ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

WATER SUPPLY AND ENVIRONMENTAL ENGINEERING MASTER OF SCIENCE PROGRAM

Development of a planning strategy for sustainable water systems using the Life Cycle Assessment a case of Ethiopian emerging town

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ABSTRACT

Purpose: the objective of this paper is to develop a planning strategy of emerging towns water supply system based on the sustainability assessment tool called Life cycle assessment (LCA). The analysis applied to one of the Ethiopian small town called Fitche ***Methods:*** the method utilized in this paper is fragmented life cycle assessment for each component of the water supply systems based on well-known EPD (Environmental Product declaration), simplified CMLCA tool and, excel tools. ***Result and discussion:*** after complete assessment of the small-town water supply system, the borehole water abstraction has more impact (45-50%) on the system than the stream water utilization, Using hydroelectric is much better (85-95%) than using the diesel pumps, Less mineral content of the borehole water treatment has less impact (5-10%) than treatment of the spring water, The water supply infrastructure developed at the very initial stage of design affects the environment, Pit latrine coverage of the town is significantly high, so it increases of the borehole water contamination level directly related with it,The absence of liquid waste disposal system is the main risk of the spring water contamination. . ***Conclusion***: in respect of the planning strategy; the results obtained from the LCA, which is basically from the most defined and relevant impact categories, known as GWP-CC (global warming potential and the climate change), nonrenewable energy source, and water consumption are good indicators of an emerging town water supply system impact. Therefore, it is essential to formulate the planning strategy of the water supply system of an emerging town based on carbon foot print and water foot print

Keywords: emerging town, life cycle assessment water supply system, planning strategy

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LIST OF ACRONYMS AND ABBREVIATION

AISUWRS	Assessing and Improving the Sustainability of Urban Water Resources and Systems Project
CHIAT	Chemical Hazard Identification and Assessment
DEPA	Danish Environmental Protection Agency
EOL	End of Life
EPD	Environmental Product Declarations
EIOA	Environmental input-output analysis (EIOA)
E/E	Eco-efficiency analysis
FT	Feasibility report
FU	functional unit
HCES	Household Centered Environmental Sanitation
LCA	Life Cycle Assessment
LCC	life cycle costing
MCDA	Multi Criteria Decision Aid
MDG	Millennium Development Goal
MIPS	Material intensity per service unit
MFA	Material Flow Assessment
MRA	Microbial Risk Assessment
NAIADE	Novel Approach to Imprecise Assessment and Decision Environments
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
SEESAW	Socio Economic and Environmental Sustainability Assessment of Urban Water Systems

SFA	Substance flow analysis
SMART	Simple Multiple Attribute Rating Technique
SWARD	Sustainable Water Asset Resource Decision
STRAD	Strategic Adviser
UAP	Universal Access Plan
URWARE	Urban Water Research Model
WS	Water Supply and Sanitation
TRACI	Tool for the Reduction of Chemical and other Environmental Impacts

CHAPTER ONE

1. INTRODUCTION

Despite its poor and largely rural population, and despite a historic legacy of low investment in infrastructure, Ethiopia has been making substantial progress in increasing water supply coverage. While achievement of the ambitious plan for universal access will be a challenge, reaching the water supply Millennium Development Goal (MDG) target looks achievable, irrespective of data source used. For sanitation, progress is also being made in increasing coverage through promotion of behavior change and low-cost technology solutions. The achievement of both government and MDG targets for sanitation appear less likely, but recent progress has been promising, on the back of a strong policy of increased promotion of hygiene and sanitation behaviour change.

The urban population in Ethiopia is increasing rapidly. If managed proactively, urban population growth presents a huge opportunity to shift the structure and location of economic activity from rural agriculture to the larger and more diversified urban industrial and service sectors. If not managed proactively, rapid urban population growth may pose a demographic challenge as cities struggle to provide jobs, infrastructure and services, and housing. The central challenge for the Ethiopian Government is to make sure that cities are attractive places in which to work and live, while fostering smart urbanization. Making urbanization a national priority will accelerate Ethiopia's progress towards reaching middle-income status. The government has already taken steps to make evidence-based, informed decisions for well-managed urban growth, and this urban growth shall be walk together with the basic infrastructure developments

1.1. Background of the study

Water supply is the most important sector of development throughout the world. Target 10 of the Millennium Development Goals states that to halve by 2015 the portion of people without sustainable access to safe water supply and sanitation. Studies and findings state that the water supply coverage in Ethiopia is one of the lowest in the world, which is about 39.4 percent. *(Ethiopian Economics Association 02, 27, 2013*.

Water supply scheme in Ethiopia has been growing with respect to the growing enormous population from time to time. Ethiopia achieved the MDG 7c target on the access to drinking water supply in 2015. Accordingly, over 52 million people in Ethiopia have access to clean and safe water, compared to only 6 million people in 1990.Next to this achievement, failure of the implemented water supply infrastructure, lack of provision, insufficient water supply, and uneven distribution has reported in recent study reports, among several reasons rapid urbanization and the fast formation of emerging town in the country.

The government of Ethiopia in 2006 has adopted a Universal Access Plan (UAP) to achieve 98% access for rural water supply and 100% access for urban water supply and sanitation by 2012. The cost was estimated at USD 2.5bn. During the first phase until 2012 the focus is on affordable and appropriate technologies and service standards. The rural areas have been set with consumption of 15 litter / capita / day with a catchment radius of 1.5km and the urban areas have been set with consumption of 20 litter / capita / day with a catchment radius of 0.5km. *(Wikipedia 2010, refe. water supply in Ethiopia)*

Water supply planning policy in Ethiopia is targeted to develop the appropriate water supply planning parameters, design criteria and standards along with acceptable, desirable and permissible ranges and limits.

The water supply scheme in Ethiopia has encountered massive challenges such as: sustainability of water supply scheme, lack of financial and skilled person, poor cost recovery, poor absorptive capacity and so on.

To address and alleviate the above challenges and reflected problems, it is essential to develop a sustainable water supply planning strategy. To develop more sustainable water supply planning strategy, there is a need to systematically evaluate water supply systems. Life Cycle Assessment (LCA) is one of the methodological tools that have proven strength to provide quantitative analysis result from “Source to Tap” approach. LCA has been widely applied to evaluate existing water systems and to propose alternatives and sustainable practices. In addition to that, it is useful as an information tool for the examination of alternative future scenarios for strategic planning.

Developing a life cycle assessment for emerging town's water supply system involves making methodological decisions about the level of detail which is retained through different stages of the process. In this study it will be tried to discuss and apply the methodology to strategic planning of which holds a high degree of model segmentation in order to enhance modelling of a system from Source to Tap.

1.2. Statement of the problem

The water supply provision in Ethiopia has changed significantly in the last decades. The water supply investment particularly in water supply has increased from approximately ETB 1.19 Billion in 2005 to ETB 2.0 Billion in 2015. However, those who benefited from the investment are facing the problem of sustainability of the implemented water supply system. One of the main challenges fronting the sector is weak system coordination in planning, implementation and monitoring. The water supply system has significant potential for the development of the emerging towns due to the exiting policy environment. However, practical challenges bottlenecked the sector and progress on main priority sustainability has been slow.

Researches done so far assessed and evaluated different aspects of small and emerging town's water supply systems in Ethiopia. Issues like, sustainability challenges, determinant factors, functionality rate, project performance, level of service evaluation, and similar issues discussed in one and another form in shallow and deep ways. However, the contribution of those studies towards the development of planning strategy is limited.

Water supply planning in Ethiopia is facing many challenges and limitations: The major ones include the deprived application and implementation of appropriate planning methods and parameters for the supply scheme including the per capita consumption rates and the service provision radius. The lack of consistent and appropriate design criteria, standards and engineering modalities can also be considered as the limiting factors for water supply planning throughout the country.

1.3. Objectives of the study

1.3.1. Principal Objective

The main objective of this M.Sc. study is to develop a sustainable water supply system planning strategy built on life-cycle assessment for selected emerging towns in Ethiopia. The study is based on comparison of the installed water supply systems in emerging towns of Ethiopia **(one small town)** in the past ten years from an LCA perspective. The LCA considers the stages of collection, treatment and distribution of potable water through the emerging town's network and the utilization of water also in consideration. The results of this study will provide a general recommendation on sustainable water supply planning strategy.

1.3.2 Specific objectives

- Examine the applicability level of LCA to the emerging towns water supply system
- List or identify the basic components of water supply system for LCA analysis
- Contextualized water supply system data Source to Tap = “cradle to grave” for emerging town and preparation for LCA process
- Utilization and application of LCA

1.4. Research questions

In order to achieve the above mentioned research objectives and seek answers for the stated problems, the following major research questions were designed

1. What is a typical characteristic of emerging town’s water supply system?
2. What is sustainable water supply planning strategy?
3. What are the strengths and weakness of applying life-cycle assessment for carrying out a sustainable water supply planning strategy? (This is evaluated by considering water systems of emerging towns)
4. How is the sustainable water supply planning strategy integrated with the life-cycle assessment methodology?
5. How are the LCA results combined with the other aspects of water supply system sustainability in order to identify the most sustainable alternative for water supply in emerging towns of Ethiopia?

1.5. Scope and limitation of the study

The study is scoped with planning strategy for sustainable water systems for the emerging Ethiopian small towns.

1.6. Significance of the study

The finding of the study will serve as an input for development of a planning strategy for emerging town’s water supply system. Besides, the study may also be utilized by the later researchers intending to work on the same subject or in the same study area. Moreover, this study will be a guideline for designers and engineers of this area in which regulation and policy of water management works takes place.

CHAPTER TWO

2. LITERATURE REVIEW

There is a range of different types of support for planning theory found in the literature. Some are presented as strategic planning methodologies which can be defined as long-term planning approaches that should reach overall goals. Some are more concrete models and terms of references for planning WS-projects. Yet others are frameworks that can be seen as an approach for viewing the structure of the issue in a holistic way. Finally there are toolboxes that are collections of different types of tools which can support the planning in various ways.

2.1 Urban Water Supply-An Overview

Urban settlements by their very nature need a minimum of basic services for their healthy existence. Of all the shelter and environmental issues facing cities in developing countries the provision of adequate quantities of clean and affordable water is the most fundamental need *(Bidyut Mohanthy, (ed), 1993, p.3).* Safe drinking water supply is a vital human need for health and efficiency. Disease and death particularly of children every year and drudgery of women are directly attributable to lack of this essential service. Water supply is a necessary part of the infrastructure required to attain the goals of social and economic development. Water supply is a public good because of its interrelationship with health status *(Logan, John, 1960, p. 475).* The development literature abounds these days with statements that reflects the gravity of water crisis as it exists or that may arise in the foreseeable future in many countries, regions and urban areas. However the state of most of Ethiopian urban areas in this respect is far from satisfactory. However various aspects of urban Ethiopian are being paid more attention both by policy makers and academicians. One such issue is related to access to water in urban Ethiopia Moreover the distributional and consumption variation are more acute and visible in the case of urban drinking water supply.

2.1.1 Components of Urban Water Supply System

The water supply system possesses the following components.

(A). Source of Water supply: This includes quantity and quality of various sources of water, collection of water and its conveyance from the source to the town. A naturally clean water supply needs a clean water source.

(b). Purification of Water: This covers physical, chemical and bacterial treatment of raw water. Regardless of the quality of raw water, desired quality of effluent needs to be produced by suitable treatment methods. Chlorine residual keeps down the bacterial growth.

(C) Transmission and distribution system: This includes storage of treated water, its conveyance, distribution and prevention of wastage. The aim of any water supply system is to provide potable water to the consumers. The benefit of the system is available to the public only when they get adequate quantity of water at sufficient pressure at their points. This is achieved through the distribution system. The purpose of the distribution system is to convey fulltime water to the consumer at convenient points. Water reaches the consumer through his house connection pipes, which is connected to the street mains, which itself form a vast net work of pipelines called trunk mains, branch mains, sub branches, street mains etc. The distribution system forms the most expensive component of any water supply. It is also the link between the consumer and the water distribution agencies. The distribution system consists of a network of pipes of varying diameters with several valves, meters and appurtenances connected to it. It may also have intermediate sumps, break pressure tanks, standpipes etc. connected to the same. The numerous stand posts also form part of the distribution system.

2.2 water supply planning theory Techniques available for assessing sustainability

2.2.1 Multi-criteria analysis (MCA)

The term “multi-criteria analysis” describes a suite of techniques that are used for ranking options across a defined set of criteria. It is also used as a general term for assessments that utilize such techniques. The weighting techniques integrate different criteria by assigning relative importance to criteria in the decision–making process. Various ways of carrying out this valuation or allocation of relative scores are possible.

Many weighting techniques exist for MCA which means that it may be difficult for a decision maker to choose the appropriate technique or that a certain familiar technique is always chosen. Different techniques vary with regard to the way criteria are incorporated, the application and weights, the mathematical algorithms used, the framework used to describe preferences, the level of uncertainty embedded in the process and the opportunity for stakeholders to participate *(Dodgson and Spackman 2000).*

From the suite of MCA techniques three broad approaches can be identified. These are: the value-based or additive score approach, the goal or reference point approach and the outranking approach. The preference structure required for each of these MCA approaches varies *(Stewart 1992).* This means there are differing requirements for how preferences between criteria need to be expressed.

A value-based approach to MCA produces an additive score for each option based on criteria weightings. At its simplest, each option is scored in relation to each criterion, and these scores are multiplied by predetermined single factor weightings. The weighted scores are then added up. With this approach, there is an implied internal 'currency' to the analysis and that each unit of this currency is of the same value. This structure can easily result in problematic assumptions regarding the equivalence of certain trade-offs embedded within the analysis *(Stewart 1992).*This issue remains even when simple linear weighting is replaced with more complicated weighting functions.

The goal or reference point approach is based on the decision-maker specifying a goal or desired level for each criterion. It also requires the criteria to be ranked on importance. Linear programming can then be used to sort options in sets that meet or come closest to meeting the maximum number of criteria *(Stewart 1992).*

Variations on this approach include setting ideal and lower limit or constraint levels for each criterion. A process of goal setting, option analysis and goal refinement is a common feature with this approach. The outranking approach takes into account indifference and preference thresholds and bases option rankings on outranking relationships. These relationships set out which of two options is preferred and why. The ELECTRE tool is commonly used to conduct MCA based on outranking *(Stewart 1992).* The tool uses concordance and discordance indices to represent the arguments for and against a particular ranking relationship. This approach is most useful for gaining insight into preference structuring *(Stewart 1992).* The outcome of an MCA will obviously be dependent on the weighting technique chosen and the preferences or weightings expressed. However, potentially more important for the outcome of an assessment employing MCA will be the actual criteria that are chosen.

2.2.2 Life cycle assessment (LCA)

Life cycle assessment is a framework for examining the biophysical impacts resulting from a product based on an analysis of the material flows that are generated *(Miettinen and Hamalainen 1997).* Life cycle assessment can also be allied to a process or service. The term 'life cycle' refers to the analysis including all stages of a product's life from 'cradle to grave' including: the manufacture, usage, and decommission of all components. It is the consecutive and interlinked stages of the production system, for the product, process or service, from the extraction of natural resources to the final disposal.

The key techniques in LCA are inventory analysis and impact assessment. Inventory analysis entails defining the system and developing a material account detailing all significant material and energy flows crossing the system boundary *(Miettinen and Hamalainen 1997)*. Impact assessment involves aggregating the inventory data into impact categories. Material flows are given relative impact scores related to each category. The standardized LCA methodology includes impact classes: Abiotic and biotic resource consumption, global warming potential, ozone depletion potential, ecotoxicity, acidification precursors, photochemical oxidants and nutrients *(SETAC 1992).* Pollutants are aggregated based on equivalency potentials (i.e. for global warming potential, one kilogram of methane is considered equivalent to 22 kilograms CO2) Impact assessment aims to provide an understanding of the magnitude and significance of material and energy flows in terms of potential environmental impact.

While equivalency potentials may provide a reasonable indication of global warming or ozone depletion potential, the aggregation of other material flows based on relative impact, for other effect categories is more problematic. In particular assuming linear equivalencies for the impacts of aqueous pollutants is less realistic. Site-specific issues are also not addressed in LCA and this means that the potential for pollutants to exceed threshold limits at specific sites will be missed within the standard LCA *(Potting, and Hauschild 1997).* Similarly, data on temporal variation in emissions is not collected within an LCA inventory. This means that if chemical toxins were a potential issue, then ecological risk assessment techniques would need to be used in conjunction with LCA.

2.2.3 Cost benefit analysis

Like MCA, Cost-benefit analysis is an integration method that can be used to address issues across both the biophysical and socio-economic spheres within a single analysis. Unlike MCA, however Cost-benefit analysis considers only the one criterion, monetary value, with respect to all issues *(Soderbaum 2000).* In Cost-benefit analysis the multiple consequences of a certain action are transformed into a single measure, the ratio of monetary cost to monetary benefit. As many issues affecting the sustainability of urban water are not directly measurable in monetary terms, externality costing techniques are used to find proxy values so these issues can be included in the analysis.

Cost-benefit analysis involves estimating the stream of future costs and benefits in monetary terms and discounting these back to present values based on a predetermined discount rate *(Hanley and Spash 1993).* The outcome is expressed in terms of a present value net benefit or cost, or more commonly as the ratio of the benefits to costs (a ratio greater than one means that a proposal is economically viable). Cost-benefit analysis aims to provide a 'whole of society', economic perspective, including all externalities and excludes all transfer payments. Cost-benefit analysis has a long history as a means of determining the relative merits of infrastructure proposals. Since the 1930's it has been a requirement for particular federally funded water resource projects in the United States *(Hanley and Spash 1993).* Significant methodological advances have occurred in the past 70 years with Cost benefit analysis now routine in many Government decision-making forums.

