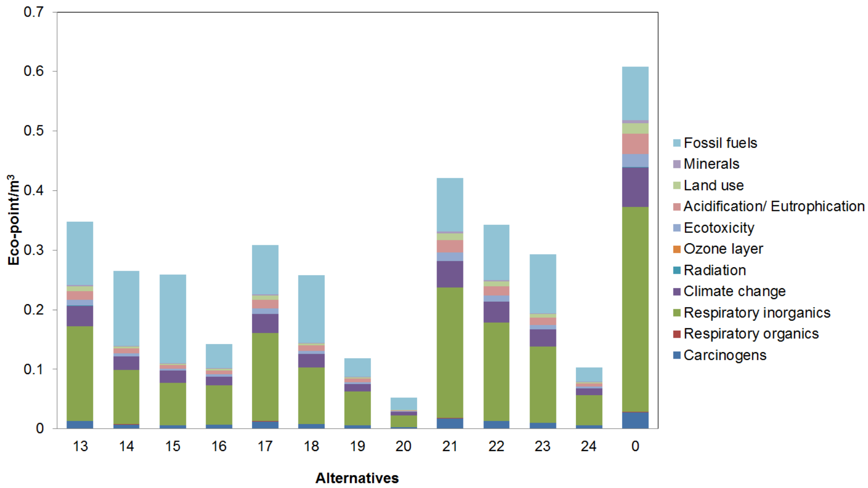

Figure 4.8: Environmental impacts by impact categories for scenario 0 compared to a) alternatives 13 to 24 (intermediates systems) of scenario 1.

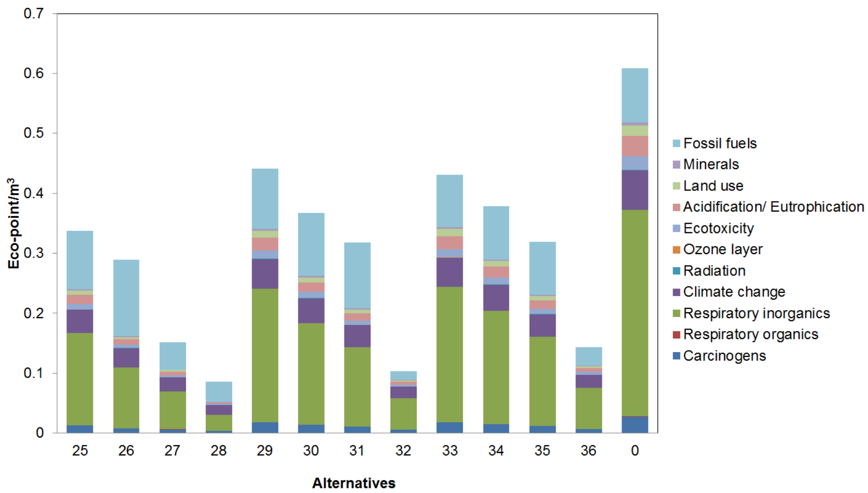

Figure 4.9: Environmental impacts by impact categories for scenario 0 compared to alternatives 25 to 36 (advanced systems) of scenario 1.

The global warming potential over 100 years displayed in Figure 4.10 show similar trends as discussed above. From the GWP results, one may conclude that the application of RWH would help mitigate climate change by reducing the emissions due to truck used for transportation of water.

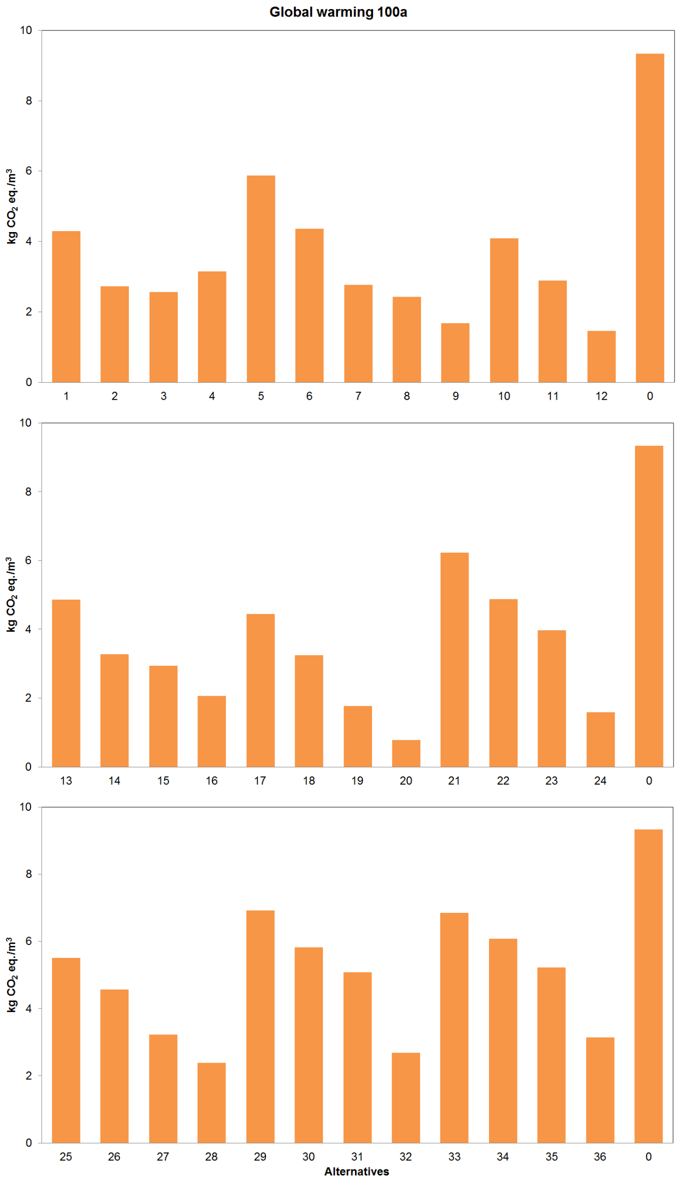

Figure 4.10: Global warming potential over 100 years for the alternatives 1 to 36 and comparison with the scenario 0.

4.6 Conclusions regarding environmental impacts

The following conclusions may be drawn from this study:

- The results show that the use of rainwater harvesting systems would reduce the impact to the environment, including the emission of greenhouse gases, when compared to buying all the required water from the water tanker services
- The ferro-cement tanks show the best results and the worst impact is observed when tanks are oversized.
- In general, the intermediate and advanced systems seem to have higher environmental impacts than the basic systems, due probably to a not optimized tank size.

5 Social sustainability assessment

5.1 Dimensions addressed in this study

There are four pre-eminent concepts in the social pillar of sustainable development: Equity, awareness for sustainability, participation, and social cohesion (Murphy 2012). Littig and Griessler (2005) identify three core dimensions of social sustainability: Basic needs and quality of life, social justice, and social coherence, while Cuthill (2009) sees social capital, social infrastructure, social justice and engaged governance as the key factors. Others (Anand and Sen 1996, Baines and Morgan 2004) consider diversity and social maturity, or the extent to which individuals and institutions are ready to accept responsibility for growth and improvement, as important aspects. Studies on the social sustainability of technological innovations, on the other hand, tend to focus on social and/or market acceptance (Wüstenhagen et al 2007, Assefa and Frostell 2007). With a view to the above, our assessment addresses six general dimensions of social sustainability:

- Quality of life
- Empowerment
- Diversity
- Social mixing/cohesion
- Equity
- Maturity/social acceptance

As indicated in chapter 1, there is no authoritative approach when it comes to social sustainability criteria, but rather various interpretations regarding what issues should be addressed (Dixon and Colantonio 2008). It has also been argued that the selection of measures often is a function of power (Littig & Griessler 2005). Influential groups are more likely to have their concerns included, and indicators come to reflect different sociocultural priorities. On this background, it is necessary to integrate criteria of different quality, and to pay due respect to the importance attributed to them by various stakeholders (Omann and Spangenberg 2002). Considering the objectives of the present project we heed this argument, and go beyond standard evaluation methodologies to include multiple social sustainability criteria addressing different levels and objectives.

There are also indications that it is necessary to develop a stronger linkage between the social and environmental pillars (Dobson 2003b, Littig & Griessler 2005, Gough et al., 2008). Murphy (2012) proposes that the parameters of the social pillar should be connected empirically to the environmental, for better incorporation of the international and intergenerational dimensions. While Murphy's main concern is to develop a better framework for policy analysis, his points are valid also as regards assessment of specific development interventions. When it comes to technical alternatives with minute differences, connecting social sustainability and performance parameters makes more sense than attempting to provide measures that are independent from the technical and environmental aspects.

5.2 Criteria and indicators selected for this study

In addition to existing literature, the selection of social sustainability criteria is informed by the observations from the baseline study. The baseline study addressed very many aspects of the social context in the targeted parts of GAMA. For some areas of investigation we did not get very accurate information, but for other areas we were left with quite clear impressions. Reportedly, reliability and quality mattered more to respondents' choice of water source than cost; power cuts and black-outs was a serious problem in all target areas; there was limited concern with climate change; water was a source of conflict in the households; there were hardly acknowledged community leaders and people did not seem to have close relationships with neighbours; and opportunities for trade and business were at the fore of many respondents' minds. We also found that questions on aesthetics did not bring very engaged or unanimous responses, whereas there were clearer tendencies when it came to social 'image' or standing.

On the background of these observations, aesthetics is not highlighted as a criterion in this assessment. Considering the nature of the intervention, **health facilitation** is. The baseline study did not yield very accurate information on health and hygiene conditions, but still indicated that there is a potential for improvement in this area. **Resource independence** including electricity requirements is included as another criterion. Community relations are not defined as one criterion, but rather subdued under the broader and more measurable criterion of **social capital**, which also includes social standing. With a view to the project objective on business development and the entrepreneurial bent among respondents, **scope for entrepreneurship** is treated as a criterion on its own. **Ease of operation** is also defined as a criterion: Whereas advocates highlight timesaving as a social impact of RWH and this no doubt is an important benefit in many cases, many households in the baseline survey reported that they did not spend too much time fetching or buying water, but yet mentioned convenience as an important factor. Therefore, ease of operation here includes time, as well as physical effort and maintenance requirements, which often are critical when it comes to implementing new technology in developing societies. **Social acceptance**, finally, is included as a criterion, since it is critical as regards business development, as well as an important indicator of how smoothly the practice will be adopted and how easy or difficult it will be to maintain and integrate it with existing patterns of behaviour.

As noted above equity, including gender and intergenerational equity, is an important dimension of social sustainability. RWH is likely to have a positive impact in this area, by reducing the workload on women on children, and by reducing water-related costs so that vulnerable households become more self-reliant. What we did see in the baseline survey, however, is that roles and responsibilities to do with water in the GAMA not necessarily are distributed according to the traditional pattern. When it comes to weighing different RWH designs up against each other, and not against other solutions, an additional challenge is how to and measure or distinguish between different kinds and degrees of impact in this area. The equity dimension is therefore rather addressed in terms of other criteria; ease of operation, resource independence, scope for entrepreneurship, and social capital. An overview of the selected criteria and indicators is presented in Table 5.1.

Table 5.1: Social sustainability criteria and indicators.

Dimension	Criterion	Indicators
Quality of life	Health facilitation	- Amount of water (O) - Quality of water (O) - Safe handling of water (O)
Empowerment	Resource independence	Independence in terms of - Power (O) - Replaceable parts (O) - Skills/knowledge (O)
Diversity	Scope for entrepreneurship	- Local content (O) - Water beyond household needs (O) - Lifetime (O)
Social mixing/cohesion	Social capital	- Social networks (O) - Self-reliance (O) - Social standing (S)
Equity	Ease of operation	Lesser requirements in terms of - Time/work (O) - Physical effort (O) - Maintenance (O)
Maturity/acceptance	Social acceptance	- Satisfaction of needs (O) - Positive perception of origin and quality (S) - Alignment with existing knowledge, attitudes and practices (O)
	Composite	Total composite for social sustainability - 'sociopoints'

The letters in brackets behind the indicators indicate whether they are objective (O) or subjective (S) indicators. For the integrated sustainability analysis described in chapter 7, each indicator is assessed and rated on a scale from 1 to 3, where 1 represents the lowest social sustainability and 3 the highest. A rating for each criterion is found by adding the ratings for the relevant indicators.

5.2.1 Health facilitation

Health facilitation is the degree to which the RWH system will facilitate good health in the household, by improving health and hygiene conditions. This is measured by the estimated amount of water provided, the quality of harvested water, and the degree to which the system involves safe handling of the water. When it comes to quantity of water, the ratings 1-3 are based on the following graduation:

- Rate 1: 130 – 229 days (demand met from around 4 to around 8 months per year, regular need to supplement with other water sources)
- Rate 2: 230 – 309 days (demand met most days, but need to supplement from a little less than 2 to months to 4,5 months of the year)
- Rate 3: 310 – 365 days (demand met almost all year, rarely need to buy)

Regarding quality, distinctions are made as follows:

- Rate 1: The system has no integrated disinfection. The water may still be quite clean, compared to water from other sources, but it must be regarded as non-potable and there is a health risk involved if the water is used for drinking and food preparation without further treatment.
- Rate 2: The system includes treatment and disinfection in the form of cartridge filters and a system for administering chlorine tablets, so the water is purified and potable. The system involves health risk only to the extent filters are not changed and/or chlorine tablets are not administered according to procedure.
- Rate 3: The system includes UV disinfection. This is fully automated and the health risk is minimal – comes in only if electricity goes off and associated safety procedures are not followed.

As to safe handling, ratings are based on the following differences:

- Rate 1: The basic designs have a water supply subsystem consisting of a tap mounted directly on the tank. Some water may spill out on the ground, and water is likely to be taken into the house or other use areas in containers that may not at all times be entirely clean. If care is not taken the area near the tap could make a breeding ground for mosquitoes and water is more likely to get contaminated through the manual handling than with more advanced systems.
- Rate 2: The intermediate designs include a head-tank plus a pipe system for transferring the water into the house. This reduces the above-mentioned risks.
- Rate 3: The more advanced designs have a water supply sub-system which is automated, with pumped constant pressure. This ensures a steady flow and stable conditions inside the pipes, which make the systems even safer than the intermediate designs, since there will be less chance of growth of pathogenic bacteria in the pipes.

5.2.2 Resource independence

By resource independence we mean the extent to which the system can supply water independently of external systems and resources. This is an important criterion in emerging countries, where political and economic conditions may vary and affect the availability of electricity, spare parts, etc. It is particularly relevant in urban fringe settlements, where infrastructure tends to be poor and households may have limited social safety nets, less predictable income sources, and be more unstable than in more established environments. In this study, resource independence is assessed by way of independence from electricity, independence/non-reliance on replaceable parts that could be difficult to get in times of crisis, and independence in terms of knowledge and skills requirements.

For resource independence as regards electricity, ratings are based on the following distinctions:

- Rate 1: Advanced designs including UV disinfection and automated water supply sub-system with pumped, constant pressure either depend on a regular supply of electricity, or that the household has a functioning generator and/or the will to carry out specific procedures to return the system to its safe and normal state after power breakdowns.

- Rate 2: Designs including electrical pump and a head tank depend on a regular supply of electricity to function optimally over time, but can still function for a limited time without extra precautions in case of power breakdowns.
- Rate 3: The basic designs considered in this study score highest, since they do not depend on electricity in any way.

As regards replaceable parts, distinctions are made as follows:

- Rate 1: Advanced designs: UV lamps are readily available in Ghana at present, but there are not many suppliers and if the users do not have means to get them through the internet, the lamps may be difficult to get in times of crisis. As for the intermediate designs, cartridge filters also need to be replaced regularly.
- Rate 2: Intermediate designs - cartridge filters and chlorine tablets require that one buys replaceable parts regularly. The parts represent a significant cost, so there is the risk that parts may not be replaced according to the recommended schedule.
- Rate 3: The basic designs do not require regular replacement of parts to function optimally.

Though intangible, skills and knowledge are important resources, and the extent to which a system depends on such resources to function properly is an important aspect of its sustainability. The ratings here are made according to the following distinctions:

- Rate 1: Monitoring and maintaining an advanced system including UV disinfection requires a certain level of technical interest or expertise. While this may be possessed or acquired by the household members, many households will prefer to buy this service from the supplier or a qualified artisan.
- Rate 2: Administering filters and chlorine tablets requires systematic follow-up and basic knowledge about water treatment, but can in most cases be handled easily by household members.
- Rate 3: The basic designs do not require any specialized skills or knowledge in order to function as specified.

5.2.3 Scope for entrepreneurship

Scope for entrepreneurship could be defined in many ways. In this assessment it is based on three indicators; local content, water beyond the demand/needs of the household, and the estimated lifetime of key components of the system.

