Suitability Analysis of Small Scale Water Supply Systems

By

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"I hereby declare that, except where specifically indicated, the work submitted herein is my original work."

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SYMBOLS

ε	kg CO_2 per unit
κ	cost per unit
$C_{P,T}$	£ per capita per day
$E_{P,T}$	kg CO_2 per capita per day
L_{P1}	Total Work Days Lost due to adverse effects caused by E. Coli. ingestion
L_{P2}	Total Work Days Lost due to cancer caused by arsenic ingestion
L_P	Total Work Days Lost

1. INTRODUCTION

1.1. BACKGROUND

According to Secretary-General Ban Ki-moon, 'water is central to the well–being of people and the planet' (World Water Day , 2013). This is reflected in the 7th Millennium Development Goal, which states that the proportion of people with no access to safe drinking water should be halved(Millenium Development Goals, 2011). In 2010, nearly 900 million people (84% in rural areas) were still lacking access to a convenient supply of safe water(WaterAid, 2011). This number is taken as an under-estimation because there is a widespread and increasingly acknowledged problem of unsustainable water interventions; where water supply and treatments systems fall into disrepair due to a variety of factors including lack of education, maintenance capabilities, spare parts etc forcing to community to resort to the previous water source. Therefore reducing the number of people with access to safe water and raising the issue of appropriate technology.

The concept of appropriate technology, as first described by Schumacher (1973), is a simple and convincing argument where the most relevant and suitable technology to a particular situation needs to be implemented. This involves considering whether the community has access to cheap, easy and reliable energy if needed; a supply chain for spare parts and education and training to ensure continuous function of the systems.

According to a recent report by WaterAid(2011) there are many factors that contribute to the decision of an appropriate technology for a small community, and the most appropriate solution can differ from stakeholder to stakeholder due to varying priorities.

Some inherent aspects of appropriate technology include being small-scale, energy efficient and decentralized. Currently decentralized water systems are an important aspect of growing populations around the world; in low-income and transitional housing in particular. These decentralized solutions are spread across various parts of the world and yet each community or situation requires an adequate water supply suitable for the location, budget and needs and preferences of the community.

1.2. PROBLEM DEFINITION

The project explored a process of deciding upon a suitable small-scale water supply system. When choosing a water treatment system, many factors need to be considered, which can fall under distinct, yet interconnected, categories:

- Economic
- Environmental
- Social

It was decided that all three aspects will be explored; in terms of the cost and embodied carbon of the materials used and the risk due to contaminants in the water, which can be related to human health effects. The last is an important measurable of the effects of a water supply system because of its wider impact on the particular community and on a larger scale on economic measures such as GDP, mortality rates. Any adverse effects due to unsanitary water can cause illness or worse, which will thus affect the productivity of the populace.

1.3. SCOPE OF PROJECT

The project developed a tool to facilitate the process of choosing a small-scale water treatment system for an individual house or a small community. The process of choosing an appropriate system can be simplified with appropriate design curves. Design curves can be used to consider various supply systems by using a few important factors in order to narrow the choices down to a select few. Flexible models are needed in order to apply it to a variety of situations.

Thus the scope of this particular project was to accumulate information on treatment systems, known as candidate technologies, in a database to enable easy comparison; to create a tool to compare a range of possible water treatment technologies; and to visualize it on a design curve. For a particular situation the tool identifies a set of suitable systems according to specified criteria or priorities. This will then be tested for reasonability, accuracy and sensitivity against case studies using a case matrix.

For example, if a community with a population of *X* and a budget of *Y* required a water system where the quality of the water is defined by stated parameters then the tool should have the capability to suggest an appropriate technology for the situation. Initially technologies that are immediately unsuitable can be eliminated with the aid of the technology review database. The aim is to use the tool to analyse a particular project in a small community and to choose the most appropriate technology.

2. LITERATURE REVIEW FOR TECHNOLOGIES

When choosing the candidate technologies, emphasis was placed on simple technologies as opposed to the larger scale ones. The final list of technologies that were chosen, and quick descriptions, are listed below in Table 1. Although this is not a comprehensive list, the technologies were chosen to provide a wide range of point-of-use technologies. Reverse osmosis was chosen in order to explore a more complicated technology and to compare it to simpler technologies. Other technology options such as slow sand filtration and micro-filtration were considered but not included because this was seen as work that could be carried out in the future because the main aim of the project was to create the tool and to show it can be used before improving it.

Technologies	Description
Biosand filter (BSF)	A technology used in households to biologically purify water.
Ceramic filter	An increasingly widely used technology at a household level.
Rapid sand filter (RSF)	A process which can be used at the household level as well as be upgraded and used at a community level.
Boiling	A process that is widely used. It is only feasible on a household scale and can be labour intensive, especially when sourcing materials.
Free chlorine treatment	A very common process, using NaDCC (Sodium dichloroisocyanurate)
PuR sachets	Another process which can easily be deployed in houses. Can be popular in emergency situations.
SODIS (solar disinfection)	A household based technology, which can be quite labour intensive.
Reverse Osmosis (RO)	A complicated process requiring infrastructure and other processes and chemicals. Needs to be on a larger scale.

Table 1: Descriptions of Candidate Technologies

2.1. BIOSAND FILTER (BSF)

BSF is an adaptation of the slow sand filter so that it does not flow continuously. A Schmutzdecke develops in the top layer of sand, which removes the pathogens from the source water improving the quality of the effluent. They can easily be constructed from locally available materials and used at a household level to purify water(Loo & Fane, 2012). Unless the source water is significantly polluted, pre-treatment isn't required and it is relatively non-labour-intensive, even though regular cleaning is required. However the technology has potential, if accepted by a community.

2.2. CERAMIC FILTER

Ceramic filters use porous ceramic media to filter microbes from the water via size exclusion. They reduce turbidity, organic matter and microbes and are easy to clean manually and to restore to the standard efficacy and flow rate if too much particulate matter accumulates (Sobsey, et al., 2008).

2.3. RAPID SAND FILTER (RSF)

Sand based filters are popular and effective and there are many variations in terms of capacity from household units to ones suitable for small communities; however for the costing analysis, they were taken to serve a few households. The filters work by utilizing layers of sand and gravel, orientated in descending grain size from top to bottom and anthracite coal is used to improve the quality of the drinking water.

2.4. BOILING

Boiling is an established treatment method and there is a variety of possible fuels, for this study it was assumed that the combustion of wood is used as a source of heat and energy. Although it is labour intensive and quite expensive in terms of fuel, it is generally well accepted as a successful treatment method. This shows that if the community can be shown the benefits of the technology, they will use it despite costs in some instances.

2.5. CHLORINE TREATMENT

Chlorination is primarily a disinfection process and is a strong oxidising agent, which destroys pathogenic microbes when introduced into water. A major objection to chlorination, especially in some developing countries, is that inhabitants do not like their water tasting of chlorine and might refuse to consume it. Therefore it is important to ensure that it is not overdosed, while if it is under dosed, the users will be at risk of infection. If need be vessels with a standardized volume can be distributed where a certain number of tablets are required to disinfect that volume of water(Clasen, et al., 2007).

Another feature of chlorination is the formation of disinfection by-products (DBPs) due to the reaction of chlorine with naturally occurring organic materials (Nikolaou, et al., 2004), which can be hazardous to health.

2.6. PUR SACHETS

The PuR sachets contain a time-release hypochlorite Ca $(ClO)_2$ to deactivate microbes and a flocculant, ferric sulphate, to remove suspended material from the water, thus clearing-up turbid water(Arvai & Post, 2012). The sachets first coagulate heavy metals and parasites to form small particles and then the flocculant causes these particle to glue together to form bigger particles, until they are large enough to fall to the bottom of the container. The disinfectant then works to further purify the water and DBPs are produced akin to chlorination. Although not as labour intensive as boiling water or SODIS, the process of purifying water still requires time and effort from the users. The costs per unit reflect their purpose of being used in emergency situations however they can also be used in the long term if cost is not an issue.

2.7. SOLAR DISINFETION (SODIS)

SODIS is a very labour intensive method of purifying water(Varbanets, et al., 2009), which involves filling up 2 litre PET bottles with water and leaving them in the sunlight for a specific period of time, this is generally done by leaving the bottles of water on roofs. Because PET bottles can be obtained cheaply both the capital and O&M costs are almost non-existent; however it may not be readily accepted and practiced in some cultures because it uses discarded items to clean drinking water and because the water is very warm.

2.8. REVERSE OSMOSIS (RO)

Reverse osmosis (RO) is a relatively complex membrane filtration technology and represents an alternative method of water purification to the other technologies, which are mainly point-of-use (POU) technologies. It removes solutes from a solution using a semi-permeable membrane, which separates water from a concentrated solution of ions, with the aid of a high pressure environment (Singh, 2006).

3. DATA AND METHODS

This section gives a brief overview of the work done from the assembly of the technology review database to the tool creation and from the case matrix to the initial testing of the tool.

3.1. TECHNOLOGY REVIEW DATABASE DEVELOPMENT

When researching the candidate technologies, ideally a report or a database containing data and information on a variety of technologies to enable quick comparisons would have been available; however one wasn't found. Therefore initially a technology review database was developed, in order to store information on the candidate technologies efficiently and to enable easy comparison between different technologies. This database is significant because it accumulates information from a wide range of sources on the candidate technologies to one place. During its development the factors described in Table 2 were identified as being useful for describing the technologies.

Factors	Explanations
Size	In terms of specific dimensions of the structures and filter media.
Production/ filtration rate	The rate that the filtrate exits the membrane and the rate that the filtrate is produced.
Life span	The life span of the technology, assuming that it is maintained well and components are replaced as needed.
Capacity	The capacity over its lifetime, per unit technology.
Costs	Both capital and operation and management costs during its lifetime (including components needing regular replacement).
Water quality required	Describes what the technology is capable of dealing with in terms of the properties of the influent.
Filter performance	Describes the effluent, in terms of filter performance {i.e. percentages and LRVs (log removal values).}
Power requirements	Whether the technology requires a power input for it to function, and if so how much.

Table 2: Explanation of factors used to compare various water treatment technologies

Some of the factors in Table 2 are not easily quantifiable and therefore a set of simple qualitative comparison scales were devised in order to enable quick and easy comparisons, this process is described in Appendix B.1.. The process of developing the tool including assumptions made for some of the technologies are described in Sections B.2. to B.9. and a simplified version of the database is shown in Table 15 in Appendix B.

This novel database was useful for storing information on the technologies and the information was subsequently used when creating the tool, which was the main aim of this project.

3.2. TOOL CREATION

Figure 1 shows the intended flow diagram of the model illustrating how the look-up tables, which contains information on the technology characteristics, kg CO_2 per unit (ε) and cost per unit (κ), the lifetime and population capacity of the technology; its capabilities in terms of reducing contaminants); and the context specific information are used in the model to generate outputs.

The model outputs a spreadsheet describing the $C_{P,T}$, $E_{P,T}$ and L_P of each technology for a population group using the context specific and technology specific look-up tables for a specified design problem (population size, design life and source water quality). The valued priorities are used to quantify the priorities of the relevant stakeholders with regards to the choice of the water treatment system.