Externalities are impacts on economic agents caused by economic activity that are not paid for or internalized in the market place *(Bowers 1997).* They can be either positive or negative in effect. Although not accounted for in the market place, externalities are 'market-derived' monetary values. Estimating the value of an externality relies therefore on techniques that can derive the value from some other existing market, or from a hypothecated market.

There are three groups of techniques for externality costing; alternative market valuations, revealed preferences, and stated preferences. Alternative market valuations are possible where actual markets for the impacts exist in other locations. Revealed preference techniques include hedonic price and travel cost *(Pearce and Turner 1990).*

These methods infer a value for the externality from observations of expenditure on other goods and services. Analysis of the impact of aircraft noise on house prices, or the willingness of people to spend time and money getting to wilderness areas are classic examples. In contrast to alternative market and revealed preferences techniques, stated preference techniques such as contingent valuation rely on hypothetical markets. The 'markets' created in contingent valuation are questionnaires which ask people to stated their willingness to pay or willingness to accept monetary payment for particular outcomes *(Pearce and Turner 1990).* Such surveys aim to determine how respondents would react in postulated hypothetical market situations that include or avoid the given externality. Significant problems exist with contingent valuation and the validity of these techniques has been questioned from various perspectives.

Corresponding with the assumption of 'monetary reductionism' is the linked assumption that all issues or impacts can be discounted back to their present value. This assumption is deeply problematic in terms of intergenerational equity and for people concerned with ensuring longer term sustainability because it means that even catastrophic impacts in the longer term would be given little value in current cost-benefit calculations.

2.2.4 Cost effectiveness analyses

Cost effectiveness analysis is used to compare alternatives that each gives the same benefit, in terms of the monetary outlays involved *(Hanley and Spash 1993).* It differs from cost-benefit analysis, in which the (monetary) costs of a proposal are compared to the monetary benefits that would arise from that proposal. Cost effectiveness analysis is then a technique for assessing options on relative cost rather than an assessment of whether an option is economically beneficial in its own right. Cost effectiveness analysis of a particular infrastructure or other asset is also known as life cycle costing. As with standard cost effectiveness analysis, life cycle costing enables cost comparisons on a common basis over a given period.

Cost effectiveness analyses most commonly compares the present value cost of alternatives. The present value cost of an option is the value of the stream of future costs associated with that option, discounted back to current monetary values based on a predetermined discount rate *(Hanley and Spash 1993).*

A second technique that can be used in cost effectiveness analysis and accounts for the time value of money is annualized costing. Annualized costing is regularly used in engineering cost analyses to spread the initial capital cost across the lifetime of an option. The cost of capital is ‘annualized’ as if it were being paid off as a loan at a particular interest or discount rate over the lifetime of the option. The result is a future value cost or constant annual cost of capital. This capital cost added to estimates of annual operating cost to give a cost per year of the option. The requirement for option costs to be broken down into only two fractions, capital and yearly operating, poses a problem for costing some options which have a more variable stream of costs over time.

The cost effectiveness technique can be used in either economic or financial appraisals. When planning urban water infrastructures, a financial analysis of option costs from the perspective of the utility is likely to be at least a consideration. For an assessment of sustainability, the economic perspective of the whole of society, as well as the financial perspective of other stakeholders, will also be important. For an economic perspective, cost effectiveness analysis ought to include all costs for an option on which a monetary value can be placed *(Pearce and Turner 1990).* This includes costs derived from both actual and hypothetical markets to all economic entities.

2.2.5 Multi-criteria integration techniques

The multi-dimensional nature of sustainability means that the integration of non-equivalent criteria is required in any assessment of options for sustainable urban water. Techniques for integration do exist, however with most techniques criteria weighting is involved and the various techniques apply significantly different logic to this process. This section first details life cycle assessment and then the various sustainability indices. Such techniques focus on the aggregation of impacts from material flows and are therefore only addressing the biophysical aspects of sustainability. Integrating across the spectrum of sustainability criteria requires aggregation techniques that are within the socio-economic sphere and the section briefly reviews both Cost benefit analysis and Multi criteria analysis.

2.2.6 Chemical risk assessment

Chemical risk assessment involves the analysis of the risks posed by chemicals to human health. It is a similar technique to quantitative ecological risk assessment in that doses are estimated and impacts are assessed through known dose-response relationships. As toxic chemicals can cause both acute and chronic illness in human, each of these types of exposures needs to be addressed within a chemical risk assessment *(Rhomberg 1997).* Through the process of chemical risk assessment, the routes by which chemicals come into contact with people are identified and amounts of possible be exposure are estimated. This involves either measurement or prediction of duration and intensity of the exposure. The effects of exposures on human health are then assessed through chemical specific dose response functions.

2.2.7 Technical risk assessment

Technical or engineering risk assessment involves various techniques that have been developed to assess the potential for infrastructures to fail. They are used to determining or predicting the probability, mode, and location of system failure *(Sundararajan 1991).* Failures can impact on range of issues from a systems reliability of service provision to vulnerability particular infrastructure options to catastrophic disaster. Beyond the direct impacts of system failure, technical risk assessment also provides a link for the impacts of failures to the system-environment of urban water. A technical failure in an urban water infrastructure may cause significant ecological, public health and socio-economic impact or risks. The range of potential sustainability issues that can be addressed by technical risk assessment and technical risk assessment in combination with other risk techniques is shown in table 1 below.

Techniques for technical risk assessment include probabilistic models, fault tree analysis, failure modes and effect analysis, and critical component analysis. As with ecological risk assessment both qualitative and quantitative assessments are possible *(Sundararajan 1991).* Fault tree analysis is probably the most widely used technique for technical risk assessment. It is a procedure for determining the combinations of events or component level failures, which could lead to a significant system level event, or catastrophic failure *(Sundararajan 1991).* The fault tree is a logic diagram constructed from 'and gates' and 'or gates' which link events at the component level. A fault tree may be analyzed qualitatively if data or estimates of component failures do not exist. More commonly, fault trees include quantitative estimates of the probability of reliabilities and give outcome of probable failures in quantitative terms.

Sustainability Issues	Potential risk assessment methods
Local toxic impact on aquatic ecology from accidental spill	Technical risk assessment and Ecological risk assessment
Health impacts of chemical pollutants in recycled water	Technical risk assessment and Chemical risk assessment
Individual waterborne infection from system	Technical risk assessment and Microbial risk assessment
Protection of public health	Technical risk assessment and Microbial risk assessment
Maintained provision of urban water service	Technical risk assessment
Vulnerability of system to sabotage or terrorist outrage	Technical risk assessment
Avoidance of disastrous fires	Technical risk assessment

Table 1 Sustainability issues for urban water addressed by technical risk assessment

2.2.8 Sustainability indexes

A number of 'sustainability tools' or indices have been developed that aggregate biophysical sustainability criteria into a single score. *Hertwich et al. (1997)* identifies three main techniques for aggregating material accounts and then cites examples of each. These examples are: the Swiss eco-points framework, the Sustainable process The Swiss eco-points framework ranks all pollutant releases due to a process or product based on the proportional contribution that the source makes to the total load of that pollutant or resource use in terms of Switzerland as a whole(Hertwich *et al.* 1997).

Similar frameworks have been developed for other countries, such as Sweden. In the case of Swiss eco-points, total acceptable pollutant loads for Switzerland are estimated and all resources are ranked in terms of predetermined 'scarcity factors'. The Sustainable process index is a framework that estimates the area of land required to operate a given process sustainably, assuming that only renewable resources are used and certain land areas would be needed if total toxic degradation or dilution were to occur *(Hertwich et al. 1997).* Similar to the sustainable process index but including further criteria, Ecological Footprint calculations also convert material and energy inventories into land areas. To these area estimates are added land use estimates and estimates of the area of land disturbed by various processes. This then gives a single area in hectares *(Wackernagel and Rees 1996).*

The Environmental priority framework is a Swedish technique which derives values for impacts from environmental economics and eco-taxation rates *(Hertwich et al. 1997).*How an economically based ranking of impacts improves on standard economic analysis such as Cost benefit analysis is however difficult to appreciate.

Although useful for general illustration and to highlight the miss-match between modern industrial economies and the goal of biophysical sustainability, there is a significant danger when single-point indicators of sustainability are used in decision-making *(Costanza 2000).* Because these techniques integrate multiple, disparate and complex impacts into seemingly simple outcomes, decision-makers may use the results without questioning the source of the numbers or the aggregation assumptions involved. Different indexes can also give significantly different results. The usefulness of any single index alone for making appropriate planning decisions for sustainable urban water is therefore restricted. .

2.2.9 Microbial risk assessment (MRA).

Drawing on the structure of chemical risk assessment *Craun et al. (1996)* developed a conceptual framework for quantitative microbial risk assessment (MRA). Microbial risk assessment involves an analysis which aims to quantify the disease risk associated with exposure to pathogenic microorganisms. Established dose response functions are used to estimate the level of risk from an exposure in terms of a probability of infection. Dose response functions represent the relationship between the number of pathogens consumed and the likelihood of infection. These functions are species specific having been established empirically through feeding studies. The data from these studies was found to best fit various sigmoidal equations when plotted as the relationship of log pathogen numbers ingested to likelihood of infection *(Buchanan, et al.2000).* In order to assess the risk of infection due to exposure to a source of pathogens, either a measured or an estimated concentration of pathogens and an estimate of exposure volume is required. Estimated pathogen concentrations can be expressed as a probability distribution.

Whole-system MRA is developed for application in the assessment of alternative sustainable urban water systems in terms of the likely impacts from waterborne pathogens on the communities served by these systems. In the methodology described, Monte Carlo simulation is used to give probabilistic outputs of pathogen risk from urban water systems.

2.2.10 Biophysical techniques

Quantitative modeling and analysis of material and energy flows and balances are the basis for a suite of assessment techniques. These methods model the inputs, outputs and accumulation of the physical constitutes including energy carriers through a defined system. *Kärrman (2000)* described these types of analyses as ‘environmental systems analyses’. Material and energy balance methods can focus on the movement of masses, volume, or metrics of energy and energy dispersion such as energy.

Other techniques, which have application in assessing the biophysical impact of urban water infrastructures, also exist. In particular, ecological risk assessment, a technique that may be used in assessing the potential impact of pollutants on non-human species and ecosystems, is outlined in this sub-section.

2.2.11 Material flow analysis (MFA)

Material accounts of economic activities can be traced back to 'tableau' models of the French economy made by Quesney in the 18th century *(Ayres 1998).* Input-output economics however limits analysis to material flows that follow economic transactions. *Kneese et al. (1970)* are probably the first to articulate the idea of tracing all materials flows generated in an economy, through society by applying a mass balance.

Brunner and Baccini (1991) in relation to their 'metabolism of the anthrop sphere' concept detail a tool for environmental management based on mass balance, which they call material flux analysis. This method, now more commonly known as substance flow analysis (SFA) *(Udo de Haes 1998)* involves modeling estimated flows of particular elements or substances, such as cadmium, chlorinated hydrocarbons or phosphate, generated by human activity. Flows are seen to come from the lithosphere and ecosphere, travel through the anthrop sphere and back into the ecosphere, forming stocks at particular points. Natural stocks are depleted; anthropogenic and 'unnatural' acrogenic stocks are built up while other materials are dispersed. Flows and stocks can then be compared to sustainable levels or at least pre-industrial equivalents.

Estimations of total material flows have also been described *(Schmidt-Bleek 1993).* These models compare options in terms of total material movement or material intensity per service unit (known as MIPS). The term 'material flow analysis' (MFA) covers the family of mass balance techniques including SFA, MIPS and water balance, which analyze flows and accumulation of materials through the physical economy and its environment *(Udo de Haes 1998).* This spectrum of techniques covers from individual elements to total material movement.

2.2.12 Energy balance and Energy analyses

Similar to materials accounts, energy balances are possible. Since the 1970s, such techniques have been used to analysis energy supply systems *(Ayres 1998).* Energy balance techniques can show the relative energy intensity of alternatives. Energy balance modeling is also important in assessing the greenhouse impact of options.

Energy has been proposed as a unifying metric for analysis of the consumption of physical resources *(Ayres et al. 1996; Connelly 1998).* Energy is a measure of the changing entropy of a system and is the useful part of energy which is available to do work. Energy is consumed or lost as a system becomes more entropic, that is it falls to a lower energy state. Energy dispersion can be estimated thus giving a single metric of the physical resources consumed by the system *(Connelly 1998).* An energy analysis of pollution releases is also feasible *(Seager and Theis 2002).*

Energy analysis cannot, however, account for some important aspects of resource usage such as whether renewable or non-renewable sources have been utilized *(Hellström 1997).* Likewise, for pollution the relative toxicity of emissions and therefore their ecological impacts are not accounted for in energy analysis. For an assessment of the sustainability of a system, further analyses beyond energy analysis are required *(Hellström 1997)*

2.2.13 Ecological risk assessment

Risk analysis involves identifying a potential hazard and then assessing both the probability of that hazard occurring and the severity of the consequences of that occurrence *(Standard Australia 1999).* Urban water systems can pose potential hazards on a number of fronts. A wastewater system, for example, creates a risk from human exposure to treated and untreated sewage, technical risks of system failure, and various risks to the environment from the discharge of pollutants or accidental spills.

In situations where multiple events with known probabilities result in a hazard, risk can be estimated quantitatively using probabilistic simulation. Quantitative ecological risk assessment provides a statistical estimate of adverse effects on a target organism or group of organisms from exposure to a particular pollutant. The assessment of exposure is based on known dose response function. It involves determining if there may be a threat to ecological health, through identification of exposure pathways; measurement or prediction of duration and intensity of the exposure and calculation of the harm resulting from the predicted/measured doses of the chemical based on a dose response function. Exposure pathways may be ongoing and routine, such as effluent released from a wastewater treatment plant or the result of an accidental, unintended release. The latter will also require assessment of the technical risk of such an accident occurring.

Quantitative risk assessment is not always practical feasible. Where obtaining quantitative data is not possible, qualitative methods are commonly used. The basis for qualitative assessed is often a risk matrix with consequence and likelihood compared. Qualitative forms of risk assessment can be used to compare a range of possible risks or to priorities where more detailed analysis is required. This is true for ecological as well as other forms of risk assessment.

In general, where quantitative techniques have been applied in the assessment of the ecological risk from urban water systems, this has involved the impact from a particular toxic compound released into the environment of specific organisms. Quantitative risk techniques can, however, also be applied to nutrient releases *(Constable et al. 2003)* and to impacts from compounds on whole local ecologies *(Rand and Newman 1998).*

2.2.14 Socio-economic techniques

Quantitative modeling and analysis exist for only a limited range of socio-economic criteria. Engineering or technical risk assessment can be used to estimate the quantitative risk of failure for alternative system options. While an analysis of a physical system, this allows the subsequent impacts on continuity of service provision and potential for release of hazardous materials to be assessed. In the latter case, risk assessment techniques can analyze the human health impacts from exposure to hazardous materials. Quantitative techniques exist for both chemical and pathogen risks.

A principal socio-economic technique is cost effectiveness analysis *(Hanley and Spash 1993)* and this is reviewed. Also covered is end-use analysis and modeling. This technique involves the detailed analysis and modeling of a utility supply (water or energy) in terms of the individual services provided.

Importantly, some socio-economic criteria such as user and institutional acceptance and institutional capacity, cannot be accessed through solely via modeling and analysis.

This means that a fulsome assessment of sustainable urban water is likely to incorporate quantitative criteria together with the aspects that can be addressed through the qualitative techniques presented here.

2.2.15 End-use analysis and modeling

End-use models specify in detail how water is utilized and predict the future demand for water services *(White 1998).* End-use models provide more accurate demand forecasts than trend-based demand models due to the detail included *(Greenberg and Harshbarger 1993).* Critically, end-use models allow accurate prediction of the conservation potentials for demand management options.

End-use modeling builds a base-case of service demand from the end-use analysis data, stock data, demographic information and historic consumption. Authors such as Howe and White (1999) and Skeel (1999) describe detailed modeling which combine: in-depth fixtures and appliances stock modeling, multiple sub-sectors and end-uses, and disaggregated demographic information. Modeled demand is correlated to historical consumption data, bulk water production, and metered customer data by sector.

End-use analysis studies survey customers for their water-using appliances (toilets, showers and taps) and water use practices (frequency of bath and shower use, frequency of clothes washing). End-use studies can utilize market research data for large appliances (e.g. clothes washers) or through industry sales statistics provided by manufacturers. It can also involve direct measurement through sub-metering at the point of use *(DeOreoet al. 1996)* and the use of logbooks in which consumers record resource use behavior *(Darmody et al.1998)*. In all cases, the goal of an end-use analysis is to quantify the demand for water or energy in as disaggregated a manner as feasible. Non-residential sectors (commercial, industrial and institutional) are modeled at varying degrees of desegregation. Forecasts of changes between and within sectors are also included.

The picture of the stock of water using equipment is developed from replacement rates, sales data, and surveys of technical efficiencies. In-depth stock modeling, within end-use models, allows more precise design of demand management measures because appliance ages and efficiency profiles are known *(White 1998).* The demographic data incorporated in an end-use model includes regional and sub-regional population forecasts, housing stock, (dwelling type mix), occupancy (number of persons per dwelling), employment data, and information on land use *(White 1998).* .

2.3 water supply planning tools and practices

2.3.1 The Urban Water toolbox

The Urban Water Program was a research program that worked with the questions connected to sustainable water and wastewater systems. The researchers came from a range of different fields like engineering, microbiology, behavioral science and social science. In 2006 the program was transformed to the company CIT Urban Water Management *(Urban Water Program, 2007).*

For enabling and guiding the different work of the project, a conceptual framework was made.

