Chapter

City-Scale Decarbonization Strategy with Integrated Hydroelectricity-Powered Energy Systems: An Analysis of the Possibilities in Guadalajara, Mexico

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Abstract

According to the UN, in the next 20 years, most of the world's population will live in urban areas. Cities consume a high amount of resources, between this water, for their sustenance, hence the greatest necessity of sustainable development plans. What viable options or strategies can we consider in Latin America such that it can resist the economic, political, and social changes that it is facing? Through prospective studies, in case of Guadalajara, it is possible to determinate how water can generate clean energy, and which are the other strategic areas to empower the city through decarbonization with an interoperative and smart loop system of co-benefits. This study can help in public policy decisions of medium-sized cities in Latin America.

Keywords: water, decarbonization, clean energy, metropolitan areas, co-benefits

1. Introduction

Today, the accelerated growth of cities and their demand for greater resources, and high levels of pollution and the lack of clear and reliable actions in planning systems took greater importance under principles established in worldwide objectives through sustainability, since its official publication in 1987. This created a bigger challenge to achieve a real global impact through the action at a local level.

The rise in the amount of CO_2 emissions in recent years is shown in the following chart of the World Bank (**Figure 1**).

According to the World Bank [1], Mexico is the country responsible for most of the CO_2 emissions in Latin America, most of which come from the consumption of liquid fuel.

Considering this, there is an urgent need for addressing this problem by taking action to diminish environmental pollution. Addressing this global issue through local action also generates awareness at local level as can be represented in the following illustration (see **Figure 2**):

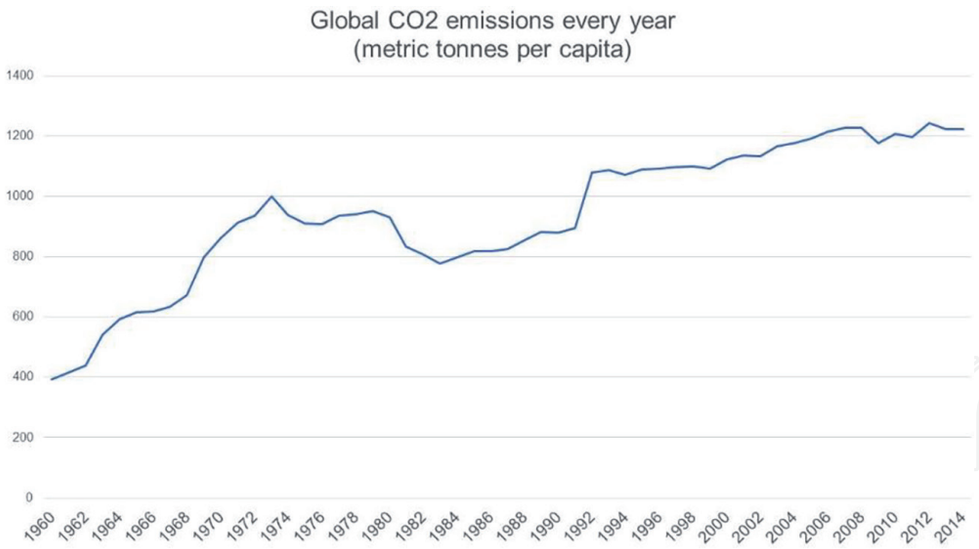

Figure 1.
Global CO_2 emissions by year (metric tons per capita). Source: Dulce García from World Bank, 2018.

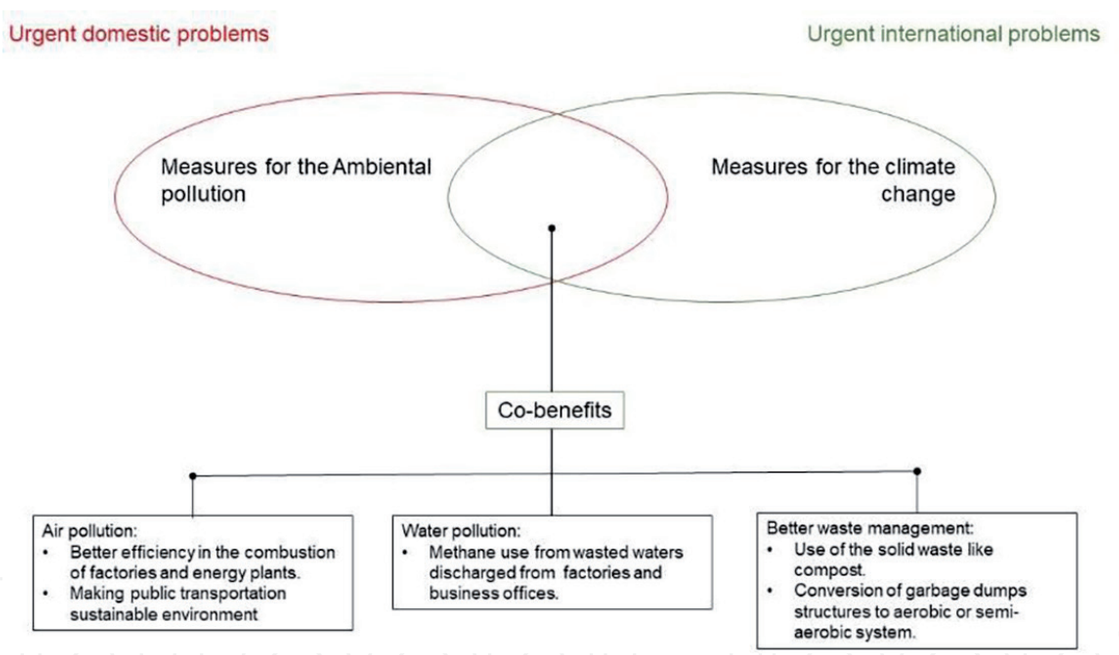

Figure 2.
Co-benefits, according of measures for the Ambiental pollution and the climate change. Source: From Approach is a new project, based in climate change concerns while also improving the local environment, 2009.

Meanwhile, co-benefits are a category of sustainability and were initially addressed by scientific literature in the 1990s as a response to public policies to anticipate climate change; in the literature, they have been understood as a measure of co-control that indicates that a single activity or policy can generate multiple benefits across several sectors or fields of study.

In many cases, the co-benefits are understood as the benefits of the climate, that is, based on the intentional decisions in which way it is possible to have benefits that have a positive impact on the environment.

Since 2007, the world has witnessed a new, historically radical reality: there are more people in the cities than in the countryside. The population that lives in the cities grows more and more. Therefore, there will be more energy consumption, which is increasingly responsible for the generation of global CO_2 emissions.

Between 1950 and 2005, the urban world population grew between 29 and 49%, and global carbon emissions jumped from 1630 to 7985 million tons ([2], p. 20).

Since the world's urban population will almost double by 2050, and most of that growth will take place in the developing countries ([3], p. 3), it is important to know and locate the necessary actions for addressing the problems faced by key cities and their metropolitan areas.

Guadalajara was chosen as the first case, since it is a city in the Latin American context with the second most important population, economic and territorial concentration in Mexico, which demands housing and services, thus amplifying the urban-environmental problem.

