Case Study:
Aguas de Cartagena, Colombia - An Example of a Water Utility Transformation to a Low Carbon Low Energy Future

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INTRODUCTION

Climate change is a global problem affecting different regions in different ways, change in temperature, stronger droughts and floods, change in the conditions to produce food, and see level rise, are among the potential impacts resulting in severe consequences worldwide, especially in developing countries that are not prepare to face them.

In Colombia, a South American country with almost 50 million people (DANE, 2005), the effects of climate variability have intensified (ENSO phenomena), making the country more vulnerable to stronger and longer precipitation and drought periods. According to the Ministry of Environment (MADS), by 2030 the country will face a flood hazard in 4.9% of its Caribbean coastal zone, floods will also affect 2% of the country total population, 50% of the territory will be affected by a modification in the hydrological regime, and there will be an increase in the potential desertification of almost 3.600.000 ha (Table 1).

Coastal zones
▪ Flood threat on 4.9% of the areas of crops and pastures of the coastal zone of the continental Caribbean, high vulnerability of most of the areas occupied by the manufacturing industry and 44.8% of the terrestrial road network of the same coastline. ▪ Potential floods of 17% of the territory of the island of San Andrés. The island's aquifers, which supply 82% of the water for human consumption in the island, would also be affected by saline intrusion. ▪ The increase in precipitation of 15% for the year 2050 is foreseen for the area of the Archipelago of San Andrés, Providencia and Santa Catalina.
Flooding
▪ By 2030, it is estimated that 2% of the total population will be affected. ▪ The loss of coverage of marine and coastal ecosystems such as mangroves, of which Colombia has the largest extension of the American Pacific. ▪ Prolonged exposure of coral reefs at high temperatures can cause irreversible damage (whitening), their subsequent death and the loss of their environmental services, such as the protection of the coast line to extreme events. ▪ Erosion of the land due to intensive agriculture and livestock growth.
Vulnerability of water resources

▪ 50% of the national territory will be affected by the modification of the hydrological regime, with consequences on the economic activities, the population's supply and increase in natural hazards. ▪ The regions of La Guajira and Nariño would decrease the average annual rainfall, while the regions of the Amazon, Orinoquía, Pacific regions and the rest of the Caribbean region would register an increase in the average annual rainfall. ▪ Decrease in the coverage of glaciers with negative effects on the availability of water for those populations that depend on these systems.
Other impacts
▪ Increase of the areas with a high desertification potential (3.576.068 ha). ▪ A third part of the areas that are currently agro ecosystems will be affected. ▪ The threats to the population and human health will result in an increase in the vulnerability for the development of malaria and dengue.

Table 1. Potential Impacts of Climate Change in Colombia. Adapted from Ministry of Environment (MADS)

The temperature in the country has raised 0.2ºC in the last decade, and although, Colombia contributes only with 0,4% of the global Green House Gas (GHG) emissions, is the 5th country with higher GHG emissions among 32 Latin American countries (IDEAM et al., 2016).

The latest emissions inventory report developed in Colombia, stated that in the country the highest emissions come from the forestry, agriculture and transport sectors, and that despite the increasing tendency in the emissions in most of the economic sectors from 1990 to 2012 (IDEAM et al., 2016), the decreasing tendency in the forestry sector helped reduce the total annual emissions from almost 201 $MtCO_{2eq}$ for 1990 to 185 $MtCO_{2eq}$ for 2012 (Figure 1).

