Technology
Arts Sciences
TH Köln

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

FACULTADES DE CIENCIAS QUÍMICAS, INGENIERÍA Y MEDICINA

PROGRAMAS MULTIDISCIPLINARIOS DE POSGRADO EN CIENCIAS AMBIENTALES

AND

TH KÖLN - UNIVERSITY OF APPLIED SCIENCES

INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

BUILDING SUSTAINABLE URBAN METABOLISM THROUGH RESILIENCE STRATEGIES IN LA PILA, SAN LUIS POTOSI, MEXICO

THESIS TO OBTAIN THE DEGREE OF

MAESTRÍA EN CIENCIAS AMBIENTALES

DEGREE AWARDED BY UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

AND

MASTER OF SCIENCE

NATURAL RESOURCES MANAGEMENT AND DEVELOPMENT

DEGREE AWARDED BY TH KÖLN – UNIVERSITY OF APPLIED SCIENCES

PRESENTS:

Alicia Anahí Cisneros Vidales, Arch.

CO-DIRECTOR OF THESIS PMPCA

Dr. Marcos Algara Siller

CO-DIRECTOR OF THESIS ITT

Dr. Johannes Hamhaber

ASSESSOR:

Dr. Victor Manuel Gutiérrrez Sánchez

COLOGNE, GERMANY AUGUST 2018

Technology
Arts Sciences
TH Köln

PROYECTO FINANCIADO POR:

"MODELO DE SOSTENIBILIDAD PARA LA GOBERNANZA DE COMUNIDADES VULNERABLES:

ESCUELA FRANCISCO GONZÁLEZ BOCANEGRA"

FONDO: RESPONSABILIDAD CORPORATIVA CUMMINS

PROYECTO REALIZADO EN:

PMPCA

FACULTAD DE INGENIERÍA

UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

CON EL APOYO DE:

DEUTSCHER AKADEMISCHER AUSTAUSCH DIENST (DAAD)

LA MAESTRÍA EN CIENCIAS AMBIENTALES RECIBE APOYO A TRAVÉS DEL PROGRAMA NACIONAL DE POSGRADOS

(PNPC - CONACYT)

Technology
Arts Sciences
TH Köln

Erklärung / *Declaración*

Name / *Nombre*: Alicia Anahí Cisneros Vidales

Matrikel-Nr. / *N° de matricula*: **11117387 (TH Köln), 172862 (UASLP)**

Ich versichere wahrheitsgemäß, dass ich die vorliegende Masterarbeit selbstständig verfasst und keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten und nicht veröffentlichten Schriften entnommen sind, sind als solche kenntlich gemacht.

Aseguro que yo redacté la presente tesis de maestría independientemente y no use referencias ni medios auxiliares a parte de los indicados. Todas las partes, que están referidas a escritos o a textos publicados o no publicados son reconocidas como tales.

Die Arbeit ist in gleicher oder ähnlicher Form noch nicht als Prüfungsarbeit eingereicht worden.

Hasta la fecha, un trabajo como éste o similar no ha sido entregado como trabajo de tesis.

Köln, den /*el* 14.08.2018

Unterschrift / *Firma*: Alicia Anahí Cisneros Vidales

Ich erkläre mich mit einer späteren Veröffentlichung meiner Masterarbeit sowohl auszugsweise, als auch Gesamtwerk in der Institutsreihe oder zu Darstellungszwecken im Rahmen der Öffentlichkeitsarbeit des Institutes einverstanden.

Estoy de acuerdo con una publicación posterior de mi tesis de maestría en forma completa o parcial por las instituciones con la intención de exponerlos en el contexto del trabajo investigatición de las mismas.

Unterschrift / Firma: Alicia Anahí Cisneros Vidales

Building Sustainable Urban Metabolism through Resilience Strategies in La Pila, San Luis Potosí, México

A Master Thesis presented by

Alicia Anahí Cisneros Vidales

2018

"Because life is robust,

Because life is bigger than equations, stronger than money, stronger than guns and poison and bad zoning policy, stronger than capitalism,

Because Mother Nature beats last, and Mother Ocean is strong, and we live inside our mothers forever, and Life is tenacious and you can never kill it, you can never buy it,

So Life is going to dive down into your dark pools, Life is going to explode the enclosures and bring back the commons,

Oh you dark pools of money and law and quantitudinal stupidity, you over simple algorithms of greed, you desperate simpletons hoping for a story you can understand,

Hoping for safety, hoping for cessation of uncertainty, hoping for ownership of volatility, O you poor fearful jerks,

Life! Life! Life! Life is going to kick your ass."

Kim Stanley Robinson, New York 2140, 2017

Dedicated to Ino.

Abstract

In a world, whose cities are constantly growing, -consuming more resources than the ones they produce-, sustainability must be enhanced to ensure the ability of future generations to satisfy their needs. Therefore, this work aims to propose resilience strategies that enable sustainable urban metabolism for a specific Urban Socio-Ecological System (USES): The peri-urban community of *La Pila*, which is located in the Metropolitan Zone of *San Luis Potosi*, Mexico.

In this context, specific objectives included: 1) To identify the metabolic fluxes in La Pila: Water, Energy & Food; 2) To identify hazards to the metabolic fluxes; and 3) To analyze how resilient is the urban metabolism of La Pila. An adaptation of the Resilience Assessment Framework proposed by the Resilience Alliance (2010) -*USES Resilience Assessment based on Urban Metabolism*-, was done in order to achieve the objectives, through six steps: 1) Developing Systems Perspective for Urban Socio-Ecological Systems; 2) Defining the Urban Metabolism for USES; 3) Defining the Hazards to the Metabolic Fluxes; 4) Urban Resilience Assessment based on the Risk Assessment; 5) Building Resilience in USES; and 6) Resilience Strategies Implementation.

As a result, urban resilience was assessed for the urban socio-ecological system at a household scale, through the analysis of the hazards that threaten the household's supply, –considering the Water, Energy and Food inflows-, and the households themselves. Finally, resilience strategies were proposed as recommendations to build sustainable urban metabolism in La Pila.

Keywords

Urban Socio-Ecological System, Urban Metabolism, Urban Resilience

Resumen

En un mundo en el que las ciudades están creciendo constantemente, -consumiendo cada vez más recursos de los que producen-, la sustentabilidad debe de ser impulsada para garantizar la capacidad de las futuras generaciones de satisfacer sus necesidades. Por esta razón, este trabajo busca proponer estrategias de resiliencia que permitan el metabolismo urbano sustentable de un sistema urbano socio-ecológico en específico: la comunidad periurbana llamada La Pila, que se localiza dentro de la zona metropolitana de San Luis Potosí, México.

Para lograr esto se propusieron tres objetivos: 1) Definir los flujos metabólicos de Agua, Energía y Alimentos para La Pila; 2) Identificar las amenazas que pueden afectar los flujos metabólicos; y 3) Analizar qué tan resiliente es el metabolismo urbano de La Pila. Con el fin de alcanzar los objetivos, se propuso una adaptación de Marco de Evaluación de Resiliencia, propuesto por Resilience Alliance (2010), a la que se denominó Evaluación de la Resiliencia de Sistemas Urbanos Socio-Ecológicos basado en Metabolismo Urbano, y que consta de seis pasos: 1) Desarrollar de una perspectiva sistémica para sistemas urbanos socio-ecológicos; 2) Definir el metabolismo urbano para sistemas urbanos socio-ecológicos; 3) Definir las amenazas para los flujos metabólicos; 4) Evaluar la resiliencia urbana a través de la evaluación del riesgo; 5) Construir resiliencia para sistemas urbanos socio-ecológicos; y 6) Implementar estrategias de resiliencia.

Como resultado, la resiliencia urbana fue evaluada para el sistema urbano socio-ecológico a una escala de hogar, a través del análisis de amenazas que comprometen el suministro de los flujos de agua, energía y alimento, así como las amenazas que comprometen la resiliencia de la vivienda. Finalmente, se recomendaron estrategias de resiliencia que permitieran construir un metabolismo urbano sustentable en comunidad de La Pila.

Palabras clave

Sistema Urbano Socio-Ecológico, Metabolismo Urbano, Resiliencia Urbana

Zusamenfassung

In einer Welt, deren Städte ständig wachsen und die mehr Ressourcen verbrauchen als sie produzieren, muss die Nachhaltigkeit gesteigert werden, damit künftige Generationen ihre Bedürfnisse befriedigen können. Ziel der vorliegenden Arbeit ist es daher, Resilienzstrategien vorzuschlagen, die einen nachhaltigen urbanen Metabolismus für ein spezifisches urbanes sozial-ökologisches System (USÖS) ermöglichen: die Stadtrandgemeinde La Pila, die sich in der Metropolregion San Luis Potosi in Mexiko befindet.

In diesem Zusammenhang wurden drei konkrete Ziele festgelegt: 1) Identifizierung der metabolischen Flüsse in La Pila: Wasser, Energie & Lebensmittel; 2) Identifizierung von Gefahren für diese metabolischen Flüsse; und 3) Analyse der Resilienz des urbanen Metabolismus in La Pila. Eine Anpassung des von der Resilience Alliance (2010) vorgeschlagenen Resilience Assessment Frameworks - Bewertung der Systemresilienz eines urbanen sozial-ökologischen Systems (USÖS) durch urbanen Metabolismus - wurde durchgeführt, um die genannten Ziele in sechs Schritten zu erreichen: 1) Entwicklung einer Systemperspektive für das USÖS; 2) Definition des urbanen Metabolismus für das USÖS; 3) Bestimmung der Gefahren für die metabolischen Flüsse; 4) Bewertung der urbanen Resilienz auf Grundlage der Risikobewertung; 5) Aufbau von Resilienz im USÖS; und 6) Implementierung von Resilienzstrategien.

Als Ergebnis wurde die urbane Resilienz des USÖSs auf Haushaltsebene durch die Analyse jener Gefahren bewertet, die die Versorgung der Haushalte - unter Berücksichtigung der Wasser-, Energie- und Nahrungsmittelflüsse - und die Haushalte selbst bedrohen /// und die Resilienz des Wohnraumes bedrohen. Abschließend wurden Resilienzstrategien zum Aufbau eines nachhaltigen urbanen Metabolismus in La Pila empfohlen.

Schlüsselwörter

Urbanes Sozial-Ökologisches System, Urbaner Metabolismus, Urbane Resilienz

Acknowledgments

The world we live in is a complex and uncertain one, in which without the proper guidance we get lost easily. Thanks life, for putting on my path so many people to show me the way.

This work would not have been possible without the help and teaching of my co-directors and my supervisor. Thank you very much for your teaching and support Dr. Marcos Algara Siller, especially during the fieldwork. I will always remember my first time in La Pila and how important it is, to enhance solutions rather than problems. Many thanks to Dr. Johannes Hamhaber, whose talks helped me to structure and understand how *Systems Thinking* is related to cities and urban socio-ecological systems, but also to life in general. Last but not less, Dr. Victor Manuel Gutiérrez Sánchez, thank you very much for your help and support, always motivating me to go further.

This work would have not also be possible without the support from the *Deutscher Akademischer Austauschdienst* (DAAD) scholarship. Thank you very much for trusting in me and helping me to make a dream come true.

Many, many thanks to inhabitants from La Pila. Without your participation, this work would not exist. I hope this can contribute and nourish your lives, as you have nourished mine.

Special thanks to people from *Laboratorio Casa Viva*: Miguel Mares, Mario Salinas and Madigan Martínez. Your help during the fieldwork is irreplaceable. Dr. Carolin Antoni thank you very much for sharing your knowledge with me.

Professors from UASLP and TH Köln, thanks for inspiring and nurturing this work through your teaching.

Many thanks to my family, especially to my parents, without your example and support I would have not made it. Miguel Angel, thank you for sharing with me the passion for architecture. Alicia, thank you very much for your advices and support. Erika, thanks for joining me during the writing of this work.

Thank you Carlos for the unconditional support, without you this work would not have been the same.

Many thanks to my ENREM friends: Janine, Mauricio, Arantza, Viridiana, Coco, Diego, Daiana, Borami, Gaby, Mariana, Natalia, Sergio, Marcella & David. I am sure that without you this master would not have been the same.

Thank you Elena for sharing all those discussions about sustainability and the hope for a better world.

Thank you very much to my Habitat team, who supported me from the distance during this time: Guadalupe, Katia, Nahidi, Cristian, Andrea, Abel & Alejo.

Preface

Nowadays, we are living in a world in which achieving sustainability is a *must*. In this context, cities –including urban socio-ecological systems-, which are constantly growing, -consuming more resources than the ones they produce-, constitute the problem but also the solution. Therefore, this research has as main objective to propose resilience strategies that enable sustainable urban metabolism for a specific Urban Socio-Ecological System (USES): The peri-urban community of La Pila, which is located in the Metropolitan Zone of San Luis Potosi, Mexico. In order to achieve the main objective, specific objectives included: 1) To identify the metabolic fluxes in La Pila: Water, Energy & Food; 2) To identify hazards to the metabolic fluxes; and 3) To analyze how resilient is the urban metabolism of La Pila.

In the first chapter -*Towards Sustainable Urban Development*-, we explore the theme of urban development at global, Latin America and Mexico scales, in order to provide an introduction of why it is important to enhance Sustainable Urban Development. After that, in the chapter II -*Theoretical Framework*-, a conceptual framework for this work is provided, which includes the definition of Urban Socio-Ecological Systems (USES), Urban Metabolism and Urban Resilience, through the several approaches that conform the Systems Thinking Theory.

In the following chapter, the *Methodological Framework*, an adaptation of the Resilience Alliance's Resilience Assessment Framework is proposed: *USES Resilience Assessment based on Urban Metabolism,* which is composed of six steps: 1) Developing Systems Perspective for Urban Socio-Ecological Systems; 2) Defining the Urban Metabolism for USES; 3) Defining the Hazards to the Metabolic Fluxes; 4) Urban Resilience Assessment based on the Risk Assessment; 5) Building Resilience in USES; and 6) Resilience Strategies Implementation.

Later, a community from San Luis Potosi, Mexico, is presented as the case of study in the fourth chapter: *Case of Study: La Pila as an USES*. In this chapter, the Water, Energy and Food fluxes are defined through literature review for the community, considering the USES as a peri-urban area involved in a bigger system's dynamics –the Metropolitan Zone of San Luis Potosi (MZSLP)-.

In the fifth chapter -*Metabolism of Households in La Pila*-, the metabolism of the households is analyzed based on the inflows, this means the Water, Energy and Food consumption. Once having identified the inflows current state, hazards to the system's supply and the system itself are identified, and converted to risk in *USES Resilience Assessment based on Metabolism*. In this chapter Urban Resilience is assessed through the resilient system qualities: Reflectiveness, Robustness, Redundancy, Flexibility, Resourcefulness, Inclusiveness and Integration.

To conclude, recommendations to enhance a sustainable urban metabolism through resilience strategies are given in *Conclusions*, as well as further research opportunities. In the following figure, the main structure of the chapters composing this research can be observed, as well as the main concepts involved throughout this work.

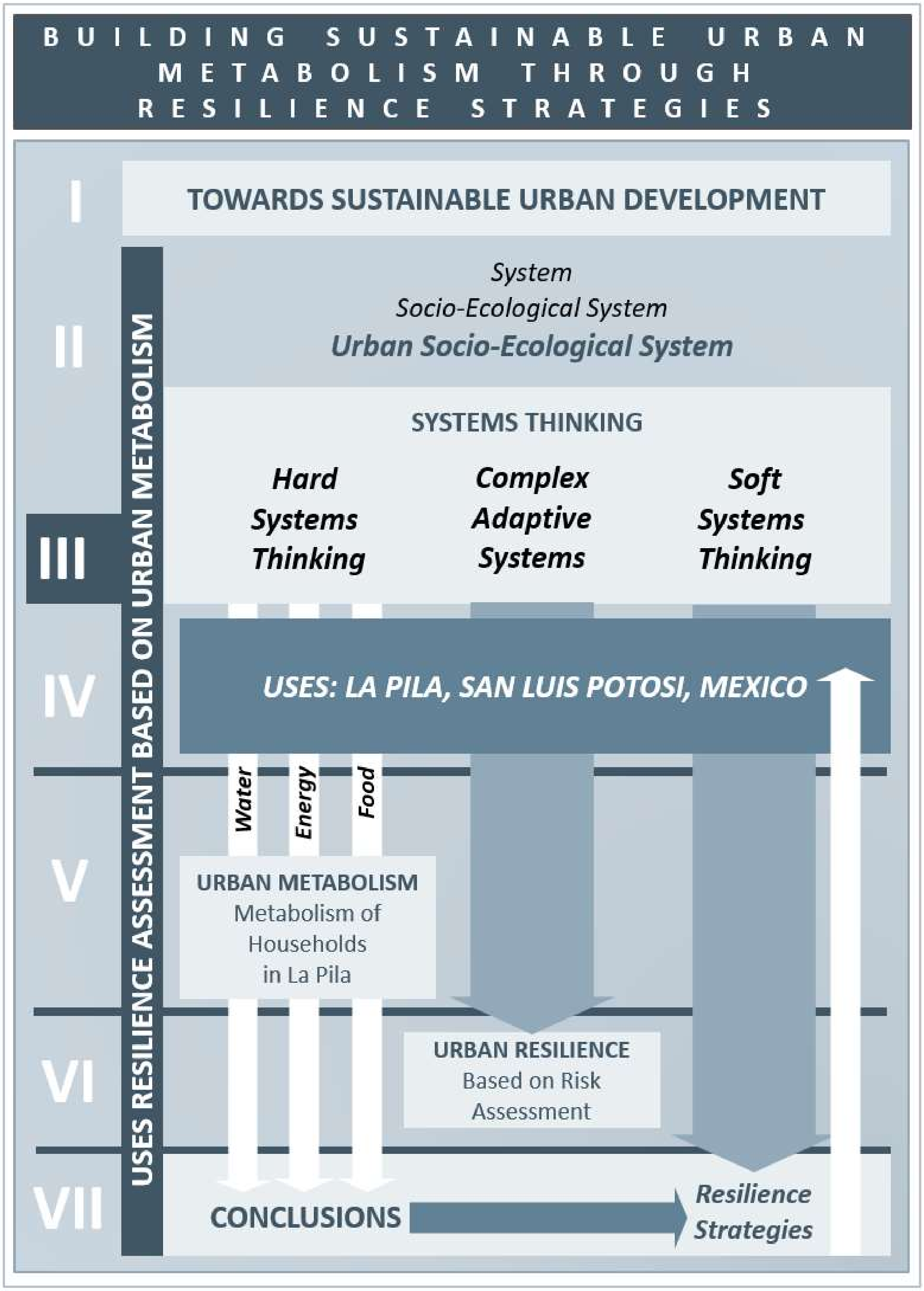

BUILDING SUSTAINABLE URBAN METABOLISM THROUGH RESILIENCE STRATEGIES
I
TOWARDS SUSTAINABLE URBAN DEVELOPMENT
II
System
Socio-Ecological System
Urban Socio-Ecological System
III
SYSTEMS THINKING
Hard Systems Thinking
Complex Adaptive Systems
Soft Systems Thinking
IV
USES: LA PILA, SAN LUIS POTOSI, MEXICO
V
Water
Energy
Food
URBAN METABOLISM
Metabolism of Households in La Pila
VI
URBAN RESILIENCE
Based on Risk Assessment
VII
CONCLUSIONS
Resilience Strategies
USES RESILIENCE ASSESSMENT BASED ON URBAN METABOLISM

Table of Contents

List of Tables

List of Figures

Abbreviations

SDG	Sustainable Development Goals
SES	Social-Ecological System
USES	Urban Social Ecological System
ST	Systems Thinking
STT	Systems Thinking Theory
HST	Hard Systems Thinking
CAS	Complex Adaptive Systems
SST	Soft Systems Thinking
UM	Urban Metabolism
UR	Urban Resilience
UNDRO	United Nations Disaster Relief Organization
UNISDR	United Nations Office for Disaster Risk Reduction
WEF Nexus	Water-Energy-Food Nexus
FAO	Food and Agriculture Organization of the United Nations.
BBA	Black Box Accounting
SD	System Dynamics
MZSLP	Metropolitan Zone of San Luis Potosi
SLP	San Luis Potosí
INEGI	Instituto Nacional de Estadística y Geografía
CFE	Comisión Federal de Electricidad
SAGARPA	Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación *Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food*[1]
GDP	Gross Domestic Product
SENER	Secretaría de Energía *Ministry of Energy (self-translated)*

[1] Translation from the Oxford Business Group.

Chapter I

Towards Sustainable Urban Development

"No city is sustainable in the sense of being an autotrophic or even self-supporting ecosystem. Cities will always be heterotrophic: Resources and supporting processes must be supplied by ecosystems beyond any formal urban borders."

(Luck *et al.*, 2001; Pickett *et al.*, 2013)

I. Towards Sustainable Urban Development

In the last decades, the majority of the cities have experienced an increasing urban growth. Despite the fact that public policies and new landscape management proposals have tried to prevent urban problems, they have not yet succeeded at implementing resilient strategies which conduct towards sustainability (Population Division, Department of Economic and Social Affairs and United Nations Secretariat, 2001). Cities have grown in size, density and complexity across the globe, especially because of their social structures, their economic systems, geopolitical settings and the evolution of technology (Decker *et al.*, 2000; C. Kennedy, Cuddihy and Engel-Yan, 2007; Satterthwaite, 2007; Dinarès, 2014).

Since 1950 the urban population grew from 746 million to 2.85 billion in 2000, and it has reached 3.96 billion in 2015 (United Nations Habitat, 2015, p1). Although the urban population is not growing as fast as originally expected, urban growth is concentrated in certain areas of the world and has large environmental impacts in those areas (Asian Development Bank, 2013). In this context, a modification in the distribution of the population from rural to urban places is a governing feature of the demographic transition of most countries (United Nations, 1980 and 2000). According to the United Nations, half of humanity, which is 3.5 billion people, live in cities and this number will continue to grow. In the next decades the 95% of urban expansion will take place in developing countries (United Nations, 2016).

In Latin America 80% of the population lives in urban areas and 30% of the total population lives in slums (UCLG, 2014). Additionally, Díaz Álvarez (2014) argued that “the population dynamics and urban patterns gleaned from medium and big cities in Latin America are determining critical operations that brake economic growth, undermine development, damage the environment, affect human health and reduce goods and services supply from environmental ecosystems” (Díaz Álvarez, 2014).

The report “World Urbanization Prospects: The 2014 Revision”, commissioned on the Department of Economic and Social Affairs (United Nations, 2014), indicates that Mexico’s average annual rate of change from urban to rural population is of 0.4 %, based on the increase of urban growth (United Nations, 2014b) (**Table I.1**).

Urban Growth in Mexico			
Year	**1990**	**2014**	**2050**
Urban	61,475.00	97,766.00	134,828.00
Rural	24,602.00	26,034.00	21,274.00
Proportion urban (per cent)	71.00	79.00	86.00

Table I.1. *Urban Growth in Mexico. Source: World Urbanization Prospects: The 2014 Revision* (United Nations, 2014b).

As shown in the table, the majority of people around the world live in urban areas (United Nations, 2014b). Unfortunately, the accelerated urban growth does not specifically correspond to a sustainable development of the area. Over the last decades a growing concern with increasing resources consumption has been observed, leading to increasing challenges on how to decrease resources consumption as well as local and global trade-offs (Baptista *et al.*, 2015).

Needless to say that cities change the social organization of energy and materials due to their intense consumption and production activities (Chen and Chen, 2015a). Moreover, the most affected by industrial growth are the poor, as well as the marginalized and the racial and ethnic minorities in urban areas who do not have the means to avoid or control industrial hazards (Robins and Kumar, 1999).

Main human impacts of urban ecosystems are unplanned urbanization and inadequate infrastructures. Unplanned urbanization threats the health and safety of human beings, as well as urban productivity, and combined with inadequate infrastructures, it accelerates environmental degradation (Mersal, 2016). Because of the fact that cities constitute the dominant form of human habitat, and most of the world's resources are either directly or indirectly consumed in cities, the role of cities in determining sustainability is becoming more and more important (Moore, Kissinger and Rees, 2013). For this reason, cities must be planned and managed to form a balance between human being and natural environment by using resources carefully and transferring them to the next generations (Mersal, 2016).

It is undeniable that, cities face major challenges –urban poverty, poor living conditions, constraints on productivity, lack of infrastructure, natural disasters risks and climate change-, but they constitute also the potential for transformational change (Revi and Rosenzweig, 2013). Ban Ki-moon, the UN Secretary General, recognized that "our struggle for global sustainability will be won or lost in cities" (United Nations, 2012), because of the intensive urbanization rates.

That is the reason why building sustainable and resilient cities, where all citizen can have the opportunity to live a decent quality of life, form part of the city's dynamic and social stability without harming the environment, vital for human development.

Sustainable development of contemporary cities is the urgent task aimed at creating resilient, healthy and ecological cities capable of satisfying completely the residents' needs. In addition, the unsustainable nature of cities is a consequence of poor planning at the micro or neighborhood level (Codoban and Kennedy, 2008). Therefore, once again the importance and urgency of designing and implementing resilience strategies to achieve sustainability at all urban scales.

Further, communities in the periurban areas are specially affected by the urban growth, as they continue under increasing pressure of resources extraction (Barkin, 2010). It is observable that communities in the periurban are very vulnerable to different kinds of hazards. Therefore the importance of building sustainable urban development for these communities through resilience strategies.

The main objective of this study is to propose resilience strategies that enable sustainable urban metabolism for the community (urban socio-ecological system) of La Pila in San Luis Potosi. In order to achieve it, the specific objectives were:

1. To identify the metabolic fluxes in La Pila: Water, Energy & Food.
2. To identify hazards to the metabolic fluxes.
3. To analyze how resilient is the urban metabolism of La Pila.

Respect to the proposed objectives, the following questions drove the research:

1. How vulnerable are metabolic fluxes to which hazards?
2. Which are the current metabolic fluxes in the community?
3. How resilient is the urban metabolism of La Pila?

The idea of "continuing to develop" needs an urgent change, and sometimes it may mean stepping away from specific undesirable development path, and onto a new one (Reyers and Lee Moore, 2017).

Sustainable urban development in developing countries requires strengthening urban planning and management to improve basic service delivery and land use to promote improved standards of urban living (Asian Development Bank, 2013). Choosing to act sustainably means choosing to build cities where all citizens live a decent quality of life, and form a part of the city's productive dynamic, creating shared prosperity and social stability without harming the environment (United Nations, 2016).

The development and implementation of the Resilience Strategy is an opportunity to identify tangible steps that contribute to a solution and that emphasize an approach to resilience-building that can be further applied by the City and its community partners to other challenges moving forward (LeTourneau *et al.*, 2016). Therefore, it is necessary to understand how a city and its suburban areas work together in order to propose resilience strategies that promote and ensure sustainable urban development.

Through this research, knowledge about the application of urban metabolism in sub-urban areas was generated. It is central, to generate information into the field of material and energetic metabolism of the modern cities, because as some authors have pointed out, such studies have arrived to the fields of architecture and urbanism with delay (Martínez-Alier, 2003), specially to Latin American cities.

In a world with so many rising social and ecological challenges, cities can also be part of the solution, because of their compactness that helps them to be more resource efficient (Dobbs *et al.*, 2012). However, in order to achieve that, cities must be conducted towards sustainability. In this context, applying resilience planning requires "translating resilience thinking to practice in each unique circumstance, while simultaneously creating support among staff, and engaging external actors" (Sellberg, Ryan, Borgström, Norström, & Peterson, 2018, p906).

Closing Remarks

In a continuously urbanized world, sustainability must be enhanced to ensure the ability of future generations to satisfy their needs. In this context, this works has as main aim to propose resilience strategies that enable sustainable urban metabolism for an urban socio-ecological system. The case of study is the community of La Pila, which is located in the southeast of San Luis Potosi, Mexico. In order to achieve the main objective, three aims were proposed: 1) To identify the metabolic fluxes in La Pila: Water, Energy & Food; 2) To identify hazards to the metabolic fluxes; and 3) To analyze how resilient is the urban metabolism of La Pila.

Respectively, the following questions drove the research: 1) Can resilience strategies enable sustainable urban metabolism? 2) How are the current metabolic fluxes in the community? 3) How vulnerable are metabolic fluxes to which hazards? and 4) How resilient is the urban metabolism in La Pila?

Chapter II

Theoretical Framework

"Understanding the urban resilience and sustainability as two concepts that promote a plurality and diversity of solutions to social-ecological problems implies that urban planning needs to take on-board yet new metaphors and paradigms to further transform cities."

(Wilkinson, 2012)

II. Theoretical Framework

In order to build Sustainable Urban Metabolism through Resilience Strategies, some concepts related to Systems Thinking Theory need to be clarified. In order to ease the understanding of such concepts this chapter is divided in five subchapters (**Fig. II.1**).

In *Urban Socio-Ecological Systems*, the definition of Socio-Ecological Systems from an urban perspective is explored, starting with the most basic characteristics of a system. After having defined an urban socio-ecological system, in the second subchapter a review the basics of *Systems Thinking Theory* –including the Hard Systems Thinking, the Complex Adaptive Systems, and the Soft Systems Thinking (SST) theories- is given in order to provide a theoretical framework that allows explaining the following concepts: Urban Metabolism, Urban Resilience, and Urban Management. This chapter also serves as an introduction to the third and fourth subchapters and a link to the first subchapter. Important for the reader is to be aware that all concepts in this theoretical framework are part of Systems Thinking Theory.

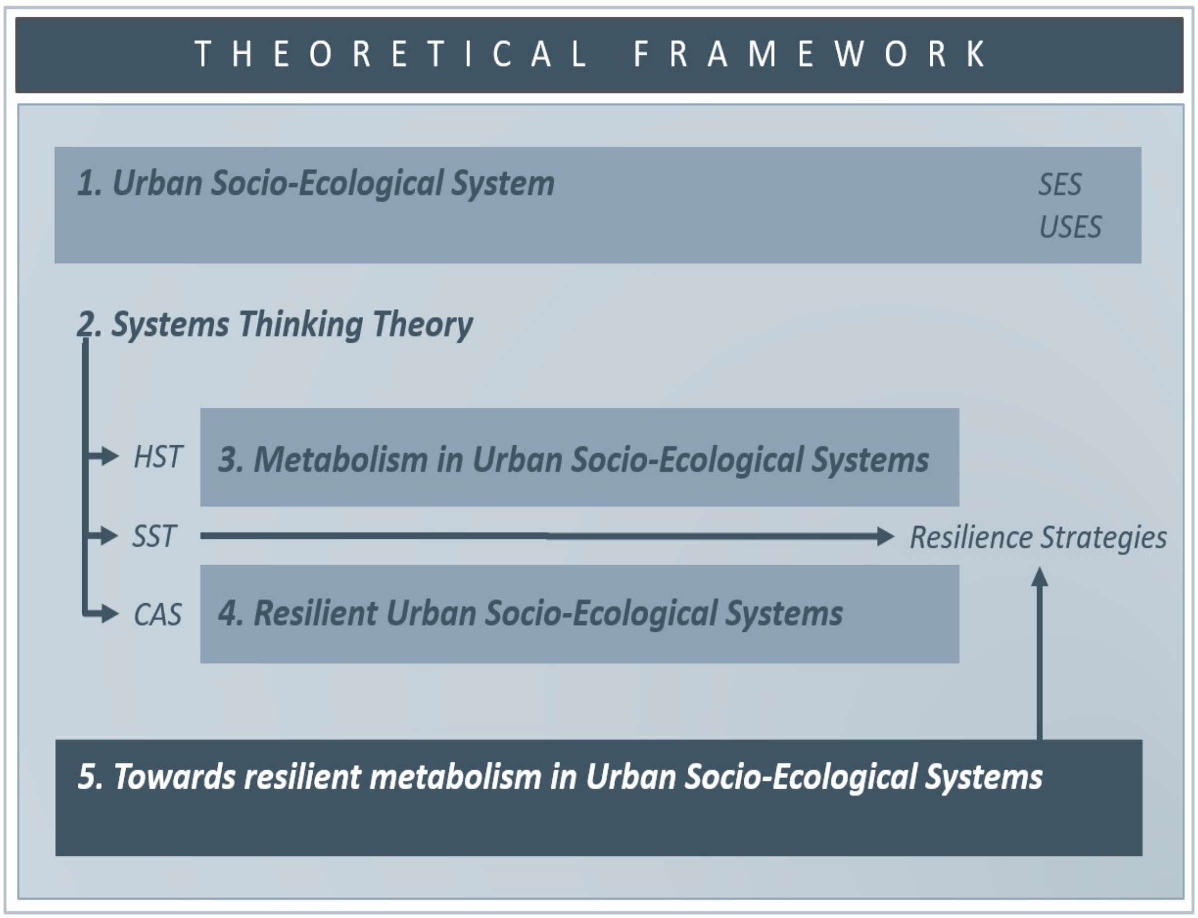


Fig. II.1. *Theoretical Framework Index. Source: Own Source.*

After that, in *Metabolism in Urban Socio-Ecological Systems*, the concept of Urban Metabolism is explained from the urban perspective, result of the application of the classical ecological of *Metabolism* into the fields of social sciences.

The concept of urban resilience is explained in the fourth subchapter - *Resilient Urban Socio-Ecological Systems*-, as a counterpart of risk and its components –hazard, vulnerability and exposure-.

Finally, in the last subchapter - *Towards resilient metabolism in Urban Socio-Ecological Systems*-, an integration of all concepts is made, in order to provide a perspective of how sustainable urban metabolism can be built through resilience strategies. In order to facilitate the following of the concepts, a graphic navigation through the topics is presented with the most important concepts, and the main interlinkages between concepts.

II.1. Urban Socio-Ecological Systems

Achieving “inclusive, safe, resilient and sustainable cities and human settlements” constitutes the eleventh of the seventeen Sustainable Development Goals (SDG) proposed by the United Nations in order to conduct our world towards sustainability (United Nations, 2015). The 11th SDG establishes “a single overall global urban policy position in a unified statement concerning the overall social, economic, and environmental functionality of cities and the urban system” (Parnell, 2016, p530).

Sustainable Development in its most conventional definition means "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). Moreover, sustainable development was envisioned as a “holistic concept addressing economic development, social inclusion, environmental sustainability and good governance” (Revi & Rosenzweig, 2013, p6).

However, it is important to state that sustainable development, as well as the notion of sustainability, can have several definitions and characteristics depending on the perspective and the approach to achieve it. As the aim is not discuss about the several conceptions of this term, this work will focus on the urgent need of conducting *Urban Socio-Ecological Systems (USES)* development towards sustainability.

This research project adopted a systemic and holistic perspective that allowed observing the several interconnections across temporal and spatial dimensions within a *USES*. The reason is that the understanding of sustainability management requires adopting a multidisciplinary systemic perspective, which helps us to understand the interconnectivity of issues –including economic, political, social and ecological-, across dimensions -temporal and spatial- (Williams *et al.*, 2017); instead of a reductionist perspective which prefers comprehending isolated and independent units, while assuming linear and reversible cause and effect relationships (Rogers *et al.*, 2013).

In this subchapter, the concept of system is explored. After that, the concept of *Socio-Ecological System (SES)* will be reviewed in order to provide a better understanding of why it is important to study urban systems as complex and dynamic entities. Finally, a definition of *Urban Socio-Ecological System (USES)* will be provided.

II.1.1. Defining a System

Defining a *SES* requires first defining what a system is. A not holistic definition of a system can be “an interconnected set of elements that is coherently organized in a way that achieves something” (Meadows, 2009, p11). A more holistic definition provided by Jackson (2003) states that a system is “a complex whole the functioning of which depends on its parts and the interactions between those parts” (Jackson, 2003, p3). Therefore, a system and its part possess structure and behavior, which is determined by the nature of interaction between its parts (Rogers *et al.*, 2013). This means that, systems consist of elements -characteristics-, interconnections -the way the elements or characteristics feed into and relate to each other-, and functions –goals- (Meadows, 2009; Arnold and Wade, 2015).

As the term 'system' is not new, it has acquired several attributes and concepts that allow their study and understanding over the years. According to Von Bertalanffy (1968) systems can be divided into closed or open. On the one hand, a system is considered closed, when it does not have exchanges with its environment[2]. On the other hand, open systems are able to take inputs from their environments, transform them and then return them as some sort of product back to the environment (Von Bertalanffy, 1968). However, to this date, most systems are considered as open, because in reality all systems are continuously interacting with other systems in their environment (Jackson, 2003; Hitchins, 2007) (**Fig. II.2**).

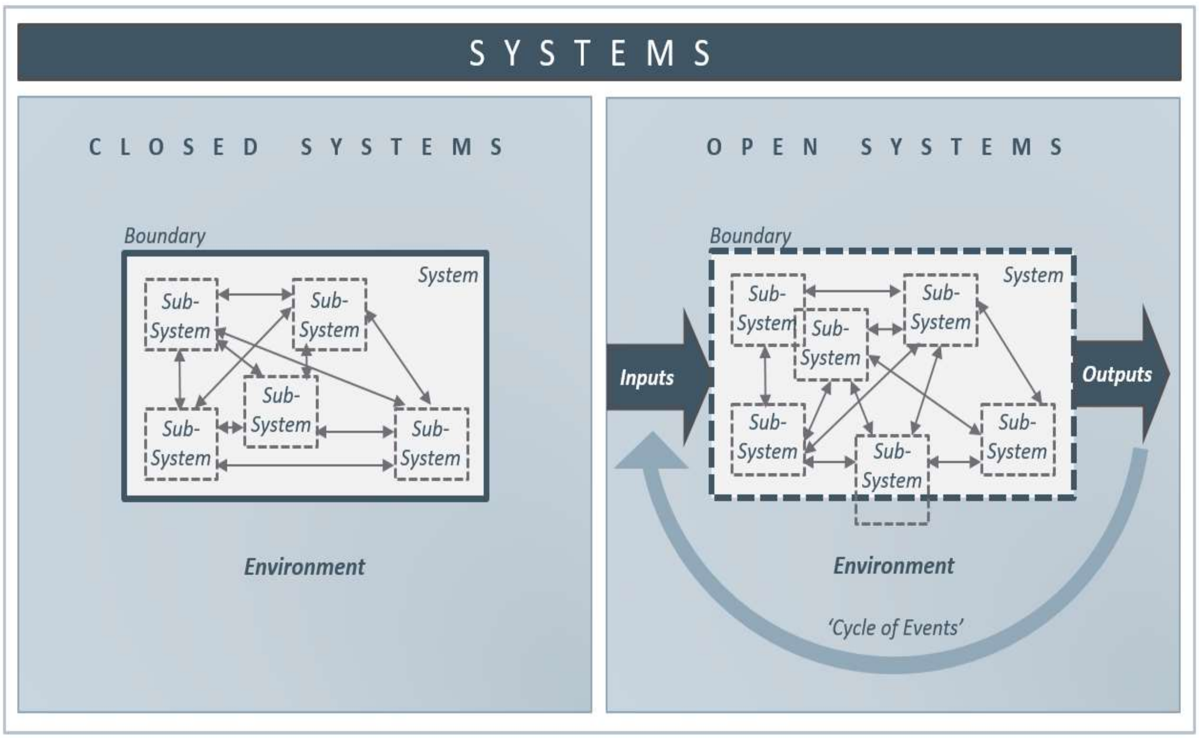


Fig. II.2. *Closed and Open Systems. Source: Based on Michael C. Jackson's Systems Thinking* (Jackson, 2003).

Because of their complexity, systems require boundaries for their study, depending on the observer and on the phenomenon observed. In this setting, an open system is composed of sub-systems with interrelationships, plus the interactions with its environment. For this reason, a system depends on the environment and adapts in reaction to changes or 'cycle of events', as Jackson (2003) named them based on the biological system (Jackson, 2003).

But, such adaptation to the 'cycle of events' depends and will be related to the purposive behavior of the system. As systems have a purposive behavior, they are able to regulate themselves and are

[2] Bertalanffy considers the biophysical realm as environment.

'controlled' in order to react or readapt to any disturbance, through 'the effective communication of information' (Jackson, 2003). Both attributes –control and information- were incorporated to the systems theory by the mathematician Norbert Wiener (1948), when he argued that systems can be locked into both kinds of feedback loops: positive or negative. If the system is locked into a positive feedback loop, it presents a behavior spinning out of control. On the opposite, if a system is locked into a negative feedback, –information-, it is able to take actions and correct its behavior in order to keep on pursuing the present goal (Wiener, 1948).

Another attribute, which is vital to comprehend systems is 'variety', which can be considered as the number of probable states a system can have (Ashby, 1956). Because of their complexity, systems change rapidly, exhibiting a high variety of states (Jackson, 2003).

To summarize, the main characteristics of a system are the following: 1) They have a purpose; 2) System's parts or components must be present in order to achieve the purpose optimally; 3) The order of the parts or components has consequences on the performance of a system; 4) Systems use feedback to attempt to maintain stability (Kim, 1999).

To conclude, it is important to remark that systems also present complexity, disorder, chaos, irregularity and unpredictability, which means that "small changes in the initial conditions of a system, can lead to large-scale consequences", which can be specially perceived when studying the 'strange attractors' or 'drivers' which govern the system and the purpose within (Jackson, 2003, p80-116).

II.1.2. Socio-Ecological System (SES)

The use of the term 'system' is not new and it has been used to describe and explain how things work in various fields –such as biology, physics, social, design, engineering, and so on- (Jackson, 2003). Describing the human interaction with its environment was not the exception, which is why the concept of *Socio-Ecological System (SES)* was born in order to "recognize the interconnectedness of humans and the environment" (Redman, Grove, & Kuby, 2004, p162).

Remembering how systems can be divided into open or closed systems, it is important to mention that most *SES* are considered as open systems, because they involve "flows of materials, organisms, and information into and out of the system" (Chapin, Kofinas, & Folke, 2009, p10).

A *SES* can be defined as a "coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner; a system that is defined at several spatial, temporal, and organizational scales, which may be hierarchically linked; a set of critical resources (natural, socioeconomic, and cultural) whose flow and use is regulated by a combination of ecological and social systems; and a perpetually dynamic, complex system with continuous adaptation" (Redman, Grove and Kuby, 2004).

In this direction, a *SES* is a system that consists of "the subsystems of nature and humans, with all their biophysical and social-cultural-political-economic characteristics". Therefore, "each subsystem has its own inherent elements, structures, functions and interconnections, which are changing over time" (Antoni, Huber-Sannwald, Reyes Hernández, & Van't Hooft, 2017, p13).

Redman et al. (2004) proposed a conceptual framework for long-term investigations for *SES* in which they emphasize the interactions at the interface of the system's social and ecological components. In this framework, they define interactions that mediate between the social and ecological elements of the *SES*: 1) Land-use decisions, especially those relating to the built environment; 2) Changes in land cover, land surface, and biodiversity; 3) Production systems; 4) Consumption patterns; and 5) Disposal networks (Redman, Grove and Kuby, 2004) (**Fig. II.3**).

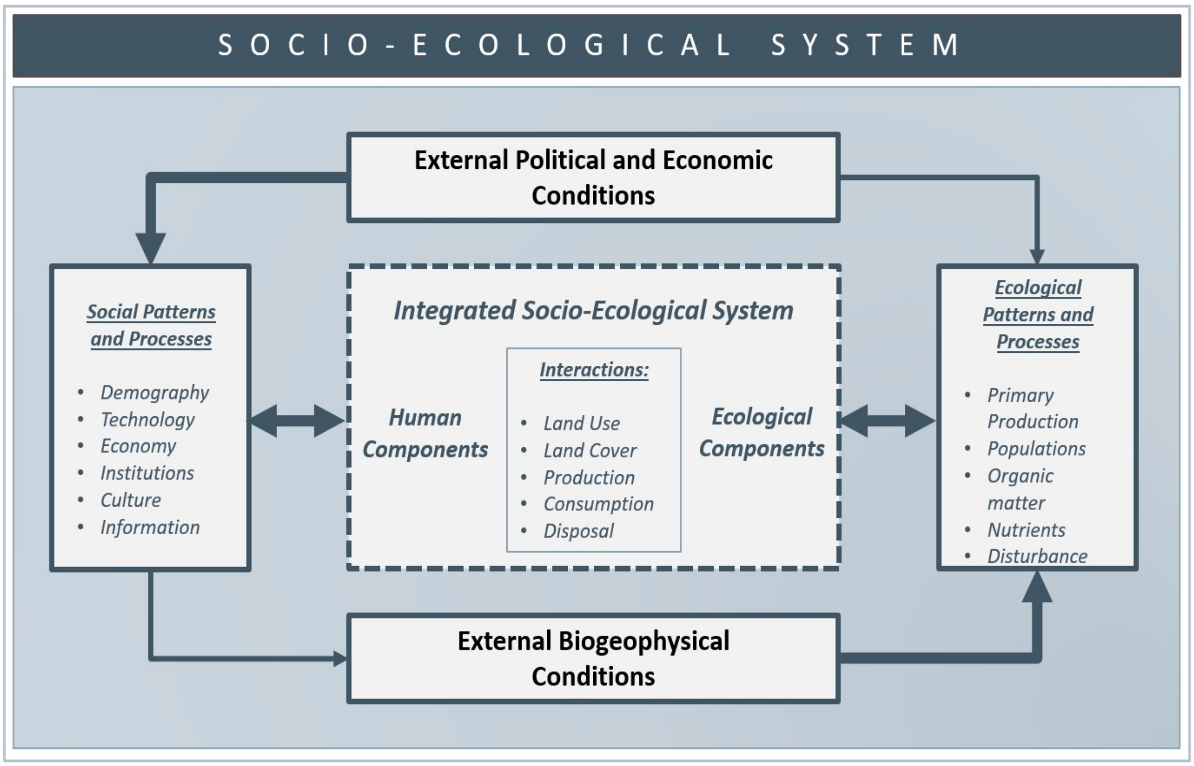


Fig. II.3. *Conceptual framework for long-term investigations of social-ecological systems (SES). Source:* (Redman, Grove and Kuby, 2004).

Redman's conceptual framework allows us to understand how complex a *SES* can be. In addition, it shows how wide the variety of -human and ecological- components, interactions, conditions, patterns and processes can be involved within an open socio-ecological system. Moreover, it is important to consider that the ecological and social sub-systems that compose a *SES* possess two important characteristics: self-organization and high adaptation (Antoni et al., 2017, p13). Self-organization means that

In addition to ecological components interacting constantly with social components at multiple levels, *SES* are susceptible to external processes which influence slow-changing component, which – at the same time-, influence faster-changing components that impact the individuals interacting within the *SES* (Resilience Alliance, 2010) (**Fig. II.4**).

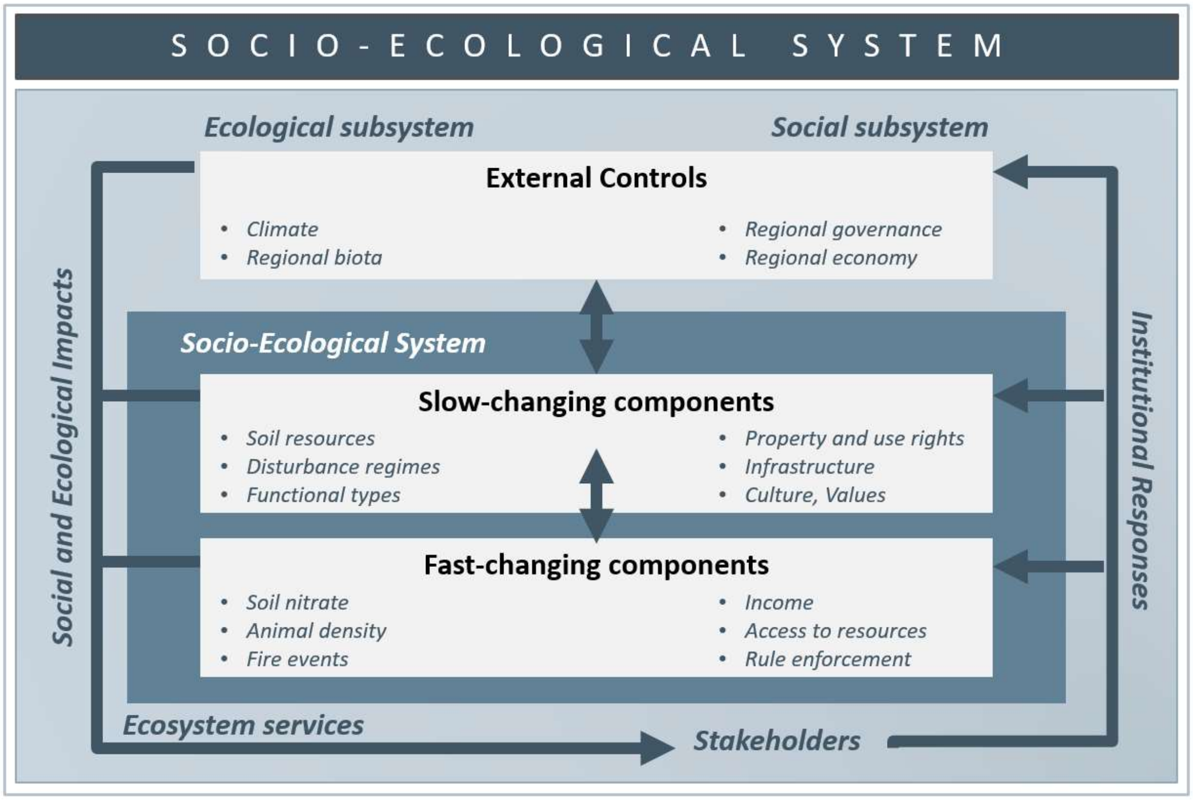


Fig. II.4. *Examples of slow-changing components and fast-changing components in socio-ecological systems (SES). Source:* (Resilience Alliance, 2010).

According to Antoni (2017), an integrated analysis of SES considers: "1) The interplay of internal and external factors, as well as their role in SES dynamics; 2) The potential thresholds whose crossing may shift the system into undesirable state; and 3) The cross-scale spatial and temporal interactions" (Antoni *et al.*, 2017).

II.1.3. Urban Socio-Ecological Systems (USES)

Until this part a *SES* has been defined as an open system, which interacts with the environment and which envelopes ecological and human subsystems with own purposes within. However, which are the characteristics that allow to consider urban systems as SES?

To this date, cities are recognized as dynamic, integrated and multi-scalar systems –human-driven ecosystems or socio-ecological systems-, which understanding is not only in the biophysical features of cities, but in the complexity socio-ecological relationships within them (Frank, Delano and Caniglia, 2017). In this context, a socio-ecological perspective helps to improve the recognition of the interconnections between society and economy, which are "nested in natural systems defined by biospheric limits" (Marcus, Kurucz and Colbert, 2010; Whiteman, Walker and Perego, 2013; Williams *et al.*, 2017).

Urban systems have a metabolism, which includes all the technical and socio-economical processes that occur in it (Christopher Kennedy, Cuddihy and Engel-Yan, 2007). In this context, several social and ecological patterns and processes defined by Redman (2004) are observable in urban systems (Redman, Grove and Kuby, 2004).

Moreover, urban systems can be considered as "hot spots of complex and dynamic interactions between society and ecosystems" (Frank, Delano, & Caniglia, 2017, p1).

The conceptualization of USES requires the understanding of cities as entities that face several global environmental challenges in a continuously transitional or transformational environment. In this context, Boyd & Juhola (2015) recognize three types of transitions and transformations that USES are facing, based on the ecological, social and technical dimensions of urban systems: 1) Socio-technical transitions; 2) Socio-environmental justice transitions; and, 3) Socio-ecological transformations (Boyd and Juhola, 2015) (**Fig. II.5**).

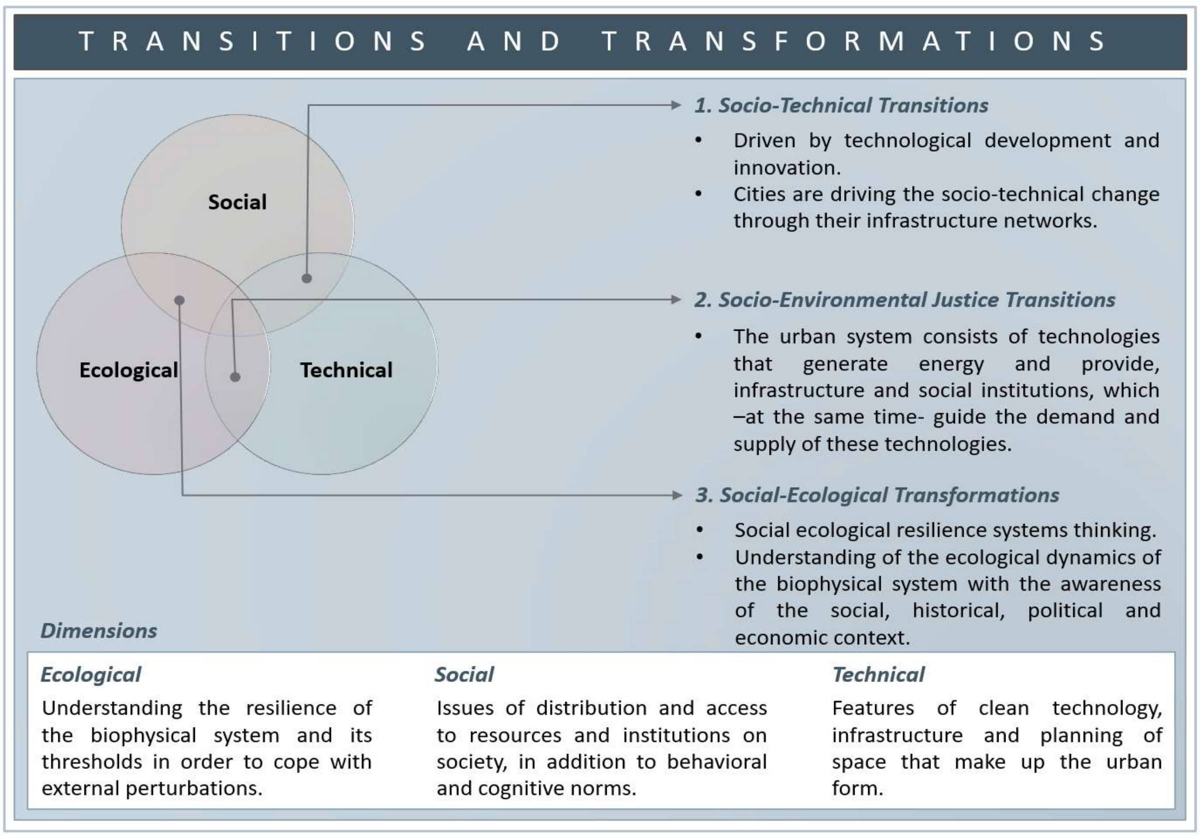


Fig. II.5. *Urban Socio-Ecological Systems: Transitions and Transformations. Source:* (Boyd and Juhola, 2015).

Hence USES have special characteristics that make them "effective platforms for transformative and sustainable development" (Revi & Rosenzweig, 2013, p9-12), which may include:

- Cities concentrate and can accelerate economic activity
- Urban infrastructure investment can enable growth, employment and poverty reduction
- Urban areas are sites of social transformation
- Local government are nimble
- Cities are sites of innovation
- Cities are interconnected with rural areas

- Cities are interconnected with the natural environment
- Cities have the potential to minimize our environmental footprint
- Cities are suited for systems-based approaches

As *SES* are complex and the relationships between sub-systems within are crucial, there is a need for joined-up thinking in addressing their problems (Jackson, 2003). That is the reason why, in the next chapter the *Systems Thinking Theory (STT)* is reviewed in order to introduce the *Hard Systems Thinking (HST)*, the *Complex Adaptive Systems (CAS),* and the *Soft Systems Thinking (SST)* as *Urban Socio-Ecological Systems (USES)* analyzing theoretical frameworks, and further as planning and managing methods.

Closing Remarks

In this subchapter, a system was defined as "an interconnected set of elements that is coherently organized in a way that achieves something" composed by elements -characteristics-, interconnections -the way the elements or characteristics feed into and relate to each other-, and functions –goals- (Meadows, 2009; Arnold and Wade, 2015). Every system can exhibit complexity, disorder, chaos, irregularity and unpredictability, and important to their functioning is considering that they have always a purpose. Additionally, the order in which interactions occur has an impact on the system's outputs and a system requires feedback to attempt to maintain certain stability (Kim, 1999).

From this perspective, a socio-ecological system was defined as a coherent complex system of both biophysical and social factors, defined at spatial, temporal, and organizational scales, perpetually dynamic, and in continuous adaptation (Redman, Grove and Kuby, 2004).

Finally the urban socio-ecological system was defined as a system with special characteristics that make them "effective platforms for transformative and sustainable development" (Revi & Rosenzweig, 2013, p9-12), which may include:

- Cities concentrate and can accelerate economic activity
- Urban infrastructure investment can enable growth, employment and poverty reduction
- Urban areas are sites of social transformation
- Local government are nimble
- Cities are sites of innovation
- Cities are interconnected with rural areas
- Cities are interconnected with the natural environment
- Cities have the potential to minimize our environmental footprint
- Cities are suited for systems-based approaches

II.2. Systems Thinking Theory

Cities, -considering all Urban Socio-Ecological Systems-, are the most complex and synamic of human systems. Therefore, it is vital a systems based approach to transform via economies of scale and scope and facilitating rapid social and institutional innovation, in order to achieve sustainable urban development (Revi & Rosenzweig, 2013, p12).

As *Urban Socio-Ecological Systems (USES)* are a complex integration of social and ecological subsystems –as reviewed in the last chapter-, several approaches have been developed to analyze, modify or influence systems. In this context, Systems Thinking emerges as an epistemology, which groups theories and approaches, whose aim is to improve the understanding of systems, contrary to reductive thinking, which rejects integration, ambiguity and paradoxes (Rogers *et al.*, 2013).

For decades, ecologists and social scientist have used systems thinking to better understand complex systems, including ecosystems and organizational systems like cities –including *USES*- (McPhearson, 2013).

In the following chapter, the basics of *Systems Thinking (ST)* are reviewed, –including the *Hard Systems Thinking (HST)*, the *Complex Adaptive Systems (CAS),* and the *Soft Systems Thinking (SST)* theories-, in order to provide a theoretical framework that allows explaining the following concepts: *Urban Metabolism (UM)*, *Urban Resilience (UR)*, and Urban Management –which will be key components of the present research-.

II.2.1. Definition and Approaches

Barry Richmond (1994) was the first using the term 'Systems Thinking' in order to define "the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure" (Richmond, 1994, p6). Since then, several definitions and approaches have emerged.

Systems Thinking is, -according to Kim (1999)-, "a perspective, a way of seeing and talking about reality that helps us better understand and work with systems to influence the quality of our lives" (Kim, 1999, p2). Such perspective requires a transdisciplinary scope that involves both, on one side scientist from different disciplines and, on the other nonscientist and other stakeholders (Hester and MacG. Adams, 2013).

According to Jackson (2003) Systems Thinking embraces holism instead of reductionism to manage complexity, change and diversity (Jackson, 2003). Systems Thinking aims to increase the understanding of a mess, without necessarily needing or achieving a singular view of what might be considered as the 'best' (Hester and MacG. Adams, 2013). In addition, Systems Thinking allows the comprehension of "the deep roots of complex system's behaviors in order to better predict them and, ultimately, adjust their outcomes" (Arnold & Wade, 2015, p670).

Hester & MacG. Adams (2013) argued that the unit of analysis of Systems Thinking are 'messes' – system of problems-, whose solution represents a "unique global solution to the mess" (Hester & MacG. Adams, 2013, p313). Consequently, balancing the interests of individual problems represents the main challenge of studying and analyzing problems from a systemic perspective. For example, decision makers usually have limited and simplified information before making a relevant decision that impacts on the system (Hester and MacG. Adams, 2013).

Following Jackson's train of thought, Systems Thinking Theory is conformed by four holistic approaches depending on their aim: 1) Improving goal seeking and viability; 2) Exploring purposes; 3) Ensuring fairness; and 4) Promoting diversity (Jackson, 2003). In the following picture, it is observable that the approaches of our interest are embedded in the first two types of systems' approaches: the *Hard Systems Thinking (HST)*, the Complexity Theory or *Complex Adaptive Systems (CAS)* -on the first type- and the Soft Systems Methodology or *Soft Systems Thinking (SST)* –on the second type- (**Fig. II.6**).

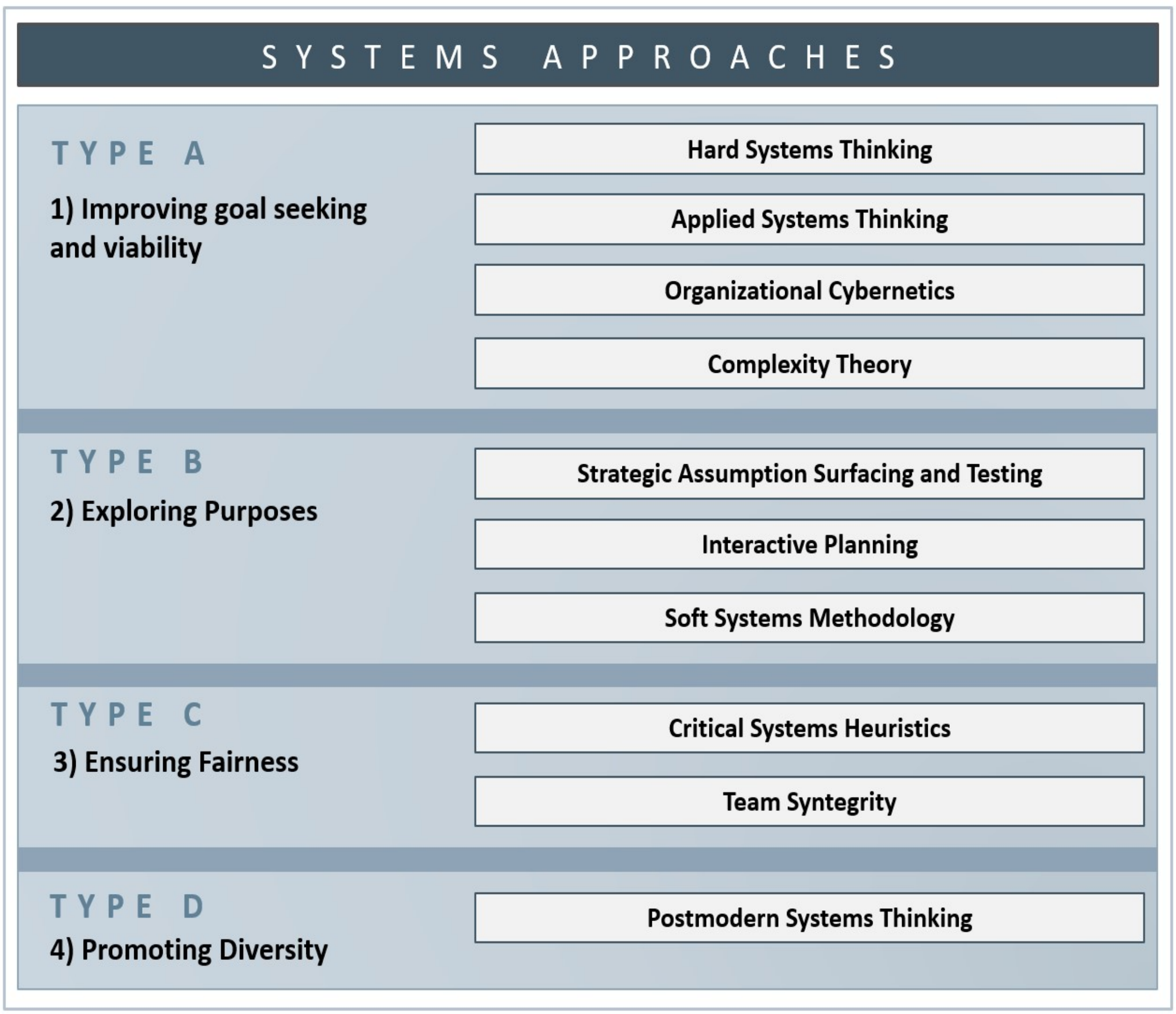


Fig. II.6. *Jackson's Systems Approaches in Systems Thinking Theory. Source:* (Jackson, 2003).

In the following lines, the differences between *Hard Systems Thinking (HST)*, the Complexity Theory or *Complex Adaptive Systems (CAS)* and the Soft Systems Methodology or *Soft Systems Thinking (SST),* are explained.

II.2.1.1. Hard Systems Thinking (HST)

Hard Systems Thinking seeks to improve goal seeking and viability (Jackson, 2003). The origin of Hard System Thinking (HST) was as a way to name all various systems approaches for solving real-world problems developed during and as a result of the Second World War, as UK scientists assisted military leaders to benefit with the use of radar, they carried scientific research into operational processes rather than into natural phenomena (Checkland, 1981).

According to Jackson (2003), the approaches that are most commonly associated with *HST* are operational research, systems analysis and systems engineering. In addition, other variants of *HST* are decision science, cost-benefit analysis, planning-programming-budgeting systems and policy analysis (Jackson, 2003).

According to the characteristics that *HST* approaches present, the *Urban Metabolism* (UM) is presented as part of these approaches, which will be explained on the third subchapter.

II.2.1.2. Complex Adaptive Systems (CAS)

Complex systems contain several variables, which interact between each other and become causally related in feedback loops. At the same time, such feedback loops' interrelationships within the system constitute its structure and determine its behavior (Jackson, 2003).

Within *Complex Adaptive Systems*, we assume that two similar-looking systems with different temporal and/or spatial context might be similar but not the same, because they can have very different direct and indirect feedback loops, with different effects or results that might not be related to the causes (Rogers *et al.*, 2013).

Determining if significant feedback loops have a positive or negative nature and identifying its interrelationships with others is central in defining system's behavior, and therefore its dynamics. Moreover, because of their nature, feedback loops can allow us to identify system archetypes, which if recognized can save time, effort and can allow to target interventions in a system to points of maximum leverage (Jackson, 2003). For example, if a negative feedback loop is found, the actions to be taken should be focus on changing this pattern in order to change the whole system's behavior.