The local content of a product is the tender price less the value of important content, that is a measure or an indication of the value added in the local country, i.e. Ghana in this case. By this definition, local content may actually be calculated and expressed as a percentage, but due to time and resource limitations it is only estimated in this assessment. Ratings are based on the following assumptions:

- Rate 1: UV disinfection solutions are imported and only mounted without any further value addition in Ghana. The same goes for PVC gutters and pipes and the automated water sub-supply system, which also has limited local content, except if pipes are produced locally. Automated first flush diverters are new in Ghana and for now imported from Australia. Resin for PE tanks is also imported. On this basis, the advanced designs with these components are rated low in local content. Cartridge filters, chlorine tablets and head-tanks are also imported. Therefore, intermediate designs with PE tanks, PVC gutters and automated first-flush are also given the lowest rating.
- Rate 2: This rating is used for advanced and intermediate designs including ferro-cement rather than PE tanks. Raw materials for ferro-cement tanks are produced in Ghana and the construction of the tank is done locally, so the value added and potential for business/entrepreneurship is higher for these designs than for similar systems based on plastic tanks. Rate 2 is also used for basic designs with PE tanks, since the other components included here are associated with higher local content.
- Rate 3: This rating is used for the basic designs with ferro-cement tanks. Here, the tanks, as well as the gutters and pipes, may involve a higher local content. Metal gutters and pipes may be made or bent in to shape locally. Manual first flush diverters can also easily be made by local artisans (but since they are not well known, they are imported for the first pilot installations in this project).

Water beyond the household's demand/needs gives an indication of the potential for using harvested water for income-generating activity, such as selling water in excess periods, or using it for gardening, provision of laundry services, catering, etc., or increasing social capital by bartering or sharing with neighbours in need. Water beyond the household's demand/needs is here measured by average yearly overflow, with the following graduation:

- Rate 1: 0-39 m3
- Rate 2: 40-79 m3
- Rate 3: 80-119 m3

The lifetime of the system gives an indication of how many years the household may be able to use harvested water for entrepreneurial activity. More detailed estimates could no doubt be made, but again there are time and resource limitations to this study, and we are most interested in the relative assessment/ranking of the selected designs. Therefore, ratings for this indicator are based on the following estimates and assumptions:

- Rate 1: The estimated lifetime for UV disinfection and cartridge filter units is 10 years. Although they may last much longer, the estimated lifetime for plastic water tanks is 15 years. For PVC gutters and pipes, the lifetime is approximately 15 years, while electric pumps are estimated to last for 20 years. On this basis, the advanced and intermediate designs with PE tanks are rated 1 on this indicator.

- Rate 2: This rate is used for advanced and intermediate designs with ferro-cement tanks, as the estimated lifetime for such tanks is 50 years. The tank is by far the most expensive component and the one that is most difficult to replace. Rate 2 is also used for the basic designs with PE tanks. Though the tanks will not last longer than the PE tanks used in advanced and intermediate designs, the basic designs come with metallic gutters and pipes, which have an estimated lifetime of 25 years.
- Rate 3: This rate is used for the basic designs with ferro-cement tanks. Here, all key components can safely be estimated to last for 20 years or more, provided they are handled and maintained properly.

5.2.4 Social capital

Social capital is here defined in Bourdieu's (1986) sense, as the sum of the resources, actual or virtual, that accrue to an individual or a group by virtue of possessing a durable network of more or less institutionalized relationships of mutual acquaintance and recognition. Selected indicators are the impact on social networks, by way of increasing the number of contacts the house-owner and/or household engage with; level of self-reliance; and projected impact on social standing or image in the eyes of others. For a bigger, more advanced assessment, social networks could be measured in accurate terms. Here, we choose a simpler approach, based on the following assumptions:

- Rate 1: Except for the first flush diverters, the basic designs consist of components that can be bought all over Accra. On the whole, installing, using and maintaining the system does not necessarily involve many new contacts.
- Rate 2: The intermediate designs come with a bigger potential for expanding and benefiting from social networks. Buying and maintaining the disinfection solution and the pump will bring the household into contact with more people, with different backgrounds, status, and kinds of knowledge.
- Rate 3: The advanced designs, with automated water sub-supply and UV-disinfection, will involve more contacts, potentially with 'higher circles', since UV disinfection only are sold from highly specialized shops and up to now may be said to have been a technology for the elite.

Self-reliance is a central aspect of empowerment. It can be an important resource for the household and its individual members in terms of social recognition, influence, and also, participation. Ratings are based on the following distinctions:

- Rate 1: This rate is used for the systems with the lowest reliability – that is, those that meet the daily water demand 229 or fewer days per year. Rate 1 is also used for basic systems that meet the daily demand between 230-309 days per year, since these systems do not include disinfection and users will have to treat the water separately if they want to drink it.

- Rate 2: This rating is used for the basic designs that have the capacity to meet demand 310 or more days per year. Advanced and intermediate designs with reliability of 230-309 days per year are included in the same category, since they provide potable water without need for further treatment, and in this sense are associated with a higher level of self-reliance than basic systems with the same capacity.
- Rate 3: This rating is used for the advanced and intermediate designs estimated to meet daily water demand 310 days or more. Since these systems give the highest reliability in terms of quantity as well as quality, they are given the highest score.

Social standing is linked to status and social class, but in a sociological sense the latter concepts have more specific meanings, whereas social standing is less tied to specific rights and duties and more linked to perceptions and images. The ratings for this indicator are based on findings from the baseline survey and the following assumptions:

- Rate 1: The basic designs do mostly include well-known components placed into a system that provides more and better water than what traditionally has been associated with rainwater harvesting in Ghana. While some people may not associate rainwater harvesting with urban life, the systems are relatively expensive, and a house-owner who can show off a well-functioning system will most likely be perceived as someone who is positively "doing something for himself" and the family – a capable and responsible provider.
- Rate 2: The intermediate designs include some more advanced components and some parts whose operation requires a certain degree of knowledge or technical interest, at the same time as they yield water of a quality that up to recently was not associated with rainwater harvesting in Ghana. House-owners with such systems are trying something new, a bit more advanced, and in this sense they may also be perceived as more "modern" and entrepreneurial than those going for the basic designs.
- Rate 3: The advanced designs with UV disinfection include components that are relatively new in Ghana, relatively "high-tech", and until now associated mainly with the elite. People who can boast such a system may be associated with high class, and are also likely to be seen as pioneers in environment-friendly technology development, or as a kind of "development agents".

5.2.5 Ease of operation

Ease of operation is here defined in terms of three indicators; time spent operating the RWH system and/or getting water from other sources, physical effort involved in getting water, and maintenance requirements. As regards time, ratings are based on the following distinctions:

- Rate 1: The intermediate designs save time, in that users can spend less time purchasing or fetching water from other sources. On the other hand getting and changing filters, and administering chlorine to achieve the quality suited to the respective uses of the water, takes some time that one might not have spent if one relied on other sources. There are also considerable differences within the category of designs, as the systems that provide more water involve more time-saving than systems yielding less water.

- Rate 2: The basic designs do also save time by reducing the time spent on getting water from other sources. While the outdoor tap means that one would have to carry water manually for indoor use, operating the basic systems in themselves takes less time than operating and monitoring the intermediate designs. Within the category of basic designs too, there are considerable differences, as the systems that provide more water involve more time-saving than systems yielding less water.
- Rate 3: The advanced designs, like the basic and intermediate ones, save time by making harvested water readily available, as collected from the roof. The fully automated sub-supply system brings the water straight into the house, and the UV-disinfection is also fully automated, so operating and monitoring the system does not take any extra time, if there is a regular electricity supply. On the other hand there are considerable differences within this category too, as the systems with higher capacity will be more time-saving than systems with lower capacity.

When it comes to physical effort, the following distinctions are made:

- Rate 1: Getting water from the basic designs for various domestic use areas will require some physical effort, as water will have to be drawn from the outdoor tap and poured into various containers for use. Water will also have to undergo further treatment before it can be used safely for drinking and cooking.
- Rate 2: Getting water from the intermediate designs involves less physical effort, as the designs include a water sub-supply system based on an electrical pump. However, some effort is required to administer chlorine and change filters.
- Rate 3: Getting water from the advanced designs will not require any special physical effort, as the system will be fully automated.

As to maintenance requirements, ratings are based on the following distinctions:

- Rate 1: The advanced designs involve a higher number of components and more technologically advanced units that require regular maintenance to function optimally.
- Rate 2: The intermediate designs involve fewer and less complex components than the advanced designs. Maintenance requirements are consequently less.
- Rate 3: The basic designs include just a few, basic components. These systems will also require maintenance, but the tasks involved will be simpler and fewer than for the advanced and intermediate designs.

5.2.6 Social acceptance

Social acceptance is here assessed in terms of satisfaction of needs, perceptions of the origin and quality of different components and solutions, and the alignment of the respective designs and their requirements with existing knowledge, attitudes and practices among the target population.

The following ratings are used for satisfaction of needs:

- Rate 1: Systems that meet the household's water needs in terms of quantity 229 days per year or less, irrespective of whether the water is disinfected or not. At this performance level, needs are not satisfied, but rainwater harvesting can be a safe and economically sound source of water in combination with other alternatives.
- Rate 2: Basic designs that meet the household's need for water between 230 and 365 days per year, as well as intermediate and advanced designs that provide water between 230 and 309 days per year. Systems at this performance level satisfy the household's needs to a considerable extent.
- Rate 3: Intermediate and advanced designs that meet the household's need for water 310 days per year or more. These systems yield a quantity that may come close to covering the household's needs, at the same time as the water quality meets a standard suited for drinking and cooking.

As regards perceptions of origin and quality, the following distinctions are made:

- Rate 1: All intermediate designs, and the advanced designs including ferro-cement tanks, are placed in this category. The intermediate designs are for a large part based on imported components. As the findings from the baseline survey indicate, many Ghanaians have mixed feelings about foreign products, especially those from China. People also have their doubts about ferro-cement tanks. Although they are seen to be long-lasting, there is a fear of leakages and bad water quality. Cartridge filters and chlorine tablets are known, but here too, people may have their doubts as to whether their use will result in high-quality water.
- Rate 2: All basic designs are given this rating. Ferro-cement tanks are perceived as above. In most cases key components, i.e. resin for PE tanks, is imported from China, while metallic gutters and pipes can be produced locally. While some question the quality, many Ghanaians place positive value on the use of local products. The advanced designs with PE tanks are also placed in this category. The reasoning is that while most components are imported, UV disinfection and a water sub-supply system that is fully automated and pumped to constant pressure, is more advanced and associated with higher-level functionality.
- Rate 3: None of the assessed alternatives are rated 3. This reflects the perceptions people have regarding their origin and quality.

On alignment with existing knowledge, attitudes and practices, the following distinctions are made:

- Rate 1: The advanced designs are rated 1, as UV disinfection is quite new in the Ghanaian market. People at the grass root have limited knowledge about how this works, and using it is not part of any widely accepted practices. Installing an advanced water sub-supply system in relation to rain harvesting may also be a strange idea to some, as they are used to small-scale, ad hoc rain harvesting, but may not associate it with the potential for a large-scale, full-time water system for their house.

- Rate 2: The intermediate designs include more known components and practices. Filtering of water is quite common in Ghana, and the use of filtered sachet water for drinking is quite widespread. Chlorination is also known, though less widespread. It requires some knowledge of disinfection, and there may be some scepticism regarding taste and smell, etc., but the effects are widely recognized and trusted. Establishing routines, changing filters, and administering chlorine systematically may be challenging for many households, but it should be possible once they gain a solid understanding of the hows and whys.
- Rate 3: The basic designs are quite well aligned with existing knowledge, attitudes, and practices, as they simply combine existing technology in more optimal ways and do not include new components apart from simple first flush diverters.

5.3 Some general observations

The results of the social sustainability assessment are discussed further in chapter 7. Here, we draw attention to just a few, general points. First of all, there are great variations in how the systems score on the selected criteria (Table 5.2). The situation is not that one category of designs scores higher on all or most criteria and another category scores less on all or most criteria. While the advanced alternatives score high on health facilitation, the basic ones score higher on resource independence. Likewise, advanced designs are associated with more social capital, while the basic ones score higher on acceptance.

There is also considerable variation at the indicator level: If we look to ease of operation, the intermediate designs score lowest, while the basic designs score higher and the advanced designs score highest. However, while the advanced designs are associated with more time-saving, they score lowest on maintenance requirements. The basic designs, on the other hand, score high on maintenance requirements and lower on physical effort and time-saving. The intermediate designs save less time, and fall in the middle range on physical effort and maintenance requirements.

This complexity is important to consider in the promotion and implementation of standardized RWH designs. It is not necessarily so that the most advanced systems are best suited for all users, or that the most basic ones are preferable in all social contexts. To select the most appropriate solution for a given household, area, or target group, assessing the situation of the users up against the score of different alternatives on the different social sustainability indicators is advisable.

When we consider the results in general and see how the ratings for all the six social sustainability criteria add up to different levels of "sociopoints" for each alternative, the assessed designs do not appear too different from each other from a social sustainability point of view. This is not surprising, since the alternatives selected for assessment are designs the project team considered as likely, comparable and good options from the outset. Also, since social sustainability has many different dimensions, differences will tend to be conflated when all the dimensions are lumped together.

Table 5.2: Social sustainability criteria and indicators for the 36 design alternatives.

#	Health facilitation	Resource independence	Ease of operation	Scope for entrepreneurship	Social capital	Acceptance/maturity	"Sociopoints" (max=54)
Basic designs							
1	1+1+1=3	3+3+3=9	2+1+3=6	2+1+2=5	1+1+1=3	1+2+3=6	32
2	2+1+1=4	3+3+3=9	2+1+3=6	2+1+2=5	1+2+1=4	2+2+3=7	35
3	3+1+1=5	3+3+3=9	2+1+3=6	2+2+2=6	1+2+1=4	2+2+3=7	37
4	3+1+1=5	3+3+3=9	2+1+3=6	2+3+2=7	1+2+1=4	2+2+3=7	38
5	1+1+1=3	3+3+3=9	2+1+3=6	2+1+2=5	1+1+1=3	1+2+3=6	32
6	1+1+1=3	3+3+3=9	2+1+3=6	2+1+2=5	1+1+1=3	1+2+3=6	32
7	2+1+1=4	3+3+3=9	2+1+3=6	2+2+2=6	1+2+1=4	2+2+3=7	36
8	3+1+1=5	3+3+3=9	2+1+3=6	2+3+2=7	1+2+1=4	2+2+3=7	38
9	2+1+1=4	3+3+3=9	2+1+3=6	3+1+3=7	1+2+1=4	2+2+3=7	37
10	1+1+1=3	3+3+3=9	2+1+3=6	2+3+2=7	1+1+1=3	1+2+3=6	34
11	2+1+1=4	3+3+3=9	2+1+3=6	2+2+2=6	1+2+1=4	2+2+3=7	36
12	3+1+1=5	3+3+3=9	2+1+3=6	3+2+3=8	1+2+1=4	2+2+3=7	39
Intermediate designs							
13	1+2+2=5	3+2+2=7	1+2+2=5	1+1+1=3	2+1+2=5	1+1+2=4	29
14	2+2+2=6	3+2+2=7	1+2+2=5	1+2+1=4	2+2+2=6	2+1+2=5	33
15	3+2+2=7	3+2+2=7	1+2+2=5	1+3+1=5	2+3+2=7	3+1+2=6	37
16	2+2+2=6	3+2+2=7	1+2+2=5	2+1+2=5	2+2+2=6	2+1+2=5	34
17	1+2+2=5	3+2+2=7	1+2+2=5	1+3+1=5	2+1+2=5	1+1+2=4	31
18	2+2+2=6	3+2+2=7	1+2+2=5	1+2+1=4	2+2+2=6	2+1+2=5	33
19	3+2+2=7	3+2+2=7	1+2+2=5	2+2+2=6	2+3+2=7	3+1+2=6	38
20	3+2+2=7	3+2+2=7	1+2+2=5	2+2+2=6	2+3+2=7	3+1+2=6	38
21	1+2+2=5	3+2+2=7	1+2+2=5	1+1+1=3	2+1+2=5	1+1+2=4	29
22	1+2+2=5	3+2+2=7	1+2+2=5	1+1+1=3	2+1+2=5	1+1+2=4	29
23	2+2+2=6	3+2+2=7	1+2+2=5	1+2+1=4	2+2+2=6	2+1+2=5	33
24	3+2+2=7	3+2+2=7	1+2+2=5	2+3+2=7	2+3+2=7	3+1+2=6	39
Advanced designs							
25	1+3+3=7	1+1+1=3	3+3+1=7	1+3+1=5	3+1+3=7	1+2+1=4	33
26	2+3+3=8	1+1+1=3	3+3+1=7	1+2+1=4	3+2+3=8	2+2+1=5	35
27	3+3+3=9	1+1+1=3	3+3+1=7	2+2+2=6	3+3+3=9	3+1+1=6	40
28	3+3+3=9	1+1+1=3	3+3+1=7	2+2+2=6	3+3+3=9	3+1+1=6	40
29	1+3+3=7	1+1+1=3	3+3+1=7	1+1+1=3	3+1+3=7	1+2+1=4	31
30	1+3+3=7	1+1+1=3	3+3+1=7	1+1+1=3	3+1+3=7	1+2+1=4	31
31	2+3+3=8	1+1+1=3	3+3+1=7	1+2+1=4	3+2+3=8	2+2+1=5	35
32	3+3+3=9	1+1+1=3	3+3+1=7	2+3+2=7	3+3+3=9	3+1+1=5	40
33	1+3+3=7	1+1+1=3	3+3+1=7	1+1+1=3	3+1+3=7	1+2+1=4	31
34	1+3+3=7	1+1+1=3	3+3+1=7	1+2+1=4	3+1+3=7	1+2+1=4	32
35	1+3+3=7	1+1+1=3	3+3+1=7	1+3+1=5	3+1+3=7	1+2+1=4	33
36	2+3+3=8	1+1+1=3	3+3+1=7	2+2+2=6	3+3+3=9	2+1+1=5	38

However, we also see some general tendencies. First, alternatives with smaller tanks and smaller yields of water rate lower on total "sociopoints", while systems with bigger tanks and more capacity relative to household size rate higher. Secondly, we see that the alternatives with ferro-cement tanks also tend to get a high score. These alternatives happen to be among those with the highest capacity, but they also score higher as compared to same-size systems with plastic tanks. One important reason for this is that ferro-cement tanks are associated with higher local content and have a significantly longer life-time than PE tanks. PE tanks are associated with more flexibility (i.e. you can sell it in a time of crisis or bring it with you if you have to move), their characteristics are well-known, and some people fear that ferro-cement tanks may leak and/or release unwanted substances into the water, so there are still good reasons to consider PE tanks in many cases. With a view to long-term sustainability and scope for entrepreneurship, however, ferro-cement may be preferable.