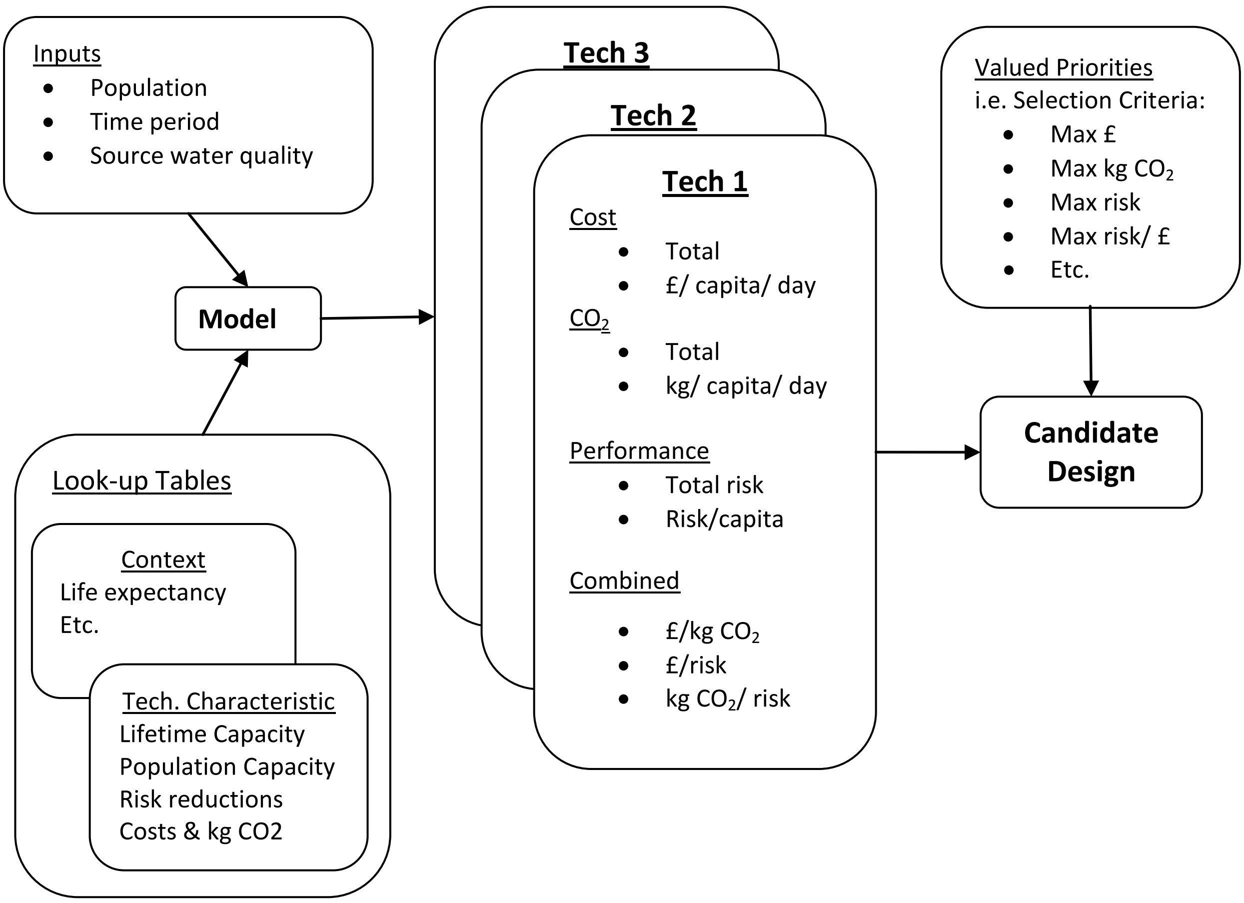

Figure 1: Flow Diagram of the Model

Embodied carbon and risks are not expressed in terms of economic cost to keep them as separate dimensions, allowing a better observation of their relationship. The carbon footprint field in particular, is continuously evolving and therefore it is preferable to express the two dimensions in lost work days and kg of CO_2, with the choice of converting to an economic cost in the future.

3.2.1. LOOK-UP TABLES

The look-up table for the non-technological portion of the case study location is a description of a region and includes important and readily available data on the social and economic context in which the water treatment technology will be implemented.

The results of the economic cost and embodied carbon calculations per unit technology explained below are extracted from the spreadsheet in Appendix C; and the unit costs and carbon footprints can be altered to reflect the local materials and prices of a new location by changing the values in Table 4. Thus the costing data of the technologies can be used in a in a range of locations from a tropical rainforest or the English countryside.

An arbitrary value was required for the analysis and although the volume of water consumed per person per day in the UK is 150L, it is much lower in developing countries or small isolated societies. According to Smieja (2011), accounting for food preparation, 8L per person per day is sufficient in some developing countries. However when taking personal hygiene into account, WHO specifies a minimum requirement of 20L per capita per day, therefore this was be used to calculate the maximum population capacity of the technologies(WHO, 2011). This value can be altered to calculate new lifetime and population capacities, which will then affect the tool outputs.

The filter lifetimes, their diameters and production rates of the ceramic filter, BSF and RSF were accounted for when calculating their population capacities. The lifetime of the technology is an important consideration because over different time periods, different numbers of units will be required to meet the needs of the population. For some technologies such as free chlorine and PuR sachets, which are only used once this was straightforward and therefore they are not shown in Table 3. For SODIS, it was assumed that the bottles last 2 months and each cycle of purifying water would take 2 days. The look-up table displaying these two input variables is shown below in Table 3.

Technology	Household level?	Community Level?	Population Capacity (people)	Lifetime Capacity (yrs)
BSF	Y	Y	18	8
Ceramic Filter	Y	Y	5	2.5
Boiling	Y			
Rapid Sand Filter	Y	Y	12	2
SODIS	Y			0.17
Reverse Osmosis		Y	1,000,000	25

Table 3: Look-up table with Population and Lifetime Capacities of the technologies

3.2.2. ECONOMIC COSTING

The costs and capabilities of the technologies will alter depending on the situation and design, accurate information for both variables was difficult to obtain therefore a high-level cost comparison is used as opposed to a detailed comparison, which will not be representative of all situations.

Each technology was broken down into *cost components* such that each component consisted of one material where possible; the cost components include structural components, membranes, and chemicals. For all required materials, values for both the cost per kg and cost per kg CO_2 were acquired in order to calculate the total material cost and embodied carbon. The only exception was for reverse osmosis, which was calculated as explained in Section 3.2.2.4. This method allows for the components of a given treatment technology to be costed regardless of the material. The calculation spreadsheet is given in Table 16 in Appendix C.

3.2.2.1. SEPARATING COST COMPONENTS

The first section of the cost calculation spreadsheet indicates whether each of the listed materials is suitable for each of the particular cost components, thus ensuring that a range of possible costs are calculated for each cost component. The specified amounts of the cost components are converted into kilograms by multiplying through with the density to ensure uniformity. This is then used to calculate both the costs and kg CO_2 per unit technology.

3.2.2.2. COSTS OF MATERIALS

When compiling the costs of the materials, costing books such as Spon(2003), Wessex(2007) and Laxton(1996) were used and the final values are shown below in Table 4. However they generally list costs for various works such as paving or roofing and not for bulk materials and so were only used to obtain values for construction materials such as concrete and steel. A wider range of sources were used to obtain prices for other materials; such as commercial websites, in particular the chlorine tablets and PuR sachets. Quantifying the amount of wood needed for boiling water was slightly problematic. The final value is a rough estimate taking into consideration the energy released when wood is burnt.

	Cost per kg of material	
Materials	**£**	**kg CO2**
Concrete	0.05	0.11
Wood	0.35	0.50
Plastic	2.70	3.3
Steel	0.20	1.5
Clay	3.00	0.20
Colloidal silver	490.00	6.3
Sand	0.02	0.0051
Gravel	0.03	0.0052
Chlorine tablet	4.75	2.1
PuR sachets	250.00	0.50
2L PET bottles	8.77	2.5
Anthracite coal	0.16	0.50

Table 4: Table of cost per kg and kg CO2 per kg of each material

3.2.2.3. COST CALCULATION

The average cost for both the capital and ongoing aspects, if applicable, per unit of each technology were obtained by first calculating maximum and minimum costs per cost component; this spreadsheet is attached in Appendix C. These average values were used to calculate the $C_{P,T}$ for each technology for seven different population groups at five different time periods as specified in Table 5, in order to refine the tool and to observe how the costs was affected over time as the population changed. The capital and ongoing costs were calculated separately because they affect $C_{P,T}$ differently. The basic structure of the equation is shown in Equation 1 and the terms in are explained in Table 6.

The $P/_{P_C}$ and $T/_{T_C}$ terms in Equation 1 are used to estimate the number of units needed to cater for the specified population and time period; therefore the two terms are rounded up to the next highest integer to calculate the complete number of units needed.

The effect of the value of a pound changing over time on the cost is an important consideration and is accounted for by calculating the opportunity cost of the capital costs for each technology. In order to do this, the interest rate in the UK as specified by the Bank of England (2012) for the 1st of November 2012, of 5%, was used.

Population Groups	1	11	101	1,001	10,001	100,001	1,000,001
Time Periods	5	10	15	20	25		

Table 5: Input Variables (Population Groups and Time Periods)

$$C_{P,T} = \frac{\kappa \frac{P}{P_C} \frac{T}{T_C} I^T}{365PT}$$

Equation 1

Description	Terms
Population Capacity	P_C
Lifetime Capacity	T_C
Average Cost per unit	κ
Population Group	P
Time Period	T
Interest Rate	I

Table 6: Explanations of Equation 1 Terms

3.2.2.4. REVERSE OSMOSIS

Although logically the location of a plant impacts operating and capital costs, especially if there is cheap labour and land; data shows that location has very little observable difference on small desalinating plants with similar capacities and processes(Park, et al., 1997). Therefore data from around the world can be applied in any location. When carrying out the process described in Section 3.2.2.1 of isolating each step in the RO process, identifying cost components, their volumes and the material used was difficult because the process alters depending on the source water.

There were a few options on how to calculate the cost. The first involved calculating the basic costs for the buildings, pipes, pumps, chemicals etc on a volume basis. Although Gilau & Small (2008) was used to estimate energy costings including the fuel, the generators and operation and management costs, finding adequate data for the infrastructure was difficult.

Another possibility was generating relationships to calculate costs for the various aspects of the plant and Fosselard & Wangnnick (1989) detailed equations relating the cost of the plant to the capacity; replacement membranes and parts; electrical energy and chemicals required, as well as details on personnel costs. However it is over two decades old; thus the prices aren't comparable to current prices and since the processes are continuously improved the relationships won't be applicable.

Ultimately Wade (2001), which compared RO plants to MSF (multi-stage flash distillation) and MED (multiple-effect distillation) plants, was used because it separated the plant into cost components including chemicals, membranes, energy, O&M and capital costs and quoted the prices in cost per m^3. This particular plant has a lifetime of 25 years and a capacity of 31,882 m^3 per day and thus assuming a requirement of 20 L per capita per day a population capacity of 1,590,000; however due to system leakages and because individual usage will invariably be more than 20L per day when water is available, the actual capacity is lower. The costs were converted to pounds using the exchange rate on the 2nd of January 2012, 1.55(fx-exchange, 2012).

The ongoing costs are quoted in cost per m^3. Assuming the ongoing costs per cubic meter of clean water will always be constant despite varying quantities of water produced, the ongoing costs are converted from cost per m^3 to cost per capita per day; thus the period of time has no effect on the ongoing cost per capita per day.

3.2.3. CARBON COSTING

The Inventory of Carbon and Energy (Hammond & Jones, 2011) was essential in the carbon costing process. Although it was detailed, it did not have the capacity to include all the materials that were of interest; therefore in some cases, estimates were made based on similar materials.

The process of calculating the $E_{P,T}$ is identical to the one used in the cost analysis, the input variables of population groups and time periods are as indicated in Table 5. The general form of the equation is shown in Equation 2 and the terms are explained in Table 7. The number of treatment units needed is estimated as explained in Section 3.2.2.3.

$$E_{P,T} = \frac{\frac{P}{P_C}\frac{T}{T_C}\varepsilon}{365PT} \quad \text{Equation 2}$$

Description	Terms
Population Capacity	P_C
Lifetime Capacity	T_C
Average kg CO_2 per unit	ε
Population Group	P
Time Period	T

Table 7: Explanations of Equation 2 Terms

3.2.4. RISK CURVES

The efficiency and performance of the technology is an important consideration and an important measurable is the effect on human health due to the reduction of the risk of contracting illnesses. Therefore the performance of the technologies is compared through the ability of the technology to reduce risks to human health, via the effect of the technologies on the levels of contaminants in the source water. These effects are then related back to lost work days.

At least one organic and one inorganic contaminant were needed; therefore E. Coli. and Arsenic were selected. Chloroform was also chosen because it is a disinfection by-product (DBP) of chlorination, which could lead to interesting observations.

Firstly dose response curves were obtained in order to show the effect of various doses of the three contaminants on human health, for example the risk of an adverse effect. Then the effects of the various treatments on the concentrations of the contaminants were recorded to enable a comparison of performances. This flagged up a recurring problem of finding adequate data. The reduction percentages of the technologies on E. Coli. and Arsenic levels are shown in Table 8.

	E Coli		**Arsenic**
Technology	**LRV**	**%**	**%**
RSF	0.3	83	80
BSF	2	99	77
Ceramic Filter	1.5	95	0
Chlorination	4		NA
Boiling	1.5	95	0
SODIS	5		0
PuR	2	99.9	98
RO	4.6		95

Table 8: Reduction of E. Coli. and Arsenic by the technologies

E. COLI.

The threshold limit for E. Coli. in drinking water is 0 counts per 100 ml(DeZuane, 1997) and the presence of E. Coli. in drinking water can have a single dose response, where a small concentration causes adverse effects thus highlighting the difficulty of quantifying the risk. Although a 100 ml sample is supposed to be representative of the water, it isn't necessarily accurate. Another factor is the prior exposure of the individuals to E. Coli., which will have a significant effect on the risk and severity of adverse effects.