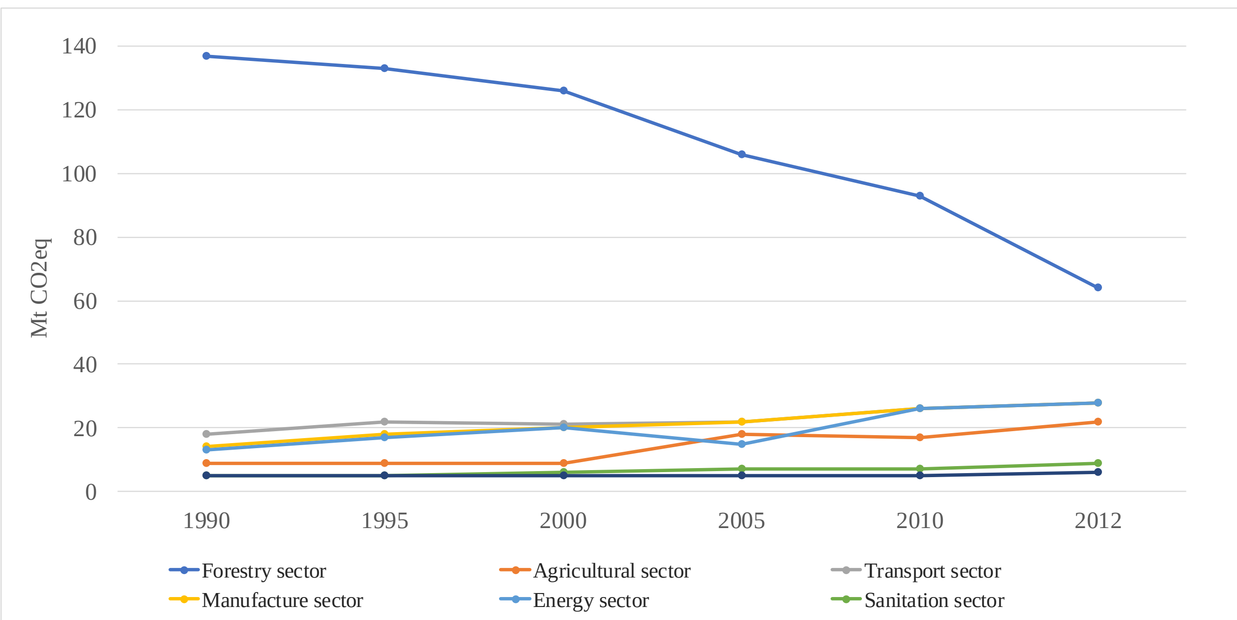

Figure 1. Total emissions (substracting the absorptions of each sector) of economic sectors in Colombia. Adapted from IDEAM et al. (2016)

It is important to notice that the sanitation sector, for which the activities are defined by the Intergovernmental Panel on Climate Change (IPCC) as included in the "elimination of solid waste, the open incineration of waste, and the treatment and elimination of wastewater", shows a historical increase, contributing with 9,2 $MtCO_{2eq}$ in 2012 (IDEAM et al., 2016). The water supply and sanitation sector, may play a crucial role in the country's climate mitigation objective to reduce GHG emissions, taking in to account that a carbon neutral urban water sector could increase by 20% the GHG reductions committed globally (WaCCliM, 2016).

In Colombia, the energy consumption represents between 10 and 40% of the total operational costs of the water and wastewater treatment systems (MME, 2016), and nearly 10% of the total costs of the water supply and sewage systems. Therefore, to develop and promote instruments aimed to improve the efficiency of water utilities has become a key issue (USAID, 2014).

The necessity to develop tools and strategies to adapt and mitigate the impacts of climate change, have become a main objective in the agenda of the national government. The transformation of the water utilities to low carbon and energy efficiency, has become one of the principal focus. The objective of this case study is to present a successful example of a water utility's path towards its transformation to energy efficiency and GHG reduction.

FACING CLIMATE CHANGE: THE REGULATORY FRAMEWORK

Since 2011, through the development of the *Colombian Strategy for Low Carbon Development* (ECDBC), the government institutions have made the effort to plan and identify short, mid and long term actions that contribute to the reduction of GHG emissions despite of national economic growth, maximizing the carbon-efficiency of the country's economic activity and contributing to social and economic development (DNP, 2011 and MADS, 2013). With the ECDBC, the government seeks to establish a pathway for economic growth that promotes competitiveness, the efficient use of resources, innovation and the development of new technologies (MADS, 2013).

As part of the institutional and political strategy for low carbon development and climate change adaptation, the *National Plan for Adaptation to Climate Change* (PNACC) was developed as an articulated initiative to reduce the vulnerability of the country and increase its capacity to respond to the impacts of climate change (DNP et al., 2012 and MADS). The plan prioritized the following actions, to be achieved by 2030 (MADS, 2017):

a. Climate change plans formulated and implemented in all the territory100 %.
b. A national indicator system of climate change adaptation, which allows to monitor the implementation of measures of adaptation.
c. Development of instruments for water resources management, with a basin approach.
d. Incorporate climate change actions in the instruments for planning and technological innovation in the main economic sectors.

Likewise, between 2011 and 2014 the Colombian government had promoted the formulation of other long term strategies for climate change adaptation including: *The National Strategy for Reducing Emissions from Deforestation and Forest Degradation (ENREDD +), The National Disaster Risk Management Plan, the Strategy for Financial Protection against Disasters* and the *National Strategy for Climate Financing*.

In 2015 Colombia committed to reduce 20% of its GHG emissions by 2030 (MADS, 2017). Consequently, the *National Development Plan 2014-2018* under the policy of "green growth", included all the strategies and related topics to climate change, making emphasis in the necessity to develop a *National Policy for Climate Change (PNCC)* (MADS, 2017). The PNCC was conceived as an articulation and planning tool for the already created programs and the future actions for climate change adaptation (MADS) (**Error! Reference source not found.**).