According to the City Prosperity Index CPI out by the UN in 2018, Guadalajara is at a basic level, this measure seeks the institutional alignment for the achievement of the objectives of Sustainable Development and the 2030 Agenda, this study shows that one of the main challenges facing the city in the category of environmental sustainability is within the category of air quality through the concentration of CO_2 with 46.07, as well as the treatment of wastewater with a percentage of 0.00 and the proportion of renewable energy generation with a percentage of 0.00, so it is essential to develop research with this orientation so that they can see the possibilities of decarbonizing Guadalajara through the generation of renewable energy through water as a measure of sustainable action [4].

It is also a city that attracts significant investment in industrial and technological matters; this central city had 1495 million inhabitants in 2010 (INEGI), together with the central nucleus of the metropolitan area that integrates a total of 4,434,878 inhabitants, this mind a contemporary urbanization with a regional influence of the phenomenon of metropolization [5].

Meanwhile, Jalisco is among the fourth largest energy consumer in the country [6–8] with some experts mentioning that the energy it produces is between 3 and 11% of the energy it consumes [7–9]. Only 3% of the energy consumed in the state is produced in Jalisco, with only 23% of the energy in Mexico coming from renewable sources, and 80% of the renewable energy coming from hydroelectric plants.

Likewise, one of the main objectives in Mexico is the development of renewable energy and the use of wind and solar farms; also, there is a lot of potential for the generation of electricity with the treatment of sewage water. Some experiments and prototypes have been developed as in the case of the one made by the Mexican Water Institute (IMTA) for the National Hydric Program (2014–2018) extracted from [10].

Specifically, in Jalisco, which is located within one of the four most populous states in the country, it is estimated that 83% of the electrical energy consumed is produced from fossil fuels and only 17% is generated from renewable sources. However, according to the data from the National Inventory of Renewable Energies (INERE), Jalisco has a high potential for renewable energy generation that has not yet been exploited. So, currently, in this situation, the energy transition model cut be promoting in projects to generate energy from various renewable sources within the state [11].

Therefore, in order to achieve this, not only clean energy but also energy efficiency in products is necessary; so, in Jalisco, a laboratory for the development of lighting technologies is being built to develop prototypes of luminaires with Internet of the things [12].

Additionally, another outstanding project is the one developed by the industrial digital company GE Power Systems, which is based on building the necessary infrastructure for the city through the creation of a power plant with HA turbines and GE digital services, which is estimated to be completed by the end of 2019; this project aims to generate 875 MV, enough to supply up to 2.8 million homes [7].

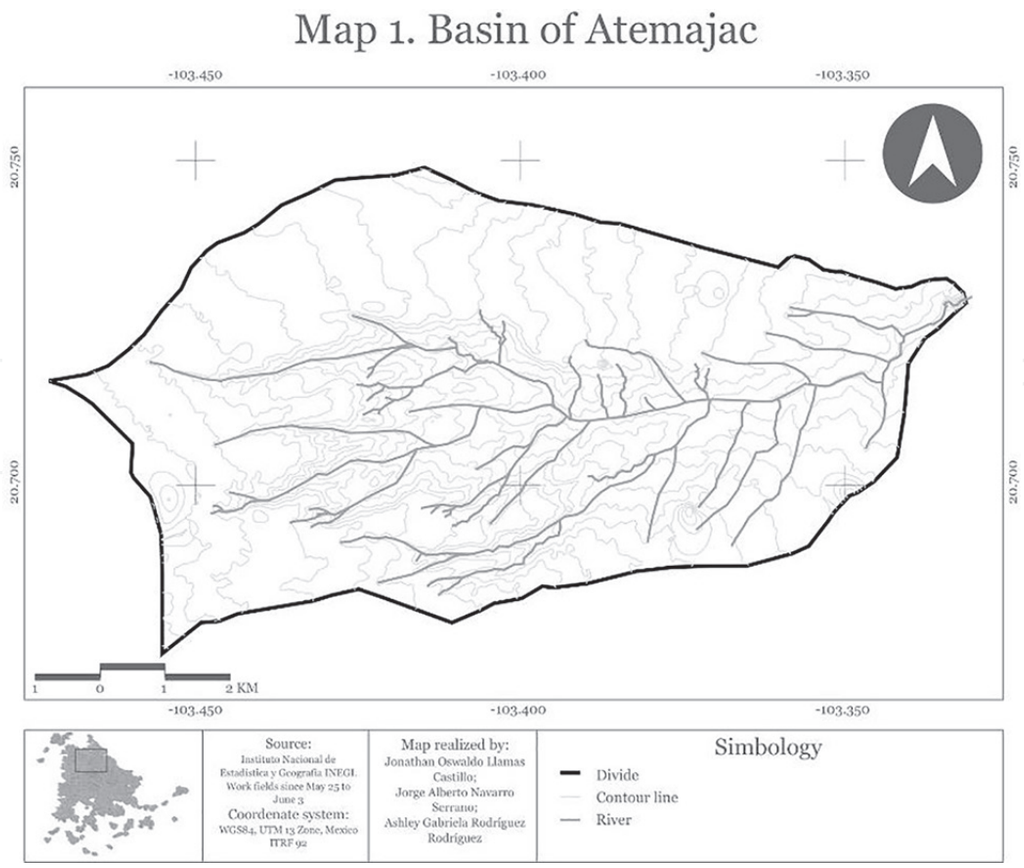

Figure 3.
Map of the basin of Atemajac and the topographical characteristics. Source: Jorge Navarro, Ashley Rodríguez and Jonathan Llamas.

It is necessary to have control actions that can help reduce or neutralize pollutant emissions, so that they meet the specific demand of the city and metropolitan areas, through their resources and services, which allows generating a balance between the environment, the reduction of social vulnerability, and a viable economic source of energy.

This research is focused on identifying through time retrospective diagnosis by means of cartographic analysis the potential of integration that exists in the water to generate clean energy as a measure of decarbonization in cities taking as a case study Guadalajara, Jalisco specifically the Atemajac river, with which a dynamic inter-operational model of the System could be established.

The study tried to verify if it is possible to integrate clean energy through water in the rivers by means of hydroelectric systems using decarbonization of the city and urban areas by attending to the specific case of the Atemajac river (see **Figure 3**).

2. Historical background

The strategical localization of Atemajac river between the capital of the kingdom of New Galicia, Guadalajara, and a little town like Zapopan, whose importance is, until the present, in a little statue, the Virgen de Zapopan, convert the river an important place in the cultural and economic situation. First, for the water like the most indispensable resource for all the activities, recreational and the "Romeria" a religious party between Zapopan and Guadalajara where the Virgen de Zapopan is taken in a way to the sanctuary. Thus, the Atemajac river is very important for social and cultural reasons, and for ecological reasons too. All of the above make this a river of much value for the region.

2.1 Precolonial and colonial period

Before the colonial period, in the Atemajac basin, there were towns formed by natives and under the government of the kingdom of Tonalá [13]; these are Zapopan, Zoquipan, and Atemaxac, all around the river and Mezquitan.

The existence of these towns will be altered by the arrival of the Spanish army to Atemajac Valley around 1530, when the social, political, and cultural situation would change. In this situation, Nuño de Guzmán found Guadalajara in 1539 in Nochistlan, today the state of Zacatecas for reach the coast of the gulf of California [14], but for the complicated situation in this place, the scarcity of water, the dry weather and other circumstances make the city move to Tonala in 1533, Tlacotan in 1541 and the Valley of Atemajac in 1542, in February 14 Guadalajara was founded in definitive way (**Figure 4**).