Ideally a mathematical model, which has been backed up with experimental data would be used for the dose response of the contaminants; instead the data is from an experiment carried out on rats(Strachan, et al., 2005), this is problematic because experimental data can contain anomalies due to a bad method, an inconsistent run or an unexpected one-off outcome, leading to inconsistencies in the curves. In addition, the reduction of risk relates to animals and not to humans; therefore an appropriate scale might be required in the future to relate the risks back to humans. The risk curves for E. Coli. are shown in Figure 2**.**

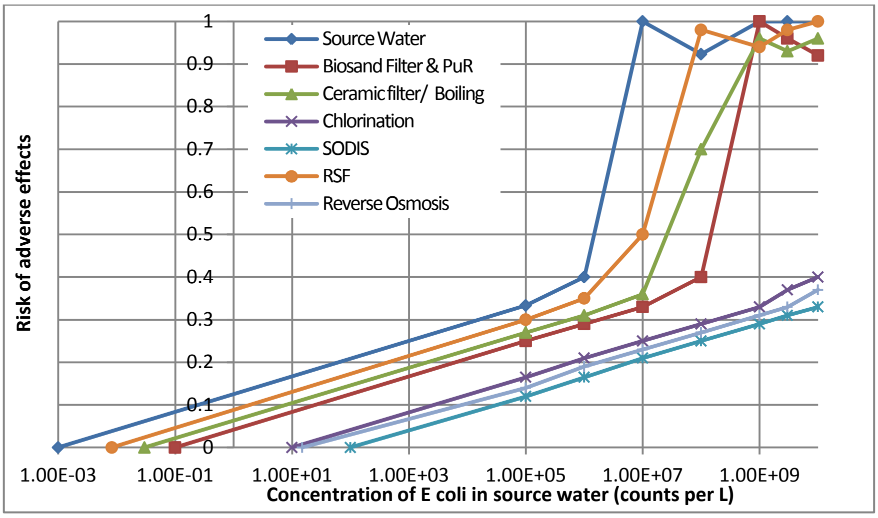

Figure 2: Risk Factor of Adverse Effects due to the presence of E. Coli. in Source Water

ARSENIC

The threshold limit for arsenic in drinking water is 0.01 mg/L(WHO, 2011), which is very low because a dose as low as 0.00017 mg/L ingested over a long period of time leads to a risk of arsenicosis whereas a concentration of 0.01 mg/L leads to an increased lifetime risk of skin cancer. The data was obtained from WHO guidelines (WHO, 2011) and although a linear relationship is slightly questionable, it is possible at low concentrations.

CHLOROFORM

The threshold limit of chloroform in drinking water is 0.3 mg/L(WHO, 2011). For the dose-response curve of chloroform a model assuming a linear potency factor for oral ingestion of 6.1×10^{-3} was used; however it is only applicable at low doses. To calculate the curve, it was assumed that an average user of the technology will weigh 70 kg and that the daily water intake is 2 L/day. The relationship of risk to the potency factor is shown in Equation 3 and the terms are explained in Table 9.

$$R_{Cl} = \frac{PF\ D_{AV}}{W} = \frac{PF\ C_{Cl}\ I_W}{W} \qquad \text{Equation 3}$$

Description	Terms
Risk of cancer due to chloroform	R_{Cl}
Potency Factor	PF
Average Daily Dose	D_{AV}
Chloroform Concentration	C_{Cl}
Daily Water Intake	I_W
Body Weight	W

Table 9: Explanations for Equation 3 Terms

Finding data for the chloroform reduction capabilities of the technologies was difficult. However chloroform is a trichloromethane (TCM), which is a type of trihalomethane (THM) and therefore the THM reduction capabilities were used to estimate the reduction of chloroform producing capabilities of the technologies.

3.2.5. EQUATING RISK

The effects of the three contaminants vary significantly, from chloroform and arsenic doses being measured against the risk of contracting cancer to E. Coli. being measured against the risk of adverse effects such as a stomach ache. This reflects how the intensity, severity and frequency of the risk can vary; because contracting cancer once can result in death whereas one can become ill due to ingestion of E. Coli. multiple times. The given risk is defined as the risk per person per lifetime and is not dependent on the period of the time that the contaminated water is consumed.

The risks are applicable to both adults and children and work days are only lost when an adult contracts an infection. However adults have to take time off to care for the young and the very old therefore not accounting for the population distribution is acceptable.

E. COLI.

Work days lost due to E. Coli. consumption can vary from half a day to over a week. The longer the adverse effect lasts, the likelihood of increased severity increases; therefore assume that on average five work days are lost per adverse effect. The number of total lost work days due to E. Coli. ($L_{P,1}$) is defined in Equation 4, where R_{EC} is risk of adverse effects, *D* is number of days lost per infection and *P* is the population group. It should also be noted that if better data on the number of lost days due to an adverse effect is given, it can easily be incorporated into the model.

$$L_{P,1} = R_{EC}\ D\ P \qquad \text{Equation 4}$$

ARSENIC

For arsenic, it is assumed that the work days lost due to one instance of cancer can be equated to losing a half of one's life. Although this seems to be a high proportion, it is a fair representation since other family members will take time off to care for those who are ill, resulting in a further loss of work days. Although the death of a child will result in a bigger loss of work days but it will be balanced out by the fact that adults are more likely to get cancer than children and that the death of adults has a relatively lower loss of days. The number of total work days lost due to arsenic ($L_{P,2}$) due arsenic consumption is defined in Equation 5, where E is the life expectancy, R_A is the risk of cancer due to arsenic and P is population group.

$$L_{P,2} = R_A\ \frac{1}{2}\ E\ P \qquad \text{Equation 5}$$

The total number of lost days (L_P) due to all contaminants is defined below in Equation 6.

$$L_P = L_{P,1} + L_{P,2} \qquad \text{Equation 6}$$

3.3. CASE STUDY

A case study was needed to test the sensitivity and effectiveness of the tool, the author travelled to Sao Paolo, Brazil with the Eco-House Initiative to carry out situational research in order to understand the conditions and life styles in the favelas and to collect data on the water sources and any treatment technologies used by the inhabitants. The Eco-House Initiative is a student group based in the Cambridge Engineering department, who advise and consult on temporary housing solutions for a South American non-governmental organization, TECHO.

However the inhabitants in the favelas tapped into the mains water supply to other areas of the city and siphoned off water free of charge; and didn't carry out any secondary treatment of this water. The main water supplier in Sao Paolo is Sabesp, the world's largest water and waste management company, and therefore water in the distribution network was assumed to be at an acceptable quality for potable water. As a result it was concluded that there was no potential to use a community as a case-study, which would have been ideal in terms of having a social background for the community and the various stakeholders as well as data on the quality of water and prices of local materials.

Therefore CamCam, an Engineers Without Borders-Cambridge branch project run in conjunction with Canadian NGO OK Clean Water was chosen as the case study instead. Information on projects in the region was made available by OK Clean Water, many projects were eliminated due to lack of information and three projects were chosen as listed below in Table 10.

Project		Population	Year (start)	Life Expectancy	Projected Population	Cost (XAF)	Cost/ capita/ day (GBP)	Technology
A	Nkuv Water Scheme	500	2006	49.6	1,000,000	20,000,000	0.14093	BSF
B	Tobin Water Point	3,000	2007	49.8	7,000	1,000,000	0.00095	Nothing
C	Yeh Water Project	312	2011	51.6	500	5,000,000	0.04604	Chlorine

Table 10: Three Case Study Systems

The three communities are situated in the Sanga river basin and therefore the quality of water at the source should be similar; although diffuse pollution due to humans and animals can occur downstream, affecting the influent. Arsenic levels in the North West Region of Cameroon are non-existent and therefore this is taken to be 0 mg/L(Nriagu, 1992). Nougang et al.(2011) states that the E. Coli. levels in the Mfoundi river is generally 6-13 CFU (colony forming units) /ml, with an average of 10 CFU/ml. No data was found on the existing levels of chloroform in ground or surface water, therefore only the reduced risk due to removal of E. Coli. could be calculated.

3.4. CASE MATRIX

GDP and life expectancy only alter between case studies, are readily available and are assumed to be accurate; thus are not tested with the case matrix. A case matrix was developed for the projects listed in Table 10 and the case matrix runs were labelled as '1XX' for Project A, '2XX' for B and '3XX' for C; the full case matrix for Case Study A is shown in

Table 17 in Appendix D. It should be noted that the projected population when expressed as a percentage of the current population is a different percentage for each case study.

The first run in the case matrix is the base case (i.e. RUN 101), which is calibrated against the data for the chosen location, to test the current conditions. For the base case, an average E. Coli. concentration (10 CFU/ml) and a time period of 15 years are assumed. The initial runs are a sensitivity analysis, to test whether the outputs alter and move as expected, it is an opportunity to test which inputs have the biggest effect on the outputs. The conditions being tested include testing the tool:

- Over the other time periods (5, 10, 20, 25 years)
- At +/- 10 % population
- At the projected population
- At +/- 20 % of cost
- At +/- 10 % of kg CO2
- At max. and min. E. Coli (6 and 13 CFU/L)

The exploratory runs are a test of reasonableness and explore the best and worst case scenarios, as highlighted in the test matrix. To generate the best possible situations, the time period was maximised to allow for economies of scale and E. Coli. levels, material costs and kg CO_2 were minimised. When generating the worst case scenarios, the projected populations, minimal time periods and maximum costs, kg CO_2 and E. Coli. levels were used. The runs were structured and systematic attempts at testing the combined changes of the various factors. Another aspect of these runs was to hypothesise situations such as a change in supplier, leading to a change in both cost and kg of CO_2.

3.4.1. CASE RUN GENERATION

For the purposes of carrying out the case matrix, an input sheet was created, where the basic project specific values are indicated in the base case with only seven inputs required for the subsequent runs to specify the time period, population, cost, kg CO_2 and levels of E. Coli., arsenic and chloroform in the source water. Examples of the input sheets for the base case and for the subsequent runs are shown in Table 18 and Table 19 respectively in Appendix E.

All 164 runs for each project were run and the $C_{P,T}$, $E_{P,T}$ and L_P for each run were computed in order to generate plots.

3.4.2. SENSITIVITY AND EXPLORATORY TESTING

Plots of $C_{P,T}$, $E_{P,T}$ and L_P against the case runs for all three case studies can be found in Appendix F. The main observation is that the responses of all three case studies in each of the three plots are very similar, although the scale on the y-axes differs. Therefore, only case study A will be considered henceforth.

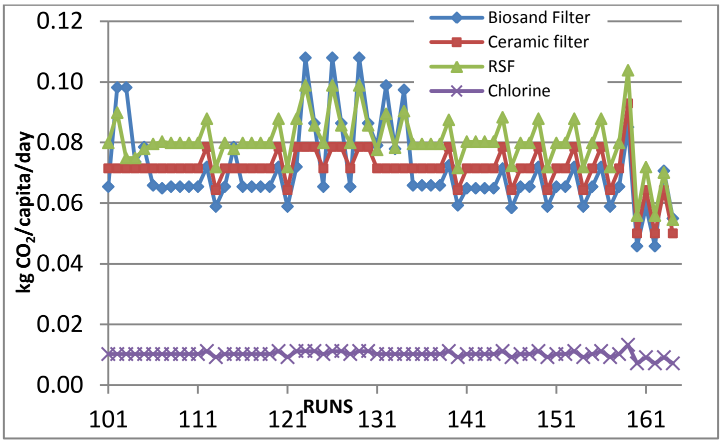

Figure 3: kg CO_2 per capita per day vs. RUNS (Case A)

In Figure 3 the line for chlorine treatment is relatively stable and is only affected by the changes in ε. The pattern of movement of the plots for other technologies is very similar although the relative fluctuations vary. Three of the technologies (BSF, RSF and ceramic filter) have a similar cost range and a hierarchy exists between the three except for $E_{P,5}$ when BSF has a higher value than the other two technologies.

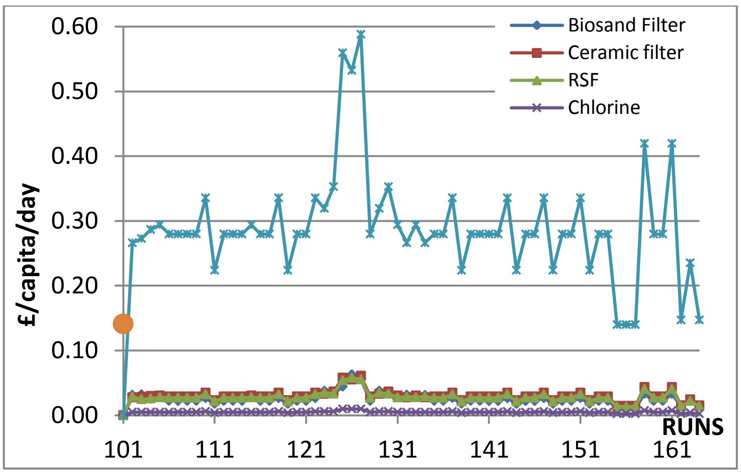

Figure 4: £ per capita per day vs. RUNS (Case A)

A similar pattern exists in Figure 4, where BSF, RSF and the ceramic filter all have a similar range and an obvious hierarchy, which is disrupted by the relative fluctuation of $C_{P,5}$ for BSF; however this is less prominent in the economic cost plots than the embodied carbon plots due to a greater response to other factors. The line for chlorine treatment is very stable as in Figure 3 and is only affected by the changes in κ. RO and PuR are not plotted on the cost plots because they have a significantly higher $C_{P,T}$ than the other technologies. The plots illustrate how $C_{P,T}$ varies absolutely as well as relative to other technologies as the inputs are altered and highlights an inherent cost hierarchy between the technologies.