The system was being regarded as having three sub-systems: users, technology and organization, Figure 1. The interactions between these were seen as essential for a functioning WS-system. Furthermore, five main sustainability criteria were chosen: health, environment, economy, socio-culture and technical function *(Malmqvist et al., 2006).* These are identical to the ones chosen in this research.

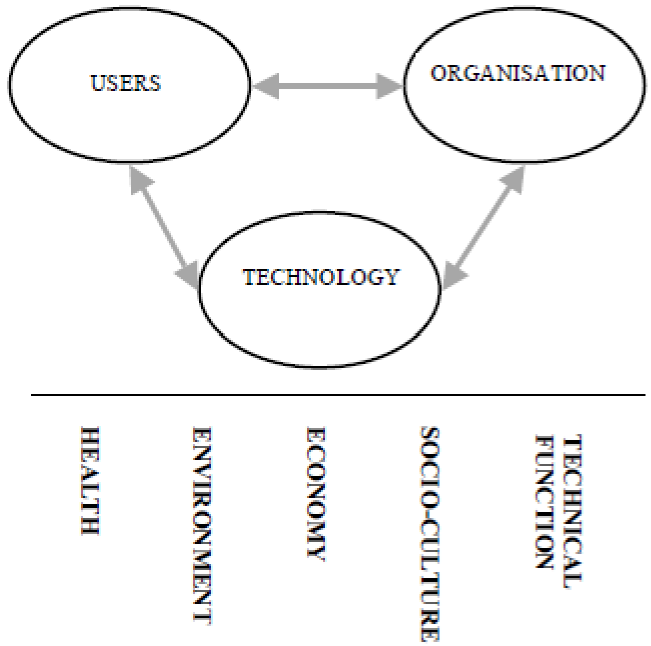


Figure 1: the Urban Water program conceptual framework

(Modified from Malmqvist et al., 2006)

Figure 1: The program has gathered the different tools into a toolbox. These tools are meant to enable the analysis of the central aspects of urban water services and the decision-making part of the planning process. For the environmental and natural resources issue two models are used: URWARE and SEWSYS. The former is a model for substance flow analysis and the latter models substance flow connected to transport and treatment in sewer networks.

For hygiene and health aspects the tools Microbial Risk Assessment, MRA, and Chemical Hazard Identification and Assessment, CHIAT, are used. The former needs data over time, place and frequency of human infections whereas the latter points out substances that can be a risk-factor for human health. For economic aspects the cost calculating database gives for example the total annual cost per: connected person, cubic meter of wastewater and kWh energy used. There are also a set of economic indicators for sustainable water management which considers the different interactions between users, organizations and technical structure. The socio-cultural set of criteria that are being used includes the existence of governmental and political support, a common worldview among stakeholders, access to awareness and capital and communication with users (ibid.).

The program also stresses the many aspects one will be confronted with when working with the sustainability concept. This can lead to complex decision-making and methods to make this possible can be valuable. The Strategic Choice Approach illuminates the problem with numerous uncertainties in decision-making as well as the difficulty with agreement when many stakeholders are involved. Therefore it can be a helpful tool when deciding in complex issues for example water and sanitation planning *(Söderberg & Kärrman, 2003).* As mentioned above this is a tool that also SWARD uses.

2.3.2. The Danish ministry of the Environment toolkit

The Danish Ministry of the Environment, the Danish Environmental Protection Agency, DEPA, Danish Cooperation for Environment in Eastern Europe, DANCEE and the European Bank for Reconstruction and Development (2002) has offered a toolkit for handling:

♣ the level of WS-service standard needed

♣ The future investments in WS-services needed

♣ The customers' requirement and willingness to pay i.e. affordability

♣ the political approval of financial structures

The toolkit is mainly aimed for east and central European countries but could with some adjustments be relevant for dense urban communities in the developing world i.e. suitable for emerging town's areas. The initiators of the toolkit stress the importance of demand analysis in all stages in an investment project to reach cost recovery and sustainability and the tools can be useful for all marketed water services *(The Danish Ministry of the Environment, 2002).*

The project cycle where the tools should be used is divided into the following parts: a project identification, a pre-feasibility step with investigation of the intuitional and regulatory framework, the budget and technical options, a feasibility step which should lead to recommended approaches for the issues studied in the previous step, an outline design, a detailed design and finally the project implementation. There is a set of tools made for the different objectives which can be viewed in Table 2.

Table 2: Tools designed for a set of categories considering different issues and suitable for different targets groups. (Modified from Danish Ministry of the Environment, 2002)

Tool category and target group	Tool
Approaches for considering service, technical solutions, demand and tariffs *Target group:* everyone who uses the toolkit	The integrated approach Proposed Scope of work for inclusion in Terms of Reference
Service level, technical profile and options *Target group:* experts within water utility planning	Establishing a technical, service and expenditure baseline The technical profile summary
Customer perceptions and willingness to pay *Target group:* consultants who are used to market research	Qualitative research approach Generic top guide Quantitative research approach Estimation of willingness to pay Generic example of survey design
Demand for water services *Target group:* the same as the previous category	Data requirements, statistical methods
Household affordability *Target group:* experts within water utility planning	Affordability assessments based on macro data: i. Household affordability (qualitative) ii. Tariff design and transfer
Political acceptability *Target group:* targets policy analysis experts	Analysis of attitudes of political parties Analysis of attitudes and assumptions Screening of key actors

Table 2 Tools designed for a set of categories considering different issues and suitable for different targets groups

The tools for surveying household affordability are explicitly recommended to be suitable in larger cities in the developing world as well. One way of analyzing affordability is to use macro-data such as average income, inequalities in income-distribution and the household's expenditure fractions between food, WS-services and other costs. When there is only little data available another approach is to carry out a household expenditure survey

2.3.3. The AISUWRS toolkit

Assessing and Improving the Sustainability of Urban Water Resources and Systems, AISUWRS, (*2007)* is an EU-project with the aim to develop modeling tools for planning and decision processes in urban areas which are dependent of groundwater as a water supply source. The research group behind the project is connected to the University of Karlsruhe, Germany. The toolkit includes a set of groundwater models for deciding contaminant quantities to ground water where the contaminants originate from sewers or other wastewater pipes. UVQ is an urban water volume and quality model, NEIMO is a network ex filtration and infiltration model, POSI and SLeakl are unsaturated transport models. The program has also constructed a decision support system for comparison between scenarios which focus on different types of improvement.

For environmental water sustainable analysis and socio-economic analysis a model named Socio Economic and Environmental Sustainability Assessment of Urban Water Systems, SEESAW, is used. The model uses a LCA approach for the environmental issues and uses environmental SIs considering groundwater (quantity, quality and protection), drinking water production (availability and efficiency) and consumption (sufficiency), wastewater treatment (leakage) and by-products (recycling).

2.3.4 SOFTWARE TOOLS

Software tools can enable the planning of WS-systems and are frequently used in the developed world. The Urban Water program, SWARD and AISUWRS, which are not focusing on the developing world, have designed or are using already existing software tools for the planning process. The applicability of these tools for this context will be examined as well if there is an actual need for them

Review of software tools

Urban Water is using Multi Criteria Decision Aid, MCDA, tools for the analysis of the different options. MCDA can be divided into five steps *(Söderberg and Kärrman, 2003)*

• *The structuring of the Decision-Making Situation:* How the problem is formulated and constructed is important for the outcome of potential options. Therefore the options and their following attributes that describes their characteristics should be defined in this step.

• *The preference articulation and modeling:* Here the decision-makers preferences must be taken into account for deciding the relative importance of the different attributes.

• *The aggregation of preferences:* In this step an evaluation on the whole set of alternatives is performed by including all attributes. This can be done in some different ways. One is to value the criteria according to their weight and then adding the scores for an overall value (linear additive model) or by using an outranking approach.

• *The exploitation of this aggregation:* The aim for this step is to investigate why some options are better accepted than others. A sensitivity analysis can be done for identifying the most significant attributes.

• *The recommendation:* This can be in the form of a ranking list or by a recommendation of the best choice.

The program uses for example the MCDA-tools method, Novel Approach to Imprecise Assessment and Decision Environments, *NAIADE,* and Strategic Adviser, *STRAD.* The former method starts with a pair-wise comparison of alternatives. The relations between two options can be stated as 'Is much greater', 'Greater', 'approximately equal to', 'and Very equal to', 'Less than' or 'Much less than'. Additionally a credibility index between 0 and 1 should be given to the alternatives. The method is based on participants reaching consensus. The STRAD method is also based on consensus-reaching and divides the planning into smaller decision areas. When combining them in different ways diverse system structures are presented which are weighted by the participants.

SWARD is also using MCDA-tools to enable the decision-making, where *PROMETHEE* and *SMART* are examples. The Preference Ranking Organization Method for Enrichment Evaluation, PROMETHEE, is an outranking method which evaluates the dominance of one alternative over another based on the stakeholders' preferences for certain indicators. The output is a suggestion for the best option available. This tool is highly mathematical and it can be difficult for the user to understand the functions behind. Simple Multiple Attribute Rating Technique, SMART, may be easier for the user to understand and requires less specialist competence. This is not an outranking method but a weighting method and does not present one option but a set of feasible options. The weighting should be done during a discussion among decision-makers *(Asheley et al., 2004).*

For gathering information about the environmental aspect of the options SWARD uses a LCA software tool named *SimaPro* using EcoIndicators99. Life cycle assessment is a method for analyzing environmental impact 'from cradle to grave' of different products or systems. This can be helpful for comparing possible alternatives' impact on different environmental issues like global warming, eutrophication and acidification. The tool helps the user to construct a process structure for a basic LCA and can enable the handling of the big amount of data since it provide the user with a database named Ecoinvent which covers 2500 processes *(Pré Consultants, 2006).* Another life-cycle assessment method, though not recommended by SWARD, is the Tool for the Reduction of Chemical and other Environmental Impacts, TRACI, produced by the US EPA. The tool can be used for evaluating the environmental and human health impact of a system. Categories used are acidification, eco-toxicity, eutrophication, global warming, human health (cancer, criteria pollutants and non-cancer), land-use, smog formation and water-use. Data needed are site specific data about material components of the systems *(Kirk et al., 2005)*

For studying technical and hydrological aspect SWARD recommend using *AQUATOR* which is a water resource system model for both natural river systems and water supply networks and using *InfoWork* for identifying cost effective infrastructure improvements. These are mainly applicable for networked WS-systems and need a great amount of data as well as expert competence.

The MFA tool can be used for identifying central material flows, quantify mass flows, identify weak points in the system and evaluate scenarios. When using it in emerging town's areas in Hanoi, central risk aspects found were groundwater abstraction, water pollutions and the need of using water and nutrition in emerging town's agriculture. The model can analyze the flows of excreta, groundwater, grey-water and organic solid waste between households, sewerage, sanitation installations, landfills and agriculture. Data needed are number of inhabitants, water consumption, type of sanitation system etc. The model could be modified for the concept of zones for getting to be more suitable for the HCES and Sanitation 21 approach *(Montanegro et al., 2006).*

2.4 Life cycle assessment and sustainability of urban water systems

Life-cycle assessment (LCA) is considered the most comprehensive approach for quantitative assessment of the environmental impacts of a product or system capable of including processes in a life-cycle perspective often quoted as processes from "the cradle to the grave" *(Hauschild, 2005).* LCA has also been referred to as a holistic approach since it covers all stages in a life cycle, **Figure 2** LCA was originally developed for assessing the environmental impacts of products but was also found applicable for services. LCA has been applied to assess environmental impacts of different technologies for both water supply and wastewater but is still in the beginning of discovering the full capabilities of application to water systems.

Figure 2 A Life-cycle assessments covering all stages in a life cycle

Fig.2. A Life-cycle assessment covering all stages in a life cycle from 1) Extraction of raw materials over 2) Manufacturing of a product or system by material processing, manufacturing and assembling to 3) Use phase and finally the 4) End of life treatment.

A clear strength of the LCA methodology is that it covers all emissions and consumptions of resources throughout the life-cycle of a product or as in this Master of Science study a service such as water supply. While carrying out the LCA all processes from extracting raw materials are included, over manufacturing of the given product or part of the system to the use stage which is usually the longest period in time of the lifespan of the product or system. The last part of the LCA is the End of Life (EoL) treatment where materials are disposed or reentering a new life-cycle by recycling. If transport of materials or products is occurring it must also be included in the LCA *(Wenzel et al., 1997).*

The International Organization for Standardization (ISO) has standardized an LCA framework consisting of 4 steps: 1) Definition of goal and scope; 2) Inventory analysis; 3) Impact assessment and finally 4) Interpretation of results (ISO, 2006). The 4 steps are often illustrated similar to **Fig**. 3

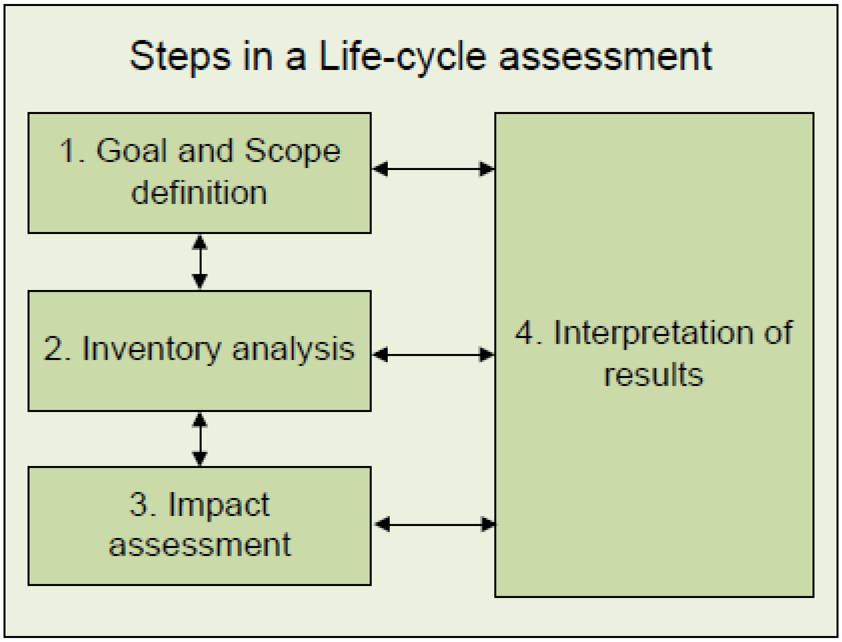


Figure 3 Steps in Life-cycle assessment

(modified according to ISO, 2006))

The 1st step is the definition of the goal and scope where the intended aim and use of the LCA is described. It also contains the system boundaries making sure that if the LCA is to be used for comparative decision making then the system boundaries must be set so the comparisons are equal. All data inventory must be quantified according to a functional unit (FU) which determines the reference unit of the LCA study.

In the 2nd step the inventory analysis is performed which covers gathering all inputs and emissions occurring throughout the life-cycle .This is often a rather time consuming step as an LCA practitioner often encounters that data are not always easily accessed

The 3rd step translates the input (e.g. resources, materials, energy) and output (e.g. emissions, substances, waste) of the inventory analysis into the impact categories divided into environment, toxicity and resources. In more details the Impact assessment step consists of 4 steps which are:

3. A) *Selection of impact categories and classification* where the categories representing the system's relevant impacts are identified;

3. B) *Characterization* where the impact of each emission is modelled through impact pathway in a common score

3.C) *Normalization* is the step where the impact scores of each impact category is related to a common reference the categories are normalized in relation to the annual contribution to the category from 1 average person in the region, converting the normalized result to the so-called personal equivalent (*Wenzel et al., 1997);* and finally

3.D) the weighting step is where the relative weight of the impact categories are assigned allowing for aggregation of the impact categories in to a one-score result.

In the final 4th step the results are interpreted meaning that the LCA result is evaluated according to the overall goal of the study. Sensitivity and uncertainty analyses are also a part of this step (ISO, 2006).

As indicated by the arrows in **Fig**.3 the 4 steps are considered iterative steps which means that interpretation of the steps will most likely lead to reconsidering and going through the steps once more.

2.5 The pros and cons of Life Cycle assessment

Pros

- It helps in realizing the planning cycle
- It allows to take more proactive approaches to maximize the benefits
- It measures changes and will help to find out the benefit.

Cons

- It is not always the reliable indicator of true life span
- May lead to mistake if not well assessed with the problem

2.6 Life cycle assessment (LCA) Tools

A number of tools are available for environmental impact assessment. Most of these tools were developed to assess the environmental impact of industrial products. Very few of them have been used for impact assessment of municipal water and wastewater facilities. The most commonly used life cycle assessment tools for the water industry include SimaPro and GaBi.

2.6.1 Semipro LCA Software

SimaPro is a commercial LCA software tool made according to the ISO standard to facilitate the LCA analysis by PRé Consultants, Netherlands. SimaPro 7.2.0 (PRé Consultants 2004 and 2007) was used to analyze the contribution of the life cycle stages to the overall environmental load produced by the treatment systems. SimaPro includes a large database, including the Ecoinvent database, containing a number of processes and several impact assessment methods allowing life cycle analysis of complex systems in an organized way. The updated SimaPro includes U. S. based databases such as USA input-output database 98 and Franklin USA98. The impact analysis model included in SimaPro contains the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) (developed by U. S. Environmental Protection Agency) and the Building for Environmental and Economic Sustainability (BEES) (developed by the National Institute of Standard and Technology) as well as other European based methods. Due to the large amount of uncertainty associated with the geographic and technological factors, these database and impact analysis methods allow a more accurate analysis of the environmental performance of the system in the North America. Instead of giving much focus on long, detailed, and expensive studies, this software allows simplified analysis within a reasonable time. It has been successfully used by several researchers to perform LCA of water and wastewater supply and treatment technologies (Ortiz et al. 2007; Lassaux et al. 2007). Although it started as a process based LCA tool, the new version of SimaPro included the economic input-output (EIO)-LCA database. Therefore, EIO-LCA was used to fill in the gaps when process data was not available.