At the same time, also in the actual state of Zacatecas, the beginning of the war of El Mixton (named after the mountain in Apozol, Zacatecas) in 1540 [13] generated important changes in the territory. This war is one of the "most organized rebellions of Indian people in America" ([14], p. 23), and resulted in an important problem for the Spanish government, which will be fixed by Antonio de Mendoza, upon request by the government Cristobal de Oñate and the war cut over in 1541. After that, Mendoza give the order to exterminate the Indians who participate in the war, but, the intervention of Fray Antonio de Segovia and other persons like Francisco de Bobadilla, make a change in the decision of the viceroy and they cut live in the lonely towns, but under the Spanish laws and with the native and peninsular vision of the life, the social situation and the territory.

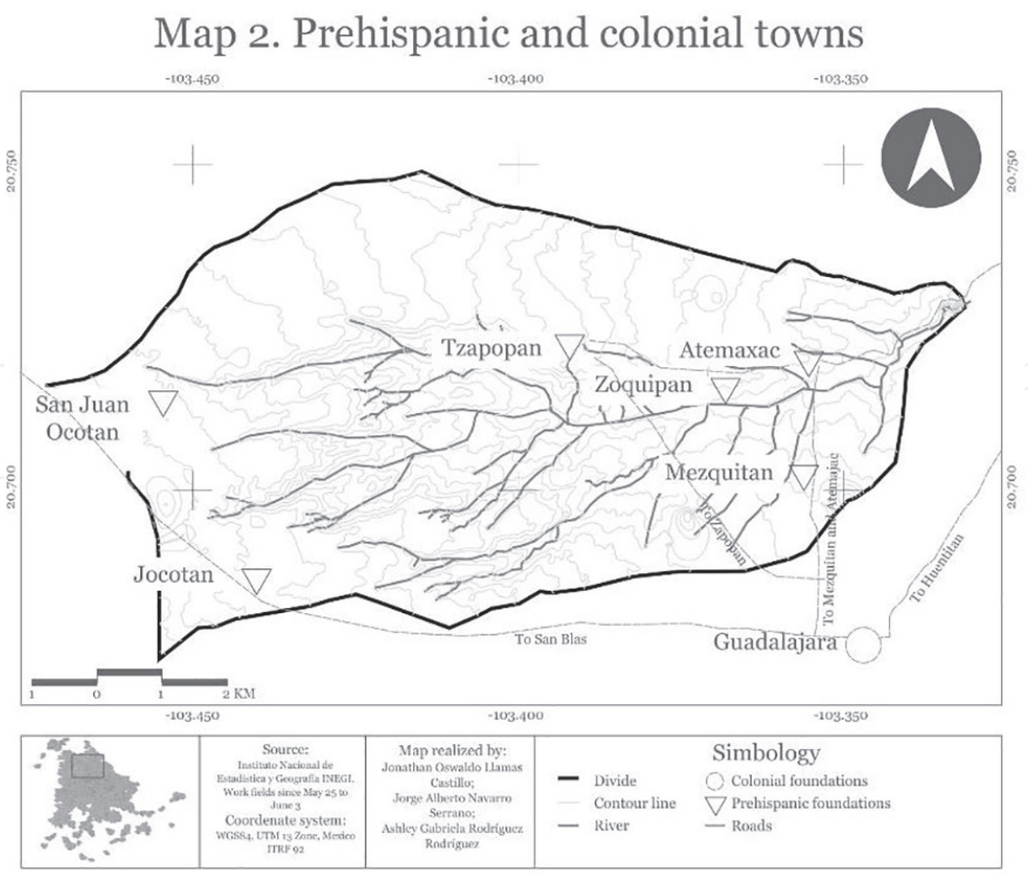

Figure 4.
Prehispanic towns like Tzapopan, Atemaxac, or Zoqiupan were present before the Spanish colonization, before the Spanish colonization, and after this process, Guadalajara was founded and the mixed of the Spanish and Indian vision make the territory. Source: Jorge Navarro, Ashley Rodríguez and Jonathan Llamas.

The water crisis in Guadalajara made the government look for a solution for this situation, and the Atemajac River seemed to be the perfect solution for this problem. Juan Rodriguez de Albuerne command to Pedro Buzeta to make a solution for the water crisis in Guadalajara [15, 16], the money is proved for a tax in the mezcal and other liquors [17], with this, Buzeta build an aqueduct under the land in tree branches, one of them, close of Colomos.

2.2 Century nineteenth, the factories and the energetical situation above the water

The independence of Mexico was declared in 1821, after which many presidents have been faced with complicated situations. In 1830, the minister of the interior and foreign affairs in the government of the president Anastasio Bustamante, Lucas Alaman, made a public polity about the industrialization in the country, for this, founded the Banco de Avio, an institution for a credits and support in the logistic and the machines [18]; the two principal objectives were: first, the financing of enterprises and industries for the creation of jobs and the stimulation of the interior market; and second, supporting the use of machines and new processes for production [19]. Meanwhile, one of the conditions for this support was the use of water as a source of energy, for its ease of use and because it was more cheap than coal.

But, in the state of Jalisco, the support for Banco de Avio never came; in this situation, all the businessmen formed groups for financing factories. Under this system, the first factory in the state of Jalisco was Jauja and Bellavista, in the city of Tepic, today the state of Nayarit.