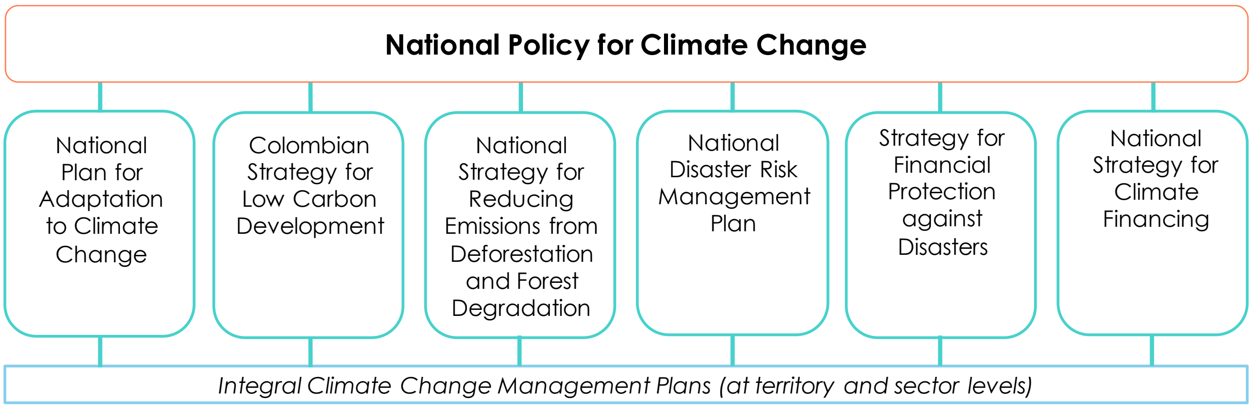

Figure 2. Articulation of the National Policy for Climate Change (MADS, 2017)

The PNCC was released in 2017 as the policy for the organization of "*climate change management in Colombia with the purpose of influencing the most important public and private decisions that define the development of the country*" (MADS, 2017). The PNCC has 5 strategic lines and 4 instrumental lines (Table 2):

Strategic Lines	Instrumental lines
1. Rural development low in carbon 2. Urban development low in carbon 3. Power development low in carbon 4. Infrastructure development low in carbon 5. Ecosystems management and conservation for a development low in carbon	1. Planning for adaption to climate change. 2. Information, science, technology and investigation. 3. Education. 4. Financing and economic instruments

Table 2. Strategic and Instrumental lines of the PNCC. Adapted from Ministry of Environment (MADS).

For the adequate implementation of the policy, it was essential to develop the *Integral Climate Change Management Plans*, at territory and sector level, as part of the planning for adaption to climate change. These plans, formulated through the ECDBC, are instruments and guidelines for the identification, evaluation and orientation of mitigation measures that contribute to the reduction of GHG emissions in each economic sector and territory (MADS, 2017). Each Ministry has the task to identify, evaluate and guide the incorporation of these measures in the policies and regulations of each sector.

According to the Ministry of Environment, through the implementation of the *Sectoral Action Plans* (PAS), the increasing trend in the emissions will be avoided. Results of projections calculated with the ECDBC, under a scenario where growth trends and technologies used by these sectors maintain the behavior of the last decade, in 2030 the emissions will have increased by more than 60% and in 2040 will be emitting more than twice the current emissions (IDEAM).

The PAS already approved belong to the following sectors: Agriculture, transport, industry, housing, sanitation (solid wastes and wastewater), energy and hydrocarbons (MADS, 2015) (Figure 3).

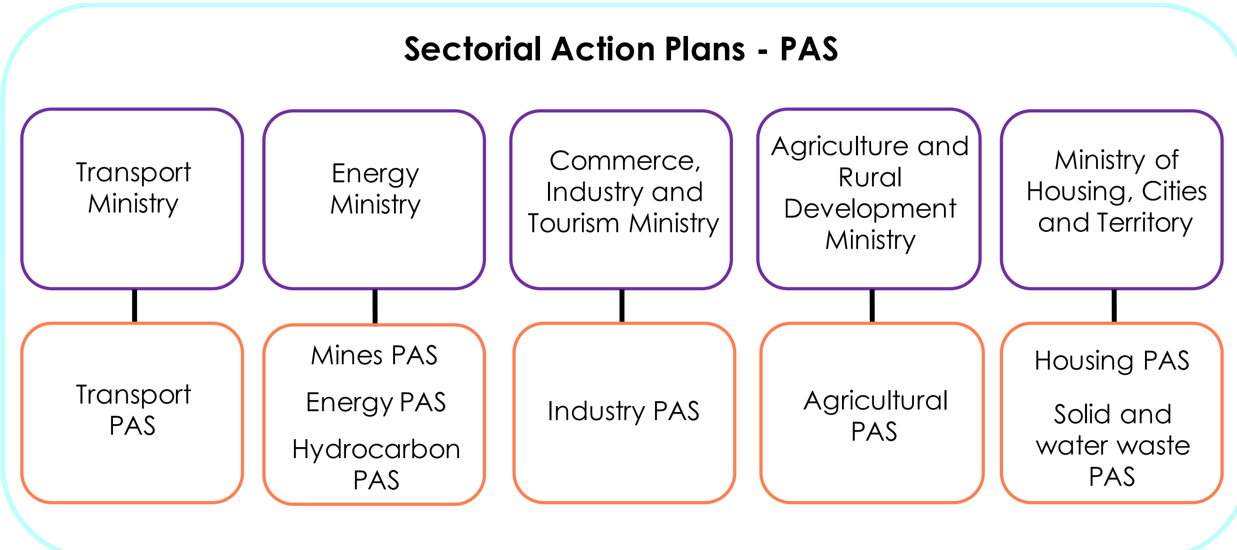

Figure 3. Sectorial Action Plans and Ministry in charge of its development and implementation (MADS)

The sectorial plan for the sanitation sector (solid wastes and wastewater) focused on the implementation and modification of municipal policies in the framework of an integral solid waste and wastewater management. For wastewater management, the policies must promote the construction of wastewater treatment plants (in Colombia only 37,3% of wastewater is treated) which would contribute to the reduction in the GHG emissions, optimization of energy efficiency for water treatment systems, and implementation of technologies and regulations for biogas recovery (MVCT, 2014).