2.6.2 GaBi LCA Software

GaBi is commonly used commercial LCA software made by PE International, Germany. It was first released in 1993. The software is designed to provide services to perform life cycle assessment, life cycle engineering, technology benchmarking/system analysis, energy efficiency analysis, greenhouse gas accounting, and environmental management systems and sustainability reporting. Similar to SimaPro, Gabi allows users to build scenarios (called plans in GaBi) and benchmark and compare the environmental impacts of different scenarios. The software is built on Gabi LCA databases, integrated with the Swiss based Ecoinvent LCI database. GaBi has been successfully used in LCA studies, such as by Vince et al. (2008) performing environmental assessments comparing different potable water supply systems. Table 3 below summarizes the databases and LCIA methods used in SimaPro and GaBi.

	Databases	LCIA Methods
SimaPro	Ecoinvent, US LCI, ELCD, US Input Output, EU and Danish Input Output, Dutch Input Output, LCA Food	ReCiPe, Eco-indicator 99, USEtox, IPCC 2007, EPD, Impact 2002+, CML-IA, Traci 2, BEES, Ecological Footprint EDIP 2003, Ecological scarcity 2006, EPS 2000, Greenhouse Gas Protocol and others
GaBi	GaBi Databases, Ecoinvent, U.S. LCI	CML 2011 – version Dec 2007, Nov 2009, Nov 2010, CML 1996, Eco-Indicator 95, Eco-Indicator 95 RF, Eco-Indicator 99, EDIP 1997, EDIP 2003, Impact 2002+, Method of Ecological Scarcity (UBP Method), ReCiPe, TRACI 2.0, USEtox
Reference	http://www.pre-sustainability.com/databases	http://www.gabi-software.com/international/databases
Note: See Abbreviation List for acronyms.		

Table 3 Databases and LCIA methods used in SimaPro and GaBi.

2.6.3 CMLCA SOFTWARE TOOL

(Characterization model and alternative application scientific software nutshell)

CMLCA is a software tool that supports the calculation of:

- life cycle assessment (LCA), including social life cycle assessment (SLCA) and life cycle sustainability assessment (LCSA)
- input-output analysis (IOA), including environmental input-output analysis (EIOA)
- life cycle costing (LCC) and eco-efficiency analysis (E/E)
- hybrid LCA, combining LCA and EIOA

CMLCA is intended to support the technical steps of the tools described. It does not support the procedural aspects, like peer review, involvement of stakeholders, quality assurance and usefulness of the analysis for the decision at stake. The program assumes that the user is aware of the basic principles of LCA, IOA, etc.

CMLCA is just one of the many software tools that are available for the stated purposes. However, its philosophy is probably somewhat different. CMLCA does not provide a flexible user interface. Exchange of data with other programs is less extensive than with some other programs. There is only a small choice in graphical output, and the graphs are not 'fancy': no 3-D bars with shadow, just straight bar charts. There is no helpdesk. It may contain programming errors.

On the other hand, it is developed with the principles of LCA, IOA, etc. in mind, so that it is quite accurate and up-to-date as to methodological details. It is, for example, fully based on matrix algebra, although the user may be unaware of that whilst using the program. This implies that process trees with a recursive flow structures (steel production needing coal and coal production needing steel), provide no computational problems and are exactly solved. Moreover, the program is very flexible in dealing with allocation of multiple processes. In contrast with some other programs, such processes need not be allocated prior to their entry in the database, and the allocation method (substitution, partitioning, or no allocation at all) may be defined for each individual unit process. The program also supports fully hybrid inventories, consisting of process-based and IO-based data. It is rich in its analytical possibilities.

The program will continue to develop, in a progressive way such that all present features will remain available, and that data saved with the present version may be retrieved in future versions. CML, the Institute of Environmental Sciences at Leiden University, has ever since the conception of LCA played a prominent role in developing LCA, and it is still at the forefront of activity, both in its methodological advances, and in its standardization and progress towards maturity. CML has also been very active in EIOA and hybrid analysis the last few years. CMLCA will follow these developments, and sometimes it will even lead these.

CMLCA is scientific software, in two senses:

- CMLCA has been developed at a university that has played an important role in LCA for more than 20 years.
- CMLCA has been designed with students and scientists as an important target group.

CMLCA, finally, is freely downloadable and need not be installed.

2.7 International publications of LCA to water systems

Internationally LCA has a longer history of being applied in the water sector. It is found that relatively few studies are published on LCA of water supply even though the number of publications is rising due to the environmental concerns and growing water stress situations around the world demanding an evaluation of environmental impacts including the effects of water withdrawal.

Publications have been made on the entire urban water cycle. For instance an LCA of the Sydney water planning was carried out to evaluate several initiatives to bring down the environmental impact of the urban water cycle covering water supply and wastewater systems. The study included several scenarios for changing water supply and wastewater systems and the outcome is a result aimed at decisions regarding future planning and projects of the complex water system *(Lundie et al., 2004). Lassaux et al. (2007)* also carried out an LCA of a water system from the well fields to the wastewater treatment plants. The study concludes that the 3 stages that contribute significantly to the global environmental load are: water discharge, wastewater treatment operation and, to a lesser extent, the building of the sewage system. Even though wastewater carries the highest environmental impact when considering the urban water cycle LCA of drinking water supply still gives us the opportunity to improve the environmental performance of water supply and should be a compulsory phase of future drinking water planning *(Vince et al., 2008).*

The other publication entitled" Water Foot printing: How to Address Water Use in Life Cycle Assessment? *(Markus Berger and Matthias Finkbeiner Published: 5 April 2010)* in these paper provides an overview of a broad range of methods developed to enable accounting and impact assessment of water use. The critical review revealed that methodological scopes differ regarding types of water use accounted for, inclusion of local water site, as well as differentiation between watercourses and quality aspects. As the application of the most advanced methods requires high resolution inventory data, the trade-off between precision and applicability needs to be addressed in future studies and in the new international standard

2.8 conclusions and recommendation of available support for planning

When considering the assessment of sustainable urban water, there are a limited number of available assessment techniques. These techniques are the 'building blocks' of any assessment for a sustainable urban water infrastructure. This is true despite the diversity of potential structures a study or assessment might take.

In water supply planning theory Techniques available for assessing sustainability which have been considered, are compared to the existing work on the assessment of options for sustainable urban water. This allows gaps in the field to be identified, where significant techniques are yet to be developed into whole-system methods

To sum it up one can recognize that some aspects are more commonly acknowledged than others. Participation of the users of the systems and their affordability are issues that are covered by almost all of the tools. These aspects are seen as central pillars for the planning of a successful and sustainable WS-system. The demand for an improved system or a new system and economical possibilities for maintaining it is a base from which other aspects can be added.

In order to be able to make a selection of tools and models that should be further analyzed, delimitation is needed. This will be done by selecting the ones that are as close as possible to the reports objective i.e. finding planning tools for selecting sustainable water supply systems in emerging town's areas of the developing world.

The selection criteria are thereby the following:

• Planners should be the target group

• The planning process should be in focus

• The tool should be aimed for planning water supply

• The main context should be the developing world and the tool must be applicable on emerging town's Areas

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. Distinction of the study area

In Ethiopia, small town water supply systems are constructed by local and regional governmental offices, non-governmental organizations and other concerned organizations. Selection of the study area will be based on standard of living and income levels, and the authors' knowledge of the area the study will be carried out for one small town area near to Addis Ababa.

Site selection criteria

Based on the reasons listed below, this project area has been selected as a case for the study

- Geographical location
- land form and topographic suitability (gentility and flatness of the slop)
- Accessibility and physical location
- Rate of occurrence for watery supply problem

3.1.1 Profile of Fitche

Fiche (also spelled Fikke) is a town in central Ethiopia. It is the administrative centre of the Semen Shewa Zone of Oromia and separate woreda. It is located about three km from the main Addis Ababa-Debremarkos road, Fiche has a latitude and longitude of 9°48′N 38°44′E and an elevation between 2,738 and 2,782 meters above sea level.

According to the 1994 population and housing census of Ethiopia, the projected current (2008) population is about 41,905

Figure 4 Location map of fiche in Ethiopian context

3.2.2 Climate

The monthly average, maximum, and minimum temperature of Fitche varies between 12.8^{0}C - 15.7^{0}C. Maximum temperature occurs in May and the minimum in October and November.

The average annual rainfall at Fitche, as determined from the available data for the years 1980 to 1997 is 1,018 mm. The Fitche area is located in the Central Highlands of Ethiopia and as a result it has two rainy seasons. Because it is located in the Central Highlands of Ethiopia, where the ITCZ reaches the area late and leaves early, the longest rainy season is from July to September. The shortest rainy season is from March to April.

3.2.3 Infrastructure and Services

Fitche has road connections by both asphalt and all weather gravel roads and is accessible all year round.

The Addis Ababa - DebreMarkos road that divides Fitche into east and west is the town's major axis along which transport and related urban activities are concentrated.

Fitche has a digital automatic telephone system. Mobile telephone and postal services are also available. The town receives a 24-hour electric supply from the country's hydroelectric grid system.

3.3.3 Demographic Conditions

Population

The 1994 Census undertaken by the Central Statistical Agency (CSA) gave the population of Fitche town as 21,187. Using this as a base, the 2008 population is estimated at 41,905.

Economic Situation

Fitche town functions primarily as a government administrative centre and as a commercial service for the surrounding woreda towns. Data from the Town Administration of Fitche shows that there are commercial establishments. In the town there is cattle breeding, poultry, metal work, hand crafts and a flour mill among its commercial establishments. For the details economic activities of the town see the following tables.

Type of Business	**Number**
Trade	518
Local Alcohol houses	90
Private Services	Number
Hotels	27
Bars and Restaurants	18
Snack Bars	9
Type of Industry	Number
Cattle breeding	1
Poultry	1
Metal Work	50
Grain Mills	7

Hand Crafts	37
Fuel Stations	2

Table 4 Business Institutions

Source: FitcheTown Administration (2008)

Future Development of the Town

The proposed land use function is prepared in line with the planning principle of zoning. Zoning plan upholds the notion that a specific area of land (plot) should be used for specific urban function. In this regard, it determines the value of the land and the kind of investment expected to be made in a particular plot of land.

The total area of land which is proposed to accommodate different urban functions is estimated based on medium variant population projection. Accordingly, the respective size of plots needed to accommodate major land use categories are given as follows:

No.	**Land use function**	**Area (ha)**	**Percentage**	**Remark**
01	Residential area	472.0	44.0	
02	Commerce & Business	62.0	5.6	
03	Administration	46.5	4.3	
04	Education and Health Services	101.1	9.4	
05	Industries and Warehouses	44.5	4.1	
06	Agriculture	48.0	4.5	
07	Recreation	45.0	4.2	
08	Road system and Transportation	168.0	15.7	
09	Area to be covered with Forest	84.5	7.9	

Total Proposed Urban Area	1071.6	100.0

Table 5 Land Use Area Distribution of Fitche

NUPI, Aug. 1995

3.3.4 Basic Social Services

Sanitation Services

The overall sanitation of the town is poor. There is no system for collecting, transporting, and dumping waste in the town. The sanitation condition in the town is discussed in the following paragraphs

Solid Waste Management

In the town there are no skips for solid waste collection and definite solid waste disposal site. The majority of households have no containers for storing garbage. The residents of the town dispose of domestic waste in any open spaces especially along stream courses, gullies, streets road verge and in drainage ditches.

Liquid Waste Disposal

There is no liquid waste disposal system in the town. Waste resulting from bathing and other domestic washing activities is almost entirely drained in the town resident's compound and disposed out into the roads. As the roads are dusty gravel roads the liquid is easily absorbed and also evaporated. There is no specific site for liquid waste disposal

Toilet Facilities

There are public toilet facilities in the town to provide service for the community but are not in good condition. In addition, most of the excreta disposal facilities in Fitche Town comprise pit latrines which are frequently poorly constructed, offensive and over filled. According to the town's municipality the majority of households use toilets in their own compound and the prevalence of open defecation is also significant and demands improvement.

Sludge Disposal Method

The municipality does not own a vacuum truck for sludge disposal. Accordingly households dig a new pit when the old one is filled. Some hotels in the town higher private owned vacuum trucks from nearby town give sludge disposal service. There is no disposal site for sludge and dispose it elsewhere out of the town in the nearby farm lands.

3.3.5 Population and Water Demand Projection

The 1994 population and housing census of Ethiopia were used as a base for population projections. Population figures and data collected from field visits was used to estimate the maximum daily water demands for Fitche for the Stage I and Stage II design horizons.

These are presented in table 6

Year	**2008**	**2020 Stage I**	**2030 Stage II**
Population	41,905	70,628	104,316
Average Daily Water Demand (m^3/day)	1,333	3,443	7,132
Max Daily Water Demand (m^3/day)	1,599	4,132	8,558
Max Daily Water Demand (l/s)	18.51	47.8	99.1
Peak Hour Water Demand (l/s)	33.3	86.1	158.5

Table 6 Population and Water Demand Projections for Design Horizons

3.2 System description

3.2.1 Existing system

The existing water supply of Fitche town currently relies upon springs and boreholes. There are some 15 springs in Fitche supplying an approximate 10.8 l/s. Some of these springs are located within the town and have a high potential for contamination. There are three boreholes which also supply the system. They have all been drilled fairly between (2001-2008G.C) but are all relatively low yielding. (1-1.8l/s) Some of the spring sources supply directly to consumers in the town, whereas others such as Amdeie Abera, Torban Ashe, Abo Tsebel supply the 300, 50 and 75m^3 reservoirs before being distributed to consumers. In all, the total supply for the town consists of 13.8l/s (1192 m^3/day) at present the water is distributed to the consumers through 2824 house and yard connection; 121 government and public connection; 50 commercial connections; and 34 public taps.

Boreholes have been constructed in two areas, at Worabessa (the well field at Fitche town) and at Degem, 10km from Fitche. The Norconsult Feasibility report says that FT1 was tested at a continuous discharge of 8.3 l/s for 72 hours; However, this information is suspect since shortly after implementation of IREP, the yield declined to 1.8 l/s (reportedly within 1 month of pumping) and currently functions at this low yield. A second borehole was drilled at the locality Torban Ashe in the proposed well field site at Worabessa, close to Abo Tsebel springs. Currently it is pumping 1 l/s.A third borehole was drilled recently (in March 2008) at a site southwest of the town in Worabessa stream catchment; depth was 100m. Although the drilling company recommended a discharge of 1.5 to 2 l/s, actual potential is reported to be less than 1 l/s. This borehole is implemented and pipeline and electromechanical works are installed. The submersible pumps are driven by EEPCO power from the country’s grid system. The system is not automated, and the controlling mechanism employed is through an estimate of the time it usually takes to fill the reservoirs.

The transmission line from Amdeie Abera Spring and Degem borehole to the existing 300m3 service reservoirs at Torban Ahse comprised between 2 1/2” and 6” diameter GI and DCI pipe mains but their actual lengths are not known. From Torban Ahse reservoir water is distribution to the town by gravity.

The transmission line from three springs at Torban Ashe connected to Abo Tsebel springs and Torban Ashe Borehole and supplying Abebech Gobena 50m3 Reservoir, Mekanyesus 72 m3 Reservoir and FicheHigh School. From the reservoirs water is distribution to the town by gravity. Other springs are supplying FitcheHospital and the town directly. These mains are galvanized iron (GI) pipes comprised between 2” and 3” diameter but their actual lengths are not known.

There are three reservoirs in Fitche water supply system. The 75m3 reservoir at Mekanyesus was constructed in 1963 E.C.; 50m3 reservoir at Abebech Gobena constructed in 1963 E.C and 300m3 reservoir at Torban Ashe constructed by Water Works Construction Enterprise through IREP in 2005. The 300m3 reservoir is in good condition.

Figure 5: 300m^3 Service Reservoirs in Fitche at Torban Ashe

The water is not treated chemically and is distributed directly. At intervals, the reservoirs are cleaned and filled with water to which chlorine tablets are added.

Water meters are installed at the outlet of the boreholes but there are no water meters at the reservoir inlet or outlets.

The distribution network in the town is constructed from GS and PVC pipes comprised of between 2"and 6" diameter. The actual length of pipe in the scheme is not known.

Water is distributed to the consumers through 2,824 house and yard connection; 121 government and public connection; 50 commercial connections; and 34 public taps.

The fountains are of stone masonry construction and equipped with faucets, water meter and gate valve. Some of them do not have proper chambers for the gate valves and water meters and have no drainage and fencing

3.2.3 The New system

During the study the planning horizon for the first and second stage was 2015 and 2025 but the implementation of this project has been extended to date. The design horizons have been changed to 2020 and 2030 for stage I and Stage II.

The change in design horizon resulted in new population and water demand figure from previous study report and recommendations. In addition, the town current development plan has also forced to redesign the water supply scheme component. The existing settlement pattern and the proposed development plan prepared by National Urban Planning Institute/NUPI form the basis for design of the distribution system However, in planning the layout of the pipes to cover the town's proposed development plan, care was being taken not to make the cost of the distribution too expensive as the development plan looked more ambitious than what has been observed on site. Therefore, a compromise was made between the existing development and the proposed NUPI plan in deciding the areas to be covered by the primary distribution network.