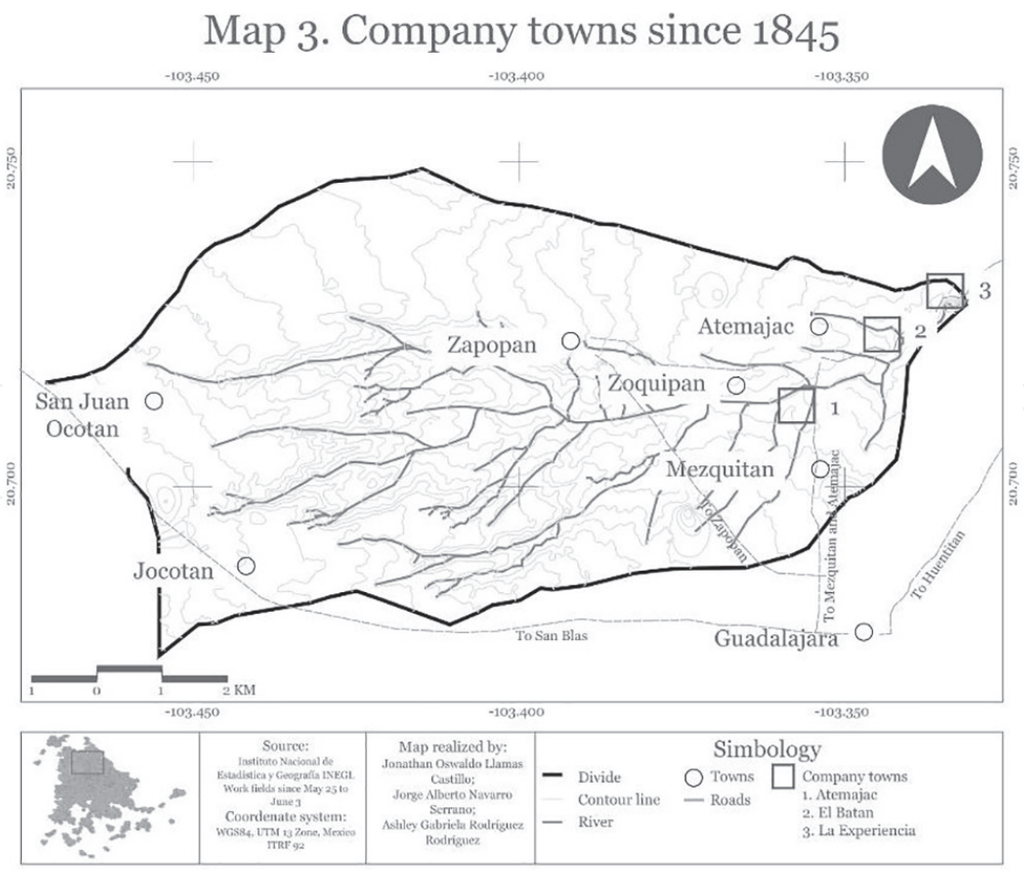

Figure 5.
The foundation of the company towns in the downside of the basin was possible for the existence of the river and a big market like Guadalajara and other cities, Atemajac, El Batán and La Experiencia take the energy of the water and give an industrial vocation to the river. Source: Jorge Navarro, Ashley Rodríguez and Jonathan Llamas.

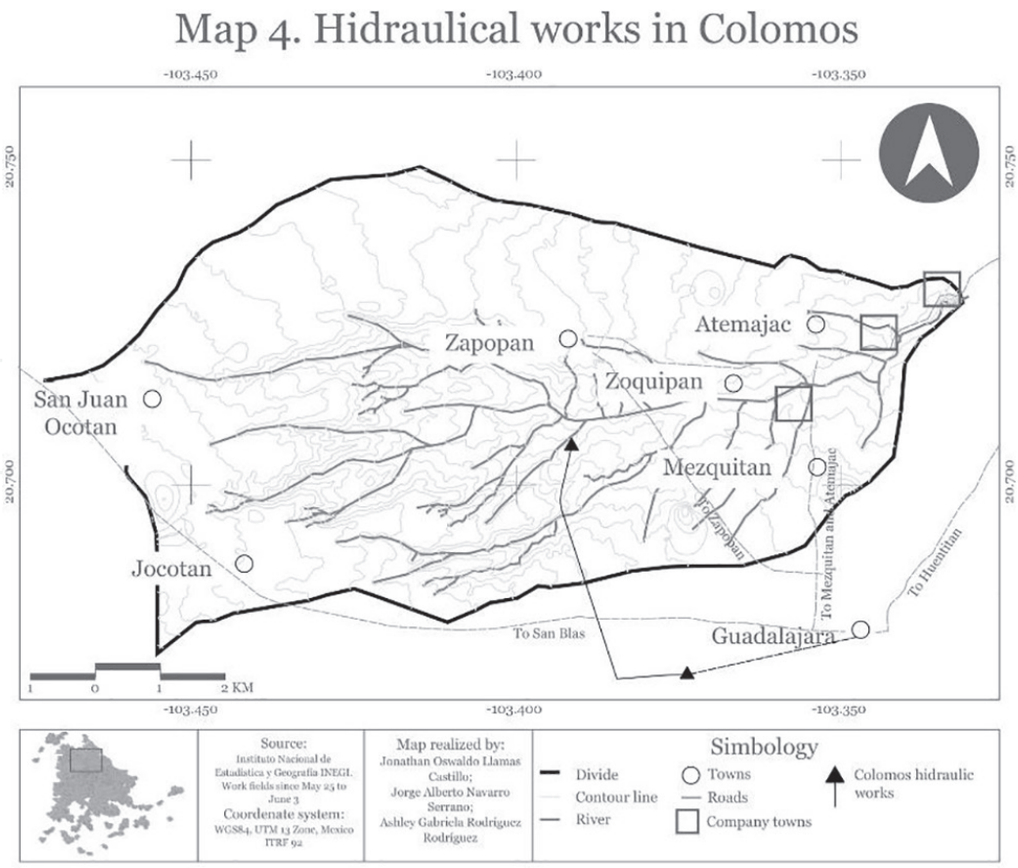

Figure 6.
At the end of the nineteenth century, the water of the Atemajac River was taken by the government for the city of Guadalajara from the place called Colomos. This generated the change in the energy fountain in the factories and the abandon of the Atemajac river for the population. Source: Jorge Navarro, Ashley Rodríguez and Jonathan Llamas.

Two important businessmen found three factories in Atemajac River, with water being the most important element to make energy and the Company Town being the model for urbanization around these factories. These factories are Atemajac and El Batan, the first dedicated to textile and the second to paper, both were founded by José Palomar in 1843 and 1844 [19].

In the case of Atemajac, Palomar built a dam in the place where the rivers Atemajac and Barranca Ancha or Culebras join, the "Zoquipan Dam" feeds a hydraulic wheel for the creation of energy for the factory. A similar situation happened in El Batán, with the own building in 1845 [9], besides a dam for a creation of the energy, Palomar build an aqueduct under the ground of stone for the transportation of the to make paper.

La Experiencia, a factory for textile, was founded in 1853 by Manuel Olasagarre [20]; this factory works with the energy produced by a falls where the San Juan de Dios River joins a little dam few meters up the river, with can be seen in the **Figure 2**. In the same place, in 1900, the CIJARA will build a hydroelectric to feed the three factories and a tram line from La Experiencia to Atemajac and Mexicaltzingo [21] (**Figure 5**). The construction of this plant is the result of a negotiation with the government and the "Compañia Industrial de Guadalajara, CIJARA" (Industrial Company of Guadalajara in English), if the water of Colomos will be introduced to Guadalajara (**Figure 6**), the government let to the company use the water of San Juan de Dios River for the generation of the electricity in the hydroelectrical plant. This situation makes a confrontation between the descendants of the CIJARA and the government [22], this situation still happens until today.

2.3 The grown of Guadalajara and the affectation in the river

The city of Guadalajara has seen an important growth since 1940, this was caused by the federal politics for the industrialization based on the substitution of importations, this consist in the fabrication of many product in the national factories for the local market, without a foreign product. Under this situation, many cities, besides Guadalajara like Monterrey or Mexico City, will grow.

The expansion of Guadalajara absorbs Zapopan and San Pedro Tlaquepaque. In the case of Zapopan, Atemajac River is the limit of both municipalities. First, the urbanization of the "Colonia Seattle" in the first decade of the twentieth century, second, the construction of the "Guadalajara Country Club" near of Zoquipan Dam and the construction for a road (Today Americas Avenue) between Zapopan and Guadalajara based in the old way [14], third, the construction of a new road, the actual Manuel Avila Camacho Avenue, and in last situation the construction of a park side of the Zoquipan Dam are an important fact for the urbanization of Guadalajara in the northwest side [14].

However, the affectation of Atemajac River cut be localized in this important constructions, first, the negotiation between Spanish acronym of Compañia Industrial de Guadalajara (CIJARA) and the government make an important controversy in Zapopan, the towns see in that time the river like a place of their property in the community perspective, this generate the first discharges of wastewaters, the construction of the Avila Camacho Park make possible the separation of wastewaters and rainwaters [23], also, both roads, the old and the new, the construction of Plaza Patria Mall in 1973 and Patria Avenue at the end of the same decade with the irregular neighborhoods in the downside of the river make the alteration of this.