Is important to mention that in 2016 the national government approved a national system of climate change (SISCLIMA), integrated by all the government institutions and private organizations, with the regulations, policies, plans, programs and instruments already develop, and it is intended to coordinate and articulate all measures and actions taken to reduce GHG emissions and adapt to climate change (Decree 298 of 2016).

Colombia has made regulatory and institutional efforts to coordinate and develop adequate policies, programs and actions towards climate change adaptation and mitigation. There is still a long way ahead to achieve the 20% reduction goal in the GHG emissions by 2030, and it requires strong coordination and commitment between the Government institutions, economic sectors and territories.

In Colombia, the main focus of the government and the municipalities, has been increasing the efficiency and quality of the water supply and sanitation services. Therefore, utilities have been making efforts to improve the coverage of these services in the cities. Nowadays, 92,4% of the households in Colombia have an adequate water supply system and 88% an adequate sewage system. However, there is still a big gap in the treatment of wastewater throughout the country.

Although, the sanitation sector contribution to the GHG emissions is lower compared to other sectors in Colombia, exists a prevailing necessity to change and follow a carbon neutral future to cope with climate change.

ENERGY EFFICIENCY IN WATER UTILITIES

According to Millan (2015), the total energy consumption for water utilities is between 1 and 1,5% of the total energy consumption in a country. Likewise, the energy use could mean a significant part of the production and distribution costs of drinking water and sewage systems, although, it depends on the characteristics of the energy consumption and water supply system in each country (in Colombia energy costs can be lower compared to the energy costs in Chile).

In Latin America, energy efficiency in water supply and sanitation systems can have limitations in technical, economical and institutional aspects depending on the country characteristics and circumstances (Millan, 2015). Therefore, although it is a topic of interest, there are other regional problematics that take more relevance.

Nevertheless, the actions to find energy efficient solutions, for example for desalination and water supply or sewage systems operation, are gaining importance as long as there are adequate economic incentives (Millan, 2015) and proper utility management.

As mentioned before, for water supply and sanitation utilities, energy could represent between 10 and 40% of the total operation costs in the treatment systems, which makes it relevant to implement measures related to energy efficiency. Therefore, in Colombia, in the water and sanitation PAS, the Ministry of Housing included tools and guidelines to promote the optimization of the energy efficiency, reduction of operational costs and the utilization of non-conventional energy sources in the water treatment systems (MME, 2016). Along with other important elements to improve the operation of the aqueduct and sewage systems, such as optimization of water pumping.

According to the Guidelines for Energy Optimization in Water Treatment Systems (USAID, 2014), more than 50% of the energy consumption in a wastewater treatment plant comes from the aeration stage, while in a drinking water system, 60% of the energy consumption is related to the pumping system. In Colombia, aqueducts with pumping systems have indicators of energy consumption near to 1,4 kWh/m^3, while aqueducts operated by gravity have an indicator at around 0.82 kWh/m^3.

Consequently, there is a great improvement opportunity for water utilities to reduce the energy consumption and become more energy efficient (MME, 2016). The latter, will required a great commitment of the water utility to develop and implement an adequate Integral Energy Management Plan, that leads to the identification and evaluation of energy consumption indicators and energy reduction measures (**Error! Reference source not found.**). Ultimately this will help the utility to reduce operational costs, and more importantly to follow the path towards a low energy and low carbon future.

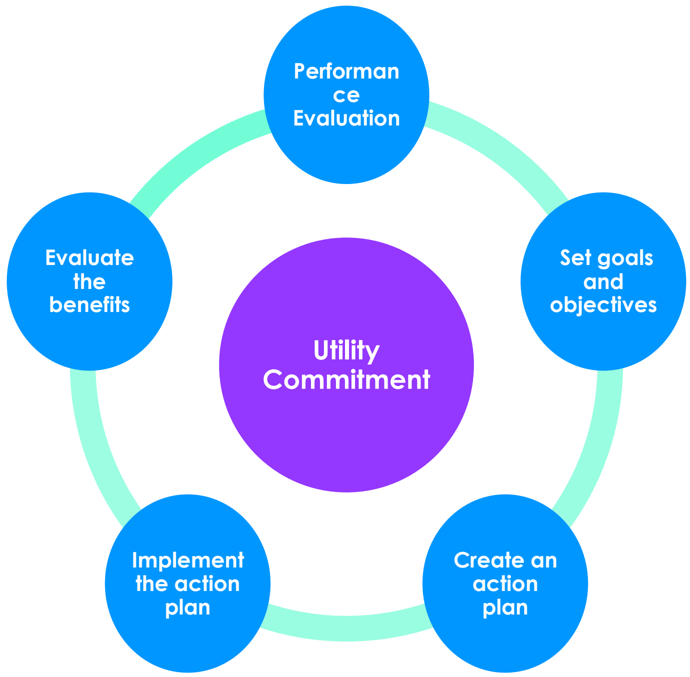

Figure 4. Stages for the implementation of an Integral Energy Management Plan. Adapted from BID, 2011

In Colombia, with the new SDG agenda, utilities are starting to understand the importance to become more efficient in their operation, not only because of the costs, but also due to the impact that their systems have in the environment; and although, energy use and GHG emissions, have not been the main focus for water utilities in the country, there have been good examples where utilities realize how an improvement and optimization of their systems, although required a great effort, can mean a more sustainable future.

