**MSc Programme in Urban Management and Development**

Rotterdam, The Netherlands

September 2018

**Thesis**

Title: Water-Energy Nexus study of the urban water cycle in Cuenca, Ecuador

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Specialization: Urban Environment, Sustainability and Climate Change

UMD 14

## MASTER'S PROGRAMME IN URBAN MANAGEMENT AND DEVELOPMENT

## (October 2017 – September 2018)

# Water-Energy Nexus study of the urban water cycle in Cuenca, Ecuador

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UMD 14 Report number: 1222
Rotterdam, October 2018

# Summary

Climate change is a high priority problem for all mankind. With extreme weather patterns and severe natural disasters affecting human settlements on an unprecedented scale, both in frequency and magnitude, every country is attempting to combat climate change by adaptation and mitigation actions. With growing awareness about the realities of global warming and climate change, the importance of resources like water and clean energy is coming to light. Water-energy nexus studies are fairly recent that explore the water-energy interlinkages and these interlinkages are inextricably linked with climate change.

Known for its water abundance and hydroelectricity, Cuenca’s urban water metabolic cycle and its management will be useful to study an excellent example of sustainable water management practices to emulate in other parts of the world. By studying the urban water metabolic cycle, the research intends to enhance the academic knowledge over better resource management of the urban water area and the energy involved in the processes. In the context of Cuenca, the research aims to highlight the role of the water-energy saving technologies as well as the importance of studying the water-energy nexus of Cuenca’s water system in assessing vulnerability to climate change-related risks and implementing adaptation/mitigation measures to prepare for a resilient future.

In this research study, semi-structured interviews, online survey questionnaire, and secondary data analysis were utilized as data collection methods to evaluate “to what extent can water-energy saving technologies (WEST) influence the water-energy nexus in Cuenca’s urban water metabolic cycle,” which was the main research question of this study. To obtain answers to the main and sub research questions, the process required the analysis of Cuenca’s current urban water metabolic cycle which also helped to verify the results obtained in another literature (Chacha 2015) on this topic. Thereafter, the threats of climate change and its effects on Cuenca’s urban water metabolic cycle were evaluated by learning from local experts working and researching in this field. In conclusion, the impact and economic feasibility of a few shortlisted water-energy saving technologies (WEST) like rainwater harvesting, solar water heaters and micro hydro turbines were assessed for implementation in urban Cuenca by creating forecast scenarios for each WEST for the next 10-15 years.

# Acknowledgements

Firstly, I would sincerely like to express gratitude for my thesis research supervisor – Dr. Alberto Gianoli! He was always there and his guidance was crucial to help me learn and strive for more.

Special thanks to Dr. Alexander Jachnow! He was my practically my second thesis research supervisor. He helped me secure a place on the 6-member Ecuador research team despite my non-existent Spanish.

Next, I would also like to express my sincere gratitude for my second thesis research supervisor – Dr. Stelios Grafakos, who had to leave IHS to go South Korea mid-way. However, his initial guidance helped me understand what I wanted to do for my thesis.

Furthermore, I would like to thank Dr. Antonio Malo, who provided me with a lot of secondary data and was willing to help me however he could while I was in Cuenca for research fieldwork.

Another special thank you is reserved for Prof Juan Leonardo Espinoza, whose guidance helped me get all the information I needed on solar water heaters, water turbines, and solar panels. His personal experiment with solar water heaters really inspired a significant part of this thesis.

I would like to convey my heartfelt thanks to Cristian Zamora, Ramiro Santacruz and Josue Larriva, who provided me with precious time in their busy schedules and enriched my thesis with the secondary and primary information.

Next, I would like to thank my parents and sister, who have always been there to support me especially when times have been tough. They will always mean a lot to me.

And lastly, the most important thanks is reserved for my partner, Viviana, without whom I could not have completed this thesis. She was my Spanish-English translator, patiently helped with conducting the interviews, transcribing of the interviews, preparing of questionnaires in Spanish, setting up appointments, email communication with all Spanish speakers, etc., was all achieved thanks to her. Without her, this thesis would not be possible.

# Abbreviations

| | |
|---|---|
| IHS | Institute for Housing and Urban Development |
| BAU | Business-As-Usual |
| CBA | Cost Benefit Analysis |
| CEA | Cost Effectiveness Analysis |
| CO2 | Carbon Dioxide |
| CO2e | Equivalent carbon dioxide emissions |
| ETAPA | Empresa de Telecomunicaciones Agua Potable y Alcantarillado |
| GDP | Gross Domestic Product |
| GHG | Greenhouse gas |
| GWh | Giga-Watt Hour |
| IEA | International Energy Agency |
| IUWM | Integrated Urban Water Management |
| kgCO2e | Equivalent to kilograms of CO2 |
| kWh | Kilo-Watt Hour |
| LCA | Life Cycle Assessment |
| LID | Low Impact Development |
| Lpd | Litres per day |
| LPG | Liquified Petroleum Gas |
| MCDA | Multi-Criteria Decision Analysis |
| PEC | Programa de Eficiencia Energetica para la Coccion |
| SWH | Solar Water Heaters |
| WT | Water turbines |
| UN | United Nations |
| WEST | Water-Energy Saving Technologies |
| WQI | Water Quality Index |
| WSADIOAF | Water supply and demand investment options assessment framework |
| WSDS | Water supply demand strategy |
| WSM | Water Saving Measures |

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# Chapter 1: Introduction

## 1.1 Background

"Water is at the core of sustainable development. Water resources, and the range of services they provide, underpin poverty reduction, economic growth and environmental sustainability. From food and energy security to human and environmental health, water contributes to improvements in social well-being and inclusive growth, affecting the livelihoods of billions" (UNESCO 2015, p.1)

Water is the most essential resource needed for survival and production of most types of goods and services. The implications of water on sustainable development "reach far beyond its social, economic and environmental dimensions" (UNESCO 2015, p.3).

### 1.1.1 Water and its Uses

Water has always been the most important resource to sustain humanity, its growth and development (UNESCO 2009, p.80). Agriculture has historically been the initial sector for any community's development, and this development revolves around the community's access to water. There are multiple cases where a country's development has shown strong links with its water system status. For example, "in Thailand poverty fell from 57% in 1962 to 10% in 2002, with initial declines led by growth in agricultural production" (UNESCO 2009, p.82). On the contrary, the floods in Mozambique (2000) resulted in a GDP drop of 23% and rise in inflation of 44% (UNESCO 2009). In developing countries especially, water plays a pivotal role in poverty alleviation through "sanitation services, adequate water supply, affordable food and enhanced resilience of poor communities facing disease, climate disasters and environmental degradation" (UNESCO 2009, p.80). Water resources-dependent industries like agriculture, forestry, fisheries, energy, etc., employ half of the global workforce (WWAP 2016). As evident, water is an essential component of national and local economies, and therefore, it is a resource that needs great attention in light of the problems faced by the world in the 21st century.

### 1.1.2 Trends in Water Use

Due to rapid population growth, UN's World Water Development Report 3 states that water withdrawals have tripled in the last 50 years (UNESCO 2009, p.101). Population growth is putting additional stress on global urban processes. Additionally to population growth, Latin America's urbanisation, which would be over 80 percent urbanised by 2030 (GWP and Bahri 2012), would also affect its urban metabolisms.

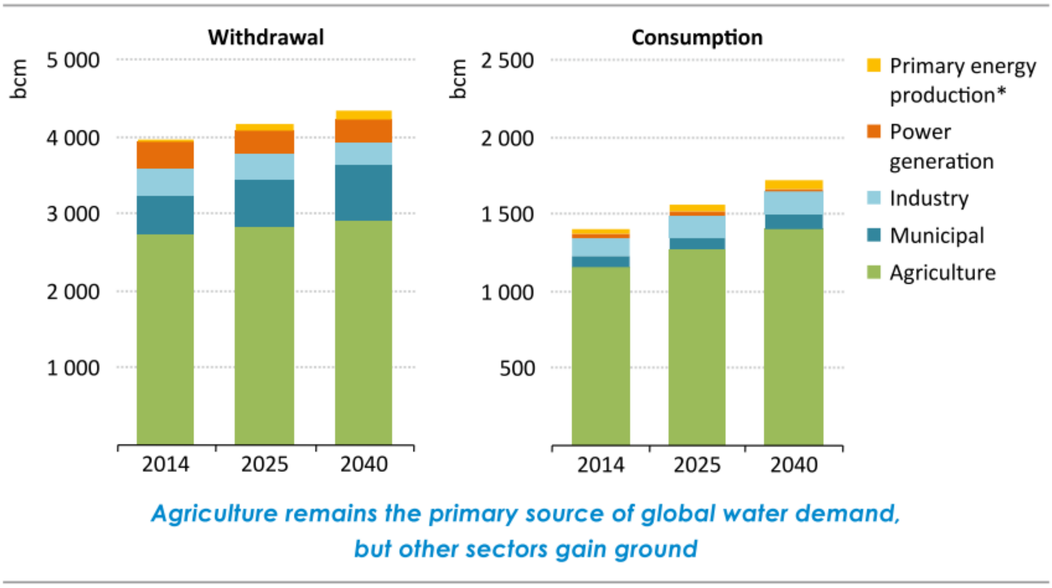


**Figure 1 – Water Withdrawal and Consumption by sectors (Source: IEA 2016, p.12)**

According International Energy Agency (IEA 2016), the three biggest freshwater withdrawing sectors are agriculture (70-85%), industry (8-12%), and energy and power generation (roughly 10%). These withdrawals are staggering when we consider that over one billion people lack access to electricity and other clean sources of energy today (UNESCO 2012).

The amount of water resources, that each country has access to, varies widely which are exacerbated by seasonal variability, especially in face of climate change. Many countries have experienced some degree of water stress – more than a billion people (around 20% of humanity) live in conditions of water stress, and this number is set to “more than triple by 2025” (WWAP 2014). IEA report predicts that by 2040, almost one out of every five countries (20% of the global territories) are set to face an unsustainably high ratio of withdrawals to supply creating a massive cause of concern (IEA 2016).

With increasing population, accelerated urbanisation and rising living standards, the demand for water by all the above-mentioned industries, especially food and energy production, are predicted to increase at exponential scales. The global water demand is expected to increase by 55% by 2050, mainly as a result of growing consumer demands, rise of consumerism and lavish lifestyles (UNESCO 2015).

## 1.2 Problem Statement

Ecuador is a developing country in South America whose economy heavily relies on its abundance of natural resources. Having a wide range of climatic variation with the coastal regions, the mountainous Andes region, and the Amazon rainforest region, the country has been blessed by an abundance of water resources with numerous rivers arising from the Andean glaciers and high precipitation for the most part of the year.

However, changes in the climate of the Earth in the past 50 years have resulted in a myriad of repercussions that pose risks to Ecuador’s availability of natural resources. Due to this, the national government has been proactive in attempting to nullify and prevent the threats that climate change poses to the country. The National Climate Change Plan (2015-2018) is one such effort setting the national climate change strategy and objectives up to 2025 (Gobeirno

Nacional de la Republica del Ecuador 2015). In recent years Ecuador has recorded sustained increases in temperature, changes in the frequency and intensity of extreme events (droughts, floods, frosts), changes in the hydrological regime and retreat of glaciers, according to the National Institute of Meteorology and Hydrology (Gobeirno Nacional de la Republica del Ecuador 2015). Between 1960 and 2006, the average annual temperature has increased while the fluctuation between the maximum and minimum temperature has also risen (Gobeirno Nacional de la Republica del Ecuador 2015, p.8).

Studies have shown that landslides, more intense rainfall, and anthropogenic activities such as mining, have resulted in the water supply from the Andean glaciers to the city of Cuenca, Ecuador, to be contaminated and unsuitable for human consumption. Therefore, increased energy is invested in water treatment plants before the distribution to meet the urban water demand of Cuenca.

Cuenca is famous in Ecuador for its water abundance and it is the centre of Ecuador's energy transition from fossil fuels to hydroelectricity. However, an increased energy investment in water treatment plants before and after its usage increases the need to study the water-energy nexus of the urban water cycle and its repercussions.

The Constitution of the Republic considers water and biodiversity as strategic sectors. This implies that the State must regulate, control and manage them under the principles of environmental sustainability, precaution, prevention, intergenerationality and efficiency (MAE 2016, p.70)

The benefits of water regulation associated with "Plan de Accion REDD+" plan (MAE 2016) represent a high priority in Ecuador. Important efforts have been made to promote a change in the energy matrix based on the development of eight emblematic hydroelectric projects. It is expected that, once completed, they will contribute significantly to the reduction of CO2 emissions in the country.

The regulation of the hydrological cycle occurs when the ecosystem stores water in the rainy periods and releases it slowly in dry periods. Thus, natural ecosystems, such as forests, provide a natural balance in the flows.

Although much of the electrical generation comes from water sources, there is some contribution from thermoelectric plants, which will maintain operating conditions to guarantee the best standards of energy efficiency and environmental performance (Ministerio de Electricidad y Energia Renovable 2017, p.46).

Climate change in the 21st century threatens to bring unforeseen scenarios for human settlements everywhere. With Cuenca relying heavily on its abundant water resources from the Andean glaciers for water and energy, it is pertinent to ensure that this interdependency of water and energy cycles is resilient in face of unforeseen futuristic scenarios. Multiple case studies have been done on urban water cycle and rainwater harvesting feasibility, however, a template needs to be established from the superior case study of Cuenca, for other cities around the world to emulate.

## 1.3 Research Objectives

- Analyze the water-energy nexus of Cuenca's urban water metabolic cycle – it will be interesting to look at the junctures where water-energy interlinkages exist in the water metabolic cycle.

- Study what future benefits water-energy saving technologies (WEST) like rainwater harvesting can add to the current system.
- Contribute to further developing the current methodology of studying water-energy interdependencies in academic research. A comprehensive water-energy nexus study is highly complex since water and energy have far-reaching ramifications in almost all sectors. Therefore, in light of climate change, a robust methodology needs to be developed that help cities forecast and prepare for the adverse effects of climate change.

## 1.4 Research Question

***To what extent can water-energy saving technologies (WEST) influence the water-energy nexus in Cuenca's water metabolic cycle?***

Sub-questions:

1) ***How does the urban water metabolic cycle of Cuenca function in the current scenario?***
   This research sub-question would help establish the Business-As-Usual (BAU) scenario by understanding how does it function with full details on the water management processes.
2) ***What are the threats or risks to Cuenca's water systems due to climate change in the 21st century?***
   This sub-question would help assess the climate change threats to Cuenca's water sector. The answers will be linked to sub-question 3.
3) **What are the water-energy saving technologies (WEST) that best suit the needs and the context of Cuenca?**
   The climate change threats would then require solutions – WEST will be the solutions that will shortlisted based on their suitability.
4) **What are the implications of water-energy saving technologies (WEST) on the water flows and the energy demand from the urban water metabolic cycle in hypothetical projections?**
   Detailed analysis on how each shortlisted WEST can influence the BAU scenario, helping the researcher assess the feasibility and performance of WEST.

## 1.5 Significance of the Study

The local government of Cuenca, Ecuador, is prioritising to work on climate change adaptation and mitigation action plans for the future. Simultaneously, the national government is also proactively working on the National Urban Agenda in collaboration with GIZ and other consultants (GFA and IHS 2018). Academic studies have analysed the water metabolism of Cuenca (Malo-Larrea 2014), Quito and other cities of Ecuador. Additionally, academic studies have also been conducted in studying the feasibility and impact of water management practices such as residential rainwater harvesting, and the influence these water management practices can have assisting Cuenca to mitigate future climate change threats such as floods, droughts and other water-related threats (Chacha 2015). This is especially significant due to the heavy reliance of Ecuador on its rich water resources. Ecuador's 58% energy comes from hydroelectricity (Ministerio de Electricidad y Energia Renovable 2017) and Ecuador aims to be fully dependent on hydroelectricity by 2025 removing fossil fuel dependency from its energy mix. Hence, it is important for Ecuador and its cities to prepare for the unforeseen impacts climate change might have on its water resources like the Andean glaciers, precipitation, rivers and ground water levels.

Multiple government plans and policies have been launched with the aim to activate stakeholders at national and local levels, clearly defining targets and responsibilities for the coming years by Cuenca's local government, as well as Ecuadorian national government. The following was the list of Ecuadorian Government plans/statutes used in this study:

1) MAE (Ministerio del Ambiente del Ecuador). (2016). *Plan de Acción Redd+.*
2) Gobeirno Nacional de la Republica del Ecuador. (2015). *Plan Nacional De Cambio Climatico 2015-2018.*
3) *Diagnóstico de las estadísticas del agua en Ecuador* – CEPAL (2012)
4) *La Gobernabilidad de la Gestion del Agua en el Ecuador* - (Global Water Partnership and SAMTAC 2003)
5) *National Energy Efficiency Plan 2016-2035*(Ministerio de Electricidad y Energia Renovable 2017)
6) *Estrategia Nacional de Cambio Climatico del Ecuador 2012-2025* (MAE 2012)

These documents elucidate the government's concern about climate change risks that render cities like Cuenca vulnerable. Meanwhile the relevance of this study is to contribute to an enhanced understanding of integrated urban water models at the urban level and the deep impact of the urban water cycle in all sectors of cities. This thesis presents a study of an urban water cycle case study of Cuenca which is renowned in Latin America for its superior water management practices and water abundance in general. However, by looking at a case where hydroelectricity is successful and the most important source of energy, a blueprint can be developed that can be emulated by other cities around the globe. Also, even if Cuenca is blessed with water abundance, regions around Ecuador suffer water scarcity (for example, Peru). Therefore, it is also important to understand how countries like Ecuador can assist in fulfilling their own water needs but also of the region around them. Furthermore, this thesis shall provoke a subsequent critical discussion on how to use forecasting of urban water management and saving measures to ensure water and energy availability in the future, making the society more sustainable and environment-friendly by studying the unforeseen adverse effects of climate change.

Known for its water abundance and hydroelectricity, Cuenca's urban water metabolic cycle and its management will be useful to study an excellent example of sustainable water management practices to emulate in other parts of the world. By studying the urban water metabolic cycle, the research intends to enhance the academic knowledge over better resource management of the urban water area and the energy involved in the processes. In the context of Cuenca, the research aims to highlight the role of the water-energy saving technologies as well as the importance of studying the water-energy nexus of Cuenca's water system in assessing vulnerability to climate change-related risks and implementing adaptation/mitigation measures to prepare for a resilient future.

## 1.6 Scope and Limitations

The scope of this research is to do a quantitative analysis of the urban water metabolic cycle of Cuenca, Ecuador. Residential water flows, energy demands, and GHG emissions are variables used in an LCA framework to study the water-energy nexus in the urban water metabolic cycle and its environmental footprint. This analysis helps build the BAU scenario that is the baseline and the main subject of study. Thereafter, using interviews and online questionnaire of water and climate experts in Cuenca, climate change-related hazards to Cuenca's water sector are evaluated. This is followed by selection of suitable WEST that address these climate change threats helping make Cuenca's water sector more resilient in theory. In the last step, detailed projection scenarios of each selected WEST are created till 2030 and compared against the BAU scenario to assess the performance of WEST on the basis of multiple criteria, following CBA and CEA methodology to determine the feasibility and potential impact of WEST.

This research study attempted to replicate the research methodology of the water-energy-climate nexus study of Mexico City by Adrian Valek at Institute of Housing and Urban Development Studies (Erasmus University of Rotterdam) (Valek 2016).

The limitations of the research study were the following:

a) Primary data for the GHG emissions was collected based on the energy consumed by the water system. However, in reality, unaccounted sources of GHG emissions in the process were difficult to ascertain due to the limited timeframe and the scope of the research study.
b) The case study of Cuenca does not represent all cities in Ecuador (and therefore the study lacks external validity). However, the research highlights the methodology by which similar analysis can be replicated in other cities in Ecuador and other cities around the globe. The research also highlights the necessity to acknowledge and study the intricacy of water-energy-climate nexus in light of 21st century climate change adaptation and mitigation commitments rising to priority list of governments around the world.
c) Language barrier was significant. Due to all documents of secondary data and the language spoken by experts interviewed being Spanish, the research was heavily reliant on a Spanish to English translator which might have slowed down or inhibited information exchange to its full potential
d) The study relies strongly on quantitative data for water and energy consumption, and their related costs. Due to the confidential nature of the monetary information, the public company ETAPA was hesitant in making the data available. This definitely affected the triangulation process of the research since some key data had to be sourced from secondary sources which could not be triangulated and could have been outdated.

# Chapter 2: Literature Review / Theory

This chapter is dedicated to discussing the concepts that arise from the research question of this study. To answer the research question, the first step was to conduct a literature review. A literature or theoretical review was conducted to understand the concepts of water-energy nexus, the urban water metabolic cycle, and water-energy saving technologies (WEST) – the three concepts introduced in the research question. The chapter also helps to analyse the methodologies utilised in other similar studies, which helps to develop the methodology used in this research. The literature review also contributes to the refining of the variables utilised and the inter-relationships of the concepts in the research question and thereafter, leads the discussion to the research methodology for this research discussed in the next chapter.

## 2.1 Water-Energy Nexus in Urban Water Metabolic Cycle

The first concept that the research question focuses on is the water-energy nexus in the urban water metabolic cycle. It is important to understand what the term 'water-energy nexus' means and how it is connected to climate change studies. In the following sections, the different dimensions of the term water-energy nexus are discussed, followed by the introduction of what constitutes a typical urban water metabolic cycle. The section then concludes with sub-sections discussing how water-energy nexus in the urban water metabolic cycle has been studied in the literature that contributes to defining an appropriate methodology for this research study.

### 2.1.1 Water-Energy Interlinkages

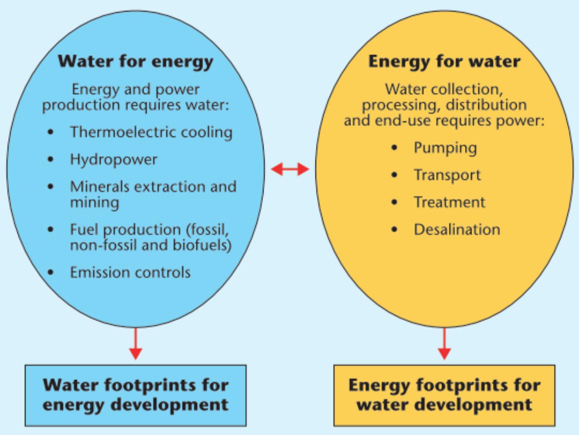


**Figure 2 - Water-Energy Interlinkages (Source: UNESCO 2009, p.117)**

Water and energy are inextricably inter-linked. Hardy et al. (2012, p.151) define the water-energy nexus as "the two-way connection, water needed for energy generation, and energy for the use of water distribution and treatment". Department of Energy (USA) (2014) refers to the water-energy nexus as "water plays a critical role in the generation of electricity and the production of fuels; energy is required to treat and distribute water." The water-energy nexus occurs when humans use water to generate energy, and also when energy is consumed to utilize/access water resources. The nexus reveals substantial trade-offs and opportunity costs associated with the ways water and energy are used. A better understanding of the water-energy nexus is absolutely essential for better "integrated resource planning that optimizes the use of invaluable and increasingly scarce resources" (Griffiths-Sattenspiel and Wilson 2009, p.5). Another definition is presented by UNESCO as water is essential in generation of all forms of energy to some degree; and energy is required for the various stages of the water use cycle. "These interlinkages and interdependencies, along with their negative and positive externalities, lie at the heart of what has become known as the 'water–energy nexus'" (WWAP 2014, p.13).

### 2.1.2 Water for Energy

Water is utilized in nearly all forms of energy generation processes. In 2014, the energy sector "accounted for roughly 10% of total worldwide water withdrawals and around 3% of total water consumption" (IEA 2016, p.12). Excluding hydropower, the power sector is responsible for 88% of total water withdrawals by the energy sector, while primary energy production uses the remaining 12% (IEA 2016). In the power sector (excluding hydroelectricity), water is used primarily for cooling (example - thermal power plants). In primary energy production, water is consumed for the different stages of the fuel cycle (example - extraction, processing and treatment in fuel refineries) and crop production (example – corn grown for biofuel production). These various applications that use water resource as an input primarily define the phrase "water for energy" in the water-energy nexus. It is defined by (Hardy et al. 2012, p.152) as "the amount of water required to produce one unit of energy, both outside the plant to procure the raw material and inside the plant for cooling systems."

Hydropower accounts for 16% of current world electricity production and also provides energy storage (IEA 2016, p.24). Hydropower elucidates the best example of what effect water shortages, caused due to fluctuations in seasonal water availability because of climate change, can have on electricity production. Hydroelectricity also best exemplifies the water-energy interdependency. Since, hydroelectric dams affect the flow of rivers and other water bodies, it is difficult to leave these out of context when studying the water cycles/metabolism of cities.

### 2.1.3 Energy for water

Energy is needed to pump, transport, process, treat and use water. The phrase "energy for water" refers to the energy demand of water cycles. Hardy et al. (2012) define "energy for water" as the energy costs of the water use cycle, including the energy costs of water pumping and treatment processes. Energy demand of water sectors "account for 60-80% of water transportation and treatment costs and 14% of total water utility costs" (UNESCO 2009, p.117). The table below shows the energy use of various processes in the water sector.

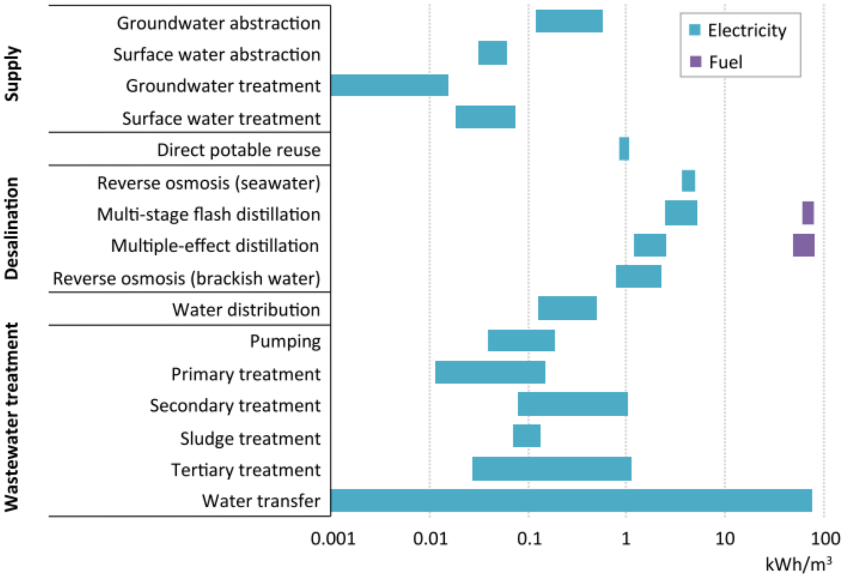


**Figure 3 -Energy usage in water sector (Source: IEA 2016, p.27)**

Energy demand in water sector is also affected by demographic, economic, social and technological drivers, similar to the factors that put pressure on the water resources of the world

(UNESCO 2009). According to IEA's World Energy Outlook 2016 report, roughly 120 million tonnes of oil equivalent (Mtoe) of energy was the water sector's total energy demand globally in 2014 which is equivalent to Australia's total energy demand (IEA 2016). This energy demand is only going to increase in the near future as easily available surface and ground water disappear, leaving water to be extracted or treated from more energy-intensive sources (IEA 2016).

As elaborated above from the two-way connection of the water-energy nexus, water and energy are two resources that are not only extremely inter-dependent but also of major concern in a fast urbanizing world in the face of adverse effects of climate change. With an increasing population and increasing economic needs, the stress on the demand for resources like water and energy is creating concerns for local, national and international governments. This has caused an increase in the need to study urban water and energy cycles to optimize the use of these resources and ensure efficiency, sustainability, and abundancy of these resources to meet future human needs. (Valek et al. 2017) note that the urban water cycle requires energy in all the various stages and it is "very resource inefficient" (Valek 2016, p.10). Similarly, (Hardy et al. 2012) demand for two types of assessments - energy audits to be carried out for the various stages of the urban water cycle, and water audits to be carried out in energy generating facilities to increase the efficiency of both water and energy usage. Due to limitations of time and availability of information, the scope of this study has been limited to the energy audits for the various stages of the urban water metabolic cycle and the following section delves deeper into the concept of urban water metabolic cycle.

### 2.1.4 Urban Water Metabolic Cycle

The concept of the urban metabolism has been considered "fundamental to developing sustainable cities and communities" (Kennedy et al. 2011, p.1965). Kennedy et al. (2011, p.1965) also state that the urban metabolism studies involve "'big picture' quantification of the inputs, outputs and storage of energy, water, nutrients, materials and wastes for an urban region." This concept of macro-scale study approach of the inputs and outputs has been applied to studying the water sector in Cuenca.

According to World Energy Outlook 2016 (IEA 2016), energy is required in each step of the processes of the water sector. The major processes of the water sector included –water supply, long-distance transport, water treatment, desalination, water distribution, wastewater collection, wastewater treatment, and water re-use.

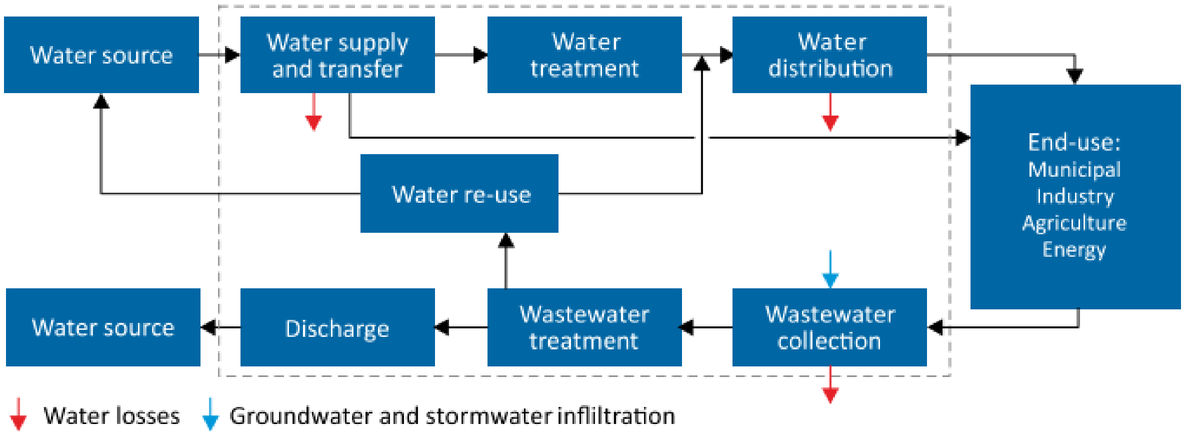


**Figure 4 - Typical Urban Water Metabolic Cycle** (Source: IEA 2016, p.29)

(Hardy et al. 2012) studied Spain's water use cycle and broke the water cycle into three big stages – 1) Extraction and water treatment, 2) Distribution/water use, and 3) Wastewater treatment. Previous studies on the urban water cycle of Cuenca, Ecuador, reflect a similar urban water metabolic cycle model. Two past studies specifically deal with Cuenca's water system development by taking a metabolic perspective in their studies. The urban water metabolism study constituting the hydrological cycle is split into four segments – analysis of 1) Freshwater availability analysis, 2) Potable water production analysis, 3) Domestic water consumption analysis, and 4) Sewerage analysis (Chacha 2015; Malo-Larrea 2014). In Valek's (2016) study of Mexico City's water cycle, there are 3 components to the urban water cycle – water supply (includes extraction, withdrawal, pumping), water treatment/re-use, and sewage.

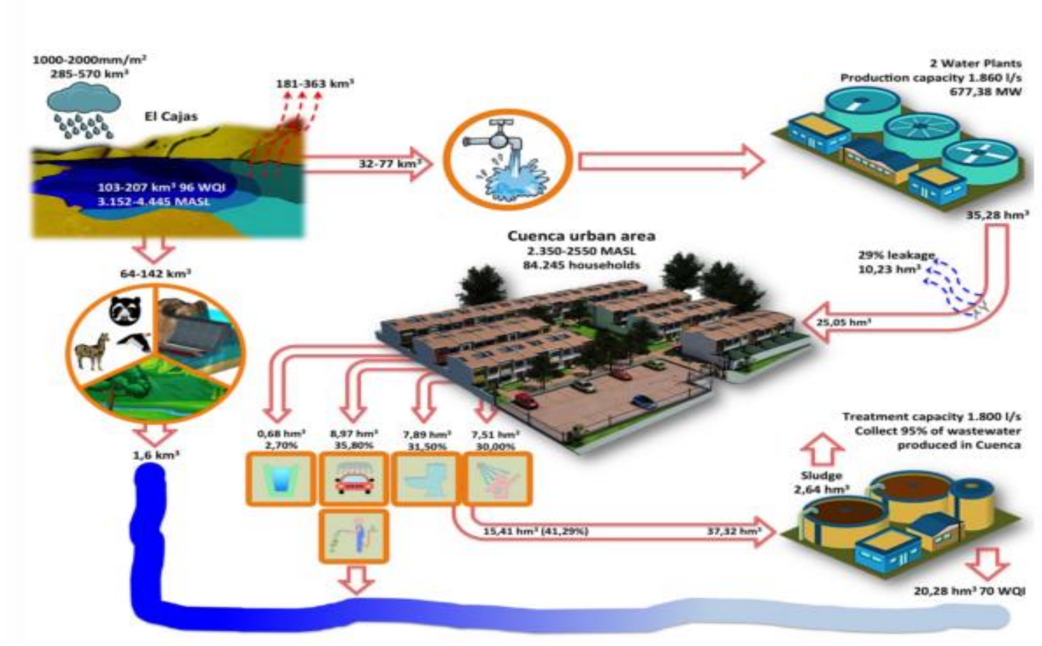


**Figure 5- Urban water cycle of households in Cuenca urban area** (Source: Chacha 2015)

Most studies conclude that the pumping of water generates the largest energy demand among all the processes in the water cycle (IEA 2016; Hardy et al. 2012), in some cases consuming up to 80-91% of electricity consumed of all water processes (Mohamed et al. 2010). In Figure 6 above, Chacha (2015) illustrates the various stages of the urban water cycle of Cuenca urban region noting the various volumetric flows of water, leakages in the distribution system (29% of all potable water produced), as well as the energy demand of the production and treatment capacities in the water system. This is a good example that will be used as a reference in this research study to confirm new findings and note improvements to the water cycle of Cuenca in this research study. Based on the various research studies and their approaches towards analysing the urban water cycle, this research will also break down the water cycle into three main stages – 1) Potable water production, 2) Distribution/residential water use, and 3) Wastewater treatment.