Map 5. Guadalajara and the basin of Atemajac in the decade of 1940

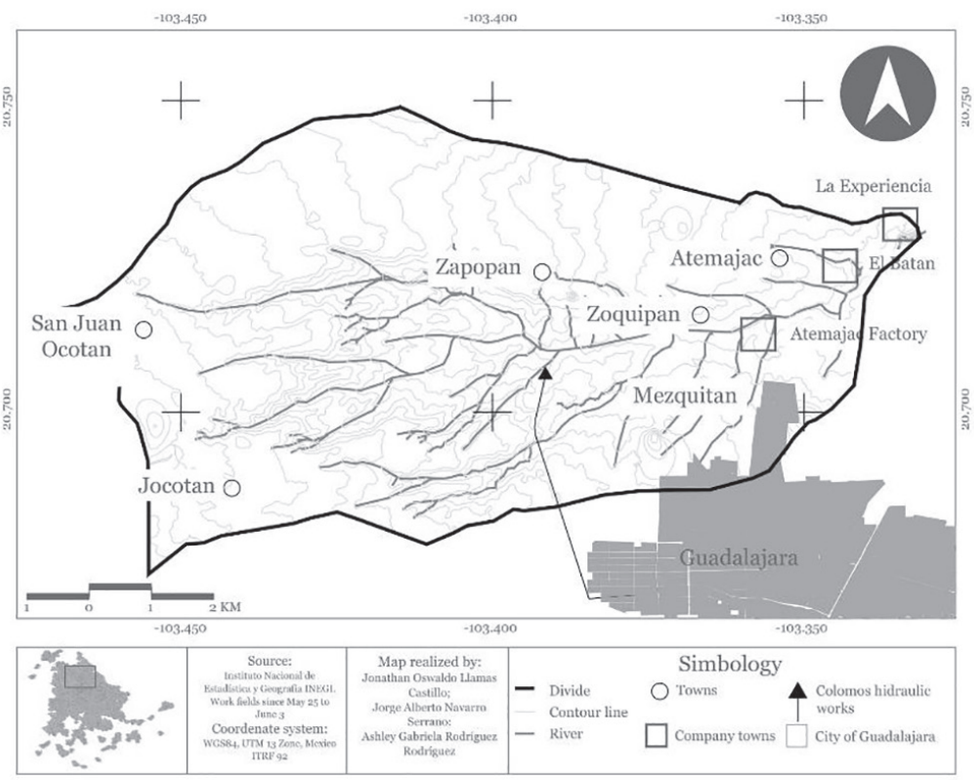

Figure 7.
From the decade of 1940 the city of Guadalajara begins to grow to the towns of Zapopan in the northwest and Tlaquepaque in the Southeast, this because of the third industrialization in Mexico, Mezquitan join to the urban area and the basin of Atemajac to. Source: Jorge Navarro, Ashley Rodríguez and Jonathan Llamas.

Today, the river is part of the Guadalajara Metropolitan Area, with 5,000,000 people; meanwhile, the Atemajac River is very rich in culture, history, and traditions, besides being an important antecedent in the creation of energy from water.

Figures 7–11 show the process of the growth of the city in the basin.

2.4 Dynamic modeling of the water-based clean energy system as a measure of decarbonization of the city

The methodology is based on the premise that dynamic systems change due mainly to the feedback cycles that occur between their elements, that is, their structure. The structure of the system is responsible for its behavior. This means that if you are looking for a profound change in a system, you must look at what changes are required in the structure, beyond addressing the symptoms of the problem. The structure of the system is represented in a causal system [24].

Likewise, the co-benefits in its categorical and conceptual badge are established within the scope of planning from public policies and up to its various scales of action as it is in programs; instruments; urban, architectural, environmental intervention projects, etc. And many areas or sectors such as the economic, social and environmental sector to achieve the reduction of public problems such as pollution [24].

Prospective studies in applied cities with effective public policy strategies as a measure of decarbonization of metropolitan areas.

Sustainability strategies based on co-benefits established in public policies as a decarbonization measure are duly located and articulated (under verifiable and quantifiable criteria) at various levels and sectors through prospective study systems in cities, which allow to easily detect the effects of pollution, as well as its action to meet the final objectives through water and clean energy generation.

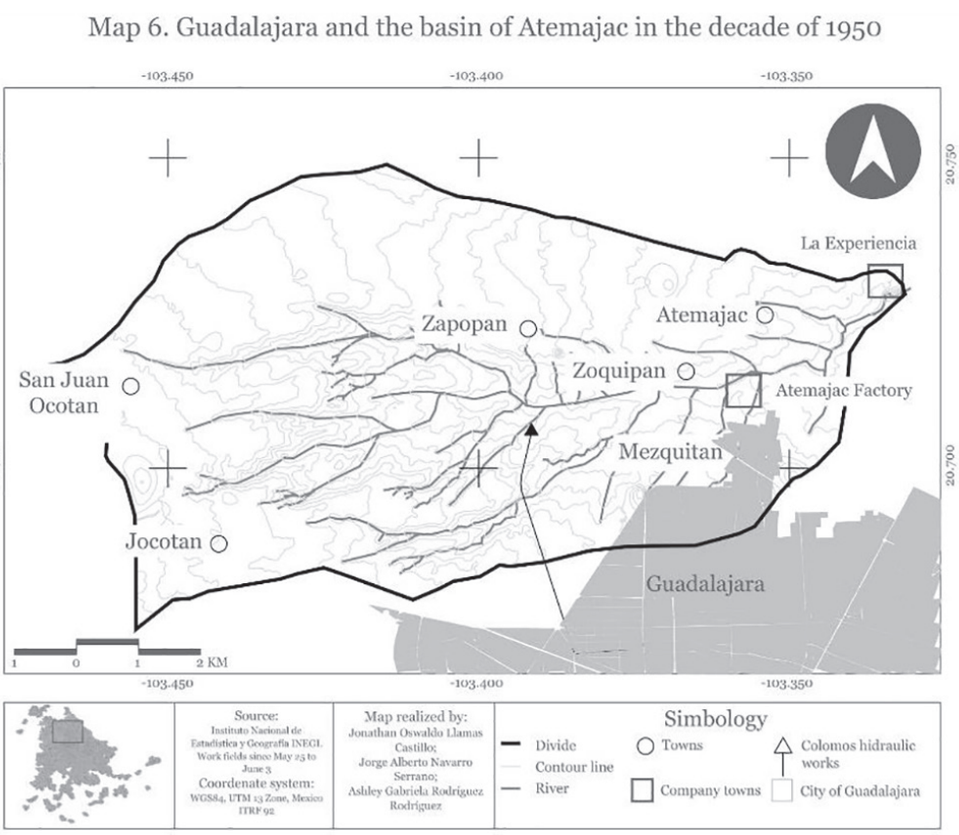

Figure 8.
In the decade of 1940, the growth of Guadalajara goes to the west, Atemajac Basin still is not part of the city. Source: Jorge Navarro, Ashley Rodríguez and Jonathan Llamas.