As expected, the cost and embodied carbon plots responded as the κ and ε respectively were altered. The effect of the time period is due to economies of scale and depends on the lifetime of the technology, whereas the population size seems to have had a minimal effect, except for reverse osmosis, which has a high population capacity and therefore both $C_{P,T}$ and $E_{P,T}$ can be seen to decrease as the population increases.

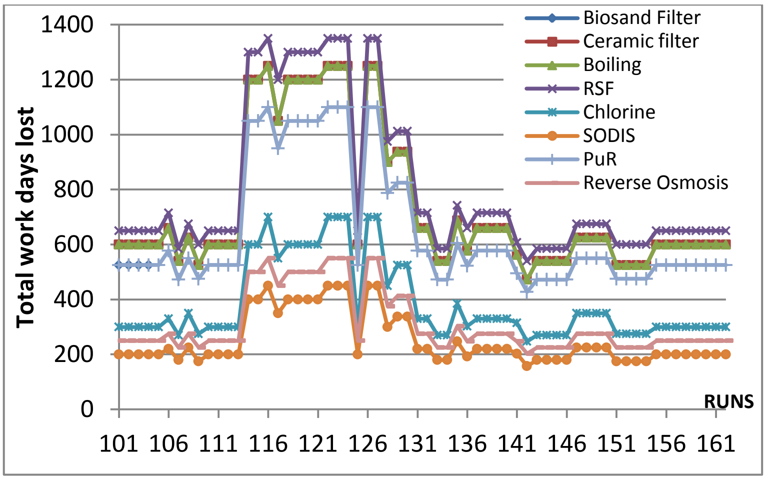

Figure 5: Total Work Days Lost vs. RUNS (Case A)

In Figure 5, as opposed to Figure 3 and Figure 4, although the range of the technologies for each case study is similar, there is a significant difference between the ranges of the three case studies. There is also a set hierarchy between the technologies. Predictably, the most significant contributors to L_P are the levels of E. Coli. in the source water and the population size. These plots illustrate that the tool is functioning as predicted and reflect simple relationships between the inputs and outputs while being sensitive to changes in the inputs.

3.4.3. COMPARISON TO IMPLEMENTED SOLUTION

Figure 4 above and Figure 11 and Figure 12 in Appendix F use orange dots to show the $C_{P,T}$ of the implemented solution in relation to the case runs, highlighting the differences between the costs of the three actual solutions, as identified in Table 10. In case study A, the $C_{P,T}$ of the implemented system is five times higher than the $C_{P,T}$ predicted for a BSF, as seen in Figure 4, and similarly in case study C, the implemented solution is nine times higher than the $C_{P,T}$ predicted for chlorination, as seen in Figure 12. This can be rationalized by assuming that a transport and supply system, consisting of pipes and pumps, has been implemented in addition to the treatment system.

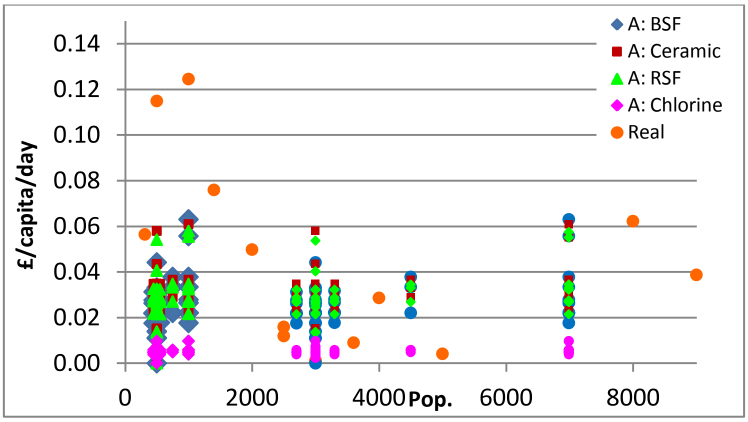

Figure 6: £ per capita per day vs. Population (Cases A & B, Implemented Solutions)

The data from 16 projects in the Kumbo area were plotted along with the case runs from case studies A and B on an plots of population against $C_{P,T}$, and is shown above in Figure 6. The implemented solutions are mostly gravity fed systems, which are chlorinated prior to usage. According to the plots the $C_{P,T}$ predicted by the tool is less than or equal to the implemented solutions, and since the implemented solutions include the cost of pipes needed to transport the water to the town, this is as expected.

4. RESULTS AND DISCUSSION

4.1. STAKEHOLDER PRIORITY ANALYSIS

The author understands the importance of the social dimension of development engineering projects, and recognizes the important of ensuring that any solution is acceptable to all stakeholders, especially the community benefitting from the intervention and this is reflected in the tool by accounting for the risk of adverse effects due to contaminants in the effluent leading to the loss of work day.

The tool only provides agnostic guidance on possible water treatment systems in terms of their performance in three independent and locally dependent dimensions; however stakeholders for a project will have varied perspectives, and thus different objectives, from each other, with the consequence that each may chose a different solution. The output from this agnostic tool can then be used to engage all the stakeholders in a discussion with the Engineers to discuss the available options and to choose a suitable system.

In order to visualize this discussion and the differing priorities, a value sheet can be used to account for the stakeholder preferences. Initially the Analytical Hierarchy Process (AHP) (Ananda & Herath, 2003) was considered because it is used to account for various stakeholder preferences; however it isn't suited for this project because it is very analytical and inherently a higher level analysis. Fundamentally AHP is a method of rationalizing preference models and this can be achieved intuitively. The implemented method is based on a process used by Loo & Fane (2012) to order technologies by rating required characteristics.

Firstly it is important to identify the stakeholders and to define their aims and priorities; this can then be used to give an ordered preference of the specified factors for each stakeholder, i.e. X_{11}, X_{21} and X_{31}, where the highest value is given to the most significant. The technologies are then rated on each factor according its performance i.e. Y_{11}, Y_{12} and Y_{13}; since a minimal value is desired for all factors, the technology with the lowest value for each factor was given the highest rating. The ratings were multiplied and summed to generate an overall score for each technology for each stakeholder as demonstrated below in Table 11 and Table 12 (The rest of the cells in Table 12 follow on from the others). Then for each stakeholder, the technology with the highest score is the most suitable.

	Stakeholders			**Technologies**		
Factors	**1**	**2**	**3**	**1**	**2**	**3**
Total Cost	X_{11}	X_{12}	X_{13}	Y_{11}	Y_{12}	Y_{13}
£ per risk	X_{21}	X_{22}	X_{23}	Y_{21}	Y_{22}	Y_{23}
Kg CO2	X_{31}	X_{32}	X_{33}	Y_{31}	Y_{32}	Y_{33}

Table 11: Preferential Orderings for factors and technologies

	Tech 1	**Tech 2**	**Tech 3**
Stakeholder 1	$X_{11} Y_{11} + X_{21} Y_{21} + X_{31} Y_{31}$		
Stakeholder 2	$X_{12} Y_{11} + X_{22} Y_{21} + X_{32} Y_{31}$		
Stakeholder 3	$X_{13} Y_{11} + X_{23} Y_{21} + X_{33} Y_{31}$		$X_{13} Y_{13} + X_{23} Y_{23} + X_{33} Y_{33}$

Table 12: Scores for each technology

An example of the analysis for Case A is shown in Table 20 in Appendix H. For the purpose of this analysis four stakeholders and their personalities and priorities were created, based on the information available for the area. However in reality when carrying out the value priority assessment, stakeholder engagement is essential and they should be consulted in order to determine their relative preferences of the factors under consideration.

The mother's group, representing the community, prioritises being healthy and having clean drinking water, which is a basic human right (UN, 2010), and therefore wants to reduce the total risk. Although the village headman desires the same outcome, his first priority is assumed to be to reduce the cost of the project. The local NGO, OK Clean Water, is assumed to prioritise reducing the health risks of the community for the lowest cost, therefore allowing them to help more people. In addition they need to generate good publicity material for donors. The Kumbo Urban Council (KUC) is the local government representative responsible for the water supplies in the area with a desire to chlorinate all the systems. It is assumed that the KUC representative wants good publicity and wants to reduce the cost per kg CO_2 to show that the council is aware of environmental issues.

This stakeholder analysis demonstrates that PuR is the least suitable technology and that depending on the most influential stakeholders, Chlorine treatment and BSF are the two most suitable technologies with RSF being third most suitable; thus illustrating that the most suitable technology can vary as a result of differing priorities and that there can be an overlap in the preferred technologies, leading to a compromise.

When the valued priority analysis was carried out with the same stakeholder priorities for an arbitrary situation, the most suitable technologies were different as shown in Table 21 of Appendix H. The most suitable is BSF followed by the ceramic filter and then RSF. This illustrates the capability of the tool to differentiate between situations. As the priorities and personalities of the stakeholders and the stakeholders themselves change, the most suitable technology according to the analysis alters.

With the preferential analysis there is a possibility that more weight can be given to livelihood generation or embodied carbon reduction, leading to a solution which creates more jobs or reduces embodied carbon respectively with a much higher risk. The use of multiple stakeholders, especially from the community is a good way of ensuring that such bias doesn't skew the overall selection and result in an illogical trade-off.

4.1.1. QUANTIFYING LIVELIHOOD EFFECTS

Another factor, which was initially considered as a priority, is the livelihood generating capacity of the technologies. This can be considered a priority for the local council, craftsmen or unemployed persons in the community.

Modelling livelihood as a percentage of the base capital and O&M cost and then adding a social labour cost, similar to the economic material cost is a possible method of accounting for livelihood generation. However difficulties were encountered in quantifying these benefits to local employment rates and thus the local economy because employment can be dependent on the version of a technology that is chosen, the extent of the system and whether it has a transport and supply aspect in addition to treatment. Difficulties were also encountered in sourcing information on the employment opportunities created by each technology.

It should be emphasised that this tool was created with the intention of being used to prompt discussions between stakeholders and incorporating the livelihood aspect into the stakeholder preference analysis supports this analysis, and this can still be carried out by the Engineer making an educated guess of the amount of jobs created during the initial construction and subsequent operational phases of each of the technologies and these can then be easily incorporated into the preference analysis.

4.2. TOOL VISUALIZATION

This section explores some of the possible visualizations of the tool and its outputs. A design curve with the technologies plotted on axes of population and risk and IsoCost curves would have been a useful output, since it would identify possible L_P and $C_{P,T}$ of each technology for a specific population. However, since only 4 different population groups were tested for each situation the points cluster as shown in Figure 6, and the generated plots are not useable or interesting.

4.2.1. TECHNOLOGY SELECTION CURVES

Two dimensions out of $C_{P,T}$, $E_{P,T}$ and L_P were plotted against each other to map the technologies and to identify the most appropriate method of visualizing the data, these plots are shown below. Logarithmic scales were chosen because they enable all the technologies to be plotted and compared on the same axes.

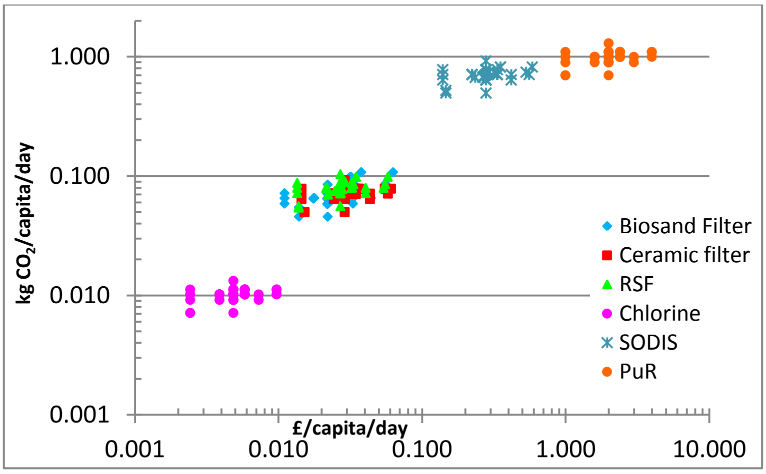

Figure 7: £ per capita per day vs. kg CO_2 per capita per day (Case A)

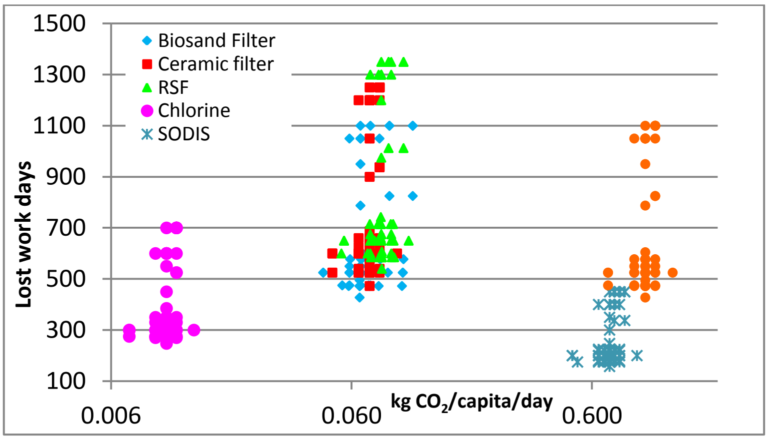

Figure 8: kg CO_2 per capita per day vs. Total Lost Work Days (Case A)

In Figure 7 a linear relationship between $C_{P,T}$ and $E_{P,T}$ is apparent, showing that the embodied carbon footprint increases as the cost of a treatment technology increases; this only true for particular location and due to the data costing and carbon footprinting data collected initially.