### 2.1.5 Framework to assess water-energy nexus in the water metabolic cycle

According to literature, conducting a holistic water-energy nexus study is extremely complex due to the large implications of water and energy usage across various sectors in the urban context (Rathnayaka et al. 2016). Therefore, in this research study, the scope is limited to the 'energy for water' connection of the water-energy nexus since the study focuses on the urban water cycle of Cuenca, Ecuador. In literature, there are numerous studies done analysing the urban water metabolic cycle. It is important to discuss the methodologies used in the past to choose the appropriate methodology for this research study.

*Methodology/Framework*

Life Cycle Assessment (LCA) is a useful methodological tool to study “urban water systems in a holistic way” (Mohamed et al. 2010, p.1100) which involves “methodological decisions about the level of detail which is retained through different stages of the process” (Lundie and Peters 2004, p.3465). In (Sapkota et al. 2015, p.4) paper on hybrid water supply systems, a generalized framework which is supported by “models and tools including water balance modelling, contaminant balance modelling, multi-criteria decision analysis (MCDA), and future change analysis” is utilized. In (Mohamed et al. 2010) study, the models used the volume of water/wastewater, energy consumed of each process, chemicals used in each process, and transportation distances as the inputs for each process of water system and generated the outputs of water-borne emissions, air-borne emissions, and solid waste. Chacha (Chacha 2015) utilizes the urban water metabolism analysis breaking the hydrological cycle into 4 components – freshwater availability, potable water production, domestic water consumption, and sewerage. The paper analyses the implementation of the Integrated Urban Water Management (IUWM) methodology by conducting feasibility analysis of rainwater harvesting in Cuenca, Ecuador. Both LCA and IUWM methodologies focus on studying water quantity and water quality in the urban water systems (GWP and Bahri 2012). The difference between the two approaches is ambiguous since both aim to ensure the study of water flows (quantity and quality), managing water sources (such as rainwater, wastewater, storm water drainage, and runoff pollution), preventing water-borne diseases, and reducing the risks of water-related hazards, while ensuring the sustainability of the water resources for future generations (GWP and Bahri 2012). This research study works within the scope of the framework setup by these methodologies.

The environmental indicators and impact categories used by (Lundie and Peters 2004) in their case study of Sydney’s water cycle were – total energy use, water use, climate change contributions (GHG emissions), eutrophication potential, photochemical oxidant formation potential, human toxicity potential, freshwater and marine aquatic ecotoxicity potential, and terrestrial ecotoxicity potential. Another study done in Alexandria city, Egypt, used the following environmental indicators to measure the impacts of the water system – carcinogens, GHG emissions, ecotoxicity, mineral depletion, respiratory organics, radiation, respiratory inorganics, ozone layer, land use (Mohamed et al. 2010). For water quality, (Chacha 2015) simply refers to the Water Quality Index (WQI), an indicator used by the public water company in Chacha’s study. The WQI simplifies our analysis of water quality by combining a host of quality tests to give one index indicating the quality of water for human consumption. This is appropriate to be used for the scope of this study. (Rathnayaka et al. 2016) discuss a range of evaluation criteria to assess the sustainability of water supply and demand management options. Of these, environmental criteria including quality and impacts of wastewater produced, quantity of wastewater produced, storm water runoff, freshwater/potable water saved, GHG emissions, energy use and recovery, renewable energy source usage, reuse and recycling of resources – seem to fit the scope of this research study.

For the purpose of this study, volume of water/wastewater flowing through the various stages in the water cycle is studied. This is accompanied with the analysis of the energy consumed for each process. The generation of this energy has an environmental footprint, which is utilised by the water cycle, sheds light on the GHG emissions in the form of equivalent carbon dioxide (CO2e) emissions. This paper used the CO2e emissions of the energy generation process as an indicator of the sustainability of the process in line with climate change mitigation and adaptation framework  utilized by Demuzere et al. (2014). For the aspect of water quality, this study does include the WQI indicator (Hossain et al. 2013; Chacha 2015) to keep a check on the quality of water for the various stages of the water cycle but does not analyse this indicator in depth. The prime focus of the study is on the water flows, associated energy consumptions, and the related GHG emissions from the water sector. These indicators were also utilized to gauge the adaptation and mitigation benefits the implemented WEST could potentially contribute to the water-energy nexus in the urban water cycle.

## 2.2 Adaptation and Mitigation Co-Benefits in Water-Energy Saving Technologies (WEST)

The concept of 'water-energy saving technologies' (WEST) represents the technological actions/measures taken to conserve water and energy resources or make their consumption more sustainable in face of two kinds of future uncertainties – gradual changes (like climate change, etc.) and system shocks (like natural disasters and energy price spikes, etc.) (George et al. 2011, p.17). WEST have a deep connection to climate change and the discussion of adaptation and mitigation efforts. Water savings are essential for urban water security (Valek 2016). In face of global climate change, countries are working towards adaptation and mitigation measures that will help reduce their vulnerability to the adverse effects of climate change. Knowledge of adaptation and mitigation co-benefits, inter-relationships are valuable for urban planners to develop "integrated climate policy making and planning practices" (Landauer et al. 2015, p.506). Water management is at the heart of the concerns arising from climate change. While some places face water scarcity due to lack of precipitation and drying rivers, other areas are endangered by flooding and rising sea levels. Therefore, while studying carbon dioxide (CO2) or greenhouse gases (GHG) emissions might be synonymous with worldwide discussions of global warming and climate change, there is a need to realize that CO2 emissions are not the only aspect of climate change that are important. Of all the other aspects and dimensions that need studying in the subject of climate change, the one subject that is absolutely pertinent to be emphasized and studied is the topic of water management in all discussions related to the changing climate.

In this research, the urban metabolic water cycle, its consequent energy uses and equivalent carbon dioxide emissions (CO2e) in the various stages of the water cycle are studied in a climate change framework. Simultaneously, this research also makes the case to emphasise the importance of adaptation and mitigation synergies. Water-energy saving technologies (WEST) reduce water-related energy consumption and mitigate GHG emissions, and therefore, are important tools that symbolize the adaptation/mitigation co-benefits. For example, while rainwater harvesting reduces storm water run-off (by capturing and storing rainwater), it also lowers the energy consumption of the water system (local collection and consumption of rainwater removes the need for treatment/pumping to households) (Valek 2016; Chacha 2015; Schmidt 2015). This dual benefit of rainwater harvesting makes it a "'no regret strategies" (Swedish Water House 2009, p.3) which means that this strategy is useful for most places around the globe with different contexts and problems (suitable for drought problems as well as places prone to flooding) and hence, make these strategies relevant to global problems such as climate change. Another synergy can be cited in green roofs and green walls that help reduce heat island effect (adaptation), reduce rainwater run-off (adaptation), sequester carbon (mitigation), and passively cool/heat buildings increasing the energy efficiency of buildings (mitigation) (Landauer et al. 2015; Demuzere et al. 2014; Herrera-gomez et al. 2017; Sadat et al. 2015). In summary, these 'water-energy saving technologies' are of immediate necessary consequence in the pursuit of sustainable management of world's water resources to mitigate or adapt to the changing climate globally.

**Supply and Demand-based Strategies for Sustainable Water Management**

In the world of economics, supply and demand are the two fundamental forces that make a market-based economy. In water management theories, increasing the sustainable management and use of water resources can also be broadly categorized into two segments – 1) Supply, and 2) Demand (Rathnayaka et al. 2016; George et al. 2011).

### Supply-based strategies and technological solutions

The supply-based strategies/solutions refer to practices that help optimize water management on the side of water distribution, storage, treatment, sewage, and other systems. The most commonly discussed strategy in literature to reduce water wastage on the supply side is increasing efficiency – that refers to minimizing of water leakages and other water losses in water distribution system (GIZ 2011; Griffiths-Sattenspiel and Wilson 2009; Valek et al. 2017). Secondly, Low Impact Development (LID) strategies (green roofs, rainwater harvesting, bio-retention areas, permeable pavement, etc.) refer to projects that essentially “reduce run-off and pollutant loadings by managing stormwater” at source site (Griffiths-Sattenspiel and Wilson 2009, p.31). Similarly, the use of rainwater harvesting (off-grid technology), public space water retention measures (Netherlands’ example of “water squares”), water recycle and re-use (example of Denmark’s water treatment plant that produces energy from the wastewater) are also methods mentioned in literature (Valek 2016). Furthermore, Chacha (Chacha 2015) adds the use of constructed wetlands as wastewater treatment and flood control systems while restoring natural habitats. These constructed wetlands have been an answer to solve Cuenca’s rural settlements wastewater treatment needs. Moreover, pressure management in the water distribution (GIZ 2011) is also another method to converse water on the supply side while still delivering water to the consumers.

### Demand-based solutions and consumption behaviours

Similarly, the ‘demand’ side of water management looks at conservation strategies that include consumer behaviour and consumption patterns, with an emphasis on reducing the demand for water from the system. The “most common demand management approach to incentivise households to conserve water” is water metering and volumetric charging (Ministry for the Environment 2009, p.4). Water metering and pricing reforms are strong tools to control domestic water demands, however, these tools are not enough (Domene and Saurí 2006; Fan et al. 2014). In some cases, for example, a survey done in Sydney found that most respondents were under the impression that they were consuming average or below average amount of water in their neighbourhoods, indicating a need for more awareness needed among respondents to understand their relative consumption to their neighbours and other countries (Randolph and Troy 2008). In the same study, although people found the water prices to be too low to encourage water conservation, they were against the idea of increasing water prices because people felt that they should not have to pay more for environmental stresses caused by others (Randolph and Troy 2008). Additionally, the theory of the ‘tragedy of the commons’ has also been found in other similar studies to play an important role in people’s behaviour explaining the high consumption and wastage of water at residential level (Corral-Verdugo and Espinoza-Gallego 2002). Therefore, water conservation campaigns are advocated by many studies in the form of interventions, education, outreach and community programs that emphasise the possibility of changing people behaviour by understanding the reasons behind the behaviours and helping them find alternate choices (Miranda 2015; Ministry for the Environment 2009; Domene and Saurí 2006). Alternatively, theories also focus on water conservation by consumers in the form of water re-use: greywater arises from clothes washing machines, baths, showers among others. This greywater instead of being discarded can be re-used for gardening, toilet flushing, and car washing, etc. (Griffiths-Sattenspiel and Wilson 2009; Guyot-Téphany et al. 2013).

In summary, the above section discusses the various approaches, strategies and tools that have been explored by studies on the ‘supply’ (water management systems) and the ‘demand’ (consumer behaviour) side. This research did not look at people’s behaviour and approaches to reduce consumption behaviour. This research study focused on technological solutions that can increase the efficiency of the water distribution systems, contributing to the rise in sustainable management of water resources. Low Impact Development (LID) strategies such as rainwater harvesting (individual and community level), green roofs, public retention spaces (Valek 2016; Guyot-Téphany et al. 2013; Chacha 2015) have been especially considered as potential mechanisms to improve the urban water cycle in Cuenca, Ecuador. The reason for focusing on LID strategies for this research is two-fold: LID strategies are easy to implement and cheap. This makes them relatively attractive solutions for municipalities in the global south, which might not have abundant resources at their disposal. LID strategies are replicable on household level, community level and even city-level. Projects like green-roofs and rainwater harvesting can be installed on individual building and household, while also help formulate city-level strategies and policies. Secondly, LID strategies like green roofs and rainwater harvesting are useful for all extreme weather scenarios – they are useful in a drought situation (help in providing alternate mechanisms to collect and store water) as well as in a flood situation (help in reducing run-offs and managing storm water).

## 2.3 Water-Energy Saving Technologies (WEST) influence on Water-Energy Nexus

The research study aims to understand the impact shortlisted WEST could have on the water-energy nexus in the urban water metabolic cycle. Using the water flows of the hydrological metabolic cycle, one study calculates the impacts of reducing leakages, pricing reforms and rainwater harvesting on the water consumed by the system, yielding a water saving percentage on an annual basis (Valek 2016; Valek et al. 2017). Similar approach was taken by Chacha (2015) but the focus was on only rainwater harvesting as a water saving measure implemented. Taking rainwater harvesting as an example, the technology fulfils two purposes – it reduces the storm water runoff to the wastewater drainages and it can also be used to fulfil some fraction of the residential or industrial water demand, hence, reducing water demand from the water grids of the city. One indicator that comes out of these two studies is the annual precipitation levels used to calculate the potential amount of rainwater that can be captured by the water saving technology. This indicator was also used in this research study to understand the potential of water savings by rainwater harvesting. For analysis of the WEST influence on the water-energy nexus, the annual water saving percentage (similar to Valek 2016 study) was calculated. Thereafter, the energy demand for the WEST hypothetical scenarios were measured by calculating the energy consumed by the implemented WEST and the energy needed for the remaining percentage of the water cycle delivered by the conventional grid as per the Business-As-Usual (BAU) scenario. Hence, in essence, the WEST reduce the water demand from the conventional grid of the water system in the urban context. This reduction of water demand creates a diversification of the water supply sources and has an implication on the energy required for treatment and distribution of water to residences and industries. The implication on the water flow of the wastewater treatment facilities is also an important factor which is studied and quantified. Similarly, WEST (for example, micro-hydropower turbines (Elbatran et al. 2015; Okot 2013; Paish 2002)) also help to reduce the energy demand from the conventional energy grid – energy demand that arises from the water metabolic cycle. Therefore, WEST can be essential in accomplishing a resilient water and energy sectors for any urban or rural context.

According to literature, the development of WEST has multiple benefits which include –

i) GHG emission reduction: Similar to the benefits of green urban infrastructure as mentioned by (Demuzere et al. 2014), WEST reduce the energy consumed to treat and transport water across the various stages of the urban water cycle. Depending on the generation process of the energy, CO2 emissions are mitigated for conventional fossil fuel relying processes among others.

ii) Water losses to sewage: Due to impermeable urban roads and buildings, rainwater fails to recharge groundwater but instead adds to the water to be managed by the downstream areas creating long term stresses on groundwater levels upstream, and flooding issues downstream (Swedish Water House 2009). WEST help retain high quality of rainwater in on-site storage tanks, ensuring less water to sewage.

iii) Evaporative cooling of buildings: (Schmidt 2015) says that water harvested from water saving measures can be used to cool buildings. Water is the cheapest and most effective method to cool a building without any energy invested in air cooling devices such as air-conditioners. This usage of harvested water has huge implications for the energy sector. Less energy required to cool buildings implies lower stress on the water-energy nexus in the energy sector.

iv) On-site local water supply: As IUWM aims, WEST help reclaiming and reusing water resources multiple times, “cascading from higher to lower quality” (GWP and Bahri 2012, p.37). Storm-water or rainwater becomes a resource increasing local sustenance, reducing the reliance on water from centralized water grid systems.

*Methodology/Framework*

The water supply and demand investment options assessment framework (WSADIOAF) shown in the figure below focuses on key performance criteria such as affordability, waterway health criteria, maximum level of GHG emissions, cost to society, and externalities to assess the performance of new measures (George et al. 2011).

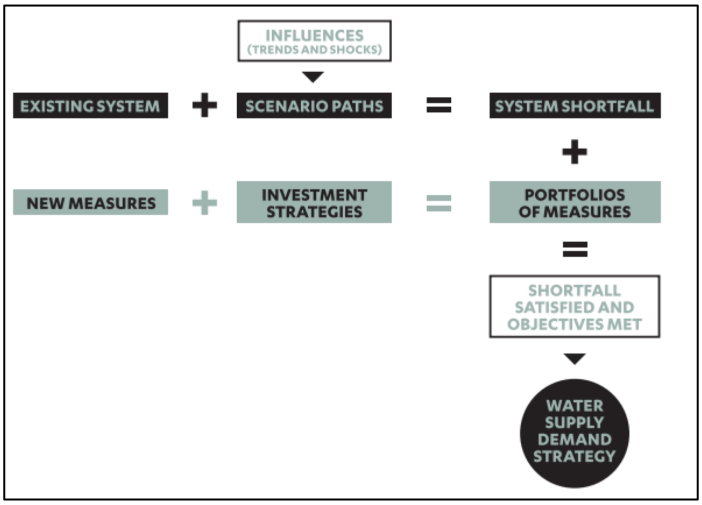


**Figure 6 - WSADIOAF (Source: George et al. 2011, p.3)**

The framework, illustrated above, was strongly influential for this study’s methodology discussed later in chapter 3. Initially, this framework looks at an existing system and analyses the “trend influences” in order to identify the factors that may change or create problem in the future (George et al. 2011, p.11). In the next step, scenario paths are developed creating a forecast into the future using the trend influences established. Thereafter, new measures that are considered solutions to respond to the influencing trends, are assessed through methods like Cost Effectiveness Analysis (CEA), Cost Benefit Analysis (CBA), Valuation, Resource

Intensity, and Multi-Criteria Decision Analysis (MCDA). These new measures are then packaged into 'portfolios of measures' and these portfolios are evaluated economically, socially and environmentally using set logic and objectives. This methodology developed by George et al. (2011) yields the water supply demand strategy (WSDS). This approach highly influenced the assessment methodology of this research study. In this research study, to assess the economic feasibility and impact of the WEST on the water metabolic cycle of Cuenca and its water-energy interlinkages, indicators such as affordability, cost to society. monetary savings by government, and externalities in the form of energy costs and GHG emissions reduction/saving have been derived in the study based on the various frameworks studied in this section. The following sub-section discusses the conceptual framework of the study. This summarizes the inter-relationships of the concepts/variables that have been discussed in this section.

## 2.4 Conceptual Framework

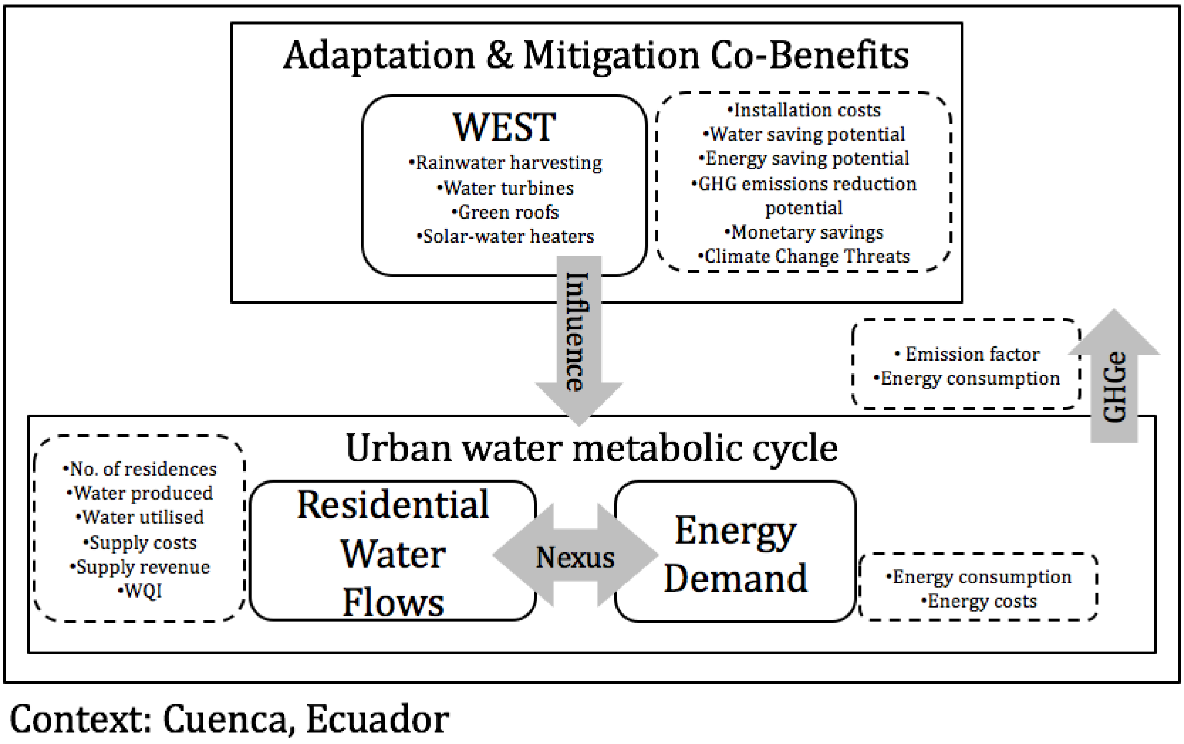


**Figure 7 - Conceptual Framework (Author 2018)**

The Conceptual framework in Figure 8 above is a simplified illustration of the relationships between the important concepts/theories that are being studied in this research. The main concepts have been obtained from the main research question of the research study. Each water-energy saving technology (WEST) is the independent variable and the research focuses on the influence the WEST can have on the dependent variable that is the water-energy nexus in the urban water metabolic cycle. The independent variable WEST represents the co-benefits of adaptation and mitigation in light of adverse unforeseen effects of climate change. As discussed in the above sub-sections of chapter 2, the urban water metabolic cycle has two components – the water flows in various stages of the water metabolic cycle and the energy input these various stages of water cycle demand for processes such as extracting, pumping, treating, and storing. This research looks at the concept of adaptation and mitigation co-benefits and how these can be applied to and influence the urban water metabolic cycle. The water-energy nexus arrow begins from inhabitants demanding two basic needs – water and energy. The ‘Nexus’ arrow indicates how energy is needed to get potable water to residences in one direction and on the other, how water flows are crucial to generating energy. This two-sided arrow represents the water-energy nexus within the urban water metabolic cycle of Cuenca.

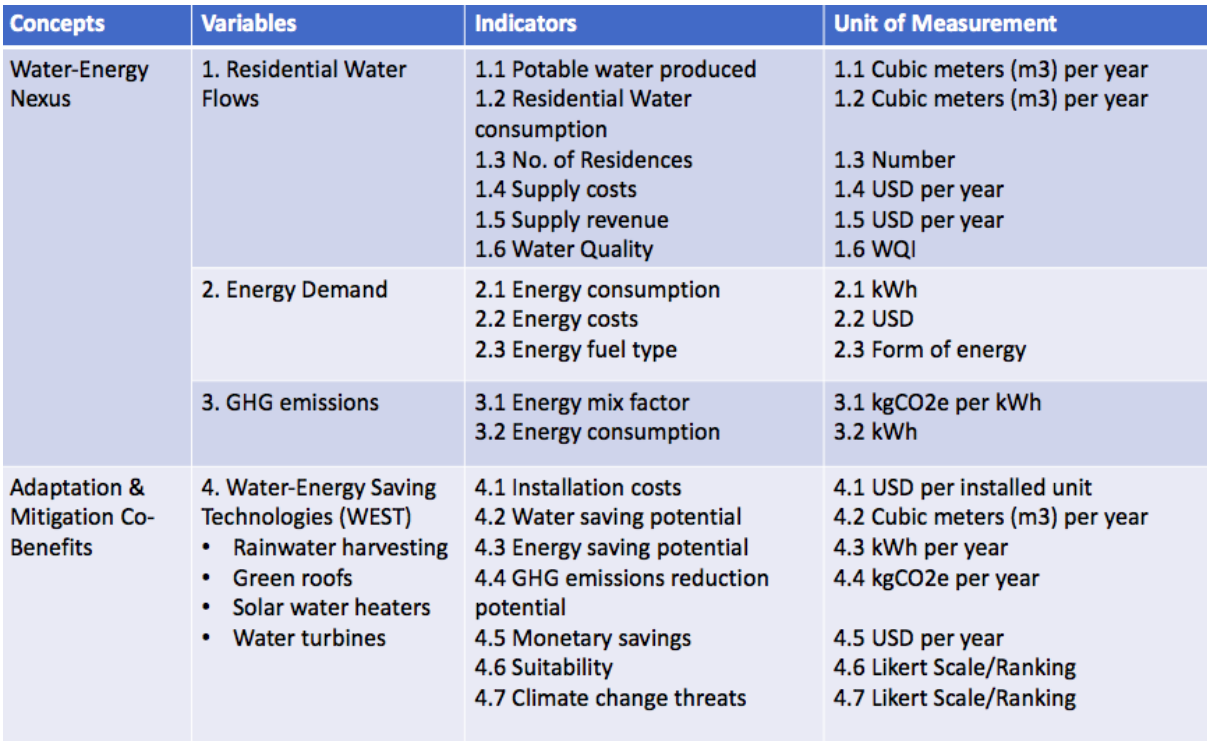
WEST are expected to influence the water-energy nexus in a positive way – making the urban water metabolic cycle more sustainable and resource efficient. WEST are expected to reduce the water and energy demand on the conventional water grid infrastructure, diminishing the water losses/run-offs to sewage after use and increase the recycling/re-using abilities of different grades of water. This research expects WEST to not have adverse effect on the water quality that is suitable for human use and simultaneously, reduce the carbon footprint (GHG emissions) of the urban water cycle.

# Chapter 3: Research Design and Methods

As explained in Chapter 1, this research aimed at investigating the effect of water-energy saving technologies (WEST) on the water-energy nexus in the urban water metabolic cycle of Cuenca. The research targeted the following steps to accomplish its research objectives – 1) study the urban water metabolic cycle and the associated water-energy nexus; 2) establish the threats climate change poses to the urban water metabolic cycle; 3) assess the technologies that are suitable and feasible to implement to make the water sector of urban Cuenca resilient to climatic threats. Based on the literature review conducted in chapter 2, an appropriate research methodology has been developed in this chapter that includes details on operationalisation, research strategy, data collection and data analysis methods.

## 3.1 Operationalization: Concepts, Variables and Indicators

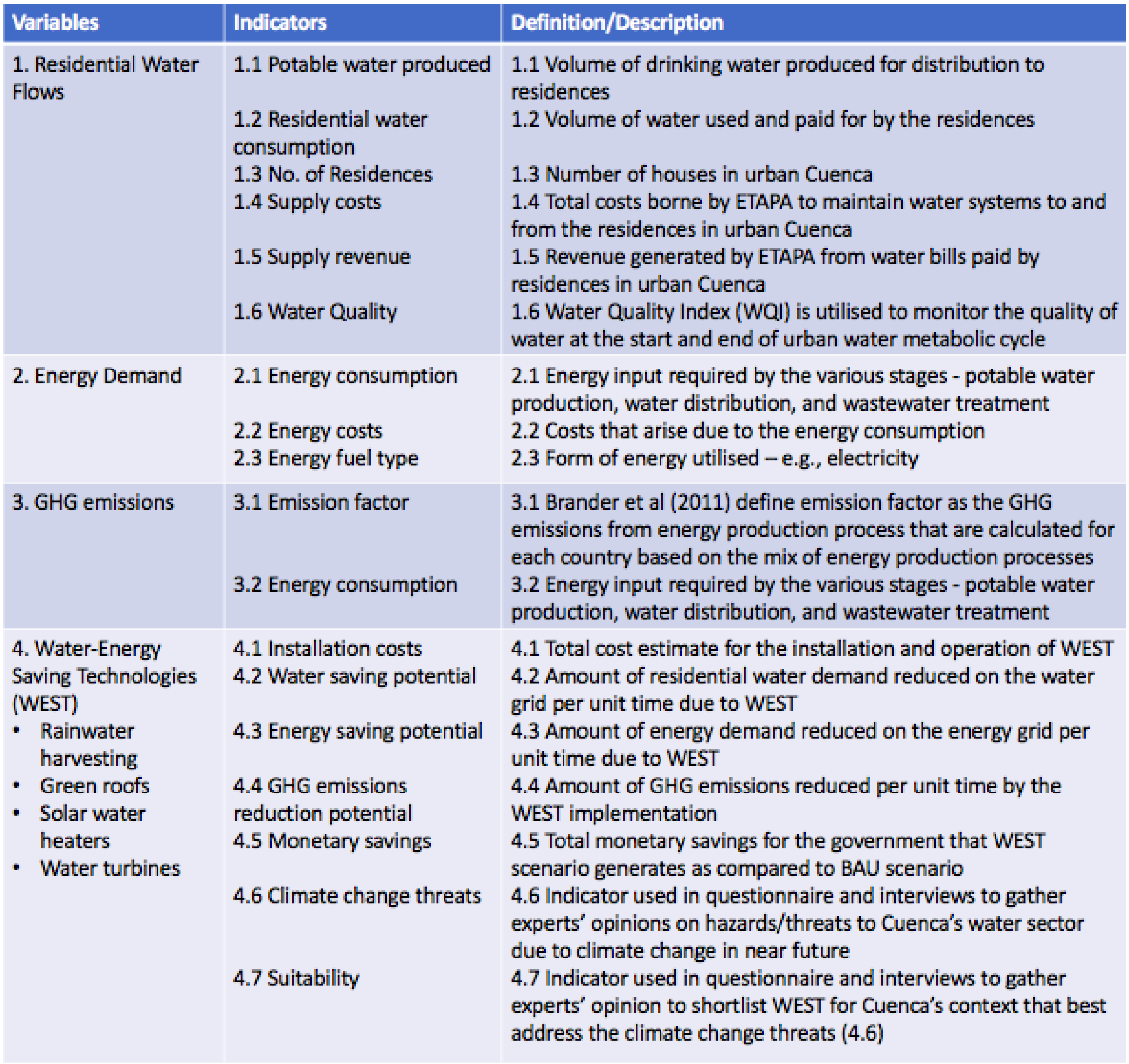
Following the conceptual framework presented in section 2.4, the concepts are re-defined and operationalized in this section.



| Concepts | Variables | Indicators | Unit of Measurement |
|---|---|---|---|
| Water-Energy Nexus | 1. Residential Water Flows | 1.1 Potable water produced<br>1.2 Residential Water consumption<br>1.3 No. of Residences<br>1.4 Supply costs<br>1.5 Supply revenue<br>1.6 Water Quality | 1.1 Cubic meters (m3) per year<br>1.2 Cubic meters (m3) per year<br>1.3 Number<br>1.4 USD per year<br>1.5 USD per year<br>1.6 WQI |
| | 2. Energy Demand | 2.1 Energy consumption<br>2.2 Energy costs<br>2.3 Energy fuel type | 2.1 kWh<br>2.2 USD<br>2.3 Form of energy |
| | 3. GHG emissions | 3.1 Energy mix factor<br>3.2 Energy consumption | 3.1 kgCO2e per kWh<br>3.2 kWh |
| Adaptation & Mitigation Co-Benefits | 4. Water-Energy Saving Technologies (WEST)<br>• Rainwater harvesting<br>• Green roofs<br>• Solar water heaters<br>• Water turbines | 4.1 Installation costs<br>4.2 Water saving potential<br>4.3 Energy saving potential<br>4.4 GHG emissions reduction potential<br>4.5 Monetary savings<br>4.6 Suitability<br>4.7 Climate change threats | 4.1 USD per installed unit<br>4.2 Cubic meters (m3) per year<br>4.3 kWh per year<br>4.4 kgCO2e per year<br>4.5 USD per year<br>4.6 Likert Scale/Ranking<br>4.7 Likert Scale/Ranking |

**Table 1- Operationalization table (Author, 2018)**

Table 1 represents the operationalization table for this research study. It enlists the main concepts of this research study as elaborated previously in chapter 2 (literature review) and enlists the variables that represent these concepts in the real world (Van Thiel 2014). The variables are also broad and therefore need specific indicators to help measure in a reliable manner. Therefore, it is important to understand the operationalization table in detail to understand the complete methodology employed in this research to find suitable answers to the revised research question and sub-questions mentioned in section 3.1. Table 2 shown below addresses the definitions and descriptions to the indicators specified in Table 1. This helps to clarify the purpose and role of each indicator in the research study.



| Variables | Indicators | Definition/Description |
|---|---|---|
| 1. Residential Water Flows | 1.1 Potable water produced | 1.1 Volume of drinking water produced for distribution to residences |
| | 1.2 Residential water consumption | 1.2 Volume of water used and paid for by the residences |
| | 1.3 No. of Residences | 1.3 Number of houses in urban Cuenca |
| | 1.4 Supply costs | 1.4 Total costs borne by ETAPA to maintain water systems to and from the residences in urban Cuenca |
| | 1.5 Supply revenue | 1.5 Revenue generated by ETAPA from water bills paid by residences in urban Cuenca |
| | 1.6 Water Quality | 1.6 Water Quality Index (WQI) is utilised to monitor the quality of water at the start and end of urban water metabolic cycle |
| 2. Energy Demand | 2.1 Energy consumption | 2.1 Energy input required by the various stages - potable water production, water distribution, and wastewater treatment |
| | 2.2 Energy costs | 2.2 Costs that arise due to the energy consumption |
| | 2.3 Energy fuel type | 2.3 Form of energy utilised – e.g., electricity |
| 3. GHG emissions | 3.1 Emission factor | 3.1 Brander et al (2011) define emission factor as the GHG emissions from energy production process that are calculated for each country based on the mix of energy production processes |
| | 3.2 Energy consumption | 3.2 Energy input required by the various stages - potable water production, water distribution, and wastewater treatment |
| 4. Water-Energy Saving Technologies (WEST)<br>• Rainwater harvesting<br>• Green roofs<br>• Solar water heaters<br>• Water turbines | 4.1 Installation costs | 4.1 Total cost estimate for the installation and operation of WEST |
| | 4.2 Water saving potential | 4.2 Amount of residential water demand reduced on the water grid per unit time due to WEST |
| | 4.3 Energy saving potential | 4.3 Amount of energy demand reduced on the energy grid per unit time due to WEST |
| | 4.4 GHG emissions reduction potential | 4.4 Amount of GHG emissions reduced per unit time by the WEST implementation |
| | 4.5 Monetary savings | 4.5 Total monetary savings for the government that WEST scenario generates as compared to BAU scenario |
| | 4.6 Climate change threats | 4.6 Indicator used in questionnaire and interviews to gather experts' opinions on hazards/threats to Cuenca's water sector due to climate change in near future |
| | 4.7 Suitability | 4.7 Indicator used in questionnaire and interviews to gather experts' opinion to shortlist WEST for Cuenca's context that best address the climate change threats (4.6) |

**Table 2 - Definition of Indicators (Author 2018)**

The operationalization tables (Table 1 and Table 2) elucidate the research question in greater detail to clarify how each concept would be measured and evaluated in the research. In this research, the independent variable is the Water-Energy Saving Technologies (WEST) and the study aims to explore and explain the impact of these WEST on the Water-Energy Nexus in the urban water metabolic cycle, which is the dependent variable in the study.