AGUAS DE CARTAGENA: TOWARDS A LOW CARBON LOW ENERGY TRANSFORMATION

Aguas de Cartagena

Cartagena de Indias is the capital of the Bolivar Department in Colombia, and is located at the shoreline of the Caribbean Sea. The city has population of around 1 Million in habitants and it is characterized by being one of the most famous touristic places in the country.

Aguas de Cartagena, the water utility, oversees the operation of the water supply system in the city since 1994. The utility provides its service in the urban area of Cartagena, the industrial zone of Mamonal and the rural area (corregimientos) with a coverage of 99.9% and 249.286 users (Table 3).

Year	Users
2015	227152

2016	235621
2017	249386

Table 3. Number of users from 2015 to 2017

The abstraction of water is made in the Dique channel through two main systems, Dolores and Gambote. From the Gambote system, the water uptake is made directly from the channel and is driven from the raw water pumping station Gambote to the Albornoz pumping station. The catchment is located 40 kilometers from the treatment plant at an elevation of 6 meters.

The Dolores System, takes water from the Dique channel, but first raw water flows from a lagoon system, Juan Gómez Bohórquez, to the Dolores pumping station. The lagoon system works as a large clarifying pond, where water is storage, and flows are regulated. In addition, there is a pumping station at the catchment point of the Dique channel called Conejos, a station that works only during the dry season of the year.

The Dolores pumping station drives the raw water to another pumping station called Piedrecitas and from Piedrecitas to the Albornoz pumping station. From Albornoz, water flows to the water treatment plant El Paraguay, where 58% of the water is distributed by gravity and 48% of the water is distributed by pumping, to the different city areas (Image 1 and Figure 5).

Image 1. Aguas de Cartagena Drinking Water System. Where 1 is the Conejos pumping station, 2 is the Dolores pumping station (flow=270.000 m^3/day), 3 is the Gambote pumping station (flow=27.000 m^3/day), 4 is the Piedrecitas pumping station (flow= flow=270.000 m^3/day), 5 is the Albornoz station (flow= flow=230.000 m^3/day) and 6 is the water treatment plant.

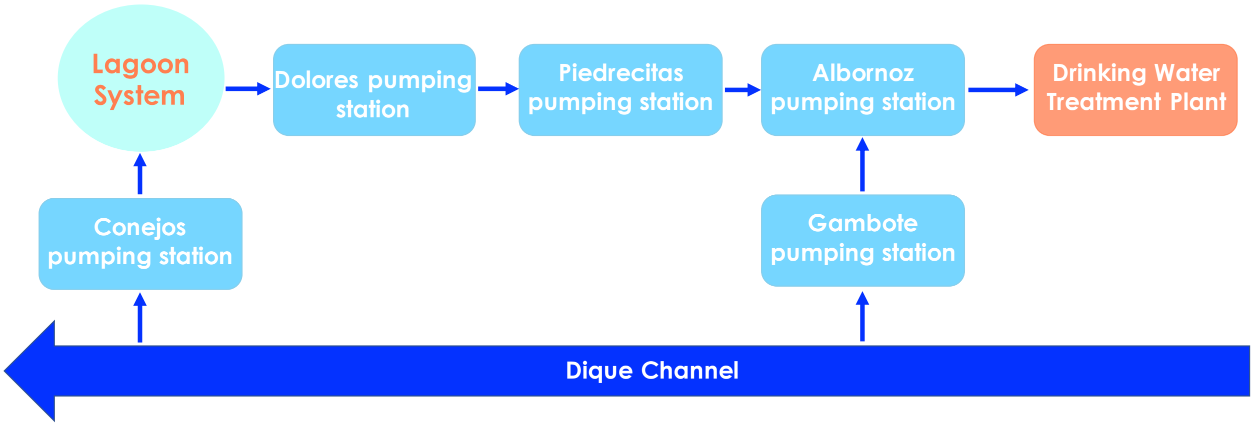

Figure 5. Diagram of the drinking water system in Cartagena

The drinking water treatment system consists of 3 plants located at 52 m.a.s.l, carrying out processes of rapid mixing, coagulation, flocculation, sedimentation, filtration and disinfection. Before the treatment plants, raw water reaches a mixing chamber consisting of two tanks with a total capacity of 2.000 m^3. From this point, and taking advantage of a raw water distribution chamber, the water is transported to the rapid mixing chambers, one that feeds Plants 1 and 2, and another that feeds Plant 3. Plants 1 and 2 have a treatment capacity of 45.000 m^3/day and plant 3 currently has a capacity of 180.000 m^3/day.