Another important observation is that as far as social sustainability is concerned, one should think carefully before selecting or promoting intermediate or advanced designs above the more basic ones. Although the three alternatives that score highest on social sustainability are advanced designs with big ferro-cement tanks, there is not much difference between these alternatives and the intermediate and basic designs with ferro-cement tanks and comparable capacity. We also see that for some sizes, basic designs score higher than the intermediate and advanced alternatives.

For some categories of users and certain areas, where infrastructural and social constraints imply that more advanced designs may not be utilized to their full potential, it may be advisable to go for simpler, more robust alternatives. On the other hand, there is the need to consider consumer trends and future market potential. While basic and intermediate designs may be just as socially sustainable as at now, the advanced designs may be more in line with the present and future preferences in the emerging market for environment-friendly building and infrastructure technologies. On the whole, it may be argued that the social sustainability assessment underscores the usefulness of promoting a set of different design alternatives to satisfy different sets of needs and meet different niches in the local water market.

6 Economic assessment

6.1 Introduction to economic assessment

The economic assessment has been done using an economic analysis model of RWH systems designed to determine the optimal storage tank size. The optimal size of the storage tank from an economic perspective is found by combining system cost and reliability, computing the long run marginal cost of supplying water to the household. By comparing marginal cost for supplying rainwater with marginal cost of being supplied by tanker service, cost efficient solutions with respect to tank size and supplement use of tanker service can be identified. The procedure is described in the following sections of this chapter.

This chapter also explains economic indicators used to characterize the alternative initial designs for household RWH systems presented in chapter 3. The range of indicators comprise simple indicators, like households annual savings due to reduced water bills and payback period, as well as indicators based on discounted cash flows, i.e. weighting initial outlays and future savings together using time cost of capital.

As discussed previously in this report, combining rainwater harvesting with other water sources is normal. The assessments have therefore been performed taking into account the possibility of buying additional water from tanker service operators.

The economic analysis model and the calculation of the economic indicators are in line with each other and results are consistent. However, the analysis model presented is focusing on economically optimal tank size determination, so for example water treatment is not included, whilst the economic indicators for the 36 alternatives comprises all relevant components and costs.

The 36 initial design alternatives illustrate in a concrete way the range available to households. The tank sizes are fixed and the alternatives are designed to span the possibilities, rather than being optimal in some strict way. The economic analysis model deals with the tank size determination and thus has a much more narrow focus.

6.2 Assessment of RWH system from an economic point of view

6.2.1 Assumptions and limitations

The economic analysis model for economically optimal tank size determination and the assessment of the economic indicators for the 36 alternatives are based on the assumptions for the designs given in chapter 3 with some additions, simplifications and limitations as given below:

- Roof size is exogenously fixed. For the calculations with the economic model determining optimal tank sizes we present 3 cases with roof sizes: 90 m^2, 150 m^2 and 200 m^2.
- Number of persons served and average water consumption per day per person is fixed. For the calculations with the economic model determining optimal tank sizes we use a water consumption of 160 litres per day in total for the household.

- Within the economic analysis model dealing with tank size determination, the tank cost is the only cost that is variable and influence system cost. Other costs for catchment, treatment and distribution of the harvested water are assumed to be invariant to the quantity of water harvested.
- Tank costs in the economic model are based on PE tanks only. Other tank materials are not included.
- Regarding the economic indicators for the 36 alternatives, treatment cost for intermediate and advanced alternatives are dependent on quantity of water. Basic alternatives have no treatment. Other costs (catchment and distribution of the harvested water) are assumed to be invariant to the quantity of water harvested.
- The 36 alternative designs differ in size and technology level, from very basic with no water treatment and head, via intermediate systems to advanced systems with filtering and UV-lamp and an automatic pump for water distribution. Thus the quality of the service delivered varies across the systems. These differences are not appraised, but rather made visible by their costs. The focus of the economic model is on the water harvesting part – especially the tank size and less on treatment. Hence, treatment systems and pumps for distribution is considered to be system costs and regarded as add-ons to the harvesting system as these costs is less sensitive to the quantity of water harvested or consumed.
- In rainfall periods the tank will typically flow over. Using more water will then increase benefits at no cost. In dry periods water can be saved by reducing demand. The effect of such an adaptive strategy is not included in the economic assessment.

6.2.2 Costs

Cost or price statistics for complete RWH systems are not readily available in Accra. Prices for relevant components like gutters, pipes, tanks, pumps, filters etc. have been collected in the market (pricelists and inquiries spring/summer 2013). This was done as part of the initial survey which also identified relevant components and collected data on capacity and quality which comprises anticipated length of service life, robustness, maintenance friendliness, etc.

Costs for transport, installations and consumables are estimates based on public pricelists, inquiries and interviews (spring/summer 2013).

For the economic tank size determination model it is assumed that the cost is 0.22GH¢ per litre tank volume. This is based on a Ghanaian plastic tank manufacturer's public pricelist for consumers (summer 2013). This is an average for tanks from 2500 litres to 30000 litres. Compared to actual prices in the pricelist the error is less than 40 GH¢. The pricelist is used for computation of the indicators.

For the economically optimal size determination model a lump sum cost equal to 2 500 GH¢ for basement and catchment system, transportation and installation was added. This is in line with initial outlay for a basic system estimated and used for indicator computations. Remark that this lump sum cost is assumed to be constant and invariant to the tank size. Hence, it does not influence the size decision.

The water price offered by tanker service varies across Accra due to transportation costs and water availability throughout the year. The average price paid by household also depends on quantity ordered. According to Van Rooijen et al. (2008) the price is also higher in the dry season than in the wet season. Based on an inquiry (spring 2013) we assume a fixed price equal to 20 GH¢ per m^3.

6.3 Method for determination of economically optimal tank size

Based on the assumptions given above, the RWH-system's reliability (number of days per year adequate quantity of water is supplied) was computed as the basis for the optimal tank size determination.

The results are presented in Table 6.1 for a daily demand of 160 litres with roof sizes of 90 m^2, 150 m^2 and 200 m^2. These cases corresponds with the basic alternatives 6, 7 and 8 and the intermediate alternatives 13, 14 and 15. For all the advanced alternatives water consumption is assumed to be greater than 160 litres per day. The tank cost and additional 2 500 GH¢ for basement and catchment system, transportation and installation is also given in Table 6.1.

Table 6.1: Reliability - water supplied # days per year dependent on tank size*

Tank size [liter]		2500	3500	5000	7000	10000	15000	20000
RWH cost GHC (no operating costs)		GHC 3.063	GHC 3.288	GHC 3.625	GHC 4.075	GHC 4.750	GHC 5.875	GHC 7.000
Roof size square m	90	193	212	234	257	280	307	323
	150	227	250	276	299	319	342	358
	200	244	269	293	312	330	351	362

*: Daily demand 160 l, calculations performed with average rainfall per month.

As can be seen, if the roof is 90 square meter and the tank is 5000 litres, the system can be expected to provide water for 234 days per year. Increasing the tank to 10000 litres will increase the expected reliability by 46 days. Increasing the tank size to 15 000 litres will increase the expectation with an additional 27 days. The additional 5000 litres will just give 16 extra days of expected water supply.

It should be noted that 160 litres is almost equal to average daily run-off for a 90 square meter roof (170 litres). Hence, for such a roof size, the rule of thumb (Thomas and Martinson, 2007) predicts that the RWH system will not be appropriate as the sole source of water. Thomas and Martinson argue that a RWH system will be very expensive when the harvesting area is small and/or the annual rainfall is out of proportion which the household's water consumption. In such a case, tanker service offers a "relief", as the household can buy supplemental water at a market price (ibid.).

The method for determining the economically optimal size of the RWH system is based on:

- Cost figures and cost calculations for a RWH system.
- Costs of alternative sources (i.e. tanker service) – as a supplement to the RWH system.

Our approach implicitly assumes that households can afford paying the initial outlay or can borrow at the relevant rate in order to fund the RWH-system. Combining RWH with tanker service allows great flexibility with respect to tank size, and thus also with respect to the household income and ability to carry upfront costs. As shown later on, most economic gains from harvesting rain can be achieved even if the household selects a tank (and investment costs) that is smaller than the optimal size.

The cost of the RWH system is comprised of initial outlay (investment cost) for the PE storage tank and additional lump sum costs as explained above. The costs used are in line with cost for basic systems with no head tank or water treatment. Taking into account additional investments on system level - independent of tank size or water consumption level - is straightforward as the total cost simply will increase by the same amount. In fact, the catchment cost will typically differ between systems with different roof sizes and roof designs. This is not taken into account in this modelling.

Based on numbers in Table 6.1 - taking into account tank cost and the additional 2 500 GH¢ – Figure 6.1 illustrates the relation between cost and number of days per year water is supplied by the RWH system.

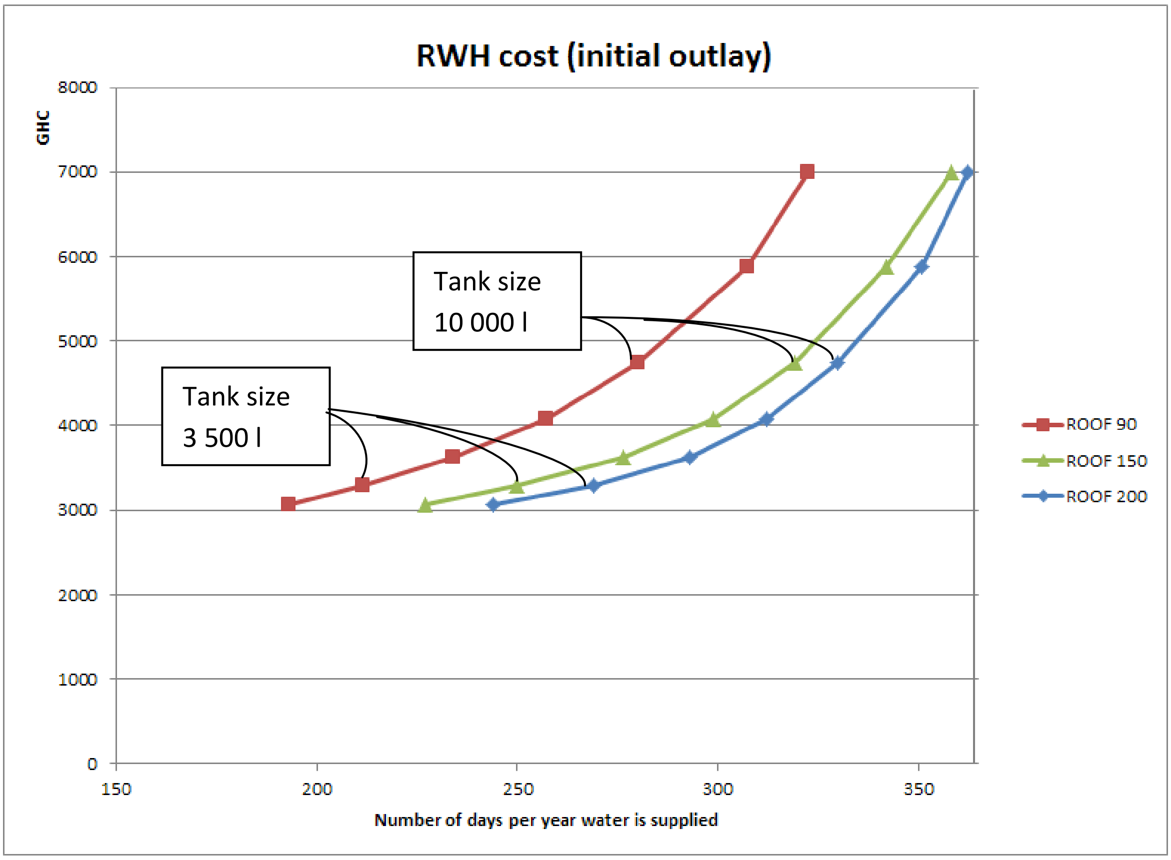

Figure 6.1: Cost (initial outlay) for number of days per year water is supplied. Water consumption 160 litre per day

As only tank costs and invariant (lump sum) system costs are taken into account, all systems with equal tanks will have equal costs independent of roof size. The costs of the 2500 litres tank systems are slightly above 3 000 GH¢ and so on, up to the maximal size of 20000 litres with a cost equal to

7 000 GH¢. As illustrated by Figure 6.1 the cost of supplying water increases as roof size decreases, and also, the marginal cost (cost gradient) is higher the smaller the roof. In order to extend the analysis to the situation where RWH is combined with water supplied from a tanker service, a formal model using net present value was developed.

6.3.1 Formal economic analysis model

For Accra we assume that the RWH can be supplemented with buying water from tanker service. We further assume that the household minimizes net present value (NPV) of expenditures for water supplied over the service life of RWH system (15 years for PE tank systems). With these assumptions a mathematical model can be stated:

$$NPV = CAPEX(N) + \sum_{t=1}^{T} P_{TS} D[365 - N] \frac{1}{(1+r)^t} \qquad (1)$$

The first term *CAPEX (N)* is the initial capital expenditures. The RWH system supplies the household with water *N* days per year. The shape of the CAPEX (N) depends on the roof size, precipitation pattern and daily water consumption. Figure 6.1 indicates the CAPEX(N) for three different roof sizes. CAPEX also includes the lump sum of 2 500 GH¢, which is just a constant. However, neither maintenance costs nor operation costs are included in this model. Water has to be supplied 365 days a year. Hence, the household will have to buy water from tanker service for *365-N* days. The second term – the sum – is the cost of buying sufficient water – quantity D per day for *365-N days* every year. The price for one unit of water from tanker service is P_{TS}. The service life of the system is *T* years, which is assumed to be exogenous. The household has to buy water every year over the life time T. The relevant cost of capital is *r.*

Equation (1) is equal to:

$$NPV = CAPEX(N) + P_{TS} D[365 - N] \frac{1}{r}\left[1 - \frac{1}{(1+r)^T}\right] \qquad (2)$$

If the RWH system should be combined with buying water from tanker services, this should be supported by the minimum we find by setting the derivative of (2) with respect to N equal to zero which yields:

$$\frac{d}{dN} CAPEX[N] = P_{TS} D \frac{1}{r}\left[1 - \frac{1}{(1+r)^T}\right] \qquad (3)$$

The interpretation of (3) is straightforward. The right hand side is the (CAPEX) cost of increasing supply one additional day every year over the service life of the RWH system by increasing the tank size. The right hand side is the cost of being supplied one day extra per year (over the service life of the RWH system) by tanker service.

The basic rule is: If it is cheaper to supply one extra day by expanding the storage tank volume than buying water – a larger tank should be used. If it is cheaper to buy water, the storage tank should be smaller. Of course the solution found by (3) has to be checked. If buying water is very cheap or very expensive (3) might not give any realistic solution. If buying water is very cheap, RWH is not economical sustainable. If buying water is very expensive, alternatives to tanker service should be assessed to complement RWH.

6.3.2 RWH supplemented with tanker service

The case where RWH is supplemented by tanker service, can be illustrated the following example:

D = 0,160 m^3	(Water requirement at a daily basis))
Roof size = 150 m^2	
T = 15 years	(Life length of the RWH system)
P_{TS} = 20 GH¢/m3	(Water price – tanker service)
r = 0,05 (5% pro anno)[3]	(Real discount rate)
Tank cost equal to 0,225 GH¢ per litre	(Based on supplier price list to consumers)

Figure 6.1 shows the relation between *CAPEX* and *N* for different roof sizes, i.e. the cost of being supplied by RWH system only. The cost for being supplied by the RWH system supplemented with tanker service was computed with the data from the example given above. The results are shown in Figure 6.2. For illustration purposes, only the results for a 150 m^2 roof are shown. The cost of buying water from tanker service is proportional to number of days supplied, hence it represented by the straight blue lines in Figure 6.2. In the figure the tanker service cost is "attached" to the RWH cost curve for tank size of different sizes (2500 litres and 7000 litres). The condition (3) is a point of tangency condition.