### 3.1.1 Independent Variable(s)

**Water-Energy Saving Technologies (WEST)**

'Water Saving Measures' (WSM) is a term used by Valek et al. (2016; 2017) that refers to interventions that reduce stress on flows of the highly centralized sources of water infrastructure grid. However, WSM term does not highlight the energy savings made as a result of the saving of water. As a result, this study included the term 'energy' in the variable name to highlight the impact of the measures on water and energy savings. Furthermore, the term WSM is generic to all measures for water conservation that can include technological solutions like rainwater harvesting, and non-technological solutions like pricing reforms and water conservation advertisement campaigns. For this research study, technological water-energy saving solutions were selected due to the overwhelming academic studies done on non-technological water conservation strategies as discussed in section 2.2 (Supply and Demand-based strategies for sustainable water management). This choice of leaving out non-technological solutions and strategies was triangulated later in the interviews with experts (chapter 4) in Cuenca. Therefore, this research focused more on the technological solutions that contribute to making the water sector more resilient in face of shocks (natural disasters) and gradual changes (climate change) (George et al. 2011). After conducting thorough literature review on the possible water-energy saving technologies, the selected WEST to be studied in this research were – ***Rainwater harvesting*** (Chacha 2015; Valek 2016; Schmidt 2015), ***micro hydropower turbines (water turbines)***(Elbatran et al. 2015; Okot 2013; Paish 2002), ***green roofs and walls*** (Sadat et al. 2015; Herrera-gomez et al. 2017), and ***solar-water heaters*** (WWAP 2014; Energetics Inc 2009). These options represent the predominant low impact development (LID) strategies as discussed in chapter 2. These options also fit the criteria for measures laid out by George et al. (2011) in the as per the water supply and demand investment options assessment framework (WSADIOAF) previously discussed in chapter 2. To develop the hypothetical WEST scenario (projection forecast), information about the WEST was gathered by interviews and questionnaire survey to experts in water-energy nexus study. As entailed in Table 1 and 2 above), there are seven indicators utilised to assess the impact of WEST to answer the research question of this study. The definitions of the seven indicators are enlisted in Table 2 above. Additionally, the role of the indicators in the data collection and analysis process would be as follows –

i) Climate change threats (indicator 4.6 in table 2) is important as it addresses the identification of climate change factors that would cause problems for Cuenca's water sector as per the opinions of the experts from Cuenca. This indicator aligns with the 'trend and shock influences' step laid out in the WSADIOAF established by George et al. (2011). In this research, the climate change threats to Cuenca's urban water metabolic cycle was gauged by interviews and questionnaire survey with experts.

ii) Suitability (indicator 4.7) helped to shortlist new measures (i.e., WEST) that are suitable as responses to the threats/hazards identified from indicator 4.6. As per WSADIOAF, this was done before developing scenario paths to conduct cost effectiveness analysis (CEA) and cost benefit analysis (CBA) for the WEST. In this research, the suitability of the WEST was evaluated by interviews and questionnaire survey with experts.

iii) Indicators 4.1 to 4.5 (in Table 1 and 2) were utilised to develop the WEST forecasts using MS Excel software. These indicators are crucial to assess the impact of the WEST on the dependent variable – water-energy nexus of the urban water metabolic cycle. The WEST forecasts would be compared with Business-As-Usual scenario to yield the water saving potential, the energy saving potential, the GHG emissions reduction potential, and the monetary savings for society that would help conclude whether a given WEST is feasible and beneficial for Cuenca. This step followed the Cost Benefit Analysis (CBA) and Cost Effectiveness Analysis (CEA) methodologies. CEA methodology is mentioned due to the non-monetary benefits of the GHG emissions reduction to society and Ecuador's national targets achievement.

The reason for focusing on low impact development (LID) technological options was primarily that they are effective, cheap and play an important role in harvesting and recycling/re-usage of water resources to help achieve a sustainable urban water management (Hellstro 2000; Chacha 2015). The limitation of studying the impact of the selected WEST was that they were not implemented in Cuenca's urban water cycle at the time of research. Therefore, similar research in other places as well as secondary data gathered from the water experts interviewed during this research was essential in creating the WEST hypothetical scenario to be compared with the BAU scenario of the water management of the urban water cycle.

### 3.1.2 Dependent Variable(s)

#### Water-energy nexus in urban water metabolic cycle

The water-energy nexus in the urban water metabolic cycle has three variables to be studied –

**Residential water flows**: Water flow comprises of 3 main processes (sub-variables): Water production, Distribution/water use, Sewage. However, the residential water flows are studied in this research due to the nature of WEST being studied. All of the WEST (except water turbines) are to be installed on the residential-level in urban Cuenca. Therefore, to assess the impact of the WEST and yield meaningful results, the non-residential water flows were left out of the analysis. Two indicators that focus on volumetric measurement of the residential water flows are potable water produced (indicator 1.1) and water utilised (indicator 1.2). The difference between these two indicators reveals the amount of water lost in the distribution processes due to water leakages or illegal connections. Water utilised is the amount of water that reaches the households, while potable water produced is the amount of drinking water that is produced for the residences by ETAPA (the public water management company). This variable handles the volumetric water flows and the resulting monetary costs/revenues generated by these volumetric water flows in urban Cuenca. This variable is essential for this research as it is necessary to build the Business-As-Usual (BAU) scenario projection that each WEST would be compared to. This variable and its indicators also play a crucial role in calculating the quantities for the 'Energy demand' variable and thereby, the 'GHG emissions' variable in the study. The water quality (indicator 1.6) is assessed by using the Water Quality Index (WQI) which has a value from 1-100 that simplifies the analysis of water quality by combining a host of quality tests to give one index indicating the quality of water for human consumption (Chacha 2015).

Formulas that inter-relate the indicators and help in assessing the BAU scenario in chapter 4:

Water lost due to leakages etc. = Potable water produced – Water utilised

Supply costs = (Cost of production of 1 $m^3$ potable water) x (Potable water produced)

Supple revenue = (No. of Residences) x (Avg. water bill per residence)

Economic profit/loss to ETAPA in a year = Supply revenue – Supply costs

Cost of production of 1$m^3$ potable water was obtained from secondary data due to unavailability of primary data. The cost of production was assumed to be directly proportional to the volume of potable water produced in the circumstance that no technology or production capacity change has taken place in the water treatment and distribution facilities. Therefore, the cost of production would only fluctuate with the change in the volume of water produced in the given year. This assumption was triangulated with experts in Cuenca during fieldwork.

**Energy Demand**: This variable has indicators 2.1 to 2.3 (Table 2) that measure the amount of energy consumed (in kWh) by the water sector, the costs of the energy consumed (in USD) and the type/form of energy consumed (e.g., electricity). The energy consumption (indicator 2.1) and the energy costs (indicator 2.2) aimed to measure the 'energy for water' segment of the water-energy nexus of the water sector, and were crucial to conducting the CBA and CEA properly for each WEST scenario and the BAU scenario. For the development of scenario forecasts until the next 15 years, the following ratios were the most important to determine –

Energy cost per unit of energy (in USD/kWh) =

$$\frac{total\ energy\ costs\ (in\ USD)\ for\ a\ given\ year}{total\ energy\ consumed\ (in\ kWh)\ in\ a\ given\ year}$$

Energy consumed per unit volume of water produced (in kWh/$m^3$) =

$$\frac{total\ energy\ consumed\ (in\ kWh)\ in\ a\ given\ year}{potable\ water\ produced\ (in\ m^3)\ in\ a\ given\ year}$$

**GHG emissions**: This variable possesses strong connection to the measurement of adaptation and mitigation co-benefits as discussed in the literature review (chapter 2). The reason behind using this variable is primarily to measure the climate change mitigation potential of the water-energy saving technologies (WEST) integrated into the urban water metabolic cycle. Sustainable urban water management implies the need to take into account the carbon footprint of the urban water cycle (Hellstro 2000). The various stages of the urban water metabolism demand large amounts of energy as discussed in chapter 2. As per the literature, majority of the GHG emissions take place during the energy production processes in the energy sector. Therefore, it is important to consider the emissions under the carbon footprint of the urban water cycle. It is also interesting to analyse if water pumps and water treatment processes use off-grid direct input of fossil fuels which might not have been considered in other academic studies. Thus, the GHG emissions measurements will shadow the Energy consumption (indicator 2.1). The indicator for GHG emissions will therefore be energy consumption (indicator 3.2) and the emission factor (indicator 3.1) for Ecuador. To determine the emission factor for Ecuador, a simple method was selected due to the limited amount of time available to conduct data collection and analysis for the research. Internationally recognized sources such as UN or IEA (International Energy Agency) were researched to find the best available energy factors for calculating emissions from electricity/energy consumption. This research uses three such found emission factors –

| Source | IEA (2010) | Ecometrica<br>Brander et al (2011) | Ramirez et al (2015) |
|---|---|---|---|
| kgCO2 per kWh | 0.262 | 0.270 | 0.351 |

**Table 3 – Ecuador's Emissions Factor from three sources (Brander et al. 2011; Ramírez et al. 2015)**

The (Brander et al. 2011) paper had the detailed analysis of the methodology by which IEA as well as this paper had calculated the energy factor. Since the IEA 2010 reading was also cited from this paper, this research selected the Brander et al (2011) value of 0.270 for the purpose of GHG emissions calculations. The calculated GHG emissions would be in units of kgCO2e per unit time, where kgCO2e would represent the equivalent kilograms of carbon dioxide emitted to standardise other GHG like methane and nitrous oxide, etc. These emissions would be directly proportional to and closely linked to the indicator Energy consumption (kWh).

## 3.2 Research Strategy and Approach

The research strategy chosen for this research is case study – the case study of Cuenca's urban water cycle. The research was based primarily on quantitative data with a purely analytical approach. The research design followed Valek's (2016) study methodology of the urban water cycle of Mexico City. The methodology was updated and improved using the WSADIOAF framework to make climate change merge with the life cycle assessment methodology better, and conduct a more detailed CBA and CEA to study the impact and feasibility of the WEST in urban Cuenca. The abovementioned research strategy is most suitable to obtain a valid answer to the question. Firstly, a case study takes a "holistic approach" referring to large body of qualitative data that provides deep understanding of the case (Van Thiel 2014, p.86).

For the development and assessment of the WEST hypothetical projection scenarios aspect of the research, co-variational approach is most suitable to the study of urban water cycle because it often focuses on "the effects of specific causes and not on the causes of specific effects" (Blatter and Blume 2008, p.318). However, the exploration of the urban water cycle of Cuenca by desk research, by analysing the secondary data provided by the water company of Cuenca, and past research papers on the water cycle of the city, as well as interviews with ground experts reveals the need for a more causal process tracing approach (Blatter and Blume 2008). This is because a causal process tracing approach allows "thickness" in the research, allowing the researcher to dig deep in a process understanding the various causes that create an effect in the system studied.

After a deep analysis of the information available, **questionnaire** was developed to be given to experts of water cycle **(21 experts)** to understand the WEST efficacy and suitability to Cuenca's context. The sampling of the experts included in the questionnaire was done by the process of snowball sampling. With some initial introductions, more experts were contacted by reference and a list of 50 experts was reached to ensure the questionnaire yield statistically reliable results. However, only 21 experts responded out of the 50 contacted. The main function of the questionnaire was two-fold:

i) To collect quantitative data on the various stages of the urban water cycle of Cuenca. Numerical data would be hard for experts to remember during an interview so it was more efficient to request it over an online questionnaire.
ii) To collect information on the efficiency and suitability of implementing the WEST in the context of Cuenca. This information was essential to develop the hypothetical scenario needed for understanding the potential impact WEST could have in achieving sustainable urban water management in the urban water cycle of Cuenca.

**Semi-structured interviews (12 experts)** – to corroborate the information obtained via the desk research and the questionnaires. The semi-structured interviews also helped get in-depth understanding of the new information about the water-energy-climate nexus of Cuenca's water cycle.

Consequently, a primary scenario of Business-As-Usual (BAU) was developed including independent analysis of the 3 different variables- residential water flows (variable 1), energy demand (variable 2), and GHG emissions (variable 3). Projections were then made to evaluate the BAU scenario till 2030.

Similarly, the results from the questionnaire used to shortlist the suitable WEST, and the selected WEST were then the subject of the cost benefit and cost effectiveness analysis including the impacts of the adaptation and mitigation measures on the water-energy nexus and GHG emissions of Cuenca's water cycle for the next 15 years. The comparison between the four scenarios – BAU scenario, rainwater harvesting scenario, water turbine scenario, and solar water heater scenario, helped analyse the efficacy of each WEST and understand Cuenca's vulnerability to climate change risks that could possibly affect its water systems in the near future. In conclusion, another scenario was developed – "Combined-WEST Implementation Plan" that would serve as a practical implementation scenario of the WEST that were found to be feasible and impactful for making Cuenca's water sector more resilient to future climatic threats.

## 3.3 Data Collection Methods and Sampling

The approach taken to collect the data, was a combination of secondary and primary sources. The data collection was done through a mix method involving questionnaire, semi-structured interviews, and desk research.

Experts to be interviewed were selected based on snowball sampling method. The experts selected to fill out questionnaire were selected partly on snowball sampling method and partly by random quota sampling.

Semi-structured interviews were arranged with the following **12 experts** related to the field of water-energy nexus in Cuenca, Ecuador:

**Professor Antonio Malo** – Professor at Universidad del Azuay who is an expert at the topic of water metabolism.

**Sebastian Chavez** – Director of Public Works & Drinking Water company in Paute

**Ramiro Santacruz** – Head of Planning Department at ETAPA (public company in-charge of potable water and sewage management)

**Cristian Zamora Matute** – City counsellor of Cuenca

**Josue Larriva** – Senior Engineer at ETAPA (at Ucubamba wastewater treatment facility)

**Catalina Alban** – Director of CGA (Environmental management department of the municipality)

**Felipe Cisneros** – Professor at PROMAS (investigates the issues of land and water), University of Cuenca

**Pedro Carrasco** – Director of AVINA (non-profit governmental organization that deals in water and environmental concerns in South America)

**Juan Diego Espinoza** – Senior Engineer at ETAPA (at Tixan potable water production facility)

**Maria Augusta Hermida** – Director of Llactalab (research group for sustainable cities at University of Cuenca)

**Rolando Celleri** – Professor at iDRHICA (Department of Water Resources and Environmental Sciences at University of Cuenca). He is an expert on rainwater harvesting and hydrological cycle of Cuenca.

**Juan Leonardo Espinoza** – Professor at Faculty of Engineering at University of Cuenca. He is an expert in research on solar panels, solar water heaters and micro hydropower turbines.

The selection of the experts to be interviewed was done via the method of purposive and snowball sampling. The experts were selected due to their relevant knowledge and professional role in the urban water metabolic cycle of Cuenca.

The semi-structured interviews were also supported by brief questionnaire based on 8 open questions (items), successfully acquiring the data needed. The purpose of the questionnaire was to grade and evaluate in a Likert Scale the importance of the adaptation and mitigation water and energy saving technologies in the local context. In other words, the main goal of the questionnaire was to acquire quantitative data evaluating the various climate change threats and the suitable WEST that had been picked out from literature and successful applications in other cities around the globe as steps to adapt to or mitigate climate change-related risks associated with the water sector.

Water flows information was available in secondary sources. Experts interviews and questionnaires helped to increase the validity of the information by the process of triangulation of data. Energy demand information was mostly available in secondary sources; however, experts' interviews were important to validate – a) the sources of energy consumption in various stages of the water cycle, and b) the energy production mix supplying energy to Cuenca's water systems. The GHG emissions were calculated once these missing links in the information from literature were filled out.

Both BAU and WEST scenarios project the GHG emissions, Residential water flows and energy demand till year 2030 or 2034 (15 years of forecast). These projections needed high level of justifying evidence to make them reliable and valid. Therefore, experts' opinions were essential to validate the formula used to create the projections.

The limitations of the study come, with assumptions based on the efficiency measures and technology implementation performance and results. They are based on secondary data, and not in first hand experimentation, the actual performance in Cuenca or different cities is open to validation and confirmation. Both scenarios depend on secondary quantitative data collection, however the indicators for urban water LCA, may need primary data collection in order to acquire present and updated data. The questionnaire, build up from the operationalization process unifies the research completely from problem statement-research questions-literature review-conceptual framework.

Data has been collected from:

1. Primary sources: In-depth interviews and a survey (questionnaire). Interview transcripts are available upon request. The questionnaire online survey template is available in Annex 3, and the results are also available upon request.
2. Secondary sources from national databases, academic publications, international organizations databases and reports.

## 3.4 Reliability and Validity of the Research

A case study typically has small number of units of study (for example: in this research, we studied the case of Cuenca's water cycle), which endangers the reliability and validity of the case study research (Van Thiel 2014, p.92). The reliability and validity of the study was achieved with interviews to experts in the topic for primary data, triangulated with secondary data collection and a survey (questionnaire). This approach was most suitable for conducting this research, since the necessary data is mostly found in academic publications and governmental reports, the missing data or more updated data is to be recovered from primary sources. Most importantly, the research focuses predominantly on quantitative data. This makes it easier to analyse the data to ensure high reliability and validity.

Use of Case study protocol - a database or a log of all steps of the study are documented so that the whole process can be reviewed and replicated in future.

By replicating the research methodology of a previous water-energy-climate nexus study in Mexico City (Valek 2016), the validity of the used methodology was tested. The methodology is found to be highly replicable regardless of city context despite the need to better it by aligning it more to a framework like the WSADIOAF used in this research study.

## 3.5 Data Analysis Methods

"The analysis of quantitative data can be either theory driven or data driven" (Van Thiel 2014, p.119). This research study was completed with data-driven analysis.

Process of data analysis followed the listed steps below:

**Analysis 1**: Illustration of the urban water metabolic cycle of Cuenca, Ecuador, including the various facilities and technologies that are used in the processes of potable and wastewater treatment. Thereafter, the next step was the determination of total and residential water flows, and energy demand for the 3 phases of the water sector as described in operationalization section. Furthermore, the third step was the calculation of supply costs (indicator 1.4) and supply revenue (indicator 1.5). This was followed by the calculation of energy costs (indicator 2.2). Finally, the evaluation of sources of GHG emissions (careful consideration to sources of GHG emissions other than the sources of energy production). To calculate GHG emissions, Ecuador's energy mix and the emissions factor was used after expert validation of the method of calculation. The abovementioned steps are a simplified insight into the data analysis methodology which was used to generate the BAU scenario (in MS Excel software) that would serve as the baseline scenario for the remaining analysis in the research. The BAU scenario revealed the strengths and weaknesses of Cuenca's current water management practices.

**Analysis 2**: Questionnaire results of 21 experts were utilised to determine the most relevant and immediate climate change threats to the water metabolic cycle of Cuenca. These findings were triangulated by results from interviews and secondary sources such as government statutes and policies. Henceforth, the questionnaire results served as an initial filtering of the WEST found in literature to evaluate the suitability and feasibility of these technologies to the needs of urban Cuenca. The shortlisted WEST progressed to the next stage of the research analysis which was to develop the scenario projections for WEST implementation for the next 15 years (either from 2015 to 2030, or 2019 to 2034).

**Analysis 3**: Three forecasts were developed, one each for rainwater harvesting, solar water heaters and water turbines, using MS Excel software. In each of the forecasts, the Cost Benefit and Cost Effectiveness Analysis (CBA and CEA) were conducted by comparing the hypothetical scenario to the BAU scenario. This yielded results on four indicators to assess the performance of each WEST– water saving potential (indicator 4.2), energy saving potential (indicator 4.3), GHG emissions reduction potential (indicator 4.4), and Monetary savings (indicator 4.5). This analysis was carried out to test the WEST for economic feasibility and impact on improving Cuenca's water sector to make it more resilient towards shocks and trends of climate change, as well as contributing to fulfilling Cuenca's residential water and energy needs more economically profitable and self-sustaining.

**Analysis 4**: Based on the performance results from the CBA and CEA for the three WEST, the ones that yielded positive performance were integrated to develop a 'Combined-WEST Implementation Plan' to generate a realistic implementation approach which would take into account a limited investment budget on behalf of the local government and a physical limit to the number of technological installations that could be done on an annual basis.

# Chapter 4: Research Findings

This chapter is dedicated to exhibiting the data collected during the fieldwork phase of the research based on the research design and methods described in Chapter 3. The data analysed is presented in a systematic manner. The chapter can be divided into 3 parts – the first part introduces Cuenca's context and discusses its current water metabolic cycle, looking at findings about the water demand and consumption practices of urban Cuenca. The processes that form part of the water metabolic cycle – pre-treatment, distribution, sewage – are all discussed in detail. In the second part, findings on climate change and its effects on Cuenca's water systems are elaborated. The current water metabolic cycle in Cuenca is assessed in depth in terms of its energy costs and environmental impact as per the life cycle assessment (LCA) framework established in Chapter 2 and 3. Water-Energy Saving Technologies (WEST) are deliberated with experts and research findings on shortlisting the appropriate WEST for Cuenca's context are presented. Lastly, the third part of Chapter 4 deals with the projection scenarios built till 2030 or 2034 (12-15 years period) with the WEST – rainwater harvesting, solar water heaters, and water turbines. Impact and economic feasibility of these technologies is analysed using the WSADIOAF framework as discussed in Chapter 3.5 and compared with the Business-As-Usual (BAU) scenario to conclude with recommendations based on the CBA and CEA conducted for each WEST.

## 4.1 Cuenca's water metabolic cycle

In this section, this report elaborates on urban Cuenca's context looking at the urban area and the population comprising it. The section proceeds to discuss the current water metabolic cycle, exploring the findings about the water demand and consumption practices of urban Cuenca. The processes that form part of the water metabolic cycle – pre-treatment, distribution, sewage – are inspected in detail. The assessment aims to draw a vivid picture about the supply of water to residents in urban Cuenca, the source and processes of the potable water, the handling processes of the wastewater generating from the houses and industries, some of the crucial technologies and natural topographical advantages utilised in the water management processes, and key challenges that the water management seeks to overcome in the near future.

### 4.1.1 Cuenca's urban area and population

Cuenca metropolitan area constitutes the third largest city in Ecuador with a total area of 3,665.32 km2 (GAD Municipal de Cuenca 2015) and a total population of 505,585 in 2010 (Chacha 2015). However, the urban centre amidst this large cantonal area was a mere 66.71 km2 in 2010 (Malo-Larrea 2014). Despite the small percentage of the area of urban Cuenca, approximately 330,000 inhabitants lived in the city of Cuenca in 2010 (Chacha 2015). For the sake of clarity, this research will continue to refer to the urban area of Cuenca by its name. If there is a need to refer to Cuenca metropolitan area, it is referred by the name Cuenca canton. Below are maps of Cuenca placing it in context of its canton and country for clear understanding of the discussion in the upcoming sections. The map below (Figure 9) shows Ecuador and then zooms in to Cuenca canton in which the urban area is coloured in yellow.

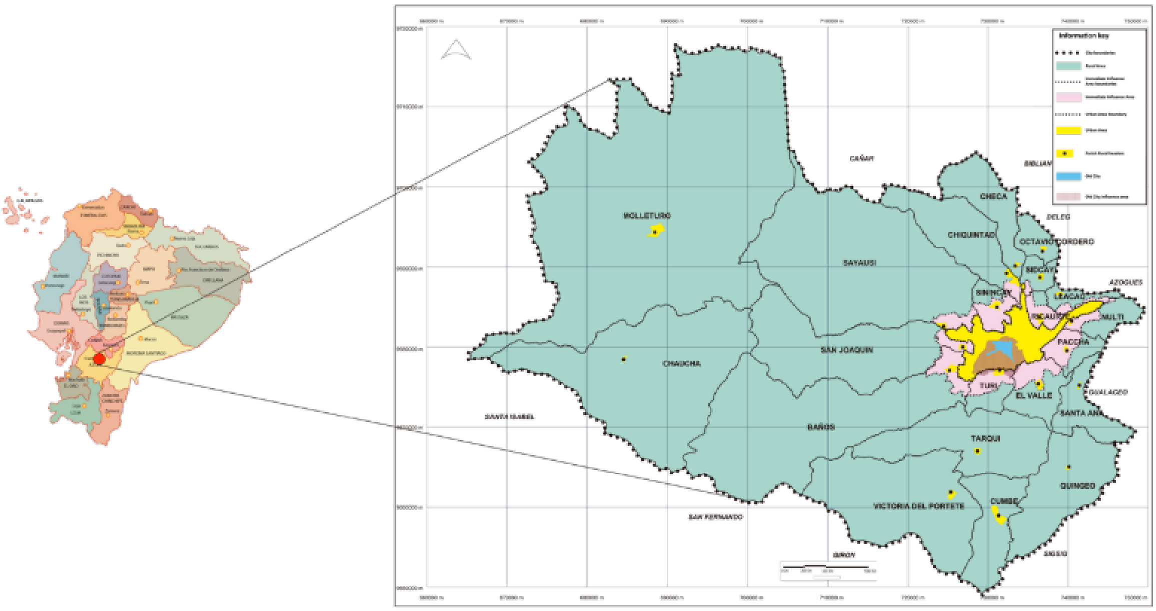


**Figure 8 - Ecuador > Cuenca canton > Cuena urban area (in yellow)** (Source: Chacha 2015)

### 4.1.2 Cuenca, its topography and the water bodies

Cuenca is a typical mountainous city high up in the Andes with an altitude between 2,350 and 2,550 metres above sea level (MASL) (GAD Municipal de Cuenca 2015). Cuenca is known for the abundance of water supplies which come from four rivers – Tomebamba, Machangara, Yanuncay and Tarqui (Chacha 2015). The figure below (Figure 10) labels the four rivers by name and illustrates the eastward flow of the rivers into the yellow area of urban Cuenca.

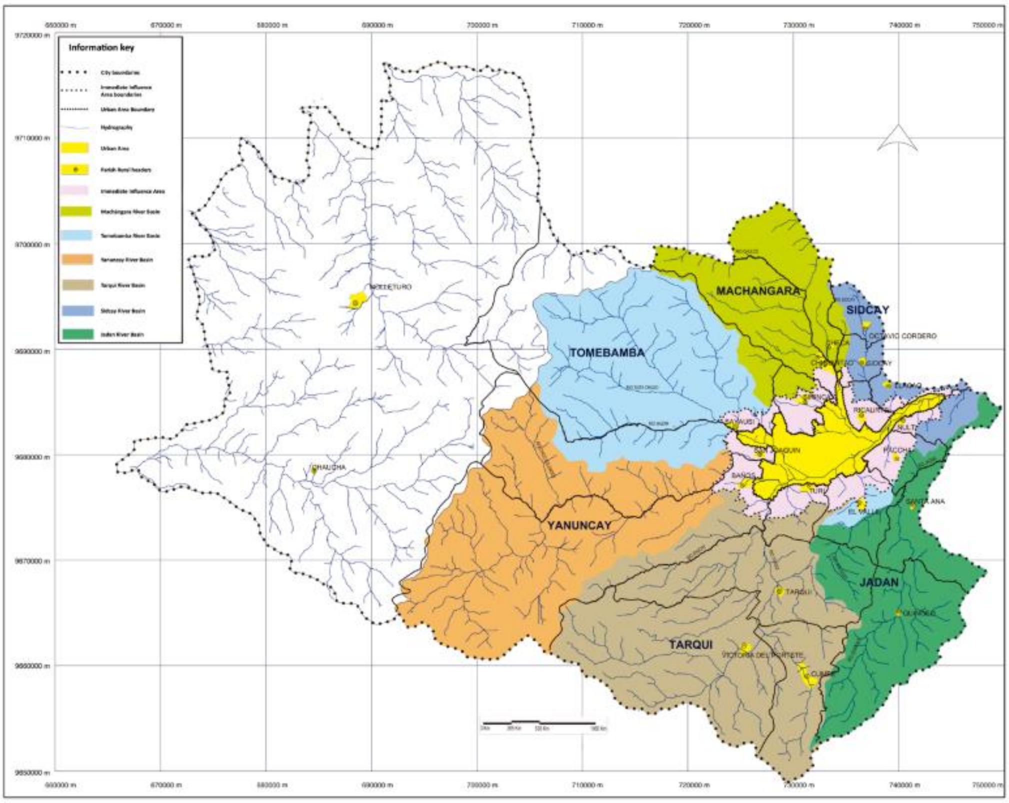


**Figure 9 - Flow of rivers into urban Cuenca (Source: Chacha 2015)**

The main freshwater source for Cuenca's urban area is El Cajas National Park. It has a total area of 285.44 km2 at an altitude between 3,152 to 4,445 MASL which is enriched by different ecosystems of herbaceous moorlands, over 300 ponds, and high number of endemic species (Chacha 2015). El Cajas National Park is placed under the world heritage sites by UNESCO.

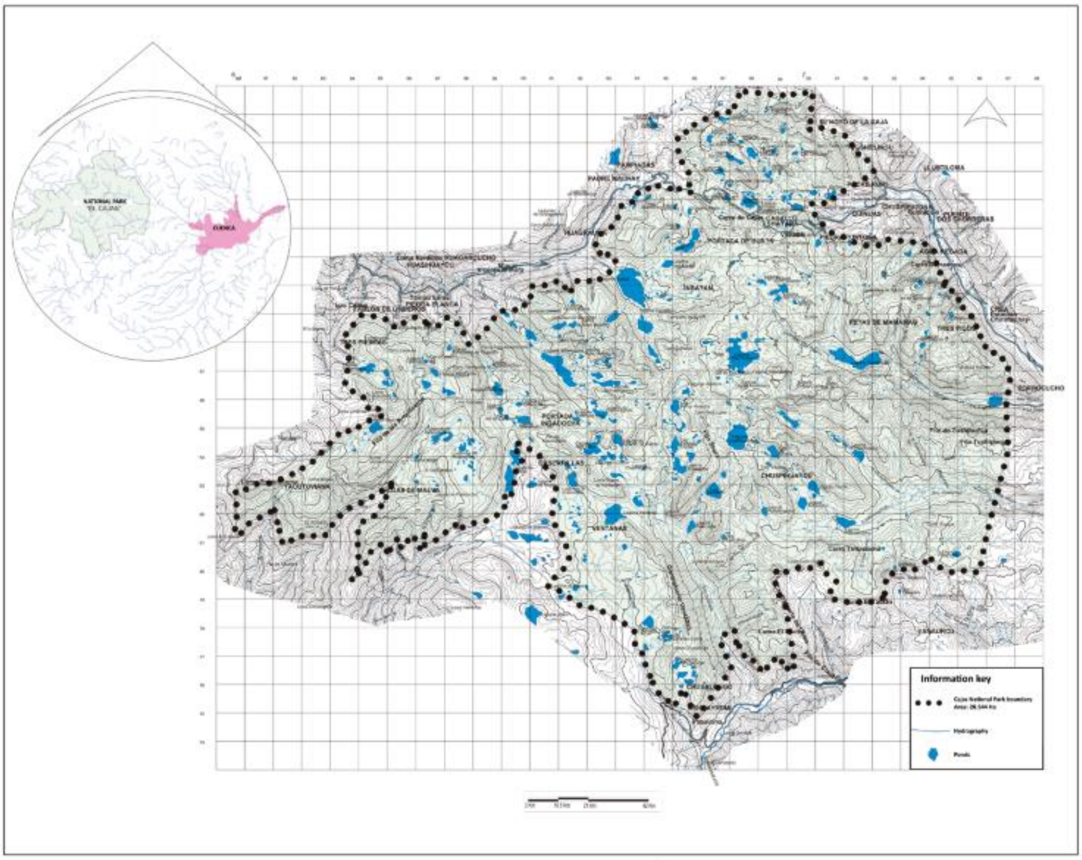


**Figure 10 - El Cajas National Park (Source: Chacha 2015)**

El Cajas National Park and the four rivers are fed with freshwater by abundant rainfall throughout the year. The average amount of rainfall in El Cajas National Park is between 1,000 mm/m2 to 2,000 mm/m2 annually. After evapotranspiration, absorption into the ground, and usage to sustain different ecosystems, around 12% of the total rainfall is used to meet human needs (Chacha 2015). The four rivers of Tomebamba, Machangara, Yanuncay and Tarqui, have an average annual mean flow approximating 1.6 km3 that is at the disposal for human usage in Cuenca’s urban area (Chacha 2015; Malo-Larrea 2014).