In all three plots the technologies are distributed such that each technology has its own area, the only exception being the clustering of BSF, RSF and the Ceramic filter. There are however slight differences, in Figure 9 BSF has a lower $C_{P,T}$ and a lower L_P compared to RSF and in Figure 8 the ceramic filter has a higher $C_{P,T}$ and a lower $E_{P,T}$ compared to RSF.

Some points of interest are that RO has a higher $C_{P,T}$ but a lower risk compared to PuR, whereas SODIS has a similar risk to RO but at a much lower $C_{P,T}$; therefore if the decision is based only on the numerical outputs SODIS is the obvious choice; however the choice between SODIS and RO will be dependent on other factors such as the population group, space available etc. SODIS is a simple yet tedious process, which works at a household level and is time intensive; whereas RO has good economies of scale and needs to be carried out on a community level, if the source water needs intense purification. RO has an added benefit of creating more livelihoods in both the construction and operation phases; where this is a priority and other factors such as a sufficient population are met, RO is a competitive and viable option.

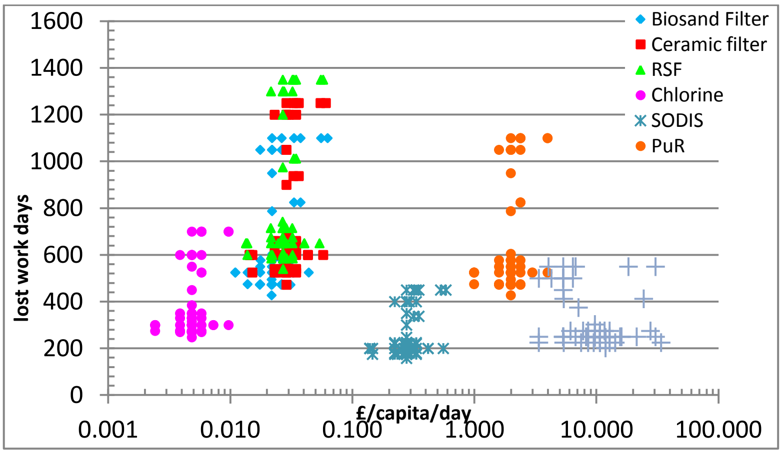

Figure 9: £ per capita per day vs. Total Lost Work Days (Case A)

Compared to PuR, SODIS is a cheaper option with a lower embodied carbon footprint; and therefore it can be argued that it is the better technology, which prompts the question of why PuR is a viable technology? SODIS has a prolonged implementation whereas there is less opportunity for mistakes and a higher speed of implementation when using PuR and thus it is a better choice for emergencies.

The cluster of BSF, RSF and ceramic filter all have a lower $C_{P,T}$ and higher risk than SODIS; however as discussed earlier other factors such as stakeholder priority analysis will be needed to select the most suitable system. On a similar note, chlorination seems to be the cheapest solution and has the lowest embodied carbon footprint and similar risk reduction capabilities to SODIS and RO. However when carrying out the stakeholder preference analysis in Section 4.1, it was shown that both BSF and chlorine are viable options, depending on which stakeholder has the most influence, thus demonstrating the importance of stakeholder consultation and preferential analysis.

As noted in Section 4.1 chlorination systems are the preferred technology of the KUC, thus demonstrating that there is no local aversion to chlorination, at least at the institutional level and therefore it is a viable solution. However some communities may have an aversion to chlorination due to issues such as the aftertaste and therefore could be incorporated into any future stakeholder priority analysis or chlorination could be rejected from the outset.

4.2.2. ISOCURVES

The plots in Appendix G incorporate all three dimensions to allow a better comparison of possible trade-offs when choosing a technology. Plotting the IsoCurves was made difficult by the range of different design options and the clustering of the plots as shown in Figure 7, where both the $C_{P,T}$ and $E_{P,T}$ values of BSF, RSF and ceramic filters overlap and the other technologies occupy discrete areas. Since the axes are scaled logarithmically, the spacing between the discrete areas shows that there are large differences between $C_{P,T}$ and $E_{P,T}$ values of some technologies; thus ultimately complicating the process of detailing the cost and kg CO_2 ranges for the curves, since ideally each range should be equivalent with an even distribution of points for each one; in order to have an equal spacing between the curves.

The clustering of the plots implies that designers have a choice to make at the low and high kg CO_2 range. According to the plots, there is a distinct lack of technologies with an $E_{P,T}$ of 0.15- 0.6, which raises the question of whether the plot is highlighting the omission of a particular set of technologies from the analysis or whether there is an actual gap in the market for a technology. Some technologies were omitted at the beginning of this project and therefore will need to be incorporated into the tool before reaching any conclusions on the presence of the gaps in the plots.

As discussed in Section 0, there is a choice of possible trade-offs between choosing a cheaper technology with a relatively higher risk; whereas the relationship between cost and embodied carbon looks to be straightforward in this case study. However this may not be case for all instances and should be checked anew for each situation.

Figure 10 is a contour plot generated by superimposing the IsoCurves of kg CO_2 from Figure 19 in Appendix G onto Figure 9. This allows all three dimensions and the technologies to be displayed on one area; it should be noted that this is only suitable for this particular area of Cameroon, however the location look-up table can be updated for a different location to generate values more suited for the secondary situation. A similar plot with IsoCurves of cost was attempted, however as shown in Figure 18 in Appendix G the distribution of the points of similar costs are isolated from the other groups except for the group with a $C_{P,T}$ range of 0.5 - 1.0, which amalgamates into the two adjacent groups of points; thus preventing any sensible IsoCurves of cost being drawn.

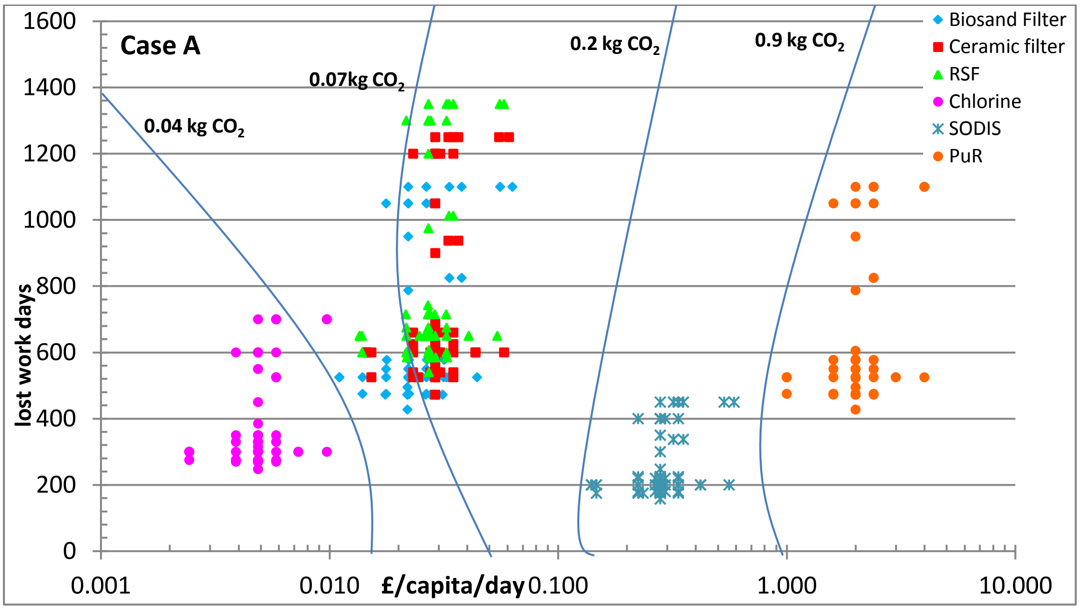

Figure 10: Design Chart with IsoCurves for kg CO_2 for Case A

This plot allows the users to compare the economical cost, embodied carbon and associated risk of the candidate technologies for a particular location at specified input parameters. Some of the technologies are interconnected in terms of cost, embodied carbon footprint and associated risk and how some are very distinct. It also displays how chlorination seems to be the 'best' technology when considering all three factors absolutely thus once again highlighting the importance of priority analysis.

5. CONCLUSIONS

The first step of this project was the creation of a novel technology review database, which amalgamates data on a variety of technologies from a range of sources in order to ease comparison across a variety of factors. To ease the process, quantative scales were created for some factors.

This database was crucial in the creation of the tool, which computes agnostic values of $C_{P,T}$, $E_{P,T}$ and L_P for each technology over a range of inputs (defined by population group, time period and quality of source water). The main feature of the tool is that the look-up tables allows the inputs be altered with ease to suit any situation and location. In addition if better data on initial assumptions such as the number of lost days due to an adverse effect, material volumes for technologies or costs and embodied carbon of materials is given, it can easily be incorporated into the model to improve its accuracy.

In order to account for the preferences of stakeholders, a method of value priority analysis was devised to rate the outputs of the tool thus ranking the preferred technologies for each stakeholder. The valued priority analysis allows the agnostic outputs of the tool to be used to promote a discussion between the stakeholders and thus reach a compromise. Other factors such as livelihood generation capabilities, pre-treatment requirements can also be included when carrying out the analysis.

Various ways of succinctly combining and displaying the outputs of the tool were considered and the clustering and distribution of some technologies and the presence of large gaps did not lend to the formation of IsoCurves. Finally the technology points were plotted on axes of cost vs. risk with IsoCurves of kg CO_2. This plot allows the users to compare the economical cost, embodied carbon and associated risk of the candidate technologies for a particular location at specified input parameters.

Although there are lots of potential technologies, the tool only calculates the outputs for the chosen candidate technologies; thus the initial candidate technology selection is a limiting factor and this is an area for future improvement. The aim of the tool is to empower the Engineers and decision makers by providing a tool which quantifies their concerns while allowing them to adapt it to the local situation. The case study of CamCam was used not to find the most suitable solution for the three locations but to demonstrate how the tool can be used. This tool has a lot of potential to be a powerful method of exploring various possible small scale water supply systems for particular project while consulting all the stakeholders.

5.1. FURTHER WORK

An important aspect of this project was to explore possible methods of carrying out the analysis and developing the tool in order to ease further work.

There are countless water treatment technologies and numerous variations for each type of technology; this proved to be problematic when identifying possible technologies at the beginning of this project. Therefore some possibilities were not explored; this is reflected in some of the model output plots where there are technology gaps as discussed in Section 4.2.2. Therefore one improvement is to explore other technologies such as micro- and ultra- filtration; these can then be included in the technology review database and then costs, embodied carbon footprints and risk reduction capabilities can be calculated and incorporated into the model.

As identified throughout the project, obtaining reliable data was particularly problematic, therefore more work can be carried out in accumulating better data for dose response curves, risk analysis due to contaminants and economic and carbon costing of the technologies, in particular RO; thus improving the accuracy of the tool.

Further testing of the model needs to be carried out with the use of another case study, ideally one where more data is available on the implemented technologies and arsenic and chloroform is present in the source water; which will be a more reliable test of the sensitivity and appropriateness of the tool.

AHP analysis was briefly considered for the stakeholder priority analysis, however it was deemed to be too analytical for the purposes of this project, but the process of priority analysis can be improved upon by using the AHP instead of the simplified method used in Section 4.1. Similarly Section 0 briefly explored the concept of quantifying livelihood, which will predominantly involve establishing assumptions and accumulating data on the livelihood benefits of the technologies and then generating a calculation to scale it according to the situation. This will enable livelihood generation to be incorporated into the stakeholder priority analysis, which is representative of reality.

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APPENDIX A: RISK ASSESSMENT RETROSPECTIVE

The risk assessment reflected the fact that the project is a desk-based project, and therefore was concentrated on ergonomics and computer usage. As expected the only associated hazards were due to improper usage of computers and therefore were dealt with as expected by ensuring regular breaks were taken and employing a proper posture.