With the numbers used for the example, the analysis indicates that the optimal tank size is close to 7000 litres (tangency between the blue line and the RWH cost line). We see that the combination of the RWH system designed for supplying water 300 days per year from the 7000 litres tank system in combination with buying water 65 days per year yields the lowest possible cost for being supplied 365 days. We also see that a 10000 litres tank yields almost identical discounted costs as the 7000 litre tank. A tank size equal to 2500 litres combined with tanker service yields a higher cost. The cost difference is approximately 1 500 GH¢ and is equal to the vertical gap between the two blue lines.

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[3] The central bank interest rate has been 18% and 12% over the last 5 years. The consumer price index for 2010 is 188.5 compared to 100 for the year 2005. Thus, the annual average increase is approx. 13.5%. The 2012 central bank interest rate is 14.50%
http://www.gocurrency.com/countries/ghana
Visited October 15th 2013. . The interbank rent for October 1st to 14th is close to 17% pro anno.
http://www.bog.gov.gh/index.php?option=com_wrapper&view=wrapper&Itemid=255 Visited October 15th 2013

Increasing the water price from tanker service yields a steeper cost line for the tanker service and the optimal tank size will increase. Also a lower discount rate will increase the discounted value of future water expenditures and motivate for a bigger tank. Figure 6.2 also illustrates that tank sizes in the range 5000 to 15000 litre will not differ much when it comes to the net present value of providing 160 litre of water every day over 15 years as long as the roof is 150 m^2.

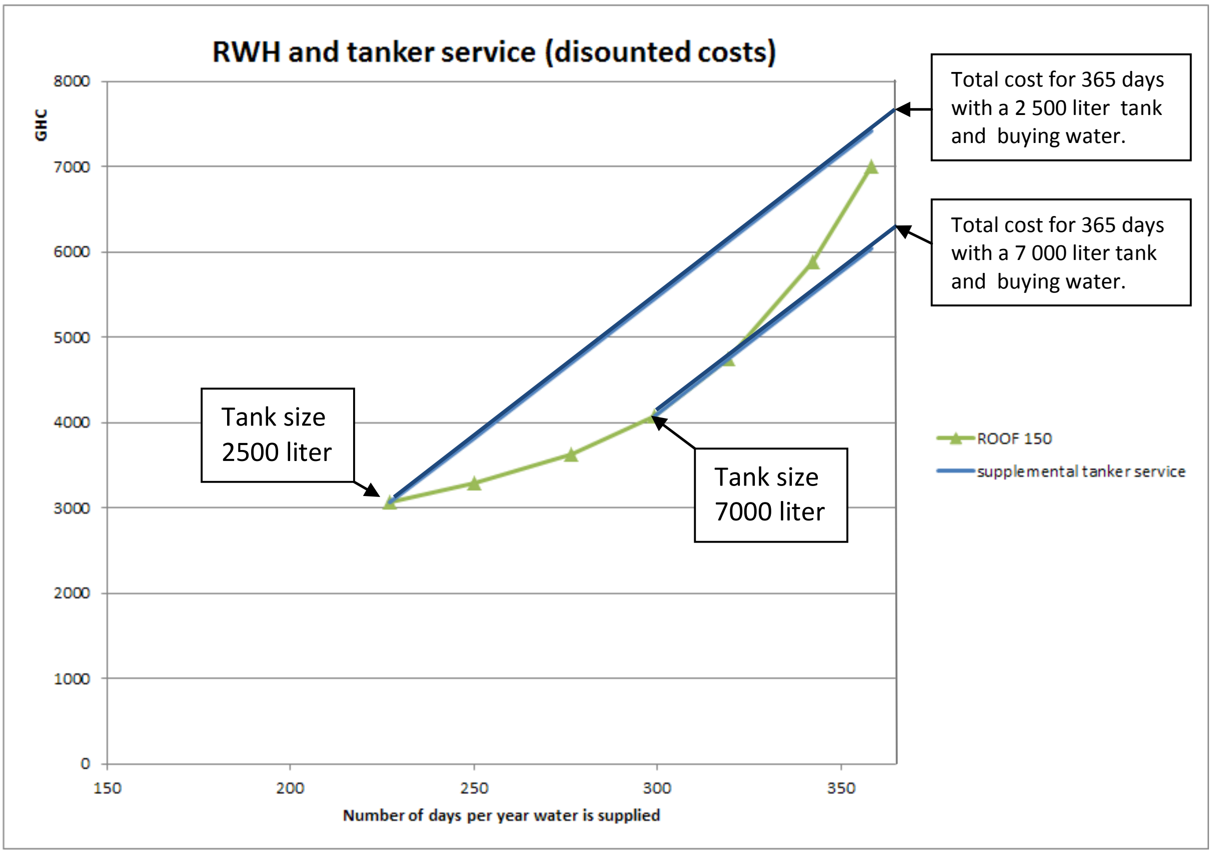

Figure 6.2: Discounted costs for RWH supplemented with buying water from tanker service. Water price from tanker service 20 GH¢/m^3

6.3.3 Tanker service versus RWH supplemented with tanker service

Above an example were RWH is supplemented with tanker service was presented. Another interesting question is whether RWH is profitable at all?

The cost of being provided by tanker service is assumed to be determined by the initial outlay for storage and the water price. As for RWH systems there will in addition be some costs for maintenance and operation also for water supply by a tanker service, but such costs are disregarded in this analysis both for the RWH systems and the tanker service.

Using tanker service only requires a storage tank. For the smallest basic RWH design (alternative 1) we have assumed a 1.8 m^3 storage tank which also seems to be the most common tank used by households supplied by tanker service in Accra. The cost of this tank is 535GH¢. In addition a base or a steel framework is needed and 850 GH¢ is used as an estimate for an inexpensive household tanker service infrastructure. Hence, being supplied by tanker service over 15 years bring along an initial outlay equal to 850 GH¢ and expenditures for buying water that will accrue to somewhat less than 1 200 GH¢ per year (160 litre per day). The result is shown in Figure 6.3.

The blue line indicates costs for tanker service only. Discounted costs for using tanker service over 15 years as sole source is about 13 000 GH¢. With a RWH system and 90 m^2 roof, the lowest discounted cost for consuming 160 litre per day over 15 years is approximately 8 000 GH¢. If the roof is 200 m^2, the analysis indicates 6 000 GH¢. With this big roof the net present value of savings by reduced water bills will be substantial.

The analysis shows that with a tanker service water price of 20 GH¢ per m^3 the tanker service as sole source will be much more expensive that when it is combined with a RWH system. With 20 GH¢ per m^3 the result seems robust for all roof sizes.

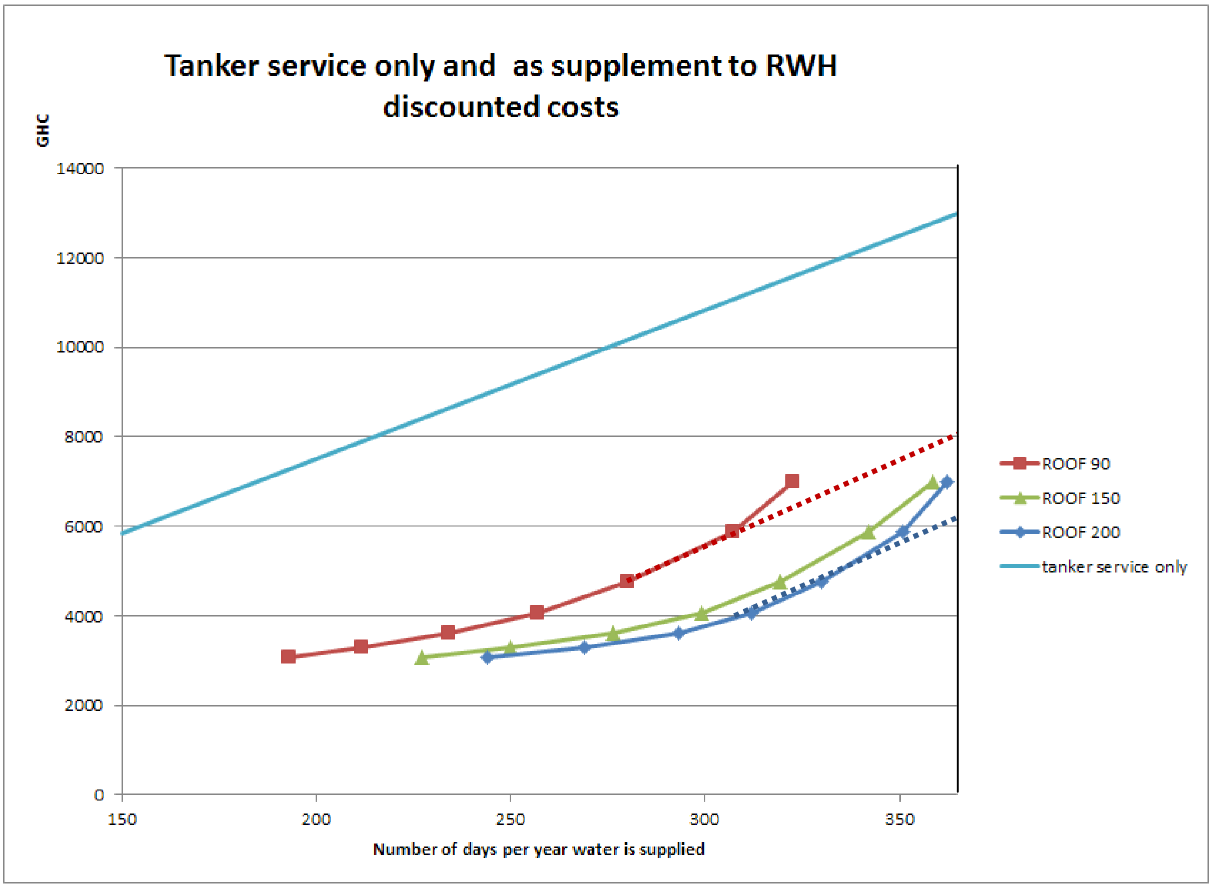

Figure 6.3: Discounted costs comparing tanker service as sole source and in combination with RWH systems. Water price: 20 GH¢ per m3

6.3.4 Sensitivity of the results

The analysis indicates that any tank size of the RWH-system will help household to save money. The worst decision in this case will be to pick either the smallest tank (2500 litre) or the biggest one (15000 litres). Even making such a decision, the household will save money in the long run. Of course this result is dependent on price and discount rate assumptions.

Reducing the water price will decrease savings from rainwater harvesting. If the price is 7 GH¢ per m^3, rainwater harvesting will not be profitable with the smallest roof. If the price is 5 GH¢ per m^3 the roof needs to be bigger than 200 m^2.

If the household has to borrow to fund the RWH system, it can be argued that the discount rate should be set equal to the borrowing rate which is close to 25% per year (fall 2013). With an inflation rate of 10%, the annual real rate is approximately 15%. With this rate, the rainwater harvesting option is profitable as long as water price is above 10 GH¢ per m^3.

6.4 Economic assessment of the initial design alternatives

The economic assessment of the initial design alternatives is about weighting benefits and costs. Most costs accrue when the rainwater harvesting system is put into place. In total, catchment system, storage, water supply and the water treatment systems are quite expensive to install, indeed in relation to average Ghanaian income levels.[4]

The assessment is meant to yield information and provide insight to a number of different stakeholders, amongst them the households. Accordingly, we use some informative economic indicators that don't include cash flow discounting in addition to a few indicators based on discounted future savings.

Households in GAMA considering rainwater harvesting can, as an alternative, buy all their water from tanker service operators. Thus, the benefits of the RWH system are assumed to be savings due to reduced water bills from buying tanker service water. As discussed above, the economically optimal solution is to combine rainwater harvesting with buying water in dry periods. Benefits or savings then depend on the quantity of water the household does not have to buy and the water price. As a result, the benefits (i.e. the savings), accrue over a long period of time following the initial outlay.

6.4.1 Indicators

As indicated, the initial outlay for installing the RWH-system is typically significant compared to the household's income. Interest rates are high, and traditionally Ghanaian households are reluctant to use banks for borrowing. It should be noted, however, that findings from the baseline survey were that 36 out of 54 respondents had taken a loan, and 37 said they might consider it. The size of the initial outlay is still considered an important constraint. Thus, we have computed the **total expenditure for the first year**. This number includes investments, consumables and the cost of buying supplemental water from tanker service.

Likewise, **annual savings** and **payback period** seem important. Annual saving is equal to reduced water bill minus consumables (i.e. filters, chlorine tablets and replacement of UV-lamp). The fewer years it takes before initial outlay is paid back, the better. If payback period is a few years the

[4] See chapter 2. Besides: Greater Accra region:544 GHC per Capita in 2006 :
GHANA LIVING STANDARDS SURVEY REPORT OF THE FIFTH ROUND (GLSS 5) ;Ghana Statistical Service September 2008 http://www.statsghana.gov.gh/docfiles/glss5_report.pdf visited Sept 2013

investment appears to be less risky and more viable than if the payback period spans almost a decade. In addition to payback period we compute **total outlay over the 3 and 10 first years** and compare this numbers with the cost of buying water from tanker service only (no RWH system). These numbers indicate gross expenditures and net benefits.

The usual way for economists to compare initial outlays with future benefits, is to discount the future cash flows and in this way compute the net present value of the "project". Doing this, we have assumed that all prices will be constant and in real terms equal to todays prevailing prices (e.g. water price, material prices and wages).

The real rate used for discounting (real) future cash flows is assumed to be 5% pro annum. This is a rough estimate based on inter bank rates in Ghana (approx. 15%) and the inflation rate over the last years (approximately 10%)(see also footnote 9, page 52). However, the financial markets in Ghana are not well functioning. The rate spread is significant. Households typically earn less than 10% pro annum[5] on saving deposits and have to pay 25% or even more when borrowing. Hence, the relevant rate differs quite a lot dependent on whether the household is a net saver or a net borrower. Although the 25% rate appears to be prohibitive for households and very few households use banks for borrowing, we have computed net present values with a real discount rate equal to 15%[6].

The RWH-systems with a PE tank are all assumed to have service life of 15 years. The life length of the concrete tanks is assumed to be 50 years. To make a comparison between the "PE" options and the "concrete" options we have to adjust for this difference in life length. In fact, one can install one concrete tank that will last for 50 years or install a PE tank and replace it twice and still the concrete tank will last 5 years longer than the series of PE tanks. Accordingly, we have computed the **Equivalent Annuity (EA)** which is the annual payment (one payment each year) over the lifetime of the actual project that is equivalent to having the NPV. For a PE tank alternative the Equivalent Annuity is a fixed payment every year over 15 years. Hence, by replacing the system every 15th year the EA payment will go on as long as the reinvestments takes place.

6.4.2 Compare and be aware

Comparing Equivalent Annuities of different alternatives yields information on the most economically beneficial alternative. The economically optimal decision is simply to select the option with the highest positive Equivalent Annuity.

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[5] October 2013. Remark also that the real rate for saving deposits is close to 0 % or even negative so the 5% used for the calculations appear to be on the upper side of what households can earn on their savings.

[6] Rough estimate based on borrowing rate approx. equal to 25% and inflation approx. equal to 10%

One should be careful stating which alternative is the best one based on the computed Equivalent Annuity only. Cost estimates as well as future benefits are uncertain. We will learn more about actual costs during installation of the RWH-systems taking place in second half of 2013. However, uncertainty about future water prices will still remain. One can also discuss the level of the discount rate. Besides, there are effects not valued. As discussed above, we have assumed fixed water consumption throughout the year. In the model all excess water will flow over and be lost. It is not hard to predict that the households will not act like the model. To the contrary, the households will certainly enjoy consuming more water than assumed in the wet periods. In the economic assessment the spilled water has no value. The quantity of water not harvested, or spilled, is substantial as it is in the range of 30%-60% of total run-off.

6.4.3 Technicalities of assessments and cost estimates

All alternatives with PE tanks are assumed to have a service life equal to 15 years. For these alternatives all parts of the system are also assumed to have a service life of 15 years. In fact the foundation will last much longer. Pumps and water treatment systems are assumed to have a life length equal to 10 years. For the basic systems we have assumed metallic gutters with a life length of 25 years. For the intermediate and advanced system PCV gutters are assumed to have 15 years of life length. Hence, some parts will last longer and some parts will probably last shorter. The effect of assuming 15 years life length of all items does not influence indicators of economic performance with a perspective up to 10 years and will only have a marginal influence on net present values and Equivalent Annuities as discounting will attenuate the effect.