Apart from these abundant water resources feeding the needs of Cuenca, it is also blessed by the mountainous topography with the city being in the valley of the mountains. The steep slopes of the Andes provide the perfect situation to utilise the gravitational force of the Earth to develop a water distribution system that consumes minimum energy. In the next section, the report explains in greater detail how the topography of Cuenca is used by the water management company ETAPA and how the water pre-treatment plants as well as the wastewater treatment plant are located in a manner to maximize water’s natural flow under the influence of Earth’s gravitational force. This topographical advantage of mountainous terrain results in minimum amount of pumping needed to distribute water to the residential areas in the city. As noted in the literature review, UNESCO (2009) and IEA (2016) reports confirmed that water transportation and treatment together account for roughly 60-80% of energy consumed by the water sector. Other reports referred to pumping of water as the largest energy intensive process in the water cycle (Hardy et al. 2012), to the extent that Mohamed et al. (2010) refers to pumping consuming 80-91% of electricity consumed of all water processes.

Hence, it is concluded that the minimized pumping requirement due to the topography and geographical features in Cuenca's location might have a big impact on keeping the energy costs for the water sector to a minimum.

### 4.1.3 Water treatment plants and the water metabolic cycle of Cuenca

Cuenca is fed by potable water from three potable water treatment facilities (Tixan, Cebollar and Sustag) and the wastewater generated from the city is collected and flows to one wastewater treatment facility in Ucubamba. The four treatment plants that form the backbone of the water metabolic cycle of Cuenca are shown at their locations and the water flows in the map below (Figure 12).

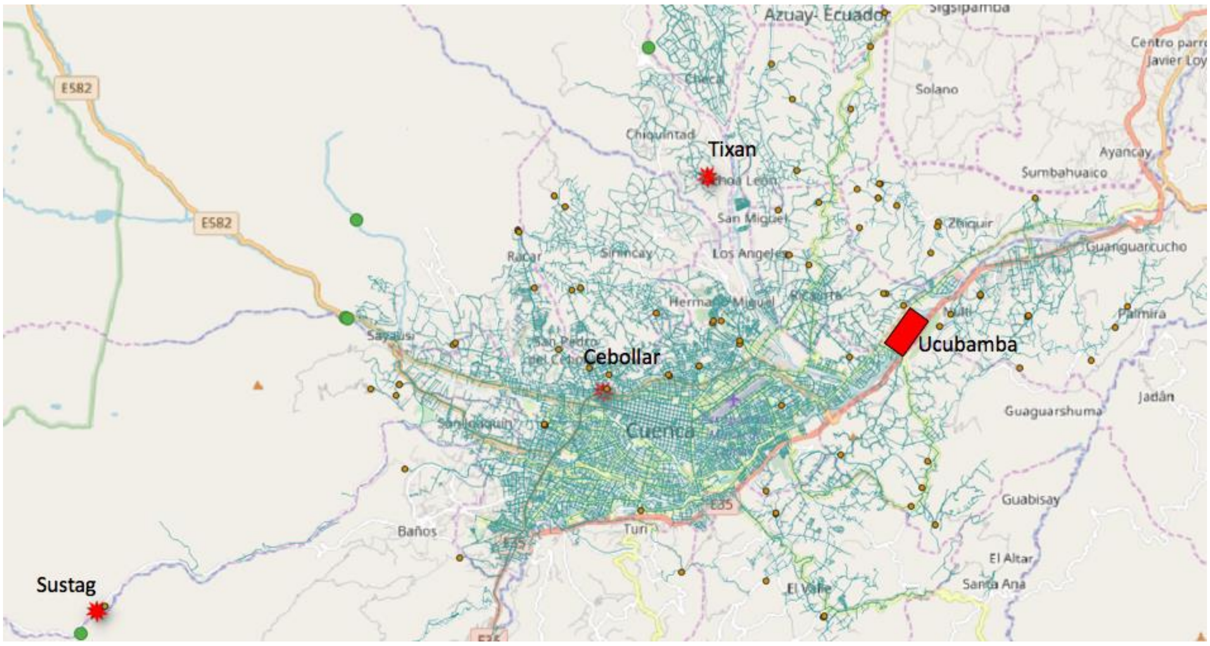


**Figure 11 - Potable and Wastewater treatment facilities of Cuenca (Source: Interview with ETAPA 2018)**

In the figure above, the three potable water production facilities (Tixan, Cebollar and Sustag) are marked with red stars. The red rectangle illustrates the Ucubamba wastewater treatment plant. The light green spherical markings in the figure are extraction points where water is extracted for potable water production. The green lines on the map represent the network of water distribution pipelines supplying water to Cuenca's residences and other sectors.

Tixan potable water production facility is located on the river Machangara, north of Cuenca city and had an annual water production flow of approximately **17,600,000 $m^3$** in 2017 (ETAPA EP 2018). Its maximum treatment capacity is 840 L/s (GAD Municipal de Cuenca 2017). However, Tixan has been operating at 600 L/s for the past decade and has the capacity to increase supply for the future needs (GAD Municipal de Cuenca 2017). Tixan is a conventional type plant integrated by the processes of coagulation, dosing, flocculation, sedimentation, filtration and disinfection (Nieves and Ramón 2014, p.77). Below is a table that gives the breakdown of electric energy usage at the Tixan plant based on the processes listed above. The most energy intensive processes are dosing and filtration.

For the process of dosing, aluminium sulphate is used. In the water, the sulphate forms small balls called flocs that are responsible for retaining bacteria, sludge and other impurities (Nieves and Ramón 2014, p.80). For the process of filtration, the filter has one layer of sand and one of carbon andradite that allows the collection all the impurities that the previous processes of sedimentation and flocculation had not detected (Nieves and Ramón 2014, p.82). In summary, these are essential steps to purify the water and the most energy conservative treatment methods that ensure that the water treatment in Tixan, minimal energy is used and the utilised energy is in the form of electricity generated locally in Cuenca. Due to increased city's water demand as a result of the development of the city and rising population, ETAPA also plans to increase the production capacity of the Tixan potable water production plant which would have an investment of USD10 million and the project is set to be completed by 2020 (GAD Municipal de Cuenca 2017).

Cebollar potable production plant is located on the river Tomebamba and has an initial treatment capacity of 930 L/s. In 2017, this plant served an annual potable water flow of approximately **26,200,000 m$^3$** to Cuenca's urban area – 45% of its total demand (ETAPA EP 2018). Cebollar is also identical to Tixan in terms of technology, except it is bigger.

Sustag is the third plant located on the river Tarqui. According to ETAPA data, Sustag delivered 11% of urban Cuenca's water needs with a yearly treated water flow of approximately **5,500,000 m$^3$** generated (ETAPA EP 2018). However, during this research fieldwork, not much information was able to be collected about the Sustag plant due to its distance from the Cuenca city as well as the importance given by the interviewed experts from ETAPA water company to this plant. Due to the limited time and the comparatively low importance to the overall system, the focus is on Tixan and Cebollar. However, information about Sustag was collected through the expert interviews.

After the discussion of the three potable water treatment plants in Cuenca, the focus moves to the sewage generated and the movement of this wastewater from city area downhill before it is disposed. Ucubamba wastewater treatment plant is downhill as seen in the figure below (Figure 13).

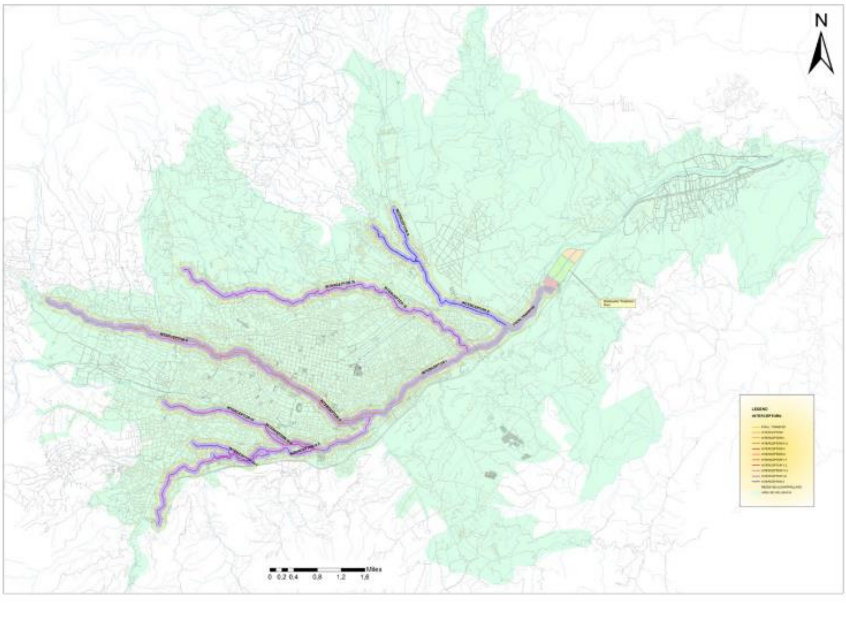


**Figure 12 - Wastewater collection system and Ucubamba wastewater treatment plant (Source: Chacha 2015)**

Ucubamba wastewater treatment plant is based on biological treatment processes consisting of "2 anaerobic ponds, 2 facultative ponds, and 2 maturation ponds" which has a treatment capacity of 1,800 L/s of wastewater (Chacha 2015, p.15). In 2017, the plant treated approximately **53,500,000 m$^3$ of wastewater** generated in Cuenca (ETAPA EP 2018). This wastewater treatment plant is the only one in Cuenca, however, due to increasing human settlements downhill from this plant in recent years, there are plans to develop a new treatment facility downhill from Ucubamba by the year 2030 in Guangarcucho. This new wastewater treatment plant in Guangarcucho has a construction budget of USD 50 million (GAD Municipal de Cuenca 2017).

In summary, the water flows through the water metabolic cycle in Cuenca is as follows: potable water from the three potable water production plants is distributed to the users (residences and industries). From the residences and industries, the wastewater that is produced flows out in the form of sewage and is collected by the wastewater collection system that takes this sewage to Ucubamba wastewater treatment facility. Rainwater and other open water entries into the cycle also join this wastewater collection system and are treated at Ucubamba before being released into river Cuenca which is formed by the joining of all the four rivers – Tomebamba, Tarqui, Machangara, and Yanuncay, downhill from Cuenca's urban area.

In terms of water quality, the **potable water** that is produced for Cuenca's consumption has a **water quality index** (WQI) result of **96** which belongs the highest quality level in the WQI rating (Hossain et al. 2013; Canada Department of Municipal Affairs and Environment 2018). However, the **post-treatment wastewater** that flows out of Ucubamba was found to have a **'Fair' quality score of 70** which means that it still meets the minimum requirement by international and Ecuadorian law but is unfit for human consumption. This WQI was also found by this research to be a problem area since this river Cuenca then becomes the water source for river Paute and is used by Paute town for their potable water consumption. Therefore, two options were discussed by ETAPA experts in the interviews – 1) to treat all the water at Ucubamba and re-use it for Cuenca city, referring to a zero-wastewater release into river Cuenca; 2) to bring up the WQI to a higher level before release so it more suitable for human consumption by human settlements downhill to river Cuenca which would mean higher energy consuming technological processes that need to be installed at the treatment plants.

### 4.1.4 Domestic water consumption analysis of urban Cuenca

As per data from (GAD Municipal de Cuenca 2015) there were **86,317 households** in Cuenca's urban area. These households consumed a total of approximately **27,000,000 $m^3$** out of a total **33,300,000 $m^3$** of potable water produced for Cuenca in 2015 (source: table in Annex 4). Therefore, as per the analysis of water consumption data for 1992 to 2013 (Malo 2018), the research concludes that the residential consumption represented 80-82% of the total water consumed by Cuenca city. As per this analysis, the **amount of water consumed per person** in Cuenca's homes was **200-210 litres per day** (lpd) (Malo 2018), which is way more than the recommended amount to meet the human needs of 50 to 100 lpd by World Health Organization (WHO) (Chacha 2015, p.14). Usage of water in an average Cuenca household has been researched by (Chacha 2015) which reflected 31.5% used for toilet flushing, 30% for showering, 2.7% for drinking and cooking, and 35.8% used for washing cars, gardening, etc.

Most interviewees agreed that the over consumption of water in Cuenca's residential population was due to two major reasons – 1) the water is very cheap, and 2) the amount of water available is abundant both in terms of rainfall as well as stored ponds in El Cajas National Park. This abundance of water has made the population complacent about the need to conserve water. As a city councillor mentioned in his interview that multiple advertising campaigns were being run in recent years to create awareness about water conservation in light of climate change which have begun to impact and reduce the overconsumption of water by people of Cuenca. This finding confirmed that local government have been working towards implementing non-technological water conservation measures to create awareness among residents to conserve water and alter their attitudes towards water resource in Cuenca.

## 4.2 Current water system and Business-As-Usual (BAU) forecast

After exploring Cuenca city's current water metabolic cycle – understanding the various processes in the management of potable water and sewage, as well as the domestic consumption practices of people in Cuenca, this research section moves forward to discuss dependent variables and indicators of residential water flows, energy demand and GHG emissions as entailed in operationalization of variables in chapter 3. The water metabolic cycle is quantitatively analysed with historic data collected from water experts (interviewees) and government bodies (like CGA and ETAPA). The water flow variable is connected to the variable of energy demand of each stage, GHG emissions associated with it, and the WQI indicator (for water quality). This section analyses the forecast of current water management practices in Cuenca till 2030, looking at the impact of these practices on associated energy costs and GHG emissions that can be expected in the near future as per the BAU (business as usual) scenario. This section 4.2 builds on the background information of section 4.1 and relates the findings about the current water metabolic cycle of Cuenca in the framework established in chapter 3 – operationalization of variables for this research study.

### 4.2.1 Residential Water Flows Analysis

Based on various data from the last three decades, a prediction (see Annex 3) for Cuenca's growth until 2030 is developed. This includes the urban population from 1992 to 2013, the number of households and urban area. Furthermore, expert interviews with representatives of the municipality highlighted steady urban sprawl with predominant low-rise buildings. Moreover, the interviews lead to the assumption that the **average household size stays at about 3.85** (based on: GAD Municipal de Cuenca 2015; Banco Interamericano de Desarrollo 2014; Malo-Larrea 2014; Chacha 2015).

Similarly, the research study also developed a forecast till 2030 regarding the water metabolic cycle of urban Cuenca using the following indicators for the variable of water flow – potable water produced (indicator 1.1 in $m^3$/year), total water consumed (in $m^3$/year), residential water consumed (indicator 1.2 in $m^3$/year). The variable 'energy demand' is calculated by the indicator energy consumption (indicator 2.1 measured in kWh) calculated from the monthly electricity bills obtained at Tixan and Cebollar treatment plants. The variable 'energy demand' is also closely related to the variable 'energy costs' (indicator 2.2 calculated in USD). The table with these indicators is available in Annex 4.

For the 'potable water produced' ($m^3$/year), data from 1992 to 2013 was provided in an interview (Malo 2018). Data for years 2017 and 2018 was obtained in another interview (ETAPA EP 2018). The indicator 'Potable water produced' basically represents the sum total of drinkable water produced by the three treatment plants at Tixan, Cebollar and Sustag (as mentioned in section 4.1) for urban area of Cuenca. Similarly, 'total water consumed' indicator represents total potable water consumed by the residences, businesses, industries, etc. in Cuenca's urban area. It is important to first take note of the large difference between the amount of 'potable water produced' and 'total water consumed'. For example, in 2000, 'total water consumed' by urban Cuenca represented a mere 46% of 'potable water produced'. This percentage increased to 73% in 2008, and as per the research's data analysis, in 2013, this percentage reached 82%. As per the interview with an ETAPA senior official, the **amount of potable water lost** due to leakages in pipes was estimated to be **approximately 25-30%**. As Chacha (2015) notes that leakages and unsuitable fares result in **economic losses of around US$2 million per month**. Although, this is an important finding in the analysis of the water metabolic cycle of Cuenca, this research does not probe further the water lost or the pricing model of the water for Cuenca's inhabitants.

**Residential water consumption** (indicator 1.2) was found by (Malo-Larrea 2014) to be approximately **80-82% of the total water consumed** through the years 1992 to 2013 with little fluctuation. This number of 80% has been utilized to co-relate the two indicators and generate values for residential water consumption forecast till 2030 in the data analysis. According to UN data, worldwide agriculture usually accounts for 70% of the water consumption, followed by 20% by industries, and 10% by domestic residential use. In industrialized nations, the situation is more inclined towards industries, for example, Belgium utilizes 80% of its water for its industries (Stephen R 2015). The high domestic consumption of 80% in Cuenca exemplifies the kind of city Cuenca is. It represents a small residential city with non-intensive industries and low indication of in-house agriculture as per the statistics suggested from the water use.

The **rate of cost of production of potable water** was calculated by Chacha (2015) to be **USD1.29 per $m^3$**. This was utilized to estimate the **supply costs** (indicator 1.4) of **USD34.4 million** in 2015. In 2015, the revenue generated by ETAPA (referring to indicator 1.5 **supply revenue**), calculated from residential water bills and secondary data, was found to be **USD 28 million** yielding an **economic loss of US$6.4 million** in 2015. This calculation is an estimate based on the secondary data which needs triangulation as the research was not able to verify with ETAPA about the economic losses due to unavailability of data on this topic.

### 4.2.2 Energy Demands and Energy Costs Analysis

In 2017, ETAPA had **energy costs of USD1.3 million** for potable water production, distribution and treatment (Santacruz 2018). This figure was triangulated with secondary sources and then used in the data analysis. From the monthly electricity bills obtained from Tixan and Cebollar potable water production facilities (bills available upon request) and secondary sources (Nieves and Ramón 2014), the following numbers were accumulated –

| **Facility name** | **Energy consumed (kWh)** | **Energy costs (USD)** | **Unit energy cost (kWh/USD)** |
|---|---|---|---|
| Tixan (bill 1) | 27,110 | 2,381 | 11.386 |
| Tixan (bill 2) | 29,554 | 3,313 | 9.363 |
| Cebollar | 33,791 | 3,609 | 8.921 |
| **Average unit energy cost (kWh/USD) = 9.900** | | | |

**Table 4 - Energy consumption and energy costs for Tixan and Cebollar ETAPA facilities (Author 2018)**

This **average unit energy cost** obtained of **9.9 kWh/USD** was an important figure utilized in the following data analysis of the research. With this energy cost rate, the breakdown of energy costs for the various units in the potable water treatment, wastewater treatment and water distribution process for the year 2017 is presented in the table below. The usage of distribution electric pumps by ETAPA at some locations was due to the need to pump water to small high-altitude water consumers where gravitational forces were not sufficient for water delivery. However, due to the lack of information available on these water distribution pumps and the interviews with ETAPA officials indicating towards a small/insignificant energy consumption of these pumps as compared to the four treatment facilities, the missing information on the distribution pumps was assumed to not have significant effect on the tallies as presented in the table below. The lack of data available was a limitation in the analysis process of the research.

| **Units in the water metabolic cycle** | **Water flows in 2017 (in m3)** | **Energy consumed in 2017 (in kWh)** | **Energy costs (in USD)** |
|---|---|---|---|
| Tixan | 17,572,997 | 339,984 | 34,377 |
| Cebollar | 26,214,642 | 405,492 | 41,001 |
| Sustag | 5,422,894 | 104,916 | 10,608 |
| Distribution Pumps | NA | NA | NA |
| Ucubamba | 53,450,038 | 12,147,163 | 1,228,245 |
| **Total** | | **12,997,556 kWh** | **USD 1,314,231** |

**Table 5 - Water flows (in m$^3$), Energy consumption (in kWh) and Energy costs (in USD) for Cuenca's water metabolic cycle (Author 2018)**

The table above with the summarized findings about the potable water produced (indicator 1.1), the energy consumption (indicator 2.1) that the water processes demand for the year 2017 reflect the core focus of this research. These energy costs (indicator 2.2) of the water metabolic cycle represent a crucial side of the water-energy interlinkage. The other side refers to the water consumption in the energy production processes but that is beyond the scope of this research study. For Cuenca's water metabolic cycle, similar calculations as in table above were repeated to forecast the energy costs that the water metabolic cycle would cost the city of Cuenca till the year 2030.

In (Valek 2016, p.83), it is concluded that Mexico city's water supply has an energy demand of 1.23 kWh/m$^3$. For the case of Cuenca, from the table above (Table 6), the **energy demand for the water supply** calculation done based on potable water produced yields an energy demand of **0.26 kWh/m$^3$** for the year 2017. This comparison reflects the low energy demand of Cuenca's water management system that can be constituted to a few factors uncovered in this research – i) the use of gravitational force for much of the production and distribution processes resulting in minimized use of electric pumps for transportation of water; ii) biological technologies utilised to treat potable water and wastewater that require low energy input, thereby minimizing the energy footprint of the water management system.

### 4.2.3 GHG Emissions Analysis

Building up on the energy demands of the various processes of the water metabolic cycle, the next step in the analysis was the calculation of the GHG emissions (dependent variable 3). GHG emissions were analysed to calculate the environmental costs of the water metabolic cycle. For example, for the year 2017, the **energy consumption (indicator 2.1 and 3.2)** by the water management processes equalled **12,997,556 kWh**. Therefore, the GHG emissions due to water management processes for the year 2017 was calculated by multiplying the energy consumed with the selected **0.270 kgCO2e/kWh emissions factor** (selection details in Chapter 3 section 3.1) to yield **3,504,141 kgCO2e** in GHG emissions. The calculations were directly dependent on the indicator of energy demand from water management (in kWh) and the results were obtained (full data available in Annex 4). However, the field visit to Cuenca revealed that the city's local energy mix was 100% hydroelectric (indicator 2.3) and Cuenca's example was a blueprint that Ecuadorian government wanted to implement in the rest of the country. Therefore, Cuenca's local emissions factor (100% hydroelectricity) yielded **0 kgCO2 per kWh**. This effectively put the GHG emissions finding to a **zero-value** which contributed to Cuenca's case study being unique and an exemplary model to be imitated elsewhere.

For the purpose of this study, GHG emissions were calculated using both the emissions factors. However, for assessing the GHG emissions reduction potential (indicator 4.4) Ecuador's national emissions factor of **0.270 kgCO2e/kWh** was utilised to evaluate the WEST in the performance having a reducing effect on the GHG emissions of the urban water cycle studied.

### 4.2.4 Summary of BAU Scenario

At this juncture, it is important to justify the rationale behind using a simple tool like MS Excel's Forecast function to generate the BAU scenario forecasts for Cuenca's water metabolic cycle till the year 2030. Based on data available from year 1992 to 2017, combined together with the secondary sources of data available in other academic studies, as well as the in-person interviews conducted with the experts from Cuenca revealed the following –

- Technologies used for water (potable and wastewater) treatment have been the most economical choice that successfully achieved ETAPA's requirements and standards established by Ecuador's constitution.
- Till the year 2030, although more water flows might be handled by the current treatment facilities, the chance that a drastic change in energy consumption for a given amount of water flow is unlikely.
- If there is an expansion of current treatment facilities, the new facilities would continue to utilize the same technologies as the current setup.

Therefore, due to the above reasons, the extrapolation of water flows indicators, energy demand indicator of the water management processes, and energy costs indicator, seemed justified and rationale based on the increase in urban population, number of residences and urban area indicators from 2018 to 2030.

To summarise the findings in Cuenca's BAU scenario, the indicators of three variables residential water flows (dependent variable 1), energy demands (dependent variable 2) and GHG emissions (dependent variable 3) have been calculated on an annual basis and presented in Table 7 below (full table available in Annex 5). Based on the data available, residential water flows (dependent variable 1) was highlighted using indicators - potable water produced (indicator 1.1), residential water consumed (indicator 1.2), total water consumed (by all sectors). Energy demands (dependent variable 2) were illustrated via the indicators of energy consumption (indicator 2.1 and 3.2) and energy costs (indicator 2.2). Lastly, the GHG emissions (dependent variable 3) were determined by indicators – emissions factor (indicator 3.1) which revealed different values for Ecuador national-level and Cuenca's local-level energy mix, and the energy consumption (indicator 2.1 and 3.2).

| Year | Potable Water Produced ($m^3$) | Total Water consumed ($m^3$) | Residential Water Consumed ($m^3$) | Energy Consumption from water management (in kWh) | Energy cost (in USD) | GHG Emissions (in kg CO2) as per Ecuador's national energy mix | GHG emissions (in kg CO2) as per Cuenca's local energy mix |
|---|---|---|---|---|---|---|---|
| 2015 | 39,983,333 | 33,372,105 | 26,697,684 | 10,560,455 | 1,067,807 | 2,847,099 | 0 |
| 2016 | 40,560,727 | 34,252,099 | 27,401,679 | 10,712,957 | 1,083,227 | 2,888,213 | 0 |
| 2017 | 49,210,534 | 35,132,093 | 28,105,674 | 12,997,556 | 1,314,231 | 3,504,141 | 0 |
| 2018 | 50,978,409 | 36,012,087 | 28,809,669 | 13,464,490 | 1,361,444 | 3,630,026 | 0 |
| 2019 | 52,746,284 | 36,892,080 | 29,513,664 | 13,931,423 | 1,408,658 | 3,755,912 | 0 |
| 2020 | 54,514,159 | 37,772,074 | 30,217,659 | 14,398,357 | 1,455,871 | 3,881,797 | 0 |
| 2021 | 56,282,034 | 38,652,068 | 30,921,654 | 14,865,291 | 1,503,085 | 4,007,682 | 0 |
| 2022 | 58,049,909 | 39,532,061 | 31,625,649 | 15,332,224 | 1,550,298 | 4,133,568 | 0 |
| 2023 | 59,817,784 | 40,412,055 | 32,329,644 | 15,799,158 | 1,597,511 | 4,259,453 | 0 |
| 2024 | 61,585,660 | 41,292,049 | 33,033,639 | 16,266,092 | 1,644,725 | 4,385,338 | 0 |
| 2025 | 63,353,535 | 42,172,043 | 33,737,634 | 16,733,026 | 1,691,938 | 4,511,224 | 0 |
| 2026 | 65,121,410 | 43,052,036 | 34,441,629 | 17,199,959 | 1,739,152 | 4,637,109 | 0 |
| 2027 | 66,889,285 | 43,932,030 | 35,145,624 | 17,666,893 | 1,786,365 | 4,762,994 | 0 |
| 2028 | 68,657,160 | 44,812,024 | 35,849,619 | 18,133,827 | 1,833,578 | 4,888,880 | 0 |
| 2029 | 70,425,035 | 45,692,017 | 36,553,614 | 18,600,760 | 1,880,792 | 5,014,765 | 0 |
| 2030 | 72,192,910 | 46,572,011 | 37,257,609 | 19,067,694 | 1,928,005 | 5,140,650 | 0 |

**Table 6 - BAU Scenario Forecast Results (Author 2018)**

The BAU scenario calculations prepared the baseline or the current status of the dependent variable. This was important for the co-variation approach of the case study. By introducing the independent variable (WEST) into Cuenca's water cycle, the alterations in the readings of these indicators was then utilised to assess the impact of WEST technologies in sections 4.5 to 4.8.

## 4.3 Climate Change and potential threats to Cuenca's water

As the world faces the threats posed by climate change, some countries are being affected differently from others. Severe weather patterns in the form of hurricanes, droughts, floods and other natural disasters are occurring on an unprecedented scale in human history. In light of such developments at the world stage and keeping in mind the mentality about water that inhabitants of Cuenca generally have, it was important to understand how climate change is likely to affect Cuenca in the near future. To accomplish this, this research utilized two methods – in-person interviews with 12 local experts, and an online survey questionnaire of 30 local experts from Cuenca. These experts were selected based on a non-probability purposive sampling and in some cases, by snowball sampling. These experts included academicians, government officials from the municipality of Cuenca, experts from ETAPA water management public company, and members of AVINA- an Ecuadorian NGO that focuses on protection and conservation of water resources of Ecuador. The questionnaire results on climate change risk hazards Cuenca's water systems face in the 21st century. These results were triangulated by in-person interviews and research findings based on secondary data. Interesting conclusions were discovered once data analysis was completed.

From the in-person interviews, the climate-related hazards that were frequently mentioned were assimilated into the online questionnaire – Floods, Droughts, Landslides, and Loss of forests. Literature review and a study of the secondary data sources for Ecuador's national policy documents as well as Cuenca municipality's plans, it was clear that these four climate-related hazards posed the biggest threat to the water system of Cuenca, atleast as per the information available and predicted by experts from various sources. These interviews were then put for further ratification via an online survey questionnaire by more number of experts to assimilate the collective knowledge of the experts in Cuenca in the field of water-energy management, and climate change to obtain which natural threats weigh heavier in affecting the water system of Cuenca.

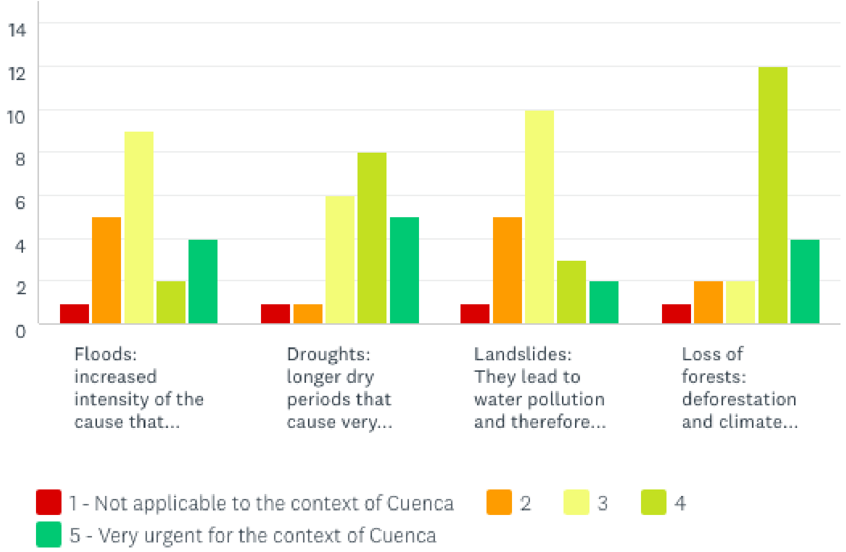


**Figure 13 – Online Questionnaire results for Likert Scale Rating of Climate-related hazards (Author 2018)**

In the first question, respondents were asked to rate the four climate-related hazards on a Likert scale from 1 to 5, with 1 being not applicable to the context of Cuenca's water management, and 5 being very urgent for the context of Cuenca's water management. If the number of people that voted a rating of 4 or 5 were added up, 'Loss of forests' received the highest rating with 16 people rating it 4 or 5, while 'droughts' was second highest rated with 13 ratings of 4 or 5. This result conveys the urgency of 'loss of forests' and its negative impact on the water system of Cuenca, followed by the threat of 'droughts' to most likely to impact the water systems of Cuenca. Both the 'loss of forests' and 'droughts' are obviously inter-related with each other because forests in the mountainous Andes region as well as Amazon region, enable evapotranspiration of water to yield heavy rains. Furthermore, forests on steep slopes slow down the runoff of rainwater, absorbing the water and keeping it stored in ground longer. It is therefore to understand why the two hazards might be closely linked to each other. The surprising bit of results here was that floods and landslides were not considered to be natural disasters that must be prioritized for Cuenca's context according to the expert panel. The reason behind floods not being considered priority could be numerous. Cuenca being high up in the Andes mountains is a major advantage in dealing with floods. The steep slopes of the Andes can always be utilized to drain off the water fast if need be. However, landslides seem to extremely common in Ecuador. Deforestation in recent years has increased the instances of landslides blocking roads, polluting the river water, and has been the cause of nuisance for the municipality of Cuenca, according to a city counsellor from the municipality of Cuenca (Zamora 2018). However, the results obtained from the first question were tested again in the second question to make the results more reliable.