APPENDIX B: TECHNOLOGY REVIEW DATABASE

B.1. QUALITATIVE COMPARISON SCALES

The qualitative comparison scales were inspired by a method from Sobsey et al. (2008) used to compare point-of-use (PoU) technologies against each other with the use of a simple scale (ranging from one to three) for each sustainability factor. This method was deemed suitable for the purposes of this particular task because the technologies are being rated against each factor but the factors are not being compared relative to each other. The factors requiring a synthetic scale are described below.

Factors	Explanation
Maintenance	Each technology has different requirements on how it should be maintained; from not needing further input or monitoring post installation to requiring regular cleaning and monitoring to requiring regular replacement of parts.
Supply chain	Some technologies may be constructed from locally sourced materials whereas others may require specialist materials. If the technology requires a regular supply of chemicals or replacement parts, the ease of supplying these is an important consideration.
Pre-/post-treatment	Some of the technologies require the influent to be treated first and in some cases the effluent needs to be treated before consumption.

Table 13: Factors requiring an artificial scale for comparison

The synthetic scales are shown below in Table 13 with a description for each value for the four factors. A quantative scale was required because numerical values are easier to compare than verbal descriptions. Although these scales are basic, they are useful in the context of the database because from the outset of a project some technologies can be rejected if they are deemed to be unsuitable for the purposes of the project.

Scale	Maintenance	Supply Chain	Pre-treatment	Post-treatment
0	None	None: unit lasts forever	None	Good storage (in small containers)
1	Occasional cleaning	Supply chain for small parts required but easily available.	Some: i.e. filtration	Some needed (chemical etc)

2	Periodic cleaning	Unit lasts forever but parts may need to be replaced occasionally if broken.	A lot i.e. flocculation, filtration	NA
3	Cleaning and replacement of small parts occasionally.	Continuous supply of parts/fuel etc is needed and they are easily available	NA	NA
4	Periodic replacement of parts (as well as cleaning).	Continuous supply of parts/fuel etc is needed and they are not easily available	NA	NA

Table 14: Description of the various artificial scales

The following sections detail how some of the information in the database was sourced. Two sources were used as starting points because they had correlating information with regards to performance. Sobsey et al. (2008) detailed human health changes, which can be an indicator of performance, while Loo & Fane (2012) detailed the capacity and lifespan of some of the technologies and the rate of production of clean water.

B.2. BIOSAND FILTER (BSF)

Tiwari et al. (2009) examined the performance of BSFs, in terms of human health improvements and reduced risk; which has a low accuracy due to a dependence on a variety of factors such as community demographic, while a Tang et al. (2010) detailed the performance capabilities of the filter at reducing pollutants etc.

Elliott et al. (2008), Tiwari et al. (2009) and Ahammed & Davra (2011) all concur on the general composition of the filter, thus indicating that the values are accurate: 0.1 m of under-drain and 0.4- 0.5 m of sand. The thickness of the vessel was assumed to be about 30 mm, whereas the diameter and the height of the structure were extracted from CAWST(2012) detailing the construction process and were then used to calculate the volumes of filter media (sand and gravel) required.

B.3. CERAMIC FILTER

Potters for Peace (1998) designs and builds ceramic water filters and have a variety of documents with information on the filters and the construction process. These were useful for obtaining sizing information, which was used to calculate volumes of materials needed for both the structure and media. The dimensions of the filter and the ratio of clay to sand were extracted from the website and the thickness of the filter was assumed to be 30 mm. This was then used to calculate the volume of material needed to make the structure, and the amounts of sand and clay required. The amount of anthracite coal and the size of the larger vessel for the collection of the clean water were determined likewise. The flow rate is generally between 3-5 l/h and therefore the filter has a capacity of 3.6-6 people respectively; hence the capacity is assumed to be 5 people.

An investigation by Baumgartner et al. (2007) to find ideal operating conditions for both a ceramic filter and a biosand filter was useful in extracting performance data of the two.

B.4. RAPID SAND FILTER (RSF)

Graham & Collins (1996) was deemed reliable because information on the RSF correlated with Solt & Shirley (1991), which was used to acquire information on the filter media and the filtration rate. Vigneswaran & Visvanathan (1995) yielded information on the quality limits of the influx. The volumes of materials needed for the structure were obtained from Qasim et al. (2000), which had information about the filter media and their exact depths.

B.5. BOILING

Boiling is known to be about 97% effective in removing coliforms and other bacteria(Clasen, et al., 2008), however if there are relatively large foreign media in the water, filtration is needed. Whether the water needs pre-treatment, such as filtration, depends on the quality of the source water and this cannot be anticipated in advance for a suitability analysis study. Therefore it was assumed that pre-treatment will not be required. Loo & Fane (2012) was used to obtain data on its effectiveness.

B.6. CHLORINE TREATMENT

Sobsey et al. (2008) detailed the efficacy of chlorination. The actual scale of treatment depends on the source water and if there is foreign media present in the water they need to be filtered out; however for this analysis, it was assumed that no prior filtration is required before chlorine addition. The likelihood of the water not requiring any pre-treatment is dependent on the water source and the method of transportation to the treatment system.

B.7. PUR SACHETS

The costs of PuR sachets were obtained from a commercial website(Butyl Products Catalogue, 2012) and information on its performance and efficacy was obtained via the Centers for Disease Control and Prevention (2012) website. Filtration may be needed prior to treatment depending on the source water quality; however for the purposes of this project it is assumed that filtration is not required.

B.8. SODIS

The performance of SODIS is dependent on the users following the guidelines and ensuring that a continuous stream of water is purified in advance to meet future needs. Both McGuigan et al.(2011) and Conroy et al. (1996) highlight the health benefits of using SODIS and were used to obtain data on its effectiveness. SODIS treats water but does not filter out any foreign media, thus it was assumed that the source water didn't need any pre-treatment.

B.9. REVERSE OSMOSIS (RO)

RO is used in the desalination of saline water, reclamation of municipal wastewater and various industries and typically only be considered if the only water source available to a community is brackish water or extremely polluted surface water. Possible stages in the process include filtration (granular, activated carbon or membrane), softening, deaeration, disinfection, chemical oxidation, coagulation and flocculation and there is a variety of chemicals, which are suitable for each stage, which are not all interchangeable. It was difficult to identify exactly which steps should be carried out without knowing the quality of the influent.

			Rapid Filtration (dual bed)		Biosand Filter		Ceramic Filter		Boiling	SODIS		Free chlorine (NaDCC)	PuR sachets		Electric Reverse Osmosis (RO)	Renewable energy RO
Factors		**Unit**	**Range**	**Typical**	**Range**	**Typical**	**Range**	**Typical**	**Typical**	**Range**	**Typical**		**Range**	**Typical**		
Required area	**Depth**	**m**	1.5-2		0.9-2	1		0.25	NA		1 bottle= 2L; 20-30L/ person/ day… for 4 people = 6sqm	Depends on tablets used/ how much water is required				
	Length	**m**				0.3			NA							
	Width	**m**				0.3			NA							
	Diameter	**m**	0.20			0.4		0.3	NA							
Filter Media	**Type**		anthracite (0.3-0.6); sand (0.2-0.4)		sand (& a bit of gravel)		sand and clay		NA		NA				NF/ Ro asymmetric or thin film composite	
	Diameter	**mm**	0.5-1.2		0.3-0.45											
	depth	**m**	0.5-1.0		0.5-1.5	1										
Filter rate		**m/h**	*0.25*		0.1-0.3	0.4	1.0-3.0									
Production Rate		**L/min**			0.25-1									0.3	3.7	0.17
		m/h			0.5-0.7		1.5-2.5									
		L/unit										20L		10L		
Life span		**years**	*2.00*			>8	2.0-3.0								5-10 / unit	5-10 /unit
Capacity		**people/unit**			< 1000											
Capital cost		**$**			15-25		8.0-10		0-10		0	0.08-0.15 /L	0.003—0.035 /L			
O&M cost		**per unit**				0	4.0-5.0				0-2					
Maintenance Requirements		**scale**		2		2		3	1		2	2		2	4	4
Supply Chain Requirements		**scale**		0		0		2	3		1	3		4		
Power Requirement				0		0		0	high (2500J / 8L)		0				High	
Pre-treatment required		**scale**		2		0		0	1		1	1		0	1	1
Water quality required	**Max.turbidity**	**NTU**	any		10.0-50	<10					<30				<1 (0.2 preferably)	
	colour	**units**				<30										
	TSS	**mg/L**	30-59			<50					10.0-15					
	TDS	**mg/L**													<400	<400
Post-treatment		**scale**		0		0		0	0		0	0		0	1	1
Removal Mechanisms			depth filtration		straining, biological activity			straining and sedimentation	disinfection		UV disinfection				Differences in solubility or diffusivity. Desalinization.	
Performance	UV254	% Reduction (%R)			32-46%	37.00%										
	BDOC				55-73%	62.00%										
	TP (phosphorous)				59-79%	69.00%										
	Fe				<95%	75.00%										
	Mn					77.00%										
	Pb					74.00%										
	Cr					69.00%										
	Chloroform					2 LRV		1.5 LRV	97%		5 LRV	4 LRV		99.90%	96%	
	Arsenic			80%					0%		0%			98%	95%	
	E coli	LRV				2 LRV		1.0-2.0 LRV	97%		5 LRV	>4 LRV		99.90%	4.6 LRV	
	faecal coliform	LRV/ %R				>1 LRV		89%								
	bacteria	LRV			<98.5%	1 LRV		2 LRV		3.0-5.5	3 LRV	3 LRV		7 LRV		
	protozoa	LRV			<100%	2 LRV		4 LRV		1.0-3.0	1 LRV	3 LRV		3 LRV	6 LRV	6 LRV
	virus	LRV			70-99%	0.5 LRV		0.5 LRV		2.0-4.0	2 LRV	3 LRV	2-4.5			
	turbidity	% R			<95%	92%										
Recontamination		scale				low		low								
Health Effects	diarrhoeal reduction					47.00%		46.00%			31%	29-37%		90%		

Table 15: Technology Review Database

APPENDIX C: UNIT COSTS AND EMBODIED CARBON CALCULATIONS

Technology	Purpose	Description	Material quantity		Suitable Materials												£			kg CO2			Type of cost?
					Concrete	Wood	Plastic	Steel	Clay	Colloidal silver*	Sand	Gravel	Chlorine tablet	PuR sachets	2L PET bottles	Anthracite coal	Max	Min	Average	Max	Min	Average	
Biosand Filter	Structural	Assume a square base (0.4*0.4)	0.6	cbm	Y		Y	?									1929.730	67.800		6387.405	7.255		**Fixed cost** (ongoing cost will be cleaning costs…)
	Filter media		0.08	cbm							Y						2.118	2.118		0.011	0.011		
	Filter media		0.016	cbm								Y					0.912	0.912		0.005	0.005		
					Total												**1932.759**	**70.830**	**1001.795**	**6387.421**	**7.270**	**3197.346**	
Ceramic filter	Structural/filter		0.005	cbm					Y								22.500	22.500		4.590	4.590		**Fixed cost** (ongoing cost will be cleaning costs…)
	Structural/filter		0.005	cbm							Y						0.132	0.132		0.001	0.001		
	Filter media		0.0005	kg						Y							0.245	0.245		1.546	1.546		
	Structural	capacity of about 50L (larger filters will require larger)	0.06	cbm	Y		Y	?									192.973	6.780		638.741	0.725		
					Total												**215.850**	**29.657**	**122.754**	**644.877**	**6.862**	**325.870**	
Boiling	Fuel	To boil 10L of water	1	kg		Y											0.354	0.354		0.177	0.177		**Ongoing cost (no fixed)**
					Total												**0.354**	**0.354**	**0.354**	**0.177**	**0.177**	**0.177**	
RSF**	Structural	Assume square base (0.2*0.2).	0.122	cbm	Y		?	?									392.378	13.786		1298.772	1.475		**Fixed cost** (ongoing cost will be cleaning costs…)
	Filter media		0.004	cbm												Y	0.704	0.704		0.352	0.352		
	Filter media		0.032	cbm							Y						0.847	0.847		0.004	0.004		
					Total												**393.929**	**15.337**	**204.633**	**1299.129**	**1.831**	**650.480**	
Free Chlorine	Tablet	To clean 10 L of water and assume filtration costs will be the same as for rapid sand filtration.	0.512	g									Y				0.002	0.002		0.005	0.005		**Ongoing cost**
					Total												**0.002**	**0.002**	**0.002**	**0.005**	**0.005**	**0.005**	
SODIS	structural	To clean 10 L of water	0.3	kg											Y		2.632	2.632		6.684	6.684		**Ongoing cost**
																	2.632	**2.632**	**2.632**	**6.684**	**6.684**	**6.684**	
PuR	sachets	To clean 10 L of water	4	g										Y			1.000	1.000		0.500	0.500		**Ongoing costs**
					Total												**1.000**	**1.000**	**1.000**	**0.500**	**0.500**	**0.500**	