For the concrete tank with life length equal to 50 years it is assumed that:

- Metallic framework for head tank – intermediate systems (life length 50 years). No replacement.
- Metallic gutters – basic systems (life length 25 years) is replaced once after 25 years
- First flush, PVC gutters and plastic head tank (life length 15 years) are replaced twice, after 15 and 30 years
- Pumps and water treatment systems (life length 10 years) are replaced 4 times, after 10, 20, 30 and 40 years.

Consumables are chorine tablets (maximum 65 GH¢ annually), filters (maximum 90 GH¢ per month) and UV lamp (60 GH¢ every second year). It differs between the 3 levels what is used and consumable costs also depend on water consumption (except for the UV-lamp)[7].

Plastic tanks cost is according to the public price lists (transportation included) summer 2013.
Concrete tank costs are based on assumption of a price of 1 750 GH¢ for a 10 cubic meter tank and simply adjusted for the actual size so that a 20 cubic meter tank is twice as expensive[8].

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[7] Consumables cost can be found by subtracting column 5 from column 6 in table 2.

Cost of catchment system is estimated based on a saddle roof design and standard length of down-pipes etc. Prices are according to market prices for materials, transportation and installation in Accra (pricelists, inquiries and interviews). Metallic gutters are somewhat cheaper and have longer life length than PVC gutters.

Costs for pumps and water treatments are based on local market prices in Accra. Transportation and installation as for catchment systems based on inquiries and interviews.

6.4.4 Results

Computation results for the economic indicators are shown in Table 6.2.

Table 6.2: Economic indicators for 36 design alternatives. RWH systems supplemented by tanker service

Alternative and desccription		System characteristics				Unit prices [GHC]	Annual savings [GHC]	Net annual savings [GHC]	Economic performance - without discounting: First year		Over 3 years		Over 10 Years		Payback	NET PRESENT VALUE		EA 5%	EA15%
#	System	Assumed water use per day, [l/day]	Tank, [type]	Tank volume , [L]	Roof area, [m²]	Tank costs [GHC]	From buying less water. Water price from tanker service equal to 20	Annual savings minus consumables chlorine, filters and UV-lamp	With RWHS + extra water to fully meet demand, [GHC]	Without RWHS (just buying water) [GHC]	With RWHS + extra water to fully meet demand, [GHC]	Without RWHS (just buying water) [GHC]	With RWHS + extra water to fully meet demand, [GHC]	Without RWHS (just buying water) [GHC]	Number of years until initial investment is paid off	At 5% pro annum. Service life 15 years for plastic tank and 50 years for concrete [GHC]	At 15% pro annum. Service life 15 years for plastic tank and 50 years for concrete [GHC]	[GHC]	[GHC]
1	Basic 2BR	80	Rambo 180	1800	50	535	370	370	2.254	584	2.712	1.753	4.315	5.844	5,5	**1.811**	136	174	23
2		80	Rambo 350	3500	90	950	498	498	2.644	584	2.826	1.753	3.465	5.844	5,1	**2.616**	359	252	61
3		80	Rambo 700	7000	150	1700	570	570	3.399	584	3.429	1.753	3.534	5.844	5,9	**2.530**	-52	244	-9
4		80	Rambo 1000	10000	200	2230	584	584	3.979	584	3.981	1.753	3.987	5.844	6,8	**2.080**	-565	200	-97
5		160	Rambo 180	1800	50	535	487	487	2.748	1.169	4.192	3.506	9.249	11.688	4,2	**3.034**	825	292	141
6		160	Rambo 350	3500	90	950	708	708	3.044	1.169	4.026	3.506	7.465	11.688	3,6	**4.795**	1.587	462	271
7		160	Rambo 700	7000	150	1700	969	969	3.596	1.169	4.020	3.506	5.503	11.688	3,5	**6.676**	2.283	643	390
8		160	Rambo 1000	10000	200	2230	1.064	1.064	4.089	1.169	4.312	3.506	5.091	11.688	3,7	**7.063**	2.242	680	383
9		160	Ferro c.	15000	90	2625	998	998	4.442	1.169	4.801	3.506	6.058	11.688	4,3	**13.399**	2.150	734	323
10	Basic 3BR	240	**Rambo 350**	**3500**	**200**	950	1.076	1.076	3.418	1.753	4.859	5.260	9.903	17.532	2,5	**8.476**	3.597	817	615
11		240	**Rambo 1000**	**10000**	**200**	2230	1.410	1.410	4.343	1.753	5.074	5.260	7.631	17.532	2,8	**10.654**	4.265	1026	729
12		240	**Ferro c.**	**15000**	**200**	2625	1.525	1.525	4.115	1.753	4.599	5.260	6.292	17.532	2,5	**22.754**	5.448	1246	818
More alternatives of the basic system design can be added by using different components																			
13	Intermediate 2BR	160	Rambo 350	3500	90	950	708	326	5.011	1.169	6.757	3.506	12.871	11.688	12,8	**-788**	-2.264	-76	-387
14		160	Rambo 700	7000	150	1700	969	579	5.606	1.169	6.810	3.506	11.026	11.688	8,7	**972**	-1.651	94	-282
15		160	Rambo 1000	10000	200	2230	1.064	670	6.127	1.169	7.136	3.506	10.668	11.688	8,4	**1.304**	-1.734	126	-297
16		160	Ferro c.	15000	90	2625	998	607	6.387	1.169	7.529	3.506	11.524	11.688	9,6	**5.463**	-1.808	299	-272
17	Intermediate 3BR	240	**Rambo 350**	**3500**	**200**	950	1.076	503	5.616	1.753	8.205	5.260	17.264	17.532	8,7	**850**	-1.429	82	-244
18		240	**Rambo 1000**	**10000**	**200**	2230	1.410	826	6.556	1.753	8.454	5.260	15.100	17.532	6,8	**2.914**	-827	281	-142
19		240	**Ferro c.**	**15000**	**200**	2625	1.525	937	6.831	1.753	8.490	5.260	14.297	17.532	6,5	**11.440**	220	627	33
20		240	**Ferro c.**	**35000**	**200**	6125	1.737	1.143	10.113	1.753	11.338	5.260	15.626	17.532	8,4	**11.687**	-1.912	640	-287
21	Intermediate 4BR	320	Rambo 350	3500	90	950	924	175	6.356	2.338	10.854	7.013	26.599	23.376	23,8	**-2.352**	-3.145	-227	-538
22		320	Rambo 700	7000	150	1700	1.328	566	6.811	2.338	10.485	7.013	23.348	23.376	8,9	**839**	-1.727	81	-295
23		320	Rambo 1000	10000	200	2230	1.608	838	7.139	2.338	10.235	7.013	21.070	23.376	6,7	**3.043**	-755	293	-129
24		320	Ferro c.	20000	300	3500	2.061	1.277	8.212	2.338	10.363	7.013	17.893	23.376	5,6	**6.050**	11.440	331	1718
More alternatives of the intermediate system design can be added by using different components																			
25	Advanced 3BR	240	**Rambo 350**	**3500**	**200**	950	1.076	506	5.488	1.753	8.069	5.260	17.103	17.532	8,4	**1.012**	-1.283	98	-219
26		240	**Rambo 1000**	**10000**	**200**	2230	1.410	840	6.413	1.753	8.283	5.260	14.831	17.532	6,6	**3.190**	-615	307	-105
27		240	**Ferro c.**	**15000**	**200**	2625	1.525	955	6.684	1.753	8.308	5.260	13.992	17.532	6,2	**10.665**	191	584	29
28		240	**Ferro c.**	**35000**	**200**	6125	1.737	1.167	10.023	1.753	11.200	5.260	15.318	17.532	8,1	**11.015**	-1.952	603	-293
29	Advanced 4BR	320	Rambo 350	3500	90	950	924	174	6.227	2.338	10.728	7.013	26.480	23.376	23,2	**-2.234**	-3.022	-215	-517
30		320	Rambo 700	7000	150	1700	1.328	578	6.670	2.338	10.322	7.013	23.104	23.376	8,5	**1.088**	-1.530	105	-262
31		320	Rambo 1000	10000	200	2230	1.608	858	6.990	2.338	10.046	7.013	20.739	23.376	6,4	**3.383**	-507	326	-87
32		320	Ferro c.	20000	300	3500	2.061	1.311	8.051	2.338	10.133	7.013	17.422	23.376	5,4	**16.213**	-2.988	888	-511
33		480	Rambo 350	3500	150	950	1.324	214	7.484	3.506	14.334	10.519	38.308	35.064	19,4	**-1.931**	-2.900	-186	-496
34		480	Rambo 700	7000	200	1700	1.735	625	7.899	3.506	13.892	10.519	34.869	35.064	8,0	**1.491**	-1.341	144	-229
35		480	Rambo 1000	10000	300	2230	2.177	1.067	8.238	3.506	13.294	10.519	30.991	35.064	5,4	**5.276**	439	508	75
36		480	Ferro c.	35000	300	6125	2.952	1.842	11.301	3.506	14.694	10.519	26.571	35.064	5,3	**23.278**	2.360	1275	354
More alternatives of the advanced system design can be added by using different components																			

Remark that the alternative cost of using tanker service is not fully taken into account. Buying water from tanker service is adequately taken into account. However, the household's necessary tanker

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[8] http://brigaders.wdfiles.com/local--files/professional%3Awater-projects/WB%20Ghana%20Model%20Change%20Announcement%20revised visited October 15th 2013

service infrastructure (foundation, steel framework and the head tank) is not included in results in Table 6.2[9].

An apparently striking result is that the basic designs seem to perform better in economic terms than the intermediate and advanced systems. This is due to the fact that the basic systems lack water treatment. Filter replacement increases monthly costs by as much as 90 GH¢ or 1 080 GH¢ per year. The uses of UV-lamps for the advanced systems add another modest annual cost of 30 GH¢. The quality of the water is improved by both filtering and the UV-lamp, but these improvements are not monetized in our assessment. The improved quality comes with a cost as the investments increases somewhat and the annual savings are reduced due to the consumables.

It is obvious that that a bigger roof is better than a smaller one. It is also straightforward that a bigger tank yield higher annual savings than a smaller tank. Of course, for the bigger tank to be economically beneficial, the discounted savings should outweigh the initial cost as explained above.

One should also keep in mind that any alternative with a given roof and a given tank size yields higher annual savings from reduced water bills as water consumption increases. This is due to the fact that as water consumption increases, the household utilizes the harvested water more effectively; less water is spilled. The improved savings will follow as water bill savings for a fixed roof and tank size is determined by the quantity of water not spilled.

What is more interesting is that the payback period and also the net present value of designs that differ just by the tank size is almost identical. This is not evident from the indicator computations, but rather a result of the analysis made in previous section and illustrated by the examples and Figure 6.2 and Figure 6.3 Thus, the economic performance is not <u>necessarily</u> very sensitive to the tank size. Increasing tank size improves reliability and hence improves savings, but increasing the tank size carries a cost that offset this gains. The examples illustrated in Figure 6.3 indicate that there are several tank sizes that economically perform almost equally well. Based on the simple formal analysis model and the examples provided, it seems to be a robust result that from an economic perspective it doesn't matter much which tank is installed. Nevertheless, installing a RWH system can be quite economically beneficial and although the size of the tank needs to be considered, the range of tank sizes that yield positive net savings can be wide.

The lesson learned is not that tanks perform equally well under all assumptions. Moving from the set of alternatives 6, 7 and 8 which corresponds to the cases analysed with the formal economic model to the set of alternatives 33, 34 and 35 one realize that although the range of well performing tank sizes is quite wide, one should indeed consider a number of different sizes. Looking at the alternatives 33, 34 and 35 which all are "high demand and big roof" alternatives, the economic performance of a small tank is quite poor. In these cases a big tank should be the preferred option.

[9] These costs were estimated to 50 GH¢ in the cases used to illustrate the formal economic analysis model.

7 Holistic sustainability assessment

7.1 Methodology

The results from the three independent sub-assessments are different with respect to scale and units. Some are additive, such as the eco-points from the LCA or the cost numbers from the economic analyses, while the social assessments give results on a relative scale. The different criteria and indicators used within each assessment and between the assessments are also not all independent of each other. There is therefore the need to consider the effects of co-linearity between criteria/indicators. Methods from multivariate analysis may be used to overcome problems caused by different scale and co-linearity. Various approaches may be taken that differ with respect to simplicity and user friendliness, both in performing the assessment and interpreting and communicating the results.

The outcome from the environmental, economic and social analysis will comprise a complex data matrix (Figure 7.1), which will be multivariate in nature. The following approaches have been evaluated, where the complexity of the method increases with presenting order:

- Visual comparison either by bar plot(s) or studying the key figures manually.
- Perform a principle component analysis (PCA) and analyse the score and loading plots. The inclusion of an optimum target case for comparison will be discussed.
- Assuming that well defined target values exists or can be postulated for all the key figures, different multivariate optimization methods may be used. One such method is to study different multivariate optimization criteria, such as the quadratic form criteria, maximum deviation criteria, variability criteria and robustness criteria, in contour plots and visually define the optimum sustainable solution.

When starting with the method development three important issues were addressed. First, the different key figures from the environmental, economic and social analysis had to be expressed on a common scale, e.g. by using fractions or variable standardization. Secondly, the need for introducing user specific weighing of the different criteria/indicators, and how this should be incorporated into the different analyses, was evaluated. Thirdly, how to define a target or an optimum case that would make it easier to develop and compare the different alternatives was also included in the evaluation.

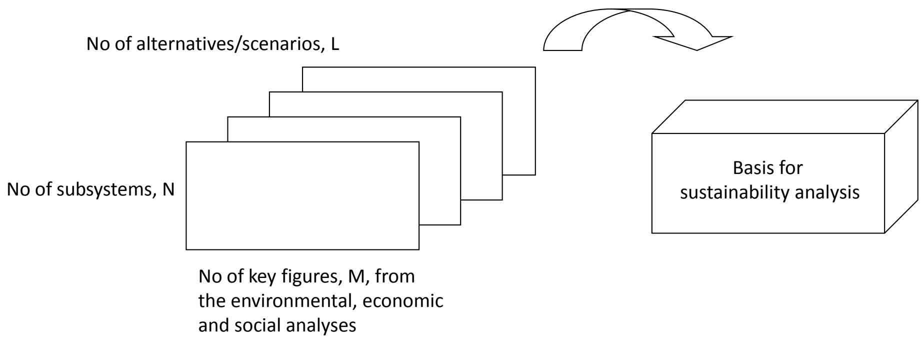

Figure 7.1: The results from the environmental, economic and social analyses will comprise a multivariate data set.

The result was that PCA was selected for the holistic assessment. PCA reduces multidimensional, complex topics by defining new variables, Principal Components, that are composites of the original system variables. PCA has the advantage that different output formats from sub-analyses on social, environmental and economic issues can be combined in one analysis, and can facilitate participation of stakeholders and transparent management.

The motivation for selecting PCA as the method was that the number of indicators from the sub-assessments was too high and varied too much in scale to analyse visually in a bar plot. At the same time, there were no clear target values for an optimal system available to compare the different designs against. The choice was therefore to compare the different initial designs against each other to assess in a relative manner which was more or less sustainable according to the selected indicators.

In order to compare the different sustainability dimensions, the indicators were standardised by dividing the values with the standard deviation. To assess the relative sustainability of the different design alternatives, the PCA was performed with indicators that had increasingly unwanted or negative impact with increasing positive value. E.g. 'pay back time' is an indicator were a small value is desired, the shorter the better. In cases were the scale was such that a high value was positive, the difference from a maximum value was used, e.g. the social indicators were included in the PCA with the scores missing to achieve the maximum value calculated as the maximum possible score minus the obtained score.

The PCA was performed without mean centring of the data. In this way the "perfect" system i.e. with zero costs, no environmental impacts and a maximum score on the social indicators would be placed in the origo of the score plots from the PCA. Such a system is of course not possible to realise, but the relative distance from origo to the design alternatives can be used to assess the relative sustainability. Numerically the scores for the first PC can be used as a composite sustainability score provided that the explained variation with the first PC is sufficient. The methodology will be discussed further in connection with the presentation of the results below.

7.2 Indicators for performance of the RWH system

The following indicators were used to describe the technical performance of the RWH systems:

- Volume of rainwater harvested per year, [m^3]. This is equivalent to the variable "satisfaction" defined in Table 3.4.
- Number of days per year the daily water demand can be satisfied by RWH assuming a constant demand strategy where the same volume of water is drawn from the tank each day irrespective of tank level or if it is in a wet or dry season, [#]. This is equivalent to the variable "reliability" defined in Table 3.4.
- Efficiency, i.e. the fraction of runoff from the roof that is collected, [%] Note that run-off is the volume of water that is collected, taking into account the roof's run-off coefficient.

All of these criteria were related to a time period of one year. However, daily rainfall data from Accra airport for a 10 year period were used in calculating the results for the different design alternatives, as discussed previously.

For all of these indicators the scales were turned for the PCA. The volume of water that had to be supplied for other sources to meet the yearly water consumption; the number of days in a year demand was not satisfied; and the fraction of run-off not collected was used in the PCA.