Moreover, variability and uncertainty are a central part of *CAS*, which must be considered when understanding the heterogeneity of *CAS*'s structure, relationships and properties that emerge from interactions (Rogers *et al.*, 2013). This means that interactions within a system can be propagated in nonlinear ways.

In order to understand *CAS*, it is vital to consider from a complexity perspective that systems have multiple possible solutions to a problem, because of their wicked nature. This means that each wicked problem is unique and can be framed in different several ways. Therefore, in *CAS* perspective, problems might not find a solution but actions can be fostered by breaking down the components of the problem (Rogers *et al.*, 2013). This is the reason why, when studying complex *USES*, a reductionist perspective will never provide a correct perception of reality (Morin, 2008; Rogers *et al.*, 2013).

Urban Resilience (UR), which concepts and methodologies will be reviewed in further subchapters belongs to this group of Systems Thinking approaches.

II.2.1.3. Soft Systems Thinking (SST)

Soft Systems Thinking (SST) refers to management. Therefore, the importance of considering this Systems Thinking approach when proposing strategies in any *USES*.

USES management is not being applied in this work, however, it will be central to the conclusions to signalize that strategies' application in *USES* management might be the next step in order to build a sustainable urban metabolism. Once more, this management approach is part of *STT*.

Closing Remarks

All in all, systems thinking is vital to solve the urban problems in the planning and policy arenas, because of their complexity and because no problem can exist in isolation (McPhearson, 2013).

However, several approaches have been developed since this science was born. This research considers three approaches from the wide range Systems Thinking –proposed by Michael Jackson (2003)-, offers: 1) *Hard Systems Thinking (HST)*; 2) *Complex Adaptive Systems (CAS)*; and 3) *Soft Systems Thinking (SST)* (Jackson, 2003).

From each one of these approaches, several methods can be found that have already been used in the last years attempting to improve the understanding, planning and management of *USES*. Therefore, from *HST*, *Urban Metabolism (UM)* is explained in the third subchapter, and from the *CAS*, *Urban Resilience (UR)* is explained in the fourth subchapter, as key elements to foster resilience strategies in the *USES*, through a managerial approach –*SST*-.

HST seeks to improve goal seeking and viability, which means that it usually points at direct solutions within a system part, while the *CAS* tries to understand the totality of the system In order to reflect on the consequences of any change made. Finally, the *SST* is the management of the system itself.

II.3. Metabolism in Urban Socio-Ecological Systems

Urban Metabolism (UM) is interpreted and approached differently across several disciplines from the natural and social science fields (Dinarès, 2014). Understanding urban metabolism is central to ensure cities' sustainability. As the cities depend on spatial relationships with the near surroundings –as well as with the global resource webs-, increasing metabolism implies a greater loss of natural resources, as well as more negative environmental effects derived from the use of such resources (Christopher Kennedy, Cuddihy and Engel-Yan, 2007)

II.3.1. Metabolism from the Ecological and Social Sciences Perspectives: Towards an Urban Sciences Conceptualization

In order to define UM, it is necessary to understand the concept from the natural and the social sciences perspectives. In the natural sciences, the term *metabolism* was first used in the field of biology to characterize chemical changes within living cells in the early 19th century. After that, the term has been used to represent processes of organic breakdown and combination, within individual organisms and between organisms and their environment (Fischer-Kowalski, 1998; Foster, 1999; Wachsmuth, 2012; Dinarès, 2014).

In the decade of 1970, Odum (1983) used the term of *metabolism* in order to conceptualize energy flows, as he applied the notion of biological metabolism to describe it in terms of solar energy equivalents (emergy) (Odum, 1984). Therefore, in the biological sciences *metabolism* can be defined as "the sum total of the chemical processes that occur in living organisms, resulting in growth, production of energy, and elimination of waste material" (Chen and Chen, 2015a). In this perspective, *metabolism* can be applied in the field of natural sciences to both, either "processes through which bodies change and reproduce themselves", or to "holistic conceptions of ecosystem relations" (Dinarès, 2014, p555).

On the other hand, in the social sciences, the first application of the concept was made by Karl Marx. Marx was a pioneer of *social metabolism*, as he was able to understood the human practices as a part of a Human-Nature Relationship (Altvater, 2006). After that, Georgescu-Roegen, influenced by Marx, on his Magnum opus "The Entropy Law and the Economic Process", refers to the economical process as an opened system that has valuable Natural Resources as input and non-valuable Wastes as output (Georgescu-Roegen, 1989).

Since then, *metabolism* has been used on the economic and social sciences in order to explain how *systems* work. For example, Martínez-Alier studied the social and economic metabolism, in terms of materials and energy flows and of the production of residues, and classifies and studies the corresponding environmental conflicts (Martínez-Alier, 2006).

Social metabolism was later defined by Toledo (2008) as "processes which enable a community to appropriate, to circulate, to transform, to consume and to excrete materials or energies from the natural environment with the best efficiency possible" (Toledo, 2008a, p24). In this context, social metabolism model allows the description and quantification of matter, work and energy's floods that are exchanged between social groups and agroecosystems that compose a specific territory. Moreover, it defines "the structural and functional condition of the different system's components" (Toledo, 2008, p3) (**Fig. II.7**).

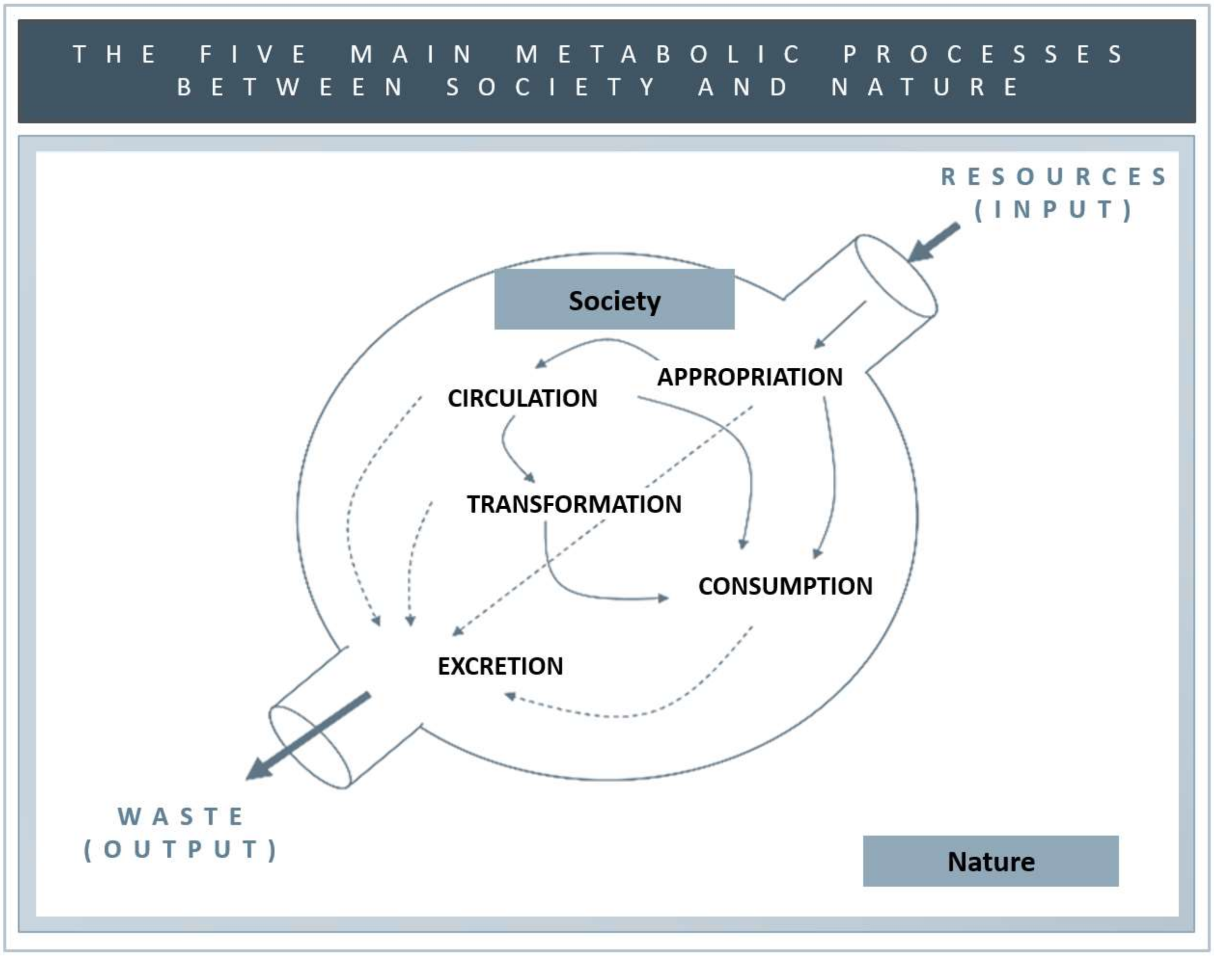


Fig. II.7. *The Five Main Metabolic Processes between Society and Nature. Source: Taken and self-translated from Victor Toledo (Víctor M. Toledo, 2008).*

In his article, *Rural Metabolisms: Towards an economical-ecological theory of nature appropriation*[3], Victor Toledo (2008) also differentiates dimensions of social metabolism. He distinguishes three main dimensions of the general process of social metabolism according to each one of the five metabolic processes: 1) Rural Metabolism; 2) Urban Metabolism; and 3) Industrial Metabolism (Víctor M. Toledo, 2008) (**Fig. II.8**).

In the **Fig. II.8**, we can appreciate how the urban dimension forms part of the consumption and excretion processes, with a low appropriation of resources. This means that cities are the socio-

[3] Self-translation from "Metabolismos rurales: hacia una teoría económico-ecológica de la apropiación de la naturaleza".

ecological systems that consume and excrete the majority of the natural resources. Meanwhile, the industrial metabolism is the main driver of transformation-related metabolic processes, with a high participation in the excretion processes.

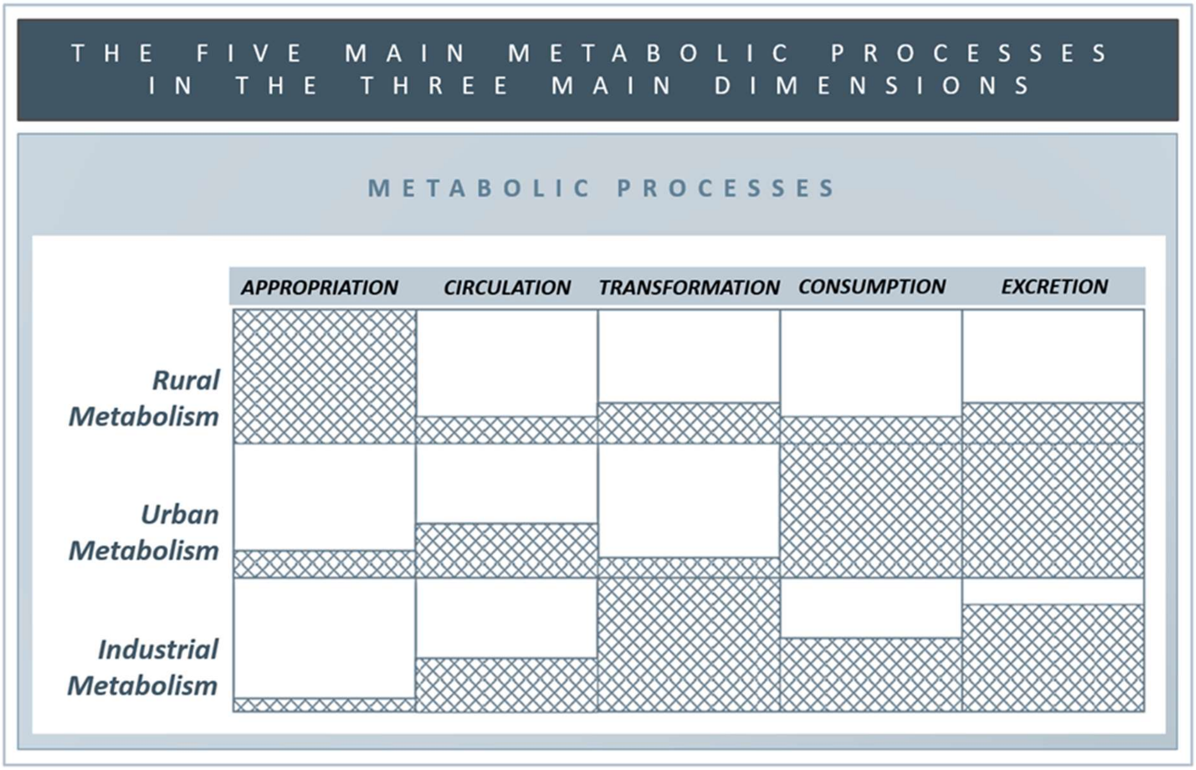


Fig. II.8. *The Five Main Metabolic Processes in the three main Dimensions of the general process of Social Metabolism. Source: Taken and self-translated from Victor Toledo* (Víctor M. Toledo, 2008).

Moreover, the metabolism of human society, according to Ramos-Martin et al. (2007) can be considered as the "processes of energy and material transformation in a society that are necessary for its continued existence" (Ramos-Martin, Mayumi and Giampietro, 2007). From this perspective, and if we take this example to the urban theory, it is noticeable that habitants from rural areas are involved in the processes of resources extraction and generation, while city's habitants consume energy, food, water and other resources, which they excrete as waste that pollutes rural environments.

Considering human society as energy processes and material transformation is, therefore, basic for the notion of urban growth, especially in migration patterns. Because of the facilities that a city offers, people who live in a rural environment tend to migrate to cities, and rural areas tend to become part of the nearest city, which leads to unsustainable urban growth. Therefore, the importance of understanding urban socio-ecological systems from its metabolism. Cities, and USES, whose metabolism is analyzed, are better prepared to understand their complexity and identify resilience strategies, which permit to develop towards sustainability (Dinarès, 2014).

II.3.2. Urban Metabolism

Although the concept of metabolism was originated from the ecological sciences as a concept that allowed describing the exchange of matter between an organism and its environment, its application to cities was first undertaken by Abel Wolman in 1965 (Kennedy, Pincetl and Bunje, 2011; Dinarès, 2014; Davoudi and Sturzaker, 2017). In 'The Metabolism of Cities', Wolman modelled the metabolism –including its inputs, such as water, food and fuel; its outputs, such as sewage, solid waste and air pollutants; and their respective transformations and flows-, of an imaginary American city, composed by one million people (Wolman, 1965). Following this direction, 'metabolism' is a metaphor brought from natural sciences to the urban sciences as a methodology that seeks treating cities as metabolic organisms, due to the fact that they have an structure and a function embedded in the metabolic processes (Chen and Chen, 2015a). A city can be considered as a system, because of its metabolism, which according to Kennedy (2007) can be defined as "the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste" (Kennedy et al. 2007b, p44).

Kennedy et al. (2007) defined urban metabolism as "the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste" (Christopher Kennedy, Cuddihy and Engel-Yan, 2007). In this context, UM can be defined as "the analysis of all technical and economic flows of energy and material associated with the production and consumption activities in cities, including imports of raw materials and products to the city from other economies or natural ecosystems, exchanges of goods and services between urban economic sectors, and materials leaving the cities' boundaries in the form of exports, gaseous emissions, or liquid and solid waste" (Warren-Rhodes and Koenig, 2001; Christopher Kennedy, Cuddihy and Engel-Yan, 2007; Chen, Chen and Fath, 2014; Chen and Chen, 2015a). This means that the urban systems are part of the whole nature dynamics. Díaz Álvarez (2014) defined the most common elements –found in the ecosystem-, that are common for both urban and natural systems (Díaz Álvarez, 2014). As it is shown in **Fig. II.9**, the cultural elements are part of the urban and natural systems, as well as the natural selection and evolution processes that occur within every population, as both are regulated by the thermodynamics laws[4].

[4] "The most important laws of thermodynamics are: 1) *The zeroth law of thermodynamics.* When two systems are each in thermal equilibrium with a third system, the first two systems are in thermal equilibrium with each other; 2) *The first law of thermodynamics, or the law of conservation of energy.* The change in a system's internal energy is equal to the difference between heat added to the system from its surroundings and work done by the system on its surroundings; 3) *The second law of thermodynamics.* Heat does not flow spontaneously from a colder region to a hotter region, or, equivalently, heat at a given temperature cannot be converted entirely into work. Consequently, the entropy of a closed system, or heat energy per unit temperature, increases over time toward some maximum value. Thus, all closed systems tend toward an equilibrium state in which entropy is at a maximum and no energy is available to do useful work; 4) *The third law of thermodynamics.* The entropy of a perfect crystal of an element in its most stable form tends to zero as the temperature approaches absolute zero. This allows an absolute scale for entropy to be established that, from a statistical point of view, determines the degree of randomness or disorder in a system" (Gordon, 2018).

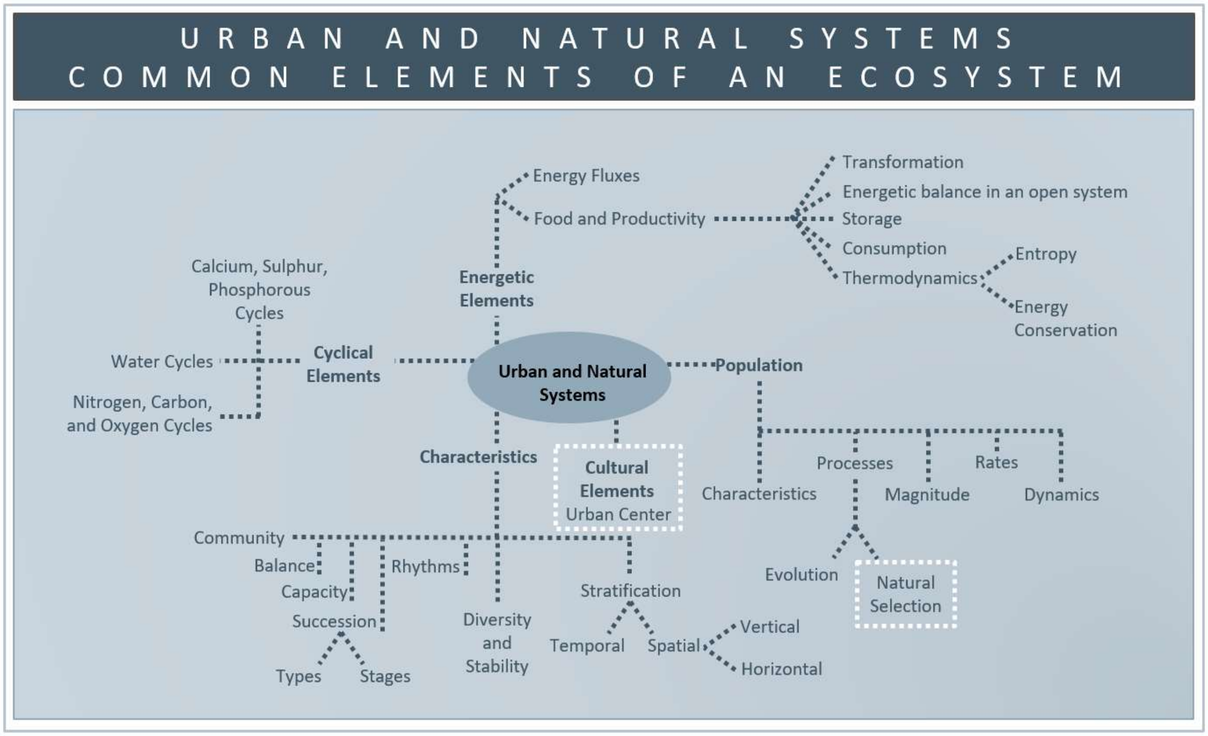


***Fig. II.9.** Urban and Natural Systems: Common Elements of an Ecosystem. Source: Taken and self-translated from* (Díaz Álvarez, 2014).

Broto et al. (2012) defines metabolism as "the exchange processes that produce the urban environment" (Broto, Allen and Rapoport, 2012). Additionally, Frank et al. (2017), consider that UM, "the process of material and energy production, flow and consumption in cities", is central when studying the "infrastructure, energy efficiency, materials recycling and waste management of urban ecosystems" (Frank, Delano and Caniglia, 2017). In this context, the UM is a "technical, political and economic endeavor that facilitates our understanding of the material and energy supply networks, seeking the efficiency and effectiveness of transformation processes, as well as reducing the environmental impact of their waste, enabling policy makers to anticipate unwanted events based on present signals" (Díaz Álvarez, 2014). According to the Global Initiative for Resource Efficient Cities[5] (2018) the UM measures the inflows, materials and outflows within a city, considering it as an urban system (Global Initiative for Resource Efficient Cities, 2018) (**Fig. II.10**).

[5] GI-REC: The Global Initiative for Resource Efficient Cities is a cooperation platform offered by UN Environment, which was launched in 2012 at the Rio+20 global summit on Sustainable Development, with the aim of "capitalizing on the potential for cities to lead action towards greater resource efficiency". To this date, the GI-REC has as a main objective "to connect many different institutions that are using systems approaches (specifically urban metabolism and morphology approaches) towards building low-carbon, resilient, and resource efficient cities". The Initiative distinguishes itself from other city sustainability activities by building on existing city networks, and having a sustainable consumption and production entry point to assist cities with realizing the economic, social and environmental benefits of resource efficiency" (Global Initiative for Resource Efficient Cities 2018).

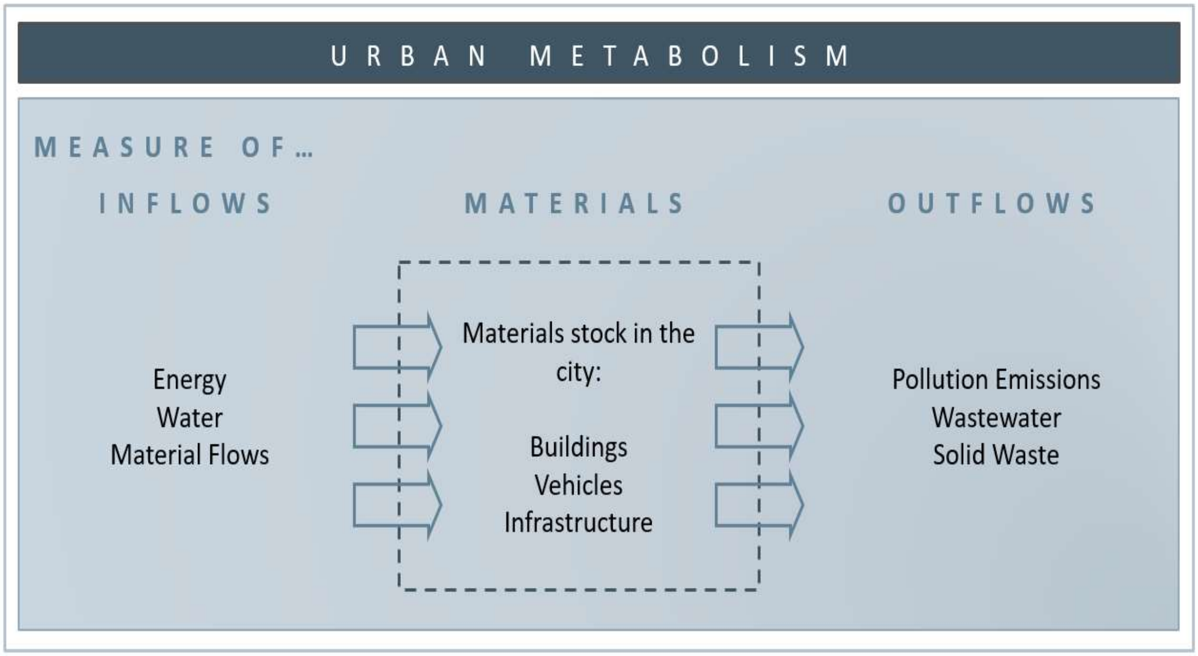


Fig. II.10. *Urban Metabolism according to the Global Initiative for Resource Efficient Cities. Source: Taken from the MOOC Sustainable Cities* (Global Initiative for Resource Efficient Cities, 2018).

As a result of their intense consumption and production activities, cities are constantly changing the social organization of energy and materials (Chen and Chen, 2015a). In this direction some metabolic processes that occur within cities threaten cities' sustainability, for example altered ground water levels, exhaustion of local materials, accumulation of toxic materials, summer heat islands and irregular accumulation of nutrients (Christopher Kennedy, Cuddihy and Engel-Yan, 2007). Some authors have proposed urban metabolism as a concept that allows analyzing the energy and material flows of cities in order to enhance urban sustainability (Chen and Chen, 2015a).

UM studies the "Urban Metabolic System", which was defined by Ferrão & Fernandez (2013) and S. Chen & Chen (2015) as "an open system with urban economy as its kernel, in which social, economic and institutional components interact with the environment by consuming energy and materials they accumulated in buildings and other stocks, and by releasing various emissions and waste to air water and soil" (Ferrão & Fernandez 2013; Chen & Chen 2015, p2). This means energy and materials flowing into the system, through the system and out of the system, which is vital to understand cities as systems. According to Dinarès (2014), Urban Metabolism is a term which provides "a conceptual framework to study how a city functions, and hence, a way to address the sustainability issue of a city" (Dinarès, 2014, p551), as it allows improving the understanding of how environmental, social and economic factors interact to shape urban phenomena and processes (Dinarès, 2014).

As a methodology, UM has been used in order to explain or understand: 1) The city as an ecosystem; 2) Material and energy flows in the city; 3) The material basis of the economy; 4) The economic drivers of rural-urban relationships; 5) The reproduction of urban inequality; 6) Resignifying socio-ecological relationships (Global Initiative for Resource Efficient Cities, 2018) (**Fig. II.11**).

URBAN METABOLISM
THEMES AND RESEARCH QUESTIONS

Theme	Key Question	Emphasis on
The city as an ecosystem	What lessons from the functioning of ecosystems can be applied to design and plan better cities?	Nature-inspired models of development in urban planning and design
Material and energy flows in the city	What methods can account for material and energy flows through the city and can these provide suggestions for their optimization?	Comparative analyses of cities and models of urban planning in relation to their efficiency in allocating materials and energy
The material basis of the economy	What policy measures can break the link between urbanization, economic growth and resource consumption?	The material limits of the economy and macroeconomic models to achieve economic and resource stability
Economic drivers of rural-urban relationships	How do economic relations shape the distribution of flows between urban regions and their surroundings?	Forms of territorial organization in relation to different modes of economic circulation
The reproduction of urban inequality	How do existing urban flows distribute resources across the city and who controls these processes?	Patterns of unequal access to resources and the control of these patterns by urban elites
Resignifying socioecological relationships	What socioecological practices have the potential to reimagine and reconfigure existing socioecological flows?	Alternative visions and models of socioecological flows in cultural production, everyday practices, and policy innovations.

Fig. II.11. *Urban Metabolism: Themes and Research Questions. Source: Taken from* (Global Initiative for Resource Efficient Cities, 2018).

In this context, several standards, indicators, indexes, approaches and methodologies have been developed, as shown in the following part. Since the use of metabolism in the urban arena, the measurement of the metabolism has changed, and the methods to do so have evolved with less and more success (C. Kennedy, Cuddihy and Engel-Yan, 2007). Therefore, it is not a surprise to find a wide variety of urban metabolism studies with different fluxes analysis all over the world. This phenomenon happens first because of the data available, which are not always the same. For example, data for metabolic analysis can be available in one city from Europe, but not in one city from Africa. Moreover, the compatibility in units, indicators and frameworks makes it even harder to measure metabolism in order to compare whether a city or urban socio-ecological system has a better or worse metabolism.

In his work '*The Changing Metabolism of Cities*', Kennedy (2007) assesses the urban metabolic change in different historical and spatial contexts through the analysis of eight cities' metabolism in terms of four main flows –that he calls cycles-, which include water, materials, energy and nutrients (C. Kennedy, Cuddihy and Engel-Yan, 2007). He concludes that even if the metabolism of such cities cannot be compared directly through results, the change produced from one period to another can give an insight of whether a city –or urban socio-ecological system-, is increasing or reducing its metabolism.

According to Broto et al. (2012), the concept of UM has on the one hand, inspired new ways of thinking about how cities can be conducted towards sustainability and on the other, raised criticisms about how certain flows are prioritized or marginalized within the city (Broto, Allen and Rapoport, 2012). In the following part, some accounting approaches are presented.

II.3.2.1. Urban Metabolism Accounting Approaches

According to Zhang et al. (2015), to this date UM has evolved from a linear methodology to a cyclic processes methodology and then to network models methodology, as a result of the continuous searching of the system's characteristics, while accounting for flows of energy and materials (Zhang et al. 2015). In this direction, UM can help to observe how urban areas function, and a valuable concept for understanding urban processes and the relations between society and nature in urban areas (Rapoport, 2011).

In the Global Initiative for Resource Efficient Cities (GI-REC) MOOC[6] *'The Metabolism of Cities'* –on its 2018 version and in partnership with the United Nations-, six approaches are proposed to measure the metabolism of a city. Such approaches are proposed as counterparts of include: 1) Territorial Approach; 2) Consumption Approach; 3) Top-Down Approach; 4) Bottom-Up Approach; 5) Temporal Approach; and 6) Spatial Approach (Global Initiative for Resource Efficient Cities, 2018). According to this, each one of these approaches accounts the inflows, materials and outflows in different ways.

The territorial approach accounts "for all resources use and pollution emissions happening inside a territory". If what is needed is accounting for "all resources use and pollution emissions that are required to satisfy the consumption needs of a city", the consumption approach offers the solution (Global Initiative for Resource Efficient Cities, 2018). The main advantages of the territorial approach are that it is easy to use, data are frequent and accurate, it enables time series and there are large pools of cases studies that can be used as examples. However, it does not allow to measure indirect flows as there is no standard methodology and sometimes, some flows are unavailable. The consumption approach, on the other hand, is perfect to understand the indirect flows and link them with the global and local scales. Moreover, it spatializes hinterland and provides a systemic overview. The disadvantages of this approach is that there are no input/output tables, which makes experts indispensable to use the approach (**Fig. II.12**).

The next two approaches are the Top-Down and the Bottom-Up approaches. The first one provides "aggregated values of cities", while the second one uses infield measures and surveys. The Top-Down main advantage is that, as there are frequently published data, it is easy to compare data to other years and/or other cities. However, there might not available data in some communities, which means that it requires institutional infrastructure to work. Moreover, as it treats the city homogenously, the results might not always show what we want to measure (**Fig. II.13**).

---

[6] MOOC: Massive Open Online Course.

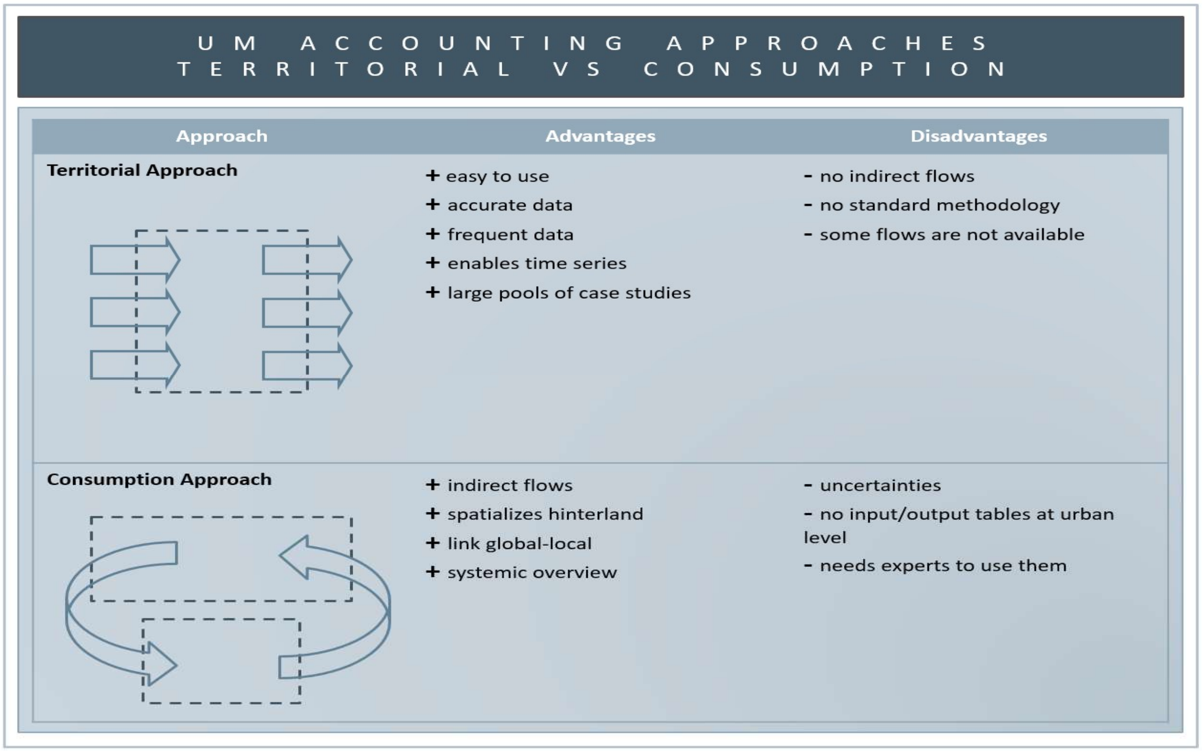


Fig. II.12. *Urban Metabolism Accounting Approaches: Territorial vs Consumption. Source: Taken from 'The Metabolism of Cities'* (Global Initiative for Resource Efficient Cities, 2018).

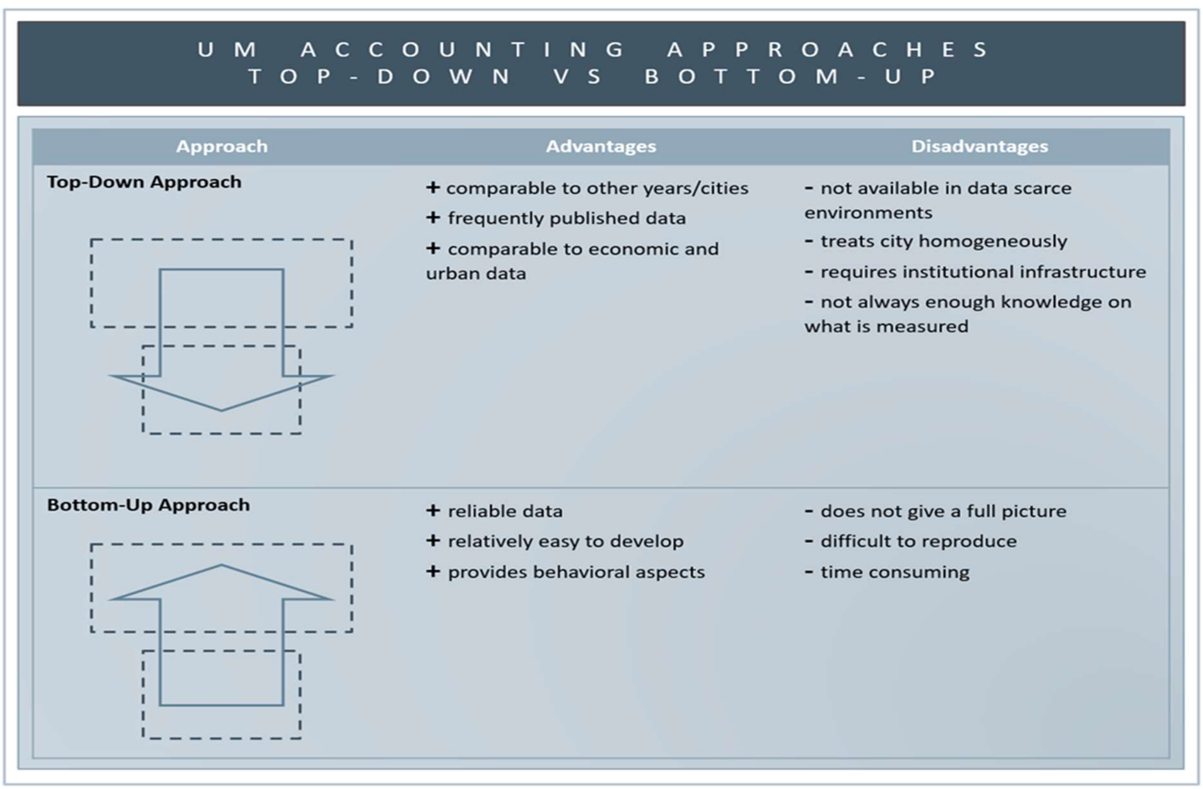


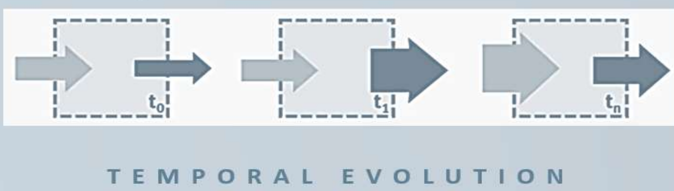
Fig. II.13. *Urban Metabolism Accounting Approaches: Top-Down vs Bottom-Up. Source: Taken from 'The Metabolism of Cities'* (Global Initiative for Resource Efficient Cities, 2018).

The las two approaches proposed by the Global Initiative for Resource Efficient Cities are the Temporal and the Spatial Approaches. The Temporal Approach (**Fig. II.14**) takes into account the evolution of the flows across time scales, while the Spatial Approach (**Fig. II.15**) takes into account the spatial resolution of problems (Global Initiative for Resource Efficient Cities, 2018).

UM ACCOUNTING APPROACHES
TEMPORAL APPROACH

INTEREST OF TEMPORAL INTERVALS

Interval	Relevance for policies
1 hour to day	Includes behavioral aspect
1-4 months	Takes into account seasonal changes
1 year	Monitoring/Compare with urban data
10 years	Identifies the effect of policies
50 years	Helps understand the role of infrastructure in resource use
100 years	Questions relationship between urbanization and resource use (hinterland)



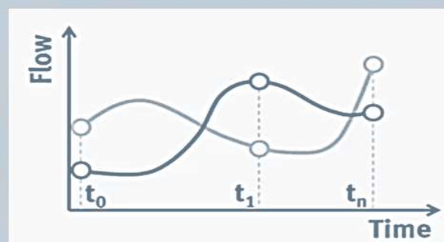


Fig. II.14. *Urban Metabolism Accounting Approaches: Temporal Approach. Source: Taken from 'The Metabolism of Cities' (Global Initiative for Resource Efficient Cities 2018).*

UM ACCOUNTING APPROACHES
SPATIAL APPROACH

Scale	Relevance for Policies
Region	Includes immediate hinterland, productive and extractive activities.
Metropolis	Accounts for commuting. Represents labor force and residential.
City	Official administrative boundaries, most available data.
Local government	Small administrative areas. Regulates permits.
Neighborhood	Homogenous spatial entity, sense of identity, proximity, food consumption.
Buildings/Households	Relation between socio-economic status and resource use, can be aggregated to any other spatial scale.

Fig. II.15. *Urban Metabolism Accounting Approaches: Spatial Approach. Source: Taken from 'The Metabolism of Cities'* (Global Initiative for Resource Efficient Cities, 2018).

II.3.2.2. Urban Metabolism Accounting Methodologies

The Global Initiative for Resource Efficient Cities (2018) identifies four main accounting methodologies for UM: 1) Data Collection Methodology; 2) Material Flow Accounting (MFA); 3) Input-Output Analysis (IOA); and 4) Life Cycle Assessment (Global Initiative for Resource Efficient Cities, 2018). A brief description is provided for each one of these methodologies and its advantages and disadvantages are presented in **Table II.1**, according to the GIREC's MOOC.

Data Collection Methodology

The Data Collection Methodology provides a general overview of a city's metabolism through the juxtaposition of data coming from different sources. The advantages are that it treats flows separately, which enables comprehensive policies. Moreover, there are many study cases. However, this methodology does not have an accounting method, it makes difficult the comparison because of the independence of the data and it is time-consuming. Finally, the sustainability of a system assessed through this methodology could be overestimated, as it does not account indirect flows.

Material Flow Accounting (MFA)

The MFA is the "systemic assessment of the flows and stocks of materials within a system defined in space and time" (Brunner & Rechberger 2004, p3). According to Adriaanse et al. (1997) material flow accounting can help to "track the physical flows of natural resources through extraction, production, fabrication, use and recycling, and final disposal accounting for all losses along the way" (Adriaanse et al. 1997, p5). The importance of this method is that allows understanding the drivers and feedbacks of the system, and not only the superficial metabolic requirement of a society, because of availability of data at small scales (Benavides Mondragón, 2017).

Input-Output Analysis (IOA)

The Input-Output Analysis (IOA) is a tool from the field of the macroeconomics that provides and overviews an economy by examining an input-output table (Global Initiative for Resource Efficient Cities, 2018).

Life Cycle Assessment

The Life Cycle Assessment is an assessment of all processes included in the manufacturing of goods and services going from the extraction to the end of life (Global Initiative for Resource Efficient Cities, 2018). According to GIREC, this method is composed of four interconnected phases: 1) Goal and scope definition; 2) Inventory Analysis; 3) Impact Assessment; and 4) Interpretation. According to Benavides (2017), this methodology assesses the environmental consequences of any product, activity or system, in order to provide information related to the implications of each stage of the unit's life (Benavides Mondragón, 2017).

Advantages and Disadvantages of UM Accounting Methodologies		
Methodology	**Advantages**	**Disadvantages**
Data Collection Methodology	+Treats each flow separately +Enables comprehensive policies +Loose framework +Lots of cases of studies	-Lack of accounting method -Difficult comparison -Very data dependent / time consuming -Black-box approach -Lack of environmental impact -It can overestimate sustainability
Material Flow Accounting (MFA)	+Consistent framework +Supports policy making through indicators +Very comparable +Available at national level +Useful for circular economy	-Low data availability -Not very relevant for cities -Aggregates all flows in tones -No environmental impact
Input-Output Analysis (IOA)	+Systematically complete +Covers the whole economy +Indirect effects +Links with global economy +Spatializes hinterland	-Almost no Input-Output tables at city level are available -Approximation for production recipes -Uncertainties -Time lag
Life Cycle Assessment	+Harmonized methodology +Comparison products and services +Upstream and downstream flows +Environmental Impact	-Sometimes arbitrary boundaries -For products and not cities -Not automatic spatialization of hinterland

Table II.1. *Advantages and Disadvantages of UM Accounting Methodologies. Source: Taken from MOOC 'The Metabolism of Cities'* (Global Initiative for Resource Efficient Cities, 2018).

II.3.2.3. Standards, Indicators and Indexes

The Global Initiative for Resource Efficient Cities (2018) identifies some standards, indicators and indexes that can help to measure urban metabolism: 1) ISO 37120, 2) The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (Global Initiative for Resource Efficient Cities, 2018). However, as they require data from the specific case of study, they will not be reviewed for the purposes of this work.

II.3.3. Urban Flows

Each process that is related to energy and materials can be considered as a flow, which can be defined as "the amount of change something undergoes during a particular length of time" (Kim, 1999, p19). Finally, vital to understand metabolism is the notion that an accelerated metabolism means that there is an overexploitation of resources –*inputs*-, and an increasing generation of waste –*outputs*-, which compromises the systems' sustainability. It has been observed, that some fluxes are more suitable, when assessing the UM. In the following part, the most important flows –water, energy, food and materials- are presented.

II.3.3.1. Water Flow

According to Kennedy (2007), water is "the largest component of urban metabolism in terms of sheer mass" (C. Kennedy et al. 2007, p45). When it is an output can be considered as wastewater. One of the main reasons to considerate water as an important flow in the metabolism analysis is that it constitutes a health determinant, because if drinking water cannot be guaranteed, vulnerability to diseases increases (Vlahov *et al.*, 2007).

II.3.3.2. Food Flow

The food or nutrients flow –according to Kennedy et al. (2007)-, is "vital to successful nutrient management strategies and urban sustainability" (Christopher Kennedy, Cuddihy and Engel-Yan, 2007). According to the UNEP (2016), studying this flow is central to reduce urban population's vulnerability to climate change associated to food insecurity (UNEP, Tong Keng Yam et al. 2016).

II.3.3.3. Energy Flow

It is central for the energy flow to understand, that it is composed by two types of emissions. The first one is the direct energy consumed, while the second one, is the primary energy consumption, which includes energy losses in the production of electricity (Christopher Kennedy, Cuddihy and Engel-Yan, 2007).

II.3.3.4. Materials Flow

This flows is usually very important to cities, especially because it constitutes a great part of the infrastructure (Christopher Kennedy, Cuddihy and Engel-Yan, 2007). This flow is also associated with the production and consumption activities in cities, including imports of raw materials and products to the city (Chen and Chen, 2015b).

Closing Remarks

After having reviewed the metabolism from the ecological sciences - as "the sum total of the chemical processes that occur in living organisms, resulting in growth, production of energy, and elimination of waste material" (Chen and Chen, 2015a)"; and the social sciences, as "processes which enable a community to appropriate, to circulate, to transform, to consume and to excrete materials or energies from the natural environment with the best efficiency possible" (Toledo, 2008a, p24); Urban Metabolism is defined as:

> *"the analysis of all technical and economic flows of energy and material associated with the production and consumption activities in cities, including imports of raw materials and products to the city from other economies or natural ecosystems, exchanges of goods and services between urban economic sectors, and materials leaving the cities' boundaries in the form of exports, gaseous emissions, or liquid and solid waste"* (Warren-Rhodes and Koenig, 2001; Christopher Kennedy, Cuddihy and Engel-Yan, 2007; Chen, Chen and Fath, 2014; Chen and Chen, 2015a).

In this context, several UM approaches, methodologies, standards, indicators are shown as part pf the evolution of the term and its applicability in the urban arena. Finally, some of the most important urban flows, that the UM considers as vital to understand a city's –or USES- metabolism, are explained.

II.4. Resilience in Urban Socio-Ecological Systems

In order to understand UR for USES, it is vital to understand what *Risk* is. Therefore, this chapter is divided into two sub-chapters. In *Risk*, we will review the traditional definition of the term, considering its three key elements -*hazard, exposure and vulnerability*-, and the risk matrix composed by the *hazards, severity and frequency* approach, which is widely used in working environments, as a mean to assess risks and ensure people's physical protection and health while working.

After that, in the second sub-chapter, *Urban Resilience*, the term 'resilience' is reviewed first from the ecological sciences perspective, and then, from the social sciences perspective, in order to provide a conceptual framework for what UR is. Finally, Urban Resilience is defined through the theoretical and practical approaches that are used in today's City's Resilience Assessment and Planning.

II.4.1.Risk

In the traditional natural disasters management perspective, 'Risk' can be defined as the combination of three determinants: *hazard* –including magnitude[7] and frequency-, *exposure* and *vulnerability* to the hazard event (Cardona *et al.*, 2012) (**Fig. II.16**).

Fig. II.16. *Key elements of Risk. Source:* (Cardona, 2012).

In this context, the UNDRO (1980) argues that *vulnerability* refers to "the propensity of exposed elements such as human beings, their livelihoods, and assets to suffer adverse effects when impacted by hazard events" (UNDRO, 1980). Meanwhile, *exposure* refers to "the inventory of elements in an area in which hazard events may occur" (Cardona, 1990; UNISDR, 2004, 2009; Cardona *et al.*, 2012). In this context, *resilience* is considered the counterpart of *risk* (**Fig. II.17**). In this context, resilience is defined as characteristic –including *coping capacity*[8] and *adaptive capacity*[9]-, desired for

[7] Severity

[8] In the context of Disasters Management, and according to the UNDRO (2009) a coping capacity is "the ability of people, organizations, and systems, using available skills and resources, to face and manage adverse conditions, emergencies, or disasters" (UNISDR, 2009).

[9] According to Cardona (2012) and in the context of Disasters Management, an adaptive capacity "refers to the ability of a system or individual to adapt to climate change, but it can also be used in the context of disaster risk" (Cardona et al. 2012, p73).

communities, societies or social-ecological systems that are affected by extreme and non-extreme weather and climate events (Cardona *et al.*, 2012). Therefore, a lack of resilience (in disaster risk management) or lack of coping and adaptive capacities (in climate change adaptation) are "limitations in access to and mobilization of the resources of the human being and their institutions, and incapacity to anticipate, adapt, and respond in absorbing the socio-ecological and economic impact" (Cardona et al. 2012, p72).

Fig. II.17. *Risk / Resilience. Source: Based on* (Asian Development Bank, 2013).

However, the Risk Assessment takes into account only the hazards that come from natural dimension, including climate change, -as well as the vulnerability and exposure-, which complicates the use of this definitions for USES. In this circumstance, a risk definition based on the *risk matrix* –often used by industry to assess risk based on the frequency and severity of the hazards-, was proposed to conduct this research as it allows the understanding of hazards that come from several dimensions –social, ecological, economical, political, and health-.

From this perspective, the approach towards risk and resilience interconnections in this research is appreciated in **Fig. II.18**. In this context, the hazards can be transformed into risks, when their exposure is assessed through *severity* and *frequency*. In this scenario, it is possible to assess the resilience of the USES, while finding its vulnerabilities. In this context, vulnerability is redefined according to Chapin (2009) as the "degree to which a system is likely to experience harm owing to exposure and sensitivity to a specified hazard or stress and its adaptive capacity to respond to that stress" (Chapin, Carpenter, et al., 2009, p241).

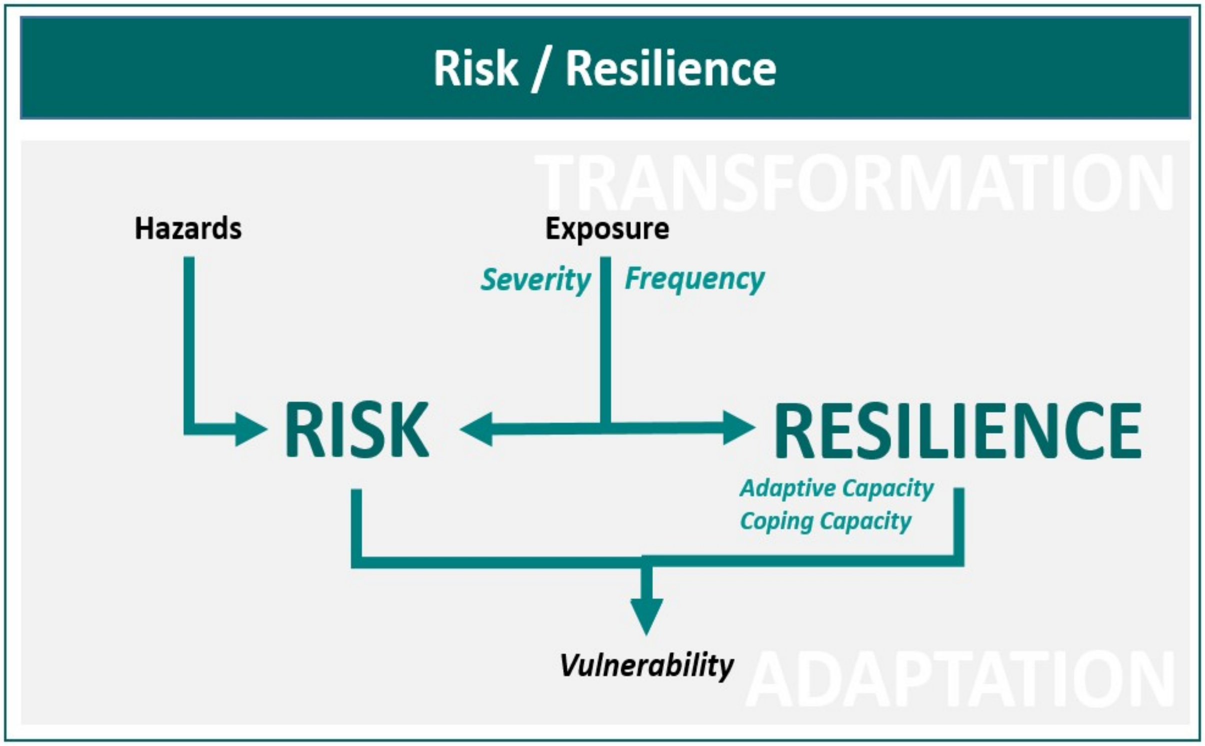


Fig. II.18. *Risk/Resilience. Based on* (Secretaría del Trabajo y Previsión Social, 2011; Asian Development Bank, 2013).

Moreover, according to Hallegatte & Corfee-Morlot (2011), understanding the nature of future risks and identifying the main drivers of urban vulnerability are key challenges for local actors (Hallegatte and Corfee-Morlot, 2011). After having explained the whole perspective of the risk concept managed in this research, the three redefined components of risk –hazards, frequency and severity-,are defined.

II.4.1.3. Defining Hazards for Urban Socio-Ecological Systems

To start with, the term *hazard* can have several meanings according to the context, and the author perspective. Hazards can be defined from the ecological and the social sciences perspectives. As a result, an evolution –in relation with the resilience conceptualization- on the term *hazard* is observable. For example, the Asian Development Bank (2013) defines urban resilience as "the ability to withstand and recover from unexpected shocks associated with natural hazards and climate change" (Asian Development Bank, 2013). In this context, *hazards* are both climate change and natural hazards, for example, hydro-meteorological events including floods, cyclones, storm surges, and droughts, as well as geophysical events, such as earthquakes, volcanic eruptions, and tsunamis. Moreover, the Asian Development Bank considers climate change as an accelerator of natural hazards (Asian Development Bank, 2013) (**Fig. II.19**).

In this direction, climate variability and change are hazards, but other events related to social, economic or political dimensions are considered only as a vulnerability's intensifier. In addition, Romeo-Lankao & Gnatz (2013) argued that "patterns of resource use and of response to hazards are mediated by each nation's economy, environment, institutions and culture" (Romero-Lankao and Gnatz, 2013).

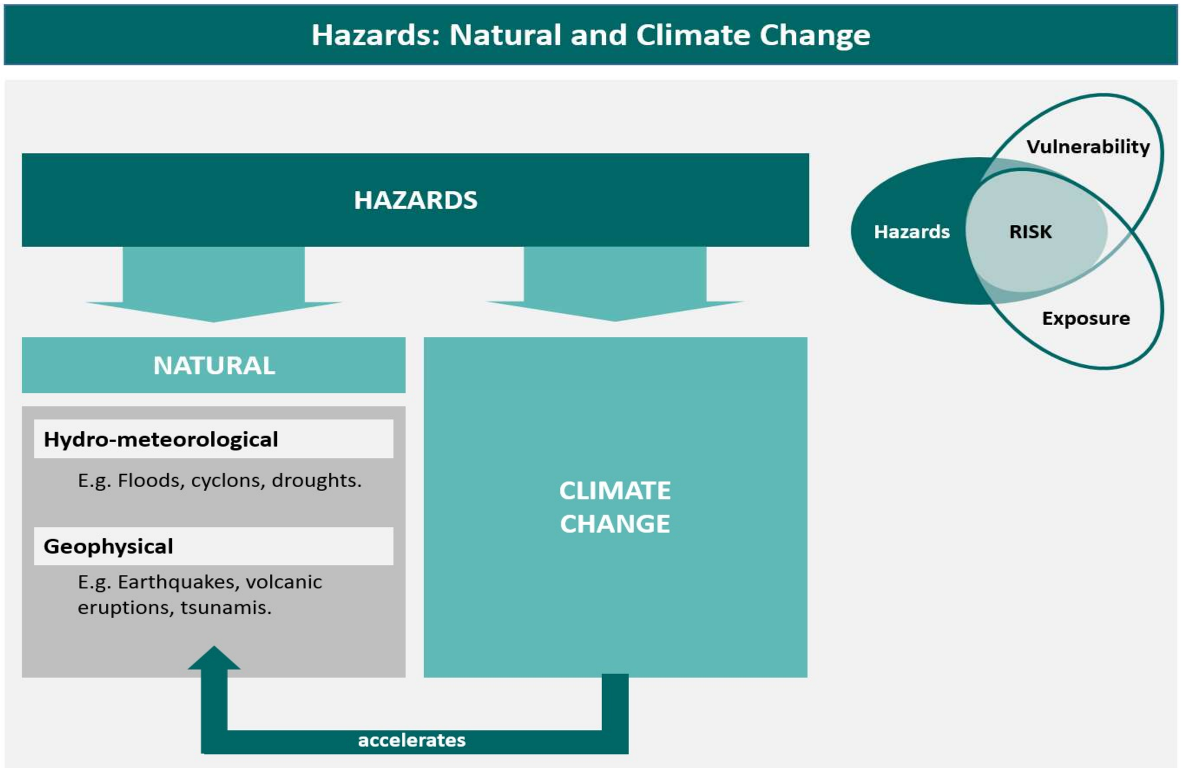


Fig. II.19. *Hazards divided on natural hazards and climate change related hazards. Source: Based on the Asian Bank Development definition of Risk* (Asian Development Bank, 2013).

Most authors that work with risk reduction, use this approach in which natural hazards and climate change are seen as the major threat to society, without taking into account social, educational and technological hazards as hazards, but as factors, dimensions or contexts.

Another example of this hazard's categorization is the one proposed by Middleton & Sternberg in 2013, in which they divided hazards for drylands in two main categories: natural and climate hazards in drylands. After that, the divided climate hazards in two categories: 1) *direct climate hazards*, which include droughts, dust storms, sand dune movement, flash floods, wildfire, dzud[10] and heat waves; and, 2) *indirect hazards*, which included biological dryland hazards and the 'desertification' hazard (Middleton and Sternberg, 2013) (**Fig. II.20**). As it is observable, hazards' source is on the nature, in other words, hazards can only come from the ecological dimension.

Contrary to the first perspective, the literature review suggests that some authors visualize ecological, social and economic issues as challenges that can become hazards, if fostered by climate change

[10] According to Middleton & Sternboy, "a dzud occurs when extreme winter cold, snow and ice render forage inaccessible or unavailable, resulting in high livestock mortality" (Middleton and Sternberg, 2013).

(Wagner and Breil, 2013). The reason is that natural hazards are also the result of complex biophysical and economic interconnected systems (Bevacqua, Yu and Zhang, 2018).

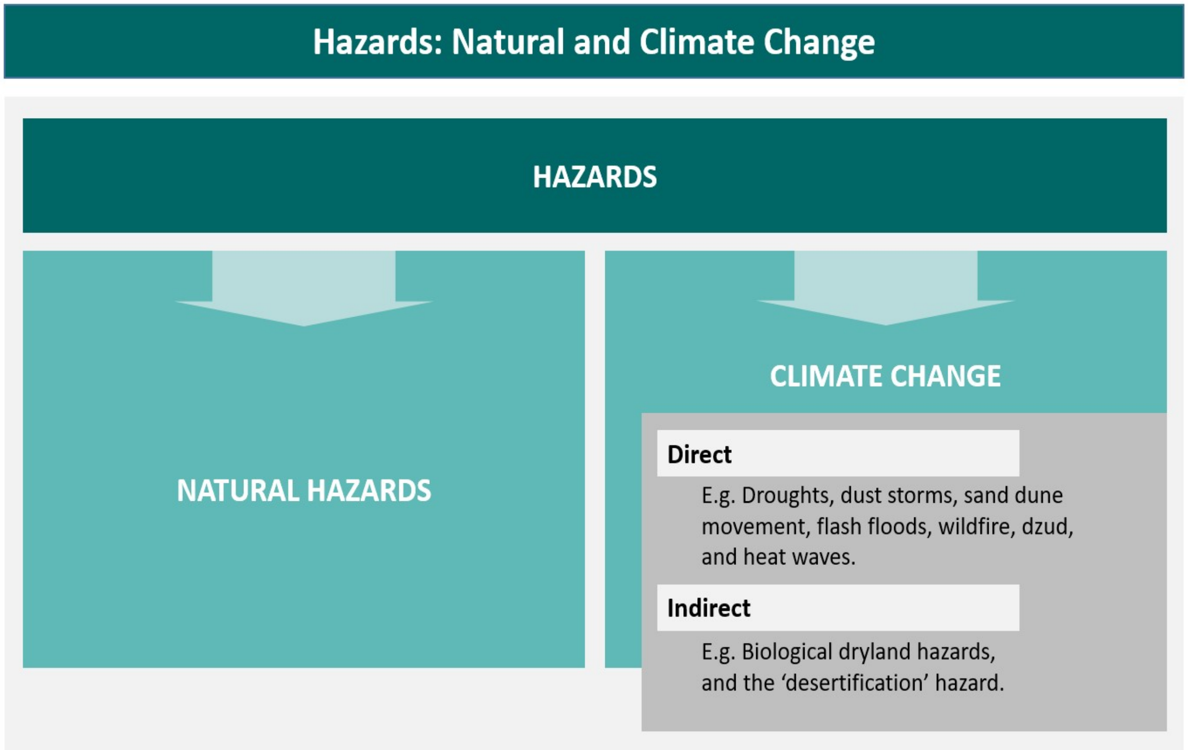


Fig. II.20. *Hazards divided on natural hazards and climate change hazards (direct and indirect). Source: Based on the Middleton & Sternberg's "Hazards for Drylands Model"* (Middleton and Sternberg, 2013).

As a result, hazards are considered as natural driven, but fostered by socio-economic factors, that can affect a system's resilience (Mochizuki *et al.*, 2014; Adriana Gracia *et al.*, 2017). In addition, anthropogenic actions exacerbate climate change and therefore, hazards are exacerbated and therefore, the frequency and severity of extreme events increases (Sharifi and Yamagata, 2016).

A more developed approach that follows this schema is the one developed by Kenny (2017), in which '*risk*' is seen as the interplay between environmental, economic and social processes (Kenny, 2017) (**Fig. II.21**). In this scenario hazards are both *natural* (variability), and *anthropogenic* (climate change); in addition, both are affected by emissions, land use change and impacts from socio-economic processes, for example socio-economic pathways, governance, and adaptation and mitigation actions.

Kita (2017) also considers that challenges can be physical, social, economic, political or environmental, and that they can increase the impact of natural and climate change related hazards (Kita, 2017). Despite the fact that this author somehow considers socio-ecological systems as complex entities, he does not consider social and economic problems as *hazards*, but only if they are combined with ecological or climate change related hazards.

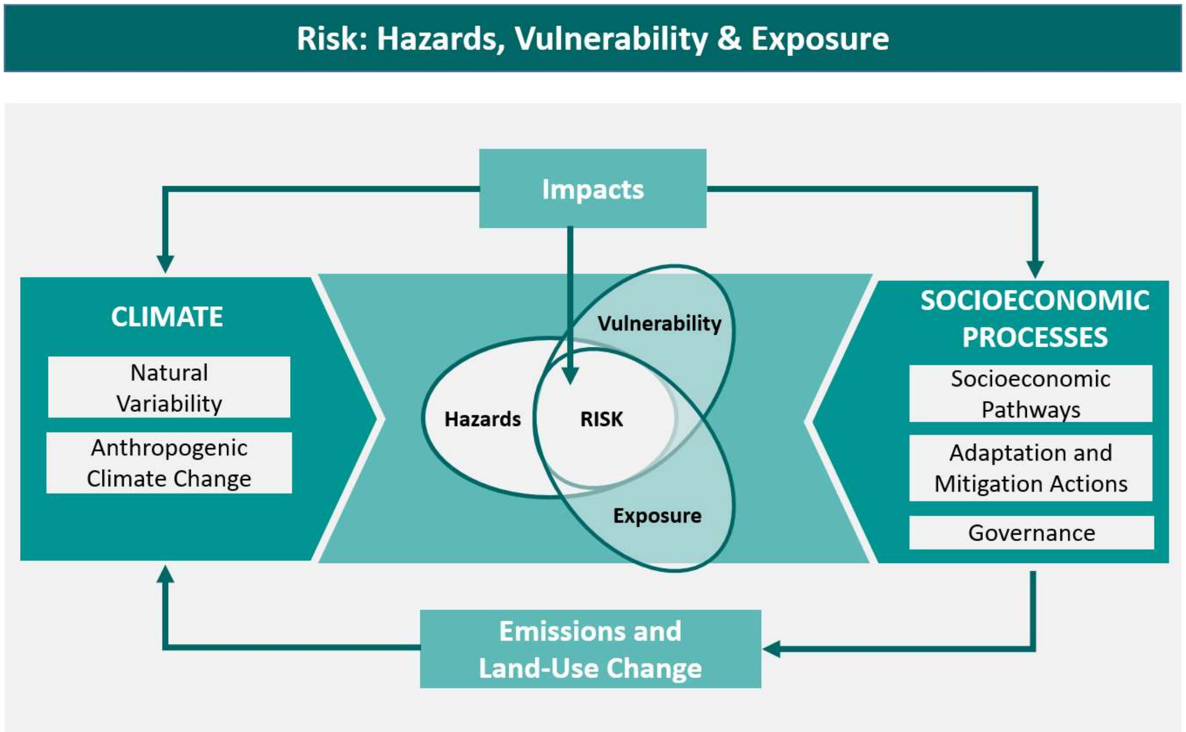


Fig. II.21. *Risk: Hazards, Vulnerability & Exposure. Risk as the interplay between environmental, economic, and social processes. Source: Based on* (Kenny, 2017).

Other authors with a multi-dimensional approach categorize *hazards* according to the sector –or system- they are affecting. That is the case of Sonwa et al. (2012), who analyze vulnerability emphasizing on three sectors: 1) food and health, 2) energy and 3) water. Having found the hazards from each sector, they make an inter-sectoral analysis, in which, they discover that human-induced pressures on forest ecosystems are more than climate change pressures (Sonwa *et al.*, 2012).

Thinking back on Sonwa's research, it is recognizable that hazards identified are: 1) climate change and variability (increase in temperature, changes in precipitation, changes in seasonal patterns, hurricanes and storms, increase in CO_2 levels, sea level rise, land see change, landscape fragmentation, resource exploitation); and 2) human-induced hazards (Sonwa *et al.*, 2012). This is a clear example, which shows that urban populations and economic sectors are not only negatively affected by hazards, but also ecological systems face hazards resulting from human pressures on the environment (Romero-Lankao and Dodman, 2011).