Table 16: Unit Cost and Embodied Carbon Footprint Calculation

APPENDIX D: CASE MATRIX

RUNs	Description	Time Frame	Population	E. Coli. (CFU/L)	Cost/ capita/day	kg CO2/ capita/day
101	Base Case; av. E.Coli.; av. Cost; base pop.	15	100%	av	100%	100%
102	Vary time frame; av. E. Coli.; av. Cost; base pop.	5	100%	av	100%	100%
103		10	100%	av	100%	100%
104		20	100%	av	100%	100%
105		25	100%	av	100%	100%
106	110% Pop	15	110%	av	100%	100%
107	90% Pop.	15	90%	av	100%	100%
108	max. E.Coli.	15	100%	max	100%	100%
109	min. E. Coli.	15	100%	min	100%	100%
110	120% cost	15	100%	av	120%	100%
111	80% . cost	15	100%	av	80%	100%
112	110% CO2	15	100%	av	100%	110%
113	90% CO2	15	100%	av	100%	90%
114	Projected Pop	15	200%	av	100%	100%
115	Projected Pop 25 yrs	25	200%	av	100%	100%
116	Proj. pop. Max E. Coli.	15	200%	max	100%	100%
117	Proj. pop. Min E. Coli.	15	200%	min	100%	100%
118	Proj. pop. 120% cost	15	200%	av	120%	100%
119	Proj. pop. 80% cost	15	200%	av	80%	100%
120	Proj. pop. 110% CO2	15	200%	av	100%	110%
121	Proj. pop. 90% CO2	15	200%	av	100%	90%
122	Proj. pop; max. E. Coli.; 120% cost; 110% CO2	15	200%	max	120%	110%
123	5 yrs; Proj. pop; max. E. Coli.; 120% cost; 110% CO2	5	200%	max	120%	110%
124	25 yrs; Proj. pop; max. E. Coli.; 120% cost; 110% CO2	25	200%	max	120%	110%
125	200% cost	15	100%	av	200%	100%
126	5 yrs; proj. pop; max. E. Coli.; 200% cost; 110% CO2	5	200%	max	200%	110%
127	25 yrs; proj. pop; max. E. Coli.; 200% cost; 110% CO2	25	200%	max	200%	110%
128	150% pop	15	150%	av	100%	100%
129	5 yrs; 150% pop; Max. E. Coli; 120% cost; 110% CO2	5	150%	max	120%	110%
130	25 yrs; 150% pop; Max. E. Coli; 120% cost; 110% CO2	25	150%	max	120%	110%
131	110% pop 25 yrs	25	110%	av	100%	100%
132	110% pop 5 yrs	5	110%	av	100%	100%
133	90% pop 25 yrs	25	90%	av	100%	100%
134	90% pop 5 yrs	5	90%	av	100%	100%
135	110% Pop; max. E.Coli.	15	110%	max	100%	100%
136	110% Pop; min. E.Coli.	15	110%	min	100%	100%
137	110% Pop; 120% cost	15	110%	av	120%	100%
138	110% Pop; 80% cost	15	110%	av	80%	100%
139	110% Pop; 110% CO2	15	110%	av	100%	110%
140	110% Pop; 90% CO2	15	110%	av	100%	90%
141	90% pop max. E. Coli.	15	90%	max	100%	100%
142	90% pop min. E. Coli.	15	90%	min	100%	100%
143	90% pop; 120% cost	15	90%	av	120%	100%
144	90% pop; 80% cost	15	90%	av	80%	100%
145	90% pop; 110% CO2	15	90%	av	100%	110%
146	90% pop; 90% CO2	15	90%	av	100%	90%
147	max. E. Coli. 120% cost	15	100%	max	120%	100%
148	max. E. Coli. 80% cost	15	100%	max	80%	100%
149	max. E. Coli.110% CO2	15	100%	max	100%	110%
150	max. E. Coli. 90% CO2	15	100%	max	100%	90%
151	min. E. Coli. 120% cost	15	100%	min	120%	100%
152	min. E. Coli. 80% cost	15	100%	min	80%	100%
153	min. E. Coli. 110% CO2	15	100%	min	100%	110%
154	min. E. Coli. 90% CO2	15	100%	min	100%	90%
155	50% cost	15	100%	av	50%	100%
156	50% cost; 110% E. Coli.	15	100%	av	50%	110%
157	50% cost; 90% E. Coli.	15	100%	av	50%	90%
158	150% cost	15	100%	av	150%	100%
159	130% CO2	15	100%	av	100%	130%
160	70% CO2	15	100%	av	100%	70%
161	150% cost; 130% CO2	15	100%	av	150%	130%
162	50% cost; 70% CO2	15	100%	av	50%	70%
163	25yrs; min E.Coli.; 80% cost; 90% CO2	25	100%	min	80%	90%
164	25yrs; min E.Coli.; 50% cost; 70% CO2	25	100%	min	50%	70%
			Worst Cases		Best Cases	

Table 17: Case Matrix for Case A

APPENDIX E: CASE MATRIX INPUT SHEETS

Technology							£ / capita / day	kg CO_2 / capita / day	Lost work days			
		Years:					15	15	E. Coli.	Arsenic	Chloroform	Total
		Population:					500	500	500	500	500	
		Cost in £	kg CO_2	Risk: E. Coli.	Risk: Arsenic.	Risk: Chloroform						
Biosand Filter	Fixed	1001.795	3197.346	0.21	0	0	0.0221	0.0654	525	0.0	0.0	525
Ceramic filter	Fixed	122.754	325.870	0.24	0	0	0.0290	0.0714	600	0.0	0.0	600
Boiling	Ongoing	0.354	0.177	0.24	0	0			600	0.0	0.0	600
RSF	Fixed	204.633	650.480	0.26	0	0	0.0271	0.0798	650	0.0	0.0	650
Chlorine	Ongoing	0.002	0.005	0.12	0	0	0.0049	0.0102	300	0.0	0.0	300
SODIS	Ongoing	2.632	6.684	0.08	0	0	0.2797	0.7105	200	0.0	0.0	200
PuR	Ongoing	1.000	0.500	0.21	0	0	2.0000	1.0000	525	0.0	0.0	525
RO	Ongoing	0.286					0.0057					
	Fixed	27290323					10.7435					
	TOTAL		0	0.1	0	0	10.7492		250	0.0	0.0	250

Interest Rate 01/11/2012, UK	*0.5%*
Inflation Rate 01/11/2012, UK	*2.2%*
Conversion of 1 kg of CO2 to £	*0.005*
E. Coli.	av
Arsenic	0
Chloroform	0
Cost of loosing one work day	*1.77*
Lost work days per infection:	*5.00*
Lost work days per cancer:	*24.80*
GDP per capita	*645.35*
Life Expectancy	*49.6*

Table 18: Input Sheet for RUN 101

Technology							£ / capita / day	kg CO_2 / capita / day	Lost work days			
		Years:					5	5	E. Coli	Arsenic	Chloroform	Total
		Population:					500	500	500	500	500	
		Cost in £	kg CO_2	Risk: E. Coli.	Risk: Arsenic.	Risk: Chloroform						
Biosand Filter	**Fixed**	1001.795	3197.346	0.21	0	0	0.0315	0.0981	525	0	0	525
Ceramic filter	**Fixed**	122.754	325.870	0.24	0	0	0.0276	0.0714	600	0	0	600
Boiling	**Ongoing**	0.354	0.177	0.24	0	0			600	0	0	600
RSF	**Fixed**	204.633	650.480	0.26	0	0	0.0290	0.0898	650	0	0	650
Chlorine	**Ongoing**	0.002	0.005	0.12	0	0	0.0049	0.0102	300	0	0	300
SODIS	**Ongoing**	2.632	6.684	0.08	0	0	0.2661	0.6759	200	0	0	200
PuR	**Ongoing**	1.000	0.5	0.21	0	0	2.0000	1.0000	525	0	0	525
RO	**Ongoing**	0.2865					0.0057					
	Fixed	27290323					30.6624					
	TOTAL		0	0.1	0	0	30.6681		250	0	0	250

E. Coli.	av
Arsenic	0
Chloroform	0
Time Period	5
Population Convertion Factor	1
Cost Convertion Factor	1
Embodied CO2 Convertion Factor	1

Interest Rate 01/11/2012, UK	0.5%
	1.005
Inflation Rate 01/11/2012, UK	2.2%
Lost work days per infection:	5.00
Lost work days per cancer:	24.80
GDP per capita	645.35
Life Expectancy	49.6

Table 19: Input Sheet for RUN 1XX

APPENDIX F: CASE RUN VISUALIZATION

F.1. COST CURVES

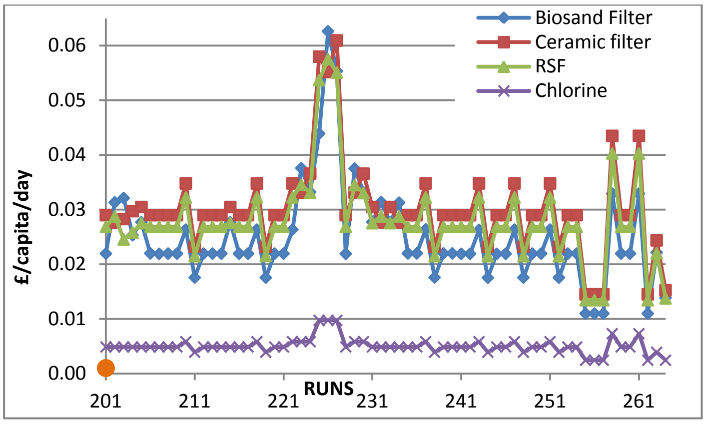

Figure 11: £ per capita per day vs. RUNS (Case B)

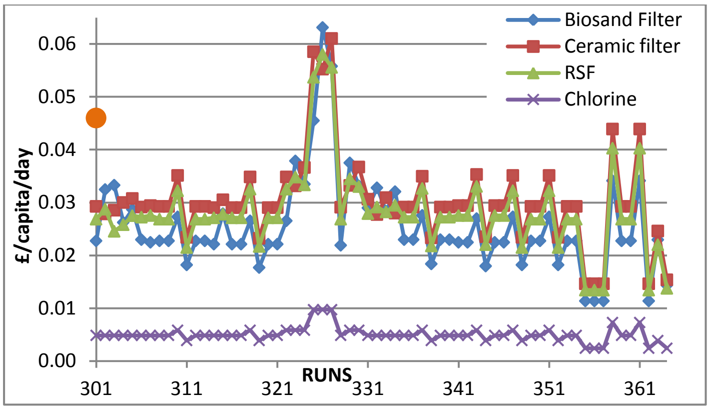

Figure 12: £ per capita per day vs. RUNS (Case C)

F.2. EMBODIED CARBON CURVES

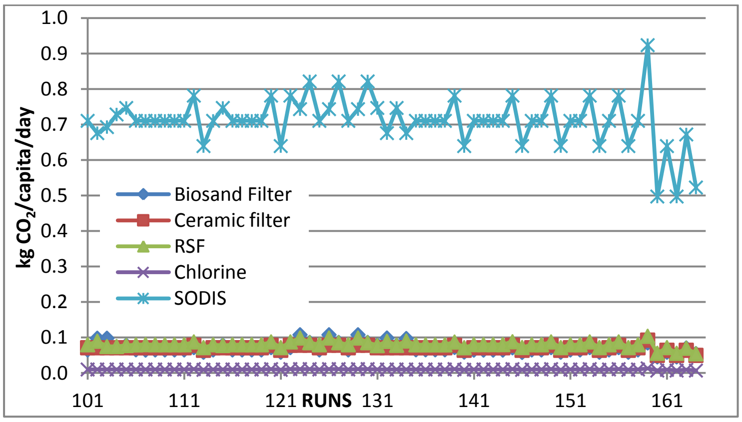

Figure 13: kg CO_2 per capita per day vs. RUNS (Case A)

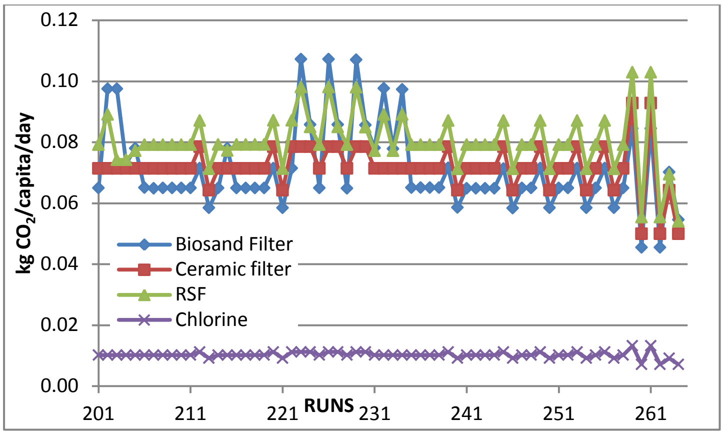

Figure 14: kg CO_2 per capita per day vs. RUNS (Case B)