7.3 Indicators for environmental and climate change impacts

The following indicators were used to describe the environmental and climate change impacts of the RWH systems:

- Total eco-points from harvesting the yearly volume of rainwater, [eco-points].
- Total CO_2 equivalents from harvesting the yearly volume of rainwater, [kg CO_2 equiv.].

The LCA analysis was related to impacts per cubic meter. This does not account for differences in impact between the design alternatives related to size/harvested water volume. The LCA results were therefore transformed by multiplying the per m^3 values with the yearly volume of harvested rainwater to obtain values for impact per year. Also, the LCA results were for the supply of water from a combination of RWH and tanker service. The aim of the holistic assessment discussed here, was to compare the different RWH system designs with each other. LCA data for the production of water by RWH were therefor used as input. In order to include the impact of the water bought from a tanker service, the total eco-points and CO_2 equivalents for this were also included in the PCA.

For all of these indicators a high positive value indicated a high negative impact and there was no need to turn the scales for the PCA.

The LCA calculated eco-point for different categories, e.g. fossil fuel consumption, land use, etc. The initial PCA results (data not shown) indicated that such detail did not improve the explained variation in the first principal component (PC) compared to use of total eco-point. The latter option was therefore used in the final PCA as an indicator of environmental impact. The emission of CO_2 equivalents was used as an indicator for climate change impact.

7.4 Indicators for social impact

The social pillar of sustainability was included with 6 criteria listed in Table 7.1 below, which also shows the specific indicators used. The social analysis also provided the sum of the different criteria in a total Socio points score. However, to avoid counting the same criteria twice this was not included in the integrated analysis. For all the social indicators, the scales for indicators used in the PCA were turned by using the difference between the maximum score and the achieved score in the analysis.

Table **7.1**: **C**riteria and indicators for social sustainability.

Criterion	Indicators
Health facilitation	- Amount of water (O) - Quality of water (O) - Safe handling of water (O)
Resource independence	Independence in terms of - Power (O) - Replaceable parts (O) - Skills/knowledge (O)
Scope for entrepreneurship	- Local content (O) - Water beyond household needs (O) - Lifetime (O)
Social capital	- Social networks (O) - Self-reliance (O) - Social standing (S)
Ease of operation	Lesser requirements in terms of - Time/work (O) - Physical effort (O) - Maintenance (O)
Social acceptance	- Satisfaction of needs (O) - Positive perception of origin and quality (S) - Alignment with existing knowledge, attitudes and practices (O)

7.5 Indicators for economic impact

The criteria selected in the economic assessment for evaluation of the different design alternatives were: Total expenditure for the first year, first three years and first ten years; annual savings; payback period; and Equivalent Annuity (EA).

Among these, the EA showed negative values for some design alternatives. Also for EA a high positive value is desired. Since there is no clear way to turn the scale, EA was not used in the PCA. Net annual savings is comprised of the savings from buying less water from a tanker service minus the cost of consumables needed for the RWH system. In the PCA this composite indicator was split in two in order to be able to see the impact from the individual contributions. The cost of buying water and the cost of the consumables per year were therefore used in the PCA.

The economic indicators used in the PCA were:

- Annual cost of buying water at market price from tanker service at a price of 20 GH¢ per m3).
- Annual maintenance cost/cost for replacement parts and consumables.
- Cost of investment in RWH system + cost of buying additional water to meet demand, calculated for the 1st year, after 3 years and after 10 years.
- Pay back time (Cost. of RWH system divided by annual savings).

7.6 Results and discussion

Initially a PCA was performed with all indicators for the environmental dimension, i.e. including eco-points for the different categories such as fossil fuel consumption, land use etc. The results (data not shown) indicated that using the total eco-points and total CO_2 equivalents was sufficient, and this was used for subsequent PCAs.

The impact of weighting was studied by performing a PCA with all variables weighted equally, and comparing the result to PCA were only one group of variables was allowed to influence. E.g. a PCA was performed with downweighting of the variables for technical performance, environmental and economic impacts to study the influence of the social indicators.

The results are presented in two types of figures showing score plots and the loading plots from the PCAs. A loading plot shows the relationships between the original variables and the PCs. A score plot shows the samples, i.e. design alternatives, plotted against the principal components. Since the first principal component describes the largest variation in the data set, plots of PC1 and PC2 are used here (see following figures).

Interpretation of the loading plots and score plots follow some simple rules:

- Variables that are placed close together in a loading plot are correlated.
- Variables that are far from each other in a loading plot are not/less correlated.
- Variables that lie far from the origo in the direction of a given PC in a loading plot have a variation that is described by the PC
- Variables that lie close to the origo in the direction of a given PC in a loading plot are not described by that PC.
- Design alternatives that have high scores in a score plot for a given principal component show high values for the variables that lie along the same PC.
- Design alternatives that are placed close together in a score plot have similar values of the variables described by the PC used in the plot.

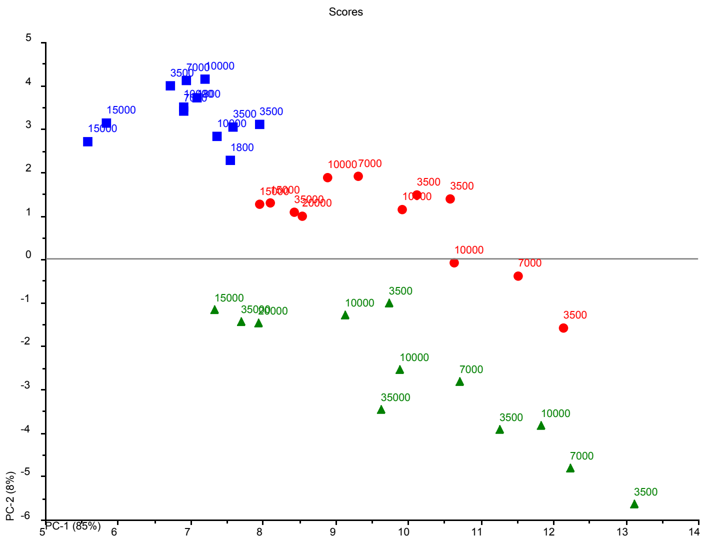

Figure 7.2: Score plot, equal weighting of performance, social, environmental and economic indicators.

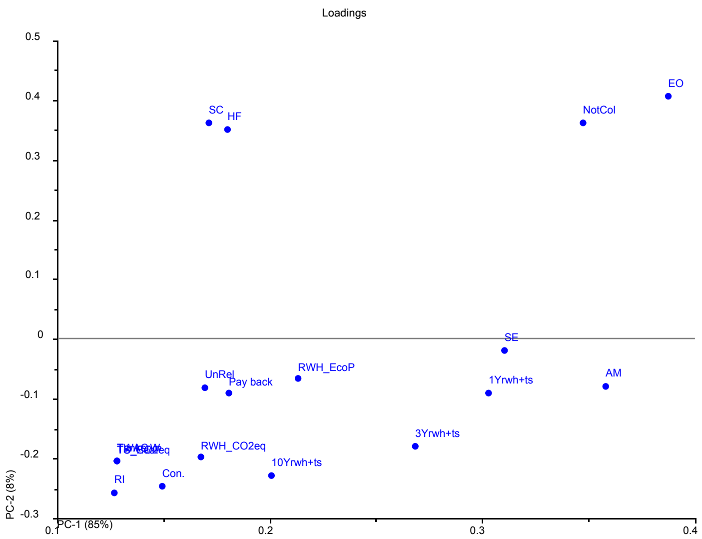

Figure 7.3: Loading plot, equal weighting of performance, social, environmental and economic indicators.

Figure 7.2 and Figure 7.3 show the score plot and loading plot from the PCA with equal weight of the different variables. Evaluating the results only along the horizontal axis (PC1) will account for 85% of the variation in the data. The score plot shows the three main design groups (basic, intermediate and advanced) and indicates that the basic systems are more sustainable than the intermediate and advanced systems. Looking at the loading plot, the variables that have the highest loading on PC1 are related to efficiency of the system (represented by the fraction of run-off not collected), short term economic indicators including both investment and cost of water (total outlays after 1 and 3 years) and the social criteria 'scope for entrepreneurship', 'social acceptance' and 'ease of operation'. The results indicate that a sustainable system should have high efficiency, low costs in the short term, be easy to operate and be based on existing technology with high local content.

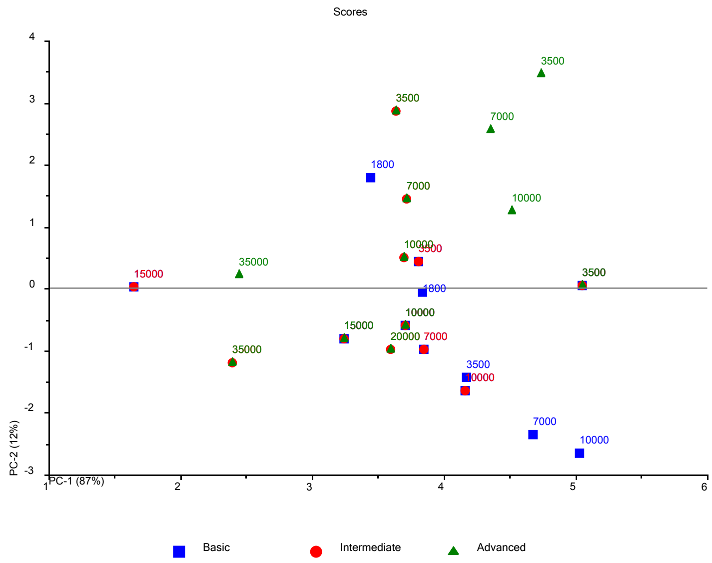

Figure 7.4 Score plot showing the influence of performance indicators with downweighting of social, environmental and economic indicators.

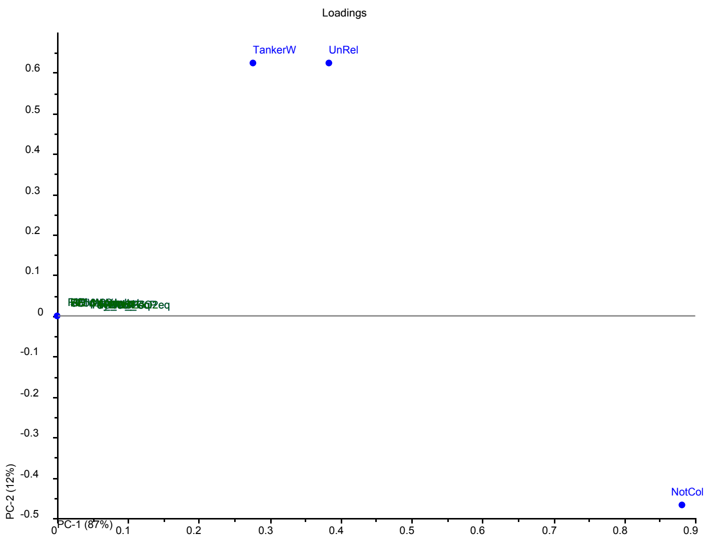

Figure 7.5: Loading plot showing the influence of performance indicators with downweighting of social, environmental and economic indicators.

Figure 7.4 and Figure 7.5 show the influence of the technical performance indicators. As expected from the results with equal weighting, the variable related to efficiency of the system has the highest loading on PC1. Looking at the score plot, one can not separate the results with respect to the main levels of design. This is as expected since the expected differences in performance between the basic, intermediate and advanced systems are related to water quality due to different water treatment and disinfection options, and ease of supply due to different supply solutions. The three groups can all be designed to have equal performance with respect to satisfaction, reliability and efficiency.

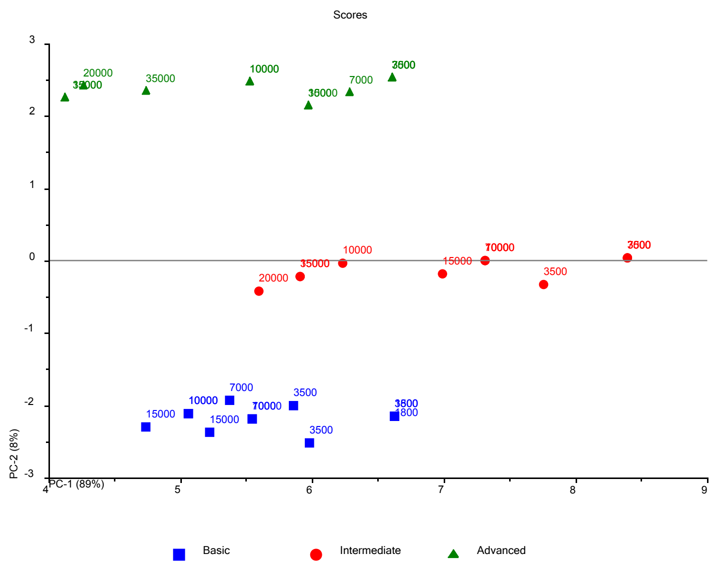

Figure 7.6: Score plot showing the influence of social indicators with downweighting of performance, environmental and economic indicators.

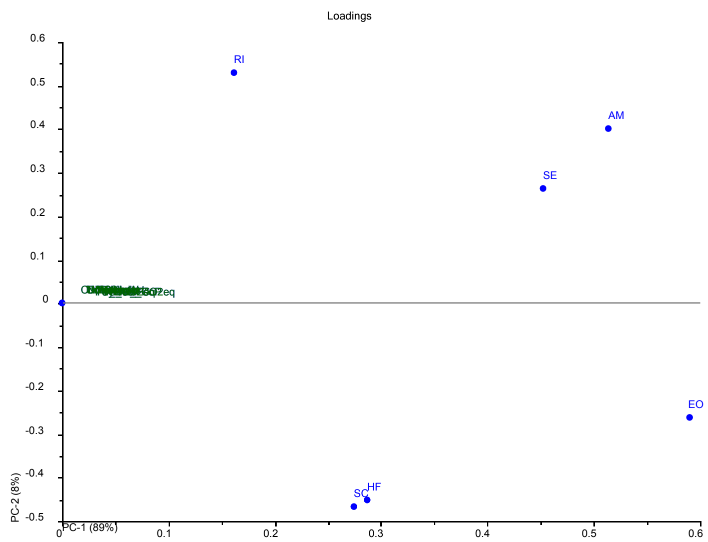

Figure 7.7: Loading plot showing the influence of social indicators with downweighting of performance, environmental and economic indicators.

Figure 7.6 and Figure 7.7 show the influence of the social indicators. If judged only by the scores on PC1, the advanced system level has the most sustainable alternative. However, the three groups are clearly separated in the direction of PC2. Evaluating sustainability as the distance from origo to the nearest design alternative in each group indicates that design levels can be equally sustainable, and that the differences between the groups are more related to the dimensions of social sustainability. Remembering that the scales were inverted for the social criteria one can see that the advanced systems score high on health facilitation and social capital, but low on resource independence. The latter is due to dependency on electricity for disinfection and pumped supply. The opposite is true for the basic designs, and the intermediate alternatives are then placed in between. The variation along PC1 is partly due to 'scope for entrepreneurship' which is correlated to collection efficiency.

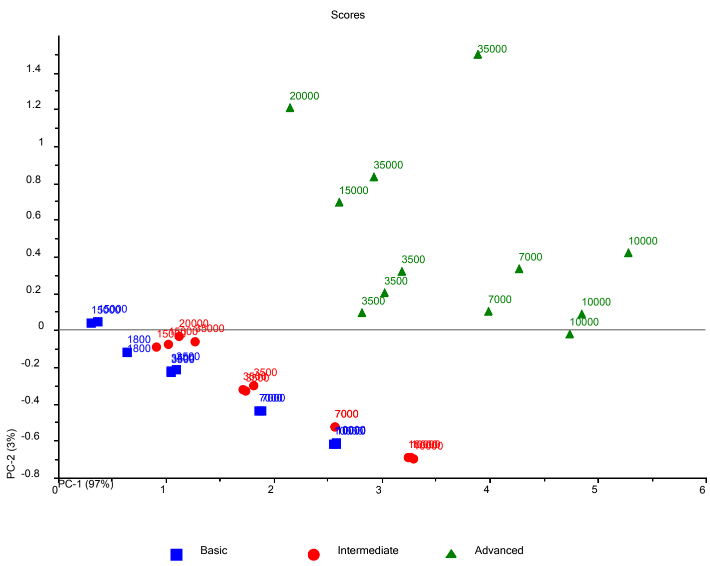

Figure 7.8: Score plot showing the influence of environmental indicators with downweighting of performance, social and economic indicators.

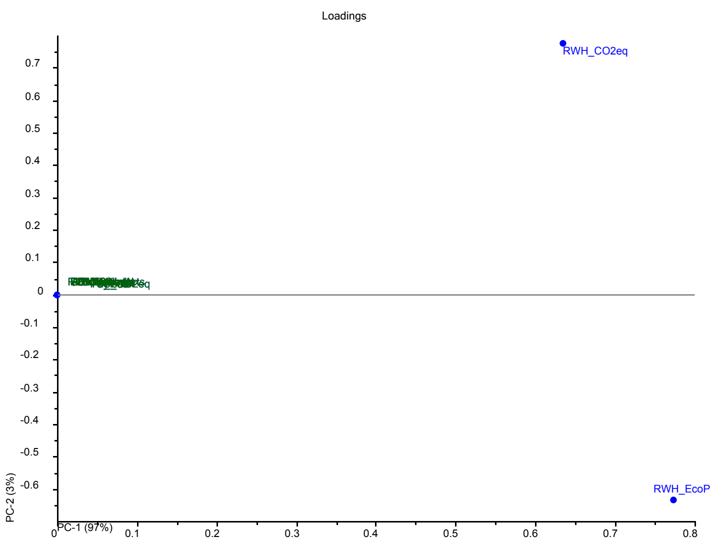

Figure 7.9: Loading plot showing the influence of environmental indicators with downweighting of performance, social and economic indicators.