What is more, ecological and man-made hazards are becoming extreme and complex due to the impacts of climate change, urbanization and changing land-use patterns (Sharifi and Yamagata, 2016; Faivre *et al.*, 2017; Bevacqua, Yu and Zhang, 2018).

Another example of this hazards' perspective, was the one proposed by Elliot, Cutts & Trono (2010), in which they characterized coastal and coastal wetland area hazards while assessing the vulnerability of coasts. For the purposes of their research, they divided hazards in three categories: 1)

Natural hazards; 2) Anthropogenic; and 3) Natural but exacerbated by human activities (Elliott, Trono and Cutts, 2010; Elliott, Cutts and Trono, 2014).

In this context, there are also examples of problems that can fall in the three categories of hazards. That will be the case of wildfires, which are a hazard themselves, but also can be produced due to: 1) Other natural hazards; 2) natural hazards exacerbated by human activity (indirectly increase on global temperatures); and 3) anthropogenic, which can be uncontrolled fires (Úbeda and Sarricolea, 2016) (**Fig. II.22**).

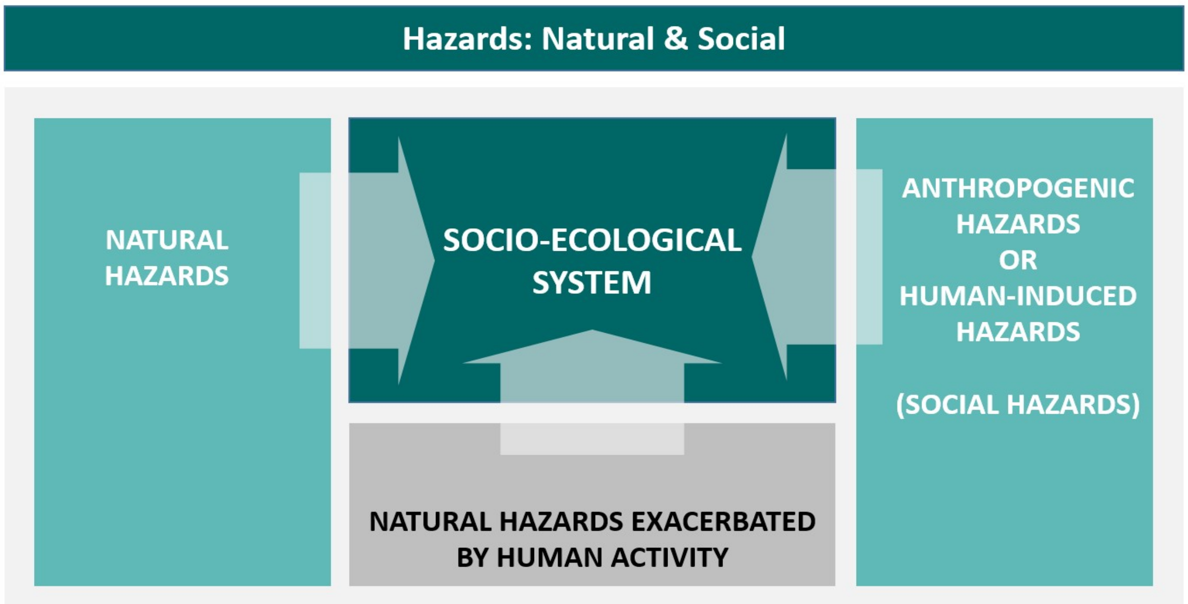


Fig. II.22. *Natural & Social Hazards. A socio-ecological system can be vulnerable to natural hazards, human-induced (anthropogenic or social) hazards, and natural hazards, which are exacerbated by human activity. Source: Based on* (Romero-Lankao and Dodman, 2011; Sonwa *et al.*, 2012; Elliott, Cutts and Trono, 2014; Úbeda and Sarricolea, 2016; Faivre *et al.*, 2017; Bevacqua, Yu and Zhang, 2018).

Technical hazards is other name for those hazards, which were induced by human activities (Renaud *et al.*, 2013). In addition, for other authors, hazards can be divided in natural and human-induced environmental hazards (including climate change) (McBean and Ajibade, 2009). In this perspective, they consider the social, economic and political challenges as hazards' intensifiers.

Such approaches are similar to the one proposed by Vastag (1996), which considers on the one hand, endogenous environmental hazards, which arise from the internal operations of the system and on the other, the exogenous environmental hazards (Vastag G, 1996). In this context, both were determined by the systems' external context: its location, it's ecological setting and the demographic characteristics of the physical environment in which it operates (Bhowmik *et al.*, 2017).

Another perspective, is the multi-dimensional, which is related to sustainability assessments, in which indicators are based on the three sustainable dimensions -ecological, social and economic- and therefore, hazards are related to each dimension. For example, in 2014, Michael, Noor and Figueroa reviewed the indicators used to assess sustainability, which were related to specific characteristics according to each case of study (Michael, Noor and Figueroa, 2014). They do not call challenges whit the term of '*hazard*', but it is observable that such problems are hazards related to sustainability's dimensions.

In the multi-dimensional perspective the system's vulnerability itself is considered as a hazard. For instance, some social hazards like poverty, according to the concept of vulnerability (Nazari *et al.*, 2015), which used in different contexts refers to the degree in which a system is susceptible to be harmed by factors and stressors (Burg, 2008; Deressa, 2010).

Hazards can also be separated into: 1) *Shocks* (sudden), which integrate natural hazards; and, 2) *Stresses* (chronical), which incorporate the socio, ecological and technical hazards that are always part of any socio-ecological system (**Fig. II.23**). This perspective considers hazards, the perturbations, the stresses and the stressors of a system (Turner *et al.*, 2003; Nazari *et al.*, 2015).

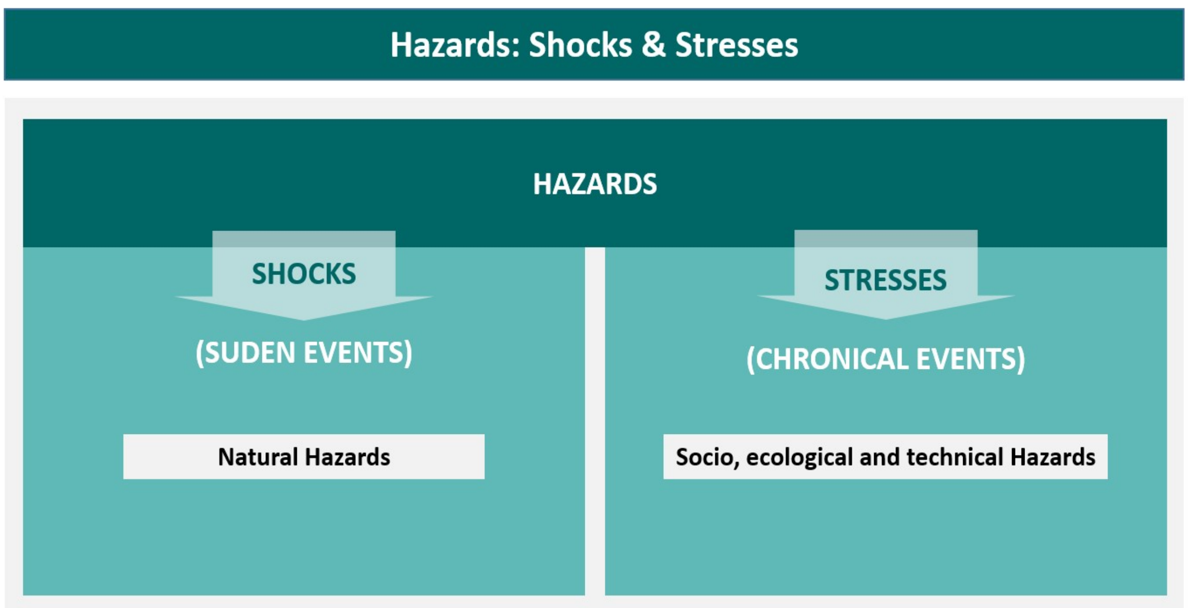


Fig. II.23. *Shocks and Stresses as Hazards. Source: Based on* (Turner *et al.*, 2003; Nazari *et al.*, 2015; The Rockefeller Foundation, 2017)**.**

This is also important to consider when defining hazards, because while chronic stressors are well-known, recurrent and can often be estimated -urbanization and ageing of infrastructure-, acute shocks are unpredictable, uncommon, and can have devastating consequences -floods, earthquakes, disease outbreaks and terrorist attacks- (Juan-García *et al.*, 2017). For example, populations are also vulnerable to wealth and culture challenges (Boyd and Juhola, 2015). Therefore, social and economic aspects, such as migration, global economics, and depreciation and inflation rates can also be considerated as hazards for certain socio-ecological systems.

Further, natural hazards and climate change-related hazards are in strong relation with social, economic and politic factors, that can eventually become stressors, and therefore, *hazards* (Romero Lankao and Qin, 2011). In this context, Romero Lankao & Qin (2011) argued that "urban centers and their populations are not only exposed to climate hazards, but also exposed to a variety of ecological and societal stresses and shocks" (Romero Lankao and Qin, 2011).

In fact, cities are challenged by a high complexity of acute and chronic problems, including hazards that can be related to economic development, social polarization and segregation as well as climate change and ecological degradation (Spaans and Waterhout, 2017). In this direction, Spaans considers problems as complex in themselves, but also as interrelated hazards, with causes and consequences in other hazards. Needless to say that the urban places are nowadays increasingly reliant on the functioning of globalized markets, food and finance systems, socio-ecological systems are also open to contagion from distant extreme events (David Harvey, 1989; Ziervogel *et al.*, 2017). Therefore, hazards can be not only ecological and climate hazards, but also, economic, political, physical and technological (Ziervogel *et al.*, 2017) (**Fig. II.24**).

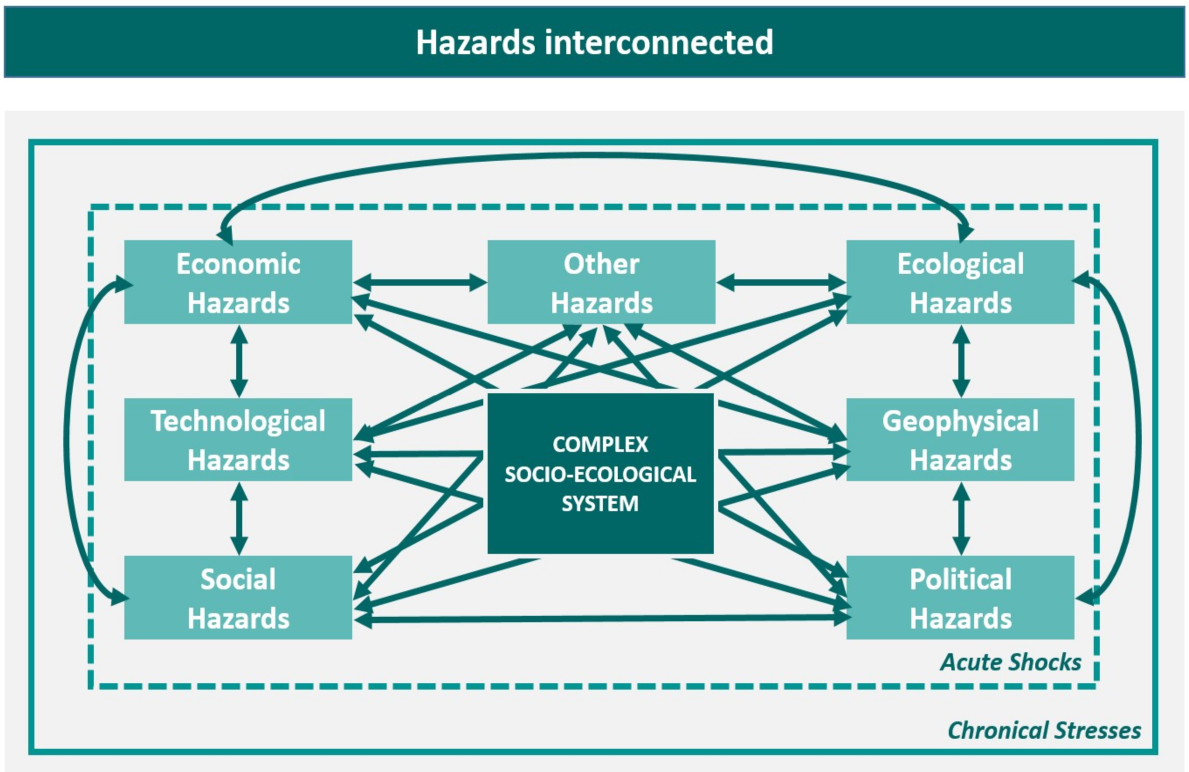


Fig. II.24. *Hazards interconnected. Hazards as part of an interconnected system in which hazards have an impact on a complex socio-ecological, as well as on other hazards. At the same time, hazards can be intensified due to other hazards. Source: Based on* (Spaans and Waterhout, 2017; Ziervogel *et al.*, 2017).

Furthermore, it is imperative to avoid hazards simplification, because a system can be resilient to a range of hazards that can include everyday hazards, small hazards, and large hazards (Fraser *et al.*, 2017). Moreover, some authors recognize the complexity and uncertainty in each urban system, and therefore define hazards, according to the specific case of study. For example, Crowe, Foley and Collier (2016), recognize that hazards can be ecological, but also, social, cultural and economic (Crowe, Foley and Collier, 2016); in addition, they can be from outside the socio-ecological system, as well, as from the inside. Despite the fact that they do not attempt to define hazards, they reflect on the flexible categorization of hazard according to each system's characteristics.

In this complexity perspective, it is central to mention, that other authors also consider the complexity of hazards, but stay with the UNISDR[11]'s hazards definition[12] (UNISDR, 2017) in order to give uniformity to the researches. That is the case of Tatebe (2015), who considers hazards as natural and climate-change related in order to keep uniformity in his research, and therefore defines the economic, social and environmental dimensions as contexts of natural hazards (Tatebe and Mutch, 2015).

In addition, Faivre et al. (2017) also added the term of "emerging hazards" to name all those hazards that might be part of our reality, but that are not yet considered as hazards (Faivre *et al.*, 2017). Once more, uncertainty to emerging hazards should be considered in order to establish conceptual, methodological, management and legal framework for disaster risk reduction, which are both: flexible and effective.

Considering complexity of hazards is therefore, very important to construct social awareness about risk exposure. Bonaiuto (2016) found that people in general tend to classify hazards according to place attachment, which means that local hazards –such as water scarcity, deforestation or floods- are not perceived as hazards, while global hazards –wars, climate change, global warming- are actually, perceived as hazards (Bonaiuto *et al.*, 2016). This categorization of hazards is also important to consider, especially when building hazards and vulnerability maps in any dimension, and when implementing resilience strategies to deal with a specific hazard.

It is observable that the term of *hazard* has evolved in the last years, and therefore, hazards perspectives can be identified according to what authors understand and interpret as *hazard*. It is undeniable that some entities and authors stay in the first two categories, when doing research in order to provide uniformity. However, as socio-ecological systems are complex and uncertain, analyzing hazards must be more extensive, especially when it is mandatory to understand the whole reality and not just a part of it (**Fig. II.25**).

To conclude this section it it important to mention that risks are classified in three categories: 1) Simple risks, which are easy to understand, categorised, and responded to; 2) Complicated risks, which are a combination of many simple risks; and 3) Complex risks, which are risks that cannot be broken into pieces in the same way as simple or complicated risks (Keys W. 2018). Following this

[11] United Nations Office for Disaster Risk Reduction.

[12] UNISDR, defines 'hazard' as "a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation". They classify hazards as biological, environmental, geological/geophysical, hydro-meteorological and technological. Moreover, they recognize that hazards can be natural, anthropogenic or socio-natural in origin (UNISDR 2017).

direction, hazards can also be simple, complicated and complex, which constitues a challenge when assessing risk and resilience for complex USES.

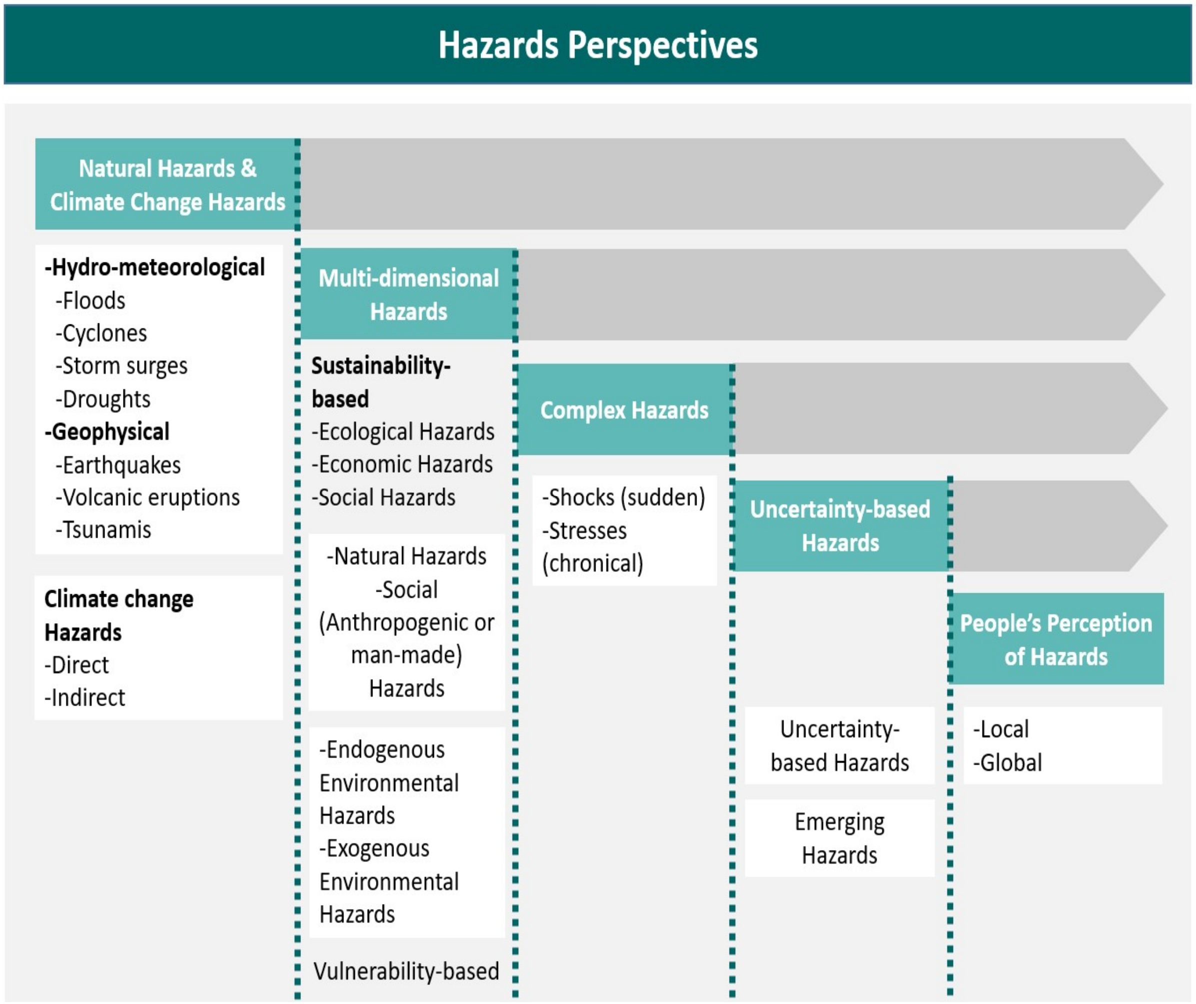


Fig. II.25. *Hazards Perspectives. Source: Own source, based on literature's review.*

II.4.1.1. Defining Frequency for Urban Socio-Ecological Systems

The frequency can be defined as the probability of something -hazard-, occurring (Aptikar, 2005). In this methodology, such probability can be remote, isolated, occasional, recurrent or frequent, as observed in **Table II.2** (Secretaría del Trabajo y Previsión Social, 2011).

Hazards Frequency for USES	
Nomenclature	**Definition**
Remote	It can exceptionally occur
Isolated	It can hardly occur
Occasional	It happens a few times
Recurrent	It happens frequently
Frequent	It happens regularly

Table II.2. *Frequency for USES. Source: Taken from NOM-031-STPS-2011* (Secretaría del Trabajo y Previsión Social, 2011).

II.4.1.2. Defining Severity for Urban Socio-Ecological Systems

The *severity* can be defined as the level of harm of hazard and according to the NOM-031-STPS-2011, it can be classified as minor, moderate, damage, or fatal, according to the definitions presented in **Table II.3** (Secretaría del Trabajo y Previsión Social, 2011).

Hazards Severity for USES	
Nomenclature	**Definition**
Minor	Without harm or temporal harm
Moderate	Harms that last more than 3 days
Damage	Permanent incapacity
Fatal	Death

Table II.3. *Severity for USES. Source: Taken from NOM-031-STPS-2011* (Secretaría del Trabajo y Previsión Social, 2011).

II.4.2. Urban Resilience

Urban Socio-Ecological Systems face a wide number of complex challenges. Firstly, they need to adapt to climate change while applying strategies to mitigate or control natural hazards, as well, as their cascading effects. Secondly, there is and increasing necessity of adopting green technologies, infrastructure and services to ensure sustainability. Thirdly, as urban environments involve a social dimension, challenges related to wealth, population growth and culture arise. What is more, more people in a specific urban area means more pollution, and with it, negative effects in health and social security (Boyd and Juhola, 2015). In this context, Urban Resilience (UR) can act as a counterpart of such challenges.

As a mean to understand UR, the concept of resilience will be explained from the natural and social sciences. After that, UR will be defined, based on some theoretical and practical approaches that are currently being used to asses city's resilience. To conclude, UR will be defined as a desired status with certain qualities.

II.4.2.1. Resilience

Resilience, a term with roots in the Latin '*resilio*', which means '*to bounce*' was first used to describe leaping, jumping or rebounding in classical times by "accomplished men of letters" such as Pliny the Elder (Reyers and Lee Moore, 2017). Since then, it has been used in several contexts with positive –and also negative- connotations. Since the 1970s resilience has become a vital concept in the study of ecosystems and some years after it became important to help in the description of systems, institutions, social systems and socio-ecological systems (Reyers and Lee Moore, 2017).

C. S. Holling (1973) defined resilience as the capacity of a system, which in spite of being under disturbances and changing conditions, is able to absorb change and to continue developing (Holling, 1973; Reyers and Lee Moore, 2017). In this direction, change stopped being considered as something *to be avoided* to something vital and –even desirable- which helps a system to become more robust, diverse and better prepared to deal with uncertainty (Reyers and Lee Moore, 2017). In this context, resilience allows the understanding of USES, as complex and dynamic entities made up of many social, ecological, economic, environmental, cultural, human, and manufactured parts (Reyers and Lee Moore, 2017).

II.4.2.1.1. Resilience from the Natural Sciences Perspective

The term *resilience* is the "ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to, and recover from the effects of a hazard promptly and efficiently by preserving and restoring essential basic structures" (UNISDR, 2011). In this context, a resilient community is that one which is able to absorb disturbances, change, reorganize and still retain the same basic structures and provide the same services (Resilience Alliance, 2007).

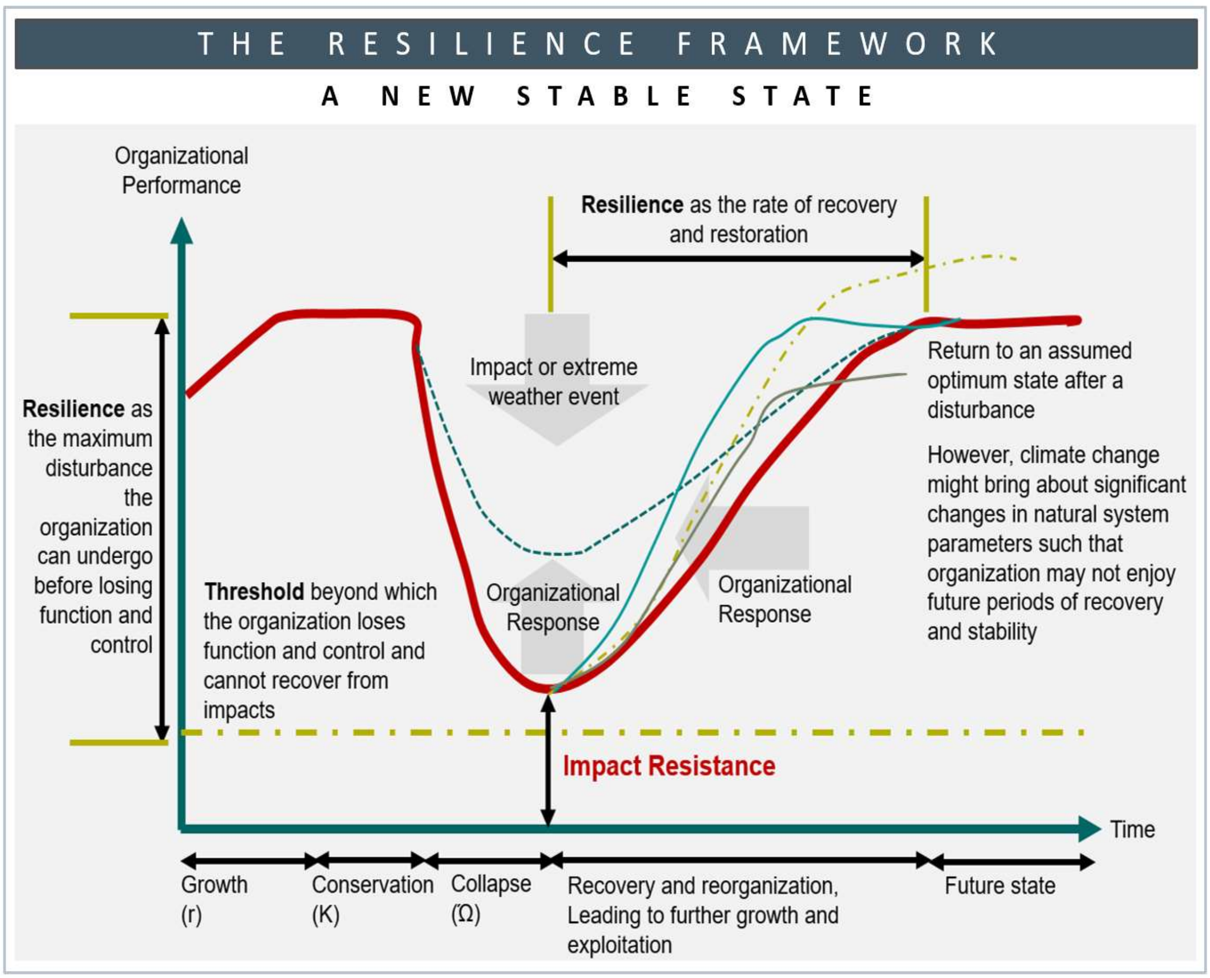


Fig. II.26. *The Resilience Framework. A new stable state. Source: Based on the Resilience Framework* (Linnenluecke and Griffiths, 2010; Lu and Stead, 2013).

The concept of resilience is used in the disasters field as a way of understanding the ability of a system to avoid damage as a result of a natural hazard impact (Johnson and Blackburn, 2014). It has been used in reference to different scales and different kinds of systems. In recent years, it has increasingly been used to conceptualize the ideal characteristics of an urban system that can withstand natural hazard events and the direct and indirect impacts of climate change (Johnson and Blackburn, 2014). Resilience is frequently presented as a counter to risk, creating a series of tensions for policy makers, politicians and for practitioners tasked with making 'resilience' happen, on-ground (Beilin and Wilkinson, 2015).

In **Fig. II.26** there is a red line representing the ecological perspective of resilience, which means that after an impact or extreme weather event the system can return to an assumed optimum state after disturbance. Moreover, such stability can also mean to reach a new stable state which can be lower or higher respectively from the normal state (Lu and Stead, 2013). Such hard science's perspective is usually used by some authors as to define a system's robustness and flexibility, for example Lu and Tead (2003): "a system's robustness is determined according to its 'strength' to carry and absorb uncertain disturbances, whilst its rapidity refers to the flexibility to rearrange itself into a new stable state (which is not always the same as its previous state) after a collapse occurs".

Central to the notion of resilience in the ecological sciences' perspective (hard sciences), are the key concepts of *coping capacity* and *adaptive capacity*, especially in the context of Disasters Management. According to the UNDRO (2009) a coping capacity is "the ability of people, organizations, and systems, using available skills and resources, to face and manage adverse conditions, emergencies, or disasters" (UNISDR, 2009, p73). Meanwhile, according to Cardona (2012), an adaptive capacity "refers to the ability of a system or individual to adapt to climate change, but it can also be used in the context of disaster risk" (Cardona et al. 2012).

II.4.2.1.2. Resilience from the Social Sciences Perspective

Pickett, Cadenasso & Grove's (2002) defined resilience from a metaphorical perspective, which results more suitable to the social sciences. To start with, they clarified that any technical term in ecology has three kinds of connotation: meaning, model, and metaphor (Pickett and Cadenasso, 2002). In this context, the meaning would be the core definition of a concept that can apply to any appropriate situation or instance; the models enable the translation of the core meaning to a real or proposed situation, as they are representations of systems; and the metaphor work as figures of speech which permit to take one thing for another, which is different, and present it as a visual analogy that can be creative when applied in new situations (Pickett and Cadenasso, 2002). Moreover, metaphors help us to understand something in terms of name or description , which is not literally applicable to it (Jackson, 2003).

As cities possess the human factor, their *adaptive capacity* differs from the common ecological systems' perspective, as they are SES with various dynamics and their resilience might be as well affected by social factors. In this context adaptive capacity refers to the mechanisms of *learning process* or *evolution of novelty* (Carpenter *et al.*, 2001).

In this context, Pickett (2014), following Yohe and Tol (2002), argued that the determinants of *social adaptive capacity* can be several (Yohe and Tol, 2002; Pickett *et al.*, 2014):

- Range of technologies available
- Available resources and their allocation
- Structure of decision-making institutions
- Human individual capital
- Social capital, including property regimes
- Access to risk spreading
- Ability to manage and critically examine information
- Public perception of stress and its local manifestation

In addition, Pickett (2014) argued that *adaptive processes* in the biophysical realm, considering Scheiner & Willig's (2011) ecological theory include (Scheiner and Willig, 2011; Pickett *et al.*, 2014):

- Genetic variation and evolution
- Organismal plasticity
- Richnes of species and functional groups
- Regulatory population feedbacks
- Stocks of limiting resources and their retention
- Key biological ecosystem structures
- Meta-community and dynamic spatial heterogeneity
- Limitation of biotic sink patches
- Scaled connectivity
- Compartmentalization of disturbance

Therefore, the *adaptive cycle*, which is the resilience framework from the ecological perspective, can only provide a temporal framework for considering how the social adaptive processes might differ, depending on the reorganizational or the conservative mode of a system (Pickett *et al.*, 2014). In **Fig. II.27**, the adaptive processes, which take part in social and biophysical realms, according to Pickett et al. (2013) can be observed. As appreciated, they include: 1) Social adaptive processes; 2) Social conditions favorable for adaptation; 3) Biophysical adaptive processes; and 4) Biophysical conditions favorable for adaptation (Pickett *et al.*, 2013).

Overall, it is observable that social systems are more complex than ecosystems because they incorporate the social dimension, and its implications in their adaptive cycle, as well as in their dynamics. That is the reason why it is important to keep a systemic socio-ecological perspective of resilience when observing a SES, especially if it is a city or a USES.

In this context, Chapin (2009) defined 'resilience' from a socio-ecological perspective as the "capacity of a social–ecological system to absorb a spectrum of shocks or perturbations and to sustain and develop its fundamental function, structure, identity and feedbacks as a result of recovery or reorganization in a new context." (Chapin *et al.*, 2009).

As we can see, the lack of integration between natural and social research, miss-match between spatiotemporal scales and lack of common vocabulary can lead to misunderstandings of concepts. However, when extrapolated, common challenges can be better understood from an interdisciplinary perspective and bring advantages to more than one field, as they can help to consider new pathways to take advantage and acquire a common meaning framework and applied approaches (Frank, Delano and Caniglia, 2017).

ADAPTIVE PROCESSES IN SOCIAL AND BIOPHYSICAL REALMS

1. Social adaptive processes	2. Social conditions favorable for adaptation	3. Biophysical adaptive processes	4. Biophysical conditions favorable for adaptation
• a. Technology development and acquisition • b. Decision-making • c. Locational choice • d. Risk spreading • e. Generating, managing and vetting information • f. Change in public perception and valuation • g. Institutional change	• a. Range of technologies available • b. Available resources • c. Demographics • d. Human capital • e. Social capital • f. Ability to deal with information • g. Information networks that work • h. Institutional change capacity	• a. Selection and Evolution • b. Meta community dynamics and change • c. Successional capacity • d. Organism-level plasticity, acclimation, etc. • e. Regulatory feedbacks on populations • f. Ecosystem nutrient retention	• a. Species and functional group richness and availability • b. Abundant resources • c. Intact, "healthy" key structures • d. Scaled connectivity • e. Compartmentalization of disturbance

Fig. II.27. *Adaptive processes in social and biophysical realms. Source: (Pickett et al., 2013).*

II.4.2.2. Urban Resilience: An USES Perspective

Urban resilience has a multidisciplinary and complex nature (Jabareen, 2013), which is the reason why such a concept is hardly theorized. The lack of vocabulary, concepts, theories, frameworks and applied approaches in the urban resilience studies have led to take terms from other disciplines to address problems raised in other fields in order to try to full-fill the terminology for urban studies (Frank, Delano and Caniglia, 2017).

Based on the facts that global climate change, the increasing effect of global teleconnections (Seto *et al.*, 2012), as well as the need of reducing risk posed by climate change (Pincetl, 2012) are transforming the shape of cities, Pickett (2014) suggests the raise of a new 'contemporary urban ecological science' (Pickett *et al.*, 2014) in order to assemble the contextual and conceptual aspects of contemporary urban change into a framework (**Fig. II.28**).

In this context, Resilience Alliance (2010) defined resilience as a system property which "refers to the magnitude of change or disturbance that a system can experience without shifting into an alternate state that has different structural and functional properties and supplies different bundles of the ecosystem services that benefit people" (Resilience Alliance, 2010, p5).

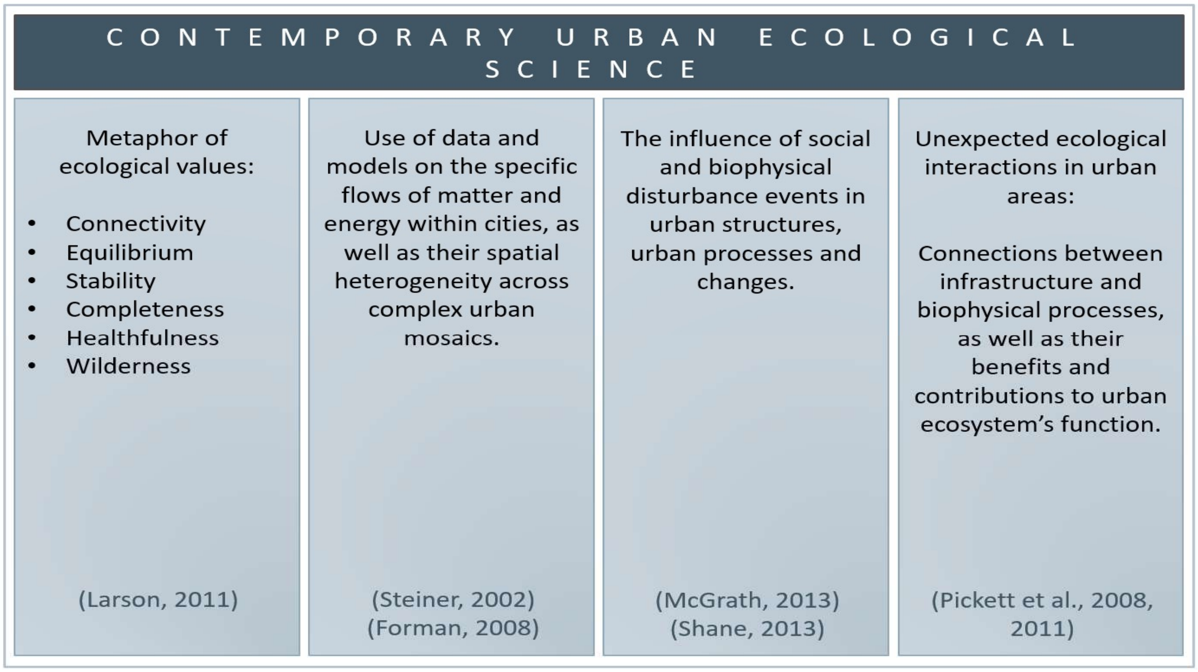


Fig. II.28. *Contemporary Urban Ecological Science. Contemporary Urban Ecological Science according to Pickett et al. (2014) considering Larson, Steiner, Forman, McGrath, Shane, and Pickett* (Steiner, 2002; Forman, 2008; Pickett, S. T. A. *et al.*, 2008; Larson, 2011; Pickett *et al.*, 2011; McGrath, 2013; Shane, 2013). *Source: Based on* (Pickett *et al.*, 2014).

The Rockefeller Foundation & ARUP (2015) defined city resilience as "the capacity of cities to function, so that the people living and working in cities –particularly the poor and vulnerable- survive and thrive no matter what stresses or shocks they encounter" (The Rockefeller Foundation & ARUP, 2015, p3). Urban resilience can also be defined as "the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience" (LeTourneau *et al.*, 2016). In this direction, Folke (2017) argued that, "resilience research emphasizes the interplay between gradual change and abrupt change" (Folke, 2017). In this context, we can have two types of changes. Changes can be rapid or gradual. Despite the fact that both affect human environment, gradual changes or stresses can be considered as more critical because, as they are less obvious, they accumulate until they reach a tipping point in which the system has to change into an entirely new system state (Reyers and Lee Moore, 2017).

In the book "Principles for Building Resilience: Sustaining Ecosystem Services in Social-Ecological Systems", published by Cambridge University Press (2014) a set of seven principles are presented and considered as crucial for building resilience in social-ecological systems. Such principles include: 1) Maintain diversity and redundancy, 2) Manage connectivity, 3) Manage slow variables and feedbacks, 4) Foster complex adaptive systems thinking, 5) Encourage learning, 6) Broaden participation, and 7) Promote polycentric governance systems (Biggs, Schlüter M. and Schoon M.L., 2015).

Important to the notion of urban resilience is that, according to Selber, Ryan, Borgström, Norström & Peterson (2018), resilience planning has contributed to "developing a social-ecological systems perspective, more adaptive and collaborative approaches to planning, and that it clarified management goals of desirable resource conditions" (Sellberg *et al.*, 2018). In this direction, 'resilience thinking' is a new concept developed to view the social and ecological systems as intertwined, which components' interactions continually produce surprises (Berkes, Colding and Folke, 2003; Folke *et al.*, 2010; Sellberg *et al.*, 2018). In this context, resilience thinking suggests ways to strengthen urban resilience through fostering learning, participation, and understanding of complexity (Biggs, Schlüter M. and Schoon M.L., 2015; Sellberg *et al.*, 2018), in order to trigger transformations at smaller scales, as this contributes to build resilience at larger scales (Folke *et al.*, 2010; Sellberg *et al.*, 2018).

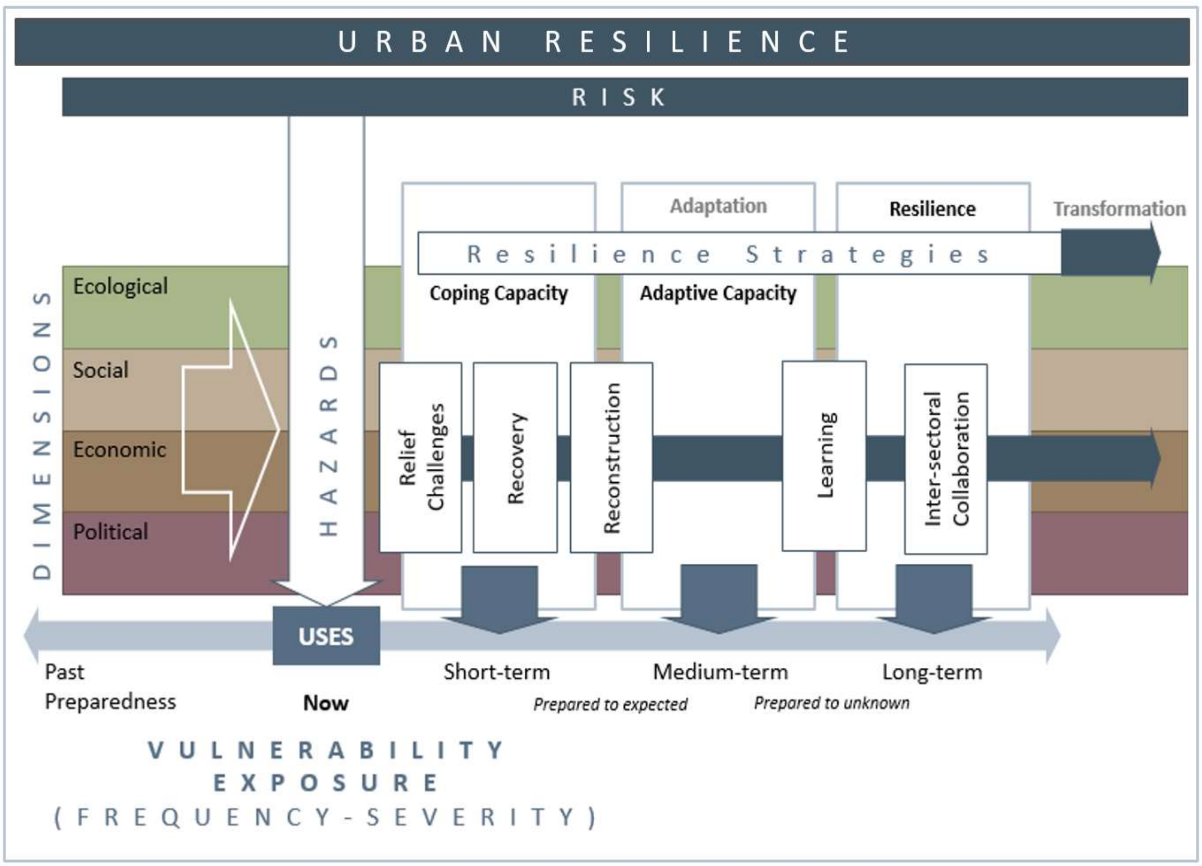


Fig. II.29. *Urban Resilience. In this work, resilience is defined as a counterpart of risk, which is composed by hazards, exposure – including severity and frequency)-, and vulnerability, considering that hazards can come from several dimensions –including ecological, social, economic and political- in short-, medium- and long-term. Additionally, resilience is considered as a desired dynamic state further than just coping or adapting to change, and willing to transform the system.*

As we can appreciate the term resilience has evolved substantially in meaning from 'recovering from change, 'to embracing change', 'to encourage it' (Reyers and Lee Moore, 2017), and from that 'to transform the system' (Sellberg *et al.*, 2018). Therefore, the term of *resilience* for the purpose of this research will integrate the ecological and the social perspectives. In this context, the concept *resilience* –considered as a desired dynamic state further than just coping or adapting to change, and willing to transform the system-, is the counterpart from risk –composed by hazards, exposure (severity and frequency) and vulnerability-. In this direction, hazards can come from several dimensions –ecological, social, economic and political-, in short-, medium- and log-term (**Fig. II.29**). However, which are the qualities that make an USES resilient? As the concept of urban resilience has different connotations according to different authors, characteristics that make a city or an USES resilient will be mentioned from two approaches.

Resilient Qualities: A theoretical approach

From this perspective, we will follow Jabareen's assumption (2013) that city's resilience is a phenomenon that is complex, non-deterministic, dynamic in structure, and uncertain in nature (Jabareen, 2013). Based on complex thinking and complex methods, Jabareen (2013) integrated a theoretical framework for defining what makes a city resilient. Such framework is composed of four main interrelated concepts as it is presented in **Table II.4** (Jabareen, 2013).

Concepts of Resilient Systems		
1	**Vulnerability analysis matrix**	Demography of vulnerability: Demographic and socio-economic aspects of urban vulnerability Informality: Scale and social, economic, and environmental conditions of informal urban spaces. Uncertainty: Lack of knowledge by an individual or group, which is relevant to achieve sustainability. Spatial distribution of vulnerability: Spatial distribution of risks, uncertainties, vulnerability and vulnerable communities in cities.
2	**Urban governance**	Equity: Poverty, inequality, environmental justice, and public participation in decision-making and space production. Integrative: Need to expand and improve local capacity through increasing knowledge, providing resources, establishing new institutions, enhancing good governance and granting more local autonomy. Economics: Economic engines.
3	**Prevention**	Mitigation: Policies and actions that aim to reduce greenhouse gas emissions. Restructuring Ability and flexibility of a city to restructure itself in order to face social, environmental, and economic challenges. Applying alternative energy: Access to clean and affordable energy.
4	**Uncertainty-oriented planning**	Adaptation: Policies that contribute to the adaptation processes, in other words, modifying ecological and social systems to accommodate climate change impacts. Spatial planning: The role of planning in macro urban dimensions. Sustainable urban form: compactness, sustainable transport, density, mixed land uses, diversity, passive solar design, greening and renewal and utilization.

Table II.4. *Components of Resilient Systems. Source:* (Jabareen, 2013).

In this context, urban governance must be emphasized through *adaptive governance,* which has been recognized as central to understand systems, because it allows linking global change to multi-level institutions in an uncertainty environment (Folke, Hahn and Olsson, 2005; Boyd and Juhola, 2015). Considering adaptive governance when analyzing USES allows to have a multi-scalar perspective with defined boundaries for the USES, but without forgetting that the system I embedded in a larger system. Moreover, it provides more flexibility when dealing with short and long term shocks and stresses. Finally, it allows the formation of social-networks and co-management as forms of management that help to deal with uncertainty (Boyd and Juhola, 2015). In this context, Boyd and Juhola (2015), proposed four principles of Adaptive Governance, which include: 1) Building (ecological) knowledge and understanding of dynamics; 2) Co-management mechanisms; 3) Multi-level networks; and 4) Ability to plan for and respond to global uncertainty (Boyd and Juhola, 2015, p1242) (**Table II.5**).

The Four Principles of Adaptive Governance	
1) Building (ecological) knowledge and understanding of dynamics	To build resilience you need to anticipate and respond to the feedbacks in a system. For this, knowledge and understanding of the (ecological) resource, process, function and dynamics is necessary.
2) Co-management mechanisms	To enhance adaptive responses mechanisms for continuous testing, monitoring, and re-evaluation (learning) are required. These mechanisms should help to channel knowledge into adaptive management processes with the recognition that complex systems are inherently uncertain and that history cannot always inform decisions adequately. This depends on leaders and changes in social norms and values.
3) Multi-level networks	The adaptive management processes require sharing of power and responsibility between user groups or communities, government agencies and non-governmental organizations, that exist and operate as social networks, often in an ad hoc and flexible manner. These adaptive processes operate at difference scales and also require support from legal, political and financial institutions.
4) Ability to plan for and respond to global uncertainty	A system that is vulnerable to an external change, such as global climate change, disease out- breaks or natural hazards, is considered non resilient. A resilient system is one in which disturbances are used as an opportunity to transform the system into a more desired state. The challenge is to accept uncertainty, be prepared for change, and enhance the adaptive capacity of the system to deal with disturbance.

Table II.5. *The Four Principles of Adaptive Governance. Source: Taken from 'Adaptive climate change governance for urban resilience'* (Boyd and Juhola, 2015).

Resilient Qualities: A practical approach

From this perspective, there are programs that encourage resilience building in cities. For example the program, 100 Resilient Cities (100RC), which is pioneered by The Rockefeller Foundation, helps cities around the world build resilience to the social, economic, and physical challenges of the 21st century (LeTourneau *et al.*, 2016). This Program considers urban resilience as the capacity of individuals, communities, institutions, businesses and systems within a city to survive, adapt, and grow no matter what chronic stress[13] or acute shock[14] it experiences (The Rockefeller Foundation,

[13] Slow moving disaster, such as high unemployment, endemic violence, chronic food and water shortages and overtaxed or inefficient public transportation system, which weaken the fabric of a city (The Rockefeller Foundation, 2017).

[14] Sudden and sharp events, such as earthquakes, disease outbreaks, terrorist attacks and floods that threaten a city (The Rockefeller Foundation, 2017).

2017). In this context, they defined that systems must be reflective, robust, redundant, flexible resourceful, inclusive and integrated in order to be considered as resilient (**Table II.6**).

Qualities of Resilient Systems		
1	**Reflectiveness**	Reflective systems refer to the acceptance of the inherent and ever-increasing uncertainty and change in today's world. This means, that systems have mechanisms to evolve, changing and modifying standards or norms based on emerging evidence, rather than seeking permanent solutions based on the status quo. Most systems learn from experiences and are able to take better decisions in the future.
2	**Robust**	Robust systems include well-conceived, constructed and managed physical assets, so that they can withstand the impacts of hazard events without significant damage or loss of function. Robust design anticipates potential failures in systems, making provision to ensure failure is predictable, safe, and not disproportionate to the cause. Over-reliance on a single asset, cascading failure and design thresholds that might lead to catastrophic collapse if exceeded are actively avoided.
3	**Redundant**	Redundancy refers to spare capacity purposely created within systems so that they can accommodate disruption, extreme pressures or surges in demand. It includes diversity: the presence of multiple ways to achieve a given need or fulfil a particular function. Examples include distributed infrastructure networks and resource reserves. Redundancies should be intentional, cost-effective and prioritized at a city-wide scale, and should not be an externality of inefficient design.
4	**Flexible**	Flexibility implies that systems can change, evolve and adapt in response to changing circumstances. It may favour decentralized and modular approaches to infrastructure or ecosystem management. Flexibility can be achieved through the introduction of new knowledge and technologies, as needed. It also means considering and incorporating indigenous or traditional knowledge and practices in new ways.
5	**Resourceful**	Resourcefulness implies that people and institutions are able to rapidly find different ways to achieve their goals or meet their needs during a shock or when under stress. This may include investing in capacity to anticipate future conditions, set priorities, and respond, for example, by mobilizing and coordinating wider human, financial and physical resources. Resourcefulness is instrumental to a city's ability to restore functionality of critical systems, potentially under severely constrained conditions.
6	**Inclusive**	Inclusion emphasizes the need for broad consultation and engagement of communities, including the most vulnerable groups. Addressing the shocks or stresses faced by one sector, location, or community in isolation of others is an anathema to the notion of resilience. An inclusive approach contributes to a sense of shared ownership or a joint vision to build city resilience.
7	**Integrated**	Integration and alignment between city systems promotes consistency in decision-making and ensures that all investments are mutually supportive to a common outcome. Integration is evident within and between resilient systems, and across different scales of their operation. Exchange of information between systems enables them to function collectively and respond rapidly through shorter feedback loops throughout the city.

Table II.6. *Qualities of Resilient Systems. Source:* (ARUP, 2015; The Rockefeller Foundation and ARUP, 2015a).

Closing Remarks

In this subchapter, *risk* was defined first from the risk management perspective as the combination of three determinants: *hazard* –including magnitude and frequency-, *exposure* and *vulnerability* to the hazard event (Cardona *et al.*, 2012). After having defined the concept from the most traditional natural sciences perspective (HST), *risk* is redefined as the result of the *severity* and *frequency* of hazard events, according to the NOM-031-STPS-2011(Secretaría del Trabajo y Previsión Social, 2011). This focus provides a rapid categorization of hazards, in which action should urgently be taken.

Central to the determination of risks that threaten any USES is, to consider that risks and hazards can be simple - easy to understand, categorized, and responded to-, complicated -a combination of many simple risks-, or complex - risks that cannot be broken into pieces in the same way as simple or complicated risks- (Keys W., 2018).

Having defined the concept of *risk,* resilience is presented as concept that was born in natural sciences, applied to the social sciences, and redefined as Urban Resilience in the urban sciences –which because of its nature are an integration of socio-ecological perspectives-. As a result, UR is defined as *a desired dynamic state further than just coping or adapting to change, and willing to transform the system* (Sellberg *et al.*, 2018), with certain desirable qualities, which include: reflectiveness, robustness, redundancy, flexibility, resourcefulness, inclusiveness and integration (The Rockefeller Foundation, 2018).

II.5. Towards Resilient Metabolism in Urban Socio-Ecological Systems

It is central for this work to comprehend that urban areas, as stated by Boyd & Juhola (2015), "act as engines of change by altering ecosystems and utilizing energy and natural resources both within and outside their geographical area" (Boyd and Juhola, 2015). Historically, urbanization has been associated with economic and social transformations (United Nations, 2014b). Urbanization is then, integrally connected to the three pillars of sustainable development: economic development, social development and environmental protection (United Nations, 2014b). However, this means that urban areas are affected by such a change, while dealing with further social, economic and infrastructure challenges in a limited resources context.

As Revi & Rosenzweig (2013) argued "urban sustainable development is complex, involving not only many sectors but also many political entities" (Revi & Rosenzweig, 2013, p42). Cities' complexity is related to their "wicked" nature, as they "involve multiple interacting systems –social, ecological, and economic-, a number of social and institutional uncertainties and imperfect knowledge" (McPhearson, 2013). Therefore, systems thinking is required to understand the city's complexity.

Understanding the urban system is vital to "reflect the interlinkages between the different drivers of urbanization, arising pressures and impact and to identify appropriate response measures in order to identify assist in the development of complex policy questions" (Minx et al. 2010, p5). Therefore, Systems Thinking Theory is needed in order to identify how resilient the urban metabolism within an USES is. In this context, it is essential to remember that the concepts related to *urban metabolism* are part of the Hard System Thinking (HST) theory, while the *urban resilience* concept is part of the Complex Adaptive Thinking (CAT). In addition, both are part of the System Thinking Theory, which also considers the Soft System Thinking (SST), which is the system-thinking arena where management and planning decisions are made.

The interlinkage between the different Systems Thinking Theory used for this research are presented in **Fig. II.30**, in which it can be observed that the proposal of resilient strategies will be a step to plan and manage the urban development and conduct it to sustainability. As it was explained in the previous subchapter –Metabolism in Urban Socio-Ecological Systems-, some metabolic processes that occur within cities threaten cities' sustainability (Christopher Kennedy, Cuddihy and Engel-Yan, 2007). In this context, the study of UM is central to understand the interconnection between urban ecosystems and the socio-natural processes that drive changes in them, as well as power relationships (Frank, Delano and Caniglia, 2017). Moreover, systems are constantly changing, as a result of the interaction between their parts while seeking to process a continuous flow of matter, energy and information from their environments (Jackson, 2003). Therefore, the importance of understanding how the resources flows in and out the USES.

Having explained this, this work is focused on three main fluxes Water, Energy and Food. The main reason for discriminating other fluxes is time. Because of the scarce time availability, it is not possible to measure all inflows and outflows going through the system. The Water, Energy and Food inflows were chosen because according to the FAO[15] (2018) this resources nexus means that "the three sectors — water security, energy security and food security — are inextricably linked and that actions in one area more often than not have impacts in one or both of the other" (FAO, 2018).

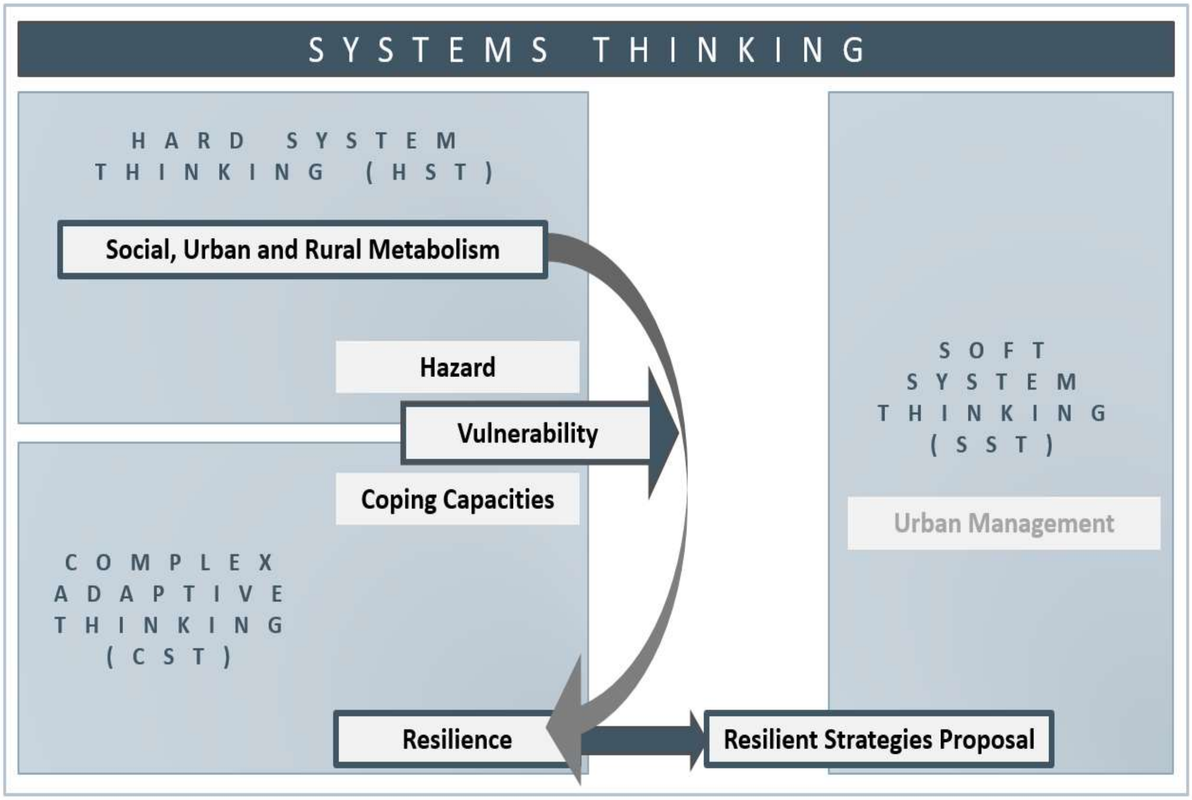


Fig. II.30. *Conceptual Framework: System Thinking. Source. Based on Michael C. Jackson's Systems Thinking* (Jackson, 2003).

In *Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus in the Context of the Sustainable Energy for All Initiative* (Climate Energy and Tenure Division and Food and Agriculture Organization of the United Nations, 2014), FAO explains how the Water-Energy-Food Nexus study can address interactions and feedbacks within a socio-ecological system:

> *"The FAO concept of Water-Energy-Food Nexus explicitly addresses interactions and feedback between human and natural systems. It focuses on the resource base, including both biophysical and socio-economic resources, on which we depend to achieve social, environmental and economic goals pertaining to water, energy and food. Interactions take place within the context of external global drivers, such as demographic change, urbanization, industrial development, agricultural modernization, international and regional trade, markets and prices, technological advancements, diversification of diets, and climate change as well as more site-specific internal drivers, like governance structures and processes, vested interests, cultural and societal beliefs and behaviours"*

[15] Food and Agriculture Organization of the United Nations.

(Climate Energy and Tenure Division and Food and Agriculture Organization of the United Nations, 2014).

Therefore, for the purpose of this work, the fluxes analyzed are Water, Food, and Energy that flow in the USES in a multi-dimensional –ecological, economic, social, political-, and multi-scaled –local, regional and global-, perspective (**Fig. II.31**).

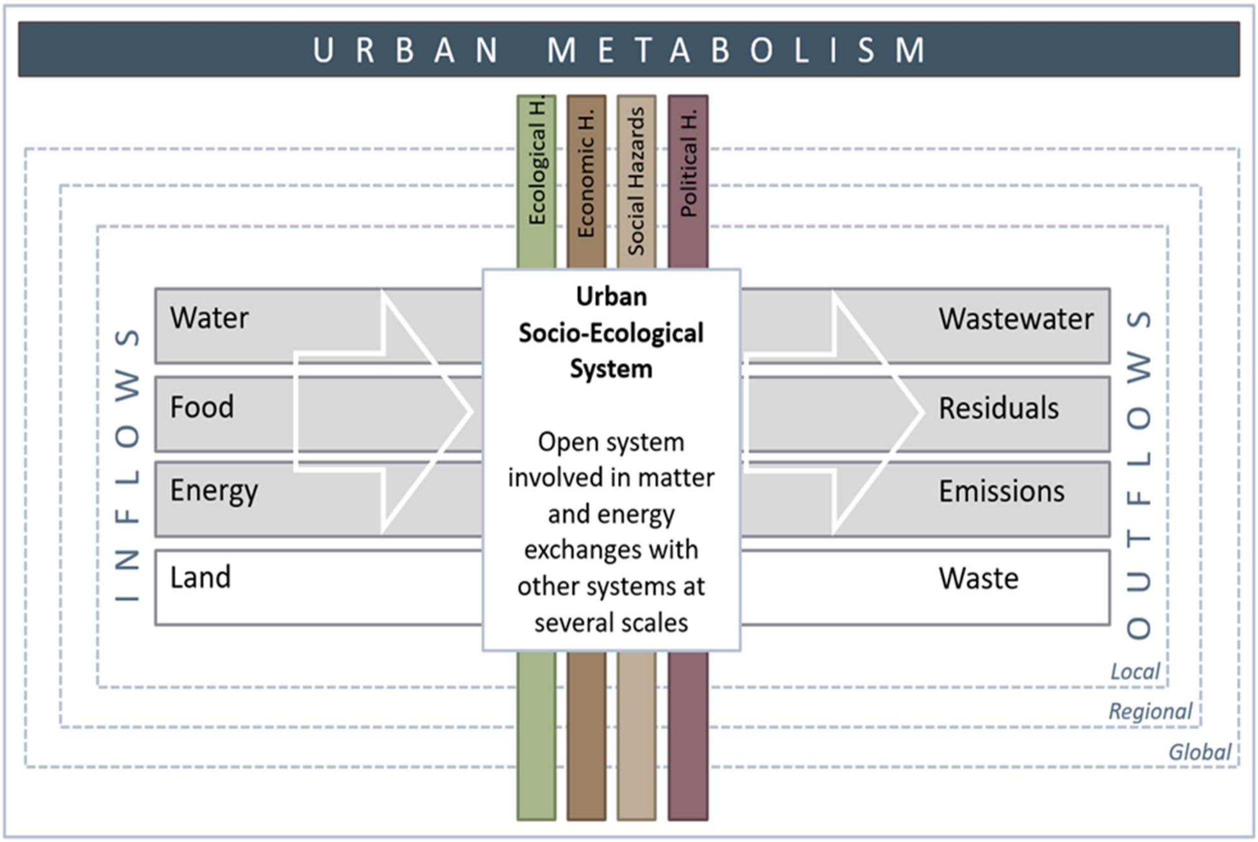


Fig. II.31. *Urban Metabolism. Source. Own source.*

However, as Michael Jackson (2003) argued, the global nature of systems is ruled by chaos and unpredictability (Jackson, 2003). In this context, USES are 'complex evolving and adaptive systems' that can unpredictably change the rules of their development as they evolve over time. In this context, solving problems in the UM does not guarantee UR. Central to this research is to consider that systems coevolve with their environments, they do not just adapt to their environments, resulting in co-response evolution between the system and its environment (Jackson, 2003).

In this context, resilience strategies are necessary to guarantee the sustainable growth of the Cities and the Urban Socio-Ecological Systems, as enhancing urban resilience allows building resilient characteristics, such as redundancy, adaptiveness, robustness, diversity, resourcefulness, reflectiveness, inclusiveness and integration, by reducing vulnerability to hazards.

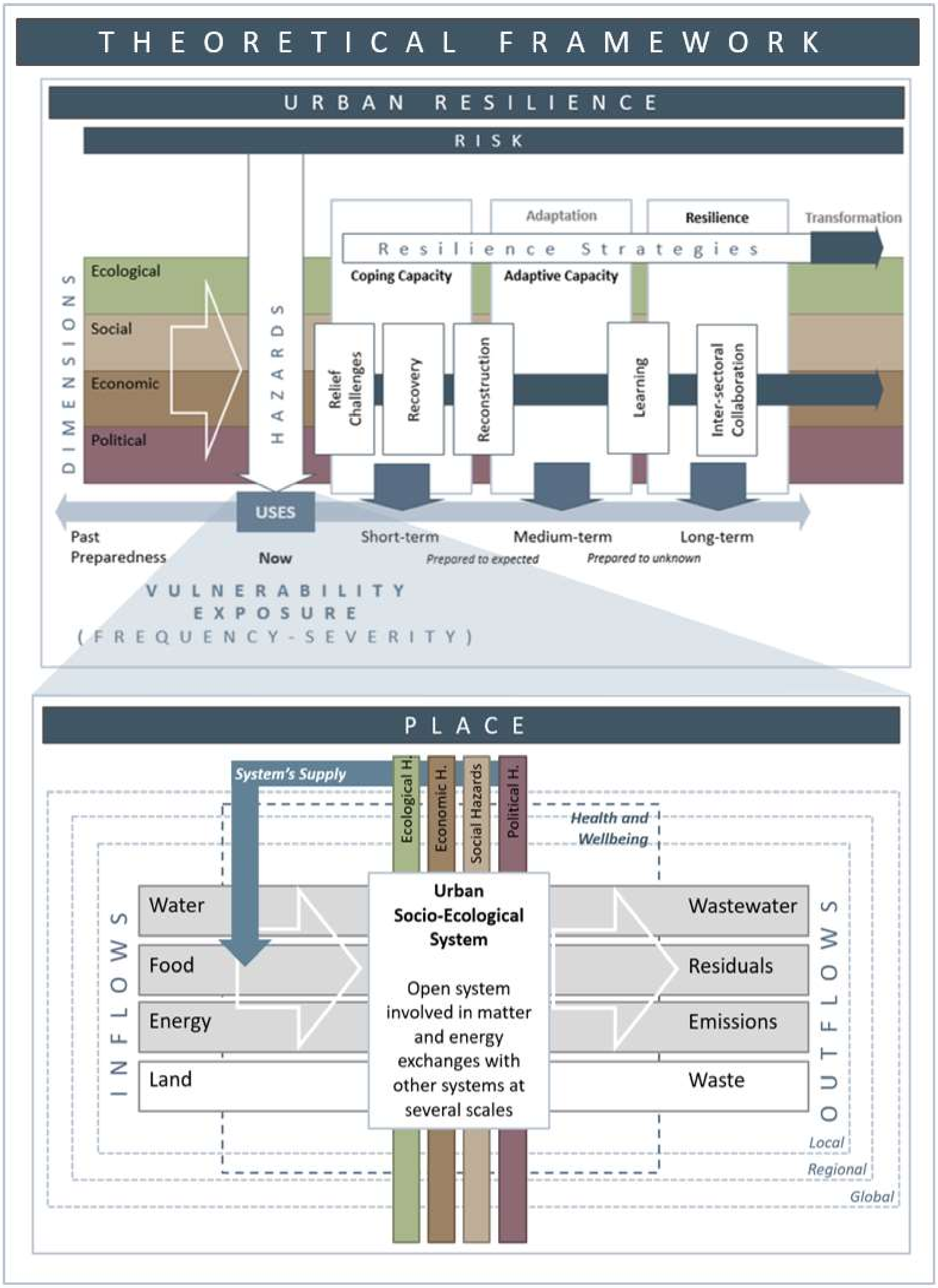


Fig. II.32. *Resilient Metabolism of an Urban Socio-Ecological System.*

Therefore, in this work, resilience strategies are proposed in order to achieve sustainable urban metabolism. Due to the complexity of any urban socio-ecological system, efforts are concentrated on proposing resilience strategies based on the risk assessment. For this reason, hazards to the system's supply inflows –Water, Energy and Food-, and to the system itself, are identified from the ecological, social, economic and political dimensions (within a health dimension), as presented in **Fig. II.32**.