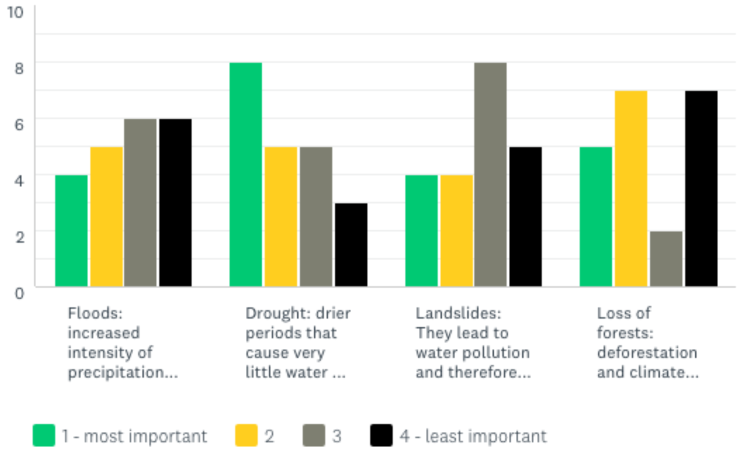


**Figure 14 - Online Questionnaire results for Ranking of Climate-related hazards (Author 2018)**

In the second question, the respondents were asked to rank the four natural disasters related to climate change in order of importance for Cuenca's context, with 1 being the most important and 4 being the least important. Similar to the first question, 'droughts' and 'loss of forests' was ranked 1st or 2nd most important by 13 and 12 respondents respectively.

The opinions of experts collected by interviews, closed questions and open questions in the questionnaire reveal different perspectives among the experts included in this study. While some experts in ETAPA believe that Cuenca's water management systems as described in section 4.1 is resilient in face of any climate change related hazards, experts from academia, non-profit organizations, public sector, do feel that Cuenca city overestimates the availability of potable drinking water from the Andes' mountains and change is required to adapt new technologies to prepare Cuenca for the uncertain near future.

## 4.4 Water-Energy Saving Technologies (WEST) Selection

Based on the discussion in previous section 4.3, this section explores the findings from the experts' interviews and questionnaires on the relevance of various technological solutions that fit the context of Cuenca as discussed in sections 4.1 to 4.3. These technological solutions are targeted solutions towards the climate change associated hazards that were discussed in section 4.3. The top-rated technologies from this survey are then used in sections 4.5 to 4.8 as projection simulations are developed and analysis is conducted to study the impact the introduction of these water-energy saving technologies (WEST) could have on Cuenca's water metabolic cycle in terms of the water savings, energy savings, economic feasibility, and overall, self-sustenance and resilience of Cuenca's water metabolic cycle. The online survey questionnaire for the WEST was also the same as the questionnaire discussed in the section 4.3.

With literature review of past researches on water metabolic cycles, 4 different technologies were selected for the questionnaire – rainwater harvesting, solar water heaters, micro water turbines, green roofs/walls. However, after the in-person interviews with some water-energy academic experts from Cuenca, solar panels were also added to the questionnaire due to its potential impact on the residential energy consumption in urban Cuenca.

In the first question related to WEST in the online survey questionnaire, the respondents were asked to rate the impact of the five technologies on the water and energy consumption of Cuenca's households. For this question, the Likert scale used had 1 representing 'very low' and 4 was maximum representing a 'very high' impact potential. The Likert scale of 1 to 4 was used instead of 1 to 5, to remove the neutrality associated with the centre reading of 3 on the Likert scale.

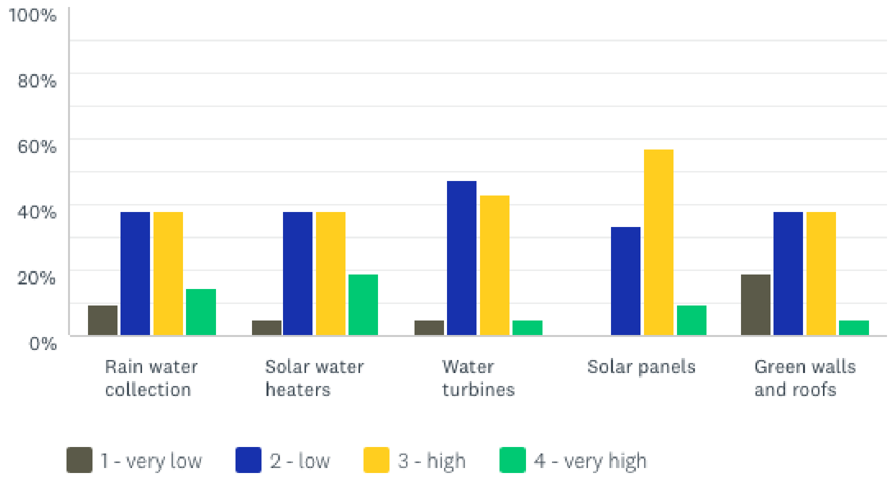


**Figure 15 - Online Questionnaire Results for Likert Scale Rating for WEST suitable for Cuenca (Author 2018)**

From the results obtained, as the graph above illustrates, the number of respondents that rated a given technology 3 or 4 – referring to high or very high impact potential were counted for each technology. Solar panels received the highest votes of 14 followed by solar water heaters (12), rainwater harvesting (11), water turbines (10), and green roofs/walls (9). For the following question, the respondents were asked to rank the WEST from 1 (most effective) to 5 (least effective).

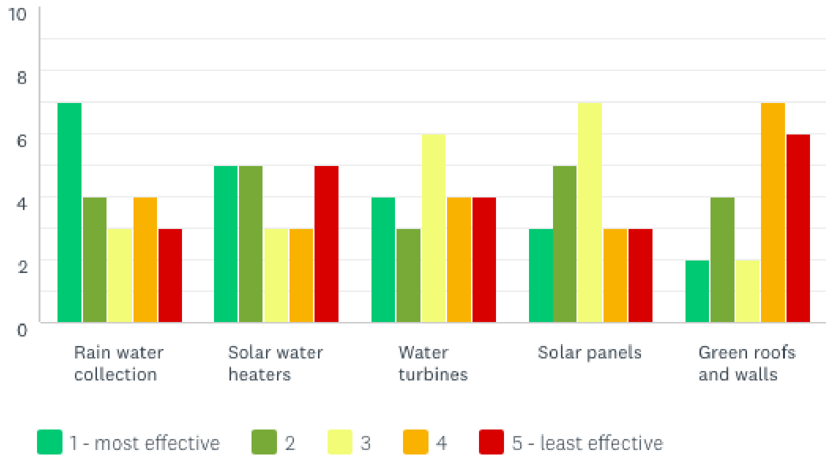


**Figure 16 - Online Questionnaire Results for Ranking of WEST suitable for Cuenca (Author 2018)**

The number of responses ranking a given technology 1 or 2 were added up to give us the following results - Rainwater harvesting - 11 votes, solar water heaters - 10 votes, water turbines - 7, solar panels - 8, and green walls/roofs – 6 votes. Combining the results obtained from both the questions, it was clear that green roofs/walls technology was not an impactful WEST as per the water and energy experts. Moreover, it was concluded that solar panels do not fit the criteria for this research study since the research aims to look at the impact of the technologies that affect and operates in the space of the water-energy nexus of Cuenca's water metabolic cycle as the research question suggests. The three selected WEST operate in the realm of the water-energy interlinkages of the water metabolic cycle. Firstly, rainwater harvesting aims to collect rainwater, reducing the runoff to the Ucubamba wastewater treatment facility, thereby saving energy in two ways – i) reducing the need of potable water for residences from the water grid, ii) reducing the volume of wastewater to be treated at Ucubamba. Secondly, solar water heaters installed in individual households reduce the need for energy from the grid in the form of electricity or gas tanks to heat water for domestic use. Solar water heaters, although do not impact the water flows from the grid, represent a huge potential impact on the energy that is consumed by the water consumed in residences for domestic use such as showers, etc. Lastly, micro water turbines work in the rivers of Cuenca to generate electricity from the water flows. This technology represents energy production utilizing kinetic energy from water flow, however, without causing consumption or withdrawal of the water sources. In the following sections from 4.5 to 4.8, the research analyses the potential each of these WEST holds in building a sustainable and carbon-free Cuenca of the future.

## 4.5 Rainwater harvesting

### Background Information on Cuenca

In his research, Chacha (2015) studies the feasibility of rainwater harvesting in Cuenca, Ecuador. The study analyses the annual precipitation patterns, the costs involved in constructing a rainwater harvesting setup on individual households, and the amount of water that these rainwater-harvesting installations could provide. In summary, Chacha's study concluded that rainwater harvesting was not feasible due to the abundance of water as well as the artificially low prices people paid for the water from ETAPA. Chacha was studying rainwater harvesting as a solution to solve potential flooding issues due to runoffs created by Andean slopes. The questionnaire survey and interviews in this study found contradicting opinions to Chacha (2015) in that flooding was not found to be of high concern to water experts in Cuenca. However, this research study focuses on revisiting rainwater harvesting for different reasons. As discussed in section 4.3, water experts in Cuenca emphasized on droughts and loss of forests being a bigger threat to Cuenca than floods. Therefore, this study aspired to explore rainwater harvesting as a mechanism to reduce run-offs and provide supplementary source of water, preparing for long periods of droughts or lack of rainfall in the Andes. Another key addition to Chacha's study that this research study wanted to bring forth in the discussion, was not to limit the analysis of the impact of rainwater harvesting only on the water flows, but to also analyse the impact of rainwater harvesting on the energy consumed by the conventional water management processes. Reducing the energy consumed in preparing water, delivering water, and handling wastewater from Cuenca's households, would thereby mean that fewer GHG emissions were emitted in the energy generation processes. Whether this translates to a reduced necessity of importing energy into Ecuador, or an increase in the energy surplus Ecuador had, this research aimed at quantifying and analysing the impacts of implementing rainwater harvesting in individual households on a more macroscopic platform of water-energy nexus that was not conducted by other studies in literature.

### Projection methodology and Results obtained

Firstly, the annual precipitation levels in Cuenca was studied from 1998 to 2012 (information obtained from Chacha 2015) and 2014 to 2017 (information obtained from Celleri 2018). This annual precipitation data was utilized to understand the generation potential of potable water by the rainwater harvesting in Cuenca. The annual precipitation in Cuenca for the available data averaged around 1017 mm per m2. Due to the lack of information and predictability about the **level of rainfall** for the future time period of 2018 to 2030, **1107 mm/m$^2$** was used in the development of the rainwater harvesting scenario. Secondly, another crucial information needed to develop the scenario was the **average roof area of households** in Cuenca. This data has been calculated in detail in (Chacha 2015, p.23) and the average value of **82.51 m$^2$** was utilized in the developing the rainwater harvesting prognoses. Furthermore, the **cost of installation of system with aboveground tank per household** with different materials was sourced from (Chacha 2015, p.33), and for this research scenario building, the **cheapest price of USD1551** (indicator 4.1) was utilized for simplicity. The prices ranged between USD1551 to 2266 depending on the material utilized. The **average monthly household water bill** was sourced to be **USD24** (INEC 2012, p.8). This value was triangulated with monthly water bills for three months from three different households in Cuenca (water bills copies available upon request), and cross-examined with the value utilized in (Chacha 2015) and (Malo 2014).

The rainwater harvesting scenario was constructed assuming the implementation on all the individual residences in urban Cuenca with the information mentioned above. The main results obtained from the scenario analysis was that rainwater harvesting would not be a feasible and profitable investment to make for Cuenca's governance of water. The table below summarizes the findings of the rainwater harvesting technology implemented at individual residences in urban Cuenca. The complete prognosis' result was developed in MS Excel and it is available in Annex 6-1 (results) and Annex 6-2 (complete).

| | **BAU Scenario** | **Rainwater harvesting scenario** | | | | |
|---|---|---|---|---|---|---|
| Time period<br>2018 to 2030 | Economic Losses to ETAPA as per BAU<br>(in USD) | Residential Water demand reduction from grid<br>(in %) | Investment costs<br>(in USD) | Energy savings<br>(in kWh) | Monetary savings from rainwater harvesting<br>(in USD) | Reduction of CO2 emissions<br>(in kgCO2) |
| Average per year | **9,800,000** | **22.01%** | **14,900,000** | **3,600,000** | **2,500,000** | **960,000** |
| Total (13yrs) | **127,000,000** | **-** | **194,000,000** | **46,000,000** | **32,600,000** | **12,500,000** |

**Table 7 - Rainwater Harvesting Scenario comparison with BAU Scenario (Author 2018)**

The table above illustrates key factors that need to be discussed as the analysis compares the BAU scenario to the rainwater harvesting scenario. As per the BAU scenario, water management processes yield **economic losses to ETAPA** on the order of approximately **USD9.8 million every year**. These losses as entailed by Chacha (2015) were a result of unsuitably low prices charged for water to Cuenca's inhabitants as well as water losses in the distribution network due to leakages of approximately 25-30%. In the rainwater harvesting scenario, it was assumed that the WEST would be able to operate with **80% efficiency** to develop a conservative and realistic projection. It was found that rainwater harvesting could **reduce the water demand** (indicator 4.2) from the water grid by **22% on average from 2018 to 2030**. The energy savings (kWh) were utilized to calculate the **reduction in GHG emissions** (indicator 4.4) which yielded a saving of **12.5 million kgCO2 emissions** in the 13-year time period.

**Analysis**

The prediction forecast was crucial to analyse the pros and cons of rainwater harvesting implementation. The overall result was found to be **negative**. Rainwater harvesting technology was not found to be a recommendable installation in Cuenca in the current context due to high implementation costs and low return on investment (ROI). Although, the **investment costs** (indicator 4.1) for the rainwater harvesting project hovers at approximately **USD194 million**, there was positive outcomes which might make this project's costs feasible and justifiable – rainwater harvesting potentially could **reduce the economic losses** (indicator 4.5) **of USD127 million in the 13-year time period** incurred by ETAPA due to reduced water distribution requirements and the forecast yielded a **total monetary savings** (indicator 4.5) **of USD32.6 million** (due to energy savings, production and treatment costs savings, etc.) in the given time period. For the **energy saving potential** (indicator 4.3), rainwater harvesting reduced energy demand by **3.6 million kWh per year**. Furthermore, an **annual reduction of 960,000 kgCO2** for a water management process that generated 3.5 million kgCO2 (calculated in section 4.2) in 2017 equates to an **approximate 27% reduction in GHG emissions annually** (indicator 4.4). If the reduced GHG emissions are weighed in terms of monetary benefits (due to increasing prices for carbon taxes), rainwater harvesting might become a practical solution in that context. The results of the rainwater harvesting projection was that this technology implemented on individual household level was not economically feasible as it lost the economies of scale, and there must be cheaper alternatives to improving Cuenca's water management. In the near future, if the prices of water were to rise in Cuenca and the installation costs of rainwater harvesting equipment was to decrease, rainwater harvesting technology could become a viable and feasible option for Cuenca's water management organization ETAPA and local government to consider. Ideally, there are multiple benefits of rainwater harvesting. Harvesting rainwater would help to reduce the water flow to the Ucubamba water treatment plant which would reduce the energy intensiveness of the water treatment process due to reduced volume of wastewater. Another advantage rainwater harvesting offers is that it would reduce the energy consumed in delivering potable drinking water to households. Both these savings are quantified in the built scenario. The savings on the energy and GHG emissions have also been discussed above that make rainwater harvesting strongly relevant in the discussion of world's water resources in face of threats from unforeseen changes in the climate in 21st century.

## 4.6 Solar water heaters

**Background Information on Cuenca**

In Cuenca's residences, hot water for showering and other domestic uses was found to be prepared by propane gas tanks. In an average household of 4 people, two 15kg gas tanks are required every month to keep the on-demand hot water running without interruption. Each gas tank costs the end-user only USD1.60 due to heavy subsidies provided by the Ecuadorian government. According to reports (Gould et al. 2018; CuencaHighLife 2018), a propane gas tank that is priced at **USD12.25** in the international market is accessible to Ecuadorians at **USD1.60**, resulting in **over USD10 per gas tank** paid by the state for importing these gas tanks. These **LPG-subsidies cost Ecuador over USD716 million each year**(Gould et al. 2018). This information was confirmed by the in-person interview with Professor Juan Leanardo Espinoza at University of Cuenca. In his interview, he also shared how he has been experimenting using a solar water heater system at his own home of four people for over one year and the results have been outstandingly impressive. It was his experiment that motivated this scenario projection for solar water heaters in this research study. Furthermore, in 2014, “developed in part to create demand for Ecuador’s growing hydroelectricity capacity and to address the cost of LPG subsidies, the Ecuadorian government had launched ‘Programa de Eficiencia Energetica para la Coccion’ (‘the program for energy efficient cooking’, **PEC**) which was built around incentives to install and use induction stoves in households” (Gould et al. 2018, p.112). As noted by Gould, the participants for PEC program were incentivized by receiving up to **80 kWh electricity per month free** for cooking for the year to increase the success of the PEC program. However, this program has not been successful yet, reaching only **740,000 stoves from 2014 to 2017** out of a targeted 3.5 million stoves till 2017 (Gould et al. 2018). One major reason cited for the low number of stoves converted from gas stoves to electric induction stoves is due to the reliance of Cuenca’s residences on the LPG propane gas cylinders for heating water in the house. The propane gas tanks were found to fulfil two residential demands – 1) cooking, and 2) heating water. Therefore, the installation of solar water heaters could incentivize the residences to be more participative towards the induction stoves as well, making the government program a success.

### Projection methodology and Results obtained

The target of creating this scenario projection was to understand if installing a solar water heater system in every household in urban Cuenca is a feasible and profitable idea. This solar water heater system would have an electric power backup due electricity being easily produced in Cuenca as well as the inability of the solar water heaters to function after sunset. The aim of the prognoses was to gather information about the economic benefits of utilizing solar water heaters over the traditional propane gas tanks; the environmental benefits in terms of reduction of GHG emissions; and the effect of solar water heaters on the water-energy nexus of the water metabolic cycle of Cuenca.

The steps to creating the forecast model for solar water heaters was easier compared to the previous rainwater harvesting (section 4.5). **Cost of installation per house (USD800)** (indicator 4.1), hot water storage capacity (**200-250 litres**), hot water temperature (60-65 degree Celsius) were key pieces of information gather for the solar water heaters from the in-person interview (Espinoza 2018). Furthermore, cost of installation of propane gas tank system per house (**USD600**), subsidized cost per gas tank (**USD1.60**), **actual cost per gas tank (USD12.25)**, number of gas tanks required per month for a family of four persons (**2**), size of propane gas tank (**15kg of propane**) were the indicators gathered to develop the baseline propane gas tanks scenario to compare the solar water heaters performance with. Other information obtained from secondary sources were – conversion of kilograms of propane gas to gallons (volume) and then, gallons of propane to Btu or kWh as in the case of this research study. Lastly, the **GHG emissions factor for propane gas tanks** was sourced from two different sources (Energetics Inc 2009) and (U.S. EIA 2018), and the value of **0.2548 kgCO2/kWh** (Energetics Inc 2009) was selected for two reasons – i) the paper had detailed emissions factor for different applications and this value was provided for domestic water heating application, ii) it was higher of the two obtained values – this was accepted to counter the lack of considering methane and nitrous oxide greenhouse gases emissions in the calculation due to the lack of data available easily on the topic.

In terms of calculations, first step was to calculate the unsubsidized economic cost of utilizing propane gas tanks for the population of urban Cuenca. This was measured by multiplying the number of gas tanks consumed by the average household in Cuenca to the actual cost of gas tank with number of residences in urban Cuenca (obtained from BAU forecast from section

4.2). The next step was to calculate the cost of implementing the solar water heater systems using the installation cost per household and the number of residences in urban Cuenca. These economic costs of utilizing the two water heating systems were used to create a forecast for a period of **16 years - 2015 to 2030**. The next step in the building of the forecast was to calculate the energy savings (in kWh) due to the solar water heaters with electric power backup. It was calculated that each gas tank contains 15kg of propane gas. 15kg of propane was converted to **7.8 gallons of propane** (volume) which yielded the energy provided equating to **209.3 kWh for each gas tank**. This value of energy was utilized to measure the total amount of energy saved per year (indicator 4.3) for urban Cuenca (in kWh) referring to the amount of energy converted from traditional fossil fuel sources to renewable energy sources (main power: solar and backup power: hydroelectricity). The amount of **energy saved for Cuenca per year averaged at 559,000,000 kWh** (indicator 4.3) for the period of 2015 to 2030. These energy savings were then utilized to calculate the GHG emissions reduction (in kgCO2) (indicator 4.4) using the emission factor of 0.2548 kgCO2/kWh (Energetics Inc 2009) which yielded an impact of **reducing around 142,000,000 kgCO2 per year in GHG emissions** on average for the 16-year period. The table below summarizes (for complete table see Annex 7) the results obtained from the scenario forecast for solar water heaters WEST implemented.

| | **Cost to State (in USD)** | | | |
|---|---|---|---|---|
| **Year** | **Gas Tanks scenario (BAU)** | **Solar water heaters scenario with electric back up power (WEST)** | **Energy savings (in kWh)** | **GHG emissions reduction (in kgCO2)** |
| 2015 | 28,615,714 | 77,865,888 | 488,919,912 | 124,592,484 |
| 2016 | 29,160,812 | 1,483,260 | 498,233,302 | 126,965,834 |
| 2017 | 29,705,910 | 1,483,260 | 507,546,692 | 129,339,185 |
| … | … | … | … | … |
| 2029 | 36,247,087 | 1,483,260 | 619,307,374 | 157,819,393 |
| 2030 | 36,792,185 | 1,483,260 | 628,620,764 | 160,192,744 |
| **Total US$** | **523,263,193** | **100,114,790** | **Average (2015 to 2030)** | |
| | | | **558,770,338** | **142,392,614** |

**Table 8 - Solar Water Heaters Forecast Results (Author 2018)**

## Analysis

As clear from the table above, solar water heater with electrical backup power was discovered to have a **highly positive feasibility forecast**. For the results for installation costs (indicator 4.1), the implementation of solar water heater systems requires an **investment of around USD78 million** from the state (in case it is being 100% sponsored by the government) initially in the **first year**. However, by 2030 this transformation of domestic water heating system from propane gas to solar/hydroelectricity yields huge economic profits for the stakeholders as can be calculated from the table above. In the 16-year period the **monetary savings** (indicator 4.5) for the state would be **USD423 million approximately**. This is due to the large sum of money that Ecuador spends in importing propane gas from the international energy market. The Azuay province, of which Cuenca is the capital, is the hydroelectricity centre of Ecuador. With numerous hydroelectric dams and an Ecuadorian vision of becoming 100% reliant on hydroelectricity for energy by 2050 (Ministerio de Electricidad y Energia Renovable 2017; Pacheco 2017), this solar water heater project could be a huge leap in the right direction to take Cuenca's residential energy demand and Ecuador's residential energy demand from imported fossil fuel-based energy to renewable energy sources like solar and hydroelectricity. Moreover, the **average amount of reduction in energy importation** (indicator 4.3) in the form of propane gas tanks between 2015 to 2030 was around **559 million kWh per year**. To put this number into context, an average house in Cuenca (4 people) consumed 300 kWh per month and therefore, 3600 kWh per year. With 559 million kWh (or 559 GWh) of energy, around 160,000 houses could be powered for the entire year which is more than sufficient energy required to sustain all residences in Cuenca till 2030. The usage of solar water heater systems would remove Ecuador's need to import this much energy from abroad and enable Ecuador to harness her renewable sources of energy to support her domestic needs. If this example was implemented across Ecuador, the country could easily become self-sufficient in the energy sector and furthermore, look to increase revenue by exporting of energy to nearby developing countries in South America. Lastly, in terms of **GHG emissions**, Ecuador in total had a cumulative emissions total of **94.5 Mt of CO2e in 2014** (Climate Watch 2018). Although, the GHG savings (indicator 4.4) of roughly **142 million kgCO2 annually** represents only **0.15%** of the country's total emissions, however, it is important to note that urban Cuenca only represents about **2.5%** of Ecuador's entire population and that hot water for domestic usage represents only a small percentage of sources of GHG emissions from a person on average.

## 4.7 Water turbines

With rainwater harvesting, the research illustrated one mechanism by which reducing volume of water flow in the water networks conserves the amount of energy consumed by the water networks. Thereafter, with solar water heaters, the research explored a mechanism to conserve energy directly inputted into the water systems by transforming the energy source to renewable. In this section, the research moves to discussing a third perspective in the narrative revolving around the water-energy interlinkages. With water turbines, the study dives in to find out how the flowing energy in river water could be harnessed cheaply to add a third dimension of utilizing water to generate energy.

### Background Information on Cuenca

As discussed in section 4.1, Cuenca has four rivers – Machangara (with a length of 30 km), Tarqui (with a length of 36 km), Tomebamba (with a length of 38 km), and Yanuncay (with a length of 36 km) (Donoso 2012, pp.17–18). These rivers provide more than sufficient water to meet the water needs of Cuenca. Azuay and Cuenca are well known in Ecuador as the centre for hydroelectricity generation. This is illustrated by the fact that **14% of Cuenca's economy** comes from **hydroelectric power generation** (Donoso 2012). In recent times, as (Pacheco 2017) wrote that Ecuador's government had accomplished a commendable job in converting Ecuador from an energy importer to an energy exporter country. This was done primarily due to **27 power plants (including 8 hydroelectric plants)** being built between 2007 to 2017 by the state. Although this had greatly increased Ecuador's energy producing capacity, (Pacheco 2017) stated that much of the installed power plants were not being utilized to their capacity or at an optimal level, and the government had defended these projects to be planned for increased energy consumption till 2023. Important idea for this research study from this article was the strong focus on capital intensive, large energy generation projects (Economy Writing 2016). However, experts also aspire to explore decentralized form of power generation – for example, micro hydro turbines or easily referred to as 'water turbines', work much like wind turbines but in flowing water. The advantage these micro hydro turbines present as opposed to large hydroelectric dams is that these turbines are compact and can be installed easily along a flowing river without disrupting the ecosystem of the river. However, hydroelectric dams represent a more capital intensive and ecosystem disruptive technology that causes harm to downstream ecosystems due to creation of reservoirs and blocking the natural flow of water.

## Projection methodology and Results obtained

The target of developing the projection scenario of water turbines from 2019 to 2033 was to examine the impact and feasibility of implementing micro hydro turbines (or water turbines) in Cuenca's rivers for Cuenca's energy demand, as well as the potential of the fast-flowing rivers of Cuenca to be tapped to harness electricity with a capital non-intensive technology.

Professor Espinoza's (2018) interview revealed that these micro hydro turbines were compact - approximately 1m x 1.5m x 1.5m in dimension, and could generate **5kW of power** that could operate 24 hours a day due to the river flows in Cuenca. The **installation cost** (indicator 4.1) of each water turbine inclusive of all operation and implementation costs would amount to **USD40,000 per turbine**. With this information in place, the first step to building the projection scenario was to calculate the residential electricity/energy demand which was calculated in two ways – i) the interview with Espinoza (2018) revealed that on an **average house in Cuenca utilizes 300 kWh per month**. Even with operationally conservative calculations, one water turbine **generated 100kWh a day** (with 20hours working and 4 hours maintenance/down time). This information was crucial for calculation of the energy saving potential (indicator 4.3) in the study. Hence, one water turbine could sustain the energy requirement of 10 residences. ii) This was confirmed by cross-checking with electricity utility bills for three houses in Cuenca (source: bills available upon request) and corroborating the residential energy demand of 300 kWh from secondary sources. The second step was to analyse the lengths of the four rivers running through Cuenca and measure the maximum number of water turbines that could be installed along the rivers of Cuenca. Espinoza (2018) also shared that the water turbines could be installed at a recommended distance of 500m from one another. Therefore, the lengths of the four rivers revealed that a maximum of **280 water turbines** could be installed with the criteria specified by the expert in this field. For the prognoses, **the installation of 100 water turbine over 5 years** was assumed to develop a realistic forecast. The table below summarizes the findings from the built scenario (see full table in Annex 8).

| **Year** | **Number of water turbines installed** | **Installation costs of water turbines (in USD)** | **Electricity generated by water turbines (in kWh)** | **Revenue generated by water turbines' electricity (in USD)** | **GHG Reduction (in kgCO2)** |
|---|---|---|---|---|---|
| 2018 | - | - | - | - | - |
| 2019 | 20 | 800,000 | 730,000 | 73,813 | 196,808 |
| 2020 | 20 | 800,000 | 1,460,000 | 147,626 | 393,616 |
| 2021 | 20 | 800,000 | 2,190,000 | 221,439 | 590,424 |
| 2022 | 20 | 800,000 | 2,920,000 | 295,252 | 787,232 |
| 2023 | 20 | 800,000 | 3,650,000 | 369,065 | 984,040 |
| 2024 | | | 3,650,000 | 369,065 | 984,040 |
| … | | | … | … | … |
| 2033 | | | 3,650,000 | 369,065 | 984,040 |
| **Total** | **100** | **4,000,000** | | **4,797,845** | **12,792,520** |
| **Units** | **units** | **USD** | | **USD** | **kgCO2** |

**Table 9 - Water Turbines Forecast Results (Author 2018)**

‘Electricity generated by water turbines’ was calculated by using the number of installed water turbines generating **100kWh per day for 365 days** for the annual total. Revenue generated (affecting indicator 4.5 - monetary savings) by the electricity was calculated by utilizing the energy price of **9.9kWh per USD** in section 4.1. The forecast was run from 2019 to 2033 to enable all 100 water turbines to operate for 15 years. This yielded a **total revenue of USD4.8 million** from the project covering the **implementation cost of USD4 million** (indicator 4.1 installation costs). The above two values were used to calculate a **net USD 0.8 million in monetary savings** (indicator 4.5) from water turbines project. The yearly electricity generation of **3.65 million kWh or 3.65 GWh** was important for the context of Cuenca since the average residential electricity demand for the time period was calculated to be around **30 GWh**. Hence, the electricity from water turbines represents a **12% coverage** of Cuenca’s residential electricity needs, helping measure the **energy saving potential** (indicator 4.3) from this technology. Lastly, the **cumulative GHG savings** (indicator 4.4) of **12.8 million kgCO2 (over 15 years)** was an important take away from the forecast.

### Analysis

As (Elbatran et al. 2015) remark in their study, micro-head hydro turbines represent a suitable energy solution for small developing countries that require good performance with “minimal initial and running cost” (Elbatran et al. 2015, p.40). Small-scale hydro with mostly “run-of-river” design with no dam or water storage has been concluded to be one of the most cost effective and environmentally benign energy technologies that not only suit the needs of less developed countries but also for “further hydro developments in Europe”(Paish 2002). Water turbine forecast results indicate that this technology would be feasible and beneficial for development of Cuenca. This research concluded with a positive result for the micro hydro ‘water turbines’ technology.

Water turbines are similar to wind turbines, except that they harness the energy in the flow of river water, without the creation of hydroelectric dams. In the presence of 4 rivers flowing through Cuenca, water turbine represents a technology that excites many water experts in the city. With each machine being small in size and able to generate enough electricity supporting 10 houses, installation of hundreds of these turbines in the rivers of Cuenca is a possibility experts agree on. The projection helps quantify the benefits of installing water turbines in Cuenca’s rivers. The projection is based on installing 100 water turbines which will have a total cost of USD4 million and these costs will be recovered within 10 years of operation by the water turbines. The technology plays in line with Ecuador’s ambition to achieve 100% generation of electricity through hydroelectric sources. The **wind turbines project** of Villonaco installed in 2013 (Economy Writing 2016), had an **investment cost of USD54 million** and generates **59 GWh of energy annually**. The water turbine prognoses developed illustrated a **similar ratio of investment to amount of energy generated annually**, with the added advantage of low capital investment to initiate the water turbine project. In recent years, Ecuador’s government has been actively following a strategy towards “an increased reliance on large-scale hydro” projects (US Department of Commerce and International Trade Association 2016). The **GHG emissions reduction** (indicator 4.5) of approximately **1 million kgCO2 annually** with a small investment as this, definitely plays a significant part in reducing Ecuador’s carbon footprint. As (Carbon Independent 2007) helps to visualize, a GHG emissions reduction of 1 million kgCO2 annually equates to roughly the same amount of GHG emissions from 100 Boeing 747-400 planes flying for 100 hours each.

## 4.8 Combined-WEST Implementation Plan

After analysing the scenarios of implementing rainwater harvesting, solar water heaters and water turbines in urban Cuenca, the research analysis condensed the results found and then, attempted to design a practical implementation plan for these WEST in urban Cuenca. As the result obtained from rainwater harvesting showed that the technology was not suitable for a water-abundant Cuenca, it was not considered for this final forecast scenario developed till 2030. The aim of this final projection was to suggest it as a feasible plan of action to implement solar water heaters and water turbine in urban Cuenca considering the limitations the municipality and urban developers might face in taking the recommendations from this research study and executing the project to fruition.

### Background Information from the three individual forecasts

According to a council meeting at Municipality of Cuenca in March 2017, **USD10 million** were established to increase the production capacity at Tixan in the upcoming few years, and **USD50 million** were approved for building a new wastewater treatment plant at Guangarcucho (further downstream from Ucubamba) in the next three-five years (GAD Municipal de Cuenca 2017). Based on this council meeting and the discussion around the budget presented, it was clear that the recommended solution from this research project regarding water-energy saving technologies (WEST) could not be expecting a budget of more than **USD50 million**. Additionally, from the results generated in sections 4.1 to 4.7, these conclusions and assumptions were drawn to be used in this final forecast–

i) Rainwater harvesting was not feasible due to high investment costs involved and therefore, not considered for this implementation recommendation.

ii) Solar water heaters (SWH) and Water Turbines (WT) would both be included in the recommended projection scenario.

iii) LPG-subsidies cost Ecuador over USD716 million each year (Gould et al. 2018). With a focus on increasing its hydroelectricity capabilities, Ecuador aspires to move from fossil fuel-based energy to renewable hydroelectric energy as it transitions from an energy-importing country to energy-exporting country to its neighbours like Colombia, Peru and rest of Latin America.

iv) Solar water heaters (SWH) yielded a potential savings of USD423 million over a 16-year period and energy transition from propane gas to a renewable combination of solar and electricity of the magnitude of approximately 559 GWh each year. However, the limitation of the prognosis was that it required a USD78 million investment in the first year of implementation.