Figure 7.8 and Figure 7.9 show the influence of the environmental indicators. Considering that PC1 explains 97% of the variation in the date, the plots should be evaluated along the horizontal axis. The score plot then shows that the environmental impact both with respect to eco-points and CO_2 equivalents increase with increasing system complexity. However, there is considerable overlap between the basic, intermediate and advanced design alternatives. A main reason for the general increase in environmental impact as the system becomes more advanced is due both to increased size - in general, the basic systems were the smallest and the advanced largest - and because adding more units increases the impacts due to increased use of energy and raw materials. The differences within the three groups may e.g. be related to choice of materials.

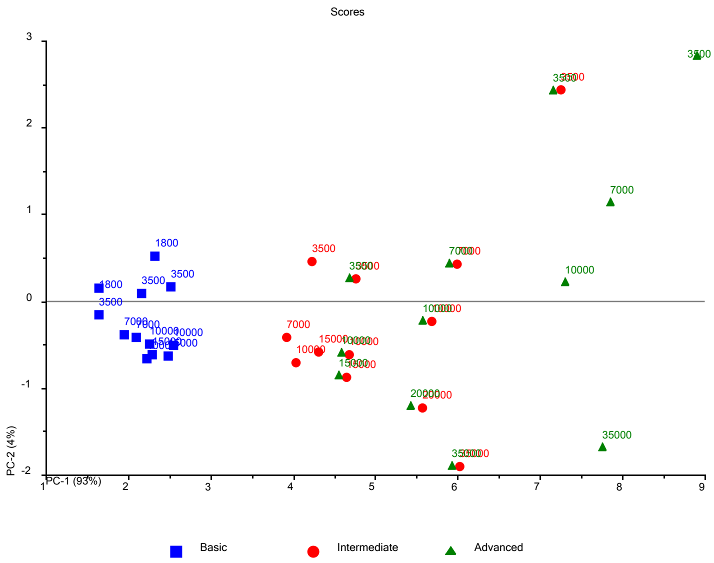

Figure 7.10: Score plot showing the influence of economic indicators with downweighting of performance, social and environmental indicators.

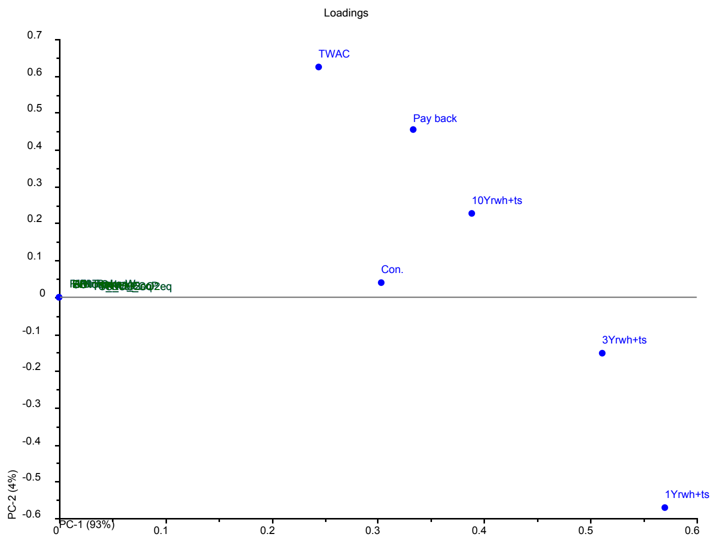

Figure 7.11: Loading plot showing the influence of economic indicators with downweighting of performance, social and environmental indicators.

Figure 7.10 and Figure 7.11 show the influence of the economic indicators. In this case, 93% of the variation is explained by PC1. Evaluating the plots along the horizontal axis shows that both investment cost and cost of buying water is important, and that the total outlay for the first year has the highest impact on PC1. The score plot shows that the economic sustainability decreases with increasing system complexity. This is in accordance with the economic sub-assessment. Interestingly, there is no clear correlation between storage tank size and the score on PC1.

The evaluation of the results from the PCA using score plots and loading plots reveals, as expected, the same dependencies as the sub-assessments when the PCAs showing the influence of the individual groups are used.

The evaluation of the PCA with equal loading of all variables indicated that a sustainable system should have high efficiency, low costs in the short term, be easy to operate and be based on existing technology with high local content. That these qualities are important in order to achieve a sustainable system should be uncontroversial, and the data indicate that the basic systems as a group are more sustainable than the intermediate or advanced.

However, one should keep in mind that the PCA only can show correlations that are included in the dataset. In this data set aspects related to water quality are only included in the scoring of social indicators. Water quality is not included in the technical performance, and adding treatment units to the designs results in increased cost and increased environmental impacts, while the benefits of improved water quality are not quantified. One should therefore not use the methodology to identify the optimal and most sustainable solution, but as a means of comparing alternatives that are descried by many indicators, which may be of different type and scale.

In the continuation of the project the methodology will be developed further and the data set extended to include results from the monitoring of the implemented RWH systems as well as updated data for actual costs and components used at the different locations. An important activity in the project is an on-going stakeholder dialogue, where the results from this assessment will be used to facilitate participation and build more awareness of the opportunities and limitations of rainwater harvesting as an alternative water source for resilience to climate change. The dialogue with the stakeholders will also help refine the discussion of the implications of the PCA comparisons and throw more light on the pros and cons of different design alternatives for different categories of users.

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Appendix I Design alternatives and expected performance.

Alternative and desccription		System characteristics										Estimated delivery performance		
#	System	Assumed water use per day, [l/day]	Tank, [type]	Tank volume, [L]	Roof area, (horisontal projection), [m^2]	First flush diverter, [Manual; Automatic]	Gutter, type and countries of origin/ production	Pump , [Not included; Manual, Electrical]	Filter, [Not included; Cartridge; Sand]	Water suply sub-system type, [Tap; Head-tank; Automated - pumped const. pressure]	Disinfection, [None; Manual - chlorine tablets; Manual - SODIS; Automated - UV]	Volume of harvested water per year, [m^3]	Average no. of days per year the system will supply daily water demand, [Days]	Fraction of runoff from the roof that is collected, [%]
1	Basic 2BR	80	Rambo 180	1800	50	Manual	ZnAl; SA+ Ghana	Not included	Not included	Tap on storage tank	None	18.48	222.13	54 %
2			Rambo 350	3500	90							24.90	308.24	40 %
3			Rambo 700	7000	150							28.49	355.85	28 %
4			Rambo 1000	10000	200							29.18	364.65	21 %
5		160	Rambo 180	1800	50							24.37	139.52	71 %
6			Rambo 350	3500	90							35.39	211.73	57 %
7			Rambo 700	7000	150							48.46	299.04	47 %
8			Rambo 1000	10000	200							53.18	330.45	39 %
9			Ferro c.	15000	90							49.89	309.14	80 %
10	Basic 3BR	240	Rambo 350	3500	200							53.82	215.13	39 %
11			Rambo 1000	10000	200							70.48	289.14	51 %
12			Ferro c.	15000	200							76.25	314.84	55 %
13	Intermediate 2BR	160	Rambo 350	3500	90	Automatic	PVC, imported	Manual	Cartridge	Head-tank	Manual - chlorine tablets	35.39	211.73	57 %
14			Rambo 700	7000	150							48.46	299.04	47 %
15			Rambo 1000	10000	200							53.18	330.45	39 %
16			Ferro c.	15000	90							49.89	309.14	80 %
17	Intermediate 3BR	240	Rambo 350	3500	200							53.82	215.13	39 %
18			Rambo 1000	10000	200							70.48	289.14	51 %
19			Ferro c.	15000	200							76.25	314.84	55 %
20			Ferro c.	35000	200							86.84	361.45	63 %
21	Intermediate 4BR	320	Rambo 350	3500	90							46.20	130.82	74 %
22			Rambo 700	7000	150							66.38	197.13	64 %
23			Rambo 1000	10000	200							80.41	243.73	58 %
24			Ferro c.	20000	300							103.06	319.74	50 %
25	Advanced 3BR	240	Rambo 350	3500	200	Automatic	PVC, imported	Electric	Cartridge	Automated - pumped const. pressure	Automated - UV	53.82	215.13	39 %
26			Rambo 1000	10000	200							70.48	289.14	51 %
27			Ferro c.	15000	200							76.25	314.84	55 %
28			Ferro c.	35000	200							86.84	361.45	63 %
29	Advanced 4BR	320	Rambo 350	3500	90							46.20	130.82	74 %
30			Rambo 700	7000	150							66.38	197.13	64 %
31			Rambo 1000	10000	200							80.41	243.73	58 %
32			Ferro c.	20000	300							103.06	319.74	50 %
33		480	Rambo 350	3500	150							66.20	124.12	64 %
34			Rambo 700	7000	200							86.74	168.72	63 %
35			Rambo 1000	10000	300							108.86	217.53	53 %
36			Ferro c.	35000	300							147.59	304.14	71 %

Alternative and desccription		Scocial sustainability indicators						
#	System	Health facilitation, max 9	Resource independence , max 9	Ease of operation, max 9	Scope for entrepreneurs hip, max 9	Social capital, max 9	Acceptan ce/maturi ty, max 9	"Sociopoints" (max=54)
1	Basic 2BR	3	9	6	5	3	6	32
2		4	9	6	5	4	7	35
3		5	9	6	6	4	7	37
4		5	9	6	7	4	7	38
5		3	9	6	5	3	6	32
6		3	9	6	5	3	6	32
7		4	9	6	6	4	7	36
8		5	9	6	7	4	7	38
9		4	9	6	7	4	7	37
10	Basic 3BR	3	9	6	7	3	6	34
11		4	9	6	6	4	7	36
12		5	9	6	8	4	7	39
13	Intermediate 2BR	5	7	5	3	5	4	29
14		6	7	5	4	6	5	33
15		7	7	5	5	7	6	37
16		6	7	5	5	6	5	34
17	Intermediate 3BR	5	7	5	5	5	4	31
18		6	7	5	4	6	5	33
19		7	7	5	6	7	6	38
20		7	7	5	6	7	6	38
21	Intermediate 4BR	5	7	5	3	5	4	29
22		5	7	5	3	5	4	29
23		6	7	5	4	6	5	33
24		7	7	5	7	7	6	39
25	Advanced 3BR	7	3	7	5	7	4	33
26		8	3	7	4	8	5	35
27		9	3	7	6	9	6	40
28		9	3	7	6	9	6	40
29	Advanced 4BR	7	3	7	3	7	4	31
30		7	3	7	3	7	4	31
31		8	3	7	4	8	5	35
32		9	3	7	7	9	5	40
33		7	3	7	3	7	4	31
34		7	3	7	4	7	4	32
35		7	3	7	5	7	4	33
36		8	3	7	6	9	5	38

Alternative and desccription		Environmental and climate change indicators												
#	System	Carcinogens	Respiratory organics	Respiratory inorganics	Climate change	Radiation	Ozone layer	Ecotoxicity	Acidification/ Eutrophication	Land use	Minerals	Fossil fuels	Total eco points	kg CO2 eq
1	Basic 2BR	0.00269	6.61303E-05	0.026644	0.009569	3.91836E-05	3.76E-07	0.000905	0.002233	0.000141	0.000242792	0.083235	0.125765	1.352841
2		0.00243	7.80198E-05	0.03158	0.011155	3.68933E-05	3.71E-07	0.000853	0.00265	0.000139	0.000241901	0.105778	0.1549428	1.578126
3		0.002602466	0.000120049	0.048226	0.016853	4.01421E-05	4.51E-07	0.000952	0.004048	0.000167	0.000276199	0.171488	0.2447725	2.385596
4		0.002763523	0.000159247	0.063625	0.02217	4.24413E-05	5.02E-07	0.001046	0.005351	0.000185	0.00030682	0.232738	0.3283863	3.139075
5		0.002235728	4.99971E-05	0.020332	0.007308	3.41946E-05	3.13E-07	0.000734	0.001703	0.00012	0.000216844	0.062461	0.0951946	1.033116
6		0.001951295	5.47063E-05	0.022371	0.007901	3.14616E-05	2.95E-07	0.000659	0.001876	0.000113	0.000210415	0.073621	0.1087884	1.117611
7		0.001861206	7.07264E-05	0.028688	0.010023	3.11105E-05	3.11E-07	0.000644	0.002403	0.000119	0.00021795	0.100638	0.1446962	1.418693
8		0.001881969	8.77475E-05	0.035328	0.012322	3.15372E-05	3.26E-07	0.000667	0.002965	0.000124	0.000229304	0.127796	0.1814323	1.744578
9		0.001927817	1.26761E-05	0.009165	0.002579	4.64137E-05	7.52E-07	0.000816	0.00069	0.000279	0.000223085	0.001792	0.0175314	0.362195
10	Basic 3BR	0.00170875	3.75865E-05	0.015679	0.005575	2.85071E-05	2.44E-07	0.000586	0.001318	9.6E-05	0.000191197	0.048727	0.0739485	0.788286
11		0.001621831	6.58804E-05	0.026781	0.009325	2.81094E-05	2.73E-07	0.000548	0.002245	0.000106	0.000205382	0.095856	0.1367836	1.320178
12		0.001654782	9.66036E-06	0.006811	0.002004	3.79477E-05	5.41E-07	0.00067	0.00052	0.000204	0.000197966	0.001489	0.0135989	0.281458
13	Intermediate 2BR	0.00350588	9.68094E-05	0.038182	0.013664	4.74389E-05	5.81E-07	0.0012	0.003212	0.00019	0.000297243	0.117518	0.1779137	1.931728
14		0.003231309	0.000102075	0.038958	0.014292	4.50911E-05	4.36E-07	0.001019	0.003254	0.000162	0.000283975	0.13254	0.1938881	2.021806
15		0.003327797	0.000116818	0.044697	0.016277	4.61283E-05	4.54E-07	0.001032	0.003743	0.000168	0.000296061	0.155067	0.2247706	2.303009
16		0.00294973	3.93296E-05	0.018321	0.005747	5.71141E-05	8.43E-07	0.001145	0.001462	0.000309	0.000269116	0.031729	0.0620288	0.810477
17	Intermediate 3BR	0.003128898	6.79047E-05	0.025293	0.00964	4.30623E-05	3.7E-07	0.000952	0.002109	0.00014	0.00025805	0.078198	0.1198307	1.362469
18		0.002700066	8.91623E-05	0.034147	0.012448	3.92461E-05	3.7E-07	0.000827	0.002851	0.00014	0.000256522	0.118525	0.1720224	1.76122
19		0.002633792	3.0243E-05	0.013326	0.00443	4.80414E-05	6.23E-07	0.000918	0.00106	0.000232	0.000239459	0.02189	0.0448074	0.624465
20		0.002750437	3.1753E-05	0.016569	0.004951	6.11493E-05	1.01E-06	0.001103	0.001277	0.000371	0.000274748	0.020119	0.0475085	0.697407
21	Intermediate 4BR	0.002836315	7.21549E-05	0.027708	0.010295	3.9931E-05	3.6E-07	0.000915	0.002316	0.000135	0.000250606	0.089688	0.1342565	1.455566
22		0.002585845	7.42332E-05	0.028507	0.010432	3.78812E-05	3.48E-07	0.000775	0.00238	0.000132	0.000243386	0.095867	0.1410348	1.475705
23		0.002478795	7.74346E-05	0.029871	0.010873	3.66E-05	3.38E-07	0.000751	0.002496	0.000129	0.000241165	0.102624	0.1495781	1.538319
24		0.00248243	2.50918E-05	0.011426	0.003799	4.65782E-05	6.06E-07	0.000847	0.000905	0.000226	0.000232766	0.014923	0.0349126	0.535157
25	Advanced 3BR	0.003598133	0.000100005	0.034381	0.021892	4.58392E-05	5.02E-07	0.001006	0.002731	0.000198	0.000371967	0.102336	0.16666	3.084941
26		0.003179281	0.00011664	0.042251	0.024084	4.20859E-05	5.07E-07	0.000922	0.003408	0.000199	0.000373153	0.136951	0.2115258	3.396531
27		0.003135779	5.74076E-05	0.021405	0.016334	5.10235E-05	7.66E-07	0.001011	0.001614	0.000294	0.000361892	0.039323	0.0835885	2.297143
28		0.003252361	5.58304E-05	0.023839	0.016394	6.41376E-05	1.16E-06	0.001205	0.001773	0.000433	0.000397341	0.033504	0.0809183	2.304819
29	Advanced 4BR	0.003297739	0.00010709	0.037264	0.022853	4.26623E-05	4.89E-07	0.000947	0.002959	0.000192	0.000362895	0.117715	0.1857406	3.221769
30		0.003064665	0.000103866	0.037168	0.022348	4.07106E-05	4.84E-07	0.000875	0.002974	0.000191	0.000359823	0.117456	0.1845813	3.150515
31		0.002960056	0.000103167	0.03748	0.022215	3.94588E-05	4.76E-07	0.000842	0.003014	0.000188	0.000358588	0.119118	0.1863175	3.131911
32		0.002978238	3.15384E-05	0.013268	0.012721	4.95729E-05	7.51E-07	0.000956	0.000977	0.000288	0.000354655	0.003868	0.0354928	1.785302
33		0.002993568	8.24344E-05	0.02873	0.019477	3.92719E-05	4.43E-07	0.000844	0.002269	0.000177	0.000343343	0.083598	0.1385536	2.743577
34		0.002806033	8.30104E-05	0.029751	0.019463	3.77177E-05	4.43E-07	0.000792	0.002366	0.000177	0.000342238	0.088764	0.1445817	2.742073
35		0.002767248	8.11553E-05	0.029484	0.019209	3.72706E-05	4.38E-07	0.000774	0.00236	0.000175	0.000342317	0.086908	0.142138	2.706052
36		0.002638183	4.02548E-05	0.016836	0.013985	4.8463E-05	8.04E-07	0.000903	0.001245	0.000307	0.000347976	0.020122	0.0564737	1.964937