.

Closing Remarks

In this work, urban metabolism is analyzed in order to propose resilience strategies that guarantee the USES resilience. The UM is analyzed through the system's supply inflows –including Water, Energy and Food-, and the system itself. After that, hazards to the system's supply inflows –Water, Energy and Food-, and to the system itself, are identified from the ecological, social, economic and political dimensions (within a health dimension). Such hazards are later transformed into risks, in order to provide an input to the Resilience Assessment.

Chapter III

Methodological Framework

"If you're not confused, you're not paying attention."

(Peters, 1988)

III. Methodological Framework

In this section, the methodological framework that drove the research is presented as an adaptation of the 'Resilience Assessment Framework' proposed by Resilience Alliance (2010) in a first sub-chapter –*Resilience Assessment Framework*. In a second, subchapter - *USES Resilience Assessment based on Urban Metabolism-,* the methodology used in this research is explained through five main stages that were developed as a result of several methods and tools related to each respective theoretical background. After having introduced the method, the five stages of the methodology are explained as steps to achieve the main goal (**Fig. III.1**).

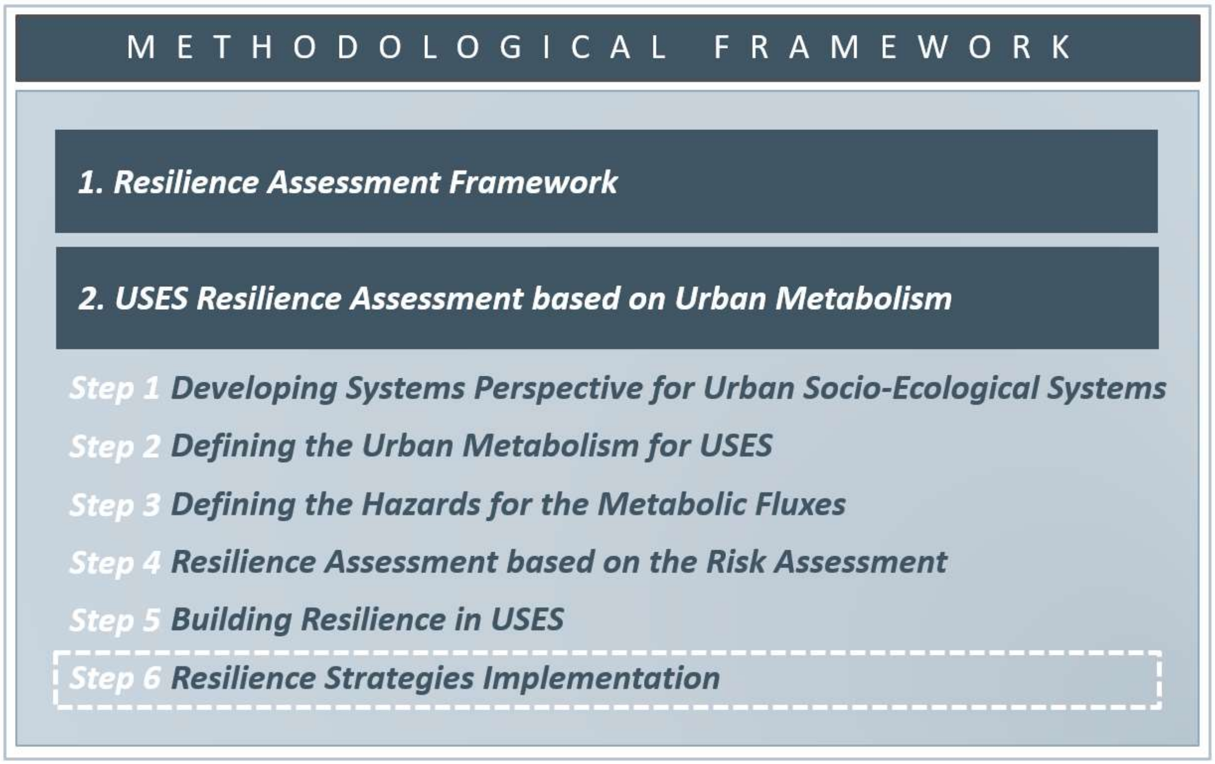


Fig. III.1. *Methodological Framework. Source: Own Source.*

In *Developing Systems Perspective for Urban Socio-Ecological Systems,* it is presented why it is so important to keep a systems perspective during this research. After that, in *Defining the Urban Metabolism for USES*, the methods and tools of Black Box Accounting and System Dynamics are introduced as a mean to understand the Water, Energy and Food inflows within a household scale.

In *Defining the Hazards to the Metabolic Fluxes*, it is explained how hazards were identified for the system's supply and the system itself, based on the study of the Urban Metabolism. Later, in *Resilience Assessment based on the Risk Assessment*, we find the tools used to convert the hazards to risks according to the frequency and severity of them. Moreover, the Resilience Framework proposed by the Rockefeller Foundation is explained as a main mean to assess the resilient characteristics of the USES La Pila, based on the data gathered at a Household scale.

After that, in *Building Resilience in USES*, we explain how the resilient characteristics can be translated into strategies. Finally, in *Resilience Strategies Implementation*, we provide a sixth step that -although it was not applied during this research because of the time it takes to assess if resilience strategies have been, or not, helpful to the USES-, provides a more complete picture of how the *USES Resilience Assessment based on Urban Metabolism* could be implemented in other researches, in which data from different time periods can be obtained.

III.1. Resilience Assessment Framework

It is essential to provide the sustainability of urban ecosystems. Such sustainability is easier to account through the identification and implementation of resilience strategies. Then, it is necessary to analyze the current state of a system in order to identify such strategies, because a sustainable urban management requires understanding the demands a city places on a wider geographical area and its ecological resource base (Moore, Kissinger and Rees, 2013). In this context, this research has as main aim to propose resilience strategies that enable sustainable urban metabolism for the community (urban socio-ecological system) of La Pila in San Luis Potosi

In order to achieve this, a Resilience Framework was required. However, because of the scale and the data that we aimed to obtain during this research, an adaptation of methodologies was necessary. Moreover, some frameworks focus on either the resilience assessment or the resilience planning, which results in incompatibility when you want to put theory into practice or viceversa. In this first subchapter, the Resilience Assessment Framework proposed by the Resilience Alliance (2010), is introduced as an assessment and planning methodology for resilience (Resilience Alliance, 2010).

Resilience Alliance is an international and multidisciplinary organization that does research in the dynamics of social-ecological systems by collaborating with other disciplines. Their main aim is to improve the understanding and the application of resilience[16], adaptive capacity, and transformation of societies and ecosystems in order to cope with change and support human well-being, as they argued in their website (Resilience Alliance, 2018).

Moreover, Resilience Alliance argues that their approach involves three complementary strategies, which include:

> "1) Contributing toward theoretical advances in the dynamics of complex adaptive systems; 2) Rigorous testing of theory through a variety of means -including participatory approaches to regional case-studies, adaptive management applications, model development, and the use of scenarios and other visioning tools-; and 3) Developing guidelines and principles that will enable others to assess the resilience of coupled human-natural systems and develop policy and management tools that support sustainable development" (Resilience Alliance, 2018).

In the book *Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners (Version 2.0)*[17], Resilience Alliance (2010) proposes a 'Resilience Assessment Framework" based on five main stages

[16] Understood as "the magnitude of change or disturbance that a system can experience without shifting into an alternate state that has different structural and functional properties and supplies different bundles of the ecosystem services that benefit people" (Resilience Alliance, 2010).

[17] The first version of this workbook *Assessing and managing resilience in social-ecological systems: A Practitioners Workbook,* constitutes a first sketch of today's Resilience Alliance's methodology (Resilience Alliance, 2007).

which start with the system's description, understanding its dynamics, probing its interactions, evaluating governance and acting on the assessment (Resilience Alliance, 2010) (**Fig. III.2**).

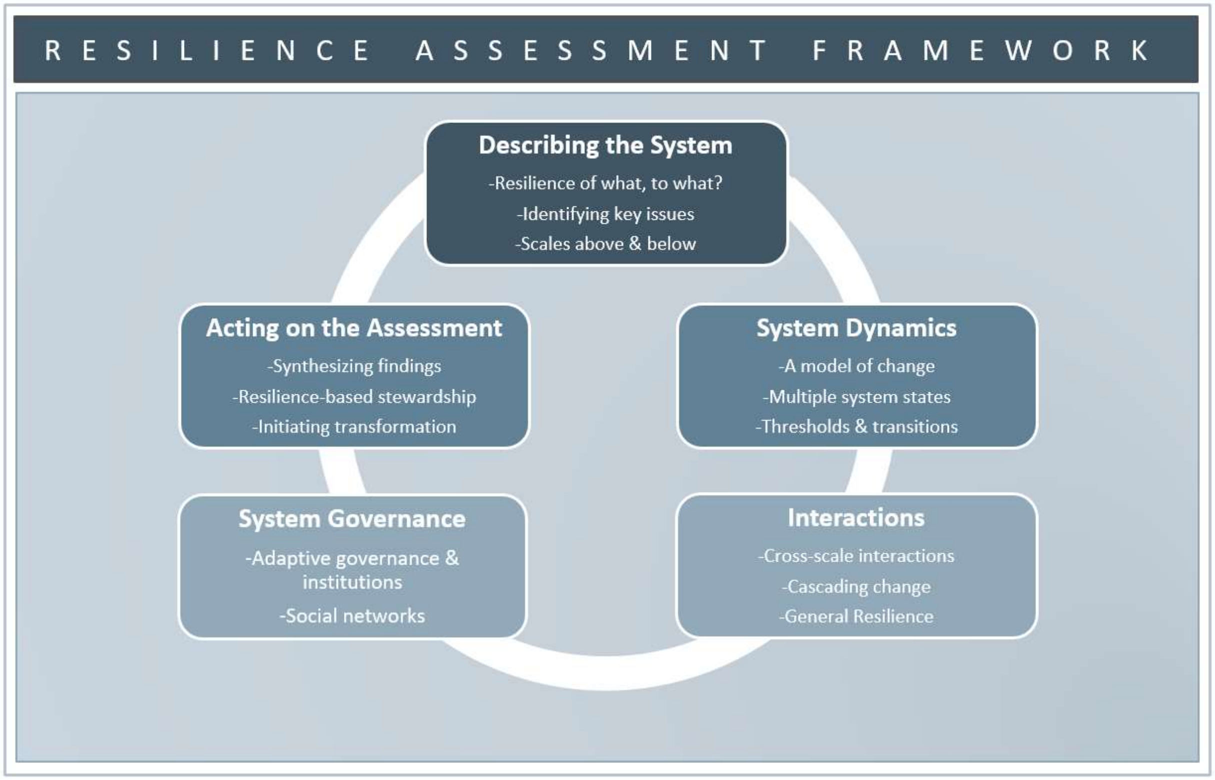


Fig. III.2. *Resilience Assessment Framework proposed by Resilience Alliance. Source: Taken from Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners* (Resilience Alliance, 2010).

Vital for the understanding of this resilience framework is that the assessment is considered as an "iterative and reflexive process at each stage and requires referring back to earlier steps and revising as necessary" (Resilience Alliance 2010, p5). In the following part, each one of these steps is stated, according to the *Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners* (Resilience Alliance, 2010)*:*

Step 1: Describing the System

- *Setting soft boundaries:* It is necessary to define the spatial and temporal boundaries for the socio-ecological system in order to find what might be critical for the system.
- *Identifying the main issues:* This requires having a diversity perspective from several stakeholders, as main issues can be not that evident.
- *Resilience of What? Key components of the Socio-Ecological System:* In this section, the key components of the socio-ecological system that are related to the main issue identified in the previous step are identified. This understanding involves the inclusion of both social – including economic, political and cultural dimensions-, as well as ecological factors.
- *Resilience to What? Disturbances, disruptions and uncertainty:* Resilience Alliance considers that a disturbance is "anything that causes a disruption to a system" (Resilience Alliance 2010,

p15). Therefore, disturbances can come from several sources and contexts as argued in the theoretical framework. What they consider important here is to characterize disturbances, by defining their frequency, duration, severity and predictability.

- *Multiple Space and time scales:* This step allows remembering that the SES under study is nested in other systems, and that disturbances or dynamics happening in larger scales can have an impact on it.

Step 2: System Dynamics

- *A conceptual model of change – the adaptive cycle:* SES can experience gradual or rapid changes always, which if missed, can lead to miss opportunities or create new challenges to achieve long-term sustainability. In this context the Resilience Alliance, proposes understanding the cycles of changes and the vulnerabilities and looking at them as opportunities to introduce change in the SES under study.
- *Multiple States:* This involves the time scale. In other words, the description of the current state, as well as the historical and potential future states. It is central to remember that systems can have several 'stable' states. In this step, it is also possible to measure the stability of a system by measuring certain resource or rate of change.
- *Thresholds and Transitions:* At this stage, it is important to understand how the SES can move from several states, sometimes learning how to ease transitions to such states. It is important to consider that every transition involves crossing tipping points –thresholds-, which separate alternative states.

Step 3: Interactions

- *The Panarchy:* According to the Resilience Alliance (2010), *panarchy* is a term used "to describe a model of hierarchically linked systems represented as adaptive cycles that interact across scales" (Resilience Alliance 2010, p29). This interlinkage can reveal potential vulnerabilities or opportunities in the SES, as "tightly linked smaller-scale systems in similar phases of the adaptive cycle may indicate vulnerability at the focal-system level to the rapid spread of disturbance across scales, causing a domino-effect collapse" (Resilience Alliance 2010, p29).
- *Interacting thresholds and cascading change:* It is important to consider the cascading change, as it allows understanding how the variables might interact.
- *General and specified resilience:* The Resilience Alliance (2010) makes here a difference between specified resilience -defined as the resilience 'of what, to what'-, and general resilience –which does not consider any particular disturbance or aspect of the system that can be affected- (Resilience Alliance, 2010).

Step 4: System Governance

- *Adaptive Governance and Institutions:* At this stage, it is central to consider formal and informal institutions within the SES –including laws, policies, and regulations-.

- *Social networks among stakeholders:* This identification and understanding of social networks among stakeholders is vital to ease the cooperation between them.

Step 5: Acting on the Assessment

- *Synthesizing the assessment findings:* In this step, a general conceptual model of the SES is built. Such model should include the slow-changing components, as well as the fast-changing components for both ecological and the social dimension of the SES under study.
- *Resilience-based stewardship:* This step raises the questions of 'which benefits and to whom the benefits flow are fundamentally important and demand effective stakeholder participation'.
- *Transformation:* It is the most important part of this methodology, as it invites to reflect on the implications of initiating transformational change and the potential that the process might be thriven by other interests.

As it was appreciated, each stage requires several information input due to the complexity of socio-ecological systems (**Table III.1**).

Resilience Assessment Framework	
Step 1: Describing the System	Setting soft boundaries Identifying the main issues Resilience of What? Key components of the Socio-Ecological System Resilience to What? Disturbances, disruptions and uncertainty Multiple Space and time scales
Step 2: System Dynamics	A conceptual model of change – the adaptive cycle Multiple States Thresholds and Transitions
Step 3: Interactions	The *Panarchy* Interacting thresholds and cascading change General and specified resilience
Step 4: System Governance	Adaptive Governance and Institutions Social networks among stakeholders
Step 5: Acting on the Assessment	Synthesizing the assessment findings Resilience-based stewardship Transformation

Table III.1. *Resilience Assessment Framework proposed by Resilience Alliance. Source: Based on 'Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners'* (Resilience Alliance, 2010).

The Resilience Assessment Framework can be summarized into four main questions in order to ease its application: 1) Resilience of What? 2) Resilience to What? 3) So What? 4) Now What? However, before answering these questions, it is necessary to have a preparation phase in which the *systems* *perspective*[18] is developed. In addition, after having answered the questions that integrate the resilience assessment, an *adaptive implementation* is needed when resilience planning for the SES is required and not only its assessment (**Fig. III.2**).

Resilience Planning Framework	
1. Preparation phase	Developing a systems perspective Review existing plans Review governance Scan policy Scope Social-ecological systems Develop learning approach
2. Resilience of what?	Defining the system Scales Socio-ecological systems Values Defining big issues
3. Resilience to what?	Resilience Assessment Drivers Shocks Alternate States, thresholds, feedbacks Controlling variables General resilience assessment
4. So what?	Assessment implications for maintaining or building resilience of the system What kind of change where? Exploring options for achieving change High-level prioritization
5. Now what?	Strategy development Implementation Planning 'Stress testing' Prioritization
6. Adaptive implementation	Test assumptions Trial innovations Implement triple loop learning

Table III.2. *The Resilience Planning framework. According to Sellberg (2018) it is also called the Clouds heuristic, and was developed by Paul Ryan and Michael Mitchell* (Resilience Alliance, 2010) *into a planning process based on lessons learned from the first wave of Resilience Planning* (Sellberg *et al.*, 2018).

It is vital to the understanding of the resilience planning framework to consider that it works as an infinite cycle that requires constant reflection on the system, as well as assessment of the resilience, while synthetizing and learning from the system's experiences as the Resilience Alliance specify in their first version of the framework (**Fig. III.3**):

[18] The system is viewed as a whole. It is the perspective of systems thinking, which is a way of thinking, that takes into account all of the components, behaviours, interactions (connectedness and relationships), contexts in an uncertain and complex environment (Gallopin, 2003). (See Theoretical Framework)

°The framework is designed for repeated updates and fine-tuning. As a system evolves or new issues emerge, it may be helpful to revisit the assessment at regular intervals. The conceptual SES model as developed is a tool for achieving long-term, sustainable environmental services" (Resilience Alliance, 2010).

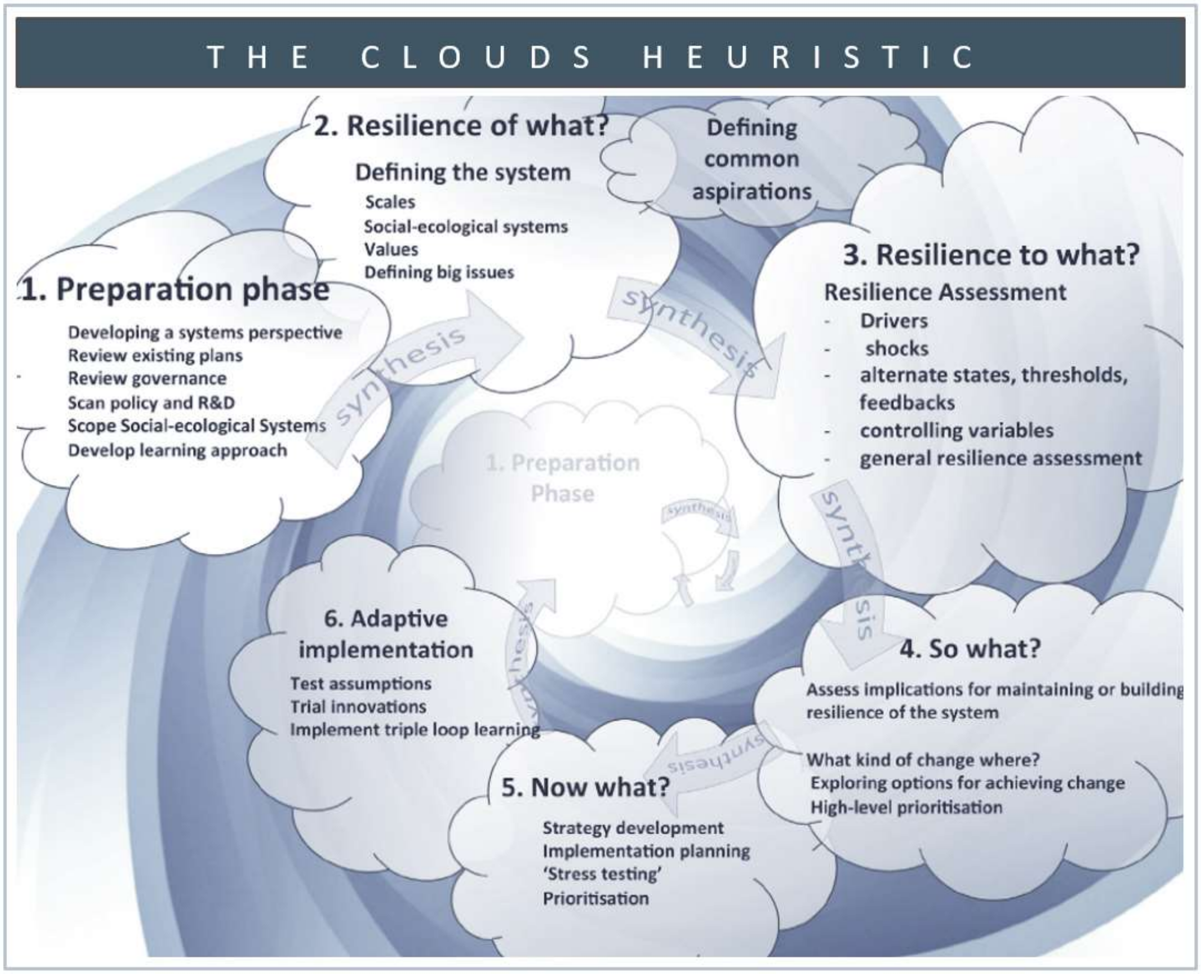


Fig. III.3. *The Clouds Heuristic. Source: Taken from Sellberg's research article 'From Resilience Thinking to Resilience Planning: Lessons from practice'* (Sellberg *et al.*, 2018)*, based on the Clouds heuristic from Paul Ryan and Michael Mitchell* (Resilience Alliance, 2010).

III.2. USES Resilience Assessment based on Urban Metabolism

The main objective of this study was *to propose resilience strategies that enable sustainable urban metabolism for the community (urban socio-ecological system) of La Pila in San Luis Potosi*. In order to achieve it, the specific objectives were: 1) To identify the metabolic fluxes in La Pila: Water, Energy & Food; 2) To identify hazards to the metabolic fluxes; 3) To analyze how resilient is the urban metabolism of La Pila. Therefore, the research questions that drove the research can be observed in **Table III.3**.

Research Objectives and Questions		
Main Objective	**Specific Objectives**	**Research Questions**
To propose resilience strategies that enable sustainable urban metabolism for the community (urban socio-ecological system) of La Pila in San Luis Potosi	To identify the metabolic fluxes in La Pila: Water, Energy & Food	Which are the current metabolic fluxes in the community?
	To identify hazards to the metabolic fluxes	How vulnerable are metabolic fluxes to which hazards?
	To analyze how resilient is the urban metabolism of La Pila	How resilient is the urban metabolism of La Pila?

Table III.3. *Research Objectives and Questions.*

In order to achieve the main aim of this research, resilience strategies for our *USES* are proposed, based on the resilience assessment of the urban metabolism. Therefore, in order to propose resilience strategies -that enable sustainable urban metabolism for the community of 'La Pila', in San Luis Potosi-, we use an adaptation of the *Resilience Assessment Framework* proposed by Resilience Alliance (2010). Such framework helps to understand integrated socio-ecological systems and their change dynamics, through five stages: 1) Describing the System; 2) Understanding the System Dynamics; 3) Probing System Interactions; 4) Evaluating Governance; and 5) Acting on the Assessment- as described in the previous subchapter (Resilience Alliance, 2010).

However, as for this research we will be analyzing the urban metabolism, an adaptation of such Resilience Assessment Framework and its key questions is proposed –*USES Resilience Assessment based on Metabolism-*. Such adaptation includes six stages. The first step is *Developing Systems Perspective for Urban Socio-Ecological Systems*. Despite the fact that this systems perspective was already developed in the theoretical framework, it is considered part of the preparation phase of the methodology used for this research. The second step of the methodology used is *Defining the Urban Metabolism for USES,* which tries to answer the question 'Resilience of what?' from the Resilience Alliance Framework (2010). This includes the achievement of the first specific objective, which consists on the identification of the metabolic fluxes in La Pila for Water, Energy and Food, once our case of study has been defined.

After that, in the third step *Defining the Hazards to the Metabolic Fluxes,* the second specific objective –to identify hazards to the metabolic fluxes- is covered by answering the question 'Resilience to what'. A fourth step is the *Resilience Assessment based on the Risk Assessment,* which covers the third specific objective of the research –to analyze how resilient is the urban metabolism of La Pila-.

<table>
<tr><th colspan="3">Resilience Assessment Framework</th><th colspan="3">USES Resilience Assessment based on Metabolism</th></tr>
<tr><th colspan="3">Resilience Alliance, 2010</th><th colspan="2">Cisneros, 2018</th><th>Aim Covered</th></tr>
<tr><td rowspan="2">Describing the System</td><td>Preparation phase</td><td>Developing a systems perspective
Review existing plans
Review governance
Scan policy
Scope Social-ecological systems
Develop learning approach</td><td rowspan="2">URBAN METABOLISM</td><td>Developing Systems Perspective for Urban Socio-Ecological Systems</td><td>*Theoretical Framework</td></tr>
<tr><td>Resilience of what?</td><td>Defining the system
Scales
Socio-ecological systems
Values
Defining big issues</td><td>Defining the Urban Metabolism for USES

*Households scale</td><td>To identify the metabolic fluxes in La Pila: Water, Energy & Food.</td></tr>
<tr><td>Understanding the System Dynamics</td><td>Resilience to what?</td><td>Resilience Assessment
Drivers
Shocks
Alternate States, thresholds, feedbacks
Controlling variables
General resilience assessment</td><td rowspan="2">URBAN RESILIENCE</td><td>Defining the Hazards to the Metabolic Fluxes

*Supply and System itself</td><td>To identify hazards to the metabolic fluxes.</td></tr>
<tr><td>Probing System Interactions</td><td>So what?</td><td>Assessment implications for maintaining or building resilience of the system
What kind of change where?
Exploring options for achieving change
High-level prioritization</td><td>Resilience Assessment based on the Risk Assessment
(Hazards and Exposure)</td><td>To analyze how resilient is the urban metabolism in La Pila.</td></tr>
<tr><td>Evaluating Governance</td><td>Now what?</td><td>Strategy development
Implementation
Planning
'Stress testing'
Prioritization</td><td rowspan="2">RESILIENCE STRATEGIES</td><td>Building Resilience in USES
Resilience Strategies Development</td><td>To propose resilience strategies that enable sustainable urban metabolism for the community of La Pila in San Luis Potosi</td></tr>
<tr><td>Acting on the Assessment</td><td>Adaptive implementation</td><td>Test assumptions
Trial innovations
Implement triple loop learning</td><td>Resilience Strategies implementation</td><td>*Implementation of the resilience strategies</td></tr>
<tr><td colspan="6">*This work does not cover the implementation and assessment of resilience strategies. However, there are some strategies that have already being implemented in La Pila.</td></tr>
</table>

Table III.4. *Resilience Framework. Source: Based on* (Resilience Alliance, 2010; Sellberg *et al.*, 2018).

The firth step answer the question 'Now what' from the Resilience Alliance's framework, while covering the general aim of this research which is the proposal of resilience strategies that enable the sustainable urban metabolism of the USES. Finally, a sixth step is proposed –*Resilience Strategies Implementation-,* as possible further step of this methodology as a reminder that the assessment of implemented strategies must be a continuous learning process (**Table III.4**).

III.2.1. Developing Systems Perspective for Urban Socio-Ecological Systems

This first step considers the preparation phase previous the field work. On the one hand, it includes the development of the systems perspective through the theoretical framework and on the other, the databases and literature review about the case of study. Both parts are considered as part of the methodology not only to provide uniformity with the Resilience Alliance's framework, but also in order to propose this methodological framework as a complete methodology that can be applied to assess and build urban metabolism through the implementation of resilience strategies.

Therefore, developing the systems perspective is important because it allows to see the USES under study as a sub-system composed by other sub-systems, while nested and interconnected to bigger or equal systems. Moreover, the systems perspective is necessary when analyzing complex systems as they are also inside different dimensions –which in this case are the ecological, the social, the economical, the political, and health- in a multi-scalar environment with several interconnections and therefore, several dynamics.

In order to characterize the USES under study, the territorial boundaries were defined as spatial boundaries and the time boundaries were the years 2017-2018. After defining the USES, the main interconnections with bigger systems were established and a databases review INEGI[19] and government institutions provided insights on the Water, Energy and Food dynamics between the USES and the system in which it is nested (See Chapter IV 'Case of Study: La Pila as an USES').

III.2.2. Defining the Urban Metabolism for USES

Once the preparation phase was achieved, the next step was defining the urban metabolism for the USES under study.

Specific Objective 1 ***To identify the metabolic fluxes in La Pila: Water, Energy & Food.***

Table III.5. *Specific Objective 1.*

This second stage had as aim to identify the metabolic fluxes in La Pila -Water, Energy and Food-. However, because of the scarce time to realize the analysis, the fluxes were analyzed at a household scale. Moreover, only inflows were measured because of the lack of data and time during the analysis and interpretation phases. From the perspective of metabolism, fluxes are generally analyzed in order

[19] INEGI: Instituto Nacional de Estadística y Geografía.

to identify how each component of the system relates to another and how they influence a specific behavior (Martínez-Alier, 2006). In this case, it is observable that rural communities tend to generate urban development patterns, because of their proximity to the urban area. Therefore, it is central to suggest resilience strategies in order to ensure a sustainable development of today's suburban areas, which are becoming part of a city.

The study of Metabolism is necessary, as social, economic and political fluxes mostly determine rural-urban development, as both, rural communities and urban communities interact in an opened system all the time (Víctor M Toledo, 2008).

In this context, urban metabolism tools are considered as means that will allow us to understand the flux that occurs between the community of 'La Pila' and the industrial corridor and that drives the current urban development. Because for the nature of this study, and considering the different UM accounting approaches, this study follows a territorial-spatial bottom-up approach according to the GI-REC (Global Initiative for Resource Efficient Cities, 2018).

According to Benavides (2011), UM offers a wide rang of methods and tools that constitute the methodology to measure the metabolism of a *USES*, which can be classified in three categories: 1) Measuring Tools, which aim is "to quantify amount of material and/or energy that flows into, through and out of the system"; 2) System Description/Analysis Tools, which aim is "to understand the structure of the system itself"; and 3) Environmental Impact Assessment Tools, which aim "to look at specific flows or aspects that are deemed key, because of theire great volume, their high impacting potential or other" (Benavides Mondragón, 2017) (**Fig. III.4**).

As we are assessing the resilience of the metabolism, rather than the metabolism itself, we discard the methods and tools from the Environmental Impact Assessment Tools for this specific aim. Geographical Information Systems (GIS) methods are also discarded because even if they are starting to be used in urban studies with increasing success, it is not possible to get the satellite images needed to conduct an analysis . However, to conduct for this research a combination of tools is proposed: The "Black Box Accounting (BBA)" from the Measuring Tools Box and "System Dynamics" from the System Description/Analysis Box. The reason is that we need to quantify the materials and energy flowing in our USES, which because of the data availability can be better achieved through the BBA. However, as this tool limits the understanding of the interactions within the USES, the second tool –System Dynamics-, will increase the comprehension and description of the whole system, when assessing and building resilience.

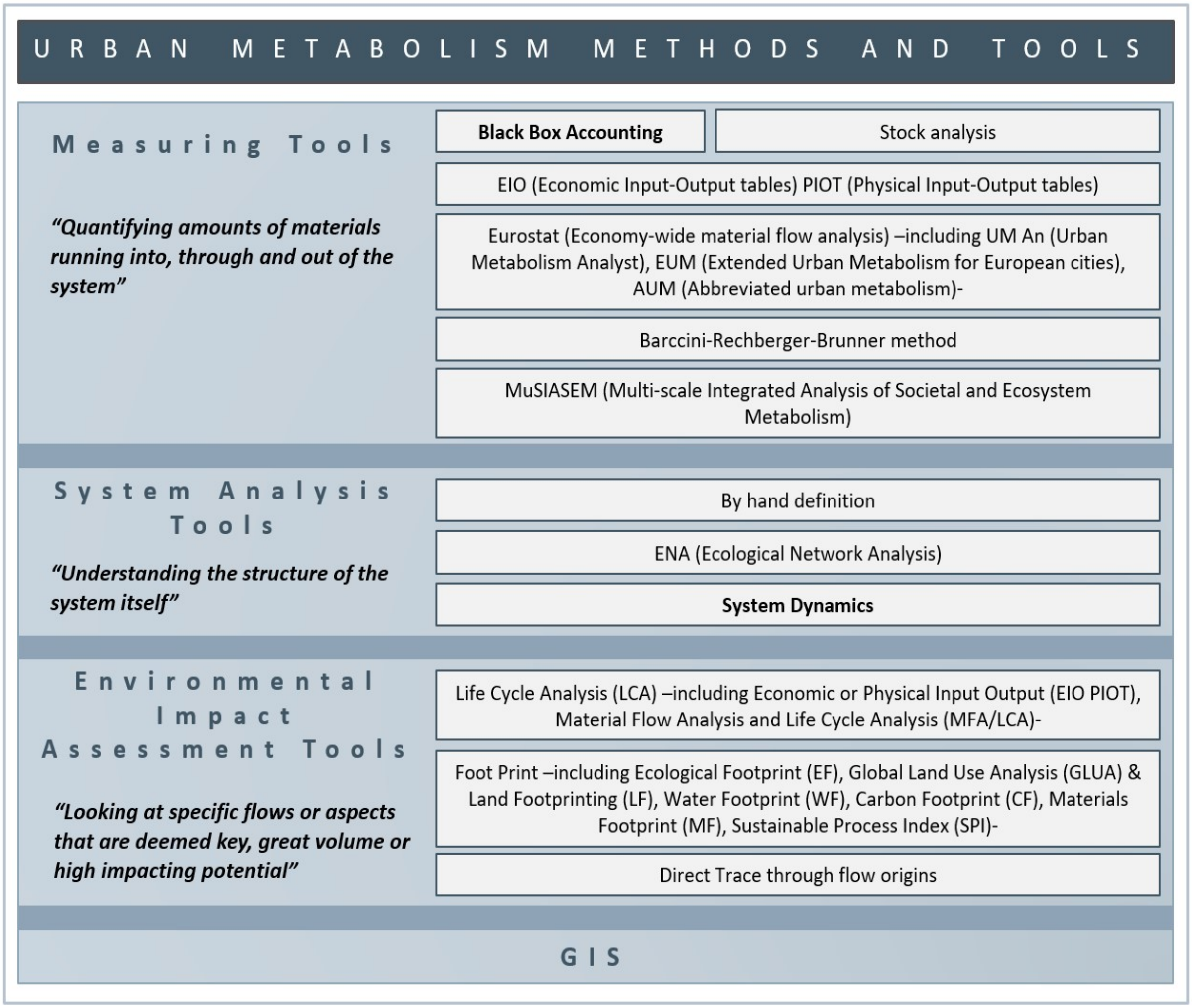


Fig. III.4. *Tools and Methods to measure Urban Metabolism. Source: Benavides' classification of Urban Metabolism Tools* (Benavides Mondragón, 2017).

III.2.2.1. The 'Black Box' Accounting

The 'Black Box' accounting is a method that allows the quantification of materials getting into and out of the system. In order to measure the inputs and outputs, this method uses accounting schemes, which consider the system they are analyzing as a black box. This means that stocks inside the system can be inferred, if the inputs and outputs are known (Benavides Mondragón, 2017).

It is one of the first methods used by 20th century urban metabolists, such as T. Weyl (1894), P Geddes (1920) and Abel Wolman (1965) (Grove, 2009; Benavides Mondragón, 2017).

According to The OECD Guide (2008) –Measuring Material Flows and Resource Productivity-, the term 'black box' is used in material flow accounting, in order "to characterize the system under scrutiny when the purpose is to record flows that cross the system boundary and not flows that are internal to the system" (OECD 2008, p43).

The main disadvantage of this method is that it does not allow to zoom in the distribution of flows, drivers, equity in access to resources or spatial issues (Pickett, Cadenasso and Grove, 2011). In addition, it is important to this work to assume that the 'black box' is contrary to the complexity analysis proposed by the resilience theory, as it breaks systems down into their parts, instead of trying to control and monitor their outputs, and manipulate their inputs properly (Jackson, 2003).

However, it is useful when doing first approximations of the metabolic behavior of a system, allowing to get gross numbers and a better understanding of it (Benavides Mondragón, 2017). In this context, and because of the complexity of our USES, in this research we measure only Water, Energy and Food flowing in households. In order to achieve this, forty inhabitants were interviewed within the time frame of two months. In the following part, the tool is explained.

III.2.2.1.1. Metabolism Tool: Interview

According to the pragmatic approach to assess urban metabolism in Europe, proposed by Minx et al. (2010), populations and households are a thematic area that works as an indicator on urban flows, as it "captures the developments in population and household size, population dynamics and household structure, which are important determinants of a city's metabolism" (Minx et al. 2010, p25).

In this work, the interview to households was used, as a mean to understand the metabolism within an Urban-Socio Ecological System. The Interview was composed by 68 questions, divided into A-N categories as follows:

- A: Household Characteristics
- B: Economy
- C: Health
- D: Work and Life
- E: Social Interlinkages
- F: Politics and Governance
- G: Environment
- H: Emotion
- I: Water Consumption
- J: Electricity Consumption
- K: Gas Consumption
- L: Food Consumption
- M: Waste Disposal
- N: Transport

The complete questionnaire can be found in the Appendix B (**Fig. B.1**, **Fig. B.2**, **Fig. B.3**, **Fig. B.4**, **Fig. B. 5**, and **Fig. B.6**), and in the **Table III.6**, main questions regarding the Water, Energy and Food fluxes are presented.

Interview Questions		
Water	**Energy**	**Food**
Do you have regular access to water? What do you when you do not have water?	How many lights do you have?	Where do you buy your food? Market, store or supermarket?
Where does drinking water come from? Bottled water / Tap water? How many carboys (19 l.) do you consume per week?	How many hours per day do you use lights?	Which are the fruits that you consume the most?
How many water litters do you consume within a month?	Do you consider that the electrical energy is expensive?	Which are the vegetables that you consume the most?
How much money do you spend for water within a month? Do you consider that water is expensive?	What do you have: Stationary tank, natural gas or gas tanks?	How many times per week do you consume meat? Which portion?
Where do you wash the dishes?	How do you heat water needed to take a shower?	How many times per day do you eat? What do you eat?
How many times per day do you brush your teeth? Where does water that you use comes from? Bottled water/ Tap water? How many times per week do you take a shower?	How many of these do you have? Computers? Fridges? TV's? Radios? Microwaves? Washing machines?	Where do you throw trash? Do you have special containers within your colony or does your community have a trash collection system?
Do you recycle water? Which system do you use? How often?	Do you use gas to cook?	Do you recycle? Do you separate trash? How?
Do you collect water from rain? Which system do you use? How often?	How often do you buy gas? How much does it cost?	How many times per week does the trash collection system collect your trash?
Have you ever had problems with the drainage? Does your home get flooded when it rains?	Do you consider that the gas is expensive?	Do you have organic waste? What do you do with it?

Table III.6. *Interview Questions.*

In order to understand the urban metabolism in the community of La Pila -considered as our USES of study-, a total of 40 households were interviewed. Once data were gathered, they were organized in Excell. Because of the complexity of the USES dynamics, the data gathered are presented and analyzed at three scales, in order to provide a better context of how resources are consumed: 1) Households Total Consumption; 2) Household A-B-C Types Consumption; and 3) A Household Analysis.

Resource's Inflows						
Inflow	**Water**		**Energy (Electricity, gas and fuel)**		**Food**	
Units	**Liters**		**kWh for electricity, Kg. for Gas, and L. for fuel**		**% from the income spent in food, MXN**	
Households Total Consumption	Per Household	Per capita	Per Household	Per capita	Per Household	Per capita
Household A-B-C Types Consumption	Per Household	Per capita	Per Household	Per capita	Per Household	Per capita
A Household Analysis	Resource consumption including other supply's sources.		Resource consumption including other supply's sources.		Resource consumption including other supply's sources.	

Table III.7. *Resource's Inflows.*

Water inflow was first analyzed by quantifying tap water consumption. After that, energy inflow will be equally presented and analyzed, considering energy that comes from electricity, and fossil fuels –gas and fuel-. Finally, food inflow is described and analyzed based on the money spent to cover it and the percentage that it represents from the household income. For each one of the fluxes, the three scales -Households Total Consumption, Household A-B-C Types Consumption and A Household Analysis-, are used as explained in the **Table III.7**.

Water

In order to calculate the liters of water flowing in the household, only tap water was considered for *Households Total Consumption* and *Household A-B-C Types Consumption*. Spent water liters were calculated using the Interapas fees tables[20], without discounting the taxes paid for the service, nor the drainage fees. The reason for not splitting these concepts was that data obtained during the interview asked about the monthly expenditure in water resources, which was changing according to the water source. Therefore, the data were standardized by not taking out the extra fees, which can only be paid through Interapas. Moreover, corrections for the average and median results were corrected using the Monte Carlo Simulation[21], through the software Crystall Ball. After that, in *A Household Analysis*, the water coming from other sources is presented through a household example.

Energy

In order to calculate the energy flowing into the household, electrical energy, gas and fossil fuels were considered as main sources. In this part, Households Total Consumption are first presented for every energy source. Later, in Household A-B-C Types Consumption, the schema proposed is followed, measuring the energy inflowing first, per household and then per capita. Finally, in a Household Analysis, energy coming from other sources is presented through a household example.

[20] See **Table IV.3.** Water Supply Fees in San Luis Potosí. Source: Translated from decree 0540 (Secretaría General de Gobierno, 2016).

[21] See **III.2.2.1.1.1. Monte Carlo Simulation.**

For the calculation of electricity, taxes were taken apart from the calculations, as everybody receives the electrical service from the same company. In the gas and fuel consumption could not be done. After having calculated the average and the median values of households energy consumption, the results were corrected using the Monte Carlo Simulation[22].

Food

The food flux was complex to analyze, as it is really hard to understand the nutritional habits that a person has in a 45-minute interview that includes other topics. However, it was easier to understand the important role that food plays in the households income expenditure. Therefore, data for food are available with a monetary value in MXN.

III.2.2.1.1.1. Monte Carlo Simulation

The Monte Carlo Simulation relies on repeated random sampling in order to obtain numerical results. It uses randomness of one value to calculate mathematical expressions -that are hard and expensive- in scarce data environments through models that calculate the vale in hundreds or thousands repetitions. In this research, it was used to provide the reader a simulation of the whole USES households' behavior, as it is acknowledge that the forty interviews are not a representative sample to measure resources consumption, but to understand the resilience through the urban metabolic dynamics. The number of repetitions used in this research was 10,000.

III.2.2.1.2. Participatory Mapping

Participatory mapping allowed collecting data related to hazards that occur inside the community. On this stage, a participatory mapping approach was used, as there is evidence that spatial social data collected through this method are helpful when analyzing, planning and managing land-use related issues (Karimi & Brown, 2017). In addition, local perceptions, which are represented on maps, are easier to understand for external decision-makers (Ramirez-Gomez et al., 2014). The main idea was to incorporate stakeholders in a participatory mapping in order to obtain and/or complete information for the four specific aims, while they also get information about how their community works.

However, this tool was used assuming that the participatory mapping has limitations (Rye & Kurniawan, 2017). For example, participatory mapping help to understand a reality through the locals' perceptions (Teixeira & Gardner, 2017), but some parts of the reality might still be unknown for some of them.

The question used for the participatory mapping can be seen in **Table III.8** and the map used can be found in the Appendix B: **Fig. B. 7**.

---

[22] See **III.2.2.1.1.1. Monte Carlo Simulation.**

Questions of the Participatory Mapping
Where do you buy your food?
Which are the areas that you consider insecure or unsafe?
Where do you buy gas? Fossil fuels?
Do you know which streets get flooded when it rains?

Table III.8. *Questions of the Participatory Mapping.*

III.2.2.2. System Dynamics

SD is computer-based method, introduced by the MIT engineer Jay Forrester. In his book, 'Urban Dynamics', he linked System Dynamics (SD) to urban systems analysis (Benavides Mondragón, 2017). According to Bevacqua et al. (2018), SD is "a mathematical modeling method used to understand and manage economic, natural, and physical systems using stocks, flows and internal feedback loops" (Bevacqua, Yu and Zhang, 2018). Although in this research there is no mathematical analysis of the USES, it is important to observe certain resilience dynamics when system's supply is disturbed. Such information will be then, better described and interpreted in the fourth step, when risk and resilience are analyzed based on the metabolic results. However, as system dynamics are part of the tools and methods to measure UM, it seemed preferable to explain their role as a tool to increase understanding of the system during the interviews. The methodology used for this research does not apply the system dynamics to measure the urban metabolism, but rather to describe the system components, behavior drivers and feedbacks to find resource efficient strategies.

III.2.3. Defining the Hazards to the Metabolic Fluxes

In this part, the hazards were defined to the metabolic fluxes, regarding the system's supply and the system itself in order to achieve the second specific objective. This methodology does not consider the measurement of outflows, but it could be included if necessary in future researches.

Specific Objective 2
To identify hazards to the metabolic fluxes.

Table III.9. *Specific Objective 2.*

Data about threats and hazards were obtained through the interviews and the participatory mapping. Moreover, some households were able to provide a copy of their electrical energy and water payment receipts. On the one hand, the interviews allowed to increase comprehension on which hazards affect the system's supply and the system itself. On the other, the receipts and the participatory mapping provided specific information for the household cases.

Hazards identified were categorized in two tables, one for the hazards to the system's supply and the second one for the hazards to the system. Each one of these tables includes the hazards to Water, Energy and Food –as inflows or part of the USES-, identified by the dimension related to them (including ecological, social, economic, political). In addition, for the table of hazards to the system, a health dimension was added in order to cover the qualitative hazards that have an impact on the system related to health. The example of the second table can be appreciated in the **Table III.10**.

Hazards Categorization			
Dimension	**Water**	**Energy**	**Food**
Ecological	Ecological hazards to the water supply and the system itself.	Ecological hazards to the energy supply and the system itself.	Ecological hazards to the food supply and the system itself.
Social	Social hazards to the water supply and the system itself.	Social hazards to the energy supply and the system itself.	Social hazards to the food supply and the system itself.
Economic	Economic hazards to the water supply and the system itself.	Economic hazards to the energy supply and the system itself.	Economic hazards to the food supply and the system itself.
Political	Political hazards to the water supply and the system itself.	Political hazards to the energy supply and the system itself.	Political hazards to the food supply and the system itself.
Health	Health hazards to the system itself.	Health hazards to the system itself.	Health hazards to the system itself.

Table III.10. *Hazards categorization.*

It is central for the Chapter VI, to consider that the hazards categorization is art of the Resilience Assessment based on the Risk Assessment, but in order to provide uniformity with the aims, it is considered as an important step to assess resilience.

III.2.4. Resilience Assessment based on the Risk Assessment

In order to analyze how resilient is the urban metabolism in the USES, this step is divided into two sections. In the first one, we have the risk definition, while in the second we have the resilience assessment.

Specific Objective 3
To analyze how resilient is the urban metabolism of La Pila.

Table III.11. *Specific Objective 3.*

III.2.4.1. Defining the Risk

Identifying hazards that have an impact on USES is the first step to define the risk. But then, how can we categorize or prioritize risks? In this study, risk is classified using the Mexican NOM-031-STPS-2011, which allows assigning a frequency and a severity category in order to get a risk hierarchy –exposure- (Secretaría del Trabajo y Previsión Social, 2011). Such norm is usually used to categorize hazards in industrial zones as a mean to implement corrective strategies that attenuate the exposure to events. Then, the risk can be categorized according to the risk hierarchy. In order to categorize risk, a frequency (See **Table III.12**) and a severity (**Table III.13**) is given for every hazard. After that, using the **Table III.14**, hazards are hierarchized and described using **Table III.15**.

Hazards Frequency		
Frequency		**Definition**
Category	**Nomenclature**	
A	Remote	It can exceptionally occur
B	Isolated	It can hardly occur
C	Occasional	It happens a few times
D	Recurrent	It happens frequently
E	Frequent	It happens regularly

Table III.12. *Hazards Frequency. Source:* (Secretaría del Trabajo y Previsión Social, 2011).

Hazards Severity		
Hazards severity		**Definition**
Category	**Nomenclature**	
I	Minor	Without harm or temporal harm
II	Moderate	Harms that last more than 3 days
III	Damage	Permanent incapacity
IV	Fatal	Death

Table III.13. *Hazards Severity. Source:* (Secretaría del Trabajo y Previsión Social, 2011).

Risk Hierarchy						
Hazards			**Severity**			
			I	**II**	**III**	**IV**
			Minor	**Moderate**	**Damage**	**Fatal**
Frequency	**E**	**Frequent**	Medium	High	Severe	Severe
	D	**Recurrent**	Low	Medium	High	Severe
	C	**Occasional**	Minimum	Low	Medium	High
	B	**Isolated**	Minimum	Minimum	Low	Medium
	A	**Remote**	Minimum	Minimum	Minimum	Low

Table III.14. *Risk Hierarchy. Source:* (Secretaría del Trabajo y Previsión Social, 2011).

Risk Description		
Risk	**Description**	
Low	Acceptable risk, no action required.	The occurrence is slightly probable.
Medium	It is necessary to take action to reduce risk.	The occurrence is probable.
High	It is urgent to take measures to reduce risk.	The occurrence is very probable.

Table III.15. *Risk Description. Source:* (Secretaría del Trabajo y Previsión Social, 2011).

It is important to consider that independent hazards and independent risks are being assessed without considering the potential risk of two combined hazards or multi-scalar dynamics. USES are complex systems within systems that are more complex, which makes difficult to measure and imagine all possibilities. However, having understood the current risks, resilience can be assessed qualitatively.

III.2.4.2. Resilience Assessment

The resilience assessment was done using the resilient characteristics of the practical approach used by the Rockefeller Foundation in their program 100 Resilient Cities, which is called *The Resilience Index*. The Resilience Index, is composed of 4 categories with three goals each, fifty-two indicators and 156 variables, based on the uniqueness of cities (ARUP, 2015). In the following table, the dimensions and drivers that might be necessary to identify, according to this methodology can be seen (**Table III.16**).

The Resilience Index: Dimensions and Drivers		
Dimension	**Driver**	
Health & Wellbeing	**1**	Meets Basic Needs: Provision of essential resources requires to meet a person's basic psychological needs.
	2	Supports Livelihoods and Employment: Livelihood opportunities & support that enable people to secure their basic needs. Opportunities might include jobs, kills training, or responsible grants & loans.
	3	Ensures Public Health Services: Integrated health facilities & services, & responsive emergency services. Includes physical & mental health, health monitoring & awareness of healthy living & sanitation.
Economy & Society	**4**	Promotes Cohesive and Engaged Communities: Community engagement, social networks & integration. These reinforce collective ability to improve the community & require processes that encourage civic engagement in planning & decision-making.
	5	Ensures Social Stability, Security and Justice: Law enforcement, crime prevention, justice, & emergency management.
	6	Fosters Economic Prosperity: While Driver 2 is about individual livelihoods, Driver 6 is about the economy on a wider scale. Important economic factors include contingency planning, sound management of city finances, the ability to attract business investment, a diverse economic profile & wider linkages
Infrastructure & Environment	**7**	Enhances and Provides Protective Natural & Man-Made Assets: Environmental stewardship, appropriate infrastructure, effective land use planning & enforcing regulations. Conservation of environmental assets preserves the natural protection afforded to cities by ecosystems.
	8	Ensures Continuity of Critical Services: Diversity of provision, redundancy, active management & maintenance of ecosystems & infrastructure, & contingency planning
	9	Provides Reliable Communication and Mobility: Diverse & affordable multimodal transport networks & systems, ICT & contingency planning. Transport includes the network (roads, rail, signs, signals etc.), public transport options & logistics (ports, airports, freight lines etc.)
Leadership & Strategy	**10**	Promotes Leadership and Effective Management: Relating to government, business & civil society. This is recognisable in trusted individuals, multistakeholder consultation, & evidence-based decision-making.
	11	Empowers a Broad Range of Stakeholders: Education for all, access to up-todate information, & knowledge to enable people & organizations to take appropriate action. Along with education & awareness communication is needed to ensure that knowledge is transferred between stakeholders & between cities
	12	Fosters Long-Term and Integrated Planning: Holistic vision, informed by data. Strategies/plans should be integrated across sectors & land-use plans should consider & include different departments, users & uses. Building codes should create safety & remove negative impacts.

Table III.16. *The Resilience Index: Dimensions and Drivers. Source:* (The Rockefeller Foundation and ARUP, 2015b).

In this context the Rockefeller Foundation considers that resilience can be achieved by: 1) reducing human vulnerability, 2) providing diverse livelihoods and employment, 3) providing effective safeguards to human health and life, 4) developing collective identity and community, 5) including comprehensive security and rule of law, 6) providing a sustainable economy, 7) reducing exposure and fragility, 8) providing effective services, 9) ensuring reliable communications and mobility, 10) encouraging effective leadership and management, 11) empowering stakeholders, and 12 integrating development planning; can a city truly become resilient (The Rockefeller Foundation, 2017) (**Fig. III.5**).

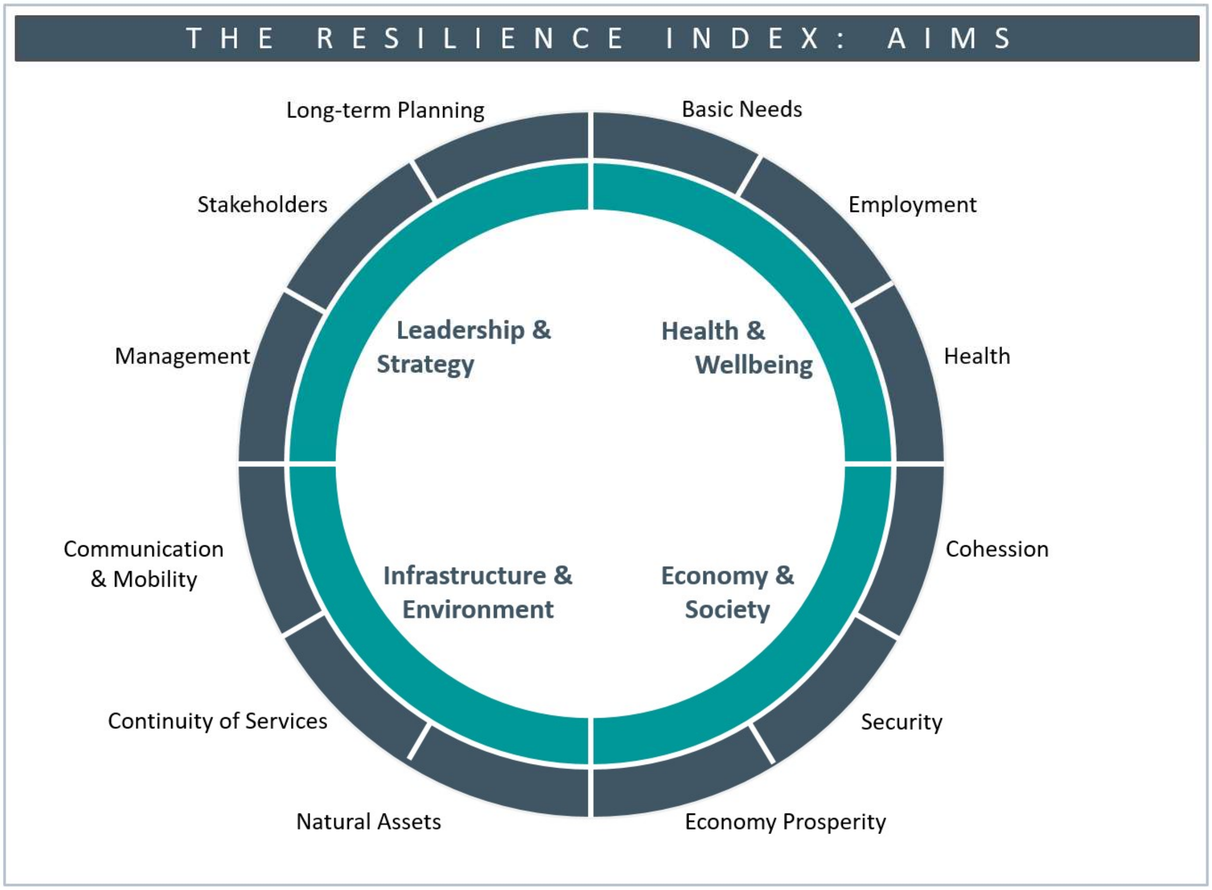


Fig. III.5*. The Resilience Index: Aims. Source: 100 Resilient Cities* (The Rockefeller Foundation, 2017).

In this context, the Resilience Index proposes indicators for each one of the aims (**Appendix B Table B.1.** The Resilience Index: Indicators. Source: Taken from the City Resilience Index (The Rockefeller Foundation and ARUP, 2015b).

Embedded in this index, we find seven qualities that are desirable in a resilient system –*Reflectiveness, Robustness, Redundancy, Flexibility, Resourcefulness, Inclusiveness*, and *Integration*- (The Rockefeller Foundation and ARUP, 2015b) (**Fig. III.6**). For the purposes of this research, such qualities will be analyzed based on the results obtained through the risk assessment, in order to identify how sustainable is the urban metabolism of our USES and be better prepared to recommend resilience strategies.

Fig. III.6. *The Resilience Index: Resilient Qualities of a System. Source: Taken from The Resilience Index* (The Rockefeller Foundation and ARUP, 2015b).

III.2.4.2.1. Qualities of Resilient Systems

In the **Table III.17.** Qualities of Resilient Systems. Source: Taken from the (The Rockefeller Foundation, 2018).**Table III.17**, the seven qualities of resilient systems –*Reflectiveness, Robustness,* *Redundancy*, *Flexibility*, *Resourcefulness, Inclusiveness*, and *Integration*- are explained according to the Rockefeller Foundation & ARUP's Resilience Index.

Qualities of Resilient Systems		
1	**Reflectiveness**	Reflective systems refer to the acceptance of the inherent and ever-increasing uncertainty and change in today's world. This means, that systems have mechanisms to evolve, changing and modifying standards or norms based on emerging evidence, rather than seeking permanent solutions based on the status quo. Most systems learn from experiences and are able to take better decisions in the future.
2	**Robust**	Robust systems include well-conceived, constructed and managed physical assets, so that they can withstand the impacts of hazard events without significant damage or loss of function. Robust design anticipates potential failures in systems, making provision to ensure failure is predictable, safe, and not disproportionate to the cause. Over-reliance on a single asset, cascading failure and design thresholds that might lead to catastrophic collapse if exceeded are actively avoided.
3	**Redundant**	Redundancy refers to spare capacity purposely created within systems so that they can accommodate disruption, extreme pressures or surges in demand. It includes diversity: the presence of multiple ways to achieve a given need or fulfil a particular function. Examples include distributed infrastructure networks and resource reserves. Redundancies should be intentional, cost-effective and prioritized at a city-wide scale, and should not be an externality of inefficient design.
4	**Flexible**	Flexibility implies that systems can change, evolve and adapt in response to changing circumstances. It may favour decentralized and modular approaches to infrastructure or ecosystem management. Flexibility can be achieved through the introduction of new knowledge and technologies, as needed. It also means considering and incorporating indigenous or traditional knowledge and practices in new ways.
5	**Resourceful**	Resourcefulness implies that people and institutions are able to rapidly find different ways to achieve their goals or meet their needs during a shock or when under stress. This may include investing in capacity to anticipate future conditions, set priorities, and respond, for example, by mobilizing and coordinating wider human, financial and physical resources. Resourcefulness is instrumental to a city's ability to restore functionality of critical systems, potentially under severely constrained conditions.
6	**Inclusive**	Inclusion emphasizes the need for broad consultation and engagement of communities, including the most vulnerable groups. Addressing the shocks or stresses faced by one sector, location, or community in isolation of others is an anathema to the notion of resilience. An inclusive approach contributes to a sense of shared ownership or a joint vision to build city resilience.
7	**Integrated**	Integration and alignment between city systems promotes consistency in decision-making and ensures that all investments are mutually supportive to a common outcome. Integration is evident within and between resilient systems, and across different scales of their operation. Exchange of information between systems enables them to function collectively and respond rapidly through shorter feedback loops throughout the city.

Table III.17. *Qualities of Resilient Systems. Source: Taken from the* (The Rockefeller Foundation, 2018).

The Resilience Index is an approach that, despite the fact it assess resilience[23], uses a HST approach. That is the reason why, for the purposes of this research we will include characteristics that were mentioned in Boyd & Juhola's *Principles of Adaptive Governance* (2015) and in Jabareen's *Resilience Framework* (2013). *Learning capacity and understanding of the dynamics*, as well as *multi-level networks* are principles of adaptive governance that must be present in the '*reflectiveness*' quality. Moreover, both authors, Jabareen (2013) and Boyd & Juhola (2015) incorporate dealing with *uncertainty* as a characteristic that any resilient system must have. That's the reason why it is located in the '*flexibility*' quality. Finally, *knowledge capacity* about the system and *co-management* (*urban governance*) are integrated in the '*resourceful*' quality of a resilient system in order to provide a bigger framework of actions that can be taken in order to develop the quality in our USES (Jabareen, 2013; Boyd and Juhola, 2015) (**Table III.18**).

USES Resilience Assessment based on Urban Metabolism		
Qualities of Resilient Systems		
The Resilience Index	***Principles of Adaptive Governance***	***Resilience Framework***
(The Rockefeller Foundation, 2018)	(Boyd and Juhola, 2015)	(Jabareen, 2013)
Reflectiveness	Learning Capacity and understanding of the dynamics Multi-level networks	
Robust		
Redundant		
Flexible	Ability to plan and respond to global uncertainty	Uncertainity
Resourceful	Knowledge Capacity Co-Management mechanisms	Urban governance
Inclusive		
Integrated		

Table III.18. *USES Resilience Assessment based on Urban Metabolism: Qualities of Resilient Systems. Source: Based on The Resilience Index* (The Rockefeller Foundation, 2018)*, the Principles of Adaptive Governance* (Boyd and Juhola, 2015)*, and Resilience Framework* (Jabareen, 2013).

III.2.5. Building Resilience in USES

In order to build sustainable urban metabolism in the USES under study, resilience strategies need to be proposed based on the resilience assessment.

General Objective
To propose resilience strategies that enable sustainable urban metabolism for the community (urban socio-ecological system) of La Pila in San Luis Potosi.

Table III.19. *General Objective.*

[23] The Resilience debate is part of the Complex Adaptive Systems debate.

In this research, the resilience strategies are proposed in the conclusions chapter based on the resilience assessment of the urban metabolism of the USES as recommendations.

III.2.6. Resilience Strategies Implementation

If implementation takes place at any period of time, it is important to consider the constant assessment of the strategies, as the dynamics of any system can change slowly or fast. This means that the information gathered at any USES assessment must be consulted constantly as part of the process for building knowledge and increase the understanding of the interactions, dynamics and thresholds of concern (Resilience Alliance, 2010) (**Fig. III.3**).

Closing Remarks

In this chapter, the Resilience Assessment Framework proposed by Resilience Alliance was reviewed and adapted in order to make it suitable for the research purposes. As a result, the *USES Resilience Assessment based on Urban Metabolism*, was created.

The methodology used for this work includes six steps:

1. *Developing Systems Perspective for Urban Socio-Ecological Systems*. It is considered part of the preparation phase of the methodology used for this research.
2. *Defining the Urban Metabolism for USES*. It answers the question 'Resilience of what?' from the Resilience Alliance Framework and first specific objective of this research: To identify the metabolic fluxes in La Pila: Water, Energy & Food.
3. *Defining the Hazards to the Metabolic Fluxes.* It was designed for the second specific objective –to identify hazards to the metabolic fluxes- by answering the question 'Resilience to what'.
4. *Resilience Assessment based on the Risk Assessment*. It covers the third specific objective of the research which is to analyze how resilient is the urban metabolism of La Pila.
   Building Resilience in USES. It answers the question 'Now what?' from the Resilience Alliance's framework, and covers the general aim of this research which is to propose resilience strategies that enable the sustainable urban metabolism of the USES.
6. *Resilience Strategies Implementation.* This is an extra step that considers *the* assessment of implemented resilience strategies as part of a continuous learning process that enhances a better understanding of the USES, its dynamics, thresholds and interactions.