Year	**Volumes of water in drinking water system (m^3)**		
	Abstraction	**Treatment**	**Distribution**
2015	107915361	85451037	85238435
2016	108882115	86239323	85045181
2017	109265371	87384700	86671367

Table 4. Changes in the annual volumes of water in the drinking water system

Piedrecitas pumping system

The Piedrecitas pumping optimization was made in 2016 due to the construction of a new refinery in Cartagena. The refinery would demand 12 million m^3/year of water, overpassing the supply capacity of the aqueduct system. Therefore, it was necessary to build a new pumping station beside the old one, with two pumps of 2.200 HP and a capacity of 6.680 m^3/h. Initially the new pumping station was equipped with soft starters for both pumps, which permitted to operate the pumping system at only one location. The old pumping station would serve as a backup station in case of any contingency or programmed maintenance of the new one.

The objective of this new station was to achieve the raw water demand for the refinery, and give the surplus to Aguas de Cartagena. The latter meant not only an expansion for the new refinery, but also a challenge and an improvement opportunity for the utility.

An energy audit identified that the new pumping station could supply the water requirements for both, the refinery and Aguas de Cartagena. To achieve this goal, it was necessary to replace the soft starters for frequency converters, making possible to adapt the pumping station to the projected water demand until 2023. The efficiency of the system would be between a 78 and 80%, although the location of the operation point will be continuously changing according to the changes in the water demand.

Furthermore, the audit also established that the change in the starters could mean a 26% reduction in the annual energy consumption and costs, about 6.002.453 Kwh/year and 0,474 million euros/year (Figure 6), and would contribute to a reduction in the GHG emissions of the utility.

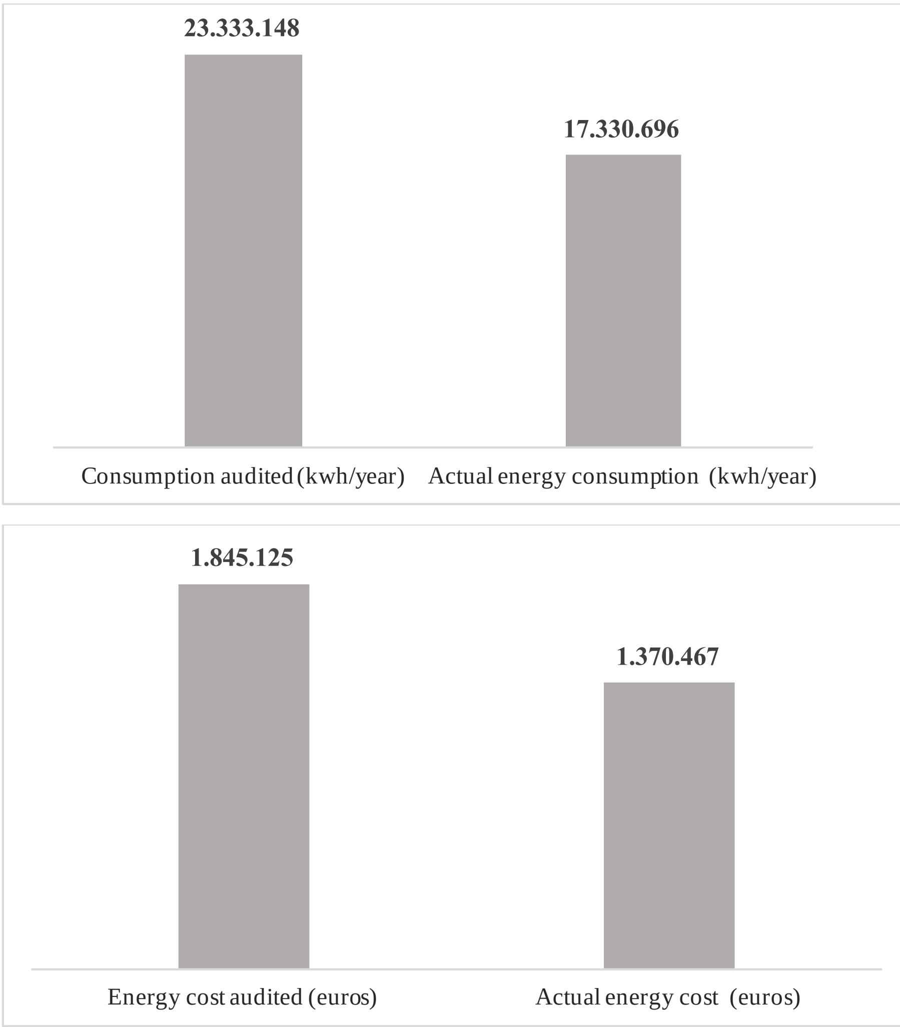

Figure 6. Reduction in energy consumption and energy costs. Adapted from the information of Aguas de Cartagena.

Towards a low carbon low energy operation

In 2015, according to the results of the utility, before the optimization of the Piedrecitas pumping system, the average energy consumption was 1713147,42 kwh per month, the average pressure was 59,5 m per month, and the operational costs per month were at around 337.000 million COP (Colombian peso) (Table 5).