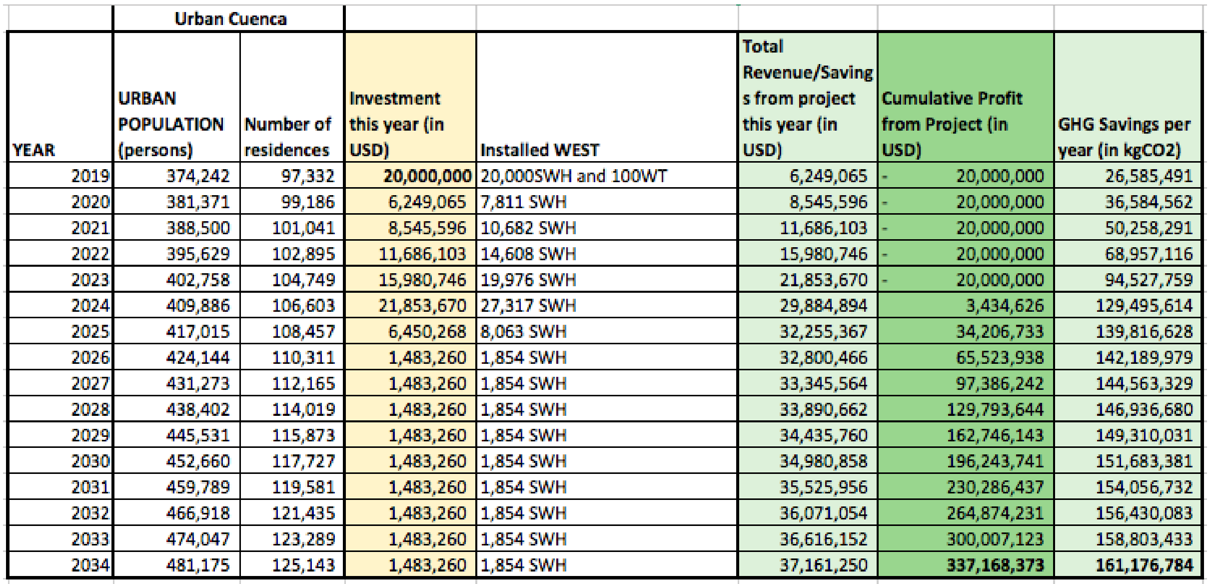
v) Water turbines (WT) yielded a roughly break-even scenario with a small profit margin in the 15 years of full operations, however, the yearly electricity generation of 3.65 million kWh or 3.65 GWh was important for the context of Cuenca since the average residential electricity demand for the time period was calculated to be around 30 GWh. Hence, the electricity from water turbines represents a 12% coverage of Cuenca's residential electricity needs. The initial investment of USD4 million was a strong positive takeaway from the scenario projection.

With the above information discovered from the research results in sections 4.2 to 4.7, the final projection was aimed at generating a pragmatic solution that could be implemented if approved. The costs of fossil fuel-based energy importation into Ecuador was an important problem that the research projection targeted to resolve. The benefits of implementing the water-energy saving technologies (WEST) like solar water heaters and water turbines, that were pursued in this research study were – a) self-sufficiency of Ecuador's energy production and consumption which would make Ecuador self-reliant in face of uncertain future of the political nature of struggle between nations over energy resources, and b) monetary savings for state and central government of Ecuador which increases the incentive for a country to become self-sufficient in the first place. Although in 2018, Ecuador boasted a strong energy production from the hydroelectric sector that enabled the exports of electricity to neighbouring countries, minimizing the import of vast sum of monetary worth of petroleum oils, petroleum gases and other forms of fuels that constituted **17% of Ecuador's imports in 2017** (Workman 2018).

## Projection methodology and Results obtained

It was assumed that only an **investment of USD20 million** (indicator 4.1 installation costs) for this water-energy saving technologies (WEST) project would be allocated for initial implementation. The calculations were done in a chronological manner (on a year to year basis) beginning from 2019. The further implementation of the subsequent phases of the project were projected to be funded via the monetary savings and revenue generated by the project. This would ensure more practicality to the implementation process. The prognosis tracked the units of solar water heaters and water turbines installed on an annual basis. The energy saved ('saved' refers to transitioning from propane gas to solar energy) from solar water heater units were quantified and the monetary benefits to the government due to reduced demand for propane gas tanks were also calculated. Similarly, the energy and the revenues generated from the electricity from the water turbines units were included in the calculation. These monetary benefits from both technologies were then invested in the next year for subsequent implementation of the project.

The following table 11(full table available in Annex 9) illustrates the investments (indicator 4.1), the installed WEST (solar water heaters and water turbines) project schematic, total monetary savings from project per year (indicator 4.5) and the associated GHG savings (indicator 4.4) with the project technologies on an annual basis from 2019 to 2034. In darker green shade, the column represents the cumulative profit from the project from 2019 to the end of the relevant year.



| | Urban Cuenca | | | | | | |
|---|---|---|---|---|---|---|---|
| YEAR | URBAN POPULATION (persons) | Number of residences | Investment this year (in USD) | Installed WEST | Total Revenue/Savings from project this year (in USD) | Cumulative Profit from Project (in USD) | GHG Savings per year (in kgCO2) |
| 2019 | 374,242 | 97,332 | **20,000,000** | 20,000SWH and 100WT | 6,249,065 | - 20,000,000 | 26,585,491 |
| 2020 | 381,371 | 99,186 | 6,249,065 | 7,811 SWH | 8,545,596 | - 20,000,000 | 36,584,562 |
| 2021 | 388,500 | 101,041 | 8,545,596 | 10,682 SWH | 11,686,103 | - 20,000,000 | 50,258,291 |
| 2022 | 395,629 | 102,895 | 11,686,103 | 14,608 SWH | 15,980,746 | - 20,000,000 | 68,957,116 |
| 2023 | 402,758 | 104,749 | 15,980,746 | 19,976 SWH | 21,853,670 | - 20,000,000 | 94,527,759 |
| 2024 | 409,886 | 106,603 | 21,853,670 | 27,317 SWH | 29,884,894 | 3,434,626 | 129,495,614 |
| 2025 | 417,015 | 108,457 | 6,450,268 | 8,063 SWH | 32,255,367 | 34,206,733 | 139,816,628 |
| 2026 | 424,144 | 110,311 | 1,483,260 | 1,854 SWH | 32,800,466 | 65,523,938 | 142,189,979 |
| 2027 | 431,273 | 112,165 | 1,483,260 | 1,854 SWH | 33,345,564 | 97,386,242 | 144,563,329 |
| 2028 | 438,402 | 114,019 | 1,483,260 | 1,854 SWH | 33,890,662 | 129,793,644 | 146,936,680 |
| 2029 | 445,531 | 115,873 | 1,483,260 | 1,854 SWH | 34,435,760 | 162,746,143 | 149,310,031 |
| 2030 | 452,660 | 117,727 | 1,483,260 | 1,854 SWH | 34,980,858 | 196,243,741 | 151,683,381 |
| 2031 | 459,789 | 119,581 | 1,483,260 | 1,854 SWH | 35,525,956 | 230,286,437 | 154,056,732 |
| 2032 | 466,918 | 121,435 | 1,483,260 | 1,854 SWH | 36,071,054 | 264,874,231 | 156,430,083 |
| 2033 | 474,047 | 123,289 | 1,483,260 | 1,854 SWH | 36,616,152 | 300,007,123 | 158,803,433 |
| 2034 | 481,175 | 125,143 | 1,483,260 | 1,854 SWH | 37,161,250 | **337,168,373** | **161,176,784** |

**Table 10 - Combined-WEST Implementation Plan Forecast Results (Author 2018)**

As observed in the table above, the project showed significant impact potential on a realistic implementation scale. The **overall profit** (indicator 4.5) from the project for the Ecuadorian government works out to be **USD337 million** over a time period of 15 years (2019 to 2034) during which all the residences in urban Cuenca would have **successfully transitioned from propane gas tanks to solar water heaters and a total of 100 water turbines would have**

]

**been installed** in the four rivers of Cuenca generating electricity that meets approximately **12% of Cuenca's residential electricity demand** every year. The investment pattern reveals that in no year between 2019 to 2034 does the investment for the project exceed USD25 million which according to this research study was an important factor in keeping the prognosis realistic and feasible.

## Analysis

There were various aspects of the projection forecast that need further discussion and analysis. Firstly, the impact of solar water heaters on Cuenca's inhabitants and the individual household holds critical importance. The crucial role that solar water heaters play in this political context alongside the induction stoves program of the government was coincidental for this research study and lends the implementation plan proposed in this prognosis serious consideration.

However, the use of solar water heaters might demand cultural and lifestyle adjustments from the users. In Espinoza's interview (2018), he described that the best time to avoid energy wastage and to maximise the availability of hot water for showers, etc., was after sunset during early evening. This was due to the fact that the solar water heaters would capture Sun's energy during the daytime and water would be warmest in evening, however, as the night progressed, by early morning the water would have lost some energy due to imperfect insulation of the water tank. Therefore, it would be best for families in Cuenca to shift their showering time from early morning to evenings and nights before sleeping. Though, he also mentioned that water does stay warm even in the morning so it would not be a necessity to change one's showering habits that might have rendered the technology unacceptable to many residents of Cuenca. This was another important impact that solar water heaters would have on the residents of Cuenca. It is important to evaluate the impact on the inhabitants' lifestyle to understand the technology's acceptance among the residents.

Secondly, the impact of solar water heaters on Ecuador's energy mix as well as importation of LPG gas cylinders would be significant. The graph below from Gould (2018), illustrates the significance of import volume of LPG gas cylinders in Ecuador. Roughly **85% of all LPG** consumed in Ecuador has to imported due to lack of production capacities. With implementation of solar water heaters as proposed in this research study and the aforementioned PEC – electric induction stoves program by the government, LPG gas cylinders demand would certainly reduce, helping Ecuador's residences (beginning from Cuenca) transition from LPG to electricity for cooking and LPG to solar/electricity for other domestic needs. This implementation in Cuenca could thereby effected on a national level making a vast contribution to shifting Ecuador's energy mix towards hydroelectricity and other renewable sources such as solar and wind. Urban Cuenca's population is 2.5% of the population of Ecuador. If implementing this project yielded **USD317 million monetary profit** (indicator 4.5) in 15-year period and **161 million kgCO2 GHG savings per year** (indicator 4.4) in urban Cuenca alone, the impact has to at the national level would have staggering statistics associated with it. The monetary profit of **USD 317 million** over 15-year period represents a **1585% profit** on the **initial investment costs of USD20 million** (indicator 4.1).

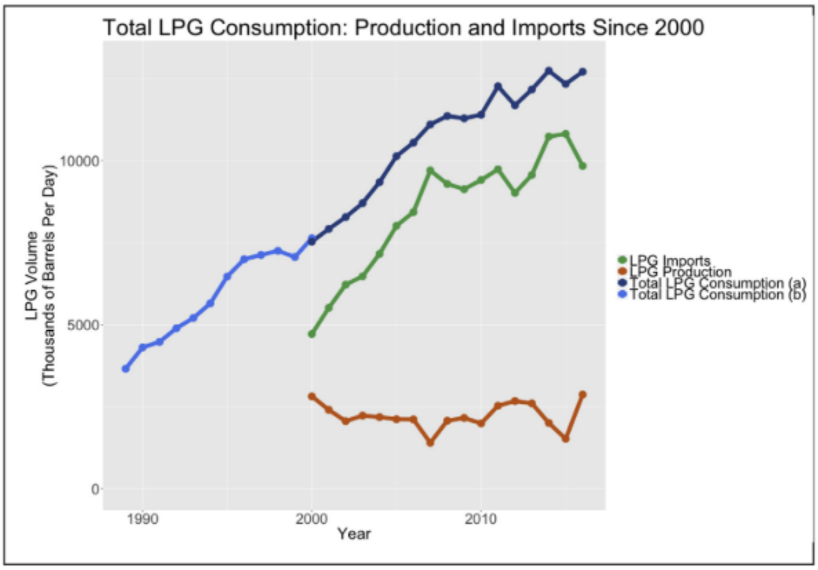


**Figure 17 - Total LPG Imports by Ecuador(Gould et al. 2018, p.69)**

The total GHG emissions from Ecuador in 2014 were **94.5 Mt CO2e** (Climate Watch 2018). Out of these emissions, the energy sector was responsible for **42 Mt CO2e** (Climate Watch 2018). The prognosis results showed that this project had a potential of saving **161 million kgCO2e per year** which translate to only **0.17% of the total country's emissions**. However, calculations per capita for urban Cuenca's inhabitants, the GHG reduction from the prognosis represented a **6.8% impact** on the total GHG emissions (indicator 4.4) emitted annually. This contributes strongly to Ecuador's target of reducing the emissions from the energy sector **20-25% below BAU scenario by 2025** (Climate Watch 2018). The water turbines and solar water heaters both contribute to shifting the energy mix of Ecuador towards renewable energy fulfilling multiple of its commitments as per the SDGs and IPCC Paris Agreement (Climate Watch 2018).

## 4.9 Chapter Conclusion – Reflection on findings

This chapter studied Cuenca's urban water metabolic cycle, analysed the threats of climate change and its effects on Cuenca's water cycle, and lastly, assessed the impact and economic feasibility study of a few selected water-energy saving technologies (WEST) like rainwater harvesting, solar water heaters and micro hydro turbines for implementation in urban Cuenca.

In the study of Cuenca's urban water metabolic cycle, the role of gravitation and mountainous topography of the Andes were discussed. It was found that Cuenca has an abundance of water resources with El Cajas National Park feeding the city with **four rivers** – Machangara, Tomebamba, Tarqui, and Yanuncay all year long. There were **three potable water treatment plants** – Tixan, Cebollar and Sustag which were responsible for producing **approximately 49 million m$^3$ of potable water** in 2017 (ETAPA EP 2018). This potable water was distributed to all the residences using gravitation, thus, minimizing the cost of treatment and distribution of water throughout the water metabolic cycle. The sewerage generated from the residences along with rainwater got collected via the wastewater collection system and was sent to **Ucubamba treatment plant** before the treated water was released in river Cuenca that flows downstream from urban Cuenca (the studied area in this research). Thereafter, in BAU projection, the water flows were studied by indicators such as total potable water produced (indicator 1.1) for urban Cuenca (in m$^3$), total water consumed (in m$^3$), and residential water consumption (indicator 1.2) (in m$^3$). The associated energy demand variable for these water flows were studied by indicators – energy consumed (kWh) (indicator 2.1) and energy costs (USD) (indicator 2.2). All energy input was found of electricity form as result for indicator 2.3. GHG emissions were also analysed using two different indicators (both constituting indicator 3.1) – GHG emissions as per Ecuador's emissions factor, and GHG emissions as per Cuenca's local emissions factor. This was done due to the uniqueness Cuenca held in the energy generated from hydroelectricity as compared to the rest of Ecuador. The data collected for these indicators was studied for a time period of 1992 to 2015, and henceforth, the BAU scenario was developed to coincide these indicators to the increasing urban population and urban area of Cuenca city till year 2030. This forecast BAU scenario was utilized as the baseline that other alternate projections were compared to in the later sections (sections 4.5 to 4.8).

In the second segment of this chapter referring to sections 4.3 and 4.4, data collection via interviews (12 experts) and questionnaire surveys (21 experts) was analysed to study the impact climate change would have on Cuenca's water metabolic cycle. The results obtained indicated that contrary to commonly held belief by the public of Cuenca that Cuenca would be threatened by floods due to its abundant water resources as a result of climate change, experts believe that Cuenca would have to deal with long periods of droughts and short periods of intense rainfall as a result of the changing climate in the near future. **Drought, water shortage and loss of forests** were the most prominent threats to Cuenca's water metabolic cycle according to the panel of experts studied. Cuenca is situated at a high altitude in the Andes mountain range which provides numerous advantages for the inhabitants. Abundant rainfall and more than sufficient water in the lagoons of El Cajas National Park means that most residents Cuenca perceive water system of Cuenca to have no problems or potential threats in the near future. The fast-flowing rivers and abundant water sources have wisely been utilized to increase Ecuador's hydroelectric capacities. A few experts revealed in the interviews that Cuenca's local electricity mix was 100% hydroelectric (indicator 2.3) and this example was supported by Ecuadorian government to be implemented in the rest of the country. However, this research study found that 100% reliance on hydroelectricity may also reduce the resilience of Cuenca city. These findings urged the research to enquire about potential mitigation or adaptation actions that could prepare Cuenca in face of these climatic threats and make the city more resilient. Through in-person interviews and questionnaires, various water-energy saving measures were explored and analysed as tools for mitigation of and adaptation to the changing climate. Some experts emphasized on policy interventions, behavioural change in residents' water consumption habits, water pricing reforms, while others focused on technologies like rainwater harvesting. Analysing and researching about these different WES measures and actions already implemented in Cuenca city, it was found that the local government had run campaigns on conserving water, creating awareness among the inhabitants and also done their research on water pricing reforms as tools to incentivize consumer behaviour. Therefore, due to the lack of technological considerations in municipality and national energy and water plans, this research narrowed down to further investigate water-energy saving technologies (WEST), and due to the constraints of time and available information, the study focused on three shortlisted WEST – **rainfall harvesting, solar water turbines and water turbines**.

Thereafter, the research progressed to the third and last segment of assessment of the impact and economic feasibility of implementing these WEST in urban Cuenca and development of a projection forecast for the next 10-15 years for each scenario. While **rainfall harvesting** (section 4.5) yielded an alternate mechanism which would remove the necessity to expand the production capacities of the four potable water treatment plants to meet the needs of urban Cuenca till 2100 and would provide a useful tool for Cuenca to be resilient in the face of severe water shortages, it was found to be **unfeasible due to two main reasons** – i) the implementation costs totalled USD194 million for the coverage of all the residences in urban

Cuenca and the return on investment on the project was not able to recover the costs due to low water prices (which in turn were due to the abundance of water in the region); ii) secondly, approximately 93% of all energy consumed by the water management systems in Cuenca was found to be consumed in the wastewater treatment facility at Ucubamba. This wastewater treatment would be required even if rainfall was collected and therefore, **rainwater harvesting did not make much impact in energy or GHG savings in the prognosis**. Overall, rainwater harvesting technology was found unfeasible for implementation in urban Cuenca. On the contrary**, solar water heaters** (SWH) implementation forecast showed spectacular results with a potential to save **USD423 million** for the state in a 15-year time period. This forecast was found to be seamlessly suitable for the government to implement as it complimented the 'Programa de Eficiencia Energetica para la Coccion ('the program for energy efficient cooking', **PEC**) (Gould et al. 2018) which was launched in 2014 and aimed at transitioning Ecuador's residences from propane gas tanks to electric energy source for cooking. Solar water heaters (section 4.6) represent a technology that would impeccably support the program and remove the necessity for propane gas tanks in Cuenca's residences permanently. Similarly, in section 4.7, **water turbines** (WT) or micro hydro turbines were also found to be complimentary to Ecuador's and Cuenca's policies on moving the energy mix towards hydroelectricity and the project yielded economic feasibility to be considered for **immediate implementation**. In section 4.8, a realistic **implementation plan (WEST project)** was developed which would run from 2019 to 2034, and only require an investment of **USD20 million** to initiate. The WEST project would yield a total of **USD337 million by 2034** resulting in a cumulative profit of USD317 million, representing a **1,585% profit** on the original investment. The WEST project would give Cuenca **100 water turbines** in the rivers to generate additional 3.65 GWh of hydroelectricity to its current capacity and all the houses in Cuenca would have switched from **LPG gas cylinders to solar water heaters**. This transition of the energy demand of residences in Cuenca from fossil fuel-based power to hydroelectricity and solar power, laying a successful blueprint for rest of Ecuador to imitate.

# Chapter 5: Conclusions and recommendations

In this research study, semi-structured interviews, online survey questionnaire, and secondary data analysis were utilized as data collection methods to evaluate "to what extent can water-energy saving technologies (WEST) influence the water-energy nexus in Cuenca's urban water metabolic cycle," which was the main research question of this study. To obtain answers to the main and sub research questions, the process required the analysis of Cuenca's current urban water metabolic cycle which also helped to verify the results obtained in another literature (Chacha 2015) on this topic. Thereafter, the threats of climate change and its effects on Cuenca's urban water metabolic cycle were evaluated by learning from local experts working and researching in this field. In conclusion, the impact and economic feasibility of a few shortlisted water-energy saving technologies (WEST) like rainwater harvesting, solar water heaters and micro hydro turbines were assessed for implementation in urban Cuenca by creating forecast scenarios for each WEST for the next 10-15 years.

In this chapter, the answers to the sub-questions and the main research question are presented by summarising the research findings and subsequent data analysis. Additionally, the impact of this research on existing literature is reflected upon, and recommendations and further research ideas are introduced.

## 5.1 Answers to the research questions

**Main Research Question: To what extent can water-energy saving technologies (WEST) influence the water-energy nexus in Cuenca's urban water metabolic cycle?**

The four sub-questions listed in chapter 1 (section 1.4) provided a backbone structure to the research study. Searching for the answers to these sub-questions helped knit together the answer to the main research question.

**Sub-question 1: How does the urban water metabolic cycle of Cuenca function in the current scenario?**

Cuenca is a typical mountainous city with an altitude between 2,350 and 2,550 MASL making the role of gravitation and mountainous topography of the Andes crucial for the water metabolic cycle. Cuenca has an abundance of water resources with El Cajas National Park feeding the city with **four rivers** – Machangara, Tomebamba, Tarqui, and Yanuncay all year long. There are **three** potable water treatment plants – Tixan, Cebollar and Sustag, which produced approximately **49 million m$^3$** of potable water (indicator 1.1) in 2017 (ETAPA 2018). This potable water reaches the **101,000 residences** (indicator 1.3 value for 2017) using gravitation, thus, minimizing the distribution costs of water throughout the water metabolic cycle. The sewerage generated from the residences along with rainwater gets collected via the wastewater collection system and is sent to Ucubamba treatment plant before the treated water (53.5 million m$^3$ in 2017) is released in river Cuenca that flows downstream from urban Cuenca. The research study discovered that the **residential consumption** (indicator 1.2) represents **80-82%** of the total water consumed by Cuenca. In 2015, 27 million m$^3$ was consumed by urban Cuenca's residences out of the total water consumption of 33.3 million m$^3$ by the city. This result is in stark contrast to the worldwide average of 70% water consumed by agriculture, 20% by industries and 10% by residences in a city. The amount of water consumed per person in Cuenca's homes is estimated at **200-210 litres per day** (lpd) which is much higher than the recommended amount of 50 to 100 lpd by WHO for meeting human needs. Additionally, it was found that **25-30%** of potable water produced is **lost in the distribution** processes due to leakages and illegal connections. The rate of cost of production of potable water is estimated at **USD1.29 per m$^3$** (Chacha 2015). This was utilised to evaluate the production costs (supply costs - indicator 1.4) of **USD34.4 million** in 2015. In 2015, the revenue generated by ETAPA (supply revenue - indicator 1.5), calculated from residential water bills and secondary data, was found to be **USD28 million** yielding an economic loss of **USD6.4 million** in 2015.

The various stages of the water metabolic cycle have associated energy demands (dependent variable 2). However, in Cuenca's case, it was found that all the distribution pumps and water treatment processes utilised energy in the form of electricity (indicator 2.3) as the usage of diesel/petroleum powered pumps was only emergency backups and considered insignificant by experts. The energy consumed (indicator 2.1) by the water management systems (including potable water production, distribution and wastewater treatment) was roughly **13 million kWh** that had an energy cost (indicator 2.2) of **USD1.3 million** in 2017. In (Valek 2016, p.83), it is concluded that Mexico city's water supply has an energy demand of 1.23 kWh/m$^3$. For the case of Cuenca, calculation done based on potable water produced resulted in an **energy demand of 0.26 kWh/m$^3$** for the year 2017. This comparison reflects the low energy demand of Cuenca's water management system due to the use of gravitational force for much of the production and distribution processes.

Furthermore, the life cycle assessment (LCA) of the urban water metabolic cycle of Cuenca also yielded the environmental footprint of the process. Firstly, the water quality (indicator 1.6) was measured to assess the environmental footprint of the water sector by using the WQI indicator (values between 0-100). The **WQI** reading for potable water produced at the start of the water metabolic cycle was found to be **96** (which is an excellent score). However, after the water flows through residences and gets treated at Ucubamba as wastewater, the resulting stream of treated sewerage that is released into the river Cuenca had a WQI reading of **70** which is a 'fair' score that surpasses the minimum level required by law in Ecuador, however, is not the ideal result for a river that supports human settlements downstream as it increases potable water production costs for downstream users. Furthermore, the environmental footprint was also assessed by calculating the GHG emissions (dependent variable 3) for the water management process. This was done using two different methods – i) using Ecuador's national emissions factor (**0.270 kgCO2e per kWh** (Brander et al. 2011)), ii) using Cuenca's local emissions factor (100% hydroelectricity yielded **0 kgCO2 per kWh**). In the case of Ecuador's national emissions factor, the energy demand of **13 million kWh** (indicator 2.1 and 3.2) in year 2017 would have had GHG emissions of **3.5 million kgCO2e**. However, the electricity utilised in Cuenca was completely generated from local hydro-powered dams. This effectively put the GHG emissions finding to a zero-value which contributed to Cuenca's case study being unique and an exemplary model to be imitated elsewhere.

Overall, this research found Cuenca's water metabolic cycle to be highly efficient and environment-friendly. There were a few reasons for this conclusion – 1) the energy costs of the water metabolic cycle are kept low due to focus on biological processes for treatment (that do not require intense energy input in contrast to processes like reverse osmosis) and utilising gravitation and the topography well to reduce energy costs in distribution and pumping. 2) The strong focus on hydroelectricity generation in Cuenca and Ecuador has seen the encouragement to utilise electricity as the energy source for all energy-consuming step in the potable water and wastewater management. These efforts have made Cuenca's emissions factor 0 kgCO2/kWh which means that the management of the water sector might be among the most environment-friendly examples in the world. However, with the unforeseen circumstances of climate change beginning to affect cities around the world, being proactive towards adapting and learning is the characteristic that is most applicable to the leaders in water management across the globe.

**Sub-question 2: What are the threats or risks to Cuenca's water systems due to climate change?**

As discussed in sections 4.3 and 4.4, data collection via interviews (of 12 experts) and questionnaire surveys (of 21 experts) was analysed to study the impact climate change would have on Cuenca's water metabolic cycle. The results obtained indicated that contrary to commonly held belief by the public of Cuenca that the city would be threatened by floods due to its abundant water resources as a result of climate change, experts believe that Cuenca would have to deal with long periods of droughts and short periods of intense rainfall as a result of the changing climate in the near future. As a result, **drought, water shortage** and **loss of forests** were the most prominent threats to Cuenca's water metabolic cycle according to the panel of experts studied. These findings were surprisingly in contrast to the situation Cuenca is in today. Cuenca is situated at a high altitude in the Andes mountain range which provides numerous advantages for the inhabitants. Abundant rainfall and more than sufficient water in the lagoons of El Cajas National Park means that most residents Cuenca perceive water system of Cuenca to have no problems or potential threats in the near future. Fast flowing rivers and steep mountainous slopes ensure extra volume of intense rainfall or storm water could easily be drained out of Cuenca towards low-lying lands and seas. The fast-flowing rivers and abundant water sources have wisely been utilized to increase Ecuador's hydroelectric capacities. Interviews and secondary data research confirmed that Cuenca's local electricity mix was 100% hydroelectric and this example was supported by Ecuadorian government to be implemented in the rest of the country. However, this research study found that 100% reliance on hydroelectricity may also reduce the resilience of Cuenca city. For example, in 2009, due to reduced rainfall in that year, much of the rivers of Cuenca dried up which led to electricity shortage in Cuenca city. Interviews described that during few months in 2009, there would be no electricity in residences for 6-8 hours a day on average and this shortage lasted for at the least one month. This threat of decreased river volume was reemphasized in the survey questionnaire with the water experts of Cuenca that believed droughts and lack of potable water to be a threat Cuenca city would need to prepare for in the face of uncertain climatic patterns in the 21st century.

**Sub-question 3: What are the water-energy saving technologies (WEST) that best suit the needs and the context of Cuenca?**

The aforementioned findings urged the research to enquire about potential mitigation or adaptation actions that could prepare Cuenca in face of these climatic threats and make the city more resilient. Through in-person interviews and questionnaires, various water-energy saving measures were explored and analysed as tools for mitigation of and adaptation to the changing climate. Some experts emphasized on policy interventions, behavioural change in residents' water consumption habits, water pricing reforms, while others focused on technologies like rainwater harvesting. Analysing and researching about these different measures and actions already implemented in Cuenca city, it was found that the local government had run campaigns on conserving water, creating awareness among the inhabitants and also done their research on water pricing reforms as tools to incentivize consumer behaviour. Therefore, due to the lack of technological considerations in municipality and national energy and water plans, this research narrowed down to further investigate water-energy saving technologies (WEST), and due to the constraints of time and available information, the study focused on three shortlisted WEST – **rainfall harvesting, solar water heaters and water turbines**.

Based on the forecasts developed for each WEST, it was concluded that solar water heaters and water turbines were the best suited technology for Cuenca's needs and context, being economically feasible and largely impactful on Cuenca's local and Ecuador's national context, while rainwater harvesting despite suiting the context of Cuenca and making a strong impact on the water saving potential indicator, failed on the basis of economic feasibility. Solar water heaters and water turbines showed the impactful change, requiring small investments as observed in section 4.8 where both technologies were successfully implemented with an **initial investment of USD 20 million**. Both these technologies are matured and feasible for immediate implementation.

**Sub-question 4: What are the implications of Water-Energy Saving Technologies (WEST) on the water flows and the energy demand from the urban water metabolic cycle in hypothetical projections?**

The assessment of the impact and economic feasibility of implementing the shortlisted WEST in urban Cuenca was achieved by the development of simple projection forecasts for the next 10-15 years for each scenario. These projection forecasts were crucial to understand the implications of the water-energy saving technologies (WEST) on the water flows and energy demand from the urban water metabolic cycle. While **rainfall harvesting** (section 4.5) yielded an alternate mechanism which would remove the necessity to expand the production capacities of the three potable water treatment plants to meet the needs of urban Cuenca until 2100 and would provide a useful tool for Cuenca to be resilient in the face of severe water shortages, it was found to be **unfeasible due to two main reasons** – **i)** the implementation costs totalled **USD194 million** for the coverage of all the residences in urban Cuenca and the return on investment on the project was not able to recover the costs due to low water prices (which in turn were due to the abundance of water in the region); **ii)** secondly, approximately **93%** of all energy consumed by the water management systems in Cuenca was found to be consumed in the wastewater treatment facility at Ucubamba. This wastewater treatment would be required even if rainfall was collected and therefore, rainwater harvesting did not make much impact in energy or GHG savings in the prognosis. Overall, rainwater harvesting technology was found unfeasible for implementation in urban Cuenca. On the contrary, **solar water heaters** (SWH) implementation forecast showed spectacular results with a potential to save **USD423 million** for the state in a 15-year time period. This forecast was found to be seamlessly suitable for the government to implement as it complimented the ‘Programa de Eficiencia Energetica para la Coccion (‘the program for energy efficient cooking’, **PEC Programme**) (Gould et al. 2018) which was launched in 2014 and aimed at transitioning Ecuador’s residences from propane gas tanks to electric energy source for cooking. Solar water heaters (section 4.6) represent a technology that would impeccably support the program and remove the necessity for propane gas tanks in Cuenca’s residences permanently. Similarly, in section 4.7, **water turbines** (WT) or micro hydro turbines were also found to be complimentary to Ecuador’s and Cuenca’s policies on moving the energy mix towards hydroelectricity and the project yielded economic feasibility to be considered for immediate implementation. In section 4.8, a realistic implementation plan (WEST project) was developed which would run from 2019 to 2034, and only require an investment of **USD20 million** to initiate. The WEST project would yield a total of **USD337 million** by 2034 resulting in a cumulative profit of **USD317 million**, representing a **1585% profit** on the original investment. The WEST project would give Cuenca **100 water turbines** in the rivers to generate additional **3.65 GWh** of hydroelectricity to its current capacity and **all the houses** in Cuenca would have switched from **LPG gas cylinders to solar water heaters**. This transition of the energy demand of residences in Cuenca from fossil fuel-based power to hydroelectricity and solar power, laying a successful blueprint for rest of Ecuador to imitate.

## 5.2 Recommendations

### (1) Implementation of Water-Energy Saving Technologies (WEST) in Cuenca

After the study analyses the significant impacts WEST can potentially have on Cuenca and if implemented on a national-level on Ecuador, the municipality needs to work with the water company ETAPA and the academia to bolster efforts into conducting in-depth studies to verify the findings of this research especially for solar water heaters. The implementation of solar water heaters matches the PEC programme's (induction stove programme) objectives to encourage residents to transition from LPG gas tanks towards electricity-based devices. Solar water heaters seem to be profitable for the government (investor) and enable the right incentives for households to increase the success of the PEC programme currently run by the government. The potential of replication WEST all over Ecuador is large. Therefore, further research studies and pilot projects must immediately be encouraged in cities like Cuenca to implement successful WEST applications and serve these models for replication across the country. With WEST, another advantage is these can promote in-house manufacturing since the technologies like solar water heaters are easy to make which will serve to develop the economy by exporting these technologies to the rest of the world.