Chapter IV

Case of Study: La Pila as an USES

"We can't impose our will on a system. We can listen to what the system tells us, and discover how its properties and our values can work together to bring forth something much better than could ever be produced by our will alone."

(Meadows, 2008)

IV. Case of Study: La Pila as an USES

Purposeful systems have 'boundaries', which are seen depending on the 'world view' (Weltanschauung) of the person observing the systems (Jackson, 2003). Despite the fact that socio-ecological systems are open system, it is necessary to establish some boundaries for any Urban Socio-Ecological System (USES) analyzed in order to improve the understanding of it.

In this chapter, La Pila is presented as the USES under study. In order to answer the research questions the resilience of the *metabolic fluxes* which develop within a *periurban* community are analyzed. In this context, it is important to define what a *periurban* socio-ecological system is by conceptualizing *periurban*. Therefore, in the first part of this chapter we define what peri-urban is.

After that, in *San Luis Potosi and La Pila: An interlinkage between urban and peri-urban*, a first explanation of the context in which La Pila interacts with the closest metropolitan area –Metropolitan Zone of San Luis Potosi (MZSLP)[24] -, as a part of a bigger system is given. This second part provides insights on the three metabolic fluxes under study -Water, Energy and Food-, and their current status within the community.

Finally, in Demographics from La Pila: Poverty, Social Backwardness and Margination, the main socio-economical characteristics –as well as main infrastructure accessibility characteristics- of La Pila are presented to provide a general context before presenting the research findings.

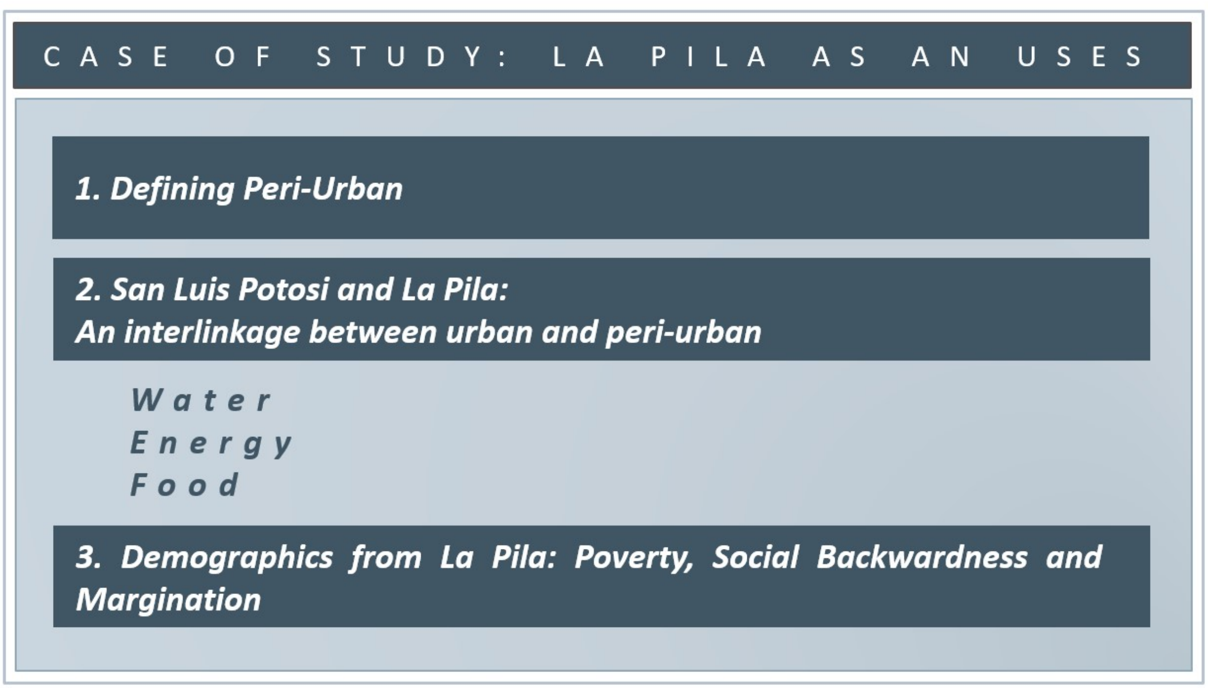


Fig. IV.1. *Case of Study: La Pila as an USES.*

[24] Self-translation of "Zona Metropolitana de San Luis Potosi (ZMSLP)".

IV.1. Defining Peri-urban

As cities attract and retain populations, it is central to understand how rural and urban systems are related in order to provide sustainable urban development. Moreover, learning about such relationship can help to understand how cities evolve and develop all over the time.

In Mexico, a locality is considered as an 'urban area' when it has 2,500 or more inhabitants (United Nations, 2005).

In between rural and urban environments, lie many types of settlements from "small towns to small cities and peri-urban areas to large cities" (World Bank & International Monetary Fund, 2013 p10).

Simelane (2012) argued that "urban systems need to be treated as open, which allows them to regulate themselves through economic success and failures of people who aspire to live in urban areas by choosing to settle in the cities" (Simelane, 2012). In this context, when considering the rural-urban relationship as an open and unregulated process, cities are sinks for rural population because of the intense migration of rural people to urban systems, especially in developing countries (Simelane, 2012).

Further, the two main processes that define the relationship that exist between rural and urban areas are urbanization and industrialization (Lucas, 2006; Simelane, 2012).

According to Sukamdi (2005), the development of rural-urban linkages is divided into four phases. Firstly, there is and evident division between rural and urban areas, with a very limited transfer of people, goods, and services from both sides. In addition, there is a wide gap in life quality and the mode of transportation between both areas is very limited. Secondly, a closer relationship between rural and urban areas is observable due to the transportations' development, which makes easier for people, goods and services to move from both sides. Moreover, at this stage economy is very often exploited by the urban economy, which encourages rural inhabitants to migrate to urban centers to find better living conditions. Thirdly, a new rural-urban interface starts to develop consisting of a mixture of characteristics. At this point, people from rural areas are forced to work in non-agricultural activities outside the urban areas because of the growing cost of living in urban centers. What is more, the urban population starts to grow faster. Finally, at the fourth stage a new urban area is developed, if the development policy goes in good direction. In the end, a new *peri-urban* area is born around the urban area. The next possible step for a *peri-urban* area will be to become a new urban area (Sukamdi, 2005) (**Fig. IV.2**).

Therefore, the development of urban areas should be directed towards making rural and peri-urban areas generative rather than parasitic urban areas by not only mobilizing the capital to develop rural-urban linkages in production and consumption but also in financial matters (Sukamdi, 2005).

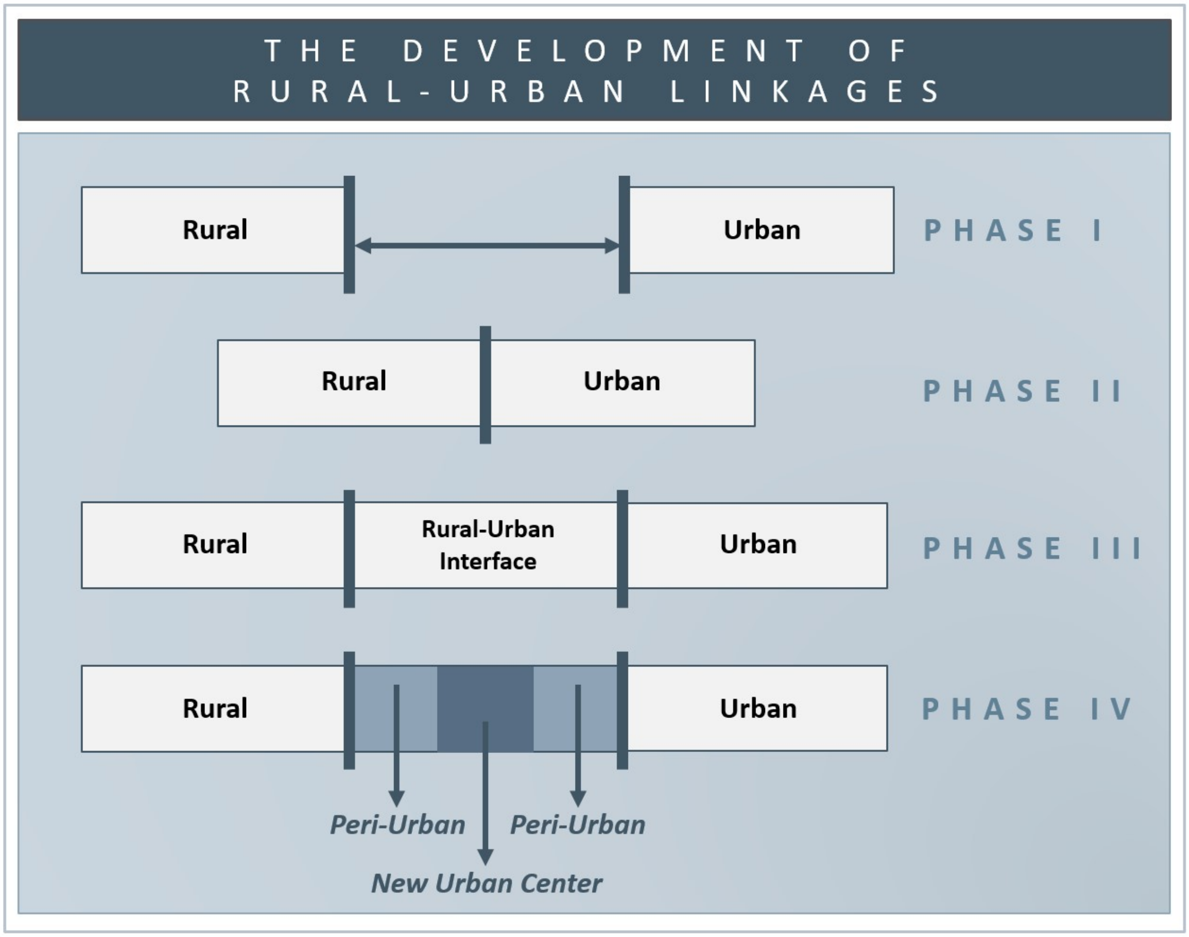


Fig. IV.2. *The Development of Rural-Urban Linkages. Source:* (Sukamdi, 2005).

For the purposes of this research, peri-urban areas are considered as opened urban socio-ecological systems, which interact with several socio-ecological systems –other rural and periurban areas-, within a larger socio-ecological system –that can be a metropolitan area-. In addition, such peri-urban socio-ecological systems are considered as a transitional state from rural to urban, which is the case of La Pila.

IV.2. San Luis Potosi and La Pila: An interlinkage between urban and peri-urban

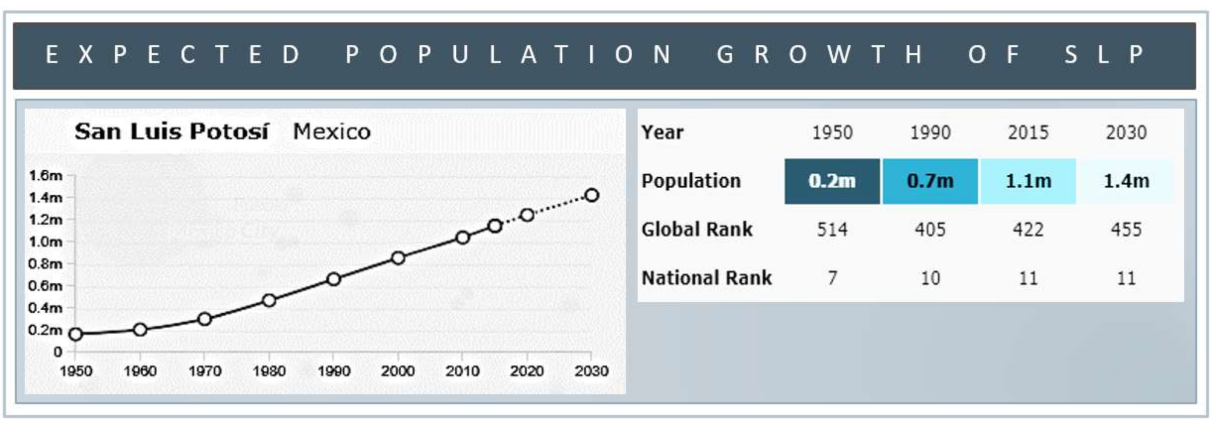
The Metropolitan Zone of San Luis Potosí (MZSLP) is located in San Luis Potosi's state –just 415 km from Mexico City, 370 km from Guadalajara, and 505 km from Monterrey-, on the west side of the Sierra Madre Oriental (Martinez, Escolero and Kralisch, 2010).

According to the World Bank and the International Monetary Fund (2013), cities produce more than the 80% of global economic activity, reducing urban poverty and increasing productivity and better-paying jobs (World Bank and International Monetary Fund, 2013). Because of its intensive and growing international industry, the city of San Luis Potosi (SLP) is part of this intense economic activity. Founded as a gold and silver mining town in 1592, today's most predominant economic activities center on industry. SLP is a crucial part of the Bajío region –alongside other cities, such as Guanajuato, Querétaro and Aguascalientes-, which is today the biggest and most important industrial region in Mexico.

The growing economic relevance of this industrial region can be appreciated in the following extract from *The Report: Mexico 2017*, published by Oxford Business Group Report (2017):

> "San Luis Potosí's GDP increased from MXN 211.3bn ($12.74 bn) in 2009 to an estimated MXN 284.5bn ($17.13 bn) in 2016 on a constant price basis, averaging around 4.4% annual growth from 2010-16. Mexico's national GDP growth, meanwhile, averaged 3.1%. Recently, the gap between national and regional growth has become wider, with the state's GDP growing at double the rate of Mexico's. In 2015 the state's economy expanded by 5.4% compared to 2.6% growth at the national level, putting it in fifth place out of 32 states in terms of GDP growth… Central players in San Luis Potosí's private sector are, therefore, expecting the region to keep growing for many years." (Oxford Business Group, 2017).

In this economical context, SLP's population is expected to reach 1.4 million inhabitants by 2030 (United Nations, 2014a) (**Fig. IV.3**).



Year	1950	1990	2015	2030
Population	0.2m	0.7m	1.1m	1.4m
Global Rank	514	405	422	455
National Rank	7	10	11	11

Fig. IV.3. *Expected Population Growth of San Luis Potosi by 2030. Source: World City Populations 1950-1930* (United Nations, 2014a).

In addition, the MZSLP suffers a process of rapid urbanization -due to the increasing demand for labor by industry and commerce-, which does not correspond to a sustainable planned development (Martinez, Escolero and Kralisch, 2010). As a result, MZSLP presents a population, urban and economic growth that leads to environmental and social problems. Such problems have special consequences in rural and peri-urban communities around the metropolitan area of SLP, and this is specially truth for our case of study: the community of La Pila.

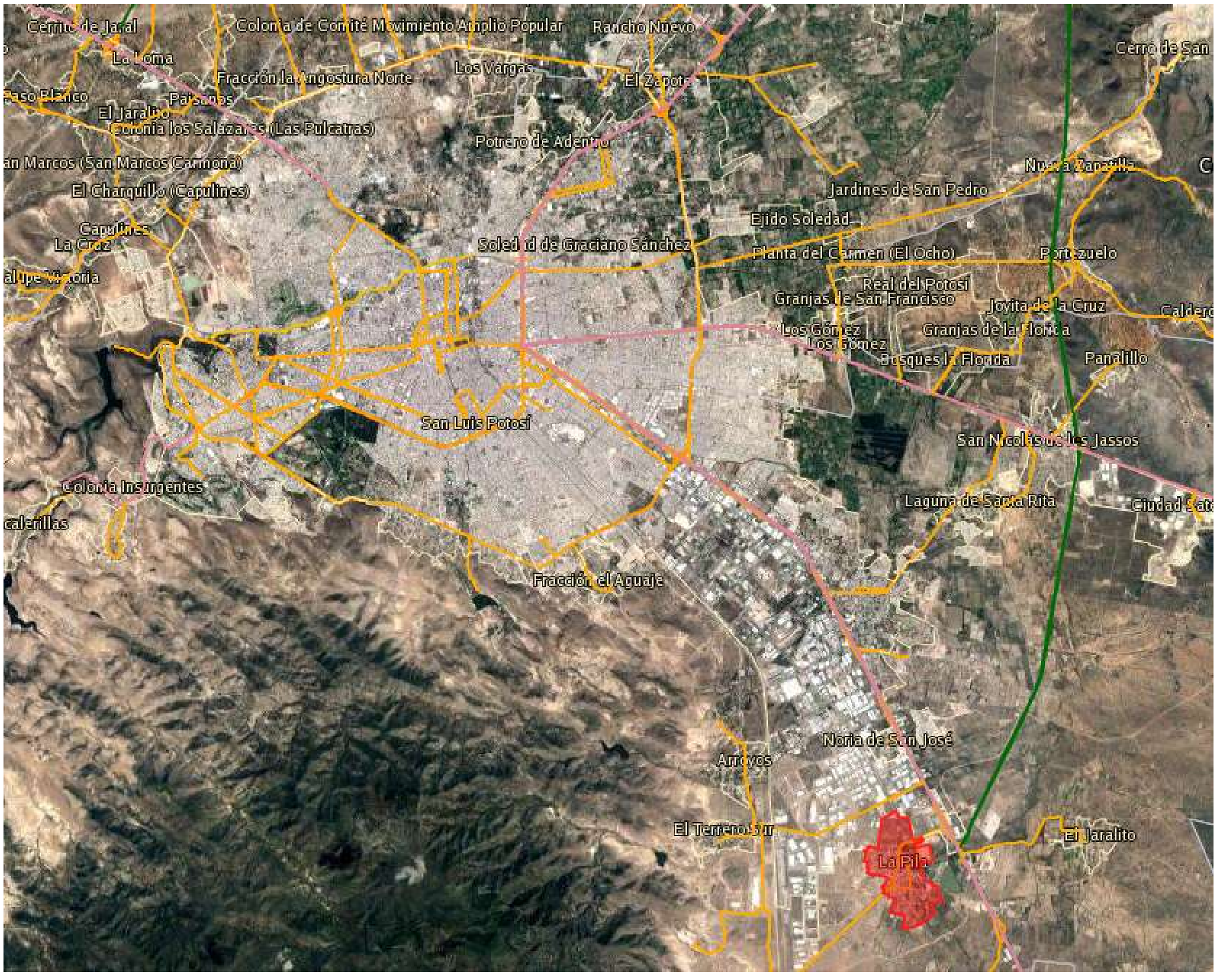


Fig. IV.4. *La Pila, San Luis Potosí, S.L.P.; La Pila is a community located in the southeast of San Luis Potosi. Source:* (INEGI through Google Maps, 2018).

La Pila, - 22°02'02.4"N 100°52'04.2"W- (INEGI, 2015b), is a community located in the south-east of the city of San Luis Potosí, connected to it through the industrial corridor. Its closeness to the city makes it dependent on the metropolitan dynamics, including the industrial (**Fig. IV.4**, **Fig. IV.5**). In the population census of 1997, the community of La Pila was still considered as a rural area or *ejido*, with a total of 1,155 inhabitants (INEGI, 1997), and in the population census of 2005 they reached a total population of 5,974 (SEDESOL, 2013d). According to INEGI[25], a community can be considered as rural

[25] INEGI= Instituto Nacional de Estadística y Geografía.

or urban depending on its number of inhabitants (INEGI, 2010b). With a total of 6,722 inhabitants – according to a population census in 2010- (SEDESOL, 2013d), INEGI considers the community of La Pila as an urban area as it exceeds the number of 2500 inhabitants (**Table IV.1**).

Population Growth in La Pila									
Year	**1997**			**2005**			**2010**		
Demographic Data	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Total Population	582	573	1,155	2,972	3,002	5,974	3,375	3,347	6,722

Table IV.1. *Population Growth in La Pila. Source: Based on INEGI Databases* (INEGI, 1997, 2005, 2010a, 2015a).

However, for the purposes of this research it is important to consider La Pila as an urban area with peri-urban characteristics, especially because of its proximity to the city, which leads to dynamics that differ from city's dynamics. Moreover, as the INEGI only establishes this parameter to divide areas into rural and urban, they leave out social, economic, demographic and spatial characteristics, which are needed in order to better define the urban and rural areas in Mexico (Bonilla Moheno, 2011), as well as to understand their dynamics.

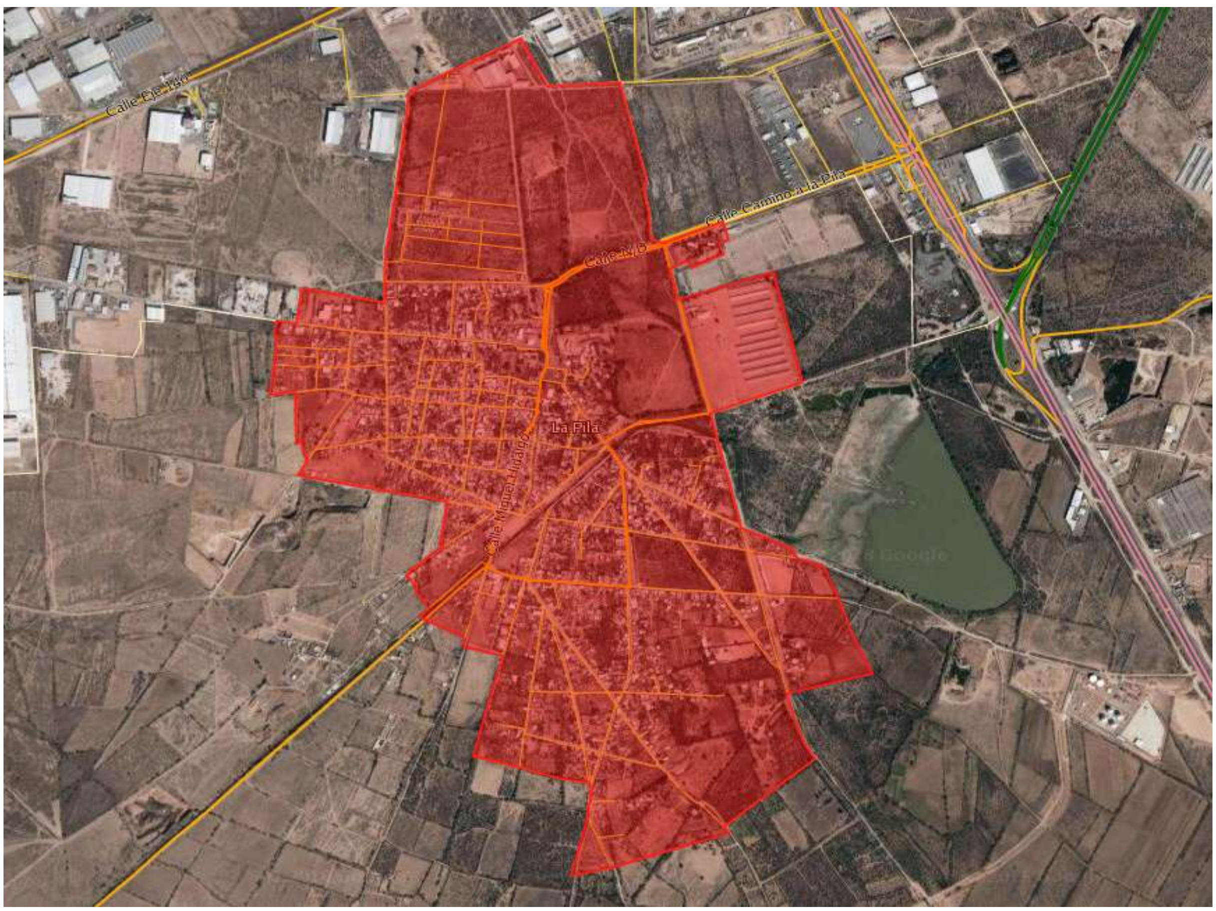


Fig. IV.5. *La Pila: An Urban Socio-Ecological System. Source:* (INEGI through Google Maps, 2018).

La Pila can also be considered peri-urban, because of its dual-nature -the urban and the rural-, and because it is also the result of the interactions and dynamics between the rural and the urban (World

Bank and International Monetary Fund, 2013). Inhabitants from rural areas are involved in the processes of resources extraction and generation, while city's habitants consume energy, food, water and other resources, which they excrete as waste that pollutes rural environments. Because of the facilities that a city offers, people who live in a rural environment tend to migrate to cities, and rural areas tend to become part of the nearest city, which leads to unsustainable urban development. This situation is observable in *La Pila*, in which we can still find rural and urban environments.

In this context, understanding the processes and principles of *Urban Metabolism* inside the community can help to propose resilience strategies in order to conduct the peri-urban towards sustainable development. Enhancing the comprehension of metabolism within *La Pila*, requires the analysis of the main fluxes: *Water*, *Energy* and *Food*. In the following part, insights about how these fluxes get in *La Pila* from MZSLP are given, in order to provide a general context of the current challenges that the community faces.

IV.2.1. Water

San Luis Potosi's valley is located in the Hydrological Region 37, which is also known as "El Salado". (Martinez, Escolero and Kralisch, 2010). According to the State's Water Commission (2015), in the zone in which the MZSLP and La Pila are located, aquifers present critical deterioration (Comisión Estatal del Agua, 2015) (**Fig. IV.6.** Hydrological Zones in San Luis Potosi's state. Source: State's Development Plan 2015-2021 (Comisión Estatal del Agua 2015).**Fig. IV.6**).

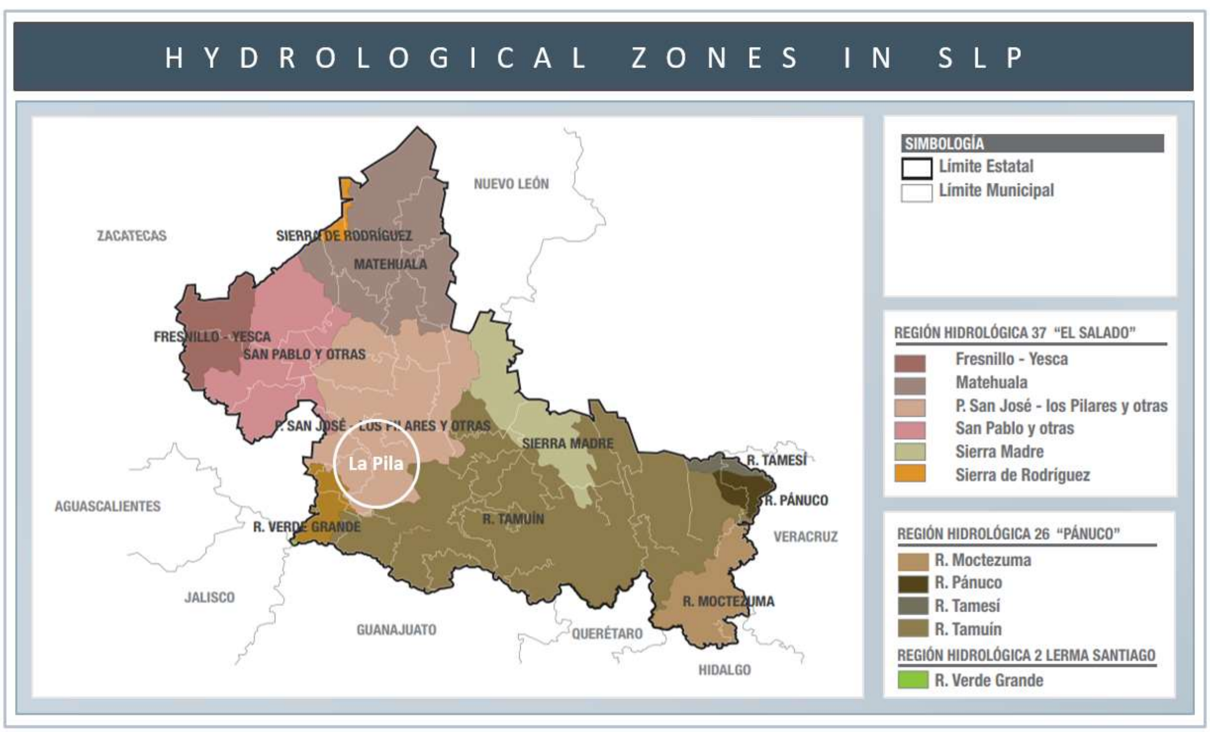


Fig. IV.6. Hydrological Zones in San Luis Potosi's state. Source: State's Development Plan 2015-2021 (Comisión Estatal del Agua 2015).

Water scarcity is a growing problem in MZSLP, as there are limited natural water resources and a bigger demand each year. Despite the fact that public policies and new landscape management proposals have tried to solve water problems, they have not yet succeeded at ensuring an effective water management. As surface water is limited available, solutions to water scarcity have been based on the development of local groundwater sources. The water supply of the metropolitan zone of San Luis Potosí –including the community of La Pila-, hinges on local groundwater sources for more than 90% of its supply, because of tis good quality, reliability and availability during droughts (Martinez, Escolero and Kralisch, 2010). In the SLP valley there are three hydrogeological sources of water that present overexploitation, and a total of 946 hydraulic uses, from which only 859 -447 deep wells and 412 wells- are currently active and provide water with a concentration of 160-450 ppm total dissolved solids (INEGI and Gobierno del Estado de San Luis Potosí, 2002). Although seventy four millions of cubic meters of ground water are annually recharged –according to INEGI estimations in 2002-, by vertical infiltration, irrigation returns, and runoffs from the mountains systems *Sierra de Álvarez* and *Sierra de San Miguelito*; the annual discharge of ground water is estimated in 110.5 Mm^3, which leaves a deficit of -36.5 Mm^3 annually (INEGI and Gobierno del Estado de San Luis Potosí, 2002).

Meanwhile, the other 10% of water supply depends on surface water (Martinez et al. 2010). In order to collect surface water, the metropolitan zone of San Luis Potosi, has a system composed by two dams -*El Peaje* and *El Potosino*-, which supply water to the San José reservoir, achieving an average flow of 300 l/s and a maximum of 489 l/s (Interapas, 2005; Martinez, Escolero and Kralisch, 2010). However, not all the surface water is used. According to Martinez (2010), the overflows from the dams have to be discharged into the Santiago riverbed, which today is an important boulevard that connects the west to the northeast of SLP. This is a consequence of the limited capacity of the purification plant -*Los Filtros*-, as well as the continuously falling storage capacity of dams –San José's capacity is only of 50%-, as a result of an infrastructure that was built more than a century ago (Martinez, Escolero and Kralisch, 2010).

Therefore, because of the increasing water demand in the metropolitan zone of SLP, a new aqueduct –*El Realito*- was constructed in 2007-2014 in order to supply a total of 400,000 inhabitants with drinking water. Such aqueduct has a distance of 133 km, and connects the dam of *El Realito* –which is located in the state of *Guanajuato*-, through three pumping stations and one water purification plant, to six water reservoirs (**Table IV.2**) –with a total capacity of 16,400 m^3- constructed for this purpose (Comisión Estatal del Agua de San Luis Potosí, 2018).

Water Reservoirs in El Realito		
Number	**Location**	**Capacity**
1	Zona Termal	5,000.00 m3
2	Hostal	2,000.00 m3
3	El Aguaje	3,000.00 m3
4	Cordillera	3,000.00 m3
5	Planta Filtros	3,000.00 m3
6	Tangamanga o Balcones	400.00 m3

Table IV.2. *Water Reservoirs in El Realito. Source:* (Comisión Estatal del Agua, 2014).

Despite the efforts to provide drinking water to all population, communities that are located in the peri-urban areas do not have access to clean water. In the case of the community of La Pila, water is supplied through a groundwater well, managed by the State's Water Commission. The State's Water Commission (translated from the Spanish: Comisión Estatal del Agua), is a decentralized organism of the Mexican Government, which is responsible of increasing the infrastructure for water supply, identifying new sources of drinking water, implementing programs for the re-use of drinking water, promoting the improvement of the organisms in charge of providing the services of drinking water in San Luis Potosi's municipalities and promoting a responsible use of water resources across the population (Comisión Estatal del Agua de San Luis Potosí, 2018).

Important for the following chapter is to state that the water supply fees depend on the cubic meters of water consumed (Secretaría General de Gobierno, 2016) (**Table IV.3**). This means that people, who consume less water, will pay less for every cubic meter of consumed water, and viceversa, depending on the average annual temperature of the city (**Table IV.4**), and the socio-economical sector they live in (**Table IV.5**).

Water Supply Fees	
Cubic meters consumed every two months	**Cost per cubic meter (MXN)**
Less than 25 m^3	5.00
Up to 30 m^3	7.50
Up to 40 m^3	10.00
Up to 50 m^3	12.50
Up to 60 m^3	15.00
Up to 100 m^3	17.50
Up to 160 m^3	20.00
Up to 200 m^3	22.50
Up to 250 m^3	30.00
Up to 251 m^3 or more	37.50

Table IV.3. *Water Supply Fees in San Luis Potosí. Source: Translated from decree 0540* (Secretaría General de Gobierno, 2016).

Climate Classification depending on the Temperature	
Average annual temperature (°C)	**Climate Type**
More than 22°C	Af[26]
From 18°C to 22°C	Aw[27]
From 12°C to 17.9°C	Cb[28]
From 5°C to 11.9°C	Cf[29]
Less than 5°C	Dc[30]

Table IV.4. *Climate Classification depending on the Temperature. Source: Self-translated from Manual de Agua Potable y Saneamiento* (Comisión Nacional del Agua, 2007).

[26] According to Interapas: Cálido.
[27] According to Interapas: Semicálido.
[28] According to Interapas: Templado semifrío.
[29] According to Interapas: Templado.
[30] According to Interapas: Frío.

For the purpose of this study, 205 liters per habitant per day will be considered as the diary water consumption to fulfill an inhabitant personal needs, as the average annual temperature of SLP is 21°C according to INEGI databases (INEGI, 2010b), and La Pila is considered as part of the socio-economical sector, according to the National Water Commission (Comisión Nacional del Agua, 2007) (**Fig. IV.5**).

Domestic Consumption per Capita			
Climate	**Consumption per Socio-Economical Sector (L./inhabitant/day)**		
	Residential	**Media**	**Popular**
Af[31] More tan 22°C	400	230	185
Aw[32] From 18°C to 22°C	300	**205**	130
Cf[33] From 5°C to 17.9°C	250	195	100

Table IV.5. *Domestic Consumption per Capita. Source: Self-translated from Manual de Agua Potable y Saneamiento* (Comisión Nacional del Agua, 2007).

Additional to the water supply fees, households pay a 15% of the total for the sewerage and storm water runoff drainage services, a 20% for the wastewater treatment services, and the respective taxes (Secretaría General de Gobierno, 2016). Wastewater is usually used for agricultural purposes in the municipalities of San Luis Potosí and Soledad de Graciano Sánchez (INEGI and Gobierno del Estado de San Luis Potosí, 2002).

IV.2.2. Energy

For the purposes of this research energy is divided in three main sources: 1) Electrical Energy or Electricity; 2) Gas; and 3) Fossil Fuels. Despite the fact that fossil fuels are mainly used for transportation they are sometimes also used in firewood burning practices. Therefore, the importance of considering fuel as an inflow within the USES.

In Mexico, the electrical energy is provided by the Electricity Federal Commission[34] (CFE). In order to calculate the cost of energy, they use a table of fees[35] that change depending on the household electricity consumption. For example, for the first 75 kWh, they charge a fee of MXN 0.793 per kWh. This means, that people paying a monthly payment of MXN 59.47 are not exceeding this consumption. However, if they exceed this Basic Energy Fee, the following 130 kWh will cost MXN 0.956 per kWh. In this case, people will be spending a monthly maximum of MXN 121.61 for electrical energy, considering an Intermediate Energy Fee. If the households exceed the 280 kWh, they are charged MXN 2.802 per kWh consumed. In the following table we show an example of the CFE calculation during March and April 2018 (**Table IV.6**).

[31] According to Interapas: Cálido.
[32] According to Interapas: Semicálido.
[33] According to Interapas: Templado.
[34] Self-translation from Comisión Federal de Electricidad (CFE).
[35] CFE measures and charges the use of electrical energy every two months, but calculations in this study are made with monthly charges.

Electrical Energy Fees			
Concept	**Electrical Energy**	**Fee per kWh**	**Total[36]**
Energy Fee	**kWh**	**MXN**	**MXN**
Basic	150	0.793	118.95
Intermediate	130	0.956	124.28
Exceeding	155[37]	2.802	434.31
	435		**677.54**

Table IV.6. *Electrical Energy Fees. Source: CFE* (Comisión Federal de Electricidad, 2018).

Gas distribution is managed by private enterprises. In the case of La Pila prices for gas vary from MXN 19.45 to MXN 21.21 according to the Energy Regulating Commission[38] (Comisión Reguladora de Energía, 2018). Therefore, in order to calculate gas consumption, an average price of MXN 20.33 was used in this study.

In Mexico, gasoline price changes continuously. For the purposes of this study, a 'stable' price of MXN 18.02 per liter will be considered for the current year, according to the article *The Price of Gasoline in Mexico for 2018* appearing in *La Economía* newspaper (*El Precio de La Gasolina 2018*, 2018). Inside the community, there is none gas station –considering the territorial division-, however, the closest one is located in the main road that connects the community with the Highway 57.

IV.2.3. Food

For the purposes of this study, food is considered as the amount of crops consumed within households. The reason for not including other food appliances was time, as the Food Flux study can require several years. However, these first insights provide a general overview on the main food source that supplies the households within La Pila.

In SLP, the cyclic crops that are produced the most include forage oat (329 051 tons per year), chili (174 882 tons per year), corn (117 744 tons per year) and tomato (116 137 tons per year). Meanwhile, the perennial crops that are produced the most are sugar cane (2 529 479 tons per year), green alfalfa (1 569 348 tons per year), pastures (1 049 434 tons per year) and orange (324 213 tons per year) (INEGI, 2014) (**Table IV.7**). However, according to the Oxford Business Group (2018), the agricultural sector in SLP "may never be able to compete with the manufacturing industry as a proportion of GDP, due to the relative volumes involved".

In their report San Luis Potosí Agricultural sector analysis, the Oxford Business Group (2018) states:

> "Some 2.75 m ha of San Luis Potosí's 6.1m-ha surface area are potential agricultural areas, with around 1.85m ha currently being cultivated. Moreover, the Ministry of

[36] The total does not consider taxes.
[37] This value changes depending on the Electrical Energy Consumption.
[38] Self-translation from Comisión Reguladora de Energía.

Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA[39]) estimates that around 225,000 people in the state work in agricultural activities, with more than 35% of the state's population estimated to be reliant on the sector. According to the Secretariat for Economic Development, this is despite just 4.7% of the state's GDP coming from the primary sector" (Oxford Business Group, 2018).

It is observable, that the industry is the major economic activity in MZSLP, which means that it also plays an important role in the MZSLP development and its surroundings.

Volume of Agricultural Production (Main Crops)			
Main Crops	**Tons per year**	**% From the National Total**	**National Place**
Cyclic Crops			
Forage oat	329,051	3.0	9/23
Green pepper, chili	174,882	7.3	4/32
Corn	117,744	15.4	2/23
Tomato	116,137	4.1	6/32
Grain sorghum	112,323	1.6	8/30
Grain corn	105,381	0.5	23/32
Onion	71,886	5.8	7/26
Forage corn	53,586	0.4	16/26
Soy	50,257	20.3	2/11
Beans	32,281	3.0	9/32
Perennial Crops			
Sugar cane	2,529,479	5.0	6/15
Green alfalfa	1,569,348	5.1	8/26
Pastures	1,049,434	2.2	10/27
Orange	324,213	8.8	3/27
Sugar cane (other uses)	267,665	38.4	1/18
Sugar cane (seed)	66,899	4.8	9/15
Tuna (cactus fruit)	10,492	2.0	7/16

Table IV.7. *Volume of Agricultural Production (Main Crops). Source: INEGI Databases* (INEGI, 2014).

According to INEGI databases (2018), agriculture, breeding or farming activities are economical activities that do not take place in La Pila (INEGI, 2018). The community of La Pila depends, therefore, in the continuous food inflow for its survival.

[39] SAGARPA= Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación.

IV.3. Demographics from La Pila: Poverty, Social Backwardness and Margination

According to SEDESOL (2013), the community of 'La Pila' presents poverty, social backwardness and margination (SEDESOL, 2013b). From the poverty indicators (**Table IV.8**) it is observable that for the year 2010, 10.91% households did not have access to WC, moreover 8.28% households did not have access to drainage and 6.34% did not have access to tap water (SEDESOL, 2013a). Moreover, 10.91% households do not have a WC, while 29.85% households do not have access to a washing machine (SEDESOL, 2013c)

Poverty Indicators in La Pila				
La Pila	**2005**		**2010**	
Indicators	**Value**	**%**	**Value**	**%**
Total of Inhabited Dwellings	**1,119.00**		**1,357.00**	
Lack of quality and spaces of housing				
Dwellings with dirt floor	326.00	29.21	144.00	10.63
Lack of access to basic services in private homes				
Homes without drainage	202.00	18.08	112.00	8.29
Homes without electricity	38.00	3.40	49.00	3.62
Homes without tap water	83.00	7.42	86.00	6.34
Homes without WC	226.00	20.20	148.00	10.91

Table IV.8. *Poverty Indicators in La Pila. Source:* (SEDESOL, 2013a).

Despite the fact that La Pila presents Social Backwardness, SEDESOL (2013) argues that the Index has reduced from -1.01532 in 2005 to -0.96485 in 2010 (**Table IV.9**).

Social Backwardness Indicators in La Pila		
La Pila	**2005**	**2010**
Total Population	**5974**	**6722**
% illiterate population: 15 years or more	16.04	10.90
% 6-14 year-old-population who does not go to school	4.34	4.94
% population with uncompleted basic education: 15 years or more	62.81	57.32
% population without access to health services	29.69	14.33
% Dwellings with dirt floor	29.13	10.61
% Homes without WC	20.20	10.91
% Homes without tap water	7.42	6.34
% Homes without sewer	18.05	8.25
% Homes without electricity	3.40	3.61
% Homes without washing machine	31.64	29.85
% Homes without fridge	31.46	26.31
Social Backwardness Index	**-1.01532**	**-0.96485**
Social Backwardness Grad	**very low**	**very low**

Table IV.9. *Social Backwardness Indicators in La Pila. Source:* (SEDESOL, 2013c).

Margination Indicators in La Pila		
La Pila	**2005**	**2010**
Total Population	**5974.00**	**6722.00**
% illiterate population: 15 years or more	16.04	10.90
% population without completed primary education: 15 years or more	35.43	29.87
% particular homes without WC	15.21	10.91
% particular homes without electricity	3.31	3.62
% particular homes without tap water	7.42	6.34
% of habitants per room in particular homes	40.25	1.31
% particular homes without fridge	29.21	10.63
% particular Homes with dirt floor	31.40	26.31
Margination Index	**-0.75456**	**-0.76113**
Margination Grad	**Medium**	**High**

Table IV.10. *Margination Indicators n La Pila. Source:* (SEDESOL, 2013b).

Finally, according to the margination indicators the margination index has increased from -0.75456 in 2005 to -0.76113 in 2010, which is the result of the increasing new homes that do not have access to electricity as observable in **Table IV.10**.

Sustainability Model for Vulnerable Communities' Governance: Elementary school Francisco González Bocanegra[40]

As in this part we are explaining the current context of La Pila's dynamics it is central to state that this research is part of a project –called-, which aims to create a sustainable primary school. The selected school is *Francisco González Bocanegra*, whose students are between 6 to 12 years old. Actions are being taken in this school, because it has been observed that the majority of the primary students do not continue their studies because their families live in extreme poverty. The current project aims to create auto-sustainable schools that allow producing food through agricultural gardens, collecting rainwater to ensure the health of the students, producing electrical energy through solar panels and recycling waste to create compost.

As this project contribute to achieve sustainability thorough the achievement of SDG's within the community, its strategies will be considered when assessing urban resilience through risk.

[40] Self-translation of *Modelo de Sostenibilidad para la Gobernanza de Comunidades Vulnerables: Escuela Francisco González Bocanegra*.

Closing Remarks

Due to the current industrial growth that the MZSLP is experiencing, urban areas are extending and the resources demands are constantly increasing. In this context of continuous change, peri-urban areas result affected as they lack the means to keep track on the urban evolution. As it was reviewed in this chapter, the peri-urban areas are considered as opened urban socio-ecological systems, which interact with several socio-ecological systems –other rural and periurban areas-, within a larger socio-ecological system –that can be a metropolitan area-. In this context, La Pila is a peri-urban interacting with the surrounding peri-urban socio-ecological systems within a bigger completely urbanized system, which is the Metropolitan Zone of San Luis Potosi. Additionally, La Pila is considered as a peri-urban socio-ecological system in a transitional state from rural to urban, because of the percentages of homes without tap water, sewer, electricity, and electronic appliances, characteristically present on urban environments. In this context, there is a complex interaction between La Pila and SLP, and as La Pila is a smaller USES within the MZSLP, its dynamics are strongly influenced by the decisions that are taken in SLP, especially those related to resources distribution. That is the case of the Water, Energy and Food fluxes. In the case of water supply, for example, it is observable that La Pila is not a priority on the current system, although its proximity to the new aqueduct *El Realito*. Finally, in the last part of this chapter, it was observed that La Pila presents poverty, social backwardness and margination (SEDESOL, 2013b), which means that a significant percentage of the population does not have access to tap water, drainage, electricity, and in some cases they do not even have a WC. Moreover, in the INEGI statistics, it can be appreciated that some of the homes do not have basic electronic appliances, such as fridge or washing machine, to satisfy their personal needs.

Chapter V

Metabolism of Households in La Pila

"Understanding energy and material flows through cities lies at the heart of developing sustainable cities."

(Nourhan, 2014)

V. Metabolism of Households in La Pila

In order to understand the urban metabolism in the community of *La Pila* -considered as our *USES* of study-, a total of 40 households were interviewed during the months of April and May 2018. Most households are headed by 18-60 year-old men and host an average of 4 to 5 family members. It is observable that, in the majority of the cases families are composed by parents and two or three children. In this chapter, data gathered regarding the Water, Energy and Food fluxes are presented and analyzed in two subchapters (**Fig. V.1**). On a first subchapter, *Water-Energy-Food Consumption in La Pila*, the fluxes' data are described and interpreted independently. Because of the diversity of families in La Pila and the complexity of the USES dynamics, the data gathered are presented and analyzed at three scales, in order to provide a better context of how resources are consumed: 1) Households Total Consumption; 2) Household A-B-C Types Consumption; and 3) A Household Analysis.

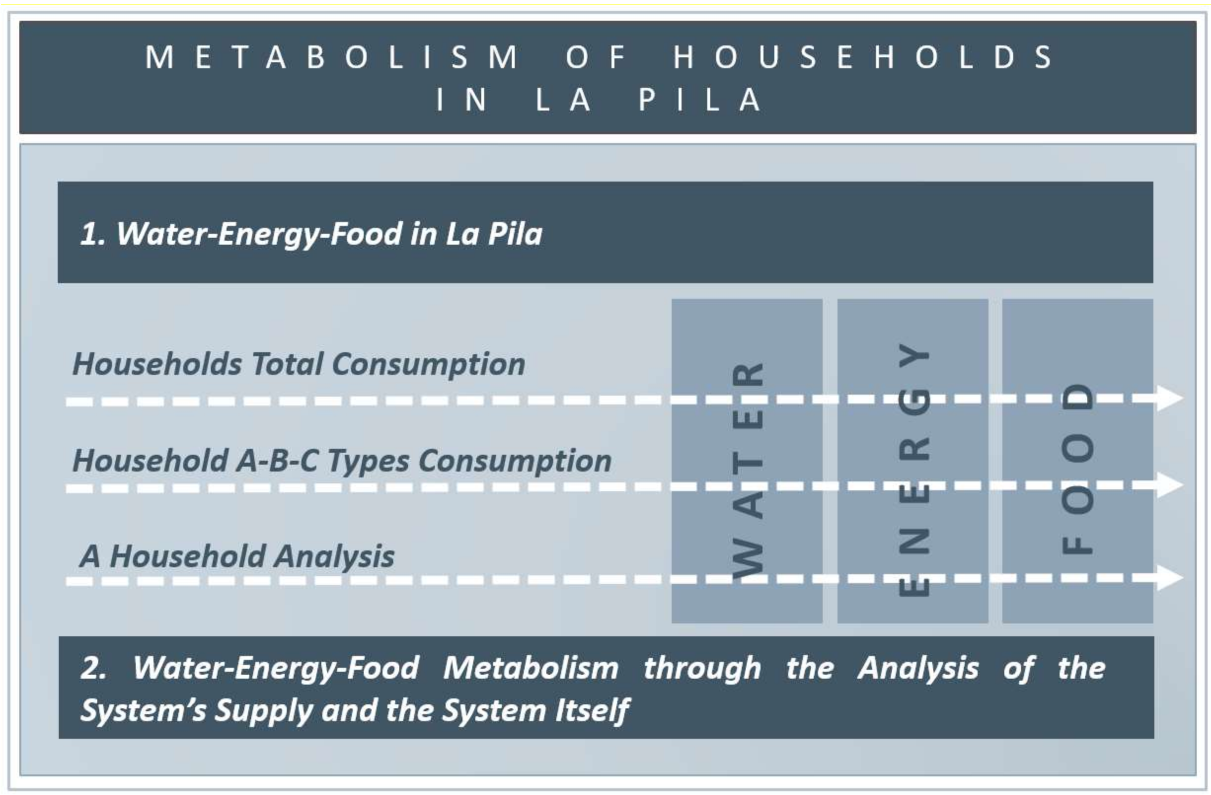


Fig. V.1. *Metabolism of Households in La Pila.*

In *Households Total Consumption*, the data for every flux are presented considering first the 40 interviewees, secondly a probabilistic correction -using the Monte Carlo method- of the 40 interviewees that can be extended for La Pila, and finally, a per capita resources consumption. The Monte Carlo method is used because it allows to have a better estimation of the community with the data gathered through the interviews. After that, in *Household A-B-C Types Consumption,* a classification of the forty interviewees is proposed based on the number of inhabitants per household. In order to classify the households, the number of inhabitants per household was used: three to four inhabitants, five inhabitants, and six or more inhabitants (**Fig. V.2**). Such classification is useful to observe how the resources consumption per household changes regarding the number of inhabitants and it also provides insights regarding the average income per household. In this part, the Monte Carlo method is also used to make a probabilistic correction of the data gathered per household type. Then, a per capita resources consumption is presented in order to obtain liters of water consumed per person per day (L/person/day). Later, in *A Household Analysis*, we present a household analysis, considering a typical family of 5 members –which was the most common familiar aggrupation according to the interviews-, as a mean to provide insights into how households' acquire, consume and excrete resources: Water, Energy and Food.

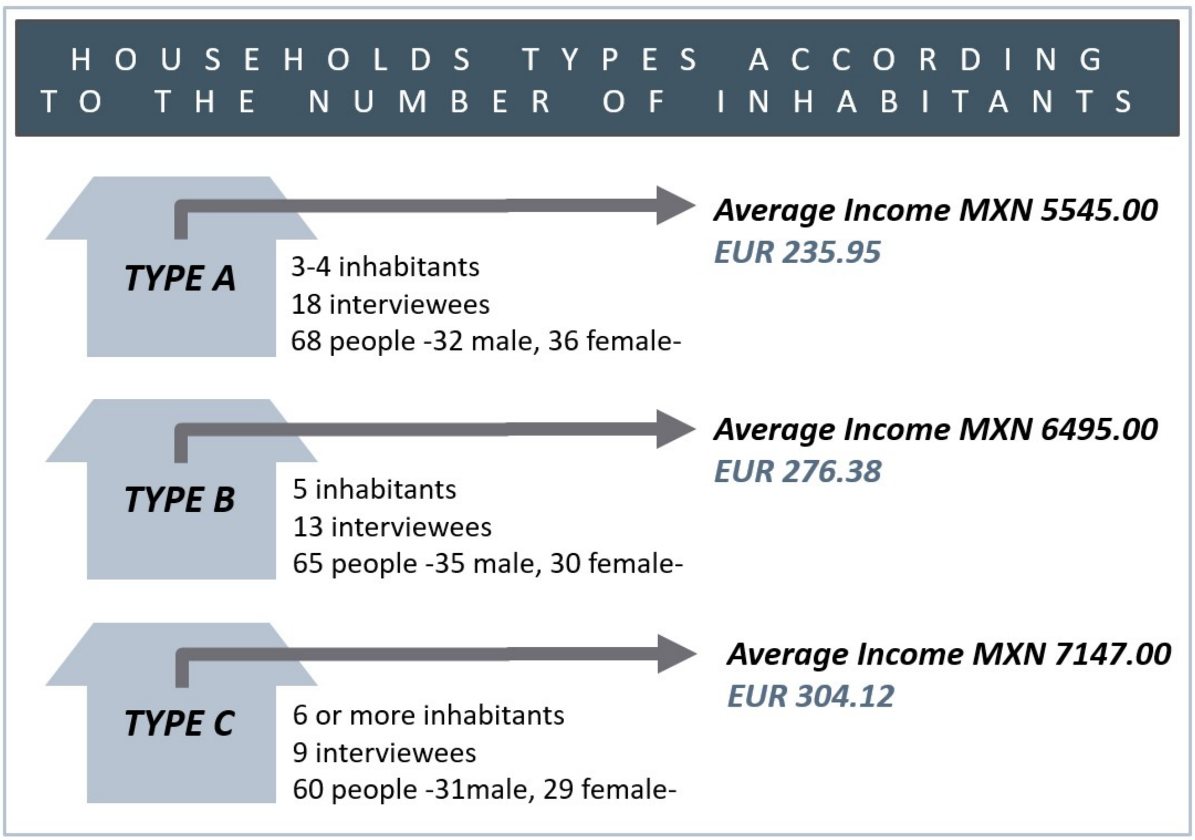


Fig. V.2. *Households Types according to the Number of Inhabitants.*

On the second subchapter, *Water-Energy-Food Metabolism through the Analysis of the System's Supply and the System Itself,* the metabolism of the households is analyzed and discussed considering the whole USES that is La Pila.

V.1. Water-Energy-Food Consumption in La Pila

In this subchapter, the resources metabolism is presented and analyzed through the data gathered during the field work. Firstly, *water flux* will be described considering tap water. After that, *energy flux* will be equally presented and analyzed, considering energy that comes from electricity, and fossil fuels –gas and fuel-. Finally, *food flux* is described and analyzed based on the money spent to cover it and the percentage that it represents from the household income. For each one of the fluxes, the three scales -*Households Total Consumption*, *Household A-B-C Types Consumption* and *A Household Analysis*-, are used.

V.1.1. Water Consumption in La Pila

In order to calculate the liters of water flowing into the household, tap and bottled water were considered, as well as extra water resources that can come from other sources. In the first part, *Households Total Consumption*, and in *Household A-B-C Types Consumption* the liters of tap water consumed are presented. After that, in *A Household Analysis*, the water coming from other sources is presented through a household example. Spent water liters were calculated using the Interapas fees tables[41], without discounting the taxes paid for the service, nor the drainage fees. The reason for not splitting these concepts was that data obtained during the interview asked about the monthly expenditure in water resources, which was changing according to the water source. Therefore, the data were standardized by not taking out the extra fees, which can only be paid through Interapas.

Households Total Consumption

The monthly average estimated water consumption per household in La Pila is 17,890.18 L. ($\dot{x}$=11,000 L.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 15616.17 L. (**Fig. V.3**). Meanwhile, the monthly average estimated water consumption per capita in La Pila is 3,098.78 L. ($\dot{x}$=2,525.00 L.). This means that if the per capita consumption within a month (3,098.78) is divided by the number of days (average of 30), inhabitants in La Pila are spending an average of 103.29 L. per capita/per day. Taking into account the average annual temperature of 21°, La Pila inhabitants are supposed to have a dairy water provision of 205 liters per capita[42] (Comisión Nacional del Agua, 2007) (**Table V.1**). This means that they are consuming about one third of what is indicated by Water National Commission (self-translation from Comisión Nacional del Agua), to fulfill their basic needs. In this scenario, La Pila inhabitants are consuming a 50.38% of their water provision to do all their diary activities, including cooking, hygiene habits –tooth brushing, showering, WC-, and cleaning among others.

[41] See **Table IV.3.** Water Supply Fees in San Luis Potosí. Source: Translated from decree 0540 (Secretaría General de Gobierno, 2016).

[42] See **Table IV.5**. Domestic Consumption per Capita. Source: Self-translated from Manual de Agua Potable y Saneamiento (Comisión Nacional del Agua, 2007).

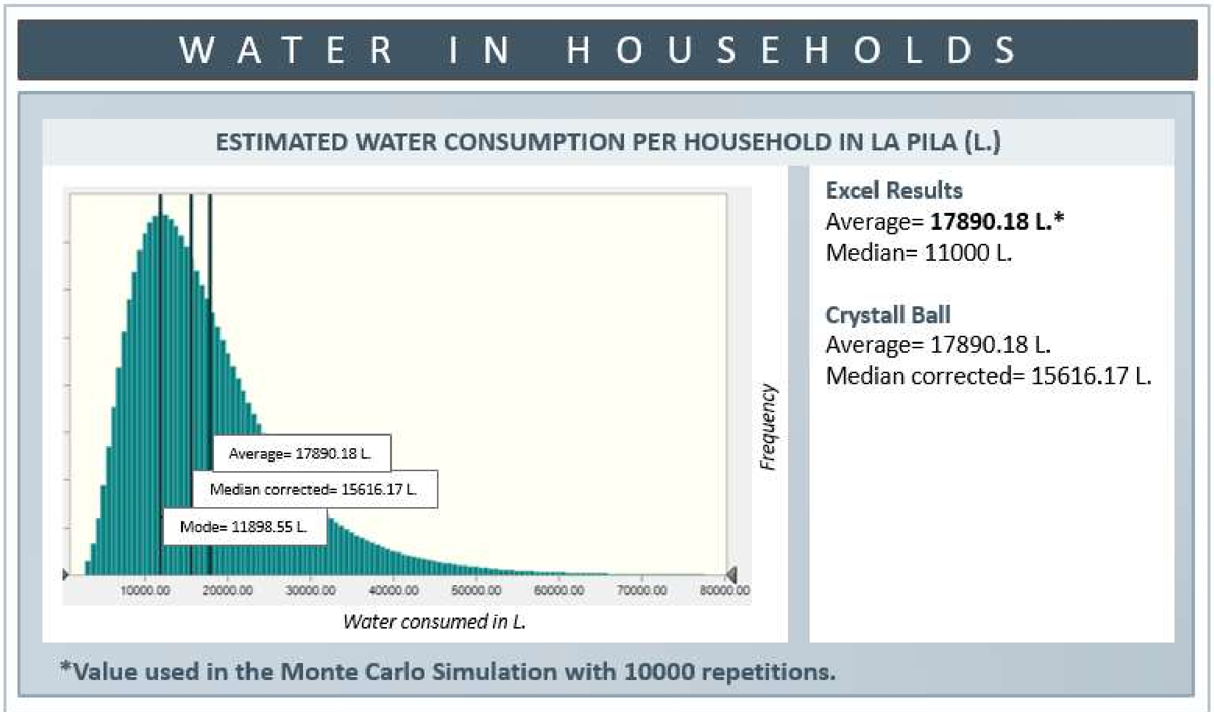


Fig. V.3. *Water in Households: Estimated Water Consumption per Household in La Pila.*[43]

Monthly Estimated Water Consumption		
	Per Household	**Per Capita**
Average	17,890.18 L.	3,098.78 L.
Median	11,000.00 L.	2,525.00 L.

Table V.1. *Monthly Estimated Water Consumption.*[44]

Household A-B-C Types Consumption

For Households with three or four inhabitants –Type A-, the monthly average estimated water consumption per household in La Pila is 14,140.21 L. (ẋ=12,500.00 L.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 11,544.91 L. (Type A in **Fig. V.4**). Meanwhile for Type B Households –five inhabitants-, the monthly average estimated water consumption per household in La Pila is 12,060.44 L. (ẋ=12,000.00 L.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 9,284.13 L. (Type B in **Fig. V.4**). Household that are Type C –households with six or more inhabitants-, the monthly average estimated water consumption per household in La Pila is 17,470.37 L. (ẋ=15,300.00 L.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 15,132.19 L. (Type C in **Fig. V.4**).

[43] See Appendix C: **Table A.1.** Hazards' categories. Source: Based on the literature review.

[44] See Appendix C: **Table C.5.** Estimated Water Consumption per Capita per Household in La Pila (L.).

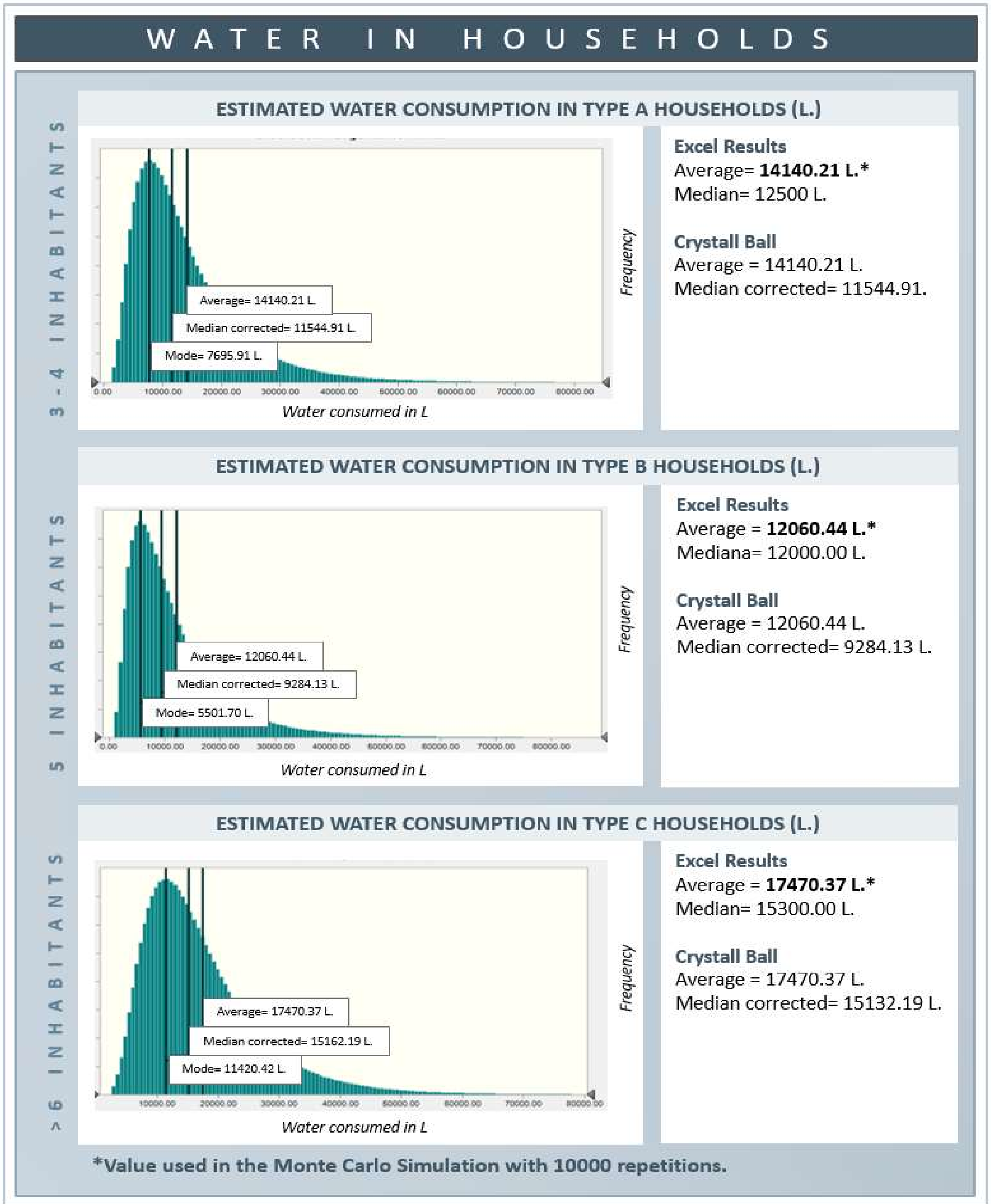


Fig. V.4. *Water in Households: Estimated Water Consumption per Household Type in La Pila.*[45]

[45] See Appendix C: **Table C.2.** Water in Households: Estimated Water Consumption in Type A Households in La Pila (L.).

As it can be appreciated in the **Table V.2**, the monthly average estimated water consumption per capita in La Pila varies independently of the number of inhabitants per household. For Type B Households we have an average water consumption of 2,412.09 L. per month, which is the lowest consumption per capita within the household types. On the contrary, the households that have less inhabitants have the highest water consumption per capita, with an average consumption of 3,828.26 L. In between, we find Type C households, with an average water consumption of 2,631.70 L. per capita per month.

As stated in the previous chapter, La Pila inhabitants are supposed to have a dairy water provision of 205 liters per capita according to the Water National Commission (2007), which means that for the households with the highest consumption –Type A-, the water consumed per person per day is 127.60 L.[46]. This means that people is spending 62.24% of their diary water provision.

Monthly Estimated Water Consumption per Household Type						
	Type A		Type B		Type C	
	Per Household	Per Capita	Per Household	Per Capita	Per Household	Per Capita
Average	14,140.21 L.	3,828.26 L.	12,060.44 L.	2,412.09 L.	17,470.37 L.	2,631.70 L.
Median	12,500.00 L.	3,166.67 L.	12,000.00 L.	2,400.00 L.	15,300.00 L.	2,550.00 L.

Table V.2. *Monthly Estimated Water Consumption per Household Type.*[47]

A Household Analysis

In La Pila, a five-member family consumes around 8,000.00 L. of tap water to satisfy their needs every month. Dividing the total of liters between the five members of the family, we can discover that the consumption per capita is of 1,600.00 L. per month. Considering a month of 30 days, the daily per capita consumption is approximately 53.33 L., which corresponds to a 26.01% of the Interapas diary water provision.