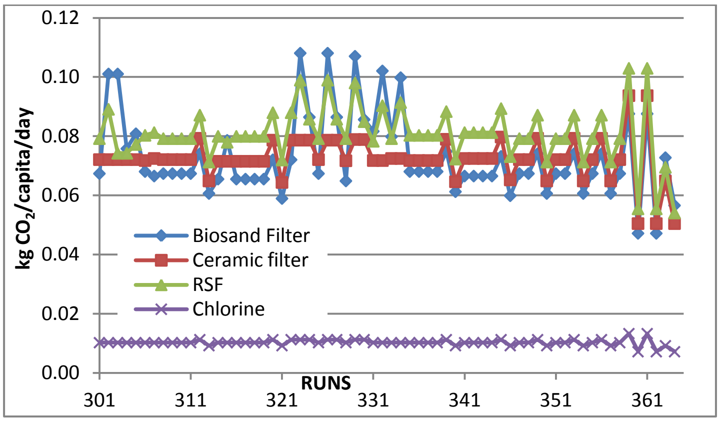

Figure 15: kg CO_2 per capita per day vs. RUNS (Case C)

F.3. RISK CURVES

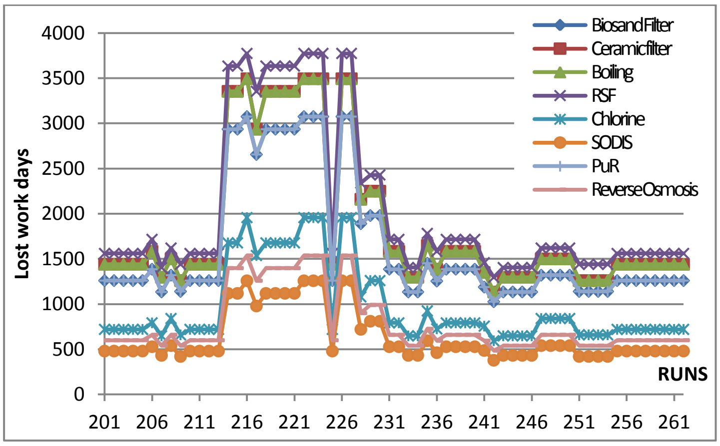

Figure 16: Total Work Days Lost vs. RUNS (Case B)

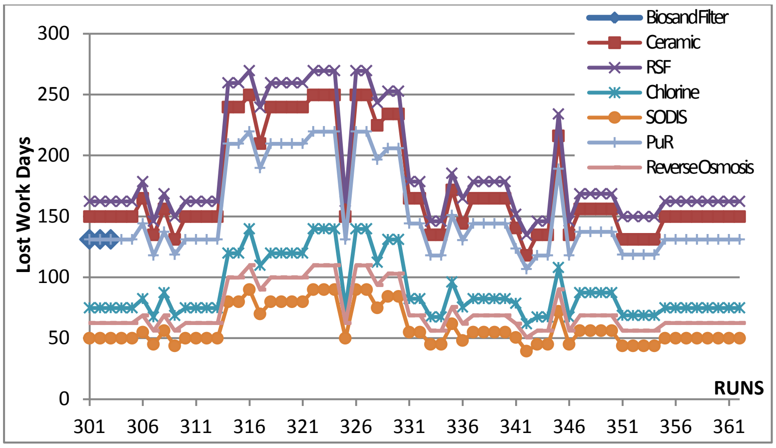

Figure 17: Total Work Days Lost (Case C)

APPENDIX G: ISOCURVES

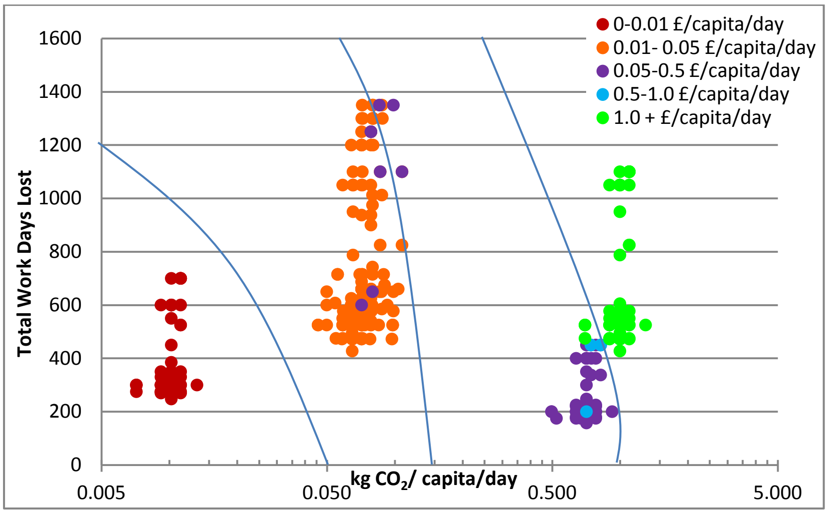

Figure 18: IsoCurve of Cost (Case A)

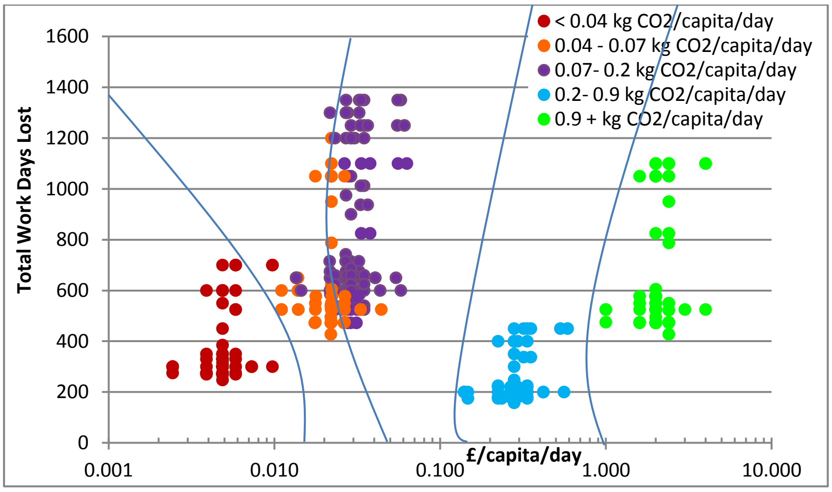

Figure 19: IsoCurve of kg CO_2 (Case A)

APPENDIX H: VALUED PRIORITY ANALYSIS

Aspects	(units)	Stakeholders				Technologies					
		Mother's Group	Head of NGO	Village Headman	KUC	BSF	Ceramic Filter	RSF	Chlorination	SODIS	PuR
Total Cost	£/capita/day	2	4	5	0	4	2	3	5	1	0
Total embodied carbon	kg CO2 /capita /day	0	1	1	3	4	3	2	5	1	0
Total risk	lost work days	5	3	2	2	3	1	0	4	5	3
Cost/risk	£/capita/day/lost work days	4	5	3	1	3	2	4	5	1	0
Embodied carbon/risk	kg CO2/ capita/ day/ lost work days	3	0	0	4	2	4	3	5	0	1
Cost/embodied carbon	£/kg CO2	1	2	4	5	5	2	4	1	3	0
		Mother's Group				**46**	**31**	**35**	**66**	**34**	**18**
		Head of NGO				**54**	**28**	**42**	**64**	**31**	**9**
		Village Headman				**59**	**29**	**45**	**57**	**31**	**6**
		KUC representative				**54**	**39**	**42**	**53**	**28**	**10**

Table 20: Valued Priority Analysis for Cameroon (Nikuv Scheme) with assumed priorities

Aspects	(units)	Stakeholders				Technologies					
		Mother's Group	Head of NGO	Village Headman	Local Govt.	BSF	Ceramic Filter	RSF	Chlorination	SODIS	PuR
Total Cost	£/capita/day	2	4	5	0	3	5	4	2	0	1
Total embodied carbon	kg CO2 /capita /day	0	1	1	3	3	5	4	2	0	1
Total risk	lost work days	5	3	2	2	3	1	0	4	5	3
Cost/risk	£/capita/day/lost work days	4	5	3	1	3	5	4	2	0	1
Embodied carbon/risk	kg CO2/ capita/ day/ lost work days	3	0	0	4	3	5	4	2	0	1
Cost/embodied carbon	£/kg CO2	1	2	4	5	4	0	3	2	5	2
		Mother's Group				**46**	**50**	**39**	**40**	**30**	**26**
		Head of NGO				**47**	**53**	**46**	**36**	**25**	**23**
		Village Headman				**49**	**47**	**48**	**34**	**30**	**23**
		Local Government Representative				**50**	**42**	**47**	**34**	**35**	**24**

Table 21: Valued Priority Analysis for an Arbitrary situation

Technical Abstract

According to Secretary-General Ban Ki-moon[1], 'water is central to the well–being of people and the planet'. In 2010, nearly 900 million people (84% in rural areas) were still lacking access to a convenient supply of safe water[2]. The concept of appropriate technology, as first described by Schumacher[3], is a simple and convincing argument where the most relevant and suitable technology to a particular situation needs to be implemented. Some inherent aspects of appropriate technology include being small-scale and decentralized. Currently decentralized water systems are an important aspect of growing populations around the world; in low-income and transitional housing in particular.

Therefore the aim of the project was to explore the process of choosing an appropriate small-scale water supply system for an individual house or small community with respect to economic, environmental and social aspects. For example, if a community with a population of *X* and a budget of *Y* required a water system where the quality of the source water is defined by stated parameters then the tool should have the capability to suggest an appropriate technology for the situation. Initially technologies that are immediately unsuitable can be eliminated with the aid of the technology review database.

Since no convenient database of technologies was available, a technology review database was created. Firstly a set of possible treatment technologies, known as candidate technologies, was identified and then information from sizing, production rates, efficacy and performance was accumulated from a wide range of sources and amalgamated into database to enable an effortless comparison between the technologies. To ease the process, quantative scales were created for some qualitative factors such as maintenance requirements.

This database was a crucial prerequisite for the subsequent creation of the agnostic tool, which is used to compare a range of possible water treatment technologies. For a particular location the tool computes values for £ per capita per day ($C_{P,T}$), kg CO_2 per capita per day ($E_{P,T}$) and total lost work days (L_P) for each technology over a range of situations; as defined by the inputs of population size, time period and source water quality.

The main feature of the tool is that the look-up tables allows the inputs be altered with ease to suit any situation. In addition if better data on initial assumptions, such as the number of lost

[1] World Water Day, 2013. *Cooperation for peace, prosperity and sustainable development.*
[2] WaterAid, 2011. *Sustainability Framework*, WaterAid.
[3] Schumacher, E.F., 1973, *Small is Beautiful.* Blond and Briggs.

days due to an adverse effect, values for material volumes of technologies or costs and embodied carbon of materials is found and incorporated into the model, its accuracy can be improved. The CamCam project, based in Cameroon, was chosen as a case study to investigate the functionality of the tool and a case matrix was devised to test its sensitivity, accuracy and reasonableness.

According to a recent report by WaterAid[4] (2011), there are many factors that contribute to the decision of an appropriate technology for a small community, and the most appropriate solution can differ from stakeholder to stakeholder due to varying priorities. Therefore a framework for carrying out valued priority analysis using the tool outputs was devised and used for the case study to rate the outputs of the tool, thus ranking the preferred technologies for each stakeholder. This illustrated how different priorities can lead to a preference of different technologies; there was however some overlap of the preferences thus showing that a compromise can be reached. The priority analysis was carried out on an arbitrary situation to demonstrate that the preferred technology differs with a change in the initial parameters of the situation as well.

The final step was to visualize the tool outputs into a design curve, various combinations were first attempted because some the distribution of the technologies did not easily lend to the formation of IsoCurves. Finally the technology points were plotted on axes of cost vs. risk with IsoCurves of kg CO_2. This plot allows the users to compare the economical cost, embodied carbon and associated risk of the candidate technologies for a particular location at specified input parameters.

The aim of the tool is to empower the Engineers and decision makers by providing a tool which quantifies their concerns while allowing them to adapt it to the local situation. The case study of CamCam was used not to find the most suitable solution for the three locations but to demonstrate how the tool can be used.

Although there are lots of potential technologies, the tool only calculates the outputs for the chosen candidate technologies; thus the initial candidate technology selection is a limiting factor and this is an area for future improvement. There is a potential to model livelihood generation because it's an important feature for some stakeholders.

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[4] WaterAid, 2011. *Sustainability Framework*, WaterAid.