### (2) Increased attention towards adaptation and mitigation co-benefits measures

Numerous researches focus the research on cities like Mexico city (Valek 2016; Valek et al. 2017), Sydney (Lundie and Peters 2004), Galapagos (Guyot-Téphany et al. 2013), Las Vegas (Shrestha 2010), Alexandria city (Mohamed et al. 2010) and these cities mostly are associated with severe water management problems, for example, Galapagos and Mexico city both have struggled with depleting fresh water resources for human consumption and water scarcity is a big problem to address in these places. However, a study of Cuenca's water metabolic cycle represents a model example of water management system where fresh water has been abundant and the water distribution network reaches over 95% of the inhabitants (Chacha 2015). Firstly, this study paves the way to assess the inequality between water abundant and water scarce cities of the world in terms of the water management systems utilized – the sources of water tapped into, technologies used to treat and distribute water, consumption patterns of inhabitants, etc. Moreover, the research study helps to emphasize the need to take drastic measures to adapt to and mitigate the threats posed by the changing climate in the 21st century. This thesis research attempts to make a strong statement that all cities of the world – whether they belong to global north or global south, whether they possess water-related problems or not – need to consider and implement adaptation and mitigation measures to help combat and prepare for the uncertain future ahead.

## 5.3 Impact of research on academic literature

Life Cycle Assessment (LCA) is useful for the "examination of alternative future scenarios for strategic planning" (Lundie and Peters 2004, p.3465). The methodology utilized in this research followed a simplified Life Cycle Assessment (LCA) methodology following the example of (Valek et al. 2017) for the study of the urban water metabolic cycle and the water-energy nexus in it. However, the methodology for the impact and economic feasibility of WEST utilised the WSADIOAF framework (George et al. 2011) that included CBA and CEA assessment tools, and comparing WEST forecast scenarios with the BAU scenarios. This combined LCA methodology with a cost-benefit analysis "with environmental externality valuation" (Molinos-Senante et al. 2010, p.4396). The LCA methodology was essential to understand the water metabolic cycle as analysed in section 4.2. However, due to the time constraint, it was important to focus on fewer indicators than other LCA studies found in literature. The cost-benefit analytical tool was essential for the economic feasibility of the shortlisted water-energy saving technologies. The uniqueness of this research study was also the attribution of technologies/measures that directly affect the water-energy interlinkages and the focus on implementation of water-energy saving technologies (WEST) due to their advantages of being light, cheap, easy-to-implement on the residential level. While (Valek et al. 2017), focused on water saving measures (WSM) that included prices reform and reducing water leakages, this research study took a different path by focusing on technologies that would not only be water saving but also energy saving, emphasizing a transition from fossil fuel to renewable technologies that have been on high priority in mitigation plans of countries across the globe. The methodology utilized in this research study was suited to the holistic approach generally demanded by local governments in developing countries – presenting the results based on a few simple indicators (water quantity, energy demand, GHG savings, monetary savings, etc.) and conducting an initial-pilot economic feasibility study of renewable technologies over an urban population of 350,000 people that aims to generate interest for further detailed researches on performance and implementation of each water-energy saving technology, surveys of consumer behaviour to understand the cultural acceptance of these technologies by residents of Cuenca.

## 5.4 Limitations and Further Research

Due to the time, language and data availability constraints, there were two big limitations of this research that sheds light on opportunities for further research to make the study more comprehensive and in-depth. Firstly, this study focuses on the urban water metabolic cycle and examines the ‘energy for water’ side of the water-energy nexus. To attain an in-depth holistic view of the water-energy nexus in a city like Cuenca, research has to be conducted on the ‘water for energy’ side of the water-energy nexus. The recommended study can include assessment of hydroelectricity power plants, thermal power plants, and other energy generating processes to sketch the water demands of these processes. Similarly, this research only evaluated the residential water flows. A further study might involve including water flows to industrial sector, agriculture sector, and other sectors. Combining these two future studies would provide a complete understanding of all the water and energy flows in and out of Cuenca, which is essential in the process of developing a circular economy in a city/a country.

Secondly, this research was inspired by reading Valek’s (2016) study on the water-energy-climate nexus of urban water cycle in Mexico City. However, one of the ideas to do this research was to be able to draw a comparison between multiple cities and their water-energy nexus findings, to better understand various responses to shocks and gradual changes that test the resilience of cities. Since water-energy nexus is a relatively new word, the number of studies are beginning to grow in number in this field. Hence, it would be interesting to read a study comparing the water metabolic cycles of a few cities. This might not only bring out the inequality in resource distribution but help to achieve equity, equality and justice, and promote collaboration between nations in a world that is continuously getting smaller with depleting resources.

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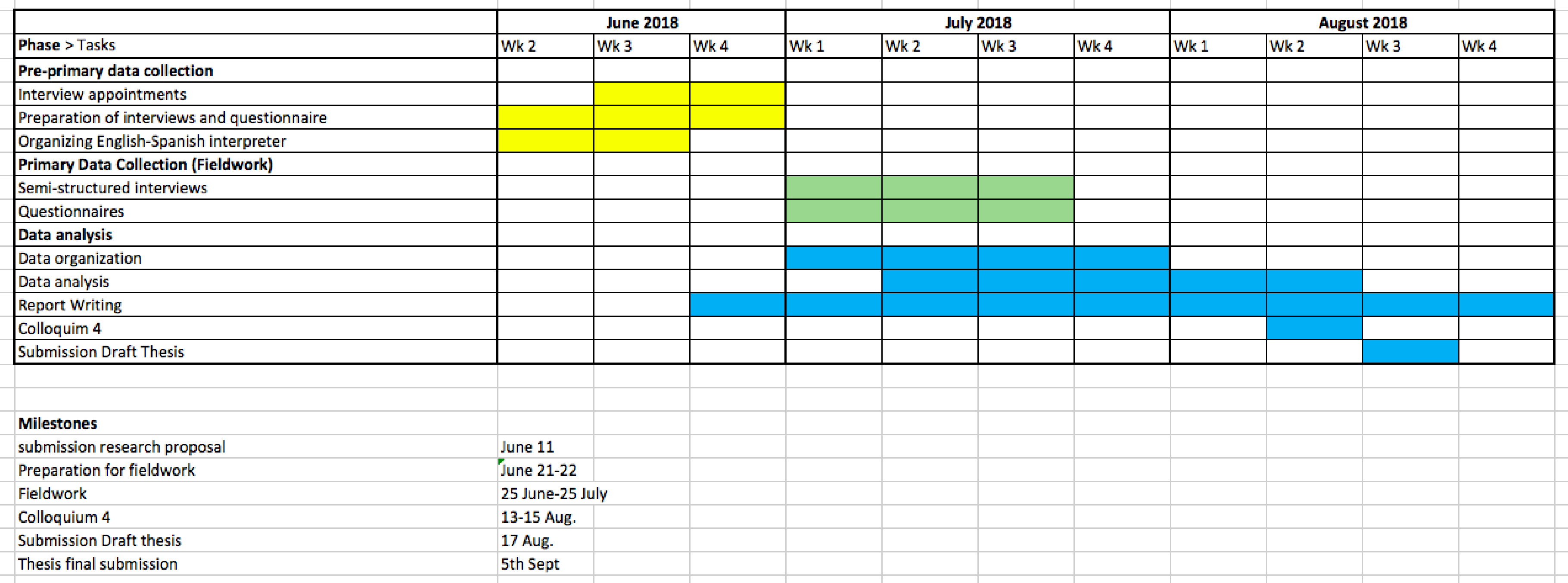
# Annex 1: Research Time schedule

## Time Schedule



| | June 2018 | | | July 2018 | | | | August 2018 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Phase** > Tasks | Wk 2 | Wk 3 | Wk 4 | Wk 1 | Wk 2 | Wk 3 | Wk 4 | Wk 1 | Wk 2 | Wk 3 | Wk 4 |
| **Pre-primary data collection** | | | | | | | | | | | |
| Interview appointments | | 🟨 | 🟨 | | | | | | | | |
| Preparation of interviews and questionnaire | 🟨 | 🟨 | 🟨 | | | | | | | | |
| Organizing English-Spanish interpreter | 🟨 | 🟨 | | | | | | | | | |
| **Primary Data Collection (Fieldwork)** | | | | | | | | | | | |
| Semi-structured interviews | | | | 🟩 | 🟩 | 🟩 | | | | | |
| Questionnaires | | | | 🟩 | 🟩 | 🟩 | | | | | |
| **Data analysis** | | | | | | | | | | | |
| Data organization | | | | 🟦 | 🟦 | 🟦 | 🟦 | | | | |
| Data analysis | | | | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | |
| Report Writing | | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |
| Colloquim 4 | | | | | | | | | 🟦 | | |
| Submission Draft Thesis | | | | | | | | | | 🟦 | |

| **Milestones** | |
|---|---|
| submission research proposal | June 11 |
| Preparation for fieldwork | June 21-22 |
| Fieldwork | 25 June-25 July |
| Colloquium 4 | 13-15 Aug. |
| Submission Draft thesis | 17 Aug. |
| Thesis final submission | 5th Sept |

**Figure 18 – Gantt Chart for Thesis Research (Author, 2018)**

# Annex 2: IHS copyright form

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# Annex 3: Research Instruments

## Online Questionnaire (in Spanish)

Link to access the complete survey online - https://www.surveymonkey.com/r/3JNWVJ5

**Erasmus University Rotterdam - Recopilación de Datos para Tesis de Master en Gestión y Desarrollo Urbano**

Cuestionario sobre las Medidas de Ahorro de Agua y Energía en la Gestión del Agua de Cuenca.

Reciba un cordial saludo. Mi nombre es Rishi Bhatnagar. Le agradezco su tiempo y colaboración para completar este cuestionario en línea. Estoy realizando una investigación para mi tesis de maestría en Gestión y Desarrollo Urbano, en relación con las medidas de ahorro de agua y energía (WESM) (por ejemplo: captación de agua de lluvia, techos verdes, etc.) y su posible impacto en el nexo agua-energía en el ciclo metabólico del agua urbana de Cuenca.

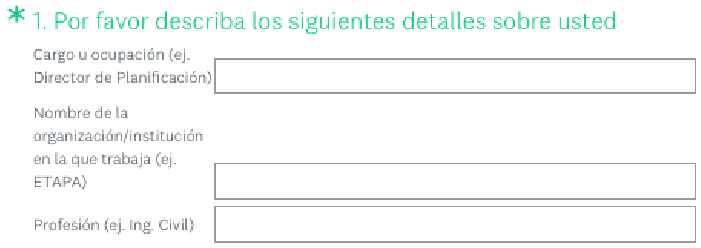
Este cuestionario está diseñado para un propósito específico: analizar diversas tecnologías de conservación de agua y energía que podrían ser adecuadas para el comportamiento topográfico y de consumo de Cuenca.

El agua es abundante en Cuenca, sin embargo, hay algunas razones para considerar seriamente estas ideas:

1. Ver a Ecuador como un potencial exportador de agua a regiones que por condiciones naturales o cambio climático, se enfrentan a la escasez de agua, sin agotar sus propios recursos hídricos.

2. Prepararse para buenas prácticas de ahorro y energía para reducir el gasto en problemas futuros, especialmente relacionados con el cambio climático.

3. Reducir los costos de agua y energía en el presente, a través del uso de nuevas tecnologías y buscar que el sistema de gestión de agua y energía del Ecuador sea mundialmente conocido por ideas que pueden replicarse en otros lugares.

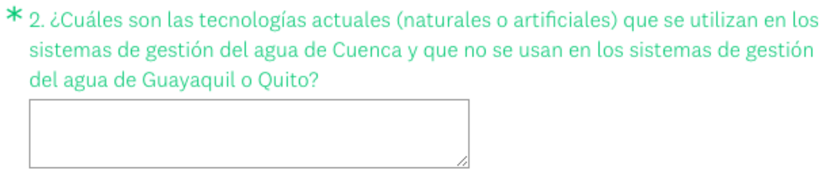


* 1. Por favor describa los siguientes detalles sobre usted

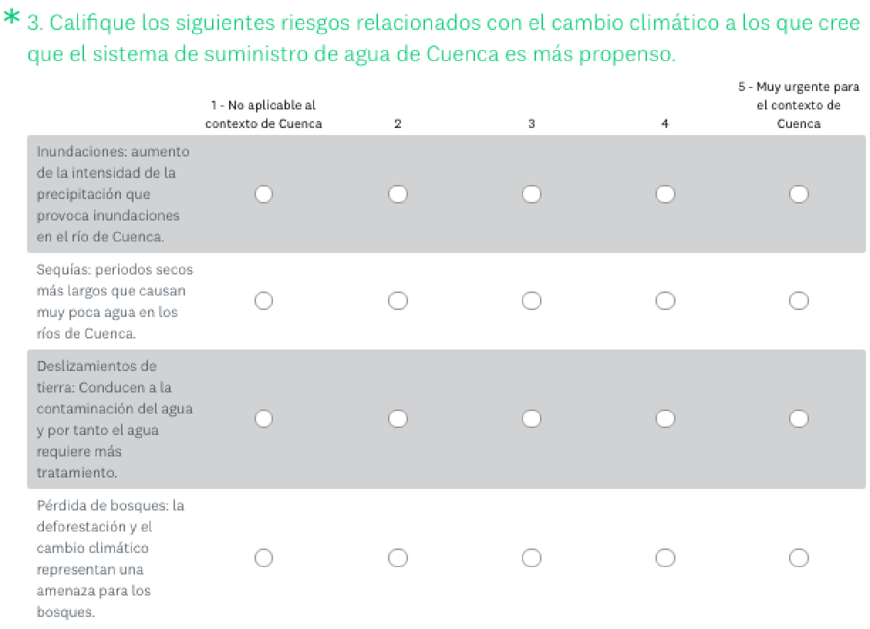
Cargo u ocupación (ej. Director de Planificación)

Nombre de la organización/institución en la que trabaja (ej. ETAPA)

Profesión (ej. Ing. Civil)

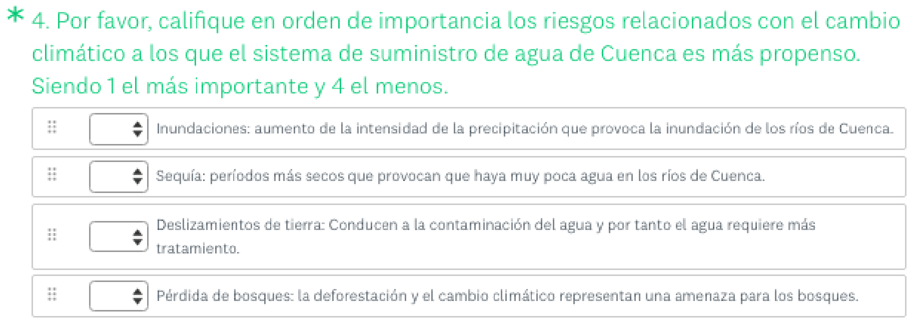


* 2. ¿Cuáles son las tecnologías actuales (naturales o artificiales) que se utilizan en los sistemas de gestión del agua de Cuenca y que no se usan en los sistemas de gestión del agua de Guayaquil o Quito?



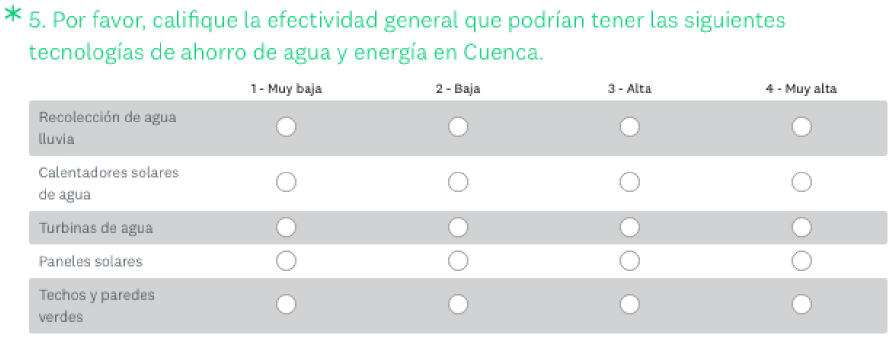
* 3. Califique los siguientes riesgos relacionados con el cambio climático a los que cree que el sistema de suministro de agua de Cuenca es más propenso.

| | 1 - No aplicable al contexto de Cuenca | 2 | 3 | 4 | 5 - Muy urgente para el contexto de Cuenca |
|---|---|---|---|---|---|
| Inundaciones: aumento de la intensidad de la precipitación que provoca inundaciones en el río de Cuenca. | ○ | ○ | ○ | ○ | ○ |
| Sequías: periodos secos más largos que causan muy poca agua en los ríos de Cuenca. | ○ | ○ | ○ | ○ | ○ |
| Deslizamientos de tierra: Conducen a la contaminación del agua y por tanto el agua requiere más tratamiento. | ○ | ○ | ○ | ○ | ○ |
| Pérdida de bosques: la deforestación y el cambio climático representan una amenaza para los bosques. | ○ | ○ | ○ | ○ | ○ |



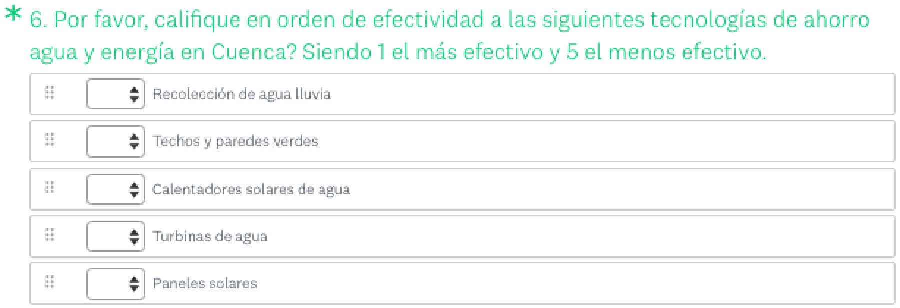
* 4. Por favor, califique en orden de importancia los riesgos relacionados con el cambio climático a los que el sistema de suministro de agua de Cuenca es más propenso. Siendo 1 el más importante y 4 el menos.

Inundaciones: aumento de la intensidad de la precipitación que provoca la inundación de los ríos de Cuenca.
Sequía: períodos más secos que provocan que haya muy poca agua en los ríos de Cuenca.
Deslizamientos de tierra: Conducen a la contaminación del agua y por tanto el agua requiere más tratamiento.
Pérdida de bosques: la deforestación y el cambio climático representan una amenaza para los bosques.



* 5. Por favor, califique la efectividad general que podrían tener las siguientes tecnologías de ahorro de agua y energía en Cuenca.

| | 1 - Muy baja | 2 - Baja | 3 - Alta | 4 - Muy alta |
|---|---|---|---|---|
| Recolección de agua lluvia | ○ | ○ | ○ | ○ |
| Calentadores solares de agua | ○ | ○ | ○ | ○ |
| Turbinas de agua | ○ | ○ | ○ | ○ |
| Paneles solares | ○ | ○ | ○ | ○ |
| Techos y paredes verdes | ○ | ○ | ○ | ○ |



* 6. Por favor, califique en orden de efectividad a las siguientes tecnologías de ahorro agua y energía en Cuenca? Siendo 1 el más efectivo y 5 el menos efectivo.

Recolección de agua lluvia
Techos y paredes verdes
Calentadores solares de agua
Turbinas de agua
Paneles solares

# Annex 4: Urban Cuenca Residences and Population Forecast

Green: Information obtained from primary and secondary sources

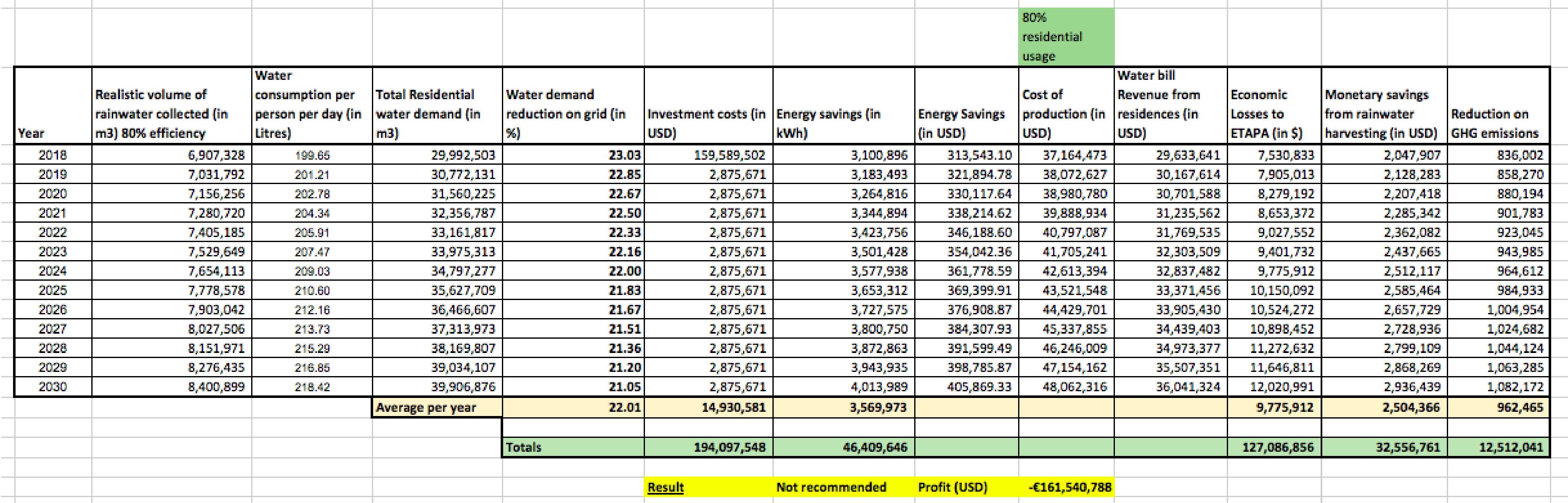
Light blue: Data generated using the Forecast function in Excel

| YEAR | URBAN POPULATION (persons) | NUMBER OF RESIDENCES | URBAN AREA (in km2) |
|---|---|---|---|
| 1992 | 210,879 | | |
| 1993 | 217,416 | | |
| 1994 | 224,155 | | |
| 1995 | 231,103 | | |
| 1996 | 238,266 | | |
| 1997 | 245,652 | | |
| 1998 | 253,266 | | |
| 1999 | 261,116 | | |
| 2000 | 269,210 | | |
| 2001 | 278,995 | | |
| 2002 | 284,380 | | |
| 2003 | 289,868 | | |
| 2004 | 295,463 | | |
| 2005 | 301,165 | | |
| 2006 | 306,977 | | |
| 2007 | 312,902 | | |
| 2008 | 318,941 | | |
| 2009 | 325,097 | | |
| 2010 | 331,888 | 86,317 | 66.71 |
| 2011 | 351,341 | 91,376 | 70.62 |
| 2012 | 358,696 | 93,289 | 72.10 |
| 2013 | 366,099 | 95,215 | 73.59 |
| 2014 | 367,113 | 95,478 | 73.79 |
| 2015 | 374,242 | 97,332 | 75.22 |
| 2016 | 381,371 | 99,186 | 76.66 |
| 2017 | 388,500 | 101,041 | 78.09 |
| 2018 | 395,629 | 102,895 | 79.52 |
| 2019 | 402,758 | 104,749 | 80.95 |
| 2020 | 409,886 | 106,603 | 82.39 |
| 2021 | 417,015 | 108,457 | 83.82 |
| 2022 | 424,144 | 110,311 | 85.25 |
| 2023 | 431,273 | 112,165 | 86.69 |
| 2024 | 438,402 | 114,019 | 88.12 |
| 2025 | 445,531 | 115,873 | 89.55 |
| 2026 | 452,660 | 117,727 | 90.99 |
| 2027 | 459,789 | 119,581 | 92.42 |
| 2028 | 466,918 | 121,435 | 93.85 |
| 2029 | 474,047 | 123,289 | 95.28 |
| 2030 | 481,175 | 125,143 | 96.72 |

# Annex 5: Water Metabolic cycle – BAU Forecast

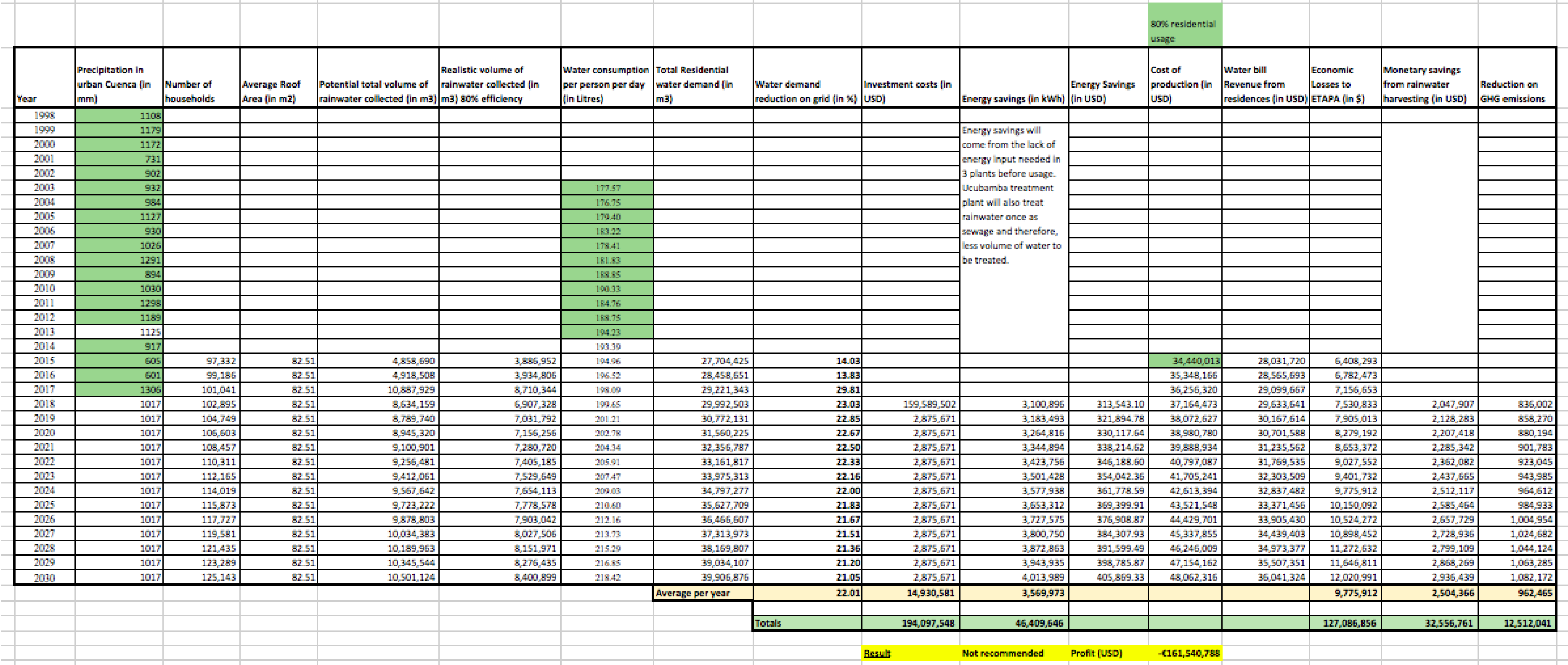
| YEAR | Potable Water Produced (m3) | Total Water consumed (m3) | Residential Water Consumed (m3) | Energy Consumption from water management (in kWh) | Energy cost (in USD) | GHG Emissions (in kg CO2) as per Ecuador's 2017 national energy mix | GHG emissions (in kg CO2) as per Cuenca's local energy mix |
|---|---|---|---|---|---|---|---|
| 1992 | 33,775,695 | 18,544,042 | | 8,920,885 | 902,024 | 2,405,070 | |
| 1993 | 33,851,299 | 17,225,549 | | 8,940,853 | 904,043 | 2,410,454 | |
| 1994 | 34,086,860 | 17,047,511 | | 9,003,070 | 910,334 | 2,427,228 | |
| 1995 | 33,845,953 | 17,484,267 | | 8,939,441 | 903,900 | 2,410,073 | |
| 1996 | 34,829,610 | 18,880,603 | | 9,199,246 | 930,170 | 2,480,117 | |
| 1997 | 50,680,784 | 21,155,527 | | 13,385,881 | 1,353,496 | 3,608,833 | |
| 1998 | 47,359,260 | 22,116,768 | | 12,508,595 | 1,264,790 | 3,372,317 | |
| 1999 | 46,976,421 | 21,313,254 | | 12,407,479 | 1,254,566 | 3,345,056 | |
| 2000 | 48,044,385 | 22,280,666 | | 12,689,551 | 1,283,087 | 3,421,103 | |
| 2001 | 45,696,305 | 22,231,733 | | 12,069,373 | 1,220,379 | 3,253,903 | |
| 2002 | 41,863,791 | 22,235,276 | | 11,057,124 | 1,118,027 | 2,981,001 | |
| 2003 | 41,553,281 | 23,103,007 | 18,786,876 | 10,975,112 | 1,109,734 | 2,958,890 | |
| 2004 | 38,226,023 | 23,480,371 | 19,061,478 | 10,096,311 | 1,020,875 | 2,721,966 | |
| 2005 | 36,941,645 | 24,348,070 | 19,721,057 | 9,757,080 | 986,574 | 2,630,509 | |
| 2006 | 36,659,449 | 25,402,092 | 20,529,468 | 9,682,546 | 979,038 | 2,610,414 | |
| 2007 | 35,412,351 | 25,353,647 | 20,375,698 | 9,353,160 | 945,733 | 2,521,612 | |
| 2008 | 35,841,634 | 26,199,729 | 21,167,889 | 9,466,543 | 957,197 | 2,552,180 | |
| 2009 | 36,549,480 | 27,480,301 | 22,409,079 | 9,653,501 | 976,101 | 2,602,584 | |
| 2010 | 37,226,117 | 28,219,860 | 23,056,619 | 9,832,215 | 994,172 | 2,650,765 | |
| 2011 | 37,226,117 | 28,901,466 | 23,693,359 | 9,832,215 | 994,172 | 2,650,765 | |
| 2012 | 38,845,733 | 30,144,776 | 24,711,810 | 10,259,990 | 1,037,426 | 2,766,093 | |
| 2013 | 38,573,088 | 31,581,561 | 25,953,582 | 10,187,979 | 1,030,144 | 2,746,679 | |
| 2014 | 39,405,938 | 32,492,112 | 25,993,689 | 10,407,952 | 1,052,387 | 2,805,984 | 0 |
| 2015 | 39,983,333 | 33,372,105 | 26,697,684 | 10,560,455 | 1,067,807 | 2,847,099 | 0 |
| 2016 | 40,560,727 | 34,252,099 | 27,401,679 | 10,712,957 | 1,083,227 | 2,888,213 | 0 |
| 2017 | 49,210,534 | 35,132,093 | 28,105,674 | 12,997,556 | 1,314,231 | 3,504,141 | 0 |
| 2018 | 50,978,409 | 36,012,087 | 28,809,669 | 13,464,490 | 1,361,444 | 3,630,026 | 0 |
| 2019 | 52,746,284 | 36,892,080 | 29,513,664 | 13,931,423 | 1,408,658 | 3,755,912 | 0 |
| 2020 | 54,514,159 | 37,772,074 | 30,217,659 | 14,398,357 | 1,455,871 | 3,881,797 | 0 |
| 2021 | 56,282,034 | 38,652,068 | 30,921,654 | 14,865,291 | 1,503,085 | 4,007,682 | 0 |
| 2022 | 58,049,909 | 39,532,061 | 31,625,649 | 15,332,224 | 1,550,298 | 4,133,568 | 0 |
| 2023 | 59,817,784 | 40,412,055 | 32,329,644 | 15,799,158 | 1,597,511 | 4,259,453 | 0 |
| 2024 | 61,585,660 | 41,292,049 | 33,033,639 | 16,266,092 | 1,644,725 | 4,385,338 | 0 |
| 2025 | 63,353,535 | 42,172,043 | 33,737,634 | 16,733,026 | 1,691,938 | 4,511,224 | 0 |
| 2026 | 65,121,410 | 43,052,036 | 34,441,629 | 17,199,959 | 1,739,152 | 4,637,109 | 0 |
| 2027 | 66,889,285 | 43,932,030 | 35,145,624 | 17,666,893 | 1,786,365 | 4,762,994 | 0 |
| 2028 | 68,657,160 | 44,812,024 | 35,849,619 | 18,133,827 | 1,833,578 | 4,888,880 | 0 |
| 2029 | 70,425,035 | 45,692,017 | 36,553,614 | 18,600,760 | 1,880,792 | 5,014,765 | 0 |
| 2030 | 72,192,910 | 46,572,011 | 37,257,609 | 19,067,694 | 1,928,005 | 5,140,650 | 0 |