This household pays around MXN 120.00[48], which is less than the monthly average MXN 230.23 (considering the water total consumption average from the forty households). According to the data given by the interviewee, this household has an income of MXN 6000.00 per month[49]. As the income is low, inhabitants try to save as much water as possible when realizing domestic scores and when taking care of personal hygiene.

---

[46] Result of dividing 3,828.26 by 30 days.

[47] See Appendix C: **Table C.2.** Water in Households: Estimated Water Consumption in Type A Households in La Pila (L.). **Table C.3.** Water in Households: Estimated Water Consumption in Type B Households in La Pila (L.). **Table C.4.** Water in Households: Estimated Water Consumption in Type C Households in La Pila (L.). **Table C.6.** Estimated Water Consumption per Capita in Type A Households (L.). **Table C.7.** Estimated Water Consumption per Capita in Type B Households (L.). **Table C.8.** Estimated Water Consumption per Capita in Type C Households (L.).

[48] Equivalent to approximately EUR 5.10.

[49] The water expenditure is the 2% of the monthly income.

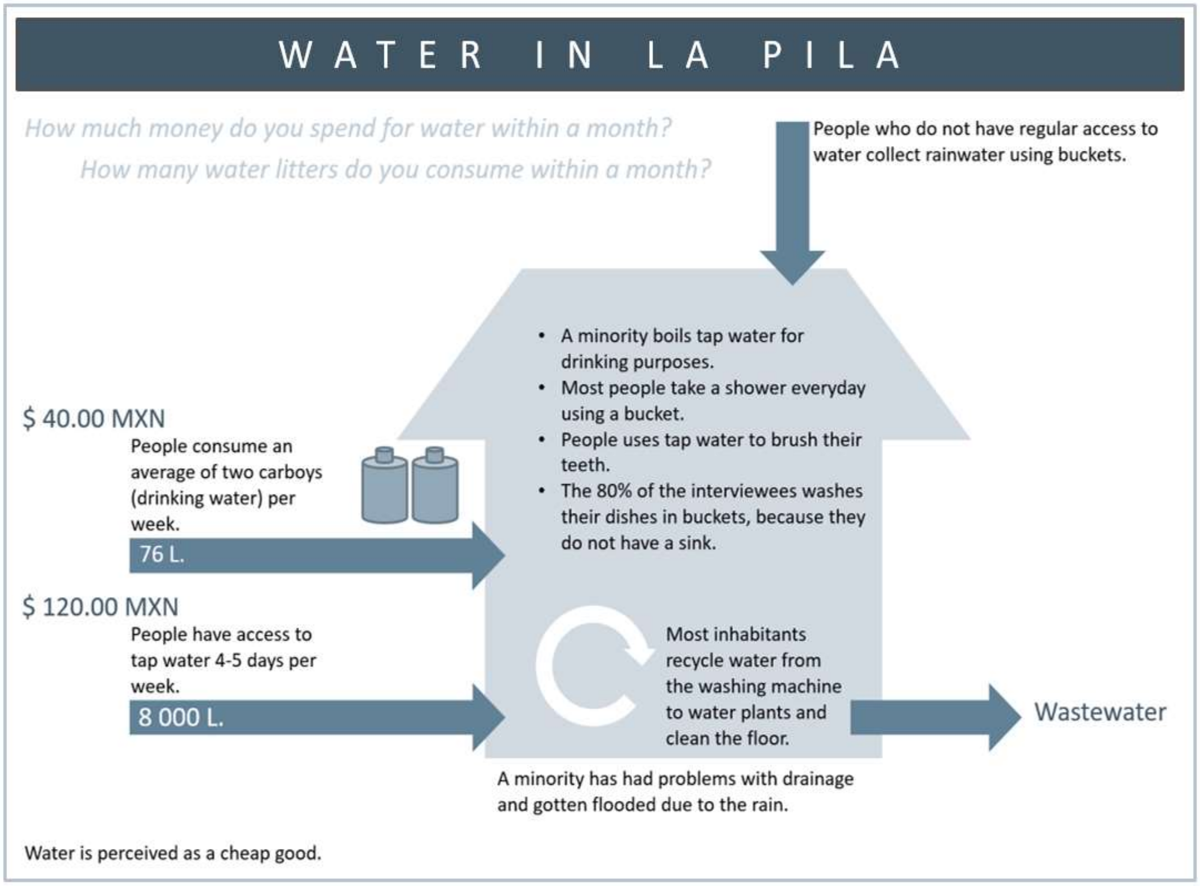


Fig. V.5. *Water in La Pila: A Household Analysis.*

Monthly Monetary Expenditure						
	Average		Median		Household	
Water	**MXN**	**230.23**	**MXN**	**175.00**	**MXN**	**120.00**
Energy						
Gas	MXN	281.16	MXN	252.50	MXN	140.00
Electrical Energy	MXN	96.03	MXN	136.92	MXN	200.00
Fuel	MXN	780.00	MXN	800.00	MXN	800.00
Food	MXN	6178.97	MXN	6421.83	MXN	3200.00

Table V.3. *Monthly Monetary Expenditure.*

Monthly Resource Expenditure						
	Average		Median		Household	
Water	**17 890**	**L.**	**11000**	**L.**	**8000**	**L.**
Energy						
Gas	13.82	Kg.	12.42	Kg.	6.89	Kg.
Electrical Energy	92.77	kWh.	84.40	kWh.	100.65	kWh.
Fuel	43.21	L.	44.32	L.	44.32	L.
Food	6178.97	MXN	6421.83	MXN	3200.00	MXN

Table V.4. *Monthly Resource Expenditure.*

It is observable that the household selected is under the average and the median water consumption (**Table V.3** and **Table V.4**). It was observed that other households can get their water supply from other sources different to the connection through Interapas. There was a case of a family, who have a well in their own garden; therefore, they satisfy their water necessities from there. Unfortunately, it was hard to measure their water consumption. Moreover, some people share the water resources with their families and their neighbors, when water is inaccessible. Consequently, there is a water input flowing in the households, which is not being considered in the water consumption calculations.

There were some households, which said that they harvest rainwater through buckets and barrels, which later is used to clean the floor or water the plants. It was observed that more than 75% of the people interviewed use bottled water to drink, and people who do not, boil water by burning firewood.

Finally, bottled water represents a small water inflow, as for the households' averages is estimated that they consume up to 38 L. within a week. In the case of the household under study, we discovered that their weekly consumption is about 76 L., which is above the average (304 L. per month) (**Fig. V.5**).

V.1.2. Energy Consumption in La Pila

In order to calculate the energy flowing into the household, electrical energy, gas and fossil fuels were considered as main sources. In this part, Households Total Consumption are first presented for every energy source. Later, in Household A-B-C Types Consumption, the schema proposed is followed, measuring the energy inflowing first, per household and then per capita. Finally, in a Household Analysis, energy coming from other sources is presented through a household example.

Households Total Consumption

The energy fluxes considered for this study were gas, electricity and fossil fuels. It is vital to observe that units are different for each one of these fluxes. Gas is described in kilograms (Kg.), while electricity is expressed in Kilowatts per Hour (kWh.), and fuel in liters (L.). Despite the fact that most urban metabolists try to convert energy and material fluxes into one single unit, for the purposes of this study, it was decided to leave the estimations of resources consumption in their original unit, as it can be unpractical to mention calories for gas or electricity when making decisions. Moreover, this study searches to understand the dynamics of the metabolism in order to find hazards that might conform potential risks to the system's supply or the system itself.

Gas

The monthly average estimated gas consumption per household in La Pila is 13.82 Kg. ($\dot{x}$=12.42 Kg.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 13.00 Kg. (**Fig. V.6**). Meanwhile, the monthly average estimated gas consumption per capita in La Pila is 3.00 Kg. ($\dot{x}$=2.50 Kg.).

This means that if the per capita consumption within a month (3.00 Kg) is divided by the number of days (average of 30), inhabitants in La Pila are spending an average of 0.1 Kg. per capita per day (**Table V.5**).

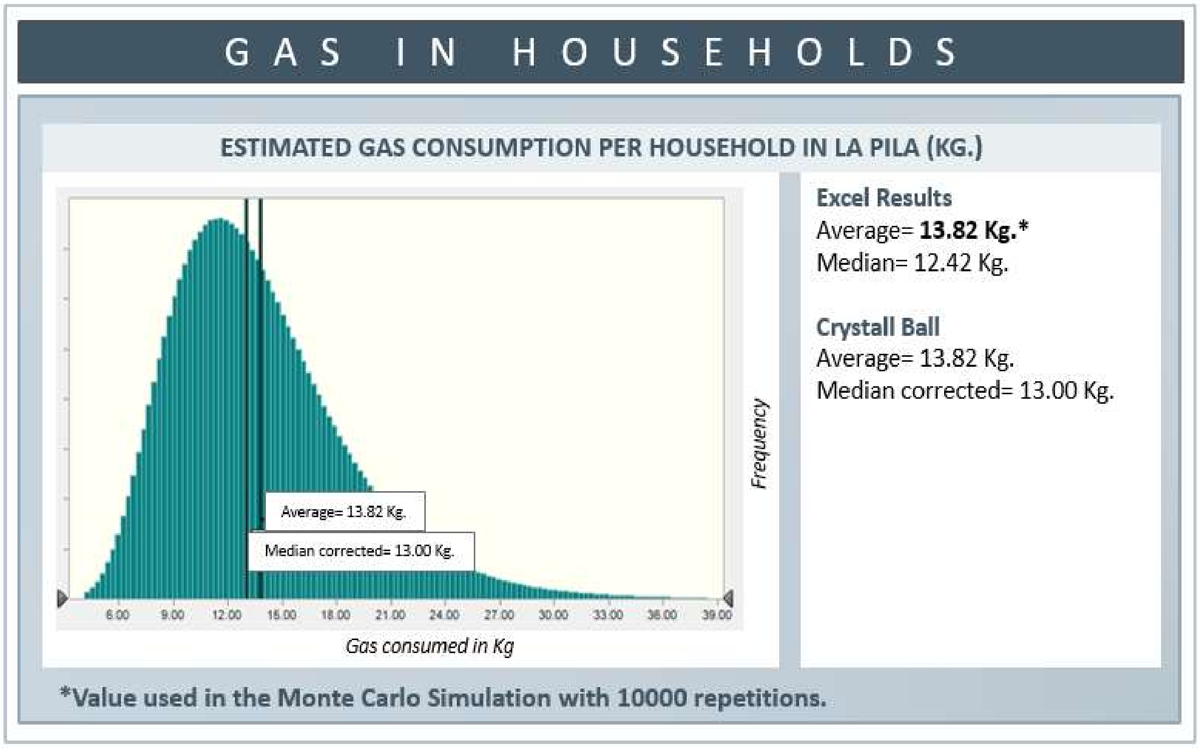


Fig. V.6. *Gas in Households: Estimated Gas Consumption per Household in La Pila.*[50]

Monthly Estimated Gas Consumption		
	Per Household	**Per Capita**
Average	13.82 Kg.	3.00 Kg.
Median	12.42 Kg.	2.50 Kg.

Table V.5. *Monthly Estimated Gas Consumption.*[51]

Electricity

A monthly average estimated consumption per household in La Pila is 92.77 KwH. (ẋ=84.40 kWh.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 81.66 kWh. This can be observed in **Fig. V.7Fig. V.6**). In this direction, the monthly average estimated electrical energy consumption per capita in La Pila is 20.17 kWh. (ẋ=17.62 kWh.). This means that if the per capita consumption within a month (20.17 kWh) is divided by the number of days (average of 30), inhabitants in La Pila are spending an average of 0.67 kWh. per capita per day (**Table V.6**).

[50] See Appendix C: **Table C.13.** Energy in Households: Estimated Gas Consumption per Household in La Pila (Kg.).

[51] See Appendix C: **Table C.25.** Estimated Gas Consumption per Capita and Household in La Pila (Kg.).

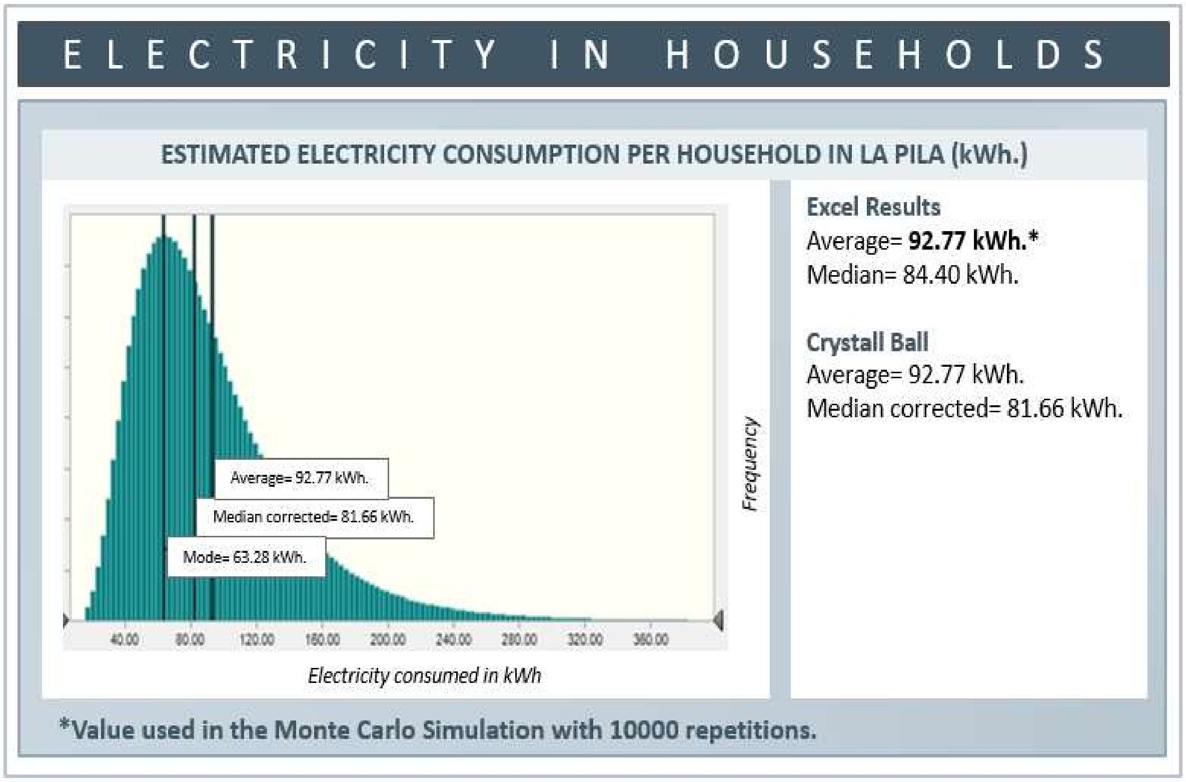


Fig. V.7. *Electricity in Households: Estimated Electricity Consumption per Household in La Pila.*[52]

Monthly Estimated Electricity Consumption		
	Per Household	**Per Capita**
Average	92.77 kWh	20.17 kWh
Median	84.40 kWh	17.65 kWh

Table V.6. *Monthly Estimated Electricity Consumption.*[53]

Fuel

A total of 43.21 L. is the monthly average estimated fuel consumption per household in La Pila (ẋ=44.32 L.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 40.82 L. (**Fig. V.8Fig. V.6**). Additionally, the monthly average estimated fuel consumption per capita in La Pila is 9.94 L. (ẋ=8.86 L.) as observed in **Table V.7**.

[52] See Appendix C: **Table C.17.** Estimated Electricity Consumption per Household in La Pila (kWh).
[53] See Appendix C: **Table C.29.** Estimated Electricity Consumption per Capita and Household in La Pila (kWh.).

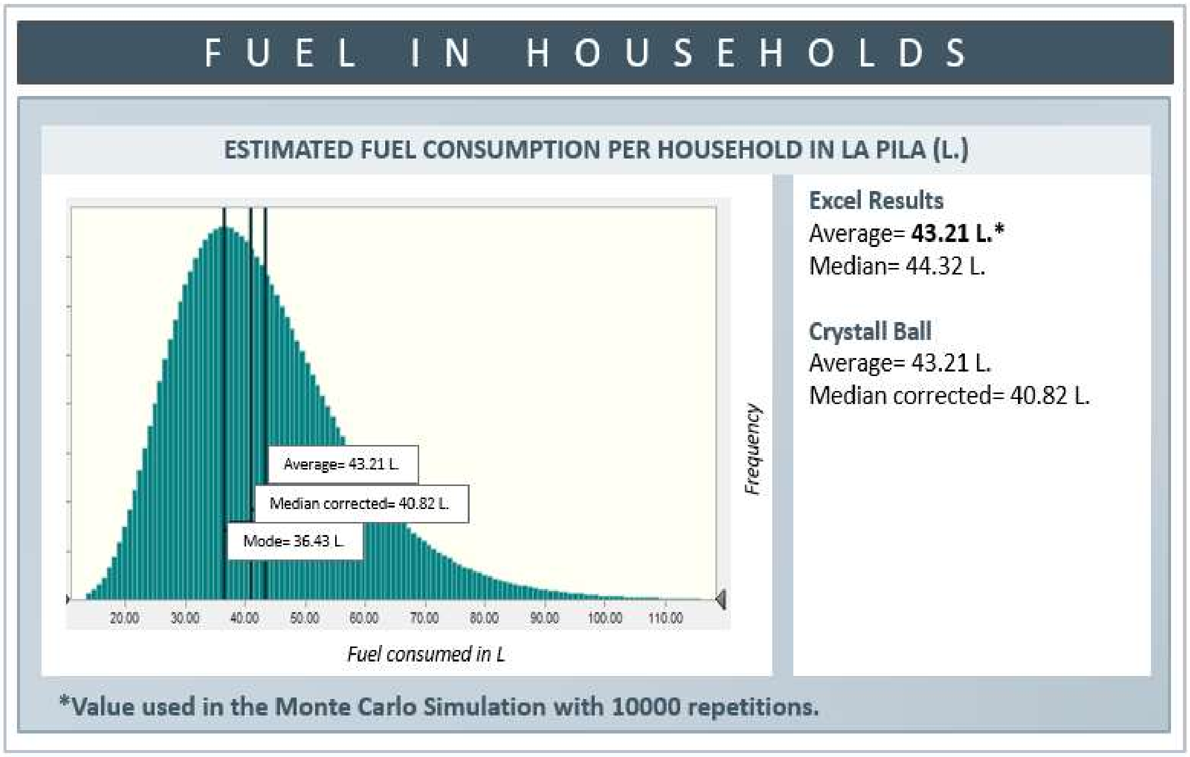


Fig. V.8. *Fuel in Households: Estimated Fuel Consumption per Household in La Pila.*[54]

Monthly Estimated Fuel Consumption		
	Per Household	**Per Capita**
Average	43.21 L.	9.94 L.
Median	44.32 L.	8.86 L.

Table V.7. *Monthly Estimated Fuel Consumption.*[55]

Household A-B-C Types Consumption

On the households' types patterns of energy consumption, irregularities on the resources consumption were found for gas consumption when analyzing data per capita. While in the electricity consumption, the Kwh per household increase depending on the number of inhabitants, for gas the results are different.

Gas

For Households with three or four inhabitants –Type A-, the monthly average estimated gas consumption per household in La Pila is 13.74 Kg. (ẋ=10.70 Kg.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 9.73 Kg. (Type A in **Fig. V.9**).

[54] See Appendix: **Table C.21.** Estimated Fuel Consumption per Household in La Pila (L.).

[55] See Appendix C: **Table C.33.** Estimated Fuel Consumption per Capita in per Household in La Pila (L.).

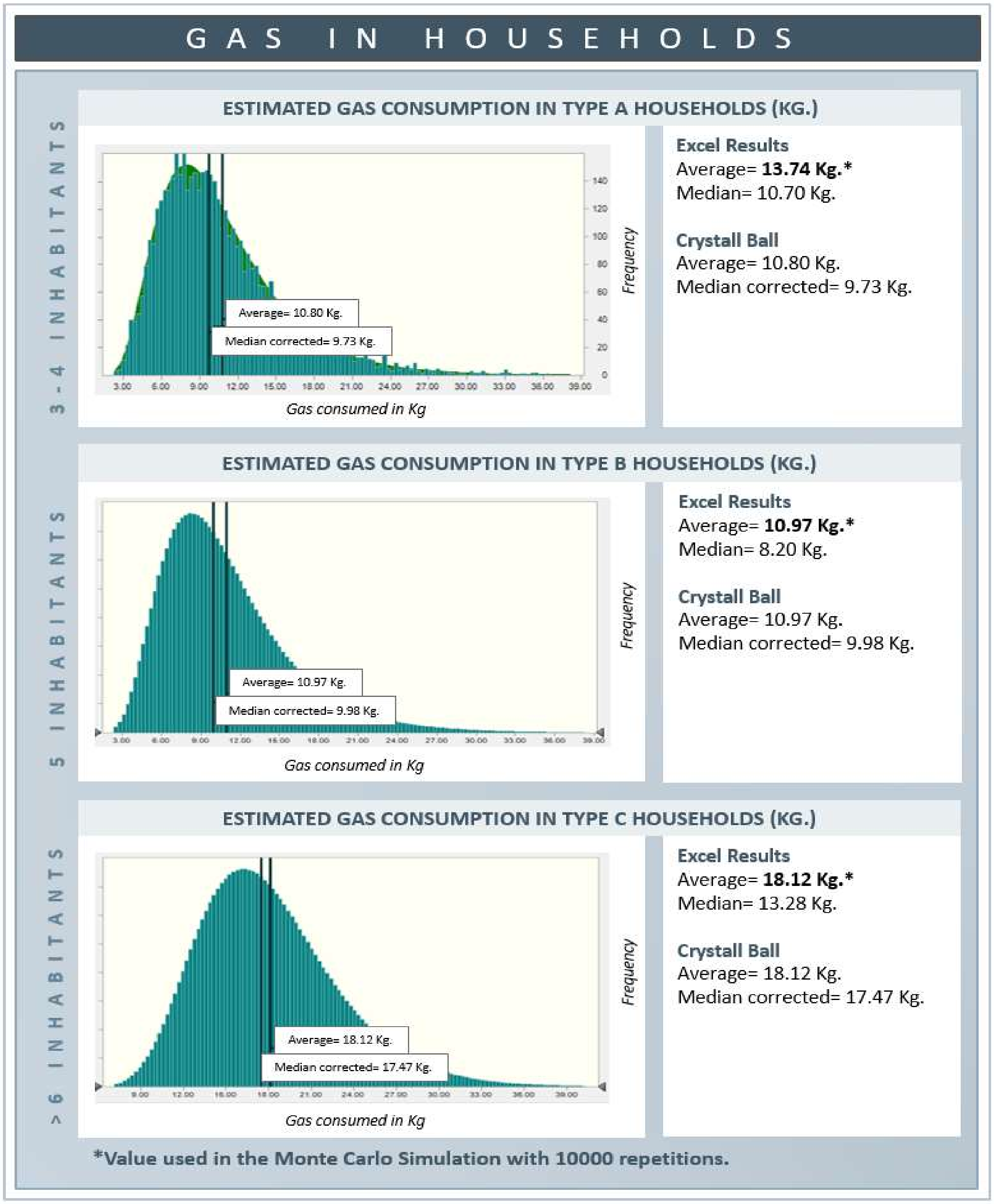


Fig. V.9. *Gas in Households: Estimated Gas Consumption per Household Type in La Pila.*[56]

[56] See Appendix C: **Table C.14.** Energy in Households: Estimated Gas Consumption in Type A Households (Kg.). **Table C.15.** Energy in Households: Estimated Gas Consumption in Type B Households (Kg.). **Table C.16.** Energy in Households: Estimated Gas Consumption in Type C Households (Kg.).

Also, for Type B Households –five inhabitants-, the monthly average estimated gas consumption per household in La Pila is 10.97 Kg. (ẋ=8.20 Kg.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 9.98 Kg. (Type B in **Fig. V.9**). Household that are Type C –households with six or more inhabitants-, the monthly average estimated gas consumption per household in La Pila is 18.12 Kg. (ẋ=13.28 Kg.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 17.47 Kg. (Type C in **Fig. V.9**).

As it can be appreciated in the **Table V.8**, the monthly average estimated gas consumption per capita in La Pila is less in Type B Households, as they spend only 2019 Kg. per capita, in contrast to 3.77 Kg. and 2.63 Kg. in Type A and Type C Households respectively. In this context, the following question is raised: Does a five-member family have a more efficient use of the resource? It is a possibility that should not be discarded, as resources are shared by a bigger number of inhabitants, but not as big as Type C Households are. The reason for this, lays on the use of the resource. Gas is usually used to cook and boil water. While for boiling water, people might need the same grams of energy, for cooking the resources is shared in one single use. It seems probable that the sharing of the resources is more efficient in five-member families.

Monthly Estimated Gas Consumption per Household Type						
	Type A		Type B		Type C	
	Per Household	Per Capita	Per Household	Per Capita	Per Household	Per Capita
Average	13.74 Kg.	3.77 Kg.	10.97 Kg.	2.19 Kg.	18.12 Kg.	2.63 Kg.
Median	10.70 Kg.	2.67 Kg.	8.20 Kg.	1.63 Kg.	13.28 Kg.	2.21 Kg.

Table V.8. *Monthly Estimated Gas Consumption per Household Type.*[57]

Electricity

For Households with three or four inhabitants –Type A-, the monthly average estimated electricity consumption per household in La Pila is 74.57 kWh. (ẋ=58.79 kWh.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 61.94 kWh. (Type A in **Fig. V.10**). Meanwhile for Type B Households –five inhabitants-, the monthly average estimated electricity consumption per household in La Pila is 94.51 kWh. (ẋ=98.46 kWh.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 83.54 kWh. (Type B in **Fig. V.10**). Household that are Type C –households with six or more inhabitants-, the monthly average estimated water consumption per household in La Pila is 126.66 kWh. (ẋ=100.65 kWh.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 117.81 kWh. (Type C in **Fig. V.10**).

[57] See Appendix C: **Table C.26.** Estimated Gas Consumption per Capita in Type A Households (Kg.). **Table C.27.** Estimated Gas Consumption per Capita in Type B Households (Kg.). **Table C.28.** Estimated Gas Consumption per Capita in Type C Households (Kg.).

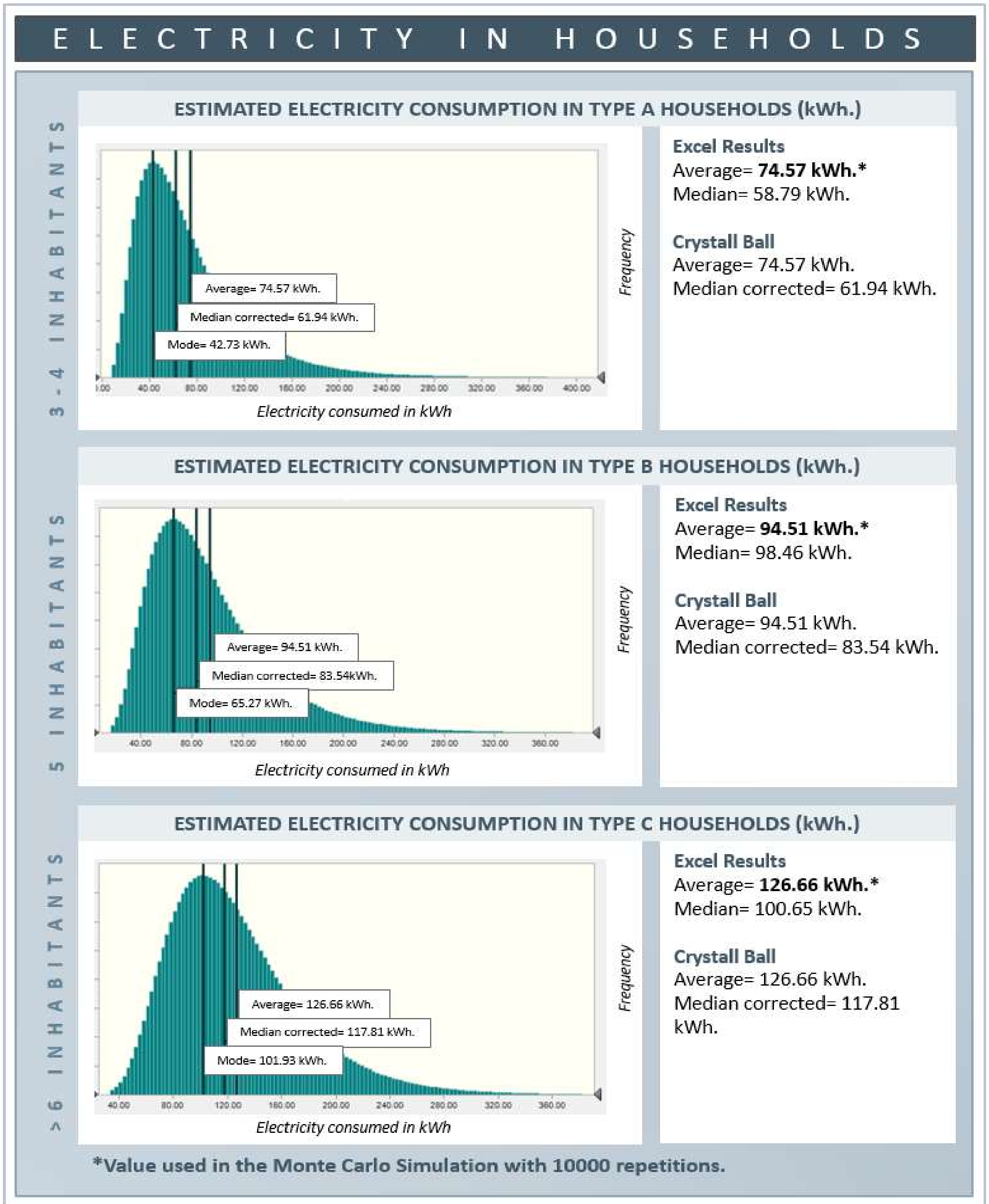


Fig. V.10. *Fuel in Households: Estimated Electricity Consumption per Household Type in La Pila.*[58]

[58] See Appendix C: **Table C.18.** Estimated Electricity Consumption in Type A Households (kWh). **Table C.19.** Estimated Electricity Consumption in Type B Households (kWh). **Table C.20.** Estimated Electricity Consumption in Type C Households (kWh).

It is observable that the pattern of electrical energy consumption follows a strange pattern. On the one hand, the monthly estimated electricity consumption per household type increases according to the number of inhabitants. On the other hand, the per capita consumption is higher for small households and lower for bigger households, as it can be observed in **Table V.9**.

Monthly Estimated Electricity Consumption per Household Type						
	Type A		Type B		Type C	
	Per Household	Per Capita	Per Household	Per Capita	Per Household	Per Capita
Average	74.57 kWh.	20.17 kWh.	94.51 kWh.	18.90 kWh.	126.66 kWh.	17.75 kWh.
Median	58.79 kWh.	17.65 kWh.	98.46 kWh.	19.69 kWh.	100.65 kWh.	14.37 kWh.

Table V.9. *Monthly Estimated Electricity Consumption per Household Type.*[59]

Fuel

In Type A Households -with three or four inhabitants-, the monthly average estimated fuel consumption per household in La Pila is 52.94 L.. (ẋ=44.32 L.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 50.93 L. (Type A in **Fig. V.11**). For Type B Households –five inhabitants-, the monthly average estimated fuel consumption per household in La Pila is 42.62 L. (ẋ=44.32 L.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 40.20 L. (Type B in **Fig. V.11**). Finally, households with six or more inhabitants -Type C– exhibit a monthly average estimated fuel consumption per household of 24.62 L. (ẋ=0.00 L.) with a median corrected through the software Crystal Ball (10,000 repetitions) of 21.03 L. (Type C in **Fig. V.11**). In **Table VI.8**, it is observable that the fuel average consumption is higher in smaller households –Type A-. This fact shows that families with less inhabitants are spending more fuel resources in transportation.

Monthly Estimated Fuel Consumption per Household Type						
	Type A		Type B		Type C	
	Per Household	Per Capita	Per Household	Per Capita	Per Household	Per Capita
Average	52.94 L.	14.05 L.	42.62 L.	8.52 L.	24.62 L.	3.79 L.
Median	44.32 L.	11.08 L.	44.32 L.	8.86 L.	0.00 L.	0.00 L.

Table V.10. *Monthly Estimated Fuel Consumption per Household Type.*[60]

[59] See Appendix C: **Table C.30.** Estimated Electricity Consumption per Capita in Type A Households (kWh.). **Table C.31.** Estimated Electricity Consumption per Capita in Type B Households (kWh.). **Table C.32.** Estimated Electricity Consumption per Capita in Type C Households (kWh.).

[60] See Appendix C: **Table C.34.** Estimated Fuel Consumption per Capita in Type A Households (L.). **Table C.35.** Estimated Fuel Consumption per Capita in Type B Households (L.). **Table C.36.** Estimated Fuel Consumption per Capita in Type C Households (L.).

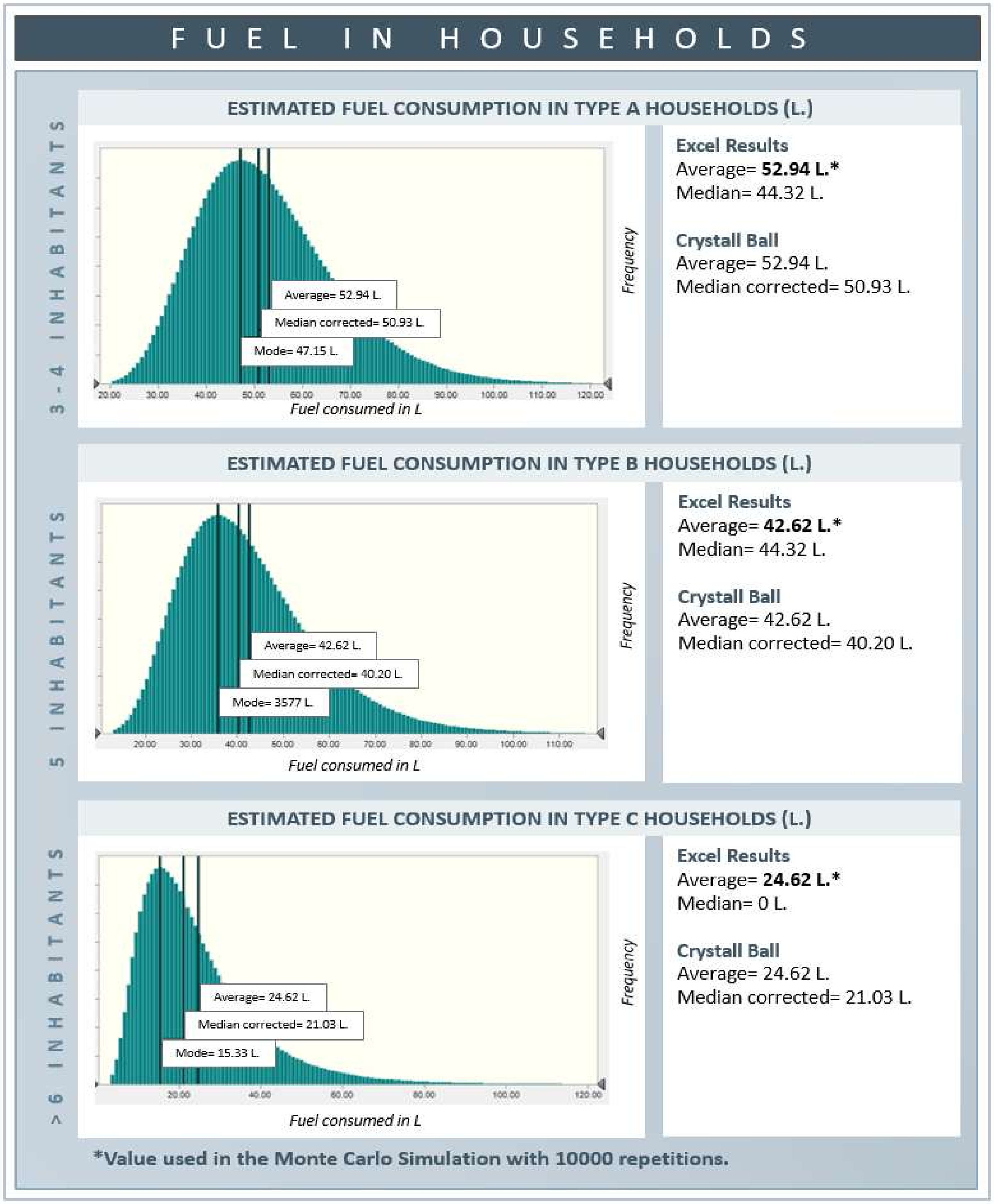


Fig. V.11. *Fuel in Households: Estimated Fuel Consumption per Household Type in La Pila.*[61]

[61] See Appendix C: **Table C.22.** Estimated Fuel Consumption in Type A Households in La Pila (L.). **Table C.23.** Estimated Fuel Consumption in Type B Households in La Pila (L.). **Table C.24.** Estimated Fuel Consumption in Type C Households in La Pila (L.).

A household analysis

Gas and Electricity

A five-member family in La Pila consumes around 6.89 kilograms of gas per month, which represents MXN 140.00 –about EUR 5.95-. However, for households in La Pila, this represents the highest investment, as gas is considered as an expensive commodity. Therefore, to avoid spending that much money in gas to cook or boil water for showering, families usually burn firewood that they collect from the surroundings.

Checking electricity consumption rates, it was discovered that people consume around 100.65 kWh per month, with a monetary expense of MXN 200.00 –about EUR 8.51- (**Fig. V.12**). It is central to observe that more than 75% of the households interviewed do not have high-energy consumption appliances, such as computers, and microwaves.

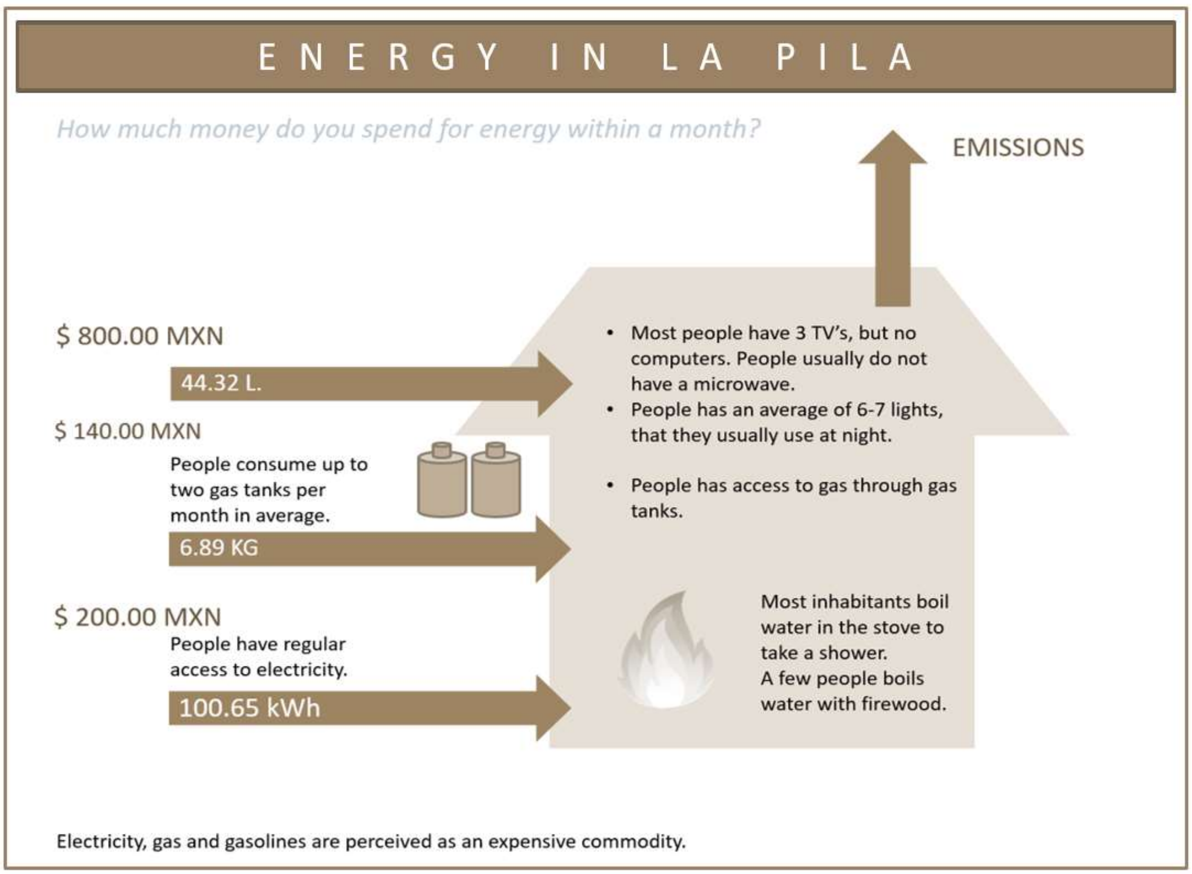


Fig. V.12. *Energy in La Pila: A Household Analysis.*

Fuel

In the energy use for transportation, people usually have a fixed budget to buy the fuel, and if they need more fuel, they wait until the next week in order to avoid exceeding the budget planed for fuel, as a mean of protecting their personal economy.

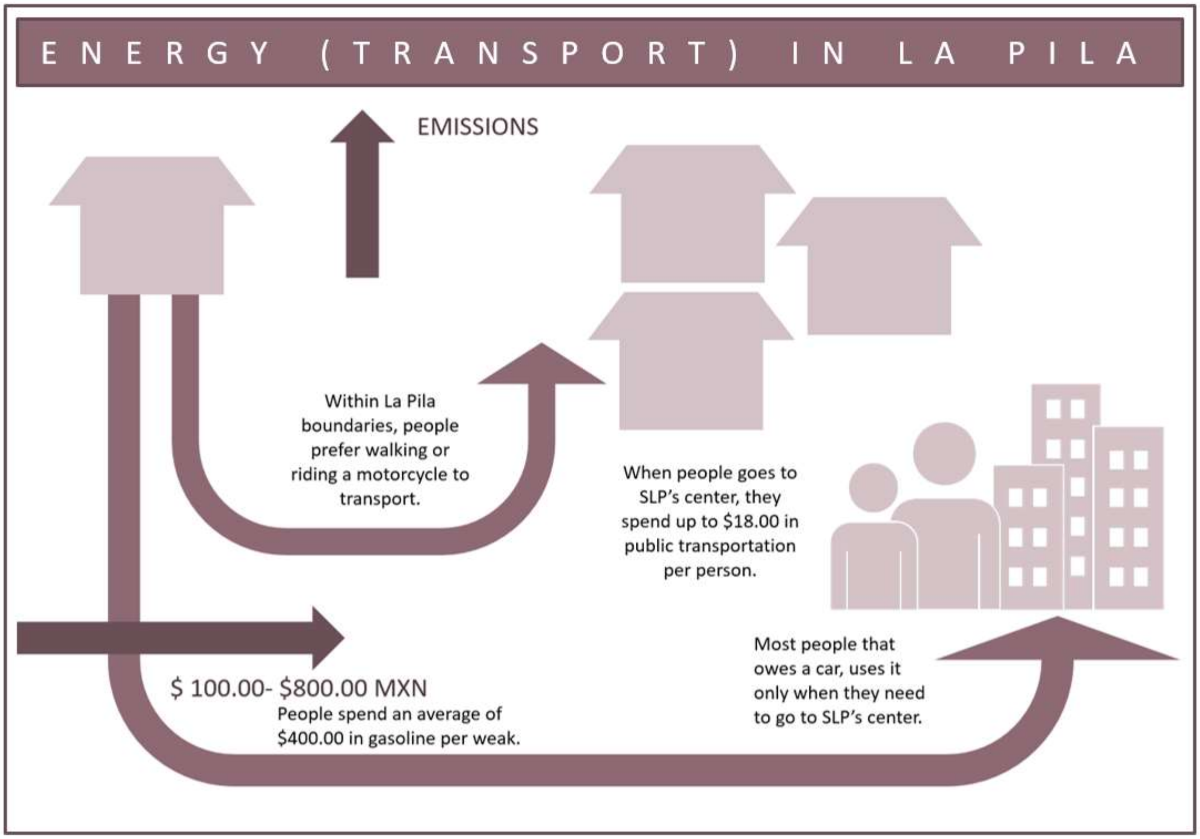


Fig. V.13. *Energy (Transport) in La Pila: A Household Analysis.*

In the case of fuels, the household example consumes 44.32 L. of fuel within a month, which means a monetary expenditure of MXN 800.00 –EUR 34.04-, traduced in a 13.33% of the households' income. Moreover, it was observed, that only a 57.5% of the households interviewed own a car or a motorcycle that requires a monthly expenditure in fuel. The distances that most people travels are within a five-kilometer ratio, because most inhabitants are worker at the industrial zone *Parque Tres Naciones*. It was appreciated, that car owners travel more often to SLP.

Fuel used by buses is not taken into account for this calculations, but it was interesting to observe that households wait up to two months to go to the downtown area in SLP, as they consider that the round-trip –MXN 18.00[62]-, represents a very high expenditure, especially if the whole family is traveling. In the case of a five-member family, this is equal to MXN 90.00 –EUR 3.82- per round-trip ticket. This is something important to consider, as families who own a car, spend less money on transportation, but consume more fuel. The paradox is that if people have more money to buy a car, they will be able to travel more often, consuming more resources, producing more emissions and increasing the unsustainability of the resource's metabolism.

[62] Less than one euro.

It was appreciated, that the household analyzed spends half of an average household in gas. However, the household analyzed spends the double than the average household in electrical energy, with a monthly consumption of 100.65 kWh. Finally, the household analyzed spends about 44.32 L. of fuel per month, which is the fuel consumption for an average household (**Table V.11** and **Table V.12**).

Monthly Monetary Expenditure						
	Average		Median		Household	
Water	MXN	230.23	MXN	175.00	MXN	120.00
Energy						
Gas	**MXN**	**281.16**	**MXN**	**252.50**	**MXN**	**140.00**
Electrical Energy	**MXN**	**96.03**	**MXN**	**136.92**	**MXN**	**200.00**
Fuel	**MXN**	**780.00**	**MXN**	**800.00**	**MXN**	**800.00**
Food	MXN	6178.97	MXN	6421.83	MXN	3200.00

Table V.11. *Monthly Monetary Expenditure.*

Monthly Resource Expenditure						
	Average		Median		Household	
Water	17 890	L.	11000	L.	8000	L.
Energy						
Gas	**13.82**	**Kg.**	**12.42**	**Kg.**	**6.89**	**Kg.**
Electrical Energy	**92.77**	**kWh.**	**84.40**	**kWh.**	**100.65**	**kWh.**
Fuel	**43.21**	**L.**	**44.32**	**L.**	**44.32**	**L.**
Food	6178.97	MXN	6421.83	MXN	3200.00	MXN

Table V.12. *Monthly Resource Expenditure.*

V.1.3. Food Consumption in La Pila

The food flux was complex to analyze, as it is really hard to understand the nutritional habits that a person has in a 45-minute interview that includes other topics. However, it was easier to understand the important role that food plays in the households income expenditure. Therefore, data for food are available with a monetary value in MXN[63].

Households Total Consumption

When interviewees were asked how much they do spend on food within a month, it was observable that a big percentage of the income is spend on food. Households spend an average of 59% of their income in food as observed in **Fig. V.14**. In such figure, it can be observed a peak of almost 90%, which must be critically used in further assumptions, as its reliability might not be accurate. However, the data is presented as it was gathered. This represents an economical and a nutritional problem as well. In addition the monthly estimated average expenditure in food per household is MXN 3,586.80 ($\dot{x}$=3,800.00), while the per capita average is MXN 760.45 ($\dot{x}$=762.50) as observed in **Table V.13**.

[63] During this study a standard Exchange rate of MXN 1=EUR 23.50 was used.

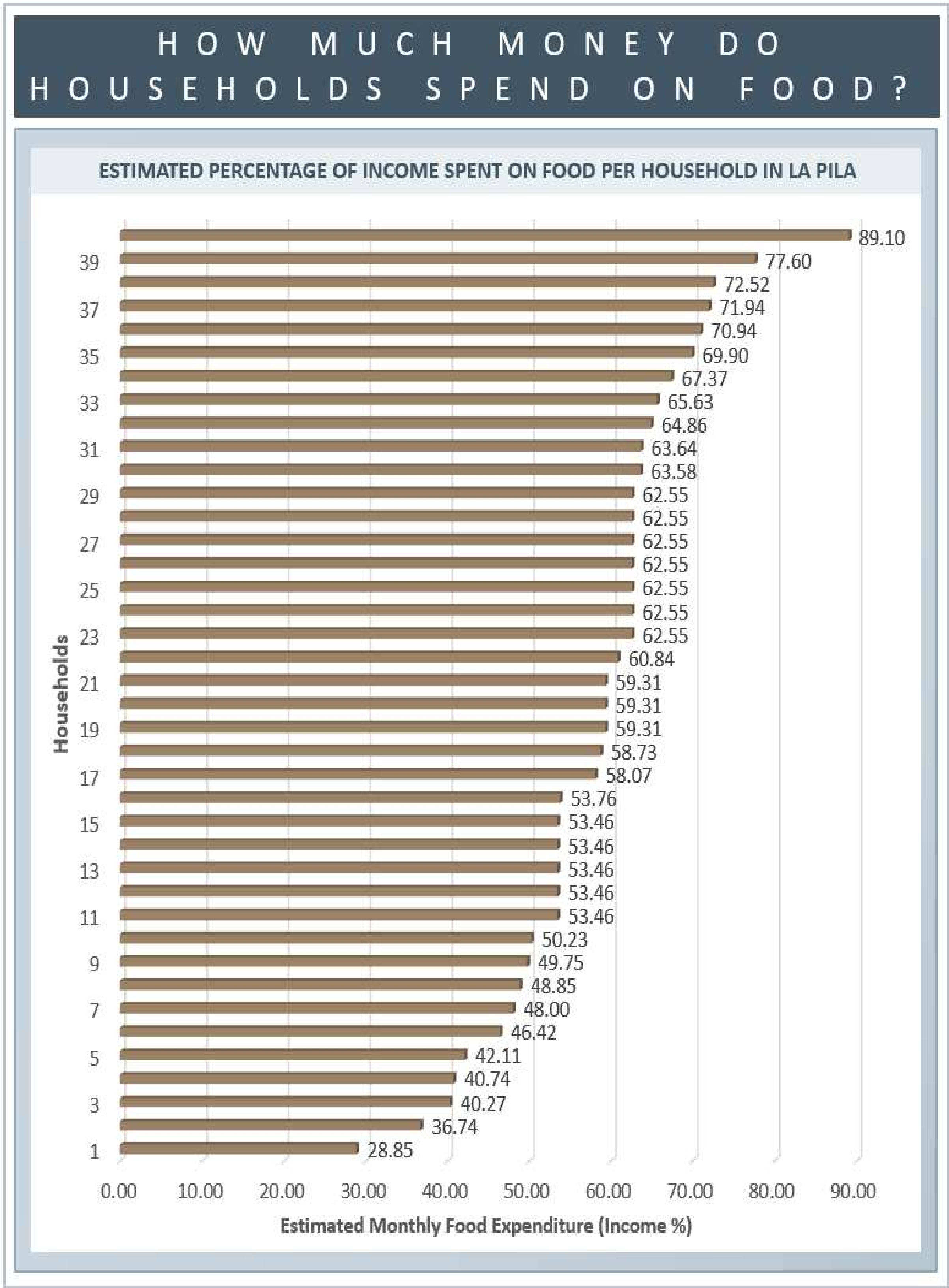


Fig. V.14. *How much money do households spend on Food?*

Monthly Estimated Food Expenditure per Household in La Pila		
	Per Household	**Per Capita**
Average	MXN 3,586.80	MXN 760.45
Median	MXN 3,800.00	MXN 762.50

Table V.13. *Monthly Estimated Food Expenditure per Household in La Pila.*[64]

Household A-B-C Types Consumption

In Type A Households -with three or four inhabitants-, the monthly average food expenditure per household in La Pila is MXN 2,900.00 (ẋ=MXN 2,900.00) (Type A in **Table V.14**). For Type B Households –five inhabitants-, the monthly average expenditure in food per household in La Pila is MXN 4,066.31 (ẋ=MXN 4066.00) (Type B in **Table V.14**). Finally, households with six or more inhabitants -Type C– exhibit a monthly average food expenditure per household of MXN 4,267.78 (ẋ=MXN 4,270.00) (Type C in **Table V.14**). It is observable that the expenditure in food is higher in bigger households; however, when looking at per capita data, Type B Households exhibit the highest expenditure in food. Such households are spending around MXN 27.10 (a little bit more than EUR 1) in food per capita per day.

Monthly Estimated Food Expenditure per Household Type						
	Type A		**Type B**		**Type C**	
	Per Household	**Per Capita**	**Per Household**	**Per Capita**	**Per Household**	**Per Capita**
Average	MXN 2,900.00	MXN 775.46	MXN 4,066.31	MXN 813.26	MXN 4,267.78	MXN 654.14
Median	MXN 2,900.00	MXN 725.00	MXN 4,066.00	MXN 813.20	MXN 4,270.00	MXN 685.71

Table V.14. *Monthly Estimated Food Expenditure per Household Type.*[65]

In La Pila, households do not produce their own food, but they prefer to buy it in the weakly markets –every Saturday and Sunday-, and convenience stores, rather than in supermarkets. Something interesting about the food supply is that convenience stores and markets get their items in Central de Abastos –the biggest market in MZSLP-, which is supplied by SLP's producers, as well as other states from Mexico, and sometimes USA producers.

A 50% of La Pila's inhabitants buy their fruit and vegetables crops in groceries stores (50%), which are often managed by people from San Luis Potosi's city. When people working on these stores were interviewed, they said that they did not own the store, but that they were working there everyday. A curious data obtained with this information is that there is also an energy flux between San Luis Potosi and the community, caused by the energy expenditure in transportation of people who does not live in La Pila, but that work there everyday.

[64] See Appendix C: **Table C.37.** Estimated Food Expenditure per Household and per Capita in La Pila.

[65] See Appendix C: **Table C.38.** Estimated Food Expenditure in Type A Households. **Table C.39.** Estimated Food Expenditure in Type B Households. **Table C.40.** Estimated Food Expenditure in Type C Households.

On second place, the weekly markets -which are usually settled on the main street during Saturdays and Sundays mornings)-, are the second favorite place to acquire food (45%). Finally, supermarkets play also an important role, despite the fact that they are not so visited by inhabitants. The reason to this phenomenon is that people who lives in La Pila and has a car, are usually able to travel to the city and get food and other goods from the downtown area of San Luis Potosi, which according to the community's inhabitants, are cheaper and have a better quality (**Fig. V.15**).

Moreover, just a 18% of the households consumes 4 Kg. of meat within a month, while only a 13% of the households consumes 3 Kg. of meat per month. A 35% of the households consumes around 2 Kg, followed by a 32% of the households, who consume 1 Kg. per month.

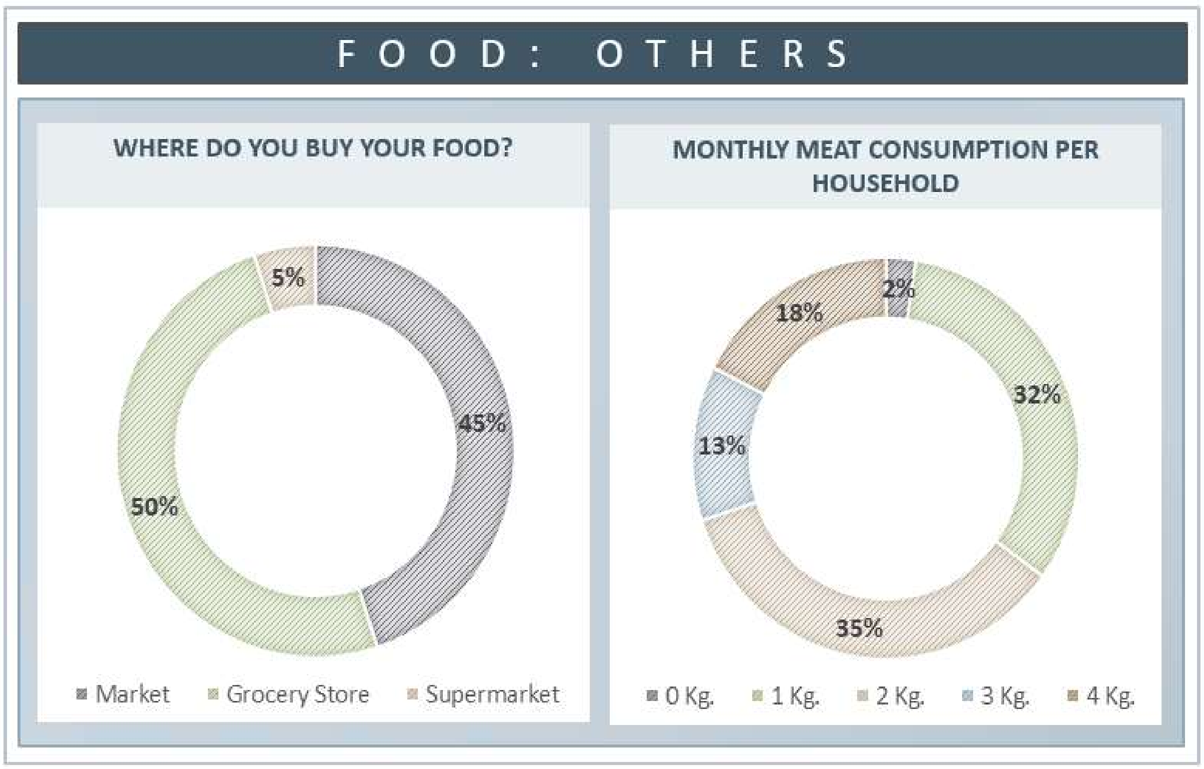


Fig. V.15. *Food: Others. 1) Where do you buy your food?; and 2) Monthly meat consumption per household.*

Finally, the study revealed that only a 2% of the households were not consuming meat at all (Monthly Meat Consumption per Household in **Fig. V.15**). The data revealed that banana (22%), apples (17%) and oranges (16%) are the most consumed fruit crops in La Pila. Meanwhile, the most consumed vegetable crops are chili (20%), tomatoes (14%) and carrot (14%) (**Fig. V.16**).

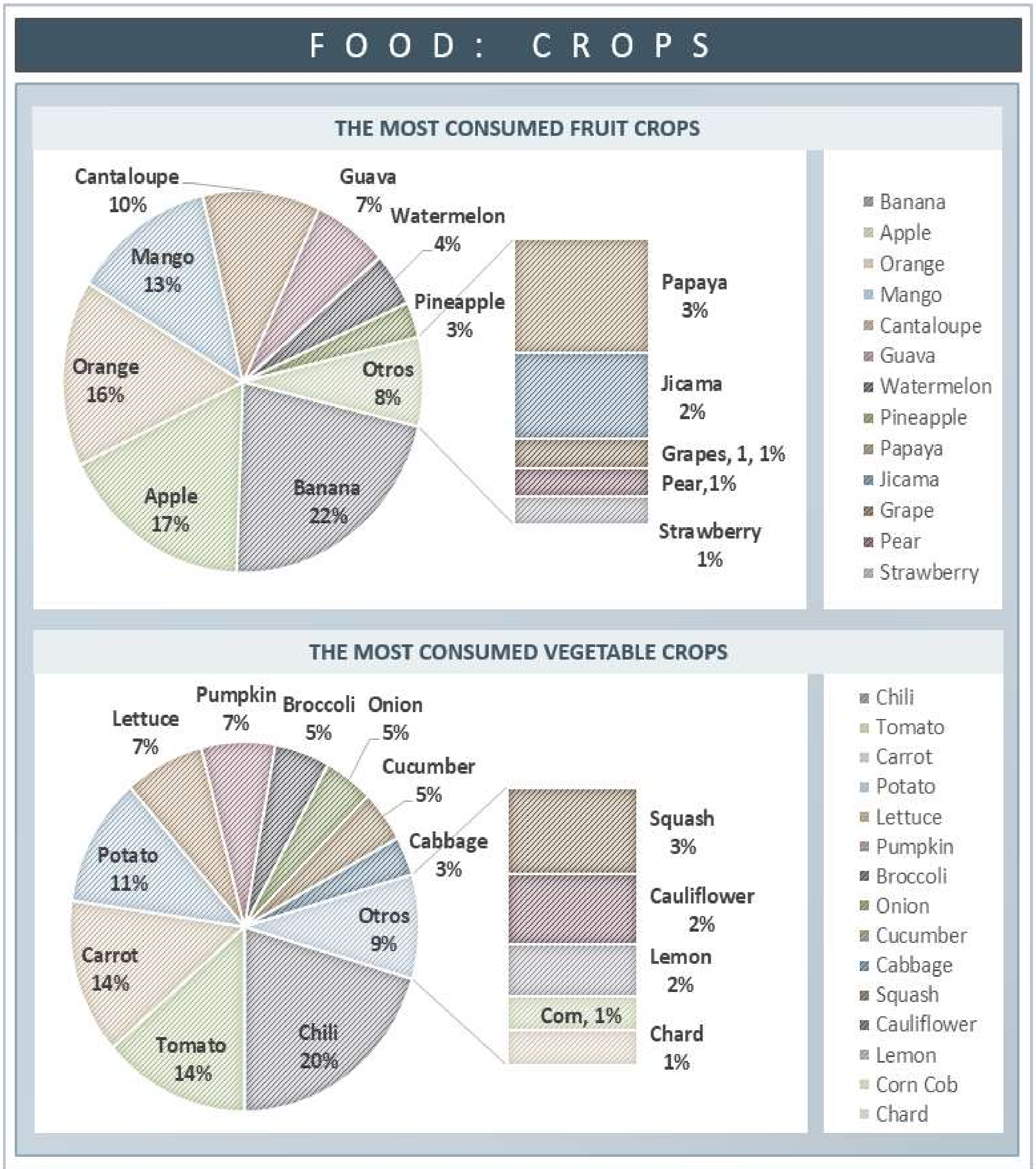


Fig. V.16. *Food: Crops. 1) The most consumed fruit crops; and 2) The most consumed vegetable crops.*

A household analysis

The household under analysis consumes an average of MXN 3200.00 within a month –EUR 136.17-, which is usually spent on local markets and convenience stores. It was observed, that most families go to the transitory local markets on Saturdays and Sundays (**Fig. V.17**). We asked the household how many times per day they eat, and the answer was four, however, two of them include only milk.

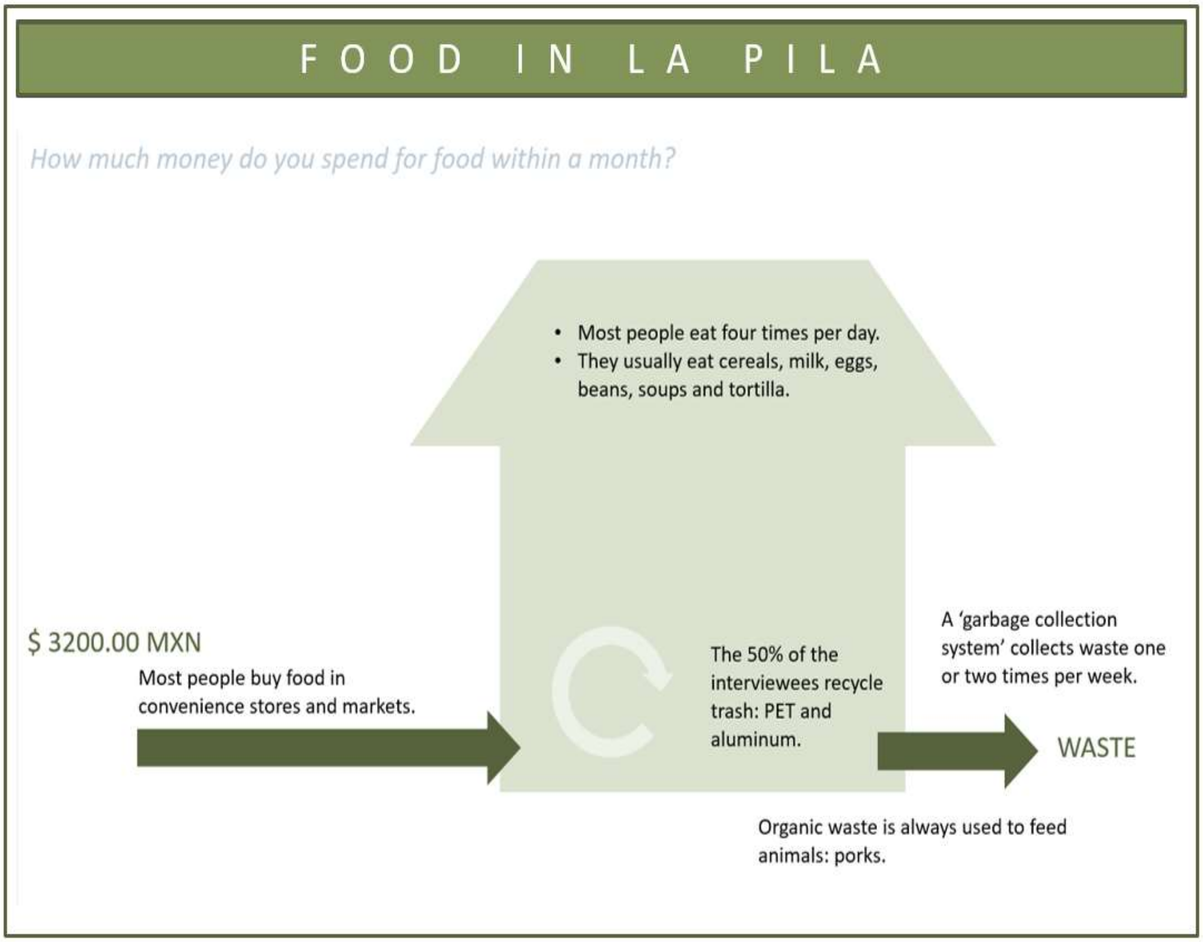


Fig. V.17. *Food in La Pila: A Household Analysis.*

A regular diet in La Pila considers eating at 7:00, 11:00, 15:00 and 20:00. The interviewee told us that before going to school children usually drink a shake or cereal, and then at school they have a lunch at a11:00 in which they eat normally *tacos* or *tortas*, filled with eggs, beans, jam, and cheese. After that, the families eat at 15.00 mostly rice, beans, vegetables and sometimes meat. At night, around 20.00, before going to sleep inhabitants drink only milk or yogurt. It is important to consider that this behavior can be only during the week, but it provides insights of which food supplies are the most demanded within the community, and which suppliers are important to the household's metabolism.