2015	Energy Consumption (kwh)	Flow (m3)	Average Pressure (m)	Operation and Maintenance (MM$)
January	1624400	7483450	59,5	337
February	1492050	6819940	59,5	310
March	1667712	7805800	59,5	356
April	1584041	7499789	59,5	339
May	1776424	7878980	59,5	351
June	1747153	7938280	59,5	371
July	1807868	8256270	59,5	379
August	1836000	8207140	59,5	405
September	1744200	8068280	59,5	385
October	1817366	8339750	59,5	390
November	1673630	7855240	59,5	367
December	1786925	8388272	59,5	414

Table 5. Performance results during 2015

In 2016, after the optimization, the average energy consumption was 1401729,08 kwh per month, the average pressure was 48 m per month, and the operational costs per month were at around 357.000 million COP (Colombian peso) (Table 6Table 5).

2016	Energy Consumption (kwh)	Flow (m3)	Average Pressure (m)	Operation and Maintenance (MM$)
January	1648385	7641900	48	438
February	1683740	8450947	48	402
March	1518021	8095617	48	393
April	1370626	8157301	48	361
May	1252356	7936146	48	343
June	1366137	8454661	48	316
July	1373926	8350594	48	348
August	1288110	8022339	48	343
September	1275684	8298764	48	325
October	1254772	7781095	48	323
November	1491255	8489298	48	322
December	1297737	8085328	48	378

Table 6. Performance results during 2016

The results show a decrease in the consumption of energy and the average pressure between 2015 and 2016, while the operation and maintenance costs remained almost unchanged. Therefore, with the optimization of the Piedrecitas system, Aguas de Cartagena accomplished the main objective, that was to reduce the energy consumption without compromising the volume of water delivered by the system, and without a considerable increase in the operational costs.

Likewise, at the end of 2016 the energy consumption and the energy costs decreased in 4.011.825 kwh and 0,317 million euros respectively, which represents a reduction in 19% compared to previous years (Figure 7). Also, the IE decreased from 0,21kwh/m3 to 0,16kwh/m3, which will allow the utility to reduce the annual consumption in 26% and save around 440.000 euros.

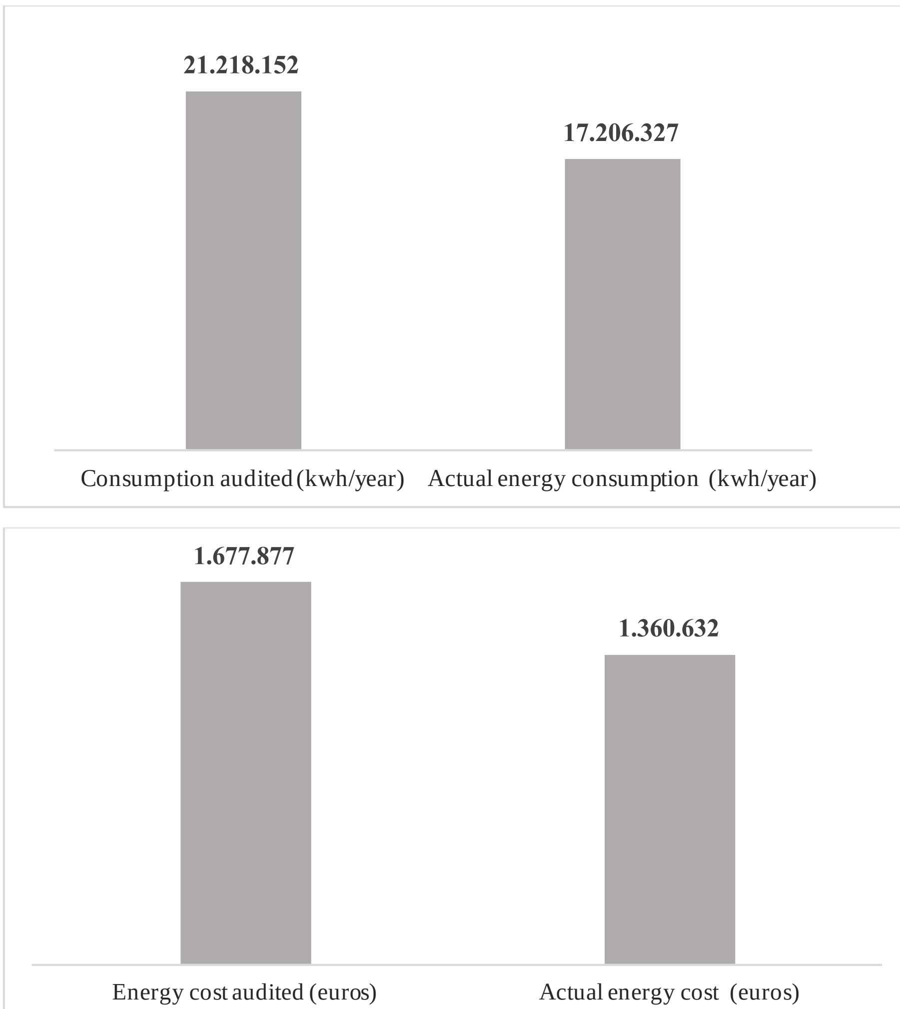

Figure 7. Reduction in energy consumption and energy costs at the end of 2016. Adapted from the information of Aguas de Cartagena.