# Annex 6-1: Rainwater Harvesting Scenario Forecast Results



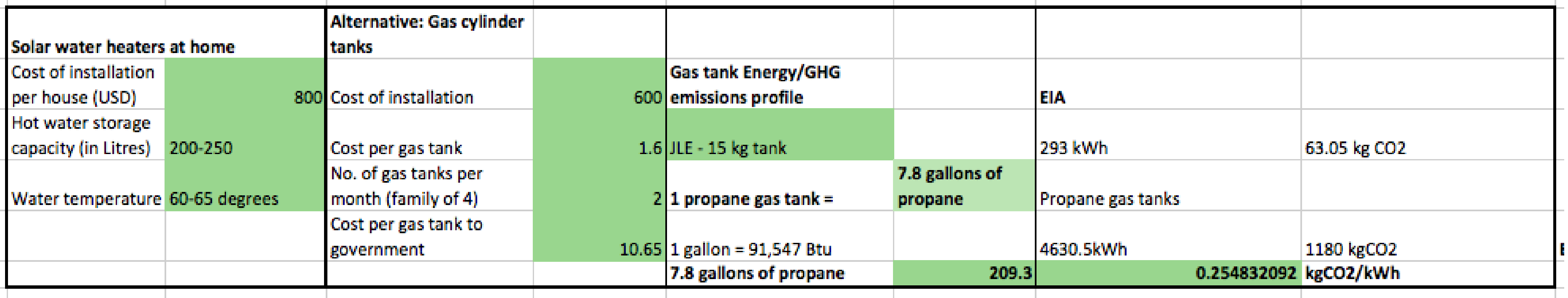
| | | | | | | | | 80% residential usage | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Realistic volume of rainwater collected (in m3) 80% efficiency | Water consumption per person per day (in Litres) | Total Residential water demand (in m3) | Water demand reduction on grid (in %) | Investment costs (in USD) | Energy savings (in kWh) | Energy Savings (in USD) | Cost of production (in USD) | Water bill Revenue from residences (in USD) | Economic Losses to ETAPA (in $) | Monetary savings from rainwater harvesting (in USD) | Reduction on GHG emissions |
| 2018 | 6,907,328 | 199.65 | 29,992,503 | **23.03** | 159,589,502 | 3,100,896 | 313,543.10 | 37,164,473 | 29,633,641 | 7,530,833 | 2,047,907 | 836,002 |
| 2019 | 7,031,792 | 201.21 | 30,772,131 | **22.85** | 2,875,671 | 3,183,493 | 321,894.78 | 38,072,627 | 30,167,614 | 7,905,013 | 2,128,283 | 858,270 |
| 2020 | 7,156,256 | 202.78 | 31,560,225 | **22.67** | 2,875,671 | 3,264,816 | 330,117.64 | 38,980,780 | 30,701,588 | 8,279,192 | 2,207,418 | 880,194 |
| 2021 | 7,280,720 | 204.34 | 32,356,787 | **22.50** | 2,875,671 | 3,344,894 | 338,214.62 | 39,888,934 | 31,235,562 | 8,653,372 | 2,285,342 | 901,783 |
| 2022 | 7,405,185 | 205.91 | 33,161,817 | **22.33** | 2,875,671 | 3,423,756 | 346,188.60 | 40,797,087 | 31,769,535 | 9,027,552 | 2,362,082 | 923,045 |
| 2023 | 7,529,649 | 207.47 | 33,975,313 | **22.16** | 2,875,671 | 3,501,428 | 354,042.36 | 41,705,241 | 32,303,509 | 9,401,732 | 2,437,665 | 943,985 |
| 2024 | 7,654,113 | 209.03 | 34,797,277 | **22.00** | 2,875,671 | 3,577,938 | 361,778.59 | 42,613,394 | 32,837,482 | 9,775,912 | 2,512,117 | 964,612 |
| 2025 | 7,778,578 | 210.60 | 35,627,709 | **21.83** | 2,875,671 | 3,653,312 | 369,399.91 | 43,521,548 | 33,371,456 | 10,150,092 | 2,585,464 | 984,933 |
| 2026 | 7,903,042 | 212.16 | 36,466,607 | **21.67** | 2,875,671 | 3,727,575 | 376,908.87 | 44,429,701 | 33,905,430 | 10,524,272 | 2,657,729 | 1,004,954 |
| 2027 | 8,027,506 | 213.73 | 37,313,973 | **21.51** | 2,875,671 | 3,800,750 | 384,307.93 | 45,337,855 | 34,439,403 | 10,898,452 | 2,728,936 | 1,024,682 |
| 2028 | 8,151,971 | 215.29 | 38,169,807 | **21.36** | 2,875,671 | 3,872,863 | 391,599.49 | 46,246,009 | 34,973,377 | 11,272,632 | 2,799,109 | 1,044,124 |
| 2029 | 8,276,435 | 216.85 | 39,034,107 | **21.20** | 2,875,671 | 3,943,935 | 398,785.87 | 47,154,162 | 35,507,351 | 11,646,811 | 2,868,269 | 1,063,285 |
| 2030 | 8,400,899 | 218.42 | 39,906,876 | **21.05** | 2,875,671 | 4,013,989 | 405,869.33 | 48,062,316 | 36,041,324 | 12,020,991 | 2,936,439 | 1,082,172 |
| | | | Average per year | **22.01** | **14,930,581** | **3,569,973** | | | | **9,775,912** | **2,504,366** | **962,465** |
| | | | | | | | | | | | | |
| | | | | Totals | **194,097,548** | **46,409,646** | | | | **127,086,856** | **32,556,761** | **12,512,041** |
| | | | | | | | | | | | | |
| | | | | | Result | Not recommended | Profit (USD) | **-€161,540,788** | | | | |

# Annex 6-2: Rainwater Harvesting Scenario Complete Calculations

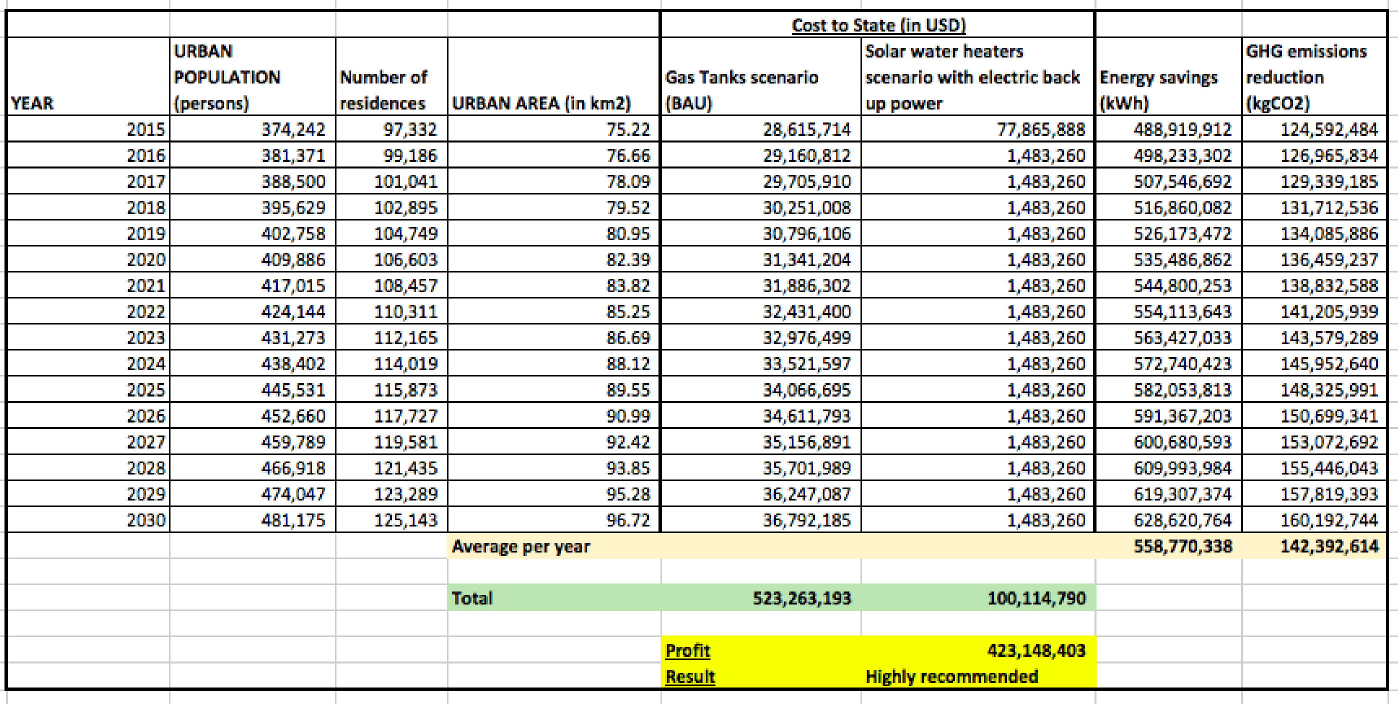


| | | | | | | | | | | | | 80% residential usage | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Precipitation in urban Cuenca (in mm) | Number of households | Average Roof Area (in m2) | Potential total volume of rainwater collected (in m3) | Realistic volume of rainwater collected (in m3) 80% efficiency | Water consumption per person per day (in Litres) | Total Residential water demand (in m3) | Water demand reduction on grid (in %) | Investment costs (in USD) | Energy savings (in kWh) | Energy Savings (in USD) | Cost of production (in USD) | Water bill Revenue from residences (in USD) | Economic Losses to ETAPA (in $) | Monetary savings from rainwater harvesting (in USD) | Reduction on GHG emissions |
| 1998 | 1108 | | | | | | | | | | | | | | | |
| 1999 | 1179 | | | | | | | | | Energy savings will come from the lack of energy input needed in 3 plants before usage. Ucubamba treatment plant will also treat rainwater once as sewage and therefore, less volume of water to be treated. | | | | | | |
| 2000 | 1172 | | | | | | | | | | | | | | | |
| 2001 | 731 | | | | | | | | | | | | | | | |
| 2002 | 902 | | | | | | | | | | | | | | | |
| 2003 | 932 | | | | | 177.57 | | | | | | | | | | |
| 2004 | 984 | | | | | 176.75 | | | | | | | | | | |
| 2005 | 1127 | | | | | 179.40 | | | | | | | | | | |
| 2006 | 930 | | | | | 183.22 | | | | | | | | | | |
| 2007 | 1026 | | | | | 178.41 | | | | | | | | | | |
| 2008 | 1291 | | | | | 181.83 | | | | | | | | | | |
| 2009 | 894 | | | | | 188.85 | | | | | | | | | | |
| 2010 | 1030 | | | | | 190.33 | | | | | | | | | | |
| 2011 | 1298 | | | | | 184.76 | | | | | | | | | | |
| 2012 | 1189 | | | | | 188.75 | | | | | | | | | | |
| 2013 | 1125 | | | | | 194.23 | | | | | | | | | | |
| 2014 | 917 | | | | | 193.39 | | | | | | | | | | |
| 2015 | 605 | 97,332 | 82.51 | 4,858,690 | 3,886,952 | 194.96 | 27,704,425 | **14.03** | | | | 34,440,013 | 28,031,720 | 6,408,293 | | |
| 2016 | 601 | 99,186 | 82.51 | 4,918,508 | 3,934,806 | 196.52 | 28,458,651 | **13.83** | | | | 35,348,166 | 28,565,693 | 6,782,473 | | |
| 2017 | 1306 | 101,041 | 82.51 | 10,887,929 | 8,710,344 | 198.09 | 29,221,343 | **29.81** | | | | 36,256,320 | 29,099,667 | 7,156,653 | | |
| 2018 | 1017 | 102,895 | 82.51 | 8,634,159 | 6,907,328 | 199.65 | 29,992,503 | **23.03** | 159,589,502 | 3,100,896 | 313,543.10 | 37,164,473 | 29,633,641 | 7,530,833 | 2,047,907 | 836,002 |
| 2019 | 1017 | 104,749 | 82.51 | 8,789,740 | 7,031,792 | 201.21 | 30,772,131 | **22.85** | 2,875,671 | 3,183,493 | 321,894.78 | 38,072,627 | 30,167,614 | 7,905,013 | 2,128,283 | 858,270 |
| 2020 | 1017 | 106,603 | 82.51 | 8,945,320 | 7,156,256 | 202.78 | 31,560,225 | **22.67** | 2,875,671 | 3,264,816 | 330,117.64 | 38,980,780 | 30,701,588 | 8,279,192 | 2,207,418 | 880,194 |
| 2021 | 1017 | 108,457 | 82.51 | 9,100,901 | 7,280,720 | 204.34 | 32,356,787 | **22.50** | 2,875,671 | 3,344,894 | 338,214.62 | 39,888,934 | 31,235,562 | 8,653,372 | 2,285,342 | 901,783 |
| 2022 | 1017 | 110,311 | 82.51 | 9,256,481 | 7,405,185 | 205.91 | 33,161,817 | **22.33** | 2,875,671 | 3,423,756 | 346,188.60 | 40,797,087 | 31,769,535 | 9,027,552 | 2,362,082 | 923,045 |
| 2023 | 1017 | 112,165 | 82.51 | 9,412,061 | 7,529,649 | 207.47 | 33,975,313 | **22.16** | 2,875,671 | 3,501,428 | 354,042.36 | 41,705,241 | 32,303,509 | 9,401,732 | 2,437,665 | 943,985 |
| 2024 | 1017 | 114,019 | 82.51 | 9,567,642 | 7,654,113 | 209.03 | 34,797,277 | **22.00** | 2,875,671 | 3,577,938 | 361,778.59 | 42,613,394 | 32,837,482 | 9,775,912 | 2,512,117 | 964,612 |
| 2025 | 1017 | 115,873 | 82.51 | 9,723,222 | 7,778,578 | 210.60 | 35,627,709 | **21.83** | 2,875,671 | 3,653,312 | 369,399.91 | 43,521,548 | 33,371,456 | 10,150,092 | 2,585,464 | 984,933 |
| 2026 | 1017 | 117,727 | 82.51 | 9,878,803 | 7,903,042 | 212.16 | 36,466,607 | **21.67** | 2,875,671 | 3,727,575 | 376,908.87 | 44,429,701 | 33,905,430 | 10,524,272 | 2,657,729 | 1,004,954 |
| 2027 | 1017 | 119,581 | 82.51 | 10,034,383 | 8,027,506 | 213.73 | 37,313,973 | **21.51** | 2,875,671 | 3,800,750 | 384,307.93 | 45,337,855 | 34,439,403 | 10,898,452 | 2,728,936 | 1,024,682 |
| 2028 | 1017 | 121,435 | 82.51 | 10,189,963 | 8,151,971 | 215.29 | 38,169,807 | **21.36** | 2,875,671 | 3,872,863 | 391,599.49 | 46,246,009 | 34,973,377 | 11,272,632 | 2,799,109 | 1,044,124 |
| 2029 | 1017 | 123,289 | 82.51 | 10,345,544 | 8,276,435 | 216.85 | 39,034,107 | **21.20** | 2,875,671 | 3,943,935 | 398,785.87 | 47,154,162 | 35,507,351 | 11,646,811 | 2,868,269 | 1,063,285 |
| 2030 | 1017 | 125,143 | 82.51 | 10,501,124 | 8,400,899 | 218.42 | 39,906,876 | **21.05** | 2,875,671 | 4,013,989 | 405,869.33 | 48,062,316 | 36,041,324 | 12,020,991 | 2,936,439 | 1,082,172 |
| | | | | | | | **Average per year** | **22.01** | **14,930,581** | **3,569,973** | | | | **9,775,912** | **2,504,366** | **962,465** |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | Totals | **194,097,548** | **46,409,646** | | | | **127,086,856** | **32,556,761** | **12,512,041** |
| | | | | | | | | | **Result** | **Not recommended** | **Profit (USD)** | **-€161,540,788** | | | | |

# Annex 7: Solar Water Heaters Scenario Forecast Results

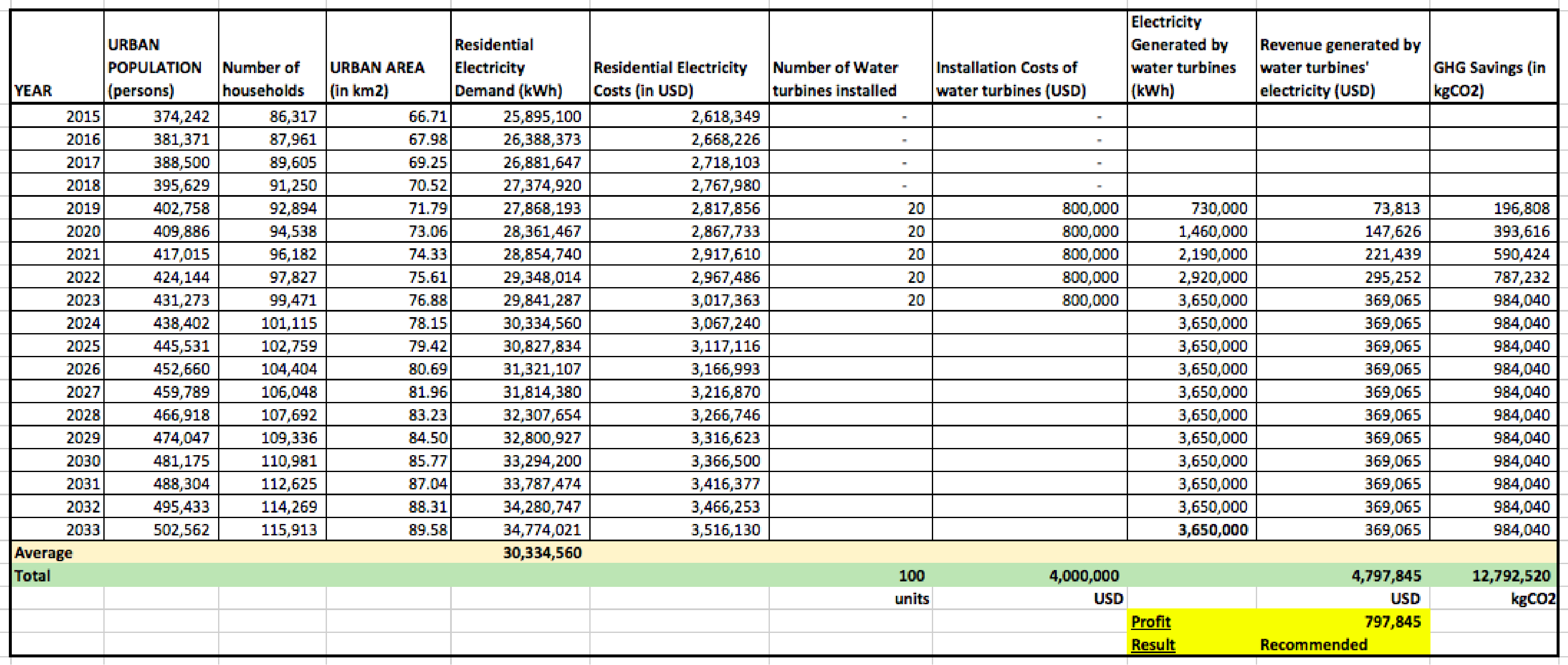


| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Solar water heaters at home** | | **Alternative: Gas cylinder tanks** | | | | | |
| Cost of installation per house (USD) | 800 | Cost of installation | 600 | **Gas tank Energy/GHG emissions profile** | | **EIA** | |
| Hot water storage capacity (in Litres) | 200-250 | Cost per gas tank | 1.6 | JLE - 15 kg tank | | 293 kWh | 63.05 kg CO2 |
| Water temperature | 60-65 degrees | No. of gas tanks per month (family of 4) | 2 | **1 propane gas tank =** | **7.8 gallons of propane** | Propane gas tanks | |
| | | Cost per gas tank to government | 10.65 | 1 gallon = 91,547 Btu | | 4630.5kWh | 1180 kgCO2 |
| | | | | **7.8 gallons of propane** | **209.3** | **0.254832092** | **kgCO2/kWh** |



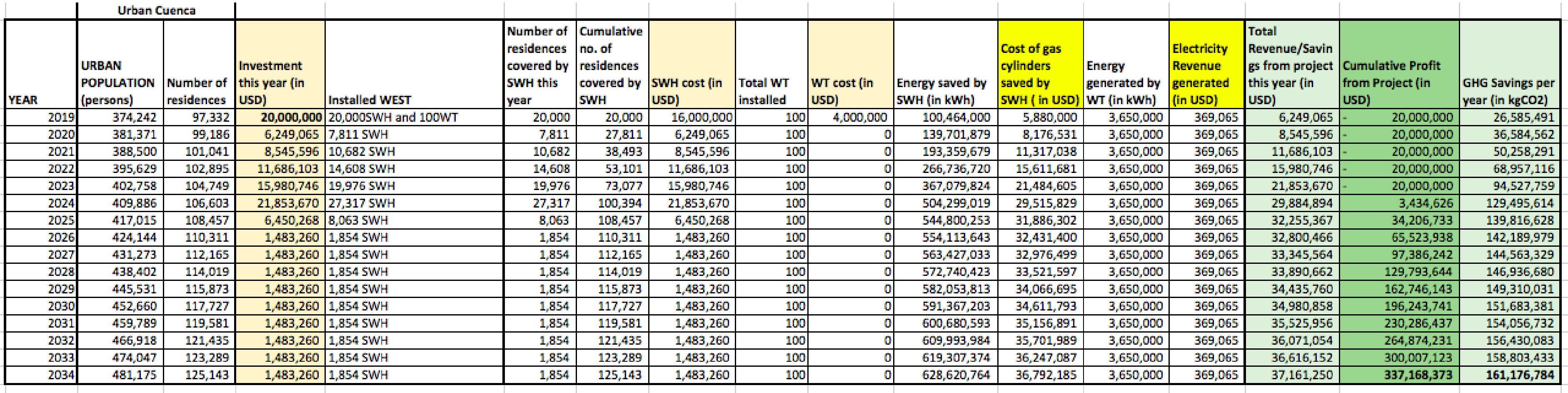
| | | | | Cost to State (in USD) | | | |
|---|---|---|---|---|---|---|---|
| **YEAR** | **URBAN POPULATION (persons)** | **Number of residences** | **URBAN AREA (in km2)** | **Gas Tanks scenario (BAU)** | **Solar water heaters scenario with electric back up power** | **Energy savings (kWh)** | **GHG emissions reduction (kgCO2)** |
| 2015 | 374,242 | 97,332 | 75.22 | 28,615,714 | 77,865,888 | 488,919,912 | 124,592,484 |
| 2016 | 381,371 | 99,186 | 76.66 | 29,160,812 | 1,483,260 | 498,233,302 | 126,965,834 |
| 2017 | 388,500 | 101,041 | 78.09 | 29,705,910 | 1,483,260 | 507,546,692 | 129,339,185 |
| 2018 | 395,629 | 102,895 | 79.52 | 30,251,008 | 1,483,260 | 516,860,082 | 131,712,536 |
| 2019 | 402,758 | 104,749 | 80.95 | 30,796,106 | 1,483,260 | 526,173,472 | 134,085,886 |
| 2020 | 409,886 | 106,603 | 82.39 | 31,341,204 | 1,483,260 | 535,486,862 | 136,459,237 |
| 2021 | 417,015 | 108,457 | 83.82 | 31,886,302 | 1,483,260 | 544,800,253 | 138,832,588 |
| 2022 | 424,144 | 110,311 | 85.25 | 32,431,400 | 1,483,260 | 554,113,643 | 141,205,939 |
| 2023 | 431,273 | 112,165 | 86.69 | 32,976,499 | 1,483,260 | 563,427,033 | 143,579,289 |
| 2024 | 438,402 | 114,019 | 88.12 | 33,521,597 | 1,483,260 | 572,740,423 | 145,952,640 |
| 2025 | 445,531 | 115,873 | 89.55 | 34,066,695 | 1,483,260 | 582,053,813 | 148,325,991 |
| 2026 | 452,660 | 117,727 | 90.99 | 34,611,793 | 1,483,260 | 591,367,203 | 150,699,341 |
| 2027 | 459,789 | 119,581 | 92.42 | 35,156,891 | 1,483,260 | 600,680,593 | 153,072,692 |
| 2028 | 466,918 | 121,435 | 93.85 | 35,701,989 | 1,483,260 | 609,993,984 | 155,446,043 |
| 2029 | 474,047 | 123,289 | 95.28 | 36,247,087 | 1,483,260 | 619,307,374 | 157,819,393 |
| 2030 | 481,175 | 125,143 | 96.72 | 36,792,185 | 1,483,260 | 628,620,764 | 160,192,744 |
| | | | **Average per year** | | | **558,770,338** | **142,392,614** |
| | | | | | | | |
| | | | **Total** | **523,263,193** | **100,114,790** | | |
| | | | | | | | |
| | | | | **Profit** | **423,148,403** | | |
| | | | | **Result** | **Highly recommended** | | |

# Annex 8: Water Turbines Scenario Forecast Results



| YEAR | URBAN POPULATION (persons) | Number of households | URBAN AREA (in km2) | Residential Electricity Demand (kWh) | Residential Electricity Costs (in USD) | Number of Water turbines installed | Installation Costs of water turbines (USD) | Electricity Generated by water turbines (kWh) | Revenue generated by water turbines' electricity (USD) | GHG Savings (in kgCO2) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2015 | 374,242 | 86,317 | 66.71 | 25,895,100 | 2,618,349 | - | - | | | |
| 2016 | 381,371 | 87,961 | 67.98 | 26,388,373 | 2,668,226 | - | - | | | |
| 2017 | 388,500 | 89,605 | 69.25 | 26,881,647 | 2,718,103 | - | - | | | |
| 2018 | 395,629 | 91,250 | 70.52 | 27,374,920 | 2,767,980 | - | - | | | |
| 2019 | 402,758 | 92,894 | 71.79 | 27,868,193 | 2,817,856 | 20 | 800,000 | 730,000 | 73,813 | 196,808 |
| 2020 | 409,886 | 94,538 | 73.06 | 28,361,467 | 2,867,733 | 20 | 800,000 | 1,460,000 | 147,626 | 393,616 |
| 2021 | 417,015 | 96,182 | 74.33 | 28,854,740 | 2,917,610 | 20 | 800,000 | 2,190,000 | 221,439 | 590,424 |
| 2022 | 424,144 | 97,827 | 75.61 | 29,348,014 | 2,967,486 | 20 | 800,000 | 2,920,000 | 295,252 | 787,232 |
| 2023 | 431,273 | 99,471 | 76.88 | 29,841,287 | 3,017,363 | 20 | 800,000 | 3,650,000 | 369,065 | 984,040 |
| 2024 | 438,402 | 101,115 | 78.15 | 30,334,560 | 3,067,240 | | | 3,650,000 | 369,065 | 984,040 |
| 2025 | 445,531 | 102,759 | 79.42 | 30,827,834 | 3,117,116 | | | 3,650,000 | 369,065 | 984,040 |
| 2026 | 452,660 | 104,404 | 80.69 | 31,321,107 | 3,166,993 | | | 3,650,000 | 369,065 | 984,040 |
| 2027 | 459,789 | 106,048 | 81.96 | 31,814,380 | 3,216,870 | | | 3,650,000 | 369,065 | 984,040 |
| 2028 | 466,918 | 107,692 | 83.23 | 32,307,654 | 3,266,746 | | | 3,650,000 | 369,065 | 984,040 |
| 2029 | 474,047 | 109,336 | 84.50 | 32,800,927 | 3,316,623 | | | 3,650,000 | 369,065 | 984,040 |
| 2030 | 481,175 | 110,981 | 85.77 | 33,294,200 | 3,366,500 | | | 3,650,000 | 369,065 | 984,040 |
| 2031 | 488,304 | 112,625 | 87.04 | 33,787,474 | 3,416,377 | | | 3,650,000 | 369,065 | 984,040 |
| 2032 | 495,433 | 114,269 | 88.31 | 34,280,747 | 3,466,253 | | | 3,650,000 | 369,065 | 984,040 |
| 2033 | 502,562 | 115,913 | 89.58 | 34,774,021 | 3,516,130 | | | **3,650,000** | 369,065 | 984,040 |
| **Average** | | | | **30,334,560** | | | | | | |
| **Total** | | | | | | **100** | **4,000,000** | | **4,797,845** | **12,792,520** |
| | | | | | | **units** | **USD** | | **USD** | **kgCO2** |
| | | | | | | | | **Profit** | **797,845** | |
| | | | | | | | | **Result** | **Recommended** | |

# Annex 9: Combined-WEST Implementation Forecast Results



| | Urban Cuenca | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | URBAN POPULATION (persons) | Number of residences | Investment this year (in USD) | Installed WEST | Number of residences covered by SWH this year | Cumulative no. of residences covered by SWH | SWH cost (in USD) | Total WT installed | WT cost (in USD) | Energy saved by SWH (in kWh) | Cost of gas cylinders saved by SWH ( in USD) | Energy generated by WT (in kWh) | Electricity Revenue generated (in USD) | Total Revenue/Savings from project this year (in USD) | Cumulative Profit from Project (in USD) | GHG Savings per year (in kgCO2) |
| 2019 | 374,242 | 97,332 | **20,000,000** | 20,000SWH and 100WT | 20,000 | 20,000 | 16,000,000 | 100 | 4,000,000 | 100,464,000 | 5,880,000 | 3,650,000 | 369,065 | 6,249,065 | - 20,000,000 | 26,585,491 |
| 2020 | 381,371 | 99,186 | 6,249,065 | 7,811 SWH | 7,811 | 27,811 | 6,249,065 | 100 | 0 | 139,701,879 | 8,176,531 | 3,650,000 | 369,065 | 8,545,596 | - 20,000,000 | 36,584,562 |
| 2021 | 388,500 | 101,041 | 8,545,596 | 10,682 SWH | 10,682 | 38,493 | 8,545,596 | 100 | 0 | 193,359,679 | 11,317,038 | 3,650,000 | 369,065 | 11,686,103 | - 20,000,000 | 50,258,291 |
| 2022 | 395,629 | 102,895 | 11,686,103 | 14,608 SWH | 14,608 | 53,101 | 11,686,103 | 100 | 0 | 266,736,720 | 15,611,681 | 3,650,000 | 369,065 | 15,980,746 | - 20,000,000 | 68,957,116 |
| 2023 | 402,758 | 104,749 | 15,980,746 | 19,976 SWH | 19,976 | 73,077 | 15,980,746 | 100 | 0 | 367,079,824 | 21,484,605 | 3,650,000 | 369,065 | 21,853,670 | - 20,000,000 | 94,527,759 |
| 2024 | 409,886 | 106,603 | 21,853,670 | 27,317 SWH | 27,317 | 100,394 | 21,853,670 | 100 | 0 | 504,299,019 | 29,515,829 | 3,650,000 | 369,065 | 29,884,894 | 3,434,626 | 129,495,614 |
| 2025 | 417,015 | 108,457 | 6,450,268 | 8,063 SWH | 8,063 | 108,457 | 6,450,268 | 100 | 0 | 544,800,253 | 31,886,302 | 3,650,000 | 369,065 | 32,255,367 | 34,206,733 | 139,816,628 |
| 2026 | 424,144 | 110,311 | 1,483,260 | 1,854 SWH | 1,854 | 110,311 | 1,483,260 | 100 | 0 | 554,113,643 | 32,431,400 | 3,650,000 | 369,065 | 32,800,466 | 65,523,938 | 142,189,979 |
| 2027 | 431,273 | 112,165 | 1,483,260 | 1,854 SWH | 1,854 | 112,165 | 1,483,260 | 100 | 0 | 563,427,033 | 32,976,499 | 3,650,000 | 369,065 | 33,345,564 | 97,386,242 | 144,563,329 |
| 2028 | 438,402 | 114,019 | 1,483,260 | 1,854 SWH | 1,854 | 114,019 | 1,483,260 | 100 | 0 | 572,740,423 | 33,521,597 | 3,650,000 | 369,065 | 33,890,662 | 129,793,644 | 146,936,680 |
| 2029 | 445,531 | 115,873 | 1,483,260 | 1,854 SWH | 1,854 | 115,873 | 1,483,260 | 100 | 0 | 582,053,813 | 34,066,695 | 3,650,000 | 369,065 | 34,435,760 | 162,746,143 | 149,310,031 |
| 2030 | 452,660 | 117,727 | 1,483,260 | 1,854 SWH | 1,854 | 117,727 | 1,483,260 | 100 | 0 | 591,367,203 | 34,611,793 | 3,650,000 | 369,065 | 34,980,858 | 196,243,741 | 151,683,381 |
| 2031 | 459,789 | 119,581 | 1,483,260 | 1,854 SWH | 1,854 | 119,581 | 1,483,260 | 100 | 0 | 600,680,593 | 35,156,891 | 3,650,000 | 369,065 | 35,525,956 | 230,286,437 | 154,056,732 |
| 2032 | 466,918 | 121,435 | 1,483,260 | 1,854 SWH | 1,854 | 121,435 | 1,483,260 | 100 | 0 | 609,993,984 | 35,701,989 | 3,650,000 | 369,065 | 36,071,054 | 264,874,231 | 156,430,083 |
| 2033 | 474,047 | 123,289 | 1,483,260 | 1,854 SWH | 1,854 | 123,289 | 1,483,260 | 100 | 0 | 619,307,374 | 36,247,087 | 3,650,000 | 369,065 | 36,616,152 | 300,007,123 | 158,803,433 |
| 2034 | 481,175 | 125,143 | 1,483,260 | 1,854 SWH | 1,854 | 125,143 | 1,483,260 | 100 | 0 | 628,620,764 | 36,792,185 | 3,650,000 | 369,065 | 37,161,250 | **337,168,373** | **161,176,784** |