Hence in the study and in this typical study as well only primary and secondary distribution lines were considered. The distribution system will be constructed in two stages; Stage I will be constructed under this project and will cover the anticipated settlement areas to the year 2020 and Stage II will be constructed in the future and will cover extensions of distribution systems for settlement areas to 2030.

Since the water source of Fitche is mainly from two directions and the topography slopes down towards the eastern part of the town it is impossible to supply the system from one central supply zone. Thus, distribution will be from two service reservoirs located in different sites. Consequently, two reservoir sites were selected to the West and South-East of the town. Domestic Demand, Commercial Demand, Institutional Demand and Industrial Demand, including a percentage for the unaccounted-for water, are distributed to the Nodes; The Nodal Demands are used for the original Municipality area.

On the maximum day simulation, the hourly factors were multiplied by global factor of 1.2 the peak hour demand is expected to occur during the maximum day on hour 8:00 at which the hourly factor is 1.6 Thus the peak demand Qpeak = 1.92avg

Diameter (mm)	**Length (m)**	
	STAGE 1	
	uPVC	**Fe/GI**
80	3,790	**-**
100	3,023	**-**
150	4,598	**-**
200	3,033	**-**
250	1,232	**-**
300	-	**287**
350		**-**
400		**-**
500		
Sub Total	15,676	**287**
Total (KM)	**15.96**	

Table 7 Distribution Pipes Network Required Stage I

3.3 Methodology

A case study was used as basis to realize the general aims of the research, i.e. the supply of potable water to the Fitche town in Oromia regional state. The reason for choosing the Fitche was that the spatial and demographic nature of the town typically represents the emerging and small towns of

Ethiopia. The Ethiopian urban development has been rapidly expanding and the demand for potable water is undeniable. Therefore, the environmental impacts coupled to water usage needs to be studied to develop a water supply planning strategy.

The methodology in this study is Life cycle assessment (LCA) which is an international standard methodology ISO14040 for assessing the environmental impact of systems throughout their entire life cycles, beginning with the extraction of raw materials, continuing with product development and manufacturing, and ending with material recycling or disposal. The LCA study is conducted in four steps: definition of goal and scope, inventory analysis, impact assessment and interpretation of results.

CMLCA 5.2. CML2001 (Centre for Environmental Studies, 2012) was the chosen impact assessment method. The impact categories considered are: WU (water use); EP (eutrophication potential); AP (acidification potential); HTP (human toxicity potential); (aquatic toxicity potential); OCP (ozone creation potential); ODP (ozone depletion potential); GWP (global warming potential); TTP (terrestrial toxicity potential); OLU (occupied land usage); TLU (transformed land usage); MD (mineral depletion); energy depletion).

For the LCA study, the function of the whole water supply system which consists literally the so-called collection, treatment and distribution of water through the town. The LCA analysis in this specific study doesn't cover the water utilization in each household since it is design to study the infrastructure elements of the water supply in general.

The functional unit is 1m3 of supply of potable water based on the above listed system boundaries. The above listed system boundaries are limited due to the lack of detailed information of the water supply system of the town.

It has been assumed that the same potable water quality comes out from spring and from boreholes, the unit is given in standard as 1m3 of treated water at the end user or the house connection. The system boundary of the LCA are in accordance with the international EPD system that were specifically issued for this service (Borghi et al 2013)

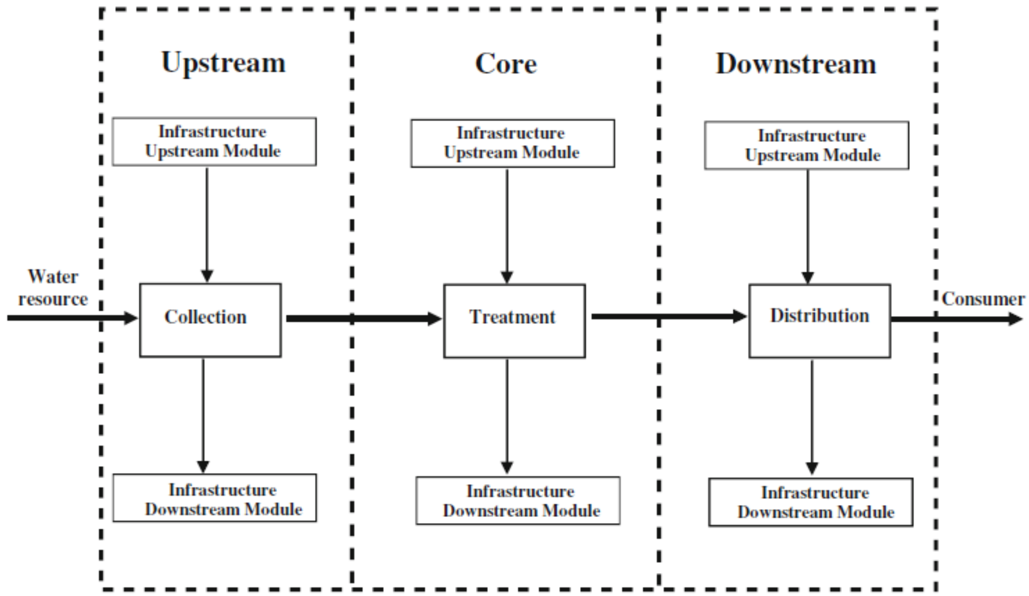


Figure 6 the system boundary of the LCA

The selection of a methodological pattern consistent with the requirements of an environmental label such as the EPDs, as defined in the document General Programmed Instructions for Environmental Product Declarations (EPD) (2008), aims at allowing comparability among different studies.

For the case of Fitche town

The upstream processes include the following life cycle phases:

- Collection of water from wells/natural springs
- Transport to treatment plant (transmission to service reservoirs)

The core process includes

- Treatment of water (chlorine tablet)

The downstream process includes

- Transportation of water to consumer through the distribution network &
- Maintenance of the distribution network

3.3.1 Method selection

The whole study was perfumed using CML characterization model and alternative application scientific software nutshell CMLCA. The current stable version is 5.2.Released in August 2012. The Authors are the Universty of Leiden, Faculty of science, Institute of Environmental science.

http://www.cmlca.eu/

Why use CMLCA tool?

Seven reasons for using CMLCA

1. CMLCA is for free. Most software for LCA will cost you several thousand of money .
2. CMLCA is extremely flexible. Most software for LCA has a pre-cooked allocation, impact assessment, etc. In CMLCA, you can control (almost) everything.
3. CMLCA is perfect for use in class room. Most software for LCA is designed for use by consultants. That means that ease of use has been more important than correctness and transparency.
4. CMLCA is perfect for use by researchers. It comprises the most extensive set of options for doing life cycle interpretation, and it includes extensive options for addressing environmental impacts in connection to EIOA.
5. CMLCA is extremely advanced in including IO-based and hybrid LCA, LCC and eco-efficiency analysis.
6. CMLCA is compatible with the framework and terminology of ISO 14040.
7. CMLCA does not require an administrator for installation, and can be transferred over the internet.

Seven reasons for not using CMLCA

1. CMLCA has no helpdesk.
2. CMLCA contains no data. Still have to buy or download these.
3. CMLCA contains no impact assessment data. You still have to incorporate GWPs and related characterization factors.
4. CMLCA is not so good for consultants. A consultant wants an easy and quick answer, and doesn't like having to choose from too many options.
5. CMLCA has no graphical interface for constructing flow diagrams.
6. CMLCA is only available in English.
7. CMLCA is only available for Windows.

3.3.2 Schematic of Fiche's water supply system

For the LCA analysis fragmented or water supply infrastructure elements were listed as follows

i. Water sources springs and boreholes **(15 springs, 3boreholes)**

ii. Transmission lines**(three transmission lines)**

iii. Service reservoirs **(three service reservoirs)**

iv. Distribution lines (**15.96KM pipe)**

v. Treatment facility **(chlorine tablet)**

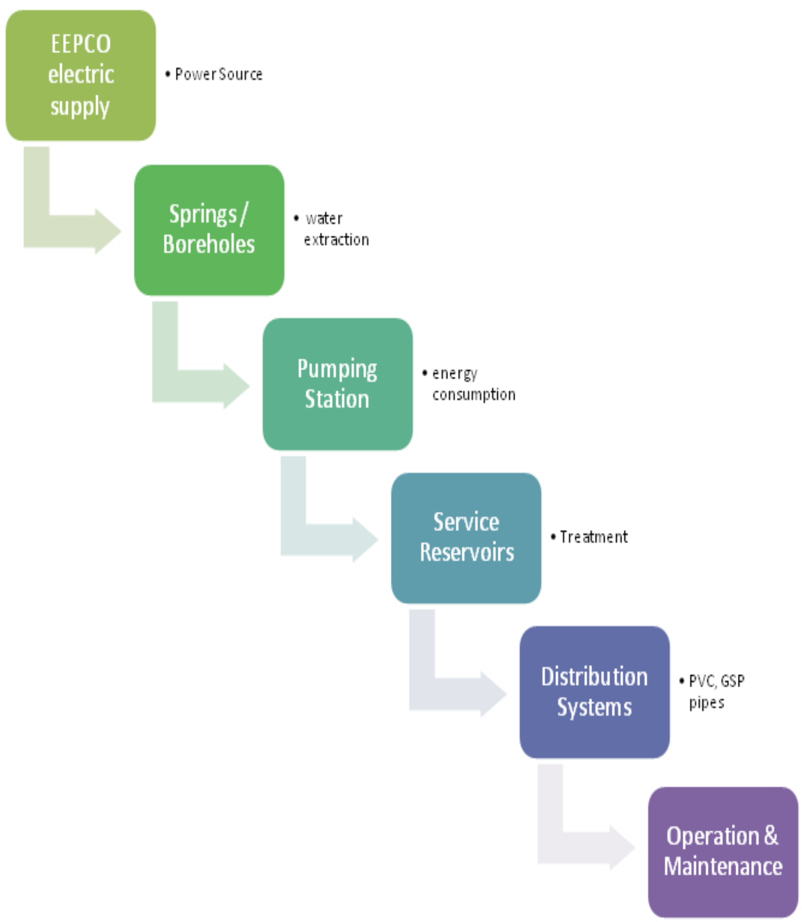


Figure 7 Schematic of Fiche's water supply system

3.3.3 Life cycle inventory

As an input, the LCA inventory encompass energy for pumping, chemical for treatment and construction materials, pipes for distribution input primarily based on data from the ministry of water resources for the Fitche town (15 towns waters supply study report). Data were obtained from the detailed design report of the water supply implementation project of the Fitche town.

- Table 8. shows water extracted from springs and boreholes

Spring Name	**Discharge (l/s)**	**Location**	**Remarks**
Two (2) at Abo Tsebel (Antara and Abo Tsebel Springs)	5.2	North west of the town	
Three (3) Springs at Torban Ashe		North west of the town	
Two (2) springs Burka Bacho and Burka Kulula for the supply of fiche Hospital	No record but assumed 0.8 l/s	One North west of the town and the second close to 300 m3 reservoir	One spring is within the town and not suitable location and has to be abandoned
Four (4) springs of Burka Dubale Springs	1.8	Close to Old Italian Road. There are residential areas above it	Downstream of residential areas and to be abandoned
Three (3) springs of Amde Abera	2	Within the town	To be abandoned
One (1) Kega Spring	1	Within the town	To be abandoned

Total (#)	10.8		(#) Excluding hospital supply

Table 8 Spring sources

- The following is summary of the borehole yields.

Borehole Source	Yield(l/s)
Degem (FT1) bh	1.8
Worabessa bh	1.0
Torban Ashe bh	1.0

Table 8 borehole yields.

From the above available data, the existing total sources available to the town are:

Springs >10 l/s

Boreholes 3.8 l/s

- Table below electric consumption and pumping of wells

	DFT1	FD1	FD2	FD3	FD4	FD5	FD6
Discharge	1.80	3	3	3	3	3	3
Head mtr	190.48	229.62	226.15	224.90	255.43	226.59	223.07
Mechanical efficiency-m%	75	75	75	75	75	75	75
Electrical efficiency -e%	87	87	87	87	87	87	87
Power required by pump motor-pt	2.192	4.405	4.338	4.314	4.900	4.347	4.279
Power required to run pumps kw	6.577	13.215	13.015	12.943	14.700	13.040	12.838
Illumination/compressor/backwash and others	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Total power	11.577	18.215	18.015	17.943	19.700	18.040	17.838
Allowance 5-10%	1.158	1.821	1.802	1.794	1.970	1.804	1.784
Generator power required at site Kw.	12.735	20.036	19.817	19.737	21.670	19.844	19.622
A max. Temperature of 40°c	0.670	1.130	1.120	1.110	1.110	1.120	1.110
25000masl Altitude,KW	0.760	1.270	1.260	1.250	1.250	1.260	1.240
Total power at site in KW	14.165	22.436	22.197	22.097	24.030	22.224	21.972
Total power at site in KVA,st	**15KVA**	**25 KVA**	**25 KVA**	**25 KVA**	**25 KVA**	**25 KVA**	**25 KVA**

Continued

	FDT 1	FDT 2	FDT 3	FDT 4	FDT 5	FDT 6	FDT 7	FDT 8
Discharge	5	5	5	5	5	5	5	5
Head mtr	169.57	165.99	164.82	168.50	173.33	168.44	171.93	170.4
Mechanical efficiency-m%	75	75	75	75	75	75	75	75
Electrical efficiency -e%	87	87	87	87	87	87	87	87
Power required by pump	5.422	5.307	5.270	5.387	5.542	5.385	5.497	5.448

motor-pt								
Power required to run pumps kw	16.265	15.921	15.809	16.162	16.625	16.156	16.491	16.344
Illumination/compressor/backwash and others	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Total power	21.265	20.921	20.809	21.162	21.625	21.156	21.491	21.344
Allowance 5-10%	2.126	2.092	2.081	2.116	2.163	2.116	2.149	2.134
Generator power required at site Kw.	33.5	32.95	32.76	33.37	34.17	33.36	33.93	33.68
A max. Temperature of 40°c	1.110	1.110	1.110	1.110	1.110	1.110	1.110	1.110
25000masl Altitude,KW	1.340	1.320	1.310	1.330	1.370	1.330	1.360	1.350
Total power at site in KW	35.990	35.380	35.180	35.810	36.650	35.800	36.400	36.140
Total power at site in KVA,st	**40KVA**	**40KVA**	**40 KVA**	**40 KVA**	**40 KVA**	**40 KVA**	**40 KVA**	**40 KVA**

- Table below transmission main water pumping to service reservoirs

Primary Pipelines	
Diameter (mm)	**Length (m)**
	uPVC
80	
100	5266
150	1855
200	902
250	1,012
300	
Sub Total	7,649
Total (KM)	7,649

Table 9 transmission main water pumping to service reservoirs

- Table below the material used for service reservoir construction

Item	Description
1	Clean sand and gravel
2	Clean water
3	Reinforcing rod
4	Pvc pipe for inlets

5	Screening and mesh for pipe
6	Cutoff valve
7	Plywood
8	Nails
9	Locks for manhole cover

Table 10 material used for service reservoir construction

- Table below the chlorine used in service reservoirs

FICHIE CHEMICAL DOSING	PR1		PR2	
	Hypochlorite		hypochlorite	
	min	Max	Min	max
concentration g/m^3	0.01	0.03	0.01	0.03
dosing rate mg/ltr	2.5	2.5	2.5	2.5
max day demand m^3	2160.00	2160.00	3456.00	3456.00
daily demand kg/day	5.40	5.40	8.64	8.64
density kg/m^3	1000	1000	1000	1000
daily demand by water volume m3	0.01	0.01	0.01	0.01
required water volume m3	0.53	0.17	0.86	0.28

total volume m^3	0.54	0.18	0.86	0.29
two tanks of each m^3 (12 HOUR SUPPLY)	0.27	0.09	0.43	0.14
two tanks of each m^3 (8 HOUR SUPPLY)	0.18	0.06	0.29	0.10
dosing rate ltr/hr	22.50	7.50	36.00	12.00

Table 11 Chemical Dosing

- Table below shows the pipe material used in distribution system

Item	pipe material
1	uPVC for pipes with DN 50 to 250 mm
2	PE for pipes with DN 50 to 150 mm and Secondary distribution lines
3	GS for pipes DN 12 mm to 100 mm diameter.
4	uPVC for pipes with DN 50 to 250 mm

Table 12 the pipe material used in distribution system

The method applied in this study is Life Cycle Assessment (LCA) which is an international standard methodology ISO14040 and ISO14044 (ISO, 2006) for assessing the environmental impact of water supply systems throughout their entire life cycles, beginning with the extraction of raw water, collection, store, treat, distribute, consume and/or disposal. A standard LCA (ISO, 2006) generally consists of 4 phases: 1. Goal and scope definition, 2. Inventory analysis, 3. Impact assessment and 4. Interpretation. Prior to the LCA I went through each phase in relationship to our study.