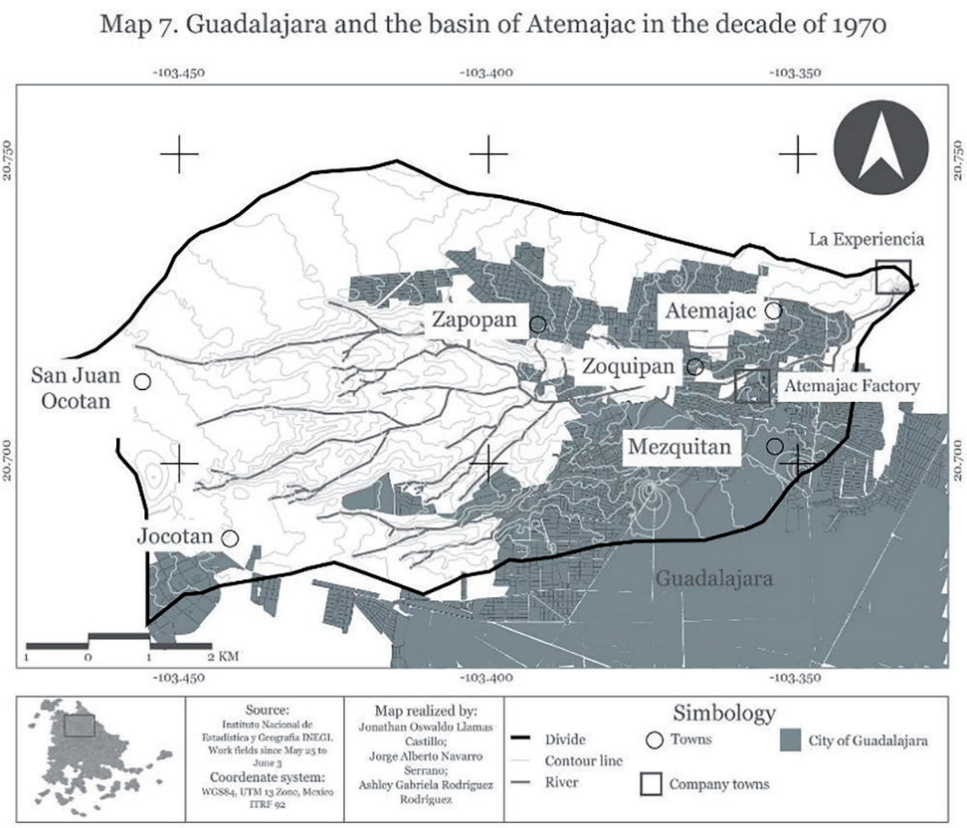

Figure 9.
Across the decade of 1970 the city is bigger, and many towns of the basin are included in the city area, Zapopan, and Atemajac converts in zones of the city and this will continue. Source: Jorge Navarro, Ashley Rodríguez and Jonathan Llamas.

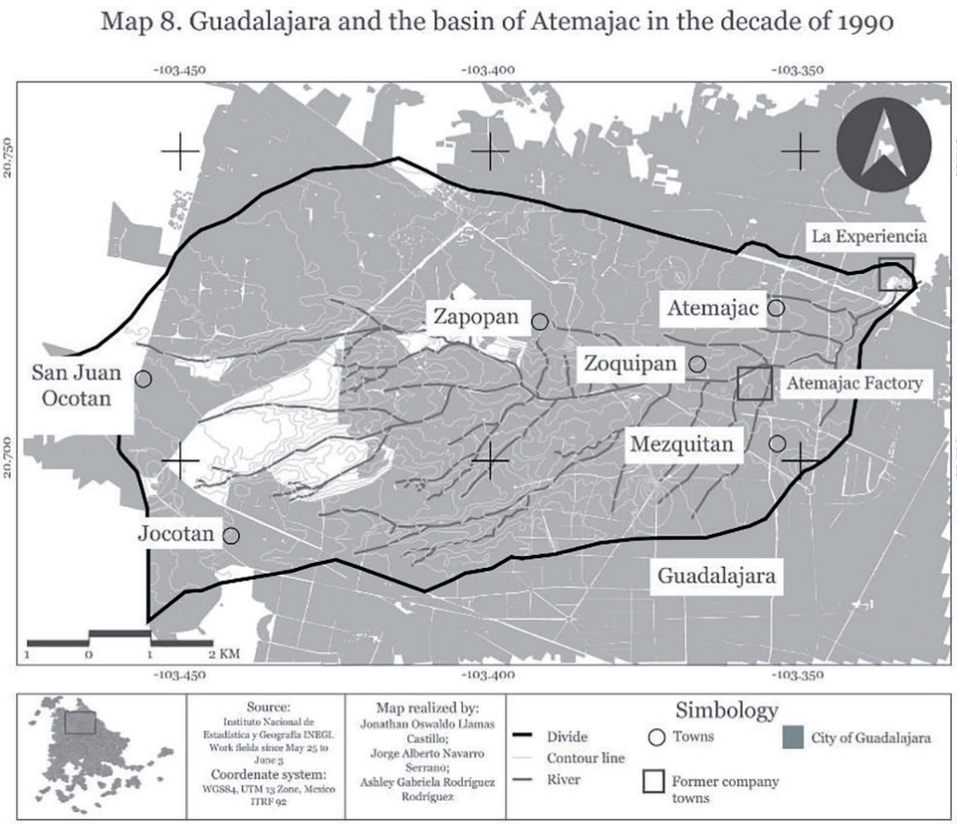

Figure 10.
Before of the twenty-first century, the basin is including in the Guadalajara Metropolitan Area, almost all the land is urbanized and the alteration in many rivers is present. Source: Jorge Navarro, Ashley Rodríguez and Jonathan Llamas.