Monthly Monetary Expenditure						
	Average		Median		Household	
Water	MXN	230.23	MXN	175.00	MXN	120.00
Energy						
Gas	MXN	281.16	MXN	252.50	MXN	140.00
Electrical Energy	MXN	96.03	MXN	136.92	MXN	200.00
Fuel	MXN	780.00	MXN	800.00	MXN	800.00
Food	**MXN**	**6178.97**	**MXN**	**6421.83**	**MXN**	**3200.00**

Table V.15. *Monthly Monetary Expenditure.*

The household's monthly resources expenditure represents the 53.33% of their income, and it is located below the average households as observed in **Table V.15** and in **Table V.16**.

Monthly Resource Expenditure						
	Average		Median		Household	
Water	17 890	L.	11000	L.	8000	L.
Energy						
Gas	13.82	Kg.	12.42	Kg.	6.89	Kg.
Electrical Energy	92.77	kWh.	84.40	kWh.	100.65	kWh.
Fuel	43.21	L.	44.32	L.	44.32	L.
Food	**6178.97**	**MXN**	**6421.83**	**MXN**	**3200.00**	**MXN**

Table V.16. *Monthly Resource Expenditure.*

V.2. Water-Energy-Food Metabolism through the Analysis of the System's Supply and the System Itself

After analyzing the system's supply, we can appreciate the inflows going through the different household types (A, B & C) - average and median-, per household (**Fig. V.18** and **Fig. V.19**) and per capita (**Fig. V.20** and **Fig. V.21**)[66].

It was observable during this fluxes analysis that when people do not have access to the resources through the traditional source, they try to find another way to supply the resource for the household. Sometimes, these practices result in higher costs. For example, people can spend up to MXN 300.00 in candles to illuminate their homes at night. This kind of homes lack electricity, because they live in the furthest areas of the community in which electrical energy infrastructure has not arrived.

It can also be appreciated that the water inflow through carboys is minimum in comparison to the tap water inflow. However, in the per capita diagrams (**Fig. V.20** and **Fig. V.21**), it is observable that the per capita consumption is lower in the Type C.

This diagrams of the inflows should be completed with outflows information in order to provide better insights on how the urban metabolism within the households and the community is.

[66] The fluxes diagrams information comes from **Table V.2.** Monthly Estimated Water Consumption per Household Type. **Table V.8.** Monthly Estimated Gas Consumption per Household Type. **Table V.9.** Monthly Estimated Electricity Consumption per Household Type. **Table V.10.** Monthly Estimated Fuel Consumption per Household Type. **Table V.14.** Monthly Estimated Food Expenditure per Household Type.

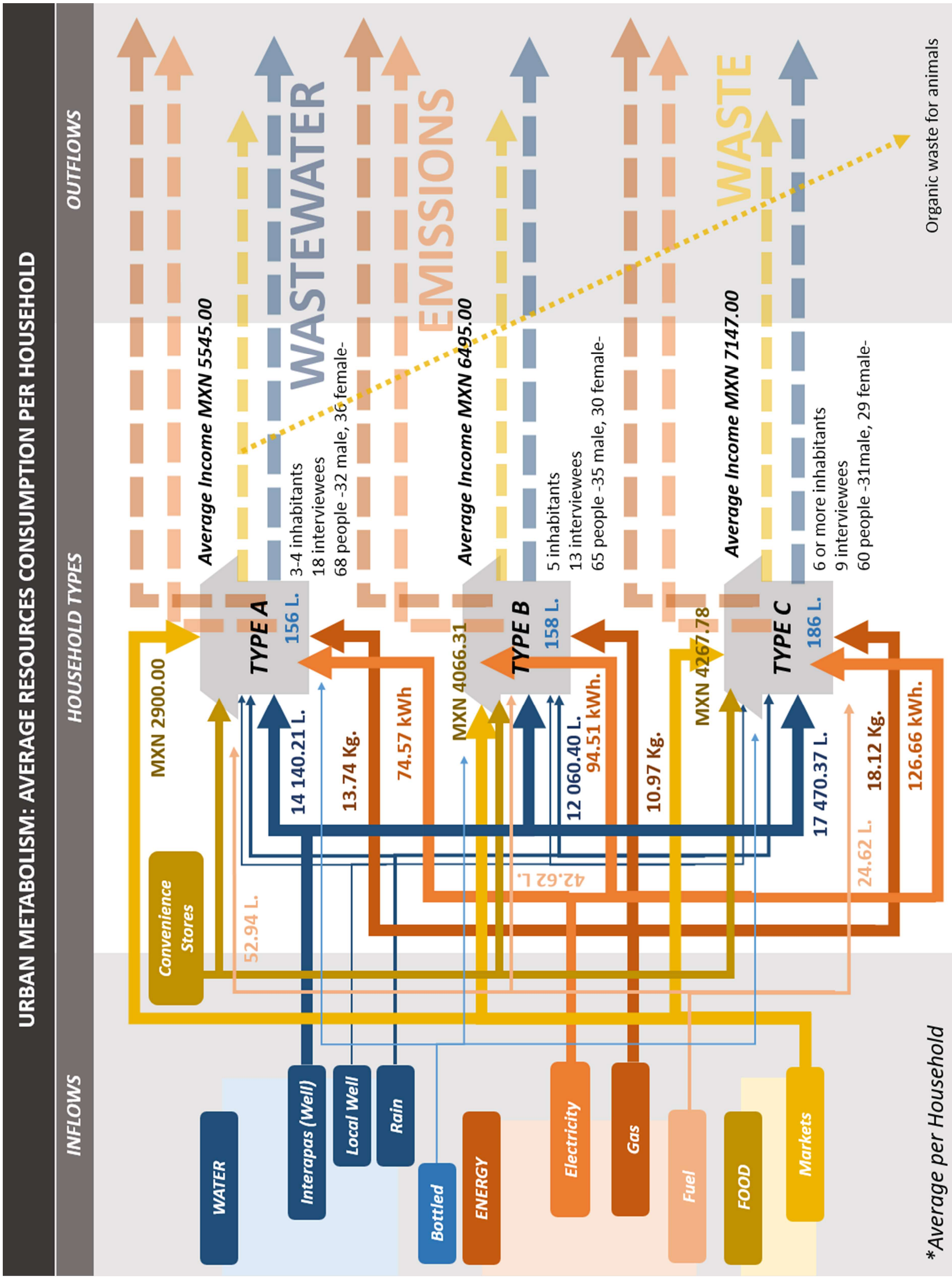


Fig. V.18. *Urban Metabolism: Average Resources Consumption per Household.*

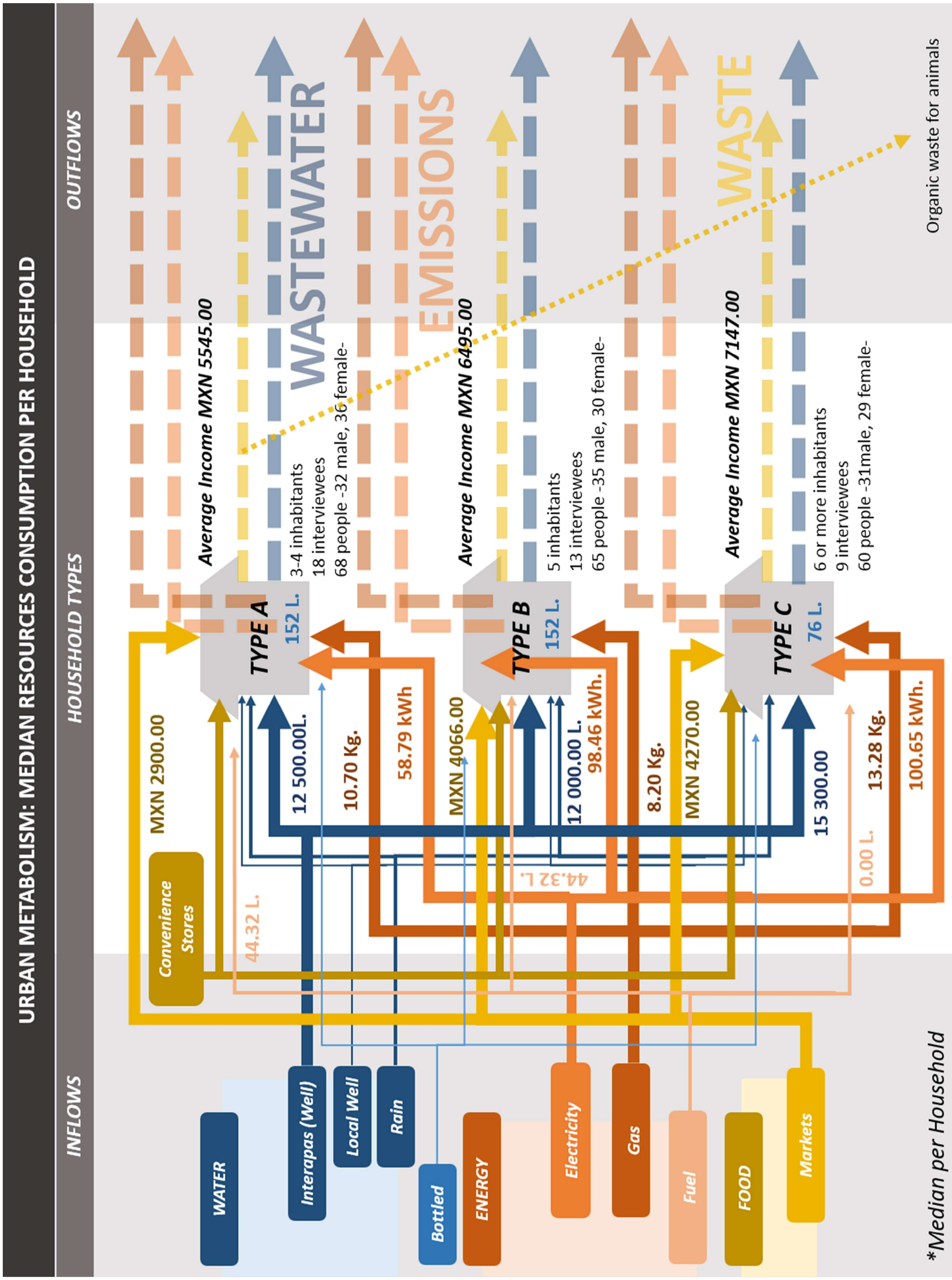


Fig. V.19. *Urban Metabolism: Median Resources Consumption per Household.*

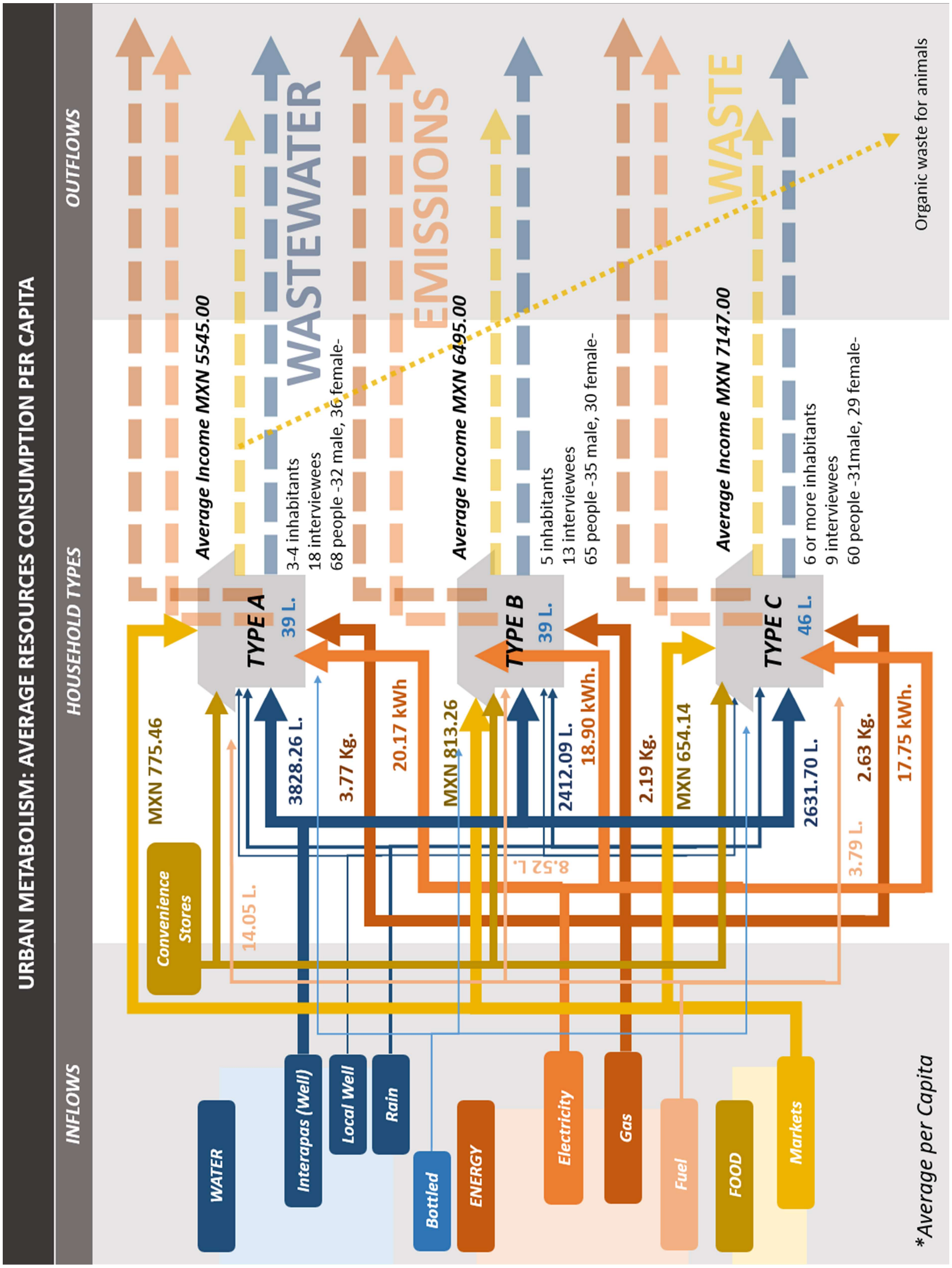


Fig. V.20. *Urban Metabolism: Average Resources Consumption per Capita.*

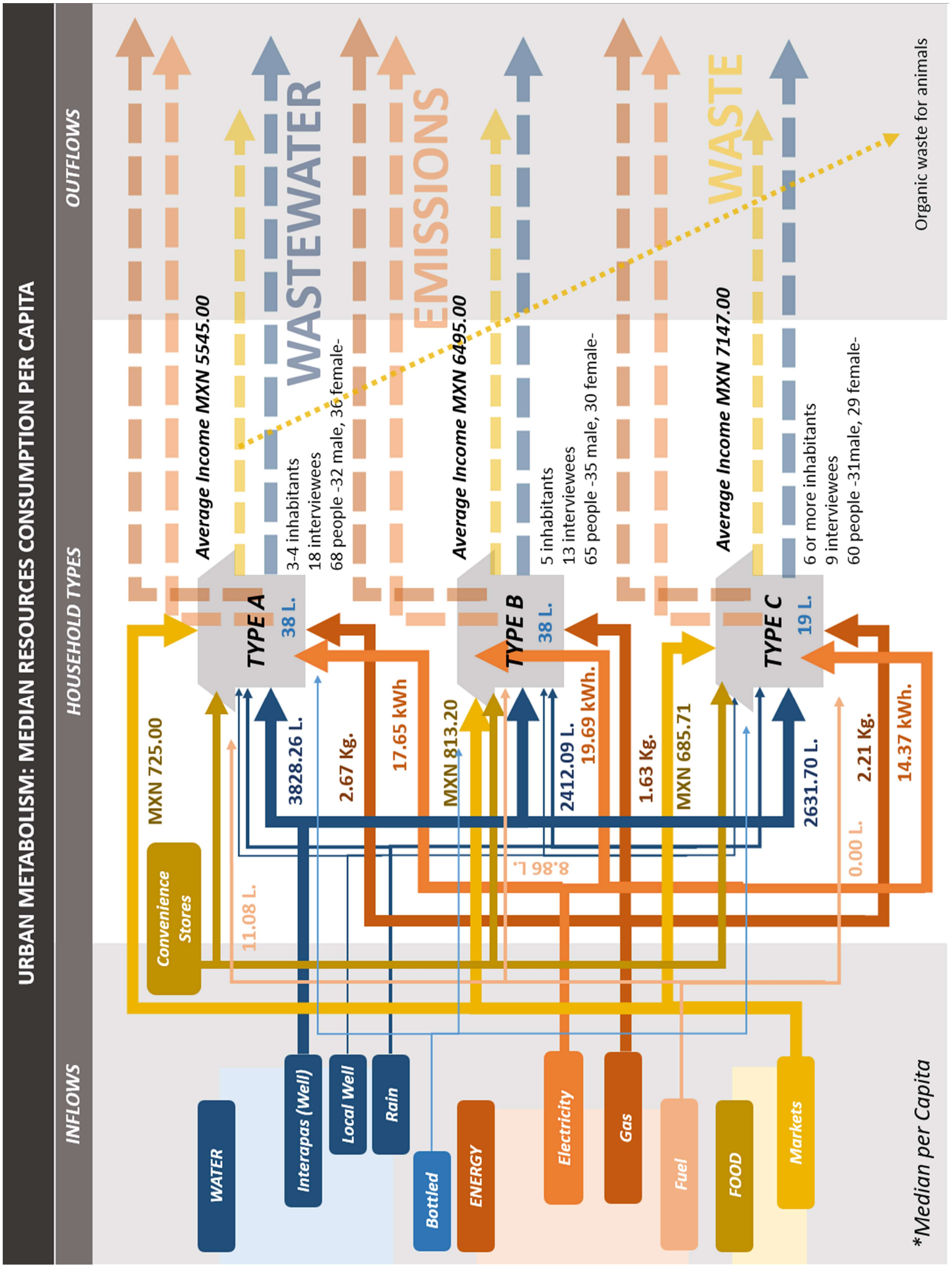


Fig. V.21. *Urban Metabolism: Average Resources Consumption per Capita.*

Closing Remarks

In this chapter, the urban metabolism of *La Pila* was analyzed through the data gathered from the resources –Water, Energy and Food- consumption. In order to achieve this, a total of 40 households were interviewed during the months of April and May 2018. A better context of how resources are consumed through three scales -1) Households Total Consumption; 2) Household A-B-C Types Consumption; and 3) A Household Analysis- in order to improve the understanding of how resources flow in households. Moreover, the per capita resources consumption was also presented in order to obtain liters of water consumed per person per day (L/person/day). Later, in *A Household Analysis*, a household analysis was presented as a mean to provide insights into how households' acquire, consume and excrete resources: Water, Energy and Food.

Finally, in the last part *Water-Energy-Food Metabolism through the Analysis of the System's Supply and the System Itself,* the metabolism of the households was analyzed and discussed considering the whole sources for Water, Energy and Food.

Chapter VI

USES Resilience Assessment based on Metabolism

"Hazards and vulnerabilities should not be displaced to future generations or to those elsewhere who lack power or access to environmentally significant decision-making processes."

(Pickett *et al.*, 2014)

VI. USES Resilience Assessment based on Metabolism

In this chapter, resilience of La Pila is finally assessed through the metabolism analysis. In order to assess how resilient is La Pila, we first need to know 'to what challenges' it should be resilient. Therefore, in the first part of this chapter –*Hazards to La Pila*-, hazards that affect the system's supply and the system itself are found, as a result of having analyzed the metabolism of households in La Pila.

After that, hazards are evaluated and converted to simple risks, in order to describe main risks to the supply's system and the system itself in *Risk Assessment in La Pila*. Finally, in *Urban Resilience in La Pila*, using the resilient qualities, according to the UR definition, general conclusions about how resilient is the USES under study -La Pila-, are drawn (**Fig. VI.1**).

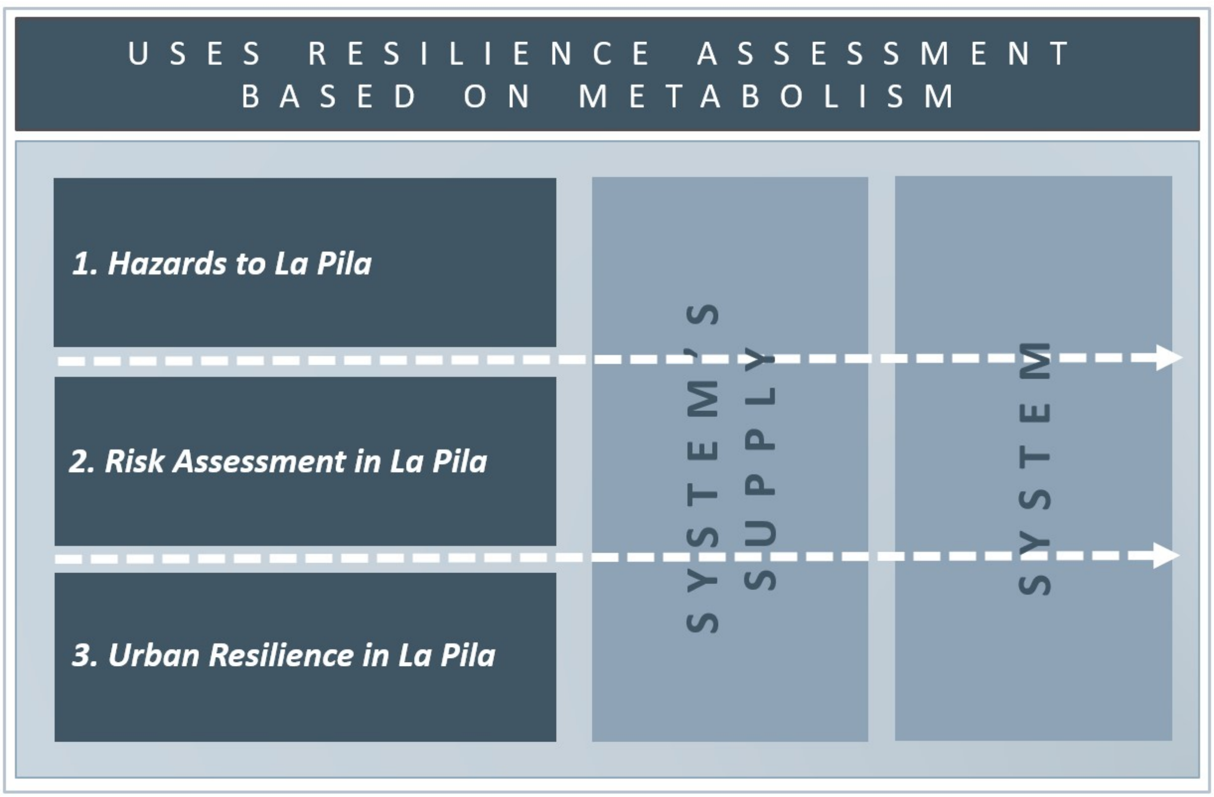


Fig. VI.1. *USES Resilience Assessment based on the Metabolism.*

VI.1. Hazards to La Pila

As the USES of La Pila is a complex entity, -conformed by the social, ecological, economic and political dimensions, hazards are organized according to the four dimensions and in relation to the inflow: Water, Energy and Food. After that, hazards to the system in general that are related to people's resilience are organized with the same structure. The questions that drove the research were focused on the most important metabolic processes within the households (**Fig. VI.2**). In this part of the interviews, the aim was not to measure the stocks nor the outflows, but rather have a better insight on hazards to the system itself, that are hardly appreciated with the Black Box Accounting Methodology.

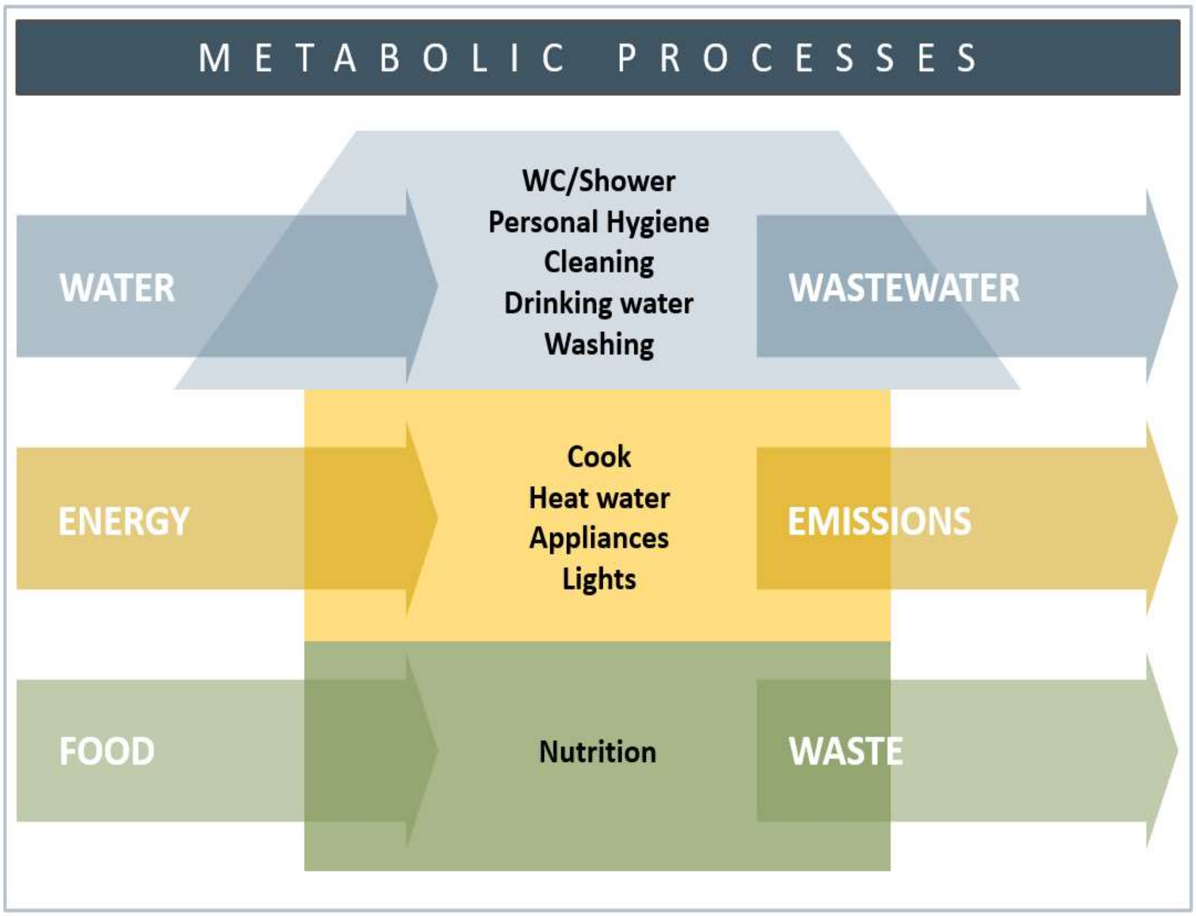


Fig. VI.2. *Metabolic Processes in Households.*

Identified hazards are divided, for the purpose of this study, in two sections. The first part is about hazards to the system's supply. It is central to consider which hazards can influence the inflows, as a mean to find vulnerabilities in such an important part of the USES. Meanwhile, on the second part, hazards having an impact on the whole system are described. These hazards are important because they allow to have a look at the coping capacities, adaptive capacities and resilient strategies that are already being implemented by the households, but that might not be the most efficient or practical.

VI.1.1. Hazards to the System's Supply

In this section, hazards to the system's supply are identified according to the literature review and the analysis of the households' inflows. Therefore, hazards are defined through the Water, Energy and Food inflows, and generalized for the whole USES in order to provide insights of La Pila's challenges. After that, a matrix of hazards to the system's supply is provided.

VI.1.1.1. Water Hazards

Despite the fact, that there is water supply and wastewater infrastructure for the majority of the houses, inhabitants of 'La Pila' employ water management practices that some would describe as underdeveloped (Penn, Loring and Schnabel, 2017), such as gathering water from rainfall and storing it in plastic trash-cans or aluminum containers. Only a 25% of the households interviewed has guaranteed access to pressurized water distribution everyday, and 58% of the households do not have access to water from two to three days per week (**Fig. VI.3**). Most homes that are far from the downtown area are the ones that do not have water supply at all due to the lack of infrastructure, as observe through the participatory mapping.

According to the interviews, a 17% tries to collect rainwater and store it in bins. Such water is used for cooking, personal needs, cleaning, and it is the source of drinking water. Additionally, a 25% of the inhabitant interviewed recycle water used for the laundry to clean floors or water plants. As a result, it is observable that in this community, limited access to sufficient clean water is a very significant problem, as it is also a threat to inhabitants' health. Although, only a 15% perceives a bad quality in water (**Fig. VI.3**).

Additionally, to the increasing water insecurity, especially during summer –according to the testimonies-, La Pila could not be able to satisfy its water supply needs in a near future. This is because of the evolution of urban settlements that accelerates the water extraction. According to Kennedy et al. (2007), this can be seen in the 'settlements timeline': At the beginning, settlements get water from shallow urban wells and boreholes, while wastewater and drainage waters are discharged to the ground or a watercourse. However, as the urban area grows on population, extraction increases and deeper wells are drilled, which results in water overexploitation (C. Kennedy, Cuddihy and Engel-Yan, 2007). After that, the city becomes dependent on periurban well fields or water imports from distant sources, which is what is already happening in the MZSLP. Despite the fact that the MZSLP is not relying on La Pila's water resources yet, it is undeniable that it might be a matter of time.

Moreover, water security is also threaten by continuous population growth due to migration and urban growth, as the demand of such a vital resource increases exponentially throughout the years. What is more, not only urban growth is a challenge to solve, but also industrial growth, as industries consume the majority of water resources in MZSLP.

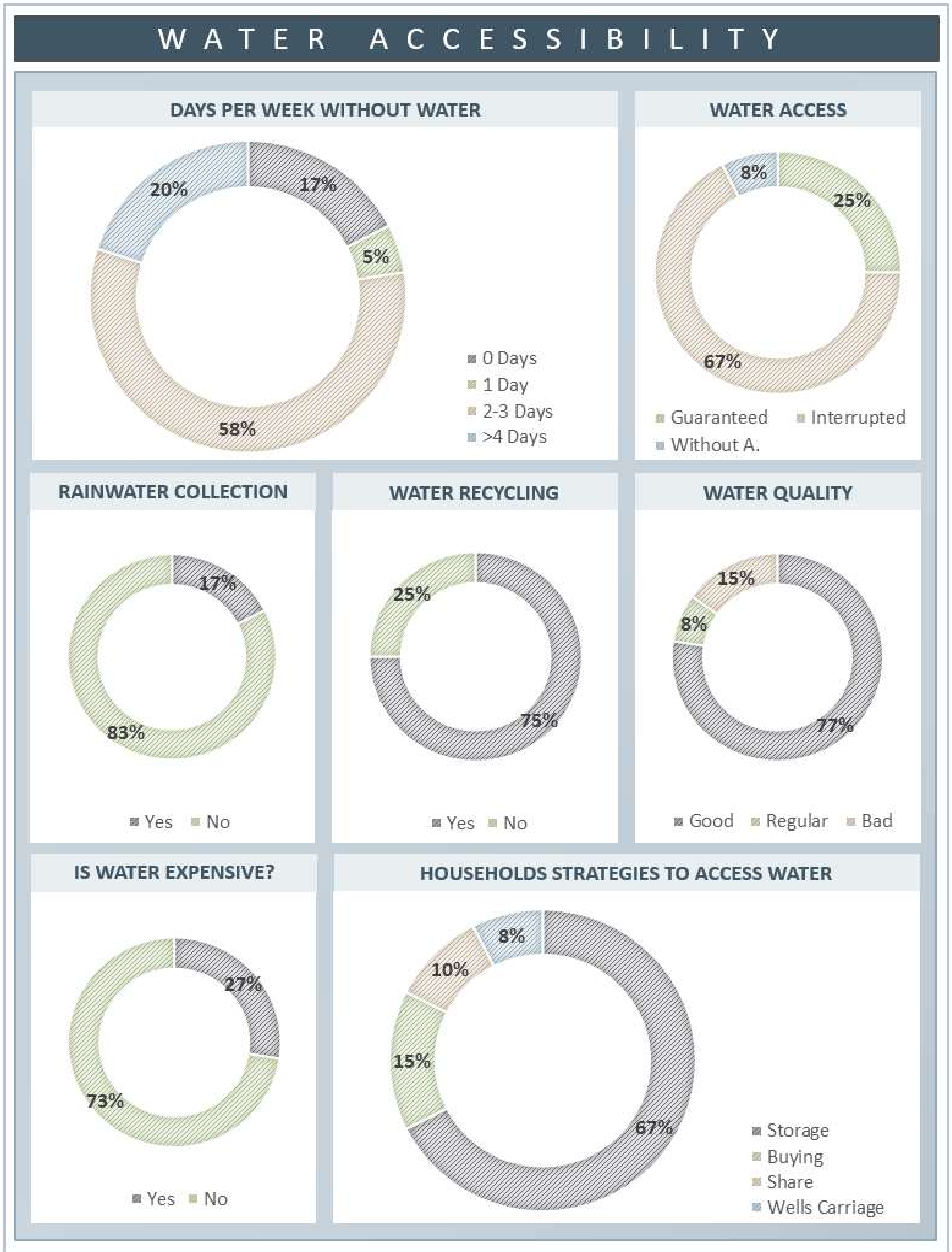


Fig. VI.3. *Water accessibility. 1) Days per week without water; 2) Water access; 3) Rainwater collection; 4) Water recycling; 5) Water quality; 6)Is water expensive; and 7) Households strategies to access water. Source: Alicia Cisneros, 2018.*

As La Pila, is located in the surroundings of the industrial zone, the demand of the resources increases, and because of the importance of the industrial sector in SLP, industry is favorited over peri-urban communities. Finally, when households were asked if they considered that water was expensive, only a 27% answered that they considered water an expensive good. It was observed, that such households had different sources for the water inflow, such as wells, water-trucking assistance and the regular services from Interapas.

VI.1.1.2. Energy Hazards

As a result of the interviews and the energy inflows analysis, it was observed that only a 80% has a guaranteed access to electricity. Moreover, a 47% of the interviews considers that electricity is an expensive good (**Fig. VI.4**). Because poverty is a major problem in La Pila, people searches cheaper solutions that reduce the gas consumption such a burning firewood to cook or heat water for showers. The main consequence of these practices are the emissions generated that constitute at the same time, a threat to people's health.

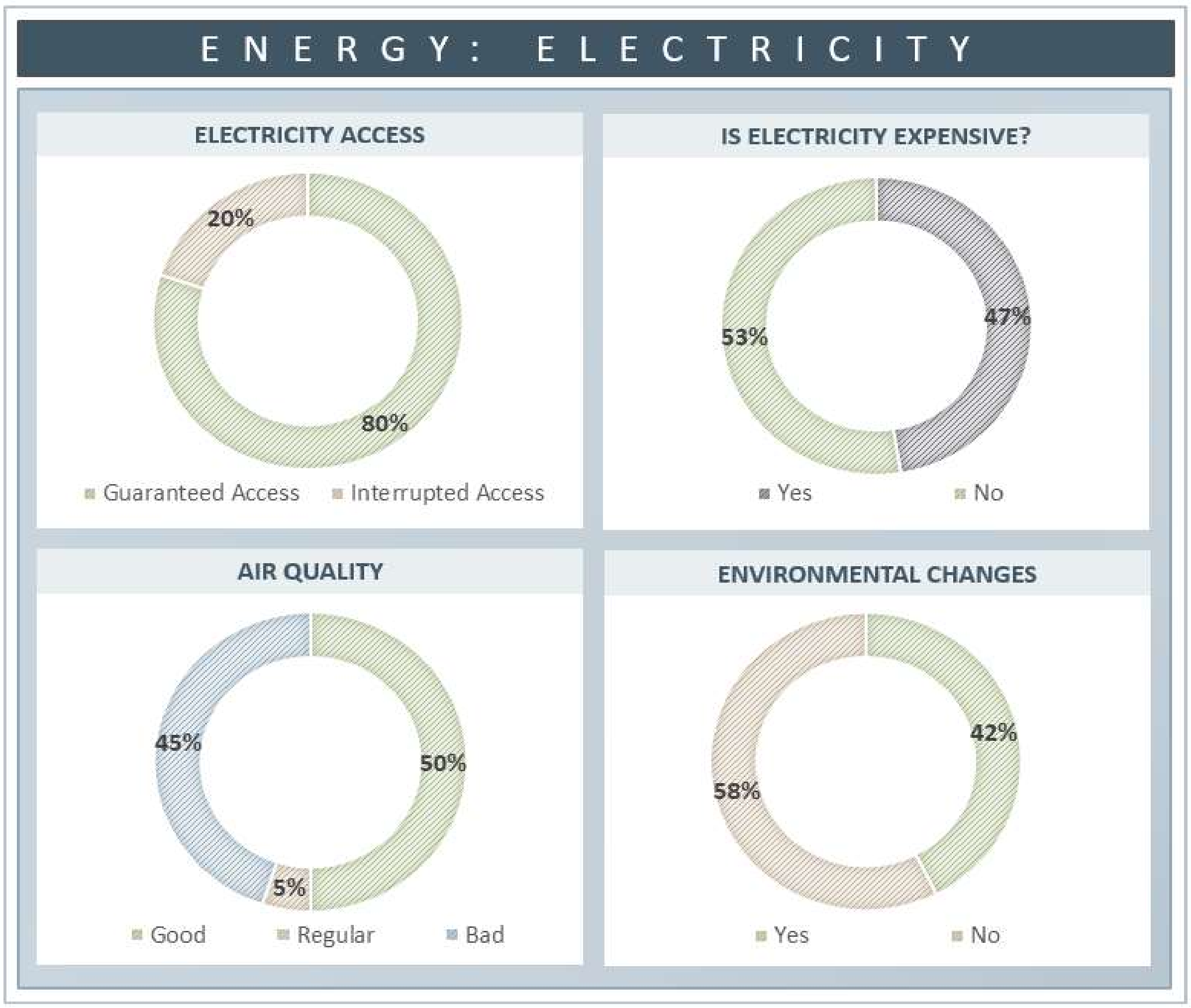


Fig. VI.4. *Energy: Electricity. 1) Electricity access; 2) Is electricity expensive?; 3) Air quality; and 4) Environmental changes. Source: Alicia Cisneros, 2018.*

Another hazard for energy's supply is linked to the political arena. In La Pila, the regulations related to schools' designs does not allow the implementation of photovoltaic cells, which must be changed if resilience must be achieved. Additionally, energy is only provided by CFE. Therefore, electricity supply depends on the same source, which means that there are not other energy alternatives if the service is under disturbance.

It was also observed that there is only one fuel station in La Pila , which if the demand increases might be a potential hazard for social and economic reasons. Socially, because the demand of the resource might increase, but economical also because the prices might rise. Finally, a non-potential but existent hazard is people going to social conflict against their neighbors to get the resources, as it has happened in Mexican cities, when fuel scarce before the prices rise. However, this is only through for few households in La Pila, as the majority do not own a car.

VI.1.1.3. Food Hazards

The major challenge to the households' food inflow relies on the food supply from La Pila, as they completely depend on the food that is brought from SLP. The main reason to this, is that La Pila's inhabitants do not produce food, as they are involved in industrial-related activities (It was observed that the majority of the household's adults are workers in the industrial zone of the MZSLP). In addition, it is cheaper to buy supplies within the community, because of the buses' prices. However, the main risk on the flow is that if food availability decreases in SLP, the most affected might be peri-urban areas because they are located further than city's inhabitants are.

Another indirect hazard that might require observation in further researches but that is not considered here is related to soil contamination, and therefore crops contamination, as a result of the industrial activities –including the wastewater required to realized them-, that are currently taking place in MZSLP. However, as the literature review did not cover this part, we cannot consider it yet as a hazard.

VI.1.1.4. Hazards Categorization to the System's Supply

In the following matrix, the most important hazards found in the Water, Food and Energy System's Supply are described. It is important to consider for this table, that hazards related to the community's supply are also taken into account, as they also form part of the resources inflows. In order to ease their identification, the four dimensions –ecological, social, economic and political-, were used as a guide according to the methodology used for this research (**Table VI.1**).

According to the interviews, the majority of the hazards to the system's supply are in the water inflows. However, this might be possible because of the extended literature available and the generalized complains about water supply during the interviews. However, it cannot be discarded that other hazards for energy and food not identified, might be also taking part in La Pila's dynamics.

Hazards to the System's Supply			
Dimension	**Water**	**Energy**	**Food**
Ecological	*Water extraction from deeper wells accelerates the appearance of faults. *Water overexploitation	*No alternative sources for electrical energy, but fossil fuels.	
Social	*Water Insecurity. *Population Growth. *Migration. *Urban Growth.	*A 20% of La Pila inhabitants does not have access to electricity. *There is only one fuel station in La Pila.	*Inhabitants depend completely on food suppliers that bring food from SLP (Mercado de Abastos).
Economic	*Industrial Growth reduces available Water Resource.	*Burning of firewood is still very common within the community, because of the gas costs.	*Inhabitants need to buy their supplies in La Pila as going to SLP is more expensive.
Political	*Lack of governmental budget to connect households to water and sewage services. *El Realito supplies a big percentage of SLP's households. Despite the fact it passes next to La Pila, it does not supply this community. *La Pila is the last part of the metropolitan area in the water supply infrastructure.	*In the case of the primary school, laws and regulations do not permit the use of solar panels. *Lack of governmental budget to connect households to electricity services. *CFE is the only electrical energy provider.	

Table VI.1. *Hazards to the System's Supply.*

VI.1.2. Hazards to the System

In this section, hazards to the system are identified according to the literature review and the analysis of the households' metabolic processes. Therefore, hazards are defined through the Water, Energy and Food metabolic processes. After that, a matrix of hazards to the system in general is provided.

VI.1.2.1. Water Hazards

Most water hazards to the households and the community in general can be found in the households' water consumption practices, as it was observed that only the 77% of the interviewees consume water from carboys. The rest boils tap water in order to use it as drinking water. Moreover, it was appreciated that a 62% of the interviewees have access to a WC, followed by a 33% who have two bathrooms and a 3% who have three bathroom. However, it was also found that a 2% of the inhabitants do not have access to a WC (WC Access in **Fig. VI.11**). What is more, only a 20% of the households has access to a sink, as most inhabitants wash dishes in barrels or buckets. This practice can rise health problems because of the possible contamination of such a vital liquid. It was also found, that the majority of the households, brush their teeth twice or three times per day. It is important to notice that most people uses tap water for brushing teeth, because in case the water source is contaminated, inhabitants will ingest the pollutants directly.

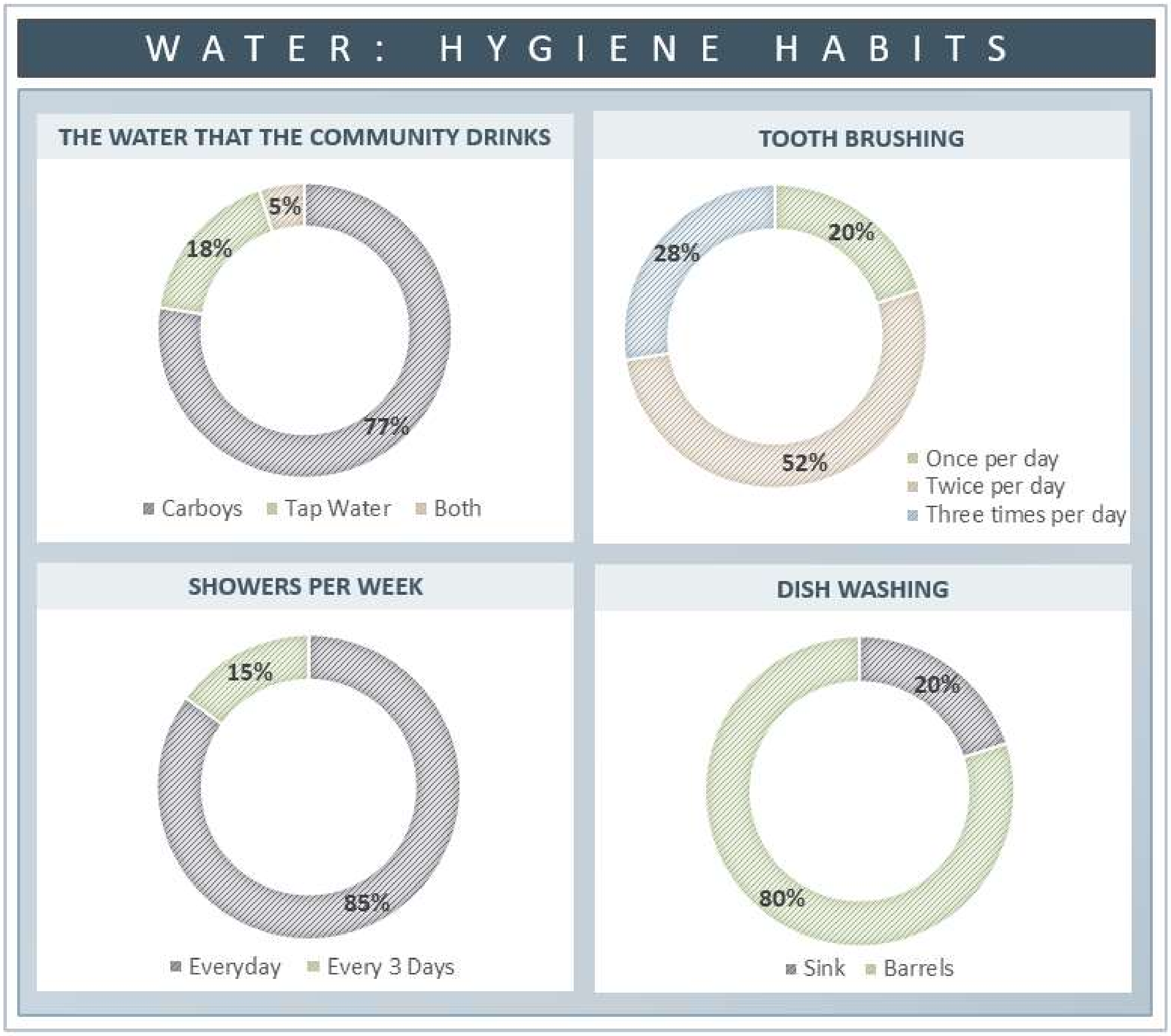


Fig. VI.5. *Water: Hygiene Habits. 1) The water that the community drinks; 2) Tooth brushing; 3) Showers per week; and 4) Dish washing.*

Finally, other water-related problems having an impact on the households are related to drainage and floods. It was observed, that a 20% of the interviewed households did not have access to drainage, and were using septic tanks, or were sharing the infrastructure with their neighbors. Only a 12.5% of La Pila interviewees said to have had problems with the drainage, and a 30% has had problems with intense rain, as their homes get flooded because of it. However, inhabitants observed that the infrastructure problems were worse some years ago, as the street Arroyo Hondo, which is still a small stream, used to get flooded easily interrupting the community's mobility (**Fig. VI.6**).

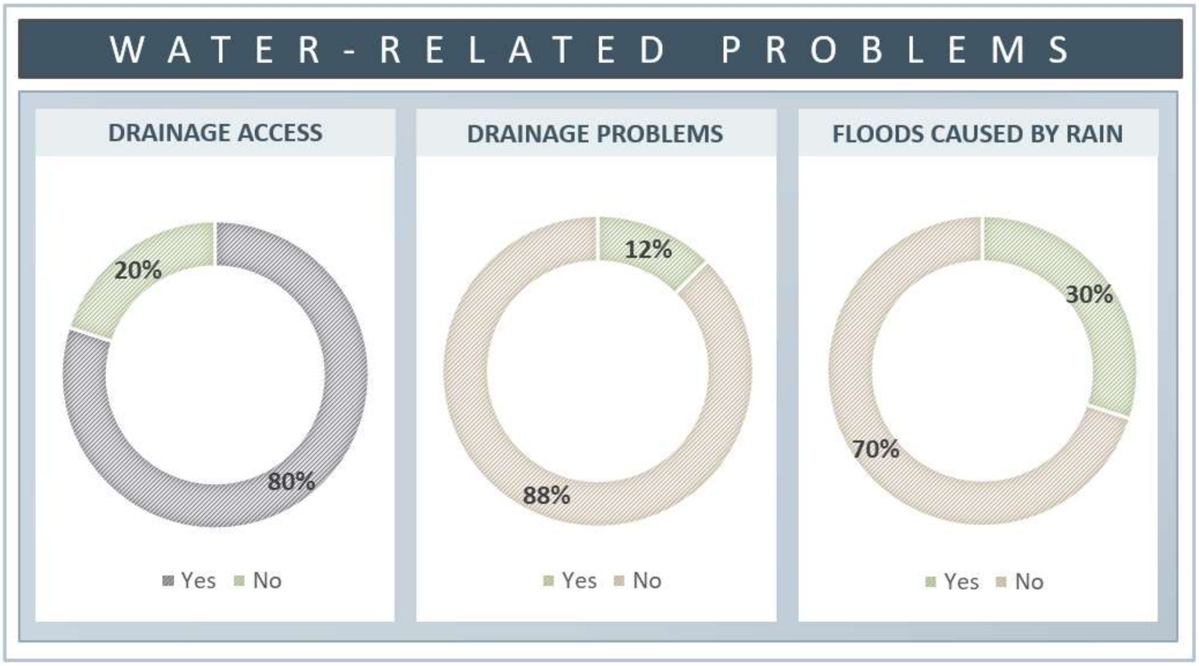


Fig. VI.6. *Water-related problems. 1) Drainage access; 2) Drainage problems; and 3) Floods caused by rain.*

VI.1.2.2. Energy Hazards

Money spent to cover the energy supply represents a high percentage of household's income: As we can see in **Fig. VI.8¡Error! No se encuentra el origen de la referencia.**, a 92% of people uses gas to cook, which is considered as an expensive good. According to some people interviewed, they sometimes cannot afford gas, which makes them opt for cheaper energy sources, such as firewood. Even if the percentage of people using firewood is low, this is also related to a health hazard -pulmonary diseases- that can have a negative impact on more households.

Moreover, it is observed that inhabitants do not have all the household appliances that are often used within cities. For example, the case of appliances with a high-energy consumption, such as fridges and computers. It can be appreciated that only a 10% of the households interviewed have a computer, while only a 85% of them own a fridge. A very small part of the households –a 30%- has a microwave. Moreover, a 77% of the interviewees own a washing machine. However, it was observed that only a 12% does not own a TV (**Fig. VI.7**).

Although, most inhabitants use gas as energy for cooking, it is observable that a 5% of interviewees uses also firewood, which increases the propensity of pulmonary illnesses. Moreover, the use of firewood is also very popular when boiling water for showers, as only a 15% have access to a heater. Meanwhile, a 50% of the households uses gas through the stove to heat water, followed by a 35% of inhabitants who prefer to use firewood to heat water for showers. Additionally, gas is considered as the most expensive good by the majority of the households –the 82% of the interviewees-, as observed in **Fig. VI.8**.

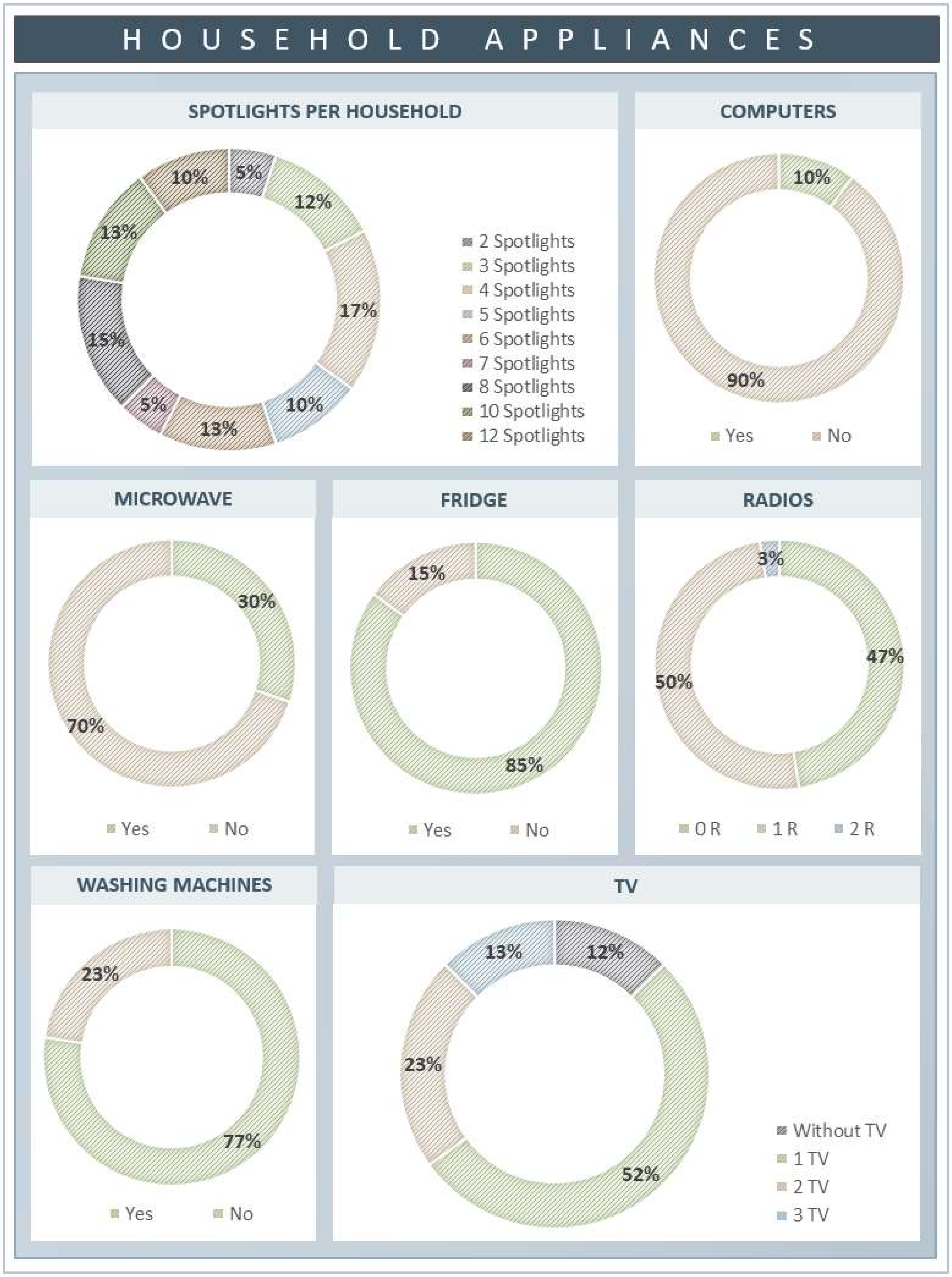


Fig. VI.7. *Household appliances. 1) Spotlights per household; 2) Computers; 3) Microwave; 4) Fridge; 5) Radios; 6) Washing machines; and 7) TV.*

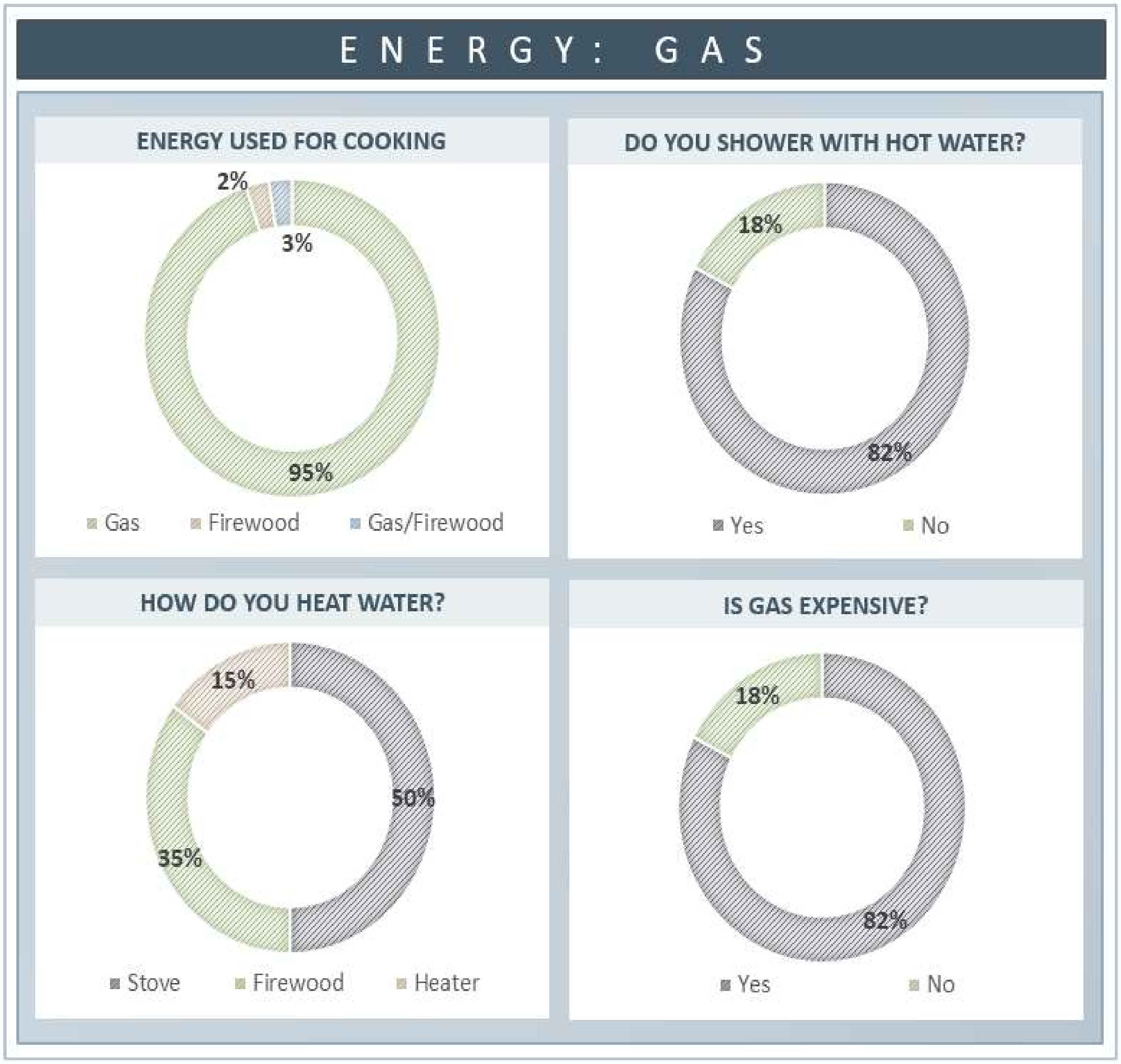


Fig. VI.8. *Energy: Gas. 1) Energy used for Cooking; 2) Do you shower with hot water?; 3) Hoe do you heat water?; 4) Is gas expensive? Source: Alicia Cisneros, 2018.*

According to **Fig. VI.4**, only 50% of the interviewees considered that the air quality was good, followed by a 45% that considered that air quality was bad, whereas a 5% considered that air quality was regular. Moreover, only a 42% has perceived detrimental environmental changes within the community.

Finally, the industrial growth demands every time more and more electrical energy from the MZSLP, which might also constitute a hazard for the community's access to electrical energy.

VI.1.2.3. Food Hazards

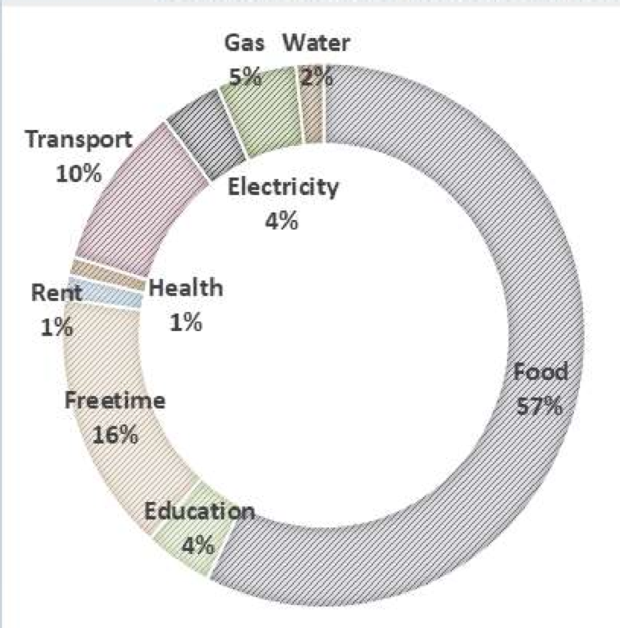
The main hazards in the food metabolism within the households are related to unappropriated diets, which are the result of a poor health education and information. What is more, inhabitants are not only dealing with unbalanced diets, but also the lack of public spaces to exercise. Some interviewees commented that they used to practice outdoor activities everyday, however, because of the insecurity and vandalism they stopped going out during the evenings.

Another hazard for the food metabolism is the households' income, as money spent to cover the food supply represents most of it, which makes them buy less food due to the continuous rising on the prices (**Fig. VI.9**).

Hazards to food that can arise from the ecological dimension are the use of pesticides, possible contamination of Hg because of mining practices in the past, and therefore contaminated crops. However, as this research did not focus on those hazards, it is highly recommended to integrate such data in further research.

AVERAGE EXPENDITURE

ESTIMATED AVERAGE EXPENDITURE PER HOUSEHOLD IN LA PILA (%)*



Average and Median Expenditure per Sector($**)		
Sector	Average	Median (x)
Food	$ 3,508.00	$ 3,200.00
Education	$ 258.33	$ 250.00
Freetime	$ 952.00	$ 800.00
Rent	$ 88.00	$ -
Health	$ 67.72	$ -
Transport	$ 605.66	$ 800.00
Electricity	$ 229.68	$ 100.00
Gas	$ 303.97	$ 187.00
Water	$ 104.00	$ 100.00
Income	**$ 6,117.36**	**$ 5,437.00**

*Values estimated considering an Average Income of MXN 6,117.36
**$=MXN, Values in Mexican Currency

Fig. VI.9. *Average Expenditure: Estimated average expenditure per Household in La Pila (%).*

Fortunately, there are some strengths found in the food system, such as the organic waste reuse, which is used to feed animals, mostly pigs. In this context, further research might demand what and which quantity of waste food are the animals eating and if there is a risk that such food might be contaminated in order to avoid bio-accumulation and or bio-magnification. Moreover, waste is usually collected one or two times per week –according to the zone of residence and is usually Thursdays or Mondays and Thursdays-, by a governmental garbage collection system. Additionally, it was observed, that a 50% of the interviewees recycle PET and aluminum, usually to sell and get an extra income (**Fig. VI.10**).

Fig. VI.10. *Food: Waste disposal. 1) Do you recycle waste?; 2) Do you separate garbage; 3) Garbage collection system; and 4) Organic waste for animals.*

VI.1.2.4. Other Hazards

In addition to the hazards already mentioned, we should not forget that because of its proximity to the industrial zone, La Pila is very vulnerable to chemical and technological hazards due to the storage of toxic substances needed in the industry. According to (2009), La Pila has bigger risks than the city of San Luis Potosi, because of its closeness to the industrial zone. In addition, the industry plays a major role in San Luis Potosi's development, as it has been observed that "obsolete factories have often closed down, leaving behind contaminated soil and groundwater" (C. Kennedy, Cuddihy and Engel-Yan, 2007).

The industry also plays a major role regarding the city's growth. When an industrial zone grows, people who work there tend to move to closer areas. It has been observed by Laboratorio Casa Viva, that some of the big construction enterprises are already thinking about buying fields from La Pila inhabitants in order to build houses for the industry workers. Considering that inhabitants from this community spend most of their income in Food and Access to Basic Services –including those related to Water and Energy- (**Fig. VI.9**), it is easy to believe that they will be willing to sell a part of their property, which in 40% of the households interviewed, exceeds the 150 m^2. Moreover, a 90% of the households own their house, which makes even easier for enterprises to buy their houses in change of an unfair price (**Fig. VI.11**).