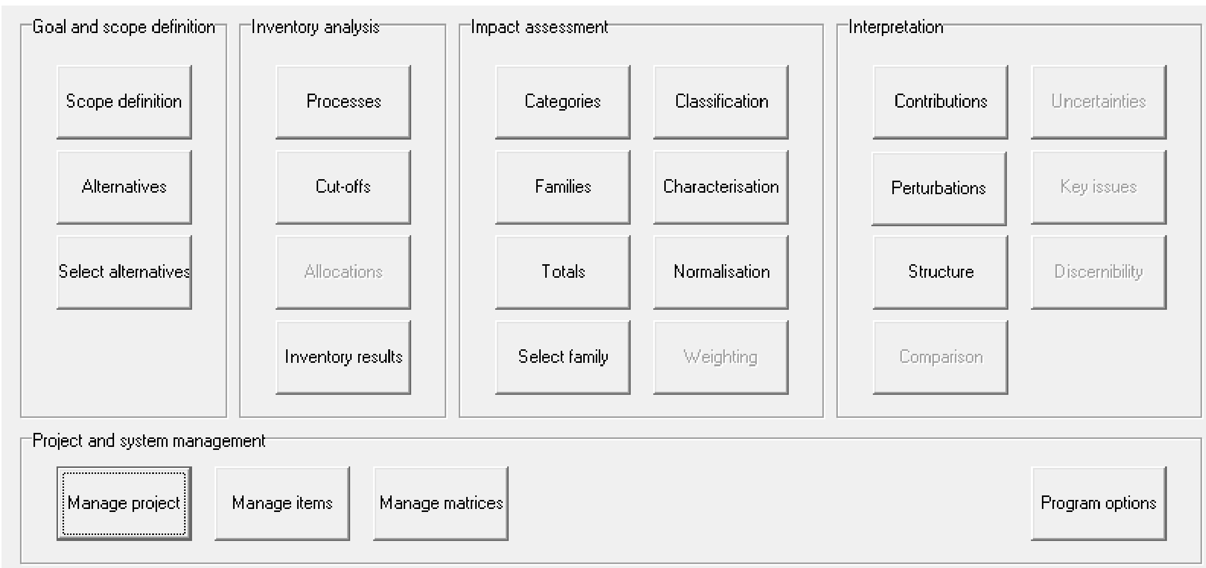


Fig … Four phases of LCA in window of CMLCA

3.4.1. Goal and scope definition:

Based on the CMLCA tool the first step is goal and definition. The defined goal was to assess the life cycle of the Fitche town water supply system to fulfill the development of sustainable water supply planning strategy. There by the goal allowed for analyzing all the system boundaries of Fitche Town water supply to identify the key elements and parameters to formulate the water supply planning strategy. The secondary objective is to compare the current scenario with two alternative scenarios (water reclamation and drought).

The functional unit of overall water supply system was production of water which fulfilled the minimum specified per-capita demand water flow requirements for water courses where freshwater was withdrawn and replacing 1m3 of potable drinking water as produced. 10% water loss due to breakdown, water leaks, maintenance operation in the distribution network made the functional unit as 1.1 m3.

The infrastructure of the treatment units was not considered because the process of treatment take place inside water tanks or reservoir in Fitche town. Other studies indicate that the environmental impact of constructing and dismantling the infrastructure materials is negligible when compared to the operation phase (Raluy et al., 2006). However, the infrastructure (Reinforced concrete reservoirs, steel and cast iron pipes, PVC pipes, cast iron, reinforced concrete, galvanized iron, HDPE) of the distribution network and sewage collection has been considered due to its relative significance.

The system boundaries were the same as specified in section 3.3.1. in Fig 8. For CMLCA Source: withdrawal or harvesting of water from springs and wells, Treatment facilities: Chemical treatment case of Fitche, Distribution to the end user piped distribution system, Energy requirement for withdrawal and harvesting water, Discharge of used water:

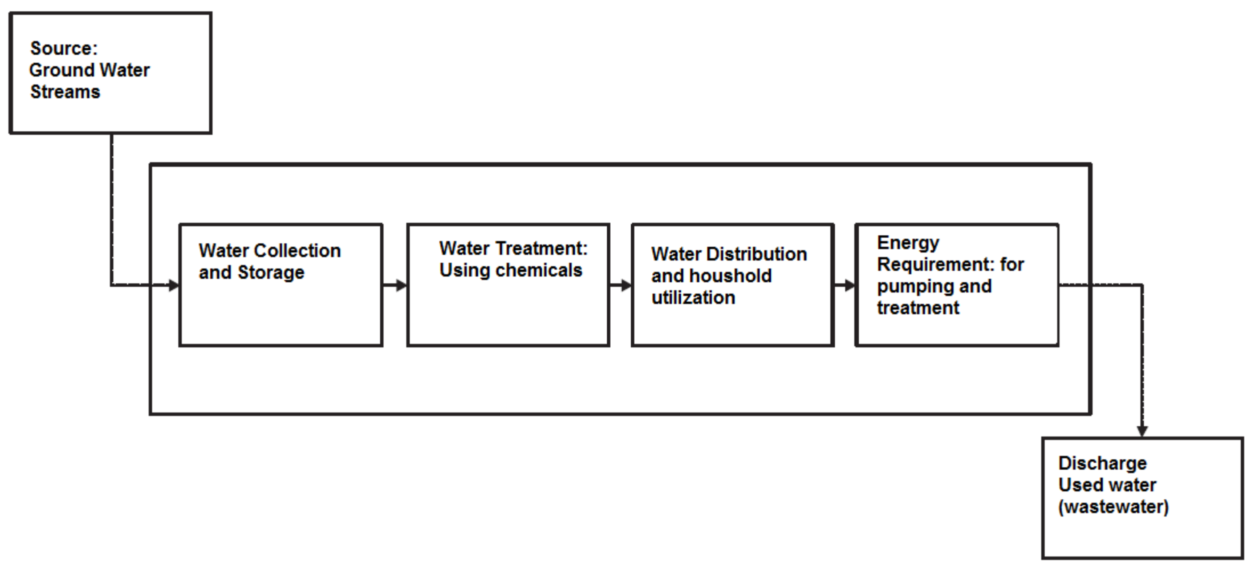
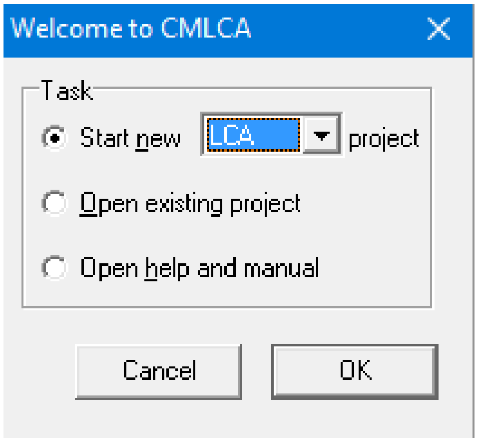
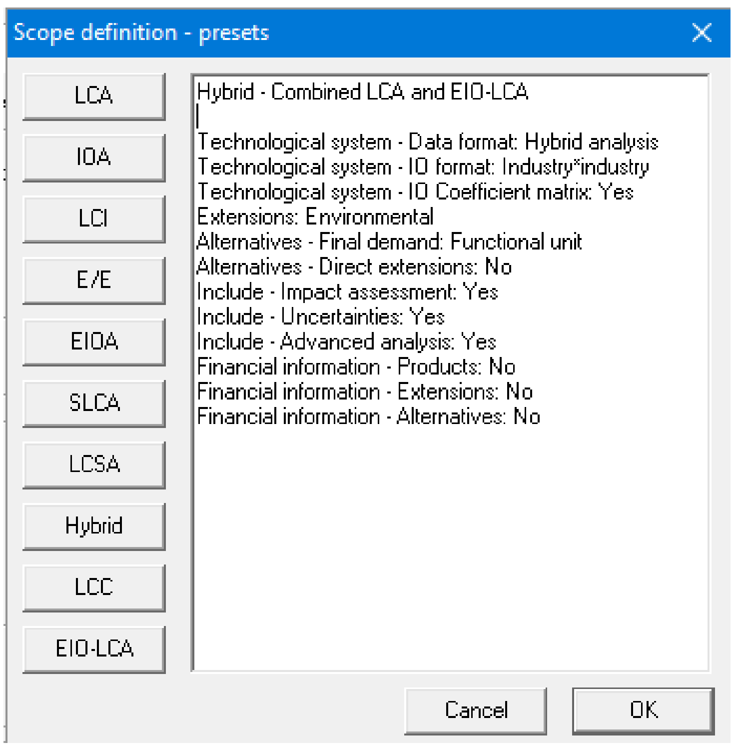


Fig (….) System boundaries for LCA analysis based on the urban water supply system (adapted Godskesen et al 2013)

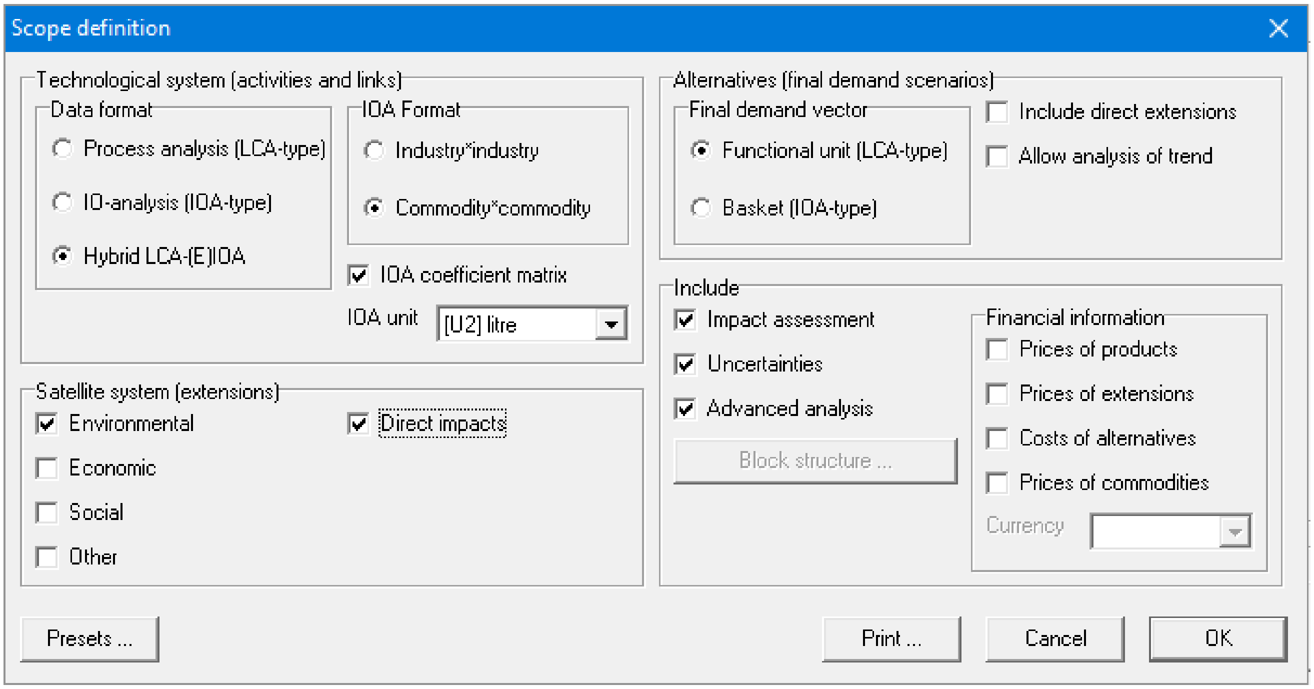
Step one: Select the LCA from listed assessment methods



Step Two: define scope: the scope of LCA of water supply system of small town was to develop a planning strategy of the water supply system. Therefore, Hybrid LCA was selected to combine LCA and Environmental input and output analysis to consider the water supply system implementation



Step Three: Hybrid Presets is selected to analyses



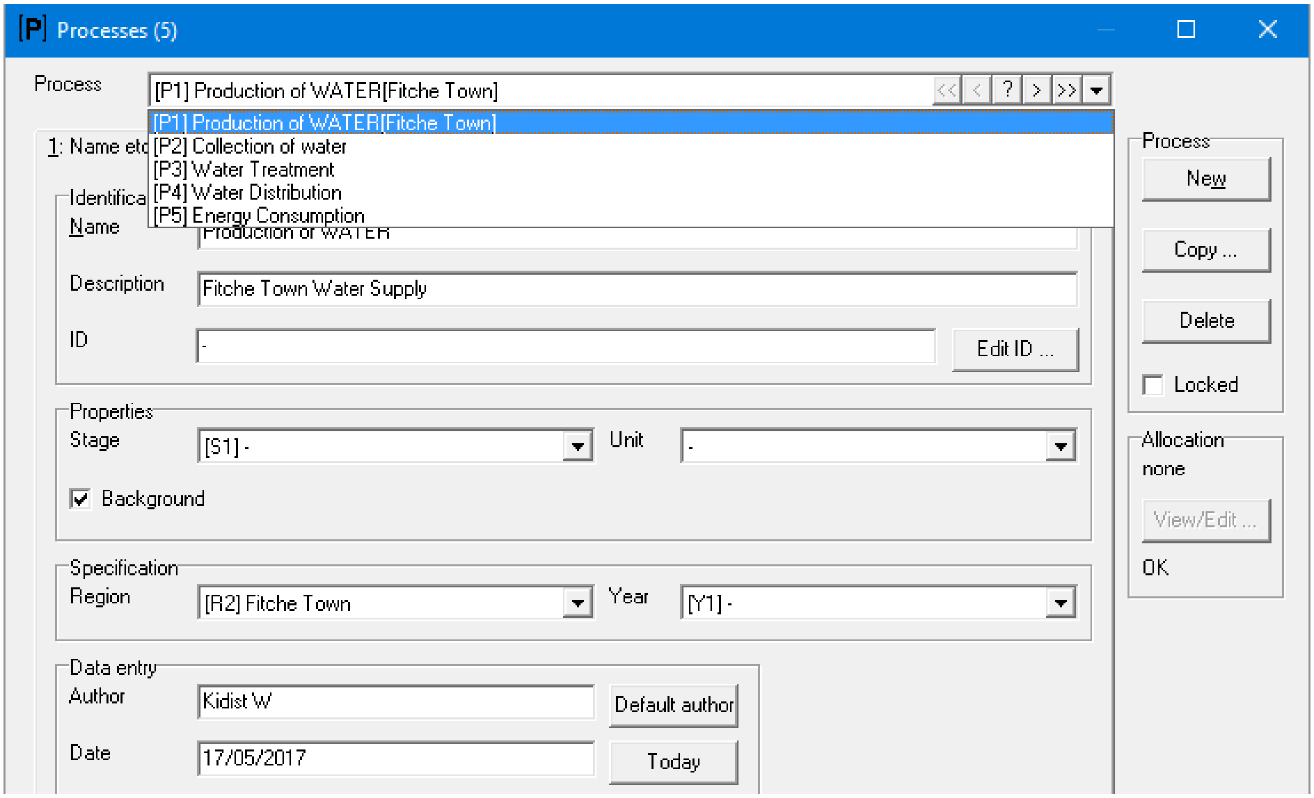
Step four: functional unit of the water supply system is production of water which fulfilled the minimum specified per-capita demand hence IOA format is selected as commodity with IOA matrix IOA unit is selected U2 liter.

3.4.2. Inventory Analysis

As an input, the LCA inventory encompass energy for pumping, chemical for treatment and construction materials, pipes for distribution input primarily based on data from the ministry of water resources for the Fitche town (15 towns waters supply study report). Inventory data, including energy and materials consumption, are presented in Tables (8-12) in section 3.3.

Data were obtained from the detailed design report of the water supply implementation project of the Fitche town..

All material, water abstraction and energy inputs were determined based on the functional unit. The basic database for specific material collected from the CML (institute of environmental science Liden University) and was used since in Ethiopia pre-developed processes database not found.



Process window: based on the system boundary specified in section 3.4.1. five processes were feed to CMLCA assumption 100% hydroelectric used source of energy

3.4.3. Impact assessment

In this specific thesis two environmental indicators were used: Freshwater Use (FWU, m3) and Cumulative Energy Demand (CED, MJ). The Freshwater use indicator shows the amount of water consumed from the different sources (spring and borehole water) throughout the whole life cycle. This indicator is especially significant in Ethiopia because of potable water availability in emerging town (Terfasa, 2013).

The cumulative energy demand indicator is a direct and easily understood indicator of the environmental implications of energy consumption, especially hydroelectric and diesel oil. For purpose of quantifying the impact of water use the freshwater ecosystem impact (FEI) used. As per (Munoz 2010) (FEI) aims to assess the ecological consequences of water use in a certain region measured as the volume of "ecosystem-equivalent" water, which refers to the volume of water likely to affect freshwater ecosystems. FEI has been calculated using the recently developed equation below:

$$FEI = \sum_{i=1}^{n} (CWU_i \cdot WTA_i)$$ (Levova, 2011)

Where: CWUi is consumptive water use of a unit process WTA is withdrawal to availability ratio and n is the set of unit processes

$$WTA = \frac{WU}{WR}$$ (Levova, 2011)

Since the study area fixed: which Fitche town; WTA can be applied as characterization factor based on the inventory level of Fitche town where water withdrawal taking place. WTA values for borehole water and spring water calculated based on hydrologic statistics and collected data. In addition to that the environmental water requirement (EWR) known, the characterization factor can be calculated as shown below (Levova, 2011)

$$CF = \left(\frac{WU}{WR - EWR}\right)^{\left(\frac{WR}{2 \times EWR}\right)}$$ (Levova, 2011)

The steps of impact assessment were: classification and characterization, normalization and weighting. Classification meant sorting all substance flows in the LCA according to their impacts on the environment. In the characterization step the intensity of impacts were determined by multiplying the quantities of substance flow by its characterization factor which is WTA.

It is unknown where water abstractions take place, but it is assumed that abstraction take place in Ethiopia in general. For this reason, the average country-level WTA for Ethiopia, according to the Aquastat online statistics (FAO 2017, http://www.fao.org/nr/water/aquastat/main/index.stm), has been used. For Ethiopia Surface water: produced internally is 120 and borehole water: produced internally is 20.