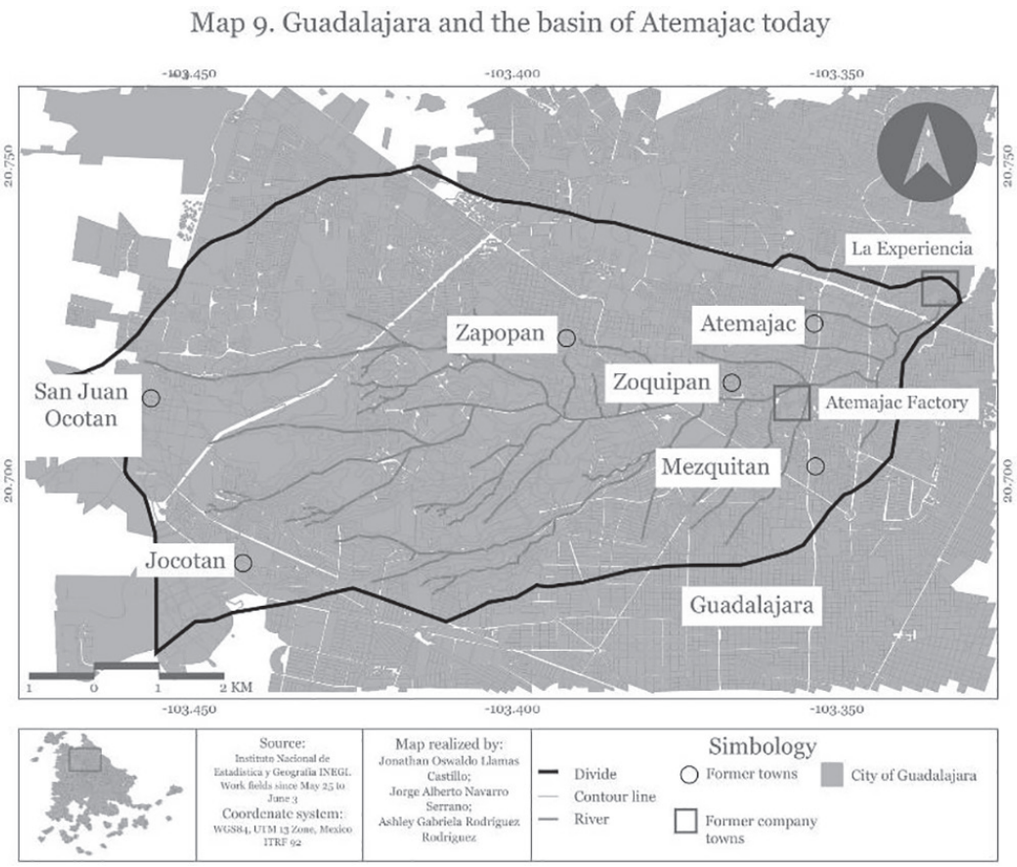

Figure 11.
In this day, the basin of Atemajac is all urbanized, inside there's old towns, new commercial environments and traditional neighborhoods, meanwhile, the city has made an alteration in the basin and the Atemajac river. Source: Jorge Navarro, Ashley Rodríguez and Jonathan Llamas.

There is a concern among government, society and companies at international, national, municipal and local levels about the relevance of having policies that foresee the effects of pollution in cities, which allows increasing the identification of variables through decarbonization strategies in an exponential way, not only in the planning systems, but also through the consumption habits of the population, until reaching the balance of the objectives searched in the System given in turn by the cycles of continuous feedback, however it is necessary constantly assessing population growth in metropolitan areas and their consumption habits which allows feedback to the system in an optimal and interoperable manner.

The decarbonization in the cities it's an idea than today is relevant because of the climate changing, the city is a complex system where the consumption of resources out of the territory is a tendency, one of them is the water, taken in the most cases of other basins; but, the possibility of take the water an energy in a local situation cut be possible [25].

The urban metabolism include the water like an important piece to moderate the problems with the climate change and the loss of the service; in this case, the city can use the water like a local source for the population and in the same scale, to make energy. It is important the information about the river and the basin, in this case the water flow in the channel, the dams for the protection, the rainwater catchment and the separation of the residual water to the clean water [26]. For a hydraulic energy obtentions, the cities cut recover the old infrastructure and build new to take this energy in a local perspective.

The possibility to obtain energy through water from the river of Atemajac cut be high, this because of the historical situation and the future in the channel, it minds, with a complete rescue of the space like a park, historical place and

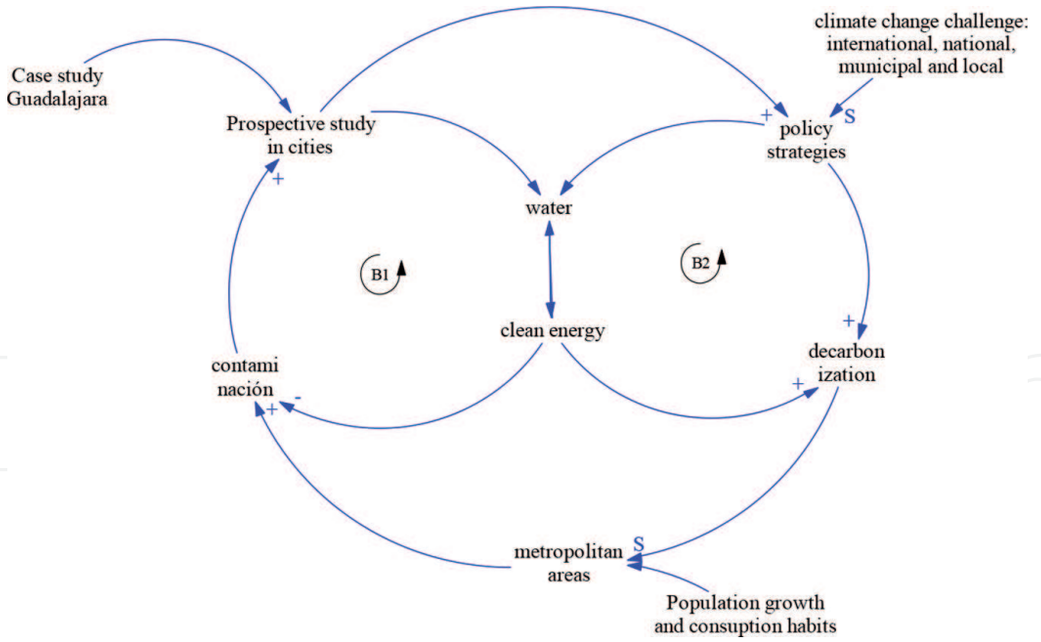

Figure 12.
General diagram about the co-benefits in the case of study by the policy strategies, decarbonization and other strategies in the metropolitan areas. Source: Author's elaborations by Vensim, 2019.

a source of water and energy. The clean water cut be good, but the wastewater also can serve [27], in the case of Guadalajara, both situations cut be possible, because of the existence of an infrastructure old and new for this, and the separation than the river have in both waters. Strengthened the actual infrastructure and recover and adapted the past will be important if Guadalajara want to have energy and come to the decarbonization from the water, special from Atemajac river. How can you conceptualize using **Figure 12**.

3. Results

Once all the variables that are immersed within the system have been linked, it is possible to model as follows by means of a simple causal diagram in **Figure 13**:

Based on the case study of Guadalajara, it is possible to say that through a co-benefits strategy in urban planning systems in cities, a co-control mechanism is generated which enables the generation of clean energy derived from the river water through hydroelectric systems, which in turn gives rise to self-sufficiency in production, involving a decarbonization mechanism of the city (**Figure 14**).

However, in the environment exogenous to the System, it can be found that urbanization and mobility of cities influence the natural course of rivers, which inhibits the energy capacity that can be derived from it through clean systems such as the hydroelectric plant. At the State and Federal levels, some strategies have been developed to be able to migrate to clean energies; it is important to integrate a joint strategy where the dynamic systems of which the city is a part are multi-operatized through strategic actions of co-control which feedback the Dynamic System until the desired balance is achieved.