The change of the soft starters in the pumps, have made possible to exceed the compliance index in the energy savings goals of the utility, as shown in Figure 8.

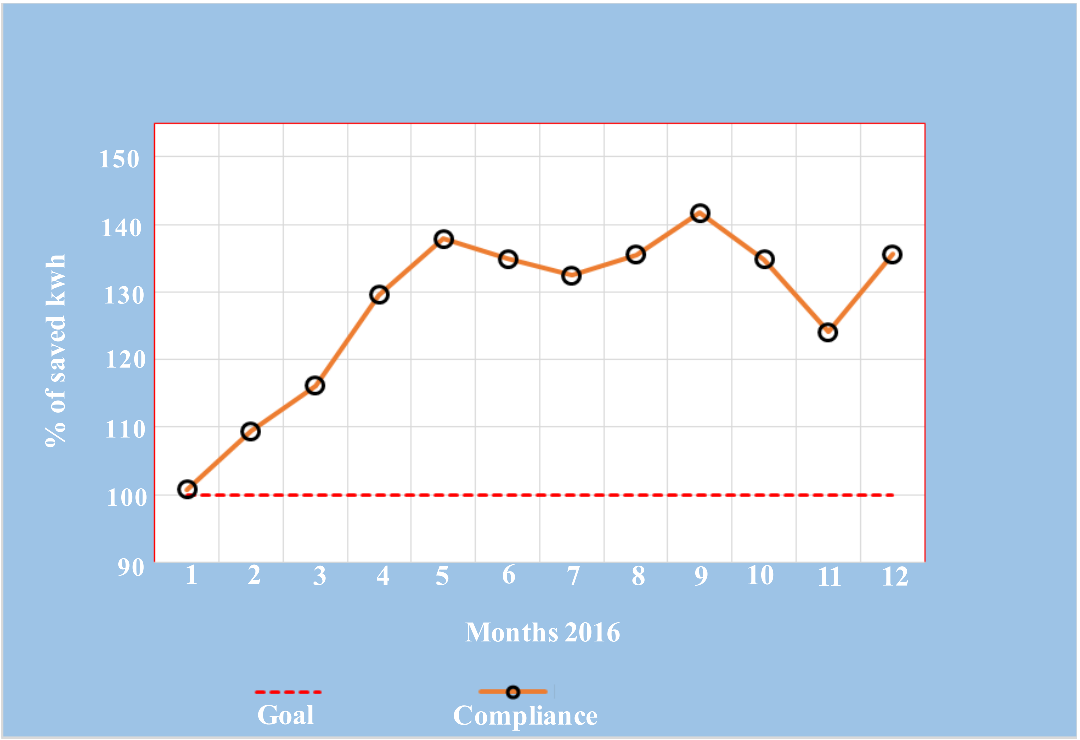

Figure 8. Compliance index of energy savings during 2016. Adapted from the information of Aguas de Cartagena.

On the other hand, during 2016, 8 months after implementing the optimization of the Piedrecitas pumping station, there was a reduction of 1609 ton in the emissions of CO_2 to the atmosphere. According to the information of Aguas de Cartagena, the utility expects an annual reduction in the GHG emissions of 2400 CO_2 ton per year.

This is a main step for Aguas de Cartagena, towards a low carbon and low energy future, and in this path they continue to identify other variables that can affect the energetic performance in operation of the aqueduct. For example, in the Dolores pumping system, the abstraction of water from the Dique channel can suggest a high energy consumption compared to other stages of th water supply system.

The case of Aguas de Cartagena is a great example of a utility that turn a difficult situation in an opportunity to improve and transform. The optimization of the Piedrecitas pumping system, have required a great commitment of the utility, and this commitment have shown positive results in the reduction of the energy consumption and GHG emissions. Aguas de Cartagena is one, of just a few examples in Colombia, on how a water utility can take action to adapt and contribute to the mitigation of climate change.

CONCLUSIONS

Climate variability is a great concern in Colombia. The country is susceptible to stronger floods and droughts, having negative impacts in the welfare of its population. Therefore, an articulated regulatory framework is being developed and implemented, in which all its institutions and organizations play a crucial role in the formulation of strategies and instruments for adapt and mitigate climate change.

The water supply and sanitation sector has lower GHG emissions when compared to other economic sectors. Nevertheless, water utilities are starting to understand the importance of their contribution in the transformation of the country towards a low carbon future, implementing alternatives to improve their energy efficiency and reduce the GHG emissions.

The example of Aguas de Cartagena showcased the effort of a water utility to increase its efficiency, with the optimization of the pumping system it was possible to reduce the energy consumption (and energy costs) in the water supply system, and consequently a reduce the GHG emissions.

Water utilities in Colombia have still a long way ahead to become carbon neutral. With the country's target to achieve the ODS and GHG reduction goals by 2030, is necessary that the government, municipalities and utilities, strength and implement the adequate strategies to become more efficient (sectorial plans) and therefore begin a path towards climate change adaptation.

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