Impact categories: As presented in section 3.4.2. the processes included in the LCA modeling of the cases and grouped in the following main four process and three process description (A0 – A3)

Water collection and storage (Abstraction & Storage):

A0. Ground water Abstraction: including well rig, well development, electricity for abstraction and transport water

A1. Stream (Surface water) water abstraction: intake structures electricity to pump for transport water to treatment plant

Water treatment:

A0. Borehole water Abstraction: construction of aeration units and chemical chambers

A1. Stream (Surface water) water abstraction: complete conventional treatment unit construction

Water Distribution:

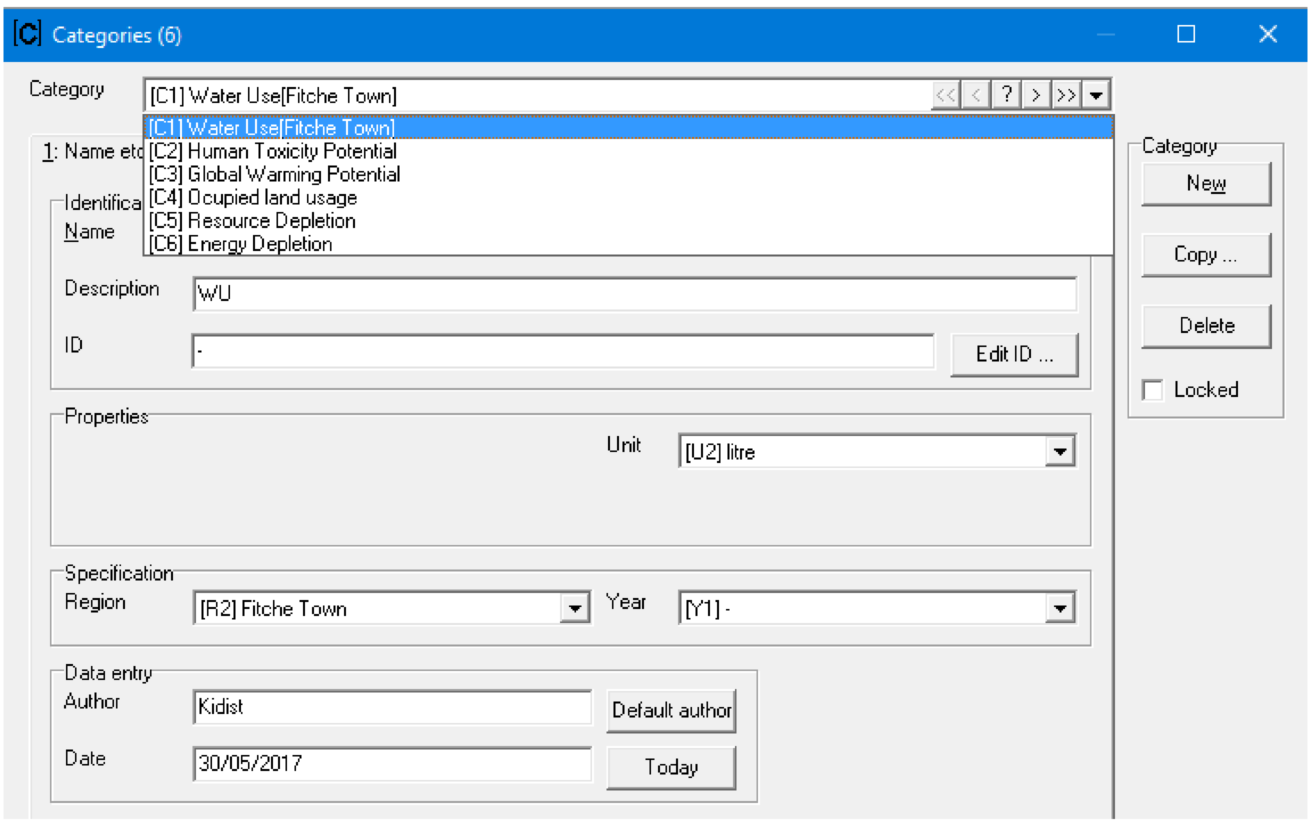
A0: pipes from reservoirs to household tap

A1: Pipes from treatment unit to balancing reservoirs and to household tap

Collection and disposal wastewater

A0 & A1: sewer pipes from house to treatment plant

For the case of Fitche based on the data availability the analysis limited to the following impact categories: WU (water use); HTP (human toxicity potential); GWP (global warming potential); OLU (occupied land usage); RD (resource depletion) ED Energy depletion .



Impact assessment categories

The inventory data is believed has major gaps and omissions. Therefore, in MCLCA 5.2 analysis it is essential to incorporate the results of economic analysis of the design review report of the Fitche town water supply. MCLCAs cannot cover all issues or every part of water supply system and, therefore, MCLCAs will always be incomplete in some way (Owens, 1999).

- The following data gaps in the MCLCA are noted:
- Uneven uncertain electricity supply
- Chemical input for water treatment were estimated the amount of chlorine at pump station and at reservoirs
- Emission of water and air at pumping station estimated in MCLCA because of lack of information

Hence, due to the above data gap: Based on the demand of water and economic allocation of the two stages the following key parameter calculated per year. Based on the following key assumption

2. The Fitche town water supply all the water for the Fitche town only
3. The borehole water recharge from the wastewater assumed to be zero
4. The input and output flow of has the loss by 20% it is assumed that wastewater produced after consumption is assumed to be 80% of supply
5. Water production is for 20 hrs. per day in both stages to calculate annual demand
6. Estimated cost divided by the design life to determine annual cost
7. Calculate the cost per functional unit to determine relative weight of each infrastructure element in overall LCA analysis
8. Each infrastructure system impact will be distributed in accordance with relative weight as specified in 3. Above

The relative Cost per functional unit is given by

$$CFU = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} w_{Pi}} x 10^5$$

(Tesfaye, 2017)

Where: CFU = cost per functional unit (birr/lit) ,

Ci = Economical cost element ,

Wpi = water demand or water production system

4. Result and discussion:

Based on the Fitche town water supply design review report: Water demand for stage One with the design period 20 year is 62 l/s. And the water demand for stage two with the design period of 50 years is 133l/s. and the economic life is given in the table below and the items categorized in the stage to reduce double calculation in LCA

Table 4.1 shows that the economical and design life of generalized water infrastructure elements. The design life values are utilized in the computation of cost per functional unit. The cost per functional unit is used as a basic reference value since the data gap is significant for the case of Fitche town. The decision to use a cost per functional unit is achieved by the argument that the data collection for the construction purpose is much accurate than the data collected for the planning activity purpose. From the demographic analysis the expected water production data is also considered as accurate data. The synthesis between those two data will provide the significant parameter to distribute the impact fairly among the lists. Based on this the computed relative coast per functional unit is given in table 4.2.

Table 4.1.Given economical & design life water supply infrastructures

Components	Econ. Life in Years	Serve in Stage One	Serve in Stage Two
Source development:			
Civil works	25	Yes	No
Mech./Elec. Works	10	Yes	No
Treatment:			
Civil works	50	Yes	Yes
Mech./Elec. Works	15	Yes	No
Collectors, transmission main	40	Yes	Yes
Pumping station:			
Civil works	50	Yes	Yes
Mech./Elec. Works	15	Yes	No
Storage	50	Yes	Yes
Distribution system	25	Yes	No
Public fountains	10	Yes	No
Office and auxiliary buildings:			
Civil works	50	Yes	Yes
Mech./Elec. Works	15	Yes	No
Power supply	15	Yes	No

Table 4.2. Relative cost per functional unit and relative weight

		CFU	CFU
ITEM	DESCRIPTION	Stage I	Stage II
		Cost / l	Cost/l
A	GENERAL ITEMS	1.44	0.57
B	DRILLING	30.21	10.15
C	PIPE WORK	108.89	24.81
D	CIVIL WORKS	38.88	8.75
.D.1	1,000 m^3 RESERVOIR (2 units)	10.94	2.17
D.2	1200m3 RESERVOIR	7.38	1.46
D.8	DISINFECTION AND CHEMICAL STORAGE	0.45	0.09
D.9	PUBLIC FOUNTAINS	1.47	0.64
D.10	ANCILARY BUILDING	3.75	0.74
D.10.1	STORE	1.47	0.29
D.10.2	OPERATORS DEWELLING	1.88	0.37
D.10.4	BOOSTER STATION	0.64	0.13
D.10.5	CONTROL ROOM	1.48	0.49
D.10.6	CONTROL ROOM WITH GEN HOUSE	3.43	1.17
D.10.7	WSS WORKSHOP	0.72	0.14
D.10.8	ACCESS ROAD	5.28	1.05
E	ELECTROMECHANICAL WORK	33.33	11.20

Table 4.3. Rank of the main water supply infrastructure elements

		CFU	CFU	Rank	Rank
ITEM	DESCRIPTION	Stage I	Stage II	Stage I	Stage II
		Cost / l	Cost/l		
A	GENERAL ITEMS	1.44	0.57	4	4
B	DRILLING	30.21	10.15	3	3
C	PIPE WORK	108.89	24.81	1	1
E	ELECTROMECHANICAL WORK	33.33	11.2	2	2

Table 4.3. Shows that the pipe work is more significant compared to the other infrastructure elements. The life cycle assessment of the water supply system is above 360% compared to drilling of well and electromechanical installation.

Table 4.4. The MCLCA result, when applying the resource impact indicator

Resource group	**Impact category**	**Characterisation value**	**Characterisation value**	**Unit**
		Stage I (20 years)	**Stage II (50 years)**	
Boreholes	Water Use	1.294×10^{6}	0.294×10^{6}	kg water reserves
	Global Warming	2.726×10^{-1}	0.620×10^{-1}	oC temperature
	Occupied land use	9.810×10^{1}	9.810×10^{1}	Ha of land eq.
	Human Toxicity Potential	7.523×10^{1}	1.713×10^{1}	kg Pb eq.
	Energy Resource depletion	1.714×10^{-1}	0.390×10^{-1}	kilowatt.
Spring water	Water Use	5.997×10^{0}	1.366×10^{0}	kg water reserves
	Global Warming	2.285×10^{-1}	0.520×10^{-1}	oC temperature
	Occupied land use	4.570×10^{-6}	4.570×10^{-6}	Ha of land eq.
	Human Toxicity Potential	9.105×10^{2}	2.074×10^{2}	kg Pb eq.
	Energy Resource depletion	1.984×10^{0}	0.445×10^{0}	kilowatt.

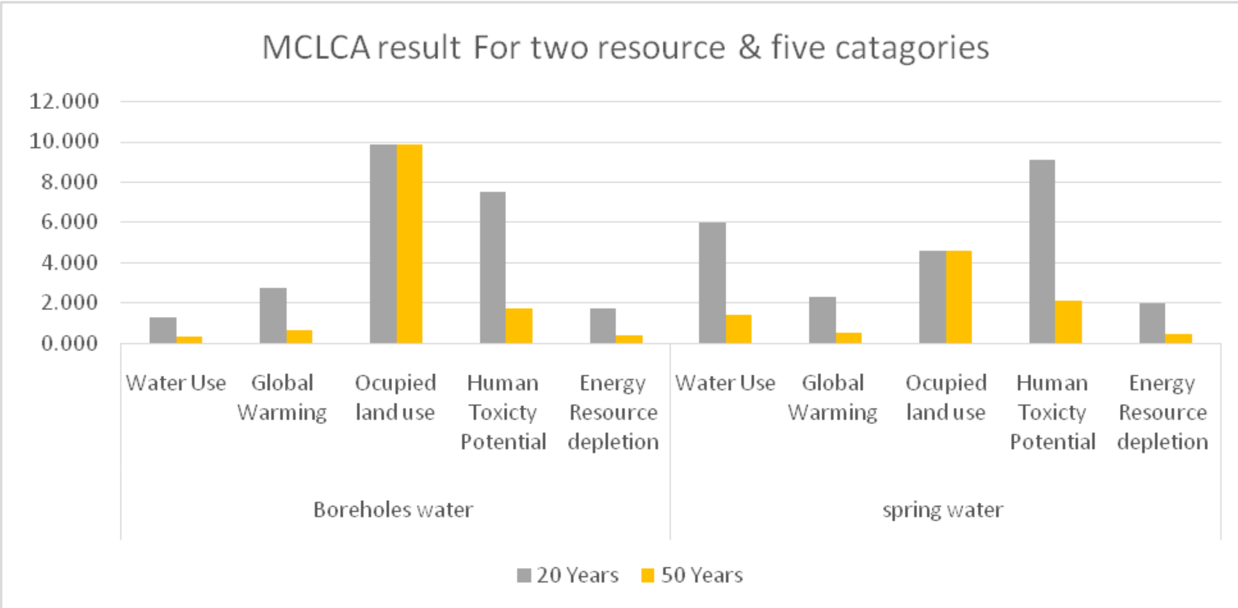


Figure 4.1. for two resource and five categories

Table 4.4 and figure 4.1. shows the MCLCA analysis result that the resource impact indicators are highly affecting the first stage of design. This implies that when the water supply infrastructure developed at the very initial stage affects the environment.

This result is a good indicator for the water supply planning strategy. Stage by stage construction and implementation of the water supply can be a good alternative.

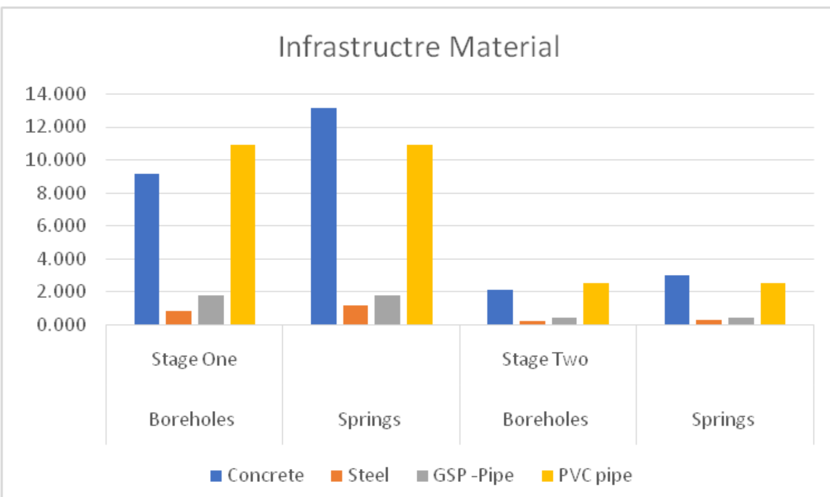
Figure 4.1 shows that water resources the impacts on land resources are the most important for the life cycle system. For the borehole water system occupied land use is much significant. This shows the borehole water needs more land for the recharge of the aquifer. Whereas, human toxicity potential is more significance in the case of spring water. Spring water is much contaminated than borehole water. Of all the impact categories classified to land resources, the occupation of land, directly by the water purification and waste treatment, boosting and reservoirs supply system, is the main contribution to this impact category.

In general the impacts on global warming are the third-most important, although the energy resource depletion potential (for diesel) may be in the significant. The releases of atmospheric emissions that contribute to the global warming potential impact category, due the generation of the required electricity for pumping, contribute the most to the impacts on air resources, i.e. at least 97%.