Alternative and desccription		Annual savings	Annual consumables	Economic performance							Equivalent Annuity	
				First year		Over 3 years		Over 10 Years		Payback		
#	System	From buying less water (at price from tanker service at 20 GHC/m3		With RWHS + extra water to fully meet demand, [GHC]	Without RWHS (just buying water) [GHC]	With RWHS + extra water to fully meet demand, [GHC]	Without RWHS (just buying water) [GHC]	With RWHS + extra water to fully meet demand, [GHC]	Without RWHS (just buying water) [GHC]	Number of years until initial investment is paid off	EA5%	EA15%
1	Basic 2BR	370	-	2 254	584	2 712	1 753	4 315	5 844	5.5	174	23
2		498	-	2 644	584	2 826	1 753	3 465	5 844	5.1	252	61
3		570	-	3 399	584	3 429	1 753	3 534	5 844	5.9	244	-9
4		584	-	3 979	584	3 981	1 753	3 987	5 844	6.8	200	-97
5		487	-	2 748	1 169	4 192	3 506	9 249	11 688	4.2	292	141
6		708	-	3 044	1 169	4 026	3 506	7 465	11 688	3.6	462	271
7		969	-	3 596	1 169	4 020	3 506	5 503	11 688	3.5	643	390
8		1 064	-	4 089	1 169	4 312	3 506	5 091	11 688	3.7	680	383
9		998	-	4 442	1 169	4 801	3 506	6 058	11 688	4.3	734	323
10	Basic 3BR	1 076	-	3 418	1 753	4 859	5 260	9 903	17 532	2.5	817	615
11		1 410	-	4 343	1 753	5 074	5 260	7 631	17 532	2.8	1026	729
12		1 525	-	4 115	1 753	4 599	5 260	6 292	17 532	2.5	1246	818
13	Intermediate 2BR	708	382	5 011	1 169	6 757	3 506	12 871	11 688	12.8	-76	-387
14		969	390	5 606	1 169	6 810	3 506	11 026	11 688	8.7	94	-282
15		1 064	393	6 127	1 169	7 136	3 506	10 668	11 688	8.4	126	-297
16		998	391	6 387	1 169	7 529	3 506	11 524	11 688	9.6	299	-272
17	Intermediate 3BR	1 076	574	5 616	1 753	8 205	5 260	17 264	17 532	8.7	82	-244
18		1 410	584	6 556	1 753	8 454	5 260	15 100	17 532	6.8	281	-142
19		1 525	588	6 831	1 753	8 490	5 260	14 297	17 532	6.5	627	33
20		1 737	594	10 113	1 753	11 338	5 260	15 626	17 532	8.4	640	-287
21	Intermediate 4BR	924	749	6 356	2 338	10 854	7 013	26 599	23 376	23.8	-227	-538
22		1 328	761	6 811	2 338	10 485	7 013	23 348	23 376	8.9	81	-295
23		1 608	770	7 139	2 338	10 235	7 013	21 070	23 376	6.7	293	-129
24		2 061	784	8 212	2 338	10 363	7 013	17 893	23 376	5.6	331	1718
25	Advanced 3BR	1 076	570	5 488	1 753	8 069	5 260	17 103	17 532	8.4	98	-219
26		1 410	570	6 413	1 753	8 283	5 260	14 831	17 532	6.6	307	-105
27		1 525	570	6 684	1 753	8 308	5 260	13 992	17 532	6.2	584	29
28		1 737	570	10 023	1 753	11 200	5 260	15 318	17 532	8.1	603	-293
29	Advanced 4BR	924	750	6 227	2 338	10 728	7 013	26 480	23 376	23.2	-215	-517
30		1 328	750	6 670	2 338	10 322	7 013	23 104	23 376	8.5	105	-262
31		1 608	750	6 990	2 338	10 046	7 013	20 739	23 376	6.4	326	-87
32		2 061	750	8 051	2 338	10 133	7 013	17 422	23 376	5.4	888	-511
33		1 324	1 110	7 484	3 506	14 334	10 519	38 308	35 064	19.4	-186	-496
34		1 735	1 110	7 899	3 506	13 892	10 519	34 869	35 064	8.0	144	-229
35		2 177	1 110	8 238	3 506	13 294	10 519	30 991	35 064	5.4	508	75
36		2 952	1 110	11 301	3 506	14 694	10 519	26 571	35 064	5.3	1275	354

Appendix II LCA inventory, values per functional unit (FU = 1 m^3).

Alternative and desccription		System characteristics									
#	System	Assumed water use per day, [l/day]	Tank, [type]	Tank volume, [L]	Roof area, (horisontal projection), [m^2]	First flush diverter, [Manual; Automatic]	Gutter, type and countries of origin/ production	Pump , [Not included; Manual, Electrical]	Filter, [Not included; Cartridge; Sand]	Water suply sub-system type, [Tap; Head-tank at height 3m; Automated - pumped const. pressure]	Disinfection, [None; Manual - chlorine tablets; Manual - SODIS; Automated - UV]
1	Basic 2BR	80	'Pre-fabricated, plastic'	1800	50	manual	metallic aluzinc from australia	Not included	Not included	Tap on storage tank	None
2		80	'Pre-fabricated, plastic'	3500	90						
3		80	'Pre-fabricated, plastic'	7000	150						
4		80	'Pre-fabricated, plastic'	10000	200						
5		160	'Pre-fabricated, plastic'	1800	50						
6		160	'Pre-fabricated, plastic'	3500	90						
7		160	'Pre-fabricated, plastic'	7000	150						
8		160	'Pre-fabricated, plastic'	10000	200						
9		160	Ferro c.	15000	90						
10	Basic 3BR	240	'Pre-fabricated, plastic'	3500	200						
11		240	'Pre-fabricated, plastic'	10000	200						
12		240	Ferro c.	15000	200						
13	Intermediate 2BR	160	'Pre-fabricated, plastic'	3500	90	Automatic	PVC, UK	Manual	Cartridge	Head-tank (1.8 m3)	Manual - chlorine tablets
14		160	'Pre-fabricated, plastic'	7000	150						
15		160	'Pre-fabricated, plastic'	10000	200						
16		160	Ferro c.	15000	90						
17	Intermediate 3BR	240	'Pre-fabricated, plastic'	3500	200						
18		240	'Pre-fabricated, plastic'	10000	200						
19		240	Ferro c.	15000	200						
20		240	Ferro c.	35000	200						
21	Intermediate 4BR	320	'Pre-fabricated, plastic'	3500	90						
22		320	'Pre-fabricated, plastic'	7000	150						
23		320	'Pre-fabricated, plastic'	10000	200						
24		320	Ferro c.	20000	300						
25	Advanced 3BR	240	'Pre-fabricated, plastic'	3500	200	Automatic	PVC, UK	Electric	Cartridge	Automated - pumped const. Pressure + overhead tank 1.8 m3	Automated - UV
26		240	'Pre-fabricated, plastic'	10000	200						
27		240	Ferro c.	15000	200						
28		240	Ferro c.	35000	200						
29	Advanced 4BR	320	'Pre-fabricated, plastic'	3500	90						
30		320	'Pre-fabricated, plastic'	7000	150						
31		320	'Pre-fabricated, plastic'	10000	200						
32		320	Ferro c.	20000	300						
33		480	'Pre-fabricated, plastic'	3500	150						
34		480	'Pre-fabricated, plastic'	7000	200						
35		480	'Pre-fabricated, plastic'	10000	300						
36		480	Ferro c.	35000	300						

	Catchment				Storage													Distribution			Operation		
#	Kg PVC	Kg Aluzinc coated steel	KWh	Transport kgkm	Kg LLDPE (0.0422x + 23.971)	Cement - kg	Sand - kg	Lime - kg	Bricks - kg	Rubble stones -kg	Crushed stones - kg	Water - L	PVC pipe - kg	Steel - kg (BRC mesh 1kg/m2)	KWh	Transportation Truc kgkm	Transportation Ship kgkm	Pump steel kg	UV reactor steel kg	Filter polypropylen kg	CaOCl2 g/m3	Kwh/m3	Rainwater m3/m3
1	0.051	0.051	0.032	1 063	0.36	0.079	0.148	0.000	0.000	0.00	0.297	0.043	0.0000	0.002	0.541	27.5	5394	0	0	0	0	0	2.15
2	0.042	0.051	0.026	999	0.46	0.084	0.159	0.000	0.000	0.00	0.318	0.047	0.0000	0.002	0.690	29.5	6876	0	0	0	0	0	1.67
3	0.044	0.057	0.026	1 105	0.75	0.121	0.227	0.000	0.000	0.00	0.455	0.066	0.0000	0.003	1.122	42.1	11177	0	0	0	0	0	1.38
4	0.047	0.065	0.026	1 224	1.02	0.137	0.258	0.000	0.000	0.00	0.516	0.075	0.0000	0.003	1.529	47.8	15235	0	0	0	0	0	1.27
5	0.039	0.039	0.024	806	0.27	0.060	0.112	0.000	0.000	0.00	0.225	0.033	0.0000	0.001	0.410	20.9	4090	0	0	0	0	0	3.41
6	0.030	0.036	0.018	703	0.32	0.059	0.112	0.000	0.000	0.00	0.224	0.033	0.0000	0.001	0.485	20.7	4837	0	0	0	0	0	2.33
7	0.026	0.034	0.015	649	0.44	0.071	0.133	0.000	0.000	0.00	0.267	0.039	0.0000	0.002	0.659	24.7	6571	0	0	0	0	0	1.88
8	0.026	0.036	0.014	672	0.56	0.075	0.141	0.000	0.000	0.00	0.283	0.041	0.0000	0.002	0.839	26.2	8358	0	0	0	0	0	1.63
9	0.021	0.025	0.013	498	0.00	0.392	1.831	0.007	0.035	0.26	0.785	0.215	0.0021	0.025	0.001	172.1	130	0	0	0	0	0	5.09
10	0.025	0.035	0.014	664	0.21	0.039	0.074	0.000	0.000	0.00	0.147	0.022	0.0000	0.001	0.319	13.6	3181	0	0	0	0	0	1.64
11	0.019	0.027	0.011	507	0.42	0.057	0.107	0.000	0.000	0.00	0.214	0.031	0.0000	0.001	0.633	19.8	6307	0	0	0	0	0	2.04
12	0.018	0.025	0.010	468	0.00	0.257	1.198	0.004	0.023	0.17	0.514	0.141	0.0014	0.017	0.001	112.7	85	0	0	0	0	0	2.23
13	0.079	0.000	0.043	554	0.51	0.059	0.112	0.000	0.000	0.00	0.224	0.033	0.0000	0.063	0.768	20.7	7961	0.0090	0	0	5	0	2.33
14	0.071	0.000	0.038	501	0.58	0.071	0.133	0.000	0.000	0.00	0.267	0.039	0.0000	0.046	0.866	24.7	8853	0.0066	0	0	5	0	1.88
15	0.073	0.000	0.039	516	0.68	0.075	0.141	0.000	0.000	0.00	0.283	0.041	0.0000	0.042	1.027	26.2	10438	0.0060	0	0	5	0	1.63
16	0.056	0.000	0.030	393	0.13	0.392	1.831	0.007	0.035	0.26	0.785	0.215	0.0021	0.069	0.001	172.1	2346	0.0064	0	0	5	0	5.09
17	0.072	0.000	0.038	509	0.34	0.039	0.074	0.000	0.000	0.00	0.147	0.022	0.0000	0.041	0.505	13.6	5235	0.0059	0	0	5	0	1.64
18	0.055	0.000	0.029	389	0.52	0.057	0.107	0.000	0.000	0.00	0.214	0.031	0.0000	0.032	0.775	19.8	7876	0.0045	0	0	5	0	2.04
19	0.051	0.000	0.027	360	0.09	0.257	1.198	0.004	0.023	0.17	0.514	0.141	0.0014	0.045	0.001	112.7	1535	0.0042	0	0	5	0	2.23
20	0.045	0.000	0.024	316	0.08	0.526	2.455	0.009	0.047	0.35	1.052	0.288	0.0028	0.059	0.001	230.8	1448	0.0037	0	0	5	0	2.70
21	0.060	0.000	0.033	425	0.39	0.045	0.086	0.000	0.000	0.00	0.172	0.025	0.0000	0.048	0.588	15.9	6099	0.0069	0	0	5	0	3.90
22	0.052	0.000	0.028	366	0.42	0.052	0.097	0.000	0.000	0.00	0.195	0.028	0.0000	0.034	0.632	18.1	6463	0.0048	0	0	5	0	2.79
23	0.048	0.000	0.026	341	0.45	0.050	0.094	0.000	0.000	0.00	0.187	0.027	0.0000	0.028	0.679	17.3	6904	0.0040	0	0	5	0	2.40
24	0.047	0.000	0.024	328	0.06	0.253	1.182	0.004	0.023	0.17	0.507	0.139	0.0014	0.037	0.001	111.1	1157	0.0031	0	0	5	0	1.99
25	0.072	0.000	0.038	510	0.21	0.039	0.074	0.000	0.000	0.00	0.147	0.022	0.0000	0.001	0.319	13.6	3181	0.0112	0.00372	0.17	0	3	1.64
26	0.055	0.000	0.029	389	0.42	0.057	0.107	0.000	0.000	0.00	0.214	0.031	0.0000	0.001	0.633	19.8	6307	0.0085	0.00284	0.13	0	3	2.04
27	0.051	0.000	0.027	360	0.00	0.257	1.198	0.004	0.023	0.17	0.514	0.141	0.0014	0.017	0.001	112.7	85	0.0079	0.00262	0.12	0	3	2.23
28	0.045	0.000	0.024	316	0.00	0.526	2.455	0.009	0.047	0.35	1.052	0.288	0.0028	0.034	0.001	230.8	174	0.0069	0.00230	0.10	0	3	2.70
29	0.060	0.000	0.033	425	0.25	0.045	0.086	0.000	0.000	0.00	0.172	0.025	0.0000	0.001	0.372	15.9	3706	0.0130	0.00433	0.19	0	3	3.90
30	0.052	0.000	0.028	366	0.32	0.052	0.097	0.000	0.000	0.00	0.195	0.028	0.0000	0.001	0.481	18.1	4797	0.0090	0.00302	0.14	0	3	2.79
31	0.048	0.000	0.026	341	0.37	0.050	0.094	0.000	0.000	0.00	0.187	0.027	0.0000	0.001	0.555	17.3	5528	0.0075	0.00249	0.11	0	3	2.40
32	0.047	0.000	0.024	328	0.00	0.253	1.182	0.004	0.023	0.17	0.507	0.139	0.0014	0.016	0.001	111.1	84	0.0058	0.00194	0.09	0	3	1.99
33	0.052	0.000	0.028	367	0.17	0.032	0.060	0.000	0.000	0.00	0.120	0.018	0.0000	0.001	0.260	11.1	2586	0.0091	0.00302	0.14	0	3	2.77
34	0.045	0.000	0.024	316	0.25	0.040	0.075	0.000	0.000	0.00	0.149	0.022	0.0000	0.001	0.368	13.8	3671	0.0069	0.00231	0.10	0	3	2.69
35	0.044	0.000	0.023	310	0.27	0.037	0.069	0.000	0.000	0.00	0.138	0.020	0.0000	0.001	0.410	12.8	4084	0.0055	0.00184	0.08	0	3	2.11
36	0.033	0.000	0.017	229	0.00	0.310	1.444	0.005	0.028	0.21	0.619	0.169	0.0017	0.020	0.001	135.8	103	0.0041	0.00136	0.06	0	3	3.48