Guadalajara has great potential for the reuse, reinjection, and disposal of rainwater, as well as giving it the correct treatment, which in turn enables the generation of energy through river water; however, by integrating the urbanization variable as this is one of the main causes of generation of CO_2 emissions due to the consumption and burning of liquid fuel, and being the runoff of the river inhibited by the urbanization of the city, which leads to this system becoming more complex

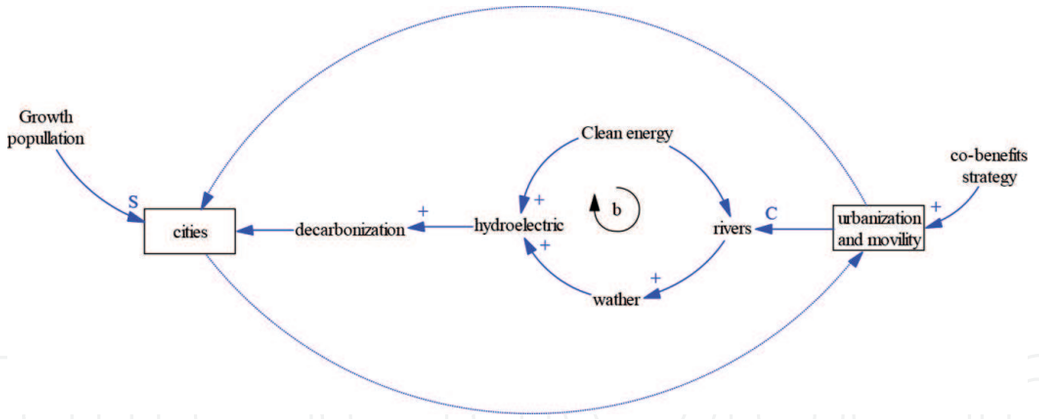

Figure 13.
General diagram about the energy and decarbonization in cities according to the water and his energy source. Source: Author's elaborations by Vensim, 2019.

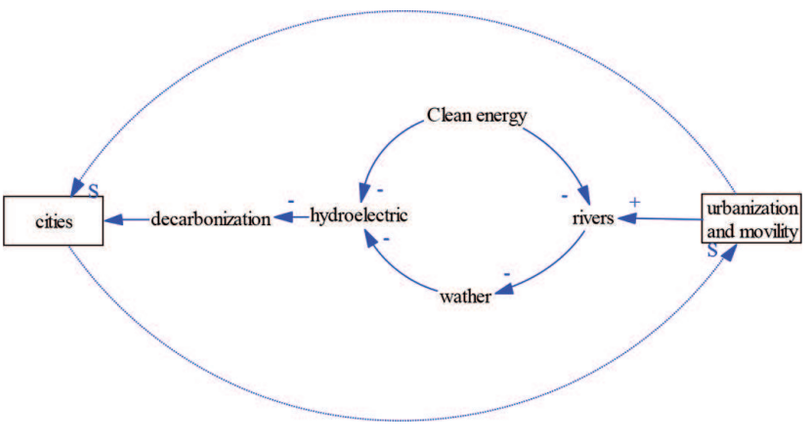

Figure 14.
General diagram about an anthropic system in the city. Source: Jorge Navarro personal files.

until generating an anthropic system without measure as can be seen in the following simple causal diagram.

Is type of growth is characterized by its two-phase transitional regime, one of them in exponential growth (urbanization) and the other in asymptotic decline (rivers). The positive feedback generated by exponential growth is narrowed by the negative feedback, which leads to the stabilization of growth. This is that every exponential process goes through a stabilizing process that limits growth. The above indicates that the exponential growth of this Sustained System does not exist in the real world (even with project that host certain initiatives in this regime as seen in the first section).

So a large increase in the positive variable in this case urbanization and mobility leads to a negative curve corresponding to the rivers, the negative curve does not appear spontaneously, on the contrary it is present at all times, but its effect depends on the influence of a variable in the positive curve (which in this case would be immersed in the planning systems and public policy that come from these prospective studies). When the positive curve begins to increase to all the variables involved in the cycle, the negative curve also increases until the domain changes and the negative curve is formed (as could be seen in the previous graph).

4. Attachment

In the next, there's some photography's about the work and walks in Atemajac river into the basin (**Figures 15–23**).

Figure 15.
Water birth in the high side of the basin of Atemajac. Source: Jorge Navarro personal files.

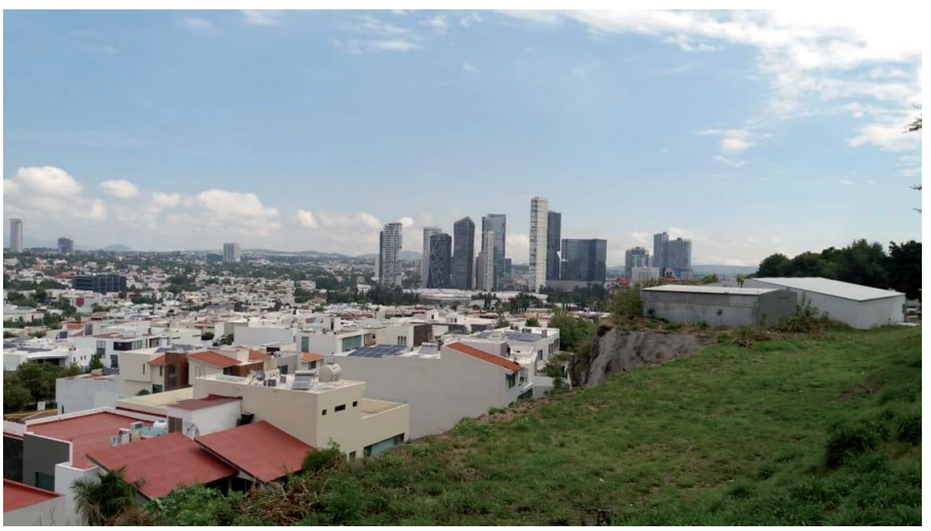

Figure 16.
Andares and Puerta de Hierro, the most rich and popular places in Guadalajara, localized in the high side of the basin of Atemajac. Source: Jorge Navarro personal files.

Figure 17.
In many places on the basin, there's an important and historical heritage with an important value, like this aqueduct from 1902 and projected by Agustin Pascal to transport water from Colomos to Guadalajara. Source: Jorge Navarro personal files.

Figure 18.
Construction of a dam clothes to Plaza Patria mall, this for contain the rains in the high side of the basin. Source: Jorge Navarro personal files.

Figure 19.
Zoquipan dam, in the past, the water conserved make the energy in Atemajac Factory, today is abandoned. Source: Jorge Navarro personal files.

Figure 20.
Atemajac river in the section of Patria Avenue and Enrique Diaz de León Avenue, clothes to Atemajac. Source: Jorge Navarro personal files.

Figure 21.
The river from Atemajac to Huentitán suffer a transformation in a polluted and dirty natural resource, the picture clothes to Alcade Avenue in the city of Guadalajara. Source: Jorge Navarro personal files.

Figure 22.
Colomitos was in the past a spa and resort, now, an urbanization reduces the territory of this water birth, know because of Pepe Guizar and his son "Guadalajara." Source: Jorge Navarro personal files.

Figure 23.
The river clothes Huentitán and Rancho Nuevo, the pollutions is present in the water and the air. Source: Jorge Navarro personal files.

5. Conclusions

It is important to understand, recognize, and relate action policies and their structure as an integral component of the city as a means to achieve sustainability, so that it is possible to locate and identify within them the planning systems. How can formulated the sustainable development of the context which the approach is proposed, in this occasion, is through the case of studies in Guadalajara.

Therefore, to verify that to achieve the imposed objectives it is necessary to have forecasting tactics that locate the indirect effects of the implemented strategies which implies that the objective of a policy or measure, generates a multi-operability and integration of the variables that compose it and the determination of the scope of the co-benefits and impacts produced for its correct implementation as a measure of decarbonization of the city through strategies that involve river water and energy.

The urban rivers and basins cut be the most important space to applicate the concept for water and energy to the decarbonization of the cities. For the source and make the energy by this recover old spaces (besides to be a recreative place, cut be a place to make energy) and strengthen the actual places. There is an important potential in the city of Guadalajara.

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