Table 4.5. Relative impact of materials during construction and operation

Infrastructure and operational material for two systems				
	Borehole water	Spring water	Borehole water	Spring water
Material	Stage One		Stage Two	
Infrastructure				
Concrete	9.112	13.143	2.076	2.994
Steel	0.789	1.139	0.180	0.259
GSP -Pipe	1.752	1.752	0.399	0.399
PVC pipe	10.865	10.865	2.475	2.475
Operation				
Electricity	262.854	481.899	59.878	109.777
Hydro	175.236	350.472	39.919	79.838
Diesel	87.618	131.427	19.959	29.939

Table 4.5. shows that PVC pipes have more significant impact in the water supply system. Since, majority of the water supply network in Fitche town is PVC



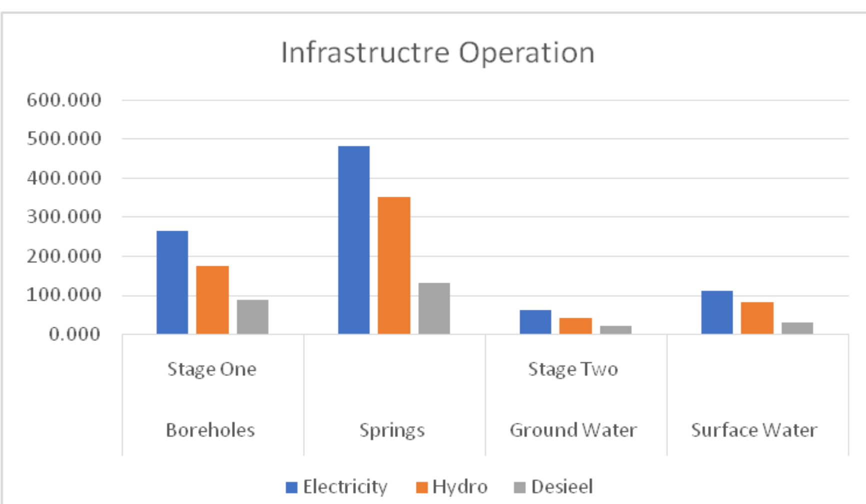
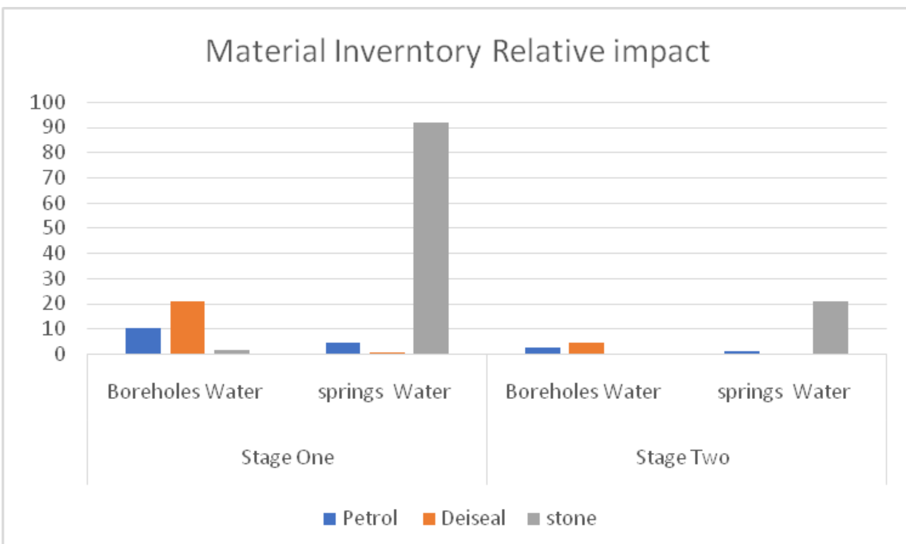
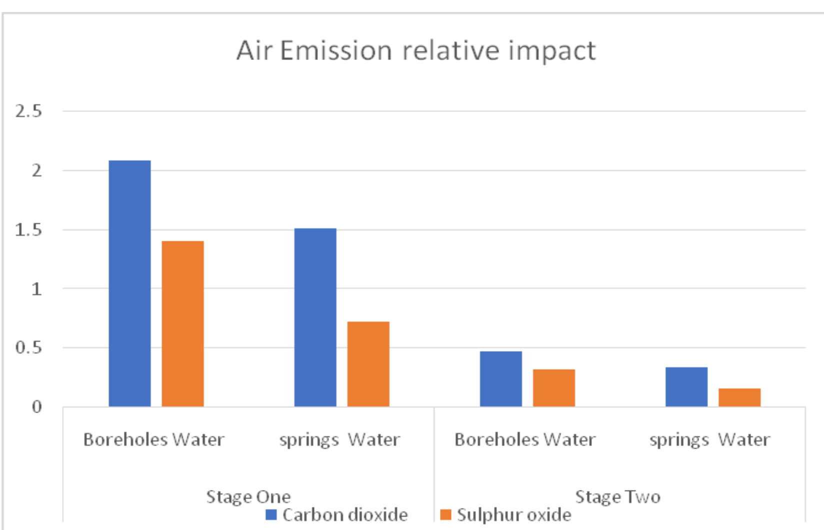


Table 4.6. selected material which can be analysed by the MCLCA internal database for raw material and air emission

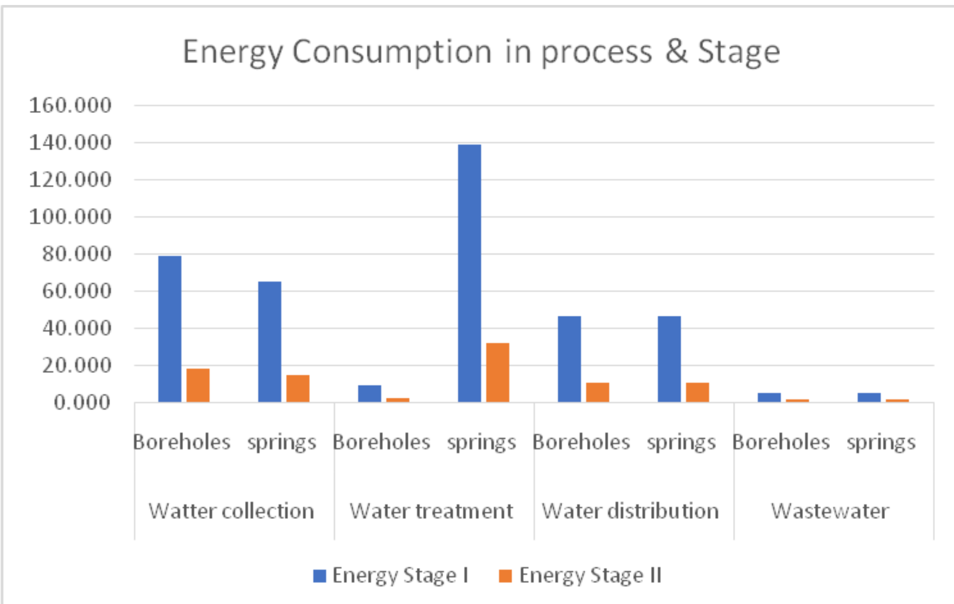
MCLCA Inventory of major raw material and air emission				
	Borehole Water	Spring Water	Borehole Water	Spring Water
Raw Material (Kg)	Stage One(20years)		Stage Two (50years)	
Petrol	10.322	4.263	2.343	0.968
Deiseal	20.868	0.748	4.737	0.170
stone	1.309	91.668	0.297	20.809
Air Emission (Kg)				
Carbon dioxide	2.079	1.511	0.472	0.343
Sulphur oxide	1.399	0.726	0.317	0.165

The relative impact of borehole water over spring water is





Energy use by different process of water supply system			
Process	**Water System**	**Energy Use I**	**Energy Use II**
Water collection	Borehole water	78.417	17.801
	Spring	64.579	14.659
Water treatment	Borehole water	9.226	2.094
	Spring	138.383	31.413
Water distribution	Borehole water	46.128	10.471
	Spring	46.128	10.471
Wastewater	Borehole water	4.613	1.047
	Spring	4.613	1.047



The research assessed the environmental impact of Ethiopian small town Fitche by the use of a LCA. After complete assessment of the small-town water supply system the results of the research revealed in the following tables. The units are as per the functional unit specified.

- The borehole water abstraction has more impact (45-50%) on the system than the stream water utilization as shown in table 4:5,
- Using hydroelectric is much better (85-95%) than using the diesel pumps, table 4.5.
- Less mineral content of the borehole water treatment has less impact (5-10%) than treatment of the spring water;

- Water loss is more (45-50%) likely to occur in pumping system compared to the gravity system;
- Pit latrine coverage of the town is significantly high, so it increases (55-60%) of the borehole water contamination level directly related with it;
- The absence of liquid waste disposal system is (80-90%) the main risk of the spring water contamination.
- The most carbon emissions are result from the production of raw water pumping

Based on the above analysis and the review of the design document of the Fitche town water supply system characteristics are: Demand driven system, community engagement in water supply system, network simplicity, long term maintenance and repair is simple, and minimized leakage.

In the context of LCA analysis the sustainable water supply planning strategy shall encompass the total material and energy flows for the entire water resource system to address directly and indirectly related environmental issues. Using LCA early in the planning process helps ensure that environmental issues are considered. Performing LCA for Ethiopian small town Fitche in this scale is the first and new undertaking assessment. Model development is one of the resource intensive processes because of its nature of scale and complexity. But the discipline has benefits beyond the performance of the LCA itself and the insights which it gives to strategic planners. For the development of the planning strategy, the process of constructing the LCA shall involve information exchanges between planning and operational staff which can enhance communication in a large organization.

Performing the integration of LCA for Fitche town shows and could enable to capture environmental effects associated with the consumption of material, which doesn’t routinely occur in the other strategic planning process. Based on the lesson from this study LCA and its application in water supply and wastewater infrastructure, small and emerging towns of Ethiopia shall apply the methodology to future planning question.

The strength of LCA for application in planning strategy is all elements in the infrastructure system addressed from A to Z. The weakness is the LCA system entirely needs robust and reliable data.

Typical water supply planning strategy of the small town:

- Ensure all customers are receiving a minimum level of service in year by 2030 Ethiopian calendar
- Have a reliable supply demand balance for the 20 and 50 year planning horizon
- have no long-term supply interruptions at customers' taps, and to achieve this ensure appropriate resilience measures are in place
- continue demand management with the implementation of our house hold water efficiency plan

5. Conclusion and Recommendation

5.1 Conclusion

The life cycle analysis of water distribution network and water supply system in general is essential for water planning and design professional and utilities to undertake so that they can understand the true long-term costs of installing, maintaining and upgrading their assets.

Selected Fitche town is one of the 15 towns which have the problematic water supply implementation project in ministry of water resource. The 15 town’s water supply project problem emerges from the planning of the projects. If the LCA was utilized during the planning study and design in the projects, such kind of project incompletion problem would not be happened. The Ethiopian government preference to look strictly at lowest bid price could lead to serious consequences in the future with networks experiencing higher costs for repair and water loss and requiring faster renewal frequency of pipe installation as a result of the lowest upfront price approach.

The MCLCA 5.2. Software shows that the two main Pipe material used in Fitche water supply project, such as ductile iron and PVC may have significant long term life cycle implications. This supports the main objective of this study which is planning strategy could be developed using the LCA method. For instance stage I (20 year) design period has more impact compared to the 50 year design period impact prediction.

Therefore: applicability of LCA for emerging small town water supply is proofed in this study. However, it is observed that none of the 15 towns used the LCA method in planning and design of the water supply system.

This thesis presents an overview of environmental evaluations by Life-cycle assessment (LCA) of water supply systems The emphasis here has been on the environmental dimension In respect of the planning strategy; the results obtained from the LCA, which is basically from the most defined and relevant impact categories, known as GWP-CC (global warming potential and the climate change), nonrenewable energy source, and water consumption are good indicators of an emerging town water supply system impact. Therefore, The Development of a planning strategy for sustainable water systems using the Life Cycle Assessment of Ethiopian emerging town as used in this research is helpful in identifying the most problematic elements of the system. This may help decision makers to make the right decision to improve the system Therefore, it is essential to formulate the planning strategy of the water supply system of an emerging town based on carbon foot print and water foot print

5.2 Recommendation

Based on observed outcome of LCA for the Fitche town as a case study the following recommendations are made:

In order to have a sustainable water supply system for emerging town's life cycle assessment must be applied to determine the environmental and economic impacts of the projects. Especially in the planning domain of the consultancy and in management domain of the utility or municipality office the data shall be monitored and recorded to identify the problematic areas during the implementation.

The power requirement and utilization is also of importance, the environmental impact indicator and the cost effect are significant in water supply system. The pumping where this energy input is primarily required. Therefore, more efficient or possible alternative energy sources may be considered for this part of the life cycle system.

The MCLCA tool and the LCA method shall be developed further for Ethiopian urban water resource sector, especially in terms of impacts on potable water supply and wastewater collection. In this respect characterisation factors should be developed and/or adapted for Ethiopian emerging towns.

In general further recommendations, can be made for future research, similar studies to this can contribute as case studies in answering the question about the possibility of implementing LCA programs in other emerging towns. Future research is also needed in the possibility of implementing alternative technologies in towns. The value of environmental LCAs for urban water systems has been shown and its importance is demonstrated. Therefore, LCA with different degrees of sophistication (life-cycle thinking as well as simple and detailed LCA) should be used to examine the consequences of all strategies, designs, interventions and changes to urban water and wastewater services. In general, the recommendations for long-term planning include the design of systems to enable more widespread, environmentally efficient water supply planning.

6. REFERENCES

- *ADF (African Development Fund) (2005) Water Supply and Sanitation*
- *Pfister S., Koehler A., Hellweg S., Assessing the Environmental Impacts of*
- *Freshwater Consumption in LCA. Environ. Sci. Technol.,* ***43****, 11, 4098–4104 (2009).*
- *Lundie S. et al., Life Cycle Assessment for Sustainable Metropolitan Water Systems*
- *Planning. Environ. Sci. Technol.,* ***38****, 3465−3473 (2004).*
- *Admassu, Mengesha, Abera Kumie, Misganaw Fantahun (2002) Sustainability of Drinking Water Supply Projects in Rural of North Gondar, Ethiopia, Ethiopian*
- *AWSA(2007) Addis Abeba water and sewerage Authority ,Draft sectoral Development program*
- *Mott MacDonald in association with AG Consult, Project Design Feb (2009), 15 Towns Water Supply and Sanitation Project design review report.*
- *Approaches and the Way Forward February 2008.*
- *Aschalew Demeke (2009): Determinants of household participation in water resource*
- *CSA (Central Statistical Agency) (2008) Summary and Statistical Report of the 2007*
- *Lundin, M., M. Bengtsson and S. Molander (2000). "Life cycle assessment of wastewater systems: Influence of system boundaries and scale on calculated environmental loads." Environmental Science and Technology 34: 180-186.*
- *Environmental Protection Authority and Ministry of Economic Development and Cooperation, 1997. Environment Policy of Ethiopia.*
- *Gebrehiwot M. (2006) An Assessment of Challenges of Sustainable Water*
- *ISO/DIS 14040 (1997). Environmental Management - Life Cycle Assessment,Principles and framework Geneva, Switzerland, International Organisation of Standardisation.*
- *Local Development Study (RLDS). A.A.U. Ethiopia*
- *Ministry of Agriculture, Ministry of Water and Energy, Ministry of Mines, Ministry of Industry 2012. National Preparatory Process for the Rio+20 Conference, Sector assessment Questionnaires.*
- *Population and Housing Census: Population Size by Age and Sex*

- *Supply: The Case of Ofla Woreda in Tigray Region. Msc Thesis, Regional and*
- *The Federal Democratic Republic of Ethiopia, Ministry of Agriculture and Rural Development, 2010. Ethiopian Strategic Investment for Sustainable Development.*

ANNEX

CFU CALCULATION

	CFU calculation_												
CF			*Stage I*	*Stage II*		*cost per year*	*Cost per year*	*Stage I*	*Stage II*	*CFU*	*CFU*		
ITEM	*DESCRIPTION*		*AMOUNT IN BIRR*	*AMOUNT IN BIRR*	*Total*	*Stage one*	*Stage Two*	*Demand of water*	*Demand of water*	*Stage I*	*Stage II*	*s/ day*	*s/day*
						cost/year	*cost/year*	*l/year*	*l/year*	*Cost / l*	*Cost/ l*	*72,000*	*72,000*
A	*GENERAL ITEMS*	*20*	*498,858*	*498,858*	*997,716*	*24,943*	*19,954*	*1734480000*	*3495240000*	*1.44*	*0.57*	*4752000*	*9576000*
B	*DRILLING*	*20*	*10,478,947*	*7,254,658*	*17,733,605*	*523,947*	*354,672*	*1734480000*	*3495240000*	*30.21*	*10.15*	*4752000*	*9576000*
C	*PIPE WORK*	*20*	*37,771,955*	*5,583,231*	*43,355,186*	*1,888,598*	*867,104*	*1734480000*	*3495240000*	*108.89*	*24.81*	*4752000*	*9576000*
D	*CIVIL WORKS*	*20*	*13,488,058*	*1,795,158*	*15,283,216*	*674,403*	*305,664*	*1734480000*	*3495240000*	*38.88*	*8.75*	*4752000*	*9576000*
.D.1	*1,000 m^3 RESERVOIR (2 units)*	*50*	*3,796,766*		*3,796,766*	*189,838*	*75,935*	*1734480000*	*3495240000*	*10.94*	*2.17*	*4752000*	*9576000*
D.2	*1200m3 RESERVOIR*	*50*	*2,558,908*		*2,558,908*	*127,945*	*51,178*	*1734480000*	*3495240000*	*7.38*	*1.46*	*4752000*	*9576000*
D.8	*DISINFECTION AND CHEMICAL STORAGE*	*50*	*155,086*		*155,086*	*7,754*	*3,102*	*1734480000*	*3495240000*	*0.45*	*0.09*	*4752000*	*9576000*

D.9	*PUBLIC FOUNTAINS*	*20*	*511,360*	*601,600*	*1,112,960*	*25,568*	*22,259*	*1734480000*	*3495240000*	*1.47*	*0.64*	*4752000*	*9576000*
D.10	*ANCILARY BUILDING*	*50*	*1,300,314*		*1,300,314*	*65,016*	*26,006*	*1734480000*	*3495240000*	*3.75*	*0.74*	*4752000*	*9576000*
D.10.1	*STORE*	*50*	*510,922*		*510,922*	*25,546*	*10,218*	*1734480000*	*3495240000*	*1.47*	*0.29*	*4752000*	*9576000*
D.10.2	*OPERATORS DEWELLING*	*50*	*650,712*		*650,712*	*32,536*	*13,014*	*1734480000*	*3495240000*	*1.88*	*0.37*	*4752000*	*9576000*
D.10.4	*BOOSTER STATION*	*50*	*220,628*		*220,628*	*11,031*	*4,413*	*1734480000*	*3495240000*	*0.64*	*0.13*	*4752000*	*9576000*
D.10.5	*CONTROL ROOM*	*20*	*514,002*	*342,668*	*856,670*	*25,700*	*17,133*	*1734480000*	*3495240000*	*1.48*	*0.49*	*4752000*	*9576000*
D.10.6	*CONTROL ROOM WITH GEN HOUSE*	*20*	*1,191,246*	*850,890*	*2,042,136*	*59,562*	*40,843*	*1734480000*	*3495240000*	*3.43*	*1.17*	*4752000*	*9576000*
D.10.7	*WSS WORKSHOP*	*50*	*248,114*		*248,114*	*12,406*	*4,962*	*1734480000*	*3495240000*	*0.72*	*0.14*	*4752000*	*9576000*
D.10.8	*ACCESS ROAD*	*20*	*1,830,000*		*1,830,000*	*91,500*	*36,600*	*1734480000*	*3495240000*	*5.28*	*1.05*	*4752000*	*9576000*
E	*ELECTROMECHANICAL WORK*	*20*	*11,563,313*	*8,005,371*	*19,568,684*	*578,166*	*391,374*	*1734480000*	*3495240000*	*33.33*	*11.20*	*4752000*	*9576000*