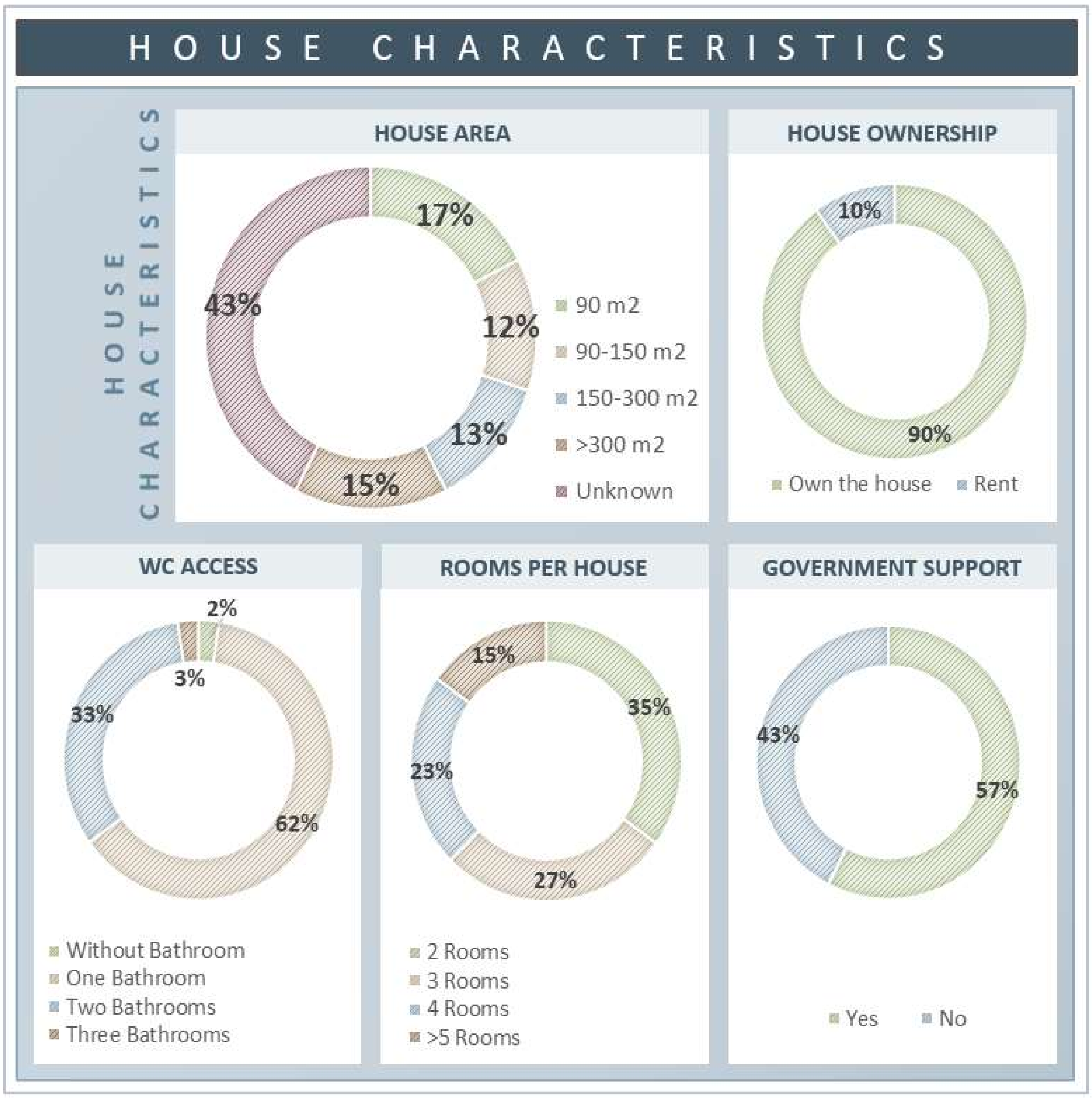


Fig. VI.11. *House Characteristics. 1) House area; 2) House Ownership; 3) WC Access; 4) Rooms per House; and 5) Government Support.*

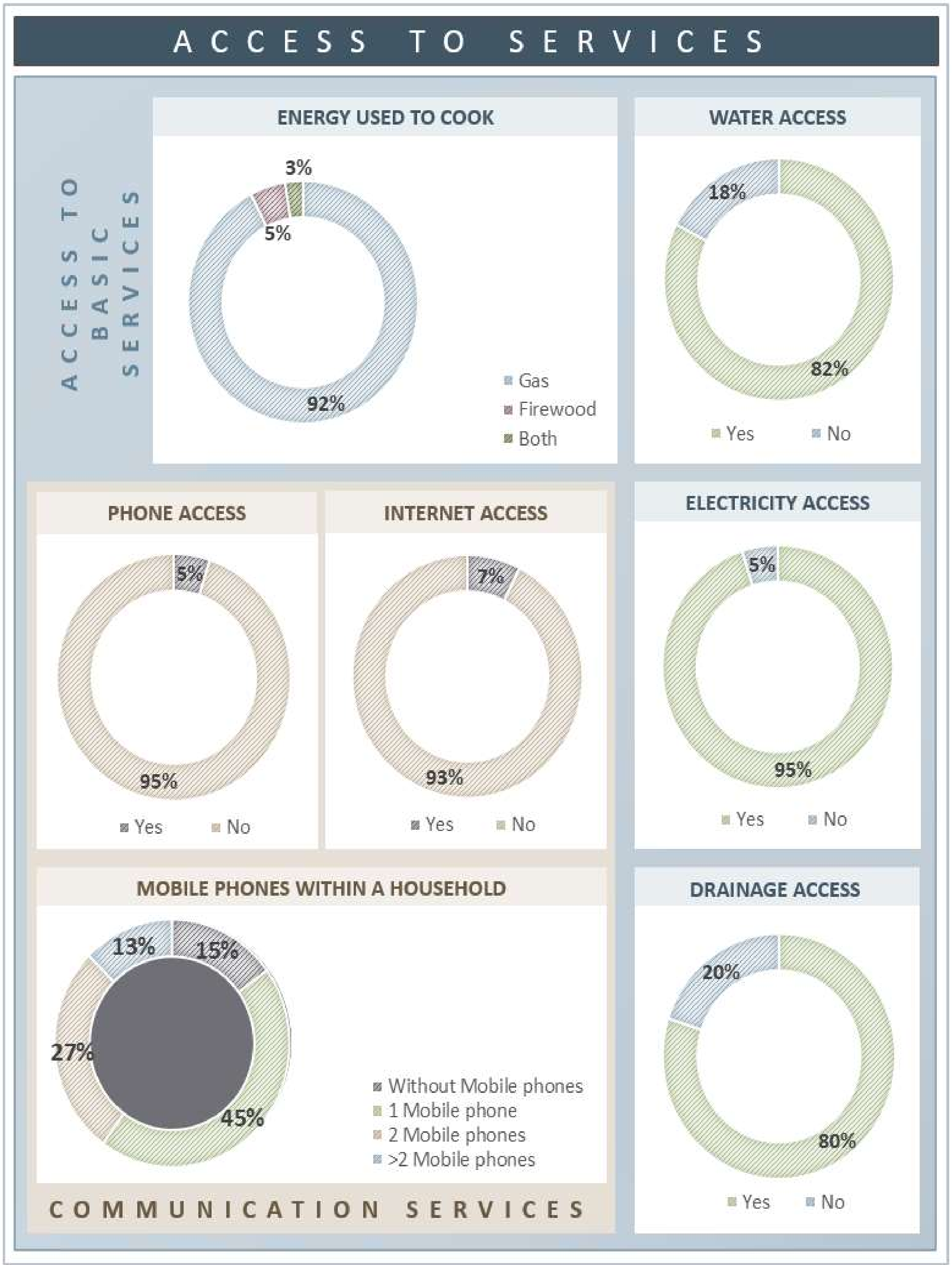


Fig. VI.12. *Access to Services. Access to Basic Services: 1) Energy used to cook; 2) Water access; 3) Electricity access; and 4) Drainage access. Communication Services: 1) Phone access; 2) Internet access; and 3) Mobile phones within a household.*

VI.1.2.5. Hazards Categorization to the System

In the following matrix, descriptions of the important hazards found in the Water, Food and Energy metabolic process within the households –and generalized to the community-, can be found. The matrix displays the hazards organized in the four dimensions –ecological, social, economical, and political-. In addition, the health dimension was added, because even if the hazard is related to the other dimensions, it is hard to identify a unique arena, from which actions should be taken to react the hazard. Because of the social-economical characteristics of La Pila, most hazards are linked to poverty, resources unequitable distribution and social backwardness (**Table VI.2**).

Hazards in the System			
Dimension	**Water**	**Energy**	**Food**
Ecological	*Floods. *Water pollution due to floods. *Pollution caused by industry.	*Air pollution caused by the burning of firewood. *Decreasing air quality.	*Use of pesticides. *Possible contamination of Hg. *Contaminated crops.
Social	*Loss or damage of personal property due to floods.	*Insecurity increases the energy consumption during the night.	*Not balanced diets due to lack of education and information. *Insecurity and vandalism discourage outdoor activities.
Economic	*Money spent to cover the water supply represents a considerable percentage of household's income. *Ageing infrastructure. *Lack of budget to install a cistern.	*Money spent to cover the energy supply represents a considerable percentage of household's income. *Failures in infrastructure.	*Money spent to cover the food supply represents most of the of household's income. *Continuous rising on the prices.
Political	*Industrial Growth.	*Industrial Growth.	*Industrial Growth.
Health	*Stomach diseases caused by drinking tap water. *A 20% of the interviewed households does not have access to drainage. *A 2% of the interviewees does not have access to WC. *A 80% of the interviewees washes dishes in barrels or buckets.	*Possible pulmonary diseases caused by the burning of firewood.	*Inappropriate diets. *Lack of public spaces to exercise

Table VI.2. *Hazards in the System.*

VI.2. Risk Assessment in La Pila

In this section, risk is assessed based on the previous identified hazards. In order to provide an insight of how resilient is La Pila regarding the USES's supply and the USES itself, risks coming from the Water, Energy and Food system's supply are first analyzed. After that, risks concerning the whole USES, due to the complicatedness of breaking down some problems.

VI.2.1. Risk in the System's Supply

The risks that threaten the system's supply can come from several dimensions: ecological social, economic, and political. In this part, we define risks for water, energy and food, depending on their frequency and severity.

VI.2.1.1. Water

As it can be observed in **Table VI.3**, the highest water-related risks for the system's supply, include the lack of governmental budget to connect households to water and sewage services, as well as the fact that La Pila is the last part of the metropolitan are in the water supply infrastructure .

Risk in the System's Supply: Assessing Water Hazards					
Dimension	**Water**	**Frequency**[67]	**Severity**[68]	**Hierarchy**[69] **(Exposure)**	**Risk**[70]
Ecological	Water extraction from deeper wells accelerates the appearance of faults.	D	III	High	**Medium**
	Water overexploitation	C	III	Medium	**Medium**
Social	Water Insecurity.	E	II	High	**Medium**
	Population Growth.	D	I	Low	**Low**
	Migration.	D	I	Low	**Low**
	Urban Growth.	E	I	Medium	**Medium**
Economic	Industrial Growth reduces available Water Resource.	D	I	Low	**Low**
Political	Lack of governmental budget to connect households to water and sewage services.	E	III	Severe	**High**
	El Realito supplies a big percentage of SLP's households. Despite the fact it passes next to La Pila, it does not supply this community.	E	II	High	**Medium**
	La Pila is the last part of the metropolitan area in the water supply infrastructure.	E	III	Severe	**High**

Table VI.3. *Risk in the System's Supply: Assessing Water Hazards.*

[67] See **Table III.12.** Hazards Frequency. Source: (Secretaría del Trabajo y Previsión Social, 2011).
[68] See **Table III.13.** Hazards Severity. Source: (Secretaría del Trabajo y Previsión Social, 2011).
[69] See **Table III.14.** Risk Hierarchy. Source: (Secretaría del Trabajo y Previsión Social, 2011).
[70] See **Table III.15.** Risk Description. Source: (Secretaría del Trabajo y Previsión Social, 2011).

Hierarchized as medium we can find he risks related to water overexploitation, the appearance of faults, water insecurity, and the growing industrial water consumption. Moreover, the fact of La Pila being the last part in the supply infrastructure is also a medium risk. They were classified as medium risks, because even if their exposure was high, it is not as urgent as providing the water accessibility to the whole community.

Finally, low risks consider the industrial –economic dimension-, population growth and the migration –social dimension-, because even though their frequency, they have not so strong severity consequences. However, despite the result provided by the matrix, it is important to reflect on how urban growth, and industrial growth could provide a resilience strategy to deal with change and satisfy everybody's needs.

VI.2.1.2. Energy

Energy-related risk is medium and low for the system's supply. Medium risks found are that there are no alternative sources for electrical energy, -such as photovoltaic cells or solar water-heating systems-, there is only one fuel source in the area of La Pila, the continuous rise in the cost of fuel that has an impact on households' budgets, and the lack of governmental budget to connect households to electricity services (**Table VI.4**).

Risk in the System's Supply: Assessing Energy Hazards					
Dimension	**Energy**	**Frequency**	**Severity**	**Hierarchy (Exposure)**	**Risk**
Ecological	No alternative sources for electrical energy, but fossil fuels.	E	I	Medium	**Medium**
Social	A 20% of La Pila inhabitants does not have access to electricity.	B	III	Low	**Low**
	There is only one fuel station in La Pila.	E	I	Medium	**Medium**
Economic	Burning of firewood is still very common within the community, because of the rise in the cost of fossil fuels.	C	III	Medium	**Medium**
Political	In the case of the primary school, laws and regulations do not permit the use of solar panels.	A	I	Minimum	**Low**
	Lack of governmental budget to connect households to electricity services.	D	III	High	**Medium**
	CFE is the only electrical energy provider.	A	I	Minimum	**Low**

Table VI.4. *Risk in the System's Supply: Assessing Energy Hazards.*

Low risks found in the risk assessment was the high inflexibility of regulations and norms that do not allow the implementation of environmental technologies in public buildings. Moreover, as CFE is the only provider of electrical energy, in case in case of disruption, the community will take a wider period of time to recover. Finally, a 20% of La Pila inhabitants does not have access to electricity because they live in the furthest points from the community, which leads to insecurity and vandalism in their surroundings.

VI.2.1.3. Food

Risks in the system's supply regarding the food inflow within the households, are low and medium, as it was observed that inhabitants get their food from distributers within La Pila, that –at the same time-, get their products from the MZSLP. The main hazard detected is that the inhabitants do not produce food, and they are already consuming resources from the rural environment (**Table VI.5**).

Risk in the System's Supply: Assessing Food Hazards					
Dimension	**Food**	**Frequency**	**Severity**	**Hierarchy (Exposure)**	**Risk**
Social	Inhabitants depend completely on food suppliers that bring food from SLP (Mercado de Abastos).	E	I	Medium	**Medium**
Economic	Inhabitants need to buy their supplies in La Pila as going to SLP is more expensive.	C	I	Minimum	**Low**

Table VI.5. *Risk in the System's Supply: Assessing Food Hazards.*

VI.2.2. Risk in the System

Once hazards were identified for the system, they were assessed using the risk's matrixes provided in the methodological framework in order to assess their frequency and severity and get the level of exposure to this hazard, as well as the risk level. The risks that threaten the system's supply can come from several dimensions: ecological social, economic, political and health. In this part, risks for water, energy and food, are categorized depending on their frequency and severity.

VI.2.2.1. Water

Water-related risk for the system are several. The highest risk are related to the lack of cistern to storage water, and the fact that the households use barrels or buckets to wash the dishes, as they do not have access to a sink (**Table VI.6**). Moreover, medium risks include the water pollution in the whole city that can be produced due to the industrial activities, and the industrial growth in ZMSLP that is an enhancer for the previous hazards. Moreover, medium risks –related to the health dimension- include a 2% of the interviewees, who do not have access to WC, and a 20% of the interviewed households does not have access to drainage.

Further, lots risks from the ecological dimension also include floods, -as well as the material loss that they mean-, water pollution due to floods and possible pollution of the wells due to the industrial activity. Moreover, low risks linked to the economic dimension are ageing infrastructure and monetary loos when households get flooded. Finally, a minor hazard that is present in the system are stomach diseases caused by drinking tap water, as it can be observed in the following table.

Risk in the System: Assessing Water Hazards					
Dimension	**Water**	**Frequency**	**Severity**	**Hierarchy (Exposure)**	**Risk**
Ecological	Floods.	B	III	Low	**Low**
	Water pollution due to floods.	A	III	Minimum	**Low**
	Pollution caused by industry.	C	III	Medium	**Medium**
Social	Loss or damage of personal property due to floods.	A	II	Minimum	**Low**
Economic	Money spent to cover the water supply represents a considerable percentage of household's income.	C	I	Minimum	**Low**
	Lack of budget to install a cistern.	E	III	Severe	**High**
	Ageing infrastructure.	B	II	Minimum	**Low**
Political	Industrial Growth.	E	II	High	**Medium**
Health	Stomach diseases caused by drinking tap water.	B	III	Low	**Low**
	A 20% of the interviewed households does not have access to drainage.	C	IV	High	**Medium**
	A 2% of the interviewees does not have access to WC.	B	IV	Medium	**Medium**
	A 80% of the interviewees washes dishes in barrels or buckets.	E	IV	Severe	**Severe**

Table VI.6. *Risk in the System: Assessing Water Hazards.*

VI.2.2.2. Energy

High energy-related risks come from the economic and the political dimensions, as there are current failures in the infrastructure, especially during the summer, which might be linked to the industrial growth, which is the sector that consumes –in combination with the commercial sector-, up to 80% of the total electrical energy produced in ZMSLP (SENER, 2017) (**Fig. VI.7**).

Risk in the System: Assessing Energy Hazards					
Dimension	**Energy**	**Frequency**	**Severity**	**Hierarchy (Exposure)**	**Risk**
Ecological	Air pollution caused by the burning of firewood.	A	III	Minimum	**Low**
	Decreasing air quality.	C	III	Medium	**Medium**
Social	Insecurity increases the energy consumption during the night.	E	II	High	**Medium**
Economic	Money spent to cover the energy supply represents a considerable percentage of household's income.	C	III	Medium	**Medium**
	Failures in infrastructure.	E	III	Severe	**High**
Political	Industrial Growth.	E	III	Severe	**High**
Health	Possible pulmonary diseases caused by the burning of firewood.	A	IV	Low	**Low**

Table VI.7. *Risk in the System: Assessing Energy Hazards.*

Moreover, medium risks for the system is the increasing use of electrical during the nights, because of the poor street lighting and the vandalism. Additionally, households spent a considerable percentage of their income in energy, which unbalances sometimes their budget.

According to the information collected from interviews half of the households, perceived a detriment in air quality, which is caused by the burning of firewood when cooking or boiling water and by the animals in the neighborhood. In the health dimension, this can also have implications as pulmonary diseases might increase, as well as air pollution.

VI.2.2.3. Food

The highest risk for the food system are related to the economic, political and health dimensions. On the one hand, the food represent the highest percentage of money spent by households. This can also be enhanced by the constant rising of prices in food supplies. Moreover, industrial growth reduces agricultural areas in the surrounding, which increases transportation costs –and food costs as well-. In this context families follow inappropriate diets that threaten their health (**Fig. VI.8**).

Risk in the System: Assessing Food Hazards					
Dimension	**Food**	**Frequency**	**Severity**	**Hierarchy (Exposure)**	**Risk**
Ecological	Use of pesticides.	A	III	Minimum	**Low**
	Possible contamination of Hg.	A	IV	Low	**Low**
	Contaminated crops.	A	III	Minimum	**Low**
Social	Not balanced diets due to lack of education and information.	E	III	Severe	**High**
	Insecurity and vandalism discourage outdoor activities.	E	II	High	**Medium**
Economic	Money spent to cover the food supply represents most of the of household's income.	E	III	Severe	**High**
	Continuous rising on the prices.	E	III	Severe	**High**
Political	Industrial Growth.	E	III	Severe	**High**
Health	Inappropriate diets.	E	IV	Severe	**High**
	Lack of public spaces to exercise	E	II	High	**Medium**

Table VI.8. *Risk in the System: Assessing Food Hazards.*[71]

Other risks related to food metabolism within households are the lack of public spaces to exercise and the insecurity, as they enhance bad health habits. From the ecological dimensions, hazards can come from contaminated crops or the use of pesticides within La Pila.

[71] For information regarding the risk calculation, **Table III.13.** Hazards Severity. Source: (Secretaría del Trabajo y Previsión Social, 2011). **Table III.14.** Risk Hierarchy. Source: (Secretaría del Trabajo y Previsión Social, 2011). **Table III.15.** Risk Description. Source: (Secretaría del Trabajo y Previsión Social, 2011).

VI.3. Urban Resilience in La Pila

Based on the risk assessment's reflection, urban resilience is assessed first for the system's supply and then, for the system itself, considering the totality of the USES under study and making generalized assumptions for the whole community, based on the behavior of the 40 households interviewed.

VI.3.1. Resilience of the System's Supply

The first section describes the resilience of the system's supply based on the resilient qualities –reflectiveness, robustness, redundancy, flexibility, resourcefulness, inclusiveness and integration-, proposed in the methodological framework.

Reflectiveness

An ever-increasing learning capacity is observed in household's water supply, as people is already making some changes to their houses so that they can be better prepared to water insecurity. Even if it is also about robustness, what is central to remark is the learning process that is taking part in the community, as a result of the implementation of eco-technologies in the elementary school Francisco González Bocanegra[72].

In the energy context, it was appreciated a low reflectiveness, as strategies that are related to photovoltaic cells have not been accepted due to political reasons, which are standards and norms, that require urgent changes in order to respond to the changing urbanism.

Additionally, because of such strategies, people is starting to grow some crops as an experiment. However, it is observable that inhabitants within La Pila, have already entered in the city's dynamic of consuming more resources than they produce.

Robustness

For the households' water supply, it was observed a low robustness level, as most families do not have a water cistern to store water. Although, most families have bought plastic and aluminum barrels (500 L. capacity) and buckets to store water, as they already know which days from the week water will not be available. As specified in the theoretical framework, it is necessary to implement design strategies in order to anticipate potential failures in the water supply. Moreover, if we observe the water inflow through La Pila, a low level of robustness will be observed, as water usually comes from only one well. In case a contamination of this well occurs, the community might have seriur problems.

Considering the electrical energy inflow through households, and because of the non-existent use of eco-technologies –such as photovoltaic panels-, electrical energy disruption can be a great problem,

[72] Chapter IV: Case of Study: La Pila as an USES.

especially because of the unsafe environment at night. Moreover, it was observed that during the months of April, May and June, a 25% of the households do not have access to electricity, which means an extra expenditure in candles for the inhabitants.

The food inflow in La Pila has a medium robustness as most people is able to supply their households within La Pila's markets and convenience stores. Central to the understanding of the food inflow is that in spite of most food coming from SLP's main market *Central de Abastos*, this food source is at the same time supplied by several producers from all over Mexico, and in the case of some fruits – especially apples- from the USA.

Redundancy

According to the graph *Households Strategies to Access Water* (**Fig. VI.3**), it was observed that in order to deal with water scarcity, a 67 % of the community inhabitants store water in buckets. A 15% of the interviewees said that they preferred to buy water from water tankers, while a 10% said that in order to access water they were sharing resources with their families and neighbors. Finally, a 8% of the households interviewed accessed water by carrying water from wells located in their properties or in the surroundings.

Although, for the water supply the USES seems to be redundant for the moment, in the case of food, a completely different situation can be found. Despite the fact, that food can come from markets, convenience stores and supermarkets, it is important to consider that these get their supplies from SLP. In case of disruption, La Pila can be affected, as it is one of the furthest points in the MZSLP. This phenomenon, although its rarity, must be considered to enhance urban resilience and therefore, a sustainable metabolism.

In the case of energy's supply, a medium redundancy can be found, as energy can be found in the system through the burning of firewood and the use of candles. However, in order to enhance resilience in this aspect it would be necessary to increase the energy sources by dividing the lines, so that if a blackout happens, only one part of the street is temporarily without electricity. Moreover, encouragement of photovoltaic panels in public buildings could also increase redundancy and decrease fees.

Flexibility

As flexibility means that systems change, evolve and adapt in response to changing circumstances (The Rockefeller Foundation, 2018), it was observable but this resilient quality is missing in Water and Energy system's supply, when talking about the community's scale. However, when observing independent households, it can be appreciated that the resource's supply can come from several sources, when water or energy insecurity arise. However, flexibility is observed in the community, as we would observe in the next part of the urban resilience assessment.

Resourceful

As observed in **Table VI.3** Table VI.3, the highest water-related risks for the system's supply, is the fact that La Pila is the last part of the metropolitan are in the water supply infrastructure. Therefore, its resourcefulness to cover the water demand is low. Despite the fact, that collected rainwater may increase water availability, it is still far away from the desirable conditions for water provisioning and use. It could be a good idea to construct a tank or a dam in the surroundings to increase resourcefulness and enhance resilience. Moreover, in the case of food supply, agricultural gardening might help to increase resourcefulness, and make the community's inhabitants less dependent on ZMSLP food supply. In the energy sector, it is mandatory to consider solar energy as a potential energy source that can replace gas and electrical energy, as it can be used instead of burning firewood to boil water for example, or cook.

Inclusive

In the system's supply there was no evidence of inclusion in any resource management. This was strange, especially in the food supply, as markets tend to consult and engage to decide prices in a join-vision.

Integrated

There is not an alignment observed between the energy and water's supplies as both depend on different decentralized institutions. This is a key point to work on, as it can provide integration between resources systems, promoting consistencies in decision-making processes and ensuring a better use of infrastructural investments. Additionally, in **Table VI.3** it is observed a lack of governmental budget to connect households to water and sewage services. What is more, considering that La Pila is the last part of the metropolitan area in the water supply infrastructure, even though the distribution system runs in the surroundings.

VI.3.2. Resilience of the System

This section includes the resilience of the system based on the resilient qualities proposed in the methodological framework.

Reflectiveness

The USES reflectiveness can be considered as medium, because of the households' behavior. On the one hand, it was observed that they are always able to deal with uncertainty related to resource's supply. For example, in the case of water supply, people is already used to deal with water scarcity, which makes them be always ready to store water. Moreover, in some cases people have themselves implemented some water collection pipes in order to maximize the rain collection. What is more, people have also implemented water recycling strategies in order to avoid unnecessary water waste during cleaning chores.

In the case of energy disrupters, they have further strategies to cope with challenges. In the case of electrical energy, they are prepared with candles, if they need gas to boil water, but they cannot afford it they just burn firewood. What is more, it was observed that households owning a car or a motorcycle, were not concerned about the fuel's price rising, as they had a fixed budget that once over was not exceeded.

The reflectiveness regarding the food metabolic processes can be considered of medium-low level, because even if people is starting to be aware about the importance of the diet, there are still so many changes that need to be done.

Robustness

Because of their adaptive nature, inhabitants from La Pila are robust as they do neve over-rely on single asset. In this context, if the behavior of the community's inhabitants is compared to the behavior of SLP's inhabitants while a blackout, La Pila's inhabitants will be more resilient to the shock, as they will have developed the capacity to withstand the impacts of hazard events without damage.

Redundancy

Although, redundancy is still not a quality for the system's supply, it is for the community's inhabitants, as they have learned to fulfill their needs through multiple ways. For example, the case of water insecurity. When water is scarce, inhabitants ask other neighbors or their families for water supply. This process is repeated across the community, resulting in an intentional social network that allows people to have water access guaranteed.

Flexibility

The implementation of managerial strategies in the elementary school might conduct to flexibility, as the introduction of knowledge allows developing a learning capacity that allows people to be better prepared to adapt in response of changing circumstances. However, considering the whole community, there is still a low flexibility when reflecting on infrastructure and ecosystem management.

Resourceful

Because of their demographic conditions, the community's inhabitants can be resourceful in a neighborhood scale. However, it is still necessary to work with the political arena in order to convince them of investing on institutional infrastructure, as this can help to build wider resilience, by mobilizing and coordinating wider human, financial and physical resources.

Inclusive

Vulnerable groups are not broadly consulted when decisions are made at the community's scale. Therefore, building social cohesion might be indispensable, if resilience is desired. Fortunately, through the university's project that is taking place in the elementary school *Francisco González*

Bocanegra, social cohesion and participation are being constructed through the engagement of the children's parents in sustainability workshops.

Integrated

A current integration is taking part within the community, through the University Autonomous of San Luis Potosi, and the enterprise Cummins, which from a transformational approach searches the application of strategies that can reduce inhabitants' vulnerability. Such project has already created an economic network that may allow the inhabitants to continue their studies, to improve their work conditions and their quality of life. However, this is still a first step towards a resilience (transformative) approach.

Closing Remarks

In this chapter, hazards to the USES of La Pila (considering the system's supply and the system itself), were first identified through the social, ecological, economic and political dimensions, and in relation to the respective inflow: Water, Energy and Food. For hazards to the system, the health dimension was added for such classification, as some hazards can be better counterbalanced through heath institutions.

After that, hazards where categorized into low, medium or high risks, depending on their severity and frequency. Finally, once having defined the risk to the supply's system and the system itself, urban resilience was assessed through the analysis of the resilient qualities: Reflectiveness, Robustness, Redundancy, Flexibility, Resourcefulness, Inclusiveness, Integration and

Chapter VII

Conclusions

"The central purpose of systems analysis is to help public and private decision and policy-makers to solve the problems and resolve the policy issues that they face."

(Miser and Quade, 1985)

VII. Conclusions

UM was analyzed in order to propose resilience strategies that guarantee the USES resilience. The UM is analyzed through the system's supply inflows –including Water, Energy and Food-, and the system itself. After that, hazards to the system's supply inflows –Water, Energy and Food-, and to the system itself, were identified from the ecological, social, economic and political dimensions (within a health dimension). Such hazards were later transformed into risks, in order to provide an input to the Resilience Assessment. In the following lines, a reflection on the objectives and research questions achievement is presented, as well as the recommendations to build sustainable urban metabolism through resilience strategies in La Pila, and the further research opportunities.

Building Sustainable Urban Metabolism through Resilience Strategies

To identify the metabolic fluxes in La Pila: Water, Energy & Food:

Which are the current metabolic fluxes in the community?

With data from forty households having been analyzed, and other supporting evidence from databases and literature review, some sense of how Water, Energy and Food flow in the household can be gleaned. At the beginning of this work, the objective was to measure the whole metabolic fluxes, this means from inflows to outflows. However, once in the fieldwork this did not seem achievable due to the lack of time for collecting, analyzing and interpreting data.

Therefore, in the methodological framework (Chapter III), it was decided to analyze only inflows at a household scale in order to provide insights of how Water, Energy and Food flow in the system. Additionally, with data from the system's supply and the system's metabolic process, the following two specific objectives were still feasible, as hazards threating the household –and the community as well- could still be identified in order to analyze the community's urban resilience.

As explained in the fifth chapter –*Metabolism of Households in La Pila*-, because of the diversity of families in La Pila and the complexity of the USES dynamics, the data gathered are presented and analyzed at three scales: 1) Households Total Consumption; 2) Household A-B-C Types Consumption; and 3) A Household Analysis. Such decision was taken, in order to provide a better context of how resources are consumed, because it is never the same looking at totalities, prototypes or specific cases of study.

Moreover, with data from the household's resources consumption, it was observed how the most important fluxes -water, energy and flood-, flow in La Pila, at a small scale. Consequently, for the selected metabolic fluxes, the main sources where found and data about the resources consumption was achieved.

When *Water-Energy-Food Metabolism was analyzed through the Analysis of the System's Supply and the System Itself*, it could be observed how the resources' inflows are going through the different household types (A, B & C) - average and median-, per household and per capita with several changes in patterns. It is important to stay, that such diagrams worked as a first insight of how the urban metabolism of households in La Pila looks like. Although, the Monte Carlo Simulation was used to provide more precision in the consumption results, more data should be collected to nurture the database, as the sample of 40 households' interviews was not representative.

It was observable during this fluxes analysis that when people do not have access to the resources through the traditional source, they try to find another way to supply the resource for the household. Unfortunately, these practices result sometimes in higher costs.

Furthermore, it is important to stablish that some managerial strategies have been implemented in the community in order to enhance water, energy and food security. Although such strategies might enhance resilience indirectly, they are mainly considered as coping or adaptive strategies in this research, as they try to solve the question *How?* Instead of the *Why?* And *What can I do about it?*

Finally, the results obtained after having completed this objective were central to define hazards after, as following Frank, Delano and Caniglia (2017), studying the production, flow and consumption of materials and energy allow to have insights on energy efficiency, materials recycling and waste management of USES (Frank, Delano and Caniglia, 2017).

To identify hazards to the metabolic fluxes:

How vulnerable are metabolic fluxes to which hazards?

Identifying how vulnerable are the metabolic inflows and processes inside the households and to which hazards, was only achieved through a systemic perspective that tried to focus on the community's dynamics, but also considering the most relevant relationships with the Metropolitan Zone of San Luis Potosi, as well as with the industrial zone located in the nearby.

Hazards identified provided insights on people's behavior. For example, though the identification of main hazards in the food metabolism within the households, it was discovered that unappropriated diets are the result of a poor health education and information, and therefore constitute also a hazard regarding the health dimension.

Water and Energy metabolism are also related to the health dimension, as water pollution and emissions generated because of the firewood burning are big threats to human and environmental health, that require immediate attention, although their low frequency.

Despite the fact that this research was only focusing on simple hazards, rather than on complicated or complex, when assessing the risk it was sometimes impossible to analyze one without taking into account the other. However, cascading effects are not defined, it will be important to have a better understanding of such relationships before applying any resilience strategy within the community of La Pila.

To analyze how resilient is the urban metabolism of La Pila:

How resilient is the urban metabolism of La Pila?

The risks that threaten the system's resilience can come from several dimensions: ecological social, economic, and political. That is the reason why defining risks to water, energy and food, was central to the urban resilience assessment depending on their frequency and severity.

Analyzing how resilient the urban metabolism of the community was one of the main challenges during this research, as it is very confusing to difference whether certain practices are enhancing resilience or keeping social backward. Unfortunately, it was observable, that vulnerable households that have lower monetary incomes are under more stress when buying goods, such as water, energy and food, however, they were the households doing the most efficient use of every resource.

It was observed that an ever-increasing learning capacity in households, as a result of the implementation of eco-technologies in the elementary school Francisco González Bocanegra. This means that the community exhibits a potential for ***reflectiveness***. Moreover, it was observed that the community's inhabitants were always able to deal with uncertainty related to resource's supply. For example, in the case blackouts, they are prepared with candles, and/or if they need gas to boil water, but they cannot afford it they just burn firewood.

In the case of ***robustness,*** it could be considered as low because of the lack of physical assets that could help to increase resilience in the system to, for example, water scarcity. Another example iif this, can be found in the food system's supply as the households buy their food within La Pila's markets and convenience stores. But, what might happen if a disruption happens in the system's supply? On the other hand, because of their adaptive nature, households from La Pila are robust as they do neve over-rely on single asset.

Water supply for the USES seems to be ***redundant*** now, as when water is scarce, inhabitants ask other neighbors or their families for water supply. This process is repeated across the community, resulting in an intentional social network that allows people to have water access guaranteed. Meanwhile, food and energy supply are not redundant enough.

Flexibility is missing in Water and Energy system's supply, when talking about the community's scale. However, at a households' scale, it can be appreciated that the resource's supply can come from several sources, when water or energy insecurity arise. In addition, the implementation of ecological technologies-related strategies in the elementary school might conduct to flexibility, as the introduction of knowledge allows developing a learning capacity that allows people to be better prepared to adapt in response of changing circumstances. However, considering the whole community, there is still a low flexibility when reflecting on infrastructure and ecosystem management.

Unfortunately, La Pila is not ***resourceful*** enough yet, as the highest water-related risks for the system's supply, is the fact that La Pila is the last part of the metropolitan are in the water supply infrastructure. Therefore, its resourcefulness to cover the water demand is low. Additionally, In the energy sector, it is mandatory to consider solar energy as a potential energy source that can replace gas and electrical energy, as it can be used instead of burning firewood to boil water for example, or cook. On the other hand, the community's inhabitants can be resourceful in a neighborhood scale due to the existent networking.

In the system's supply there was no evidence of ***inclusion*** in any resource management. In addition, vulnerable groups are not broadly consulted when decisions are made at the community's scale.

There is not an alignment or ***integration*** observed between the energy and water's supplies as both depend on different decentralized institutions. This is an opportunity that can provide integration between resources systems, promoting consistencies in decision-making processes and ensuring a better use of infrastructural investments. However, what is interesting about this resilience quality, is that there is a growing integration between different institutions -the University Autonomous of San Luis Potosi and the enterprise Cummins-, which from a transformational approach searches the application of strategies that can reduce inhabitants' vulnerability.

To propose resilience strategies that enable sustainable urban metabolism for the community (urban socio-ecological system) of La Pila in San Luis Potosi

The action of proposing resilience strategies to enhance sustainability for an USES's Urban Metabolism, is a task that should not be considered carelessly, as it involves affecting the system's interactions, components or dynamics. In the following part, recommendations to build sustainable urban metabolism in La Pila, SLP, are provided in relation to the stakeholders involved.

Resilience Strategies: Recommendations to conduct La Pila towards Sustainability

Towards La Pila residents

The Resilience Strategy builds on and dovetails with past planning efforts that benefited from expert analysis and broad community engagement. Moving forward, successful strategy implementation rests on continued community engagement and new partnerships (LeTourneau *et al.*, 2016). In order to implement a resilience strategy it is mandatory to use social participation. To fully understand the complexities of and opportunities for inclusive planning, future research should explore different ways of making participation culturally genuine and politically legitimate (Alawadi, 2017).

The highest vulnerability for households is the lack of proper water storage; therefore, a recommendation to enhance their resilience, although it is more about developing an adapting capacity, is to build a water cistern. Through this physical asset, they will be more robust and resourceful in case of water scarcity.

Towards external actors

External actors, who are already taking part in the community's development should consider the continuous and cyclic re-assessment of strategies implemented from a Systems Perspective for Urban Socio-Ecological Systems, in order to improve their understanding of social complexity and uncertainty. The main reason to do so is to avoid direct managerial solutions (Hard Systems Thinking), that might have other effects rather than the ones originally expected.

Moreover, it is observed that external actors are already implementing some strategies from a transformation perspective, in which change is being trigger through a managerial approach, which leaves out the complexity of adaptive systems and therefore, the systems' resilience. In this context it, will be important to involve external actors to participate in the community's change from a transformative perspective and enhance this capacity in the community's inhabitants, so that they become resilient and are able to cope, to adapt and to transform towards resilience and sustainability.

Towards industry

Although industry is located in the community's boundaries, they are not as vulnerable as La Pila's inhabitants are. Therefore, it is highly recommended to enhance inclusion, in order to consult and engage communities in the decision process. This might also lead to a better institutional integration between the community and the industry, that will help La Pila to become more resilient and less vulnerable.

Towards suppliers

Water and energy suppliers should consider first, ensuring the resources accessibility, and second, the building of physical assets, such as water tanks that can help to provide more water security to the inhabitants of La Pila.

Moreover, in the context of building proper water supply infrastructure, we should not forget that optimal design, control and planning of water supply systems, help to conserve the resource but also prevents unnecessary investment, operational and management costs (Vakilifard *et al.*, 2018). Therefore, smart design based on past experience and learning should be enhanced when planning the distribution of resources.

Towards government

Policy makers should be encouraged to understand the impact that dynamics from MZSLP have on the peri-urban communities, as they are more vulnerable to hazards related to resources' supply because of their location.

Moreover, a main suggestion to achieve sustainable urban metabolism for government institutions is a review on the laws, regulations and norms that apply to urban planning, as most of them are starting to become obsolete in a fast changing urban environment that is the MZSLP. As we could see in the resilience assessment, reflectiveness of the system is low because the USES has not been permitted to develop mechanisms that allow it to evolve, change and modify, mainly because of the strict regulations. There is an urgent need of learning-capacity development, especially in the political arena, were most decisions are being made. Such problem could be easily solved through co-management strategies that involve the community's residents, who most of the times are willing to cooperate and participate if a major benefit for the neighborhood will be achieved.

It is important not to forget that Inclusive decision-making processes are only achieved through social cohesion and a more collaborative urban governance. Therefore, the importance of implementing strategies to increase people's knowledge and skills to participate in the urban governance arena.

Additionally, to building sustainable cities, this contribute to achieve the 6^{th} SDG proposed by the United Nations -*Increase resilience of the population and promote social cohesion*-, as it allows making changes in social behaviors through environmental education and learning-capacity building, which prepare people to deal with the current and further shocks and stresses that might arise.

Rural communities and indigenous groups continue under increasing pressure (Barkin, 2010). Nowadays, many communities are attempting to exert greater control over their natural resources as well as their economic and political life (Barkin, Fuente and Rosas, 2009). It is central to remember, that if inhabitants acquire a greater capacity for self-governance, their social and political organizations will be able to develop strategies to support demands for more local autonomy and productive diversification (Barkin, 2010). In other words, they will become more resilient.

Towards the resilience planners

Finally, when recommending resilience strategies, it must be considered that management strategies that strive to control disturbances excessively, for example by reducing variability to improve efficiency, can erode system's resilience, making the system increasingly susceptible to even small disturbance events that it would otherwise have been able to accommodate (Resilience Alliance 2010 p15). This effect can be seen by a small comparison between a household's behavior in La Pila and one in SLP, when water supply is missing. If the water supply is disrupted in the community, people is already to deal with the uncertainty, and they might even be prepared to respond to the challenge. However, when such disruption in resources' supply occur within more complex systems, chaos can result.

In addition, developing Systems Perspective for Urban Socio-Ecological Systems, must also be integrated in the political arena, as it is a central perspective required to understand social complexity and uncertainty.

Further Research

In order to assess the resilience of the urban metabolism, this research designed a methodology *USES Resilience Assessment based on Urban Metabolism,* based on the Resilience Assessment Framework proposed by Resilience Alliance (2010) was reviewed and adapted in order to make it suitable for the research purposes. By learning and improving this framework, it could be possible to understand better the resilience of other USES through the study of their Urban Metabolism.

Moreover, further research can attempt to quantify inflows getting into other sub-systems within La Pila, such as –schools, work places, markets, hospital and so forth-, in order to increase the databases from the community and improve the understanding of it as an USES. Consequently, this would help to improve the USES's capacity to make decisions about its management.

Future studies might attempt to identify the wastewater generated from the household's metabolism. Because, as most yards are not paved, there is a percentage of water coming naturally back into the ground through infiltration.

Another central measurement that can provide insights to the community's metabolism, and that was not taken into account when measuring resources flows, is emissions, considering emission generated due to the energy's production (before getting inside the household), and the emission generated as a result of the households' metabolism. As it is appreiated, collecting data related to electricity emissions in La Pila, can provide insight on how are fossil fuels being consumed.

Beyond concerns over the sheer magnitudes of hazards assessed within La Pila, it is central to consider that for this work complex hazards were not assessed. Remembering Key's (2018) classification for risks –simple, complicated and complex-, hazards can also be divided into the same categories, however, due to the time availability to conduct this research, the combination of hazards and the complex hazards was not assessed. Therefore, in further research concerning the USES assessed, it will be of great importance to evaluate the consequences of complicated and complex risks, especially if researches are acting in the system.

A projection of scenarios will be really helpful in this context, as they allow to have a more complete perspective of how outputs from a strategy implemented can be expected. However, vital to the development of such scenarios is to consider uncertainty, as any projection requires a model of reality, which because of their nature, are not the reality itself.

When defining the hazards to food's supply, the soil contamination, and therefore crops contamination, was mention as a hazard that requires a better understanding of the agricultural dynamics, as well as the industrial activities, that are currently taking place in MZSLP. It will be important for further researches to analyze what is happening in this field, and also identify if the soil in which La Pila is located, exhibits negative effects caused by the industrial activities. Additionally, hazards to the food system can arise related to the use of pesticides, possible contamination of Hg because of mining practices in the past, and therefore contaminated crops. However, as this research did not focus on those hazards, it is highly recommended to integrate such data in further research.

In this research, it was observable that some strategies are already being implemented from a transformation perspective, in which the external actors are steering the system in a managerial hard systems perspective, opposite to the complex adaptive systems' resilience conceptualization. In this context it, will be important to review, if external actors could participate in the community's change triggering from a transformative, not detach manner, or enhance this ability in the community's inhabitants.

Appendices

"Let's face it, the universe is messy. It is nonlinear, turbulent, and chaotic. It is dynamic. It spends its time in transient behavior on its way to somewhere else, not in mathematically neat equilibria. It self-organizes and evolves. It creates diversity, not uniformity. That's what makes the world interesting, that's what makes it beautiful, and that's what makes it work."

(Meadows, 2008)

Appendix A: Theoretical Framework

A.1. A Hazards Literature Review

N	Author	Year	Hazards Category	Hazards	Reference
1	Asian Development Bank	2013	**Natural Hazards & Climate Change Hazards**	-Hydro-meteorological -Floods -Cyclones -Storm surges -Droughts -Geophysical -Earthquakes -Volcanic eruptions -Tsunamis	(Asian Development Bank, 2013)
2	Romeo-Lankao & Gnatz	2013			(Romero-Lankao and Gnatz, 2013)
3	Vuille et al.	2018			(Vuille *et al.*, 2018)
4	Lavorel et al.	2017			(Lavorel *et al.*, 2017)
5	Jiang et al.	2018			(Jiang, Zevenbergen and Ma, 2018)
6	DeFries et al.	2016			(DeFries *et al.*, 2016)
7	Middleton & Sternberg	2013		Climate change Hazards -Direct -Indirect	(Middleton and Sternberg, 2013)
8	Wagner & Breil	2013	**Multi-dimensional Hazards**	-Ecological Hazards -Economic Hazards -Social Hazards	(Wagner and Breil, 2013)
9	Bevacqua et al.	2018			(Bevacqua, Yu and Zhang, 2018)
10	Adriana Gracia et al.	2017			(Adriana Gracia *et al.*, 2017)
11	Mochizuki	2014			(Mochizuki *et al.*, 2014)
12	Sharifi & Yamagata	2016			(Sharifi and Yamagata, 2016)
13	Kenny	2017		-Natural Hazards -Social (Anthropogenic or man-made) Hazards	(Kenny, 2017)
14	Kita	2017			(Kita, 2017)
15	Sonwa	2012			(Sonwa *et al.*, 2012)
16	Romero-Lankao & Dodman	2011			(Romero-Lankao and Dodman, 2011)
17	Faivre et al.	2017			(Faivre *et al.*, 2017)
18	Elliot et al.	2014			(Elliott, Cutts and Trono, 2014)
19	Úbeda et al.	2016			(Úbeda and Sarricolea, 2016)
20	Renaud et al.	2013			(Renaud *et al.*, 2013)
21	McBean & Ajibade	2009			(McBean and Ajibade, 2009)
22	Vastag	1996		-Endogenous Environmental Hazards -Exogenous Environmental Hazards	(Vastag G, 1996)
23	Bhowmik et al.	2017			(Bhowmik *et al.*, 2017)
24	Michael et al.	2014		Sustainability-based -Ecological Hazards -Economic Hazards -Social Hazards	(Michael, Noor and Figueroa, 2014)
25	Nazari et al.	2015		Vulnerability-based	(Nazari *et al.*, 2015)
26	Burg	2008			(Burg, 2008)

27	Deressa	2010			(Deressa, 2010)
28	Nazari et al.	2015	**Complex Hazards**	-Shocks (sudden) -Stresses (chronical)	(Nazari *et al.*, 2015)
29	Turner et al.	2003			(Turner *et al.*, 2003)
30	Juan-García et al.	2017			(Juan-García *et al.*, 2017)
31	Boyd & Juhola	2015			(Boyd and Juhola, 2015)
32	Romero-Lankao & Qin	2011			(Romero Lankao and Qin, 2011)
33	Spaans & Waterhout	2017			(Spaans and Waterhout, 2017)
34	Ziervogel	2017			(Ziervogel *et al.*, 2017)
35	Harvey	1989			(D Harvey, 1989)
36	Fraser et al.	2017			(Fraser *et al.*, 2017)
37	Crowe et al.	2016	**Uncertainty-based Hazards**	Uncertainty-based Hazards	(Crowe, Foley and Collier, 2016)
38	Tatebe & Mutch	2015			(Tatebe and Mutch, 2015)
39	Faivre et al.	2017		Emerging Hazards	(Faivre *et al.*, 2017)
40	Bonaiuto	2016	**People's Perception of Hazards**	-Local -Global	(Bonaiuto *et al.*, 2016)

Table A.1. *Hazards' categories. Source: Based on the literature review.*

Appendix B: Methodological Framework

B.1. The Resilience Index from Rockefeller Foundation: Indicators.

The Resilience Index: Indicators			
Goals		Indicators	
1	**Minimal human vulnerability**	**1.1**	Safe and affordable housing
		1.2	Adequate affordable energy supply
		1.3	Inclusive access to safe drinking water
		1.4	Effective sanitation
		1.5	Sufficient affordable food supply
2	**Diverse livelihoods and employment**	**2.1**	Inclusive labour policies
		2.2	Relevant skills and training
		2.3	Dynamic local business development and innovation
		2.4	Supportive financing mechanisms
		2.5	Diverse protection of livelihoods following a shock
3	**Effective safeguards to human health and life**	**3.1**	Robust public health systems
		3.2	Adequate access to quality healthcare
		3.3	Emergency medical care
		3.4	Effective emergency response services
4	**Collective identity and community support**	**4.1**	Local community support
		4.2	Cohesive communities
		4.3	Strong city-wide identity and culture
		4.4	Actively engaged citizens
5	**Comprehensive security and rule of law**	**5.1**	Effective systems to deter crime
		5.2	Proactive corruption prevention
		5.3	Competent policing
		5.4	Accessible criminal and civil justice
6	**Sustainable economy**	**6.1**	Well-managed public finances
		6.2	Comprehensive business continuity planning
		6.3	Diverse economic base
		6.4	Attractive business environment
		6.5	Strong integration with regional and global economies
7	**Reduced exposure and fragility**	**7.1**	Comprehensive hazard and exposure mapping
		7.2	Appropriate codes, standards and enforcement
		7.3	Effectively managed protective ecosystems
		7.4	Robust protective infrastructure
8	**Effective provision of critical services**	**8.1**	Effective stewardship of ecosystems
		8.2	Flexible infrastructure services
		8.3	Retained spare capacity
		8.4	Diligent maintenance and continuity
		8.5	Adequate continuity for critical assets and services
9	**Reliable mobility and communications**	**9.1**	Diverse and affordable transport networks
		9.2	Effective transport operation & maintenance
		9..3	Reliable communications technology
		9.4	Secure technology networks

10	**Effective leadership and management**	**10.1**	Appropriate government decision-making
		10.2	Effective co-ordination with other government bodies
		10.3	Proactive multi-stakeholder collaboration
		10.4	Comprehensive hazard monitoring and risk assessment
		10.5	Comprehensive government emergency management
11	**Empowered stakeholders**	**11.1**	Adequate education for all
		11.2	Widespread community awareness and preparedness
		11.3	Effective mechanisms for communities to engage with government
12	**Integrated development planning Indicators**	**12.1**	Comprehensive city monitoring and data management
		12.2	Consultative planning process
		12.3	Appropriate land use and zoning
		12.4	Robust planning approval process

Table B.1. *The Resilience Index: Indicators. Source: Taken from the City Resilience Index* (The Rockefeller Foundation and ARUP, 2015b)

B.2. Interview Questionnaire

UASLP Universidad Autónoma de San Luis Potosí | FACULTAD DE INGENIERÍA

Modelo de sostenibilidad para la gobernanza de comunidades vulnerables

ENCUESTA FLUJOS METABOLICOS EN LA VIVIENDA, MODO DE VIDA Y BIENESTAR EN LA COMUNIDAD "LA PILA" 2018*

A. CARACTERÍSTICAS DEL HOGAR

Nombre entrevistador: Fecha:

1. Identificación.

Nombre del encuestado:____

Grado Académico: Edad:

2. Composición de la familia. ¿Cuántos integrantes tiene su familia?

No	Parentesco (Respecto a la cabeza de familia)	Sexo	Edad	Actividades a las que se dedica (% de dedicación) (horas por día)		Apoyo gubernamental (¿cuál?, ¿desde cuándo?)
				Principales	Secundarias	
1 cabeza						
2						
3						
4						
5						
6						

3. Migración

3.1. Migración prolongada

No	Parentesco (Respecto a la cabeza de familia)	Sexo	Edad	Nivel de escolaridad	Actividades que realiza	Aportes al hogar	Tiempo que lleva por fuera del hogar[1]	Tiene planes de regresar pronto al hogar? Por qué?
						En dinero al año ($)		
1								
2								
3								

[1]en referencia al hogar entrevistado

1

Fig. B.1. Interview Questions: Page 1/6.

UASLP Universidad Autónoma de San Luis Potosí | FACULTAD DE INGENIERÍA

Modelo de sostenibilidad para la gobernanza de comunidades vulnerables

ENCUESTA FLUJOS METABOLICOS EN LA VIVIENDA, MODO DE VIDA Y BIENESTAR EN LA COMUNIDAD "LA PILA" 2018*

3.2. Migración temporal (miembros de la familia que viven la mayor parte de su tiempo en la casa pero que suelen ausentarse del hogar – favor seguir el orden del cuadro "composición de la familia").

No	Tiempo al año que suele ausentarse (meses)	Actividades que realiza en dicho tiempo	Ingresos que obtiene durante este período ($)[1]	% del ingreso que aporta al hogar	Tipo de inversiones que realiza con el dinero que obtiene[2]
1					
2					
3					

[1] en referencia al período de migración

[2] en referencia al dinero obtenido por las actividades que realiza durante la migración

3.3. ¿Hay remesas?____

4. Condiciones de la vivienda

Vivienda ¿propia o rentada? __________ Número de habitaciones (con persona) __________

Área de la vivienda (m^2) __________ ¿Cuántos baños tiene? __________

Descripción	**Material**	**Acceso a servicios**	**Descripción**
Cubierta (techo)		¿Qué fuente de energía emplea para cocinar?	
Paredes			
Piso		Poseen transporte propio?	
Acceso a servicios básicos	**Descripción**		
Agua		Medios de comunicación[6]	
Energía eléctrica			
Saneamiento/Drainage			

[6] Describir medios telefónicos (fijos y móviles), internet, uso de correo electrónico

2

Fig. B.2. *Interview Questions: Page 2/6.*

UASLP Universidad Autónoma de San Luis Potosí | FACULTAD DE INGENIERÍA

Modelo de sostenibilidad para la gobernanza de comunidades vulnerables

ENCUESTA FLUJOS METABOLICOS EN LA VIVIENDA, MODO DE VIDA Y BIENESTAR EN LA COMUNIDAD "LA PILA" 2018*

B. ECONÓMICO

5. ¿En qué gasta su dinero? (Por ciento)

¿Qué porcentaje de su dinero gasta en…?	
Alimento	
Educación	
Tiempo libre	
Renta	
Salud	
Transporte	
Energía/Luz/Gas	
Agua	

6. ¿En qué le gustaría gastar más?____

7. ¿Observó un aumento de precios?____

8. ¿Desde cuándo? ¿Tuvo un impacto?____

C. SALUD

9. ¿Tiene un seguro social? Sí___ No___

10. ¿Cómo evaluas tu salud? (entre 1-5) (Ware, 1992).

5) Excelente
4) Muy bien
3) Bien
2) Más o menos
1) Mal

11. ¿Qué haces para mejorar tu salud? (alimentación, deporte etc.)______________________

12. ¿Qué estarías dispuesto a hacer para mejorar tu salud?____________________________

D. TRABAJO Y VIDA

13. ¿Ves una diferencia en el trabajo de mujer y hombre?

14. En tu casa: ¿Cuánto tiempo trabaja la mujer afuera de la casa?

15. ¿Hay periodos de desempleo? ¿Cuánto tiempo duran?

16. ¿Cuánto tiempo libre tienes?

17. ¿Qué haces en tu tiempo libre?

E. CONEXIONES SOCIALES

18. En la Pila, ¿Hay buenas relaciones sociales?

19. ¿Tienes amigos en la Pila? ¿Cuántas veces a la semana los ves?

20. ¿Consideras que hay corrupción en La Pila?

21. ¿Hay vandalismo en La Pila?

3

Fig. B.3. *Interview Questions: Page 3/6.*

UASLP Universidad Autónoma de San Luis Potosí | FACULTAD DE INGENIERÍA | Cummins

Modelo de sostenibilidad para la gobernanza de comunidades vulnerables

ENCUESTA FLUJOS METABOLICOS EN LA VIVIENDA, MODO DE VIDA Y BIENESTAR EN LA COMUNIDAD "LA PILA" 2018*

F. POLÍTICA Y GOBERNANZA

22. ¿Tienes la posibilidad de participar en la toma de decisiones en la comunidad/escuela?

G. AMBIENTE

23. ¿Tienes accesso a agua y energía?
- Garantizado
- interrumpido

24. ¿Cómo consideras la calidad del agua? ¿y del aire? (mala, buena)

25. ¿Observaste un cambio?

H. EMOCIÓN

26. ¿Te sientes seguro?

27. ¿Te consideras feliz? (Diener, 1984)

3) Muy feliz 2) feliz 1) nada feliz

I. CONSUMO DE AGUA

28. ¿Tiene abastecimiento regular de agua? ¿Hay tandeos?

29. ¿Qué hace cuándo no hay agua?

30. ¿De dónde proviene el agua para beber? ¿Garrafones o de la llave? (Si es de la llave, ¿se hierve?)

31. ¿Cuántos garrafones de agua consume a la semana?

32. ¿Cuántas veces a la semana se baña?

33. ¿Cuántas veces al día se lava los dientes? ¿De dónde proviene el agua? ¿Llave/garrafón?

34. ¿Dónde lava los trastes?

35. ¿Cuánto dinero/litros de agua gasta al bimestre?

36. ¿Considera que el agua es cara?

37. ¿Capta el agua de lluvia? ¿Por medio de qué sistema? ¿Cuántas veces?

38. ¿Recicla el agua?

39. ¿Tiene o ha tenido problemas con el drenaje?

40. ¿Su casa se inunda cuando llueve?

4

Fig. B.4. *Interview Questions: Page 4/6.*

UASLP Universidad Autónoma de San Luis Potosí | FACULTAD DE INGENIERÍA

Modelo de sostenibilidad para la gobernanza de comunidades vulnerables

ENCUESTA FLUJOS METABOLICOS EN LA VIVIENDA, MODO DE VIDA Y BIENESTAR EN LA COMUNIDAD "LA PILA" 2018*

J. CONSUMO DE ELECTRICIDAD

41. ¿Cuántos focos tiene en la casa?

42. ¿Cuántas horas al día utiliza la luz eléctrica (durante el día/noche/ambos)?

43. ¿Tiene computadoras, refrigerador, televisor, radio, horno microondas, etc.? ¿Cuántos?

44. ¿Considera que la luz es cara?

K. CONSUMO DE GAS

45. ¿Utiliza gas para cocinar?

46. ¿Utiliza gas para calentar agua para bañarse?

47. Tiene ¿tanque estacionario, tanques de gas o gas natural?

48. ¿Cada cuánto se abastece de gas?

49. ¿Cuánto dinero invierte en gas al mes/bimestre?

50. ¿Considera que el gas es caro?

L. CONSUMO DE ALIMENTOS

51. ¿Dónde compra sus alimentos? ¿Mercado, tienda de abarrotes o supermercado?

52. ¿Cuáles son las frutas que más consume?

53. ¿Cuáles son las verduras que más consume?

54. ¿Cuántas veces a la semana consume carne? ¿Qué porción?

55. ¿A qué hora come y qué come?

M. DISPOSICIÓN DE RESIDUOS

56. ¿Tiene un sistema de reciclaje en la vivienda?

57. ¿Separa la basura? ¿Cómo?

58. ¿Dónde deposita la basura? ¿Hay contenedores en la calle o hay un sistema de recolección?

59. ¿Cada cuántos días pasan a recoger la basura?

60. ¿Tiene desperdicios? ¿Qué hace con la basura orgánica?

5

Fig. B. 5. *Interview Questions: Page 5/6.*

UASLP Universidad Autónoma de San Luis Potosí | FACULTAD DE INGENIERÍA

Modelo de sostenibilidad para la gobernanza de comunidades vulnerables

ENCUESTA FLUJOS METABOLICOS EN LA VIVIENDA, MODO DE VIDA Y BIENESTAR EN LA COMUNIDAD "LA PILA" 2018*

N. TRANSPORTE

61. ¿Posee un vehículo privado?

62. ¿Tiene un seguro contra accidentes?

63. ¿Para qué lo utiliza? ¿Cuántas veces a la semana utiliza el vehículo y qué distancia recorre? (Dentro de la comunidad o para ir a SLP)

64. ¿Cuántas veces a la semana recarga gasolina? ¿Cuánto dinero invierte en gasolina a la semana?

65. ¿Cuántas veces a la semana lava su vehículo? ¿Dónde? ¿Cubeta o manguera?

66. Si no posee un vehículo, ¿Le gustaría tenerlo?

67. ¿Utiliza el transporte público? ¿Cuántas veces a la semana utiliza el vehículo y qué distancia recorre? (Dentro de la comunidad o para ir a SLP)

68. ¿Cuánto gastas en transporte público por día? ¿Cuántos camiones utilizas por día?

Acuerdo de confidencialidad

- Yo____ estoy de acuerdo en que la información recabada en esta entrevista sea utilizada para fines de investigación.
- Acuerdo de confidencialidad: La Universidad Autónoma de San Luis Potosí (UASLP) se compromete utilizar la información para fines de investigación cientifica y siempre mantener la información personal reservada.

____

Fecha, Firma

6

Fig. B.6. *Interview Questions: Page 6/6.*

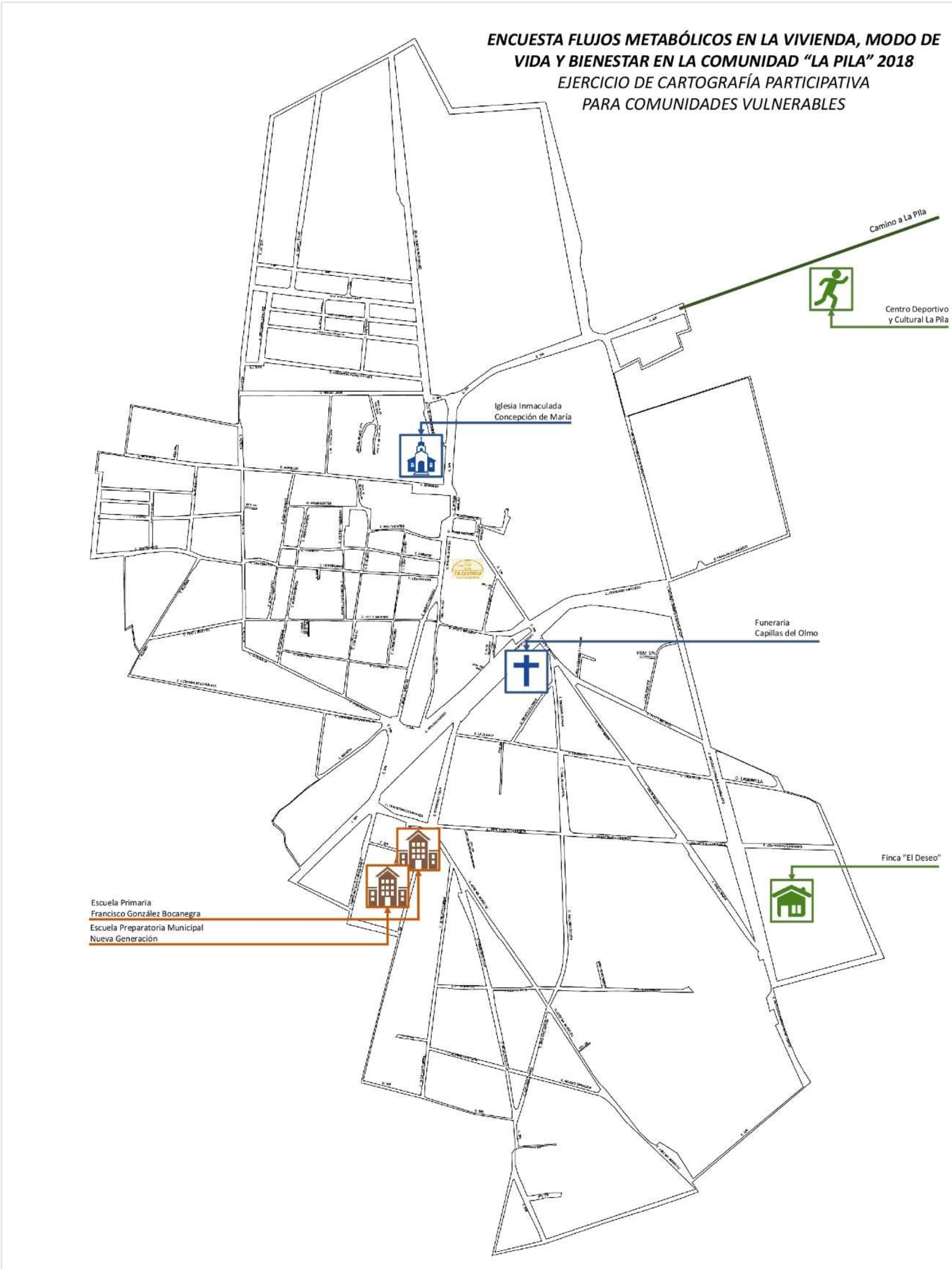


Fig. B. 7. *Participatory Mapping "La Pila". Page 1/1. Source: Based on INEGI databases* (INEGI, 2018).

Appendix C: Metabolism of Households in La Pila

C.1. Tap Water in Households and per capita

WATER IN HOUSEHOLDS: ESTIMATED WATER CONSUMPTION PER HOUSEHOLD IN LA PILA (L.)							
N	Money spent in Water every two months	Money spent in Water monthly	Cost per liter	M^3 spent every two months	M^3 spent per month	Liters spent every two months	Liters spent per month
	MXN	MXN	MXN	M^3	M^3	L	L
1	20.00	10.00	5.00	4.00	2.00	4,000.00	2,000.00
2	40.00	20.00	5.00	8.00	4.00	8,000.00	4,000.00
3	40.00	20.00	5.00	8.00	4.00	8,000.00	4,000.00
4	50.00	25.00	5.00	10.00	5.00	10,000.00	5,000.00
5	70.00	35.00	5.00	14.00	7.00	14,000.00	7,000.00
6	80.00	40.00	5.00	16.00	8.00	16,000.00	8,000.00
7	100.00	50.00	7.50	13.33	6.67	13,333.33	6,666.67
8	120.00	60.00	7.50	16.00	8.00	16,000.00	8,000.00
9	120.00	60.00	7.50	16.00	8.00	16,000.00	8,000.00
10	120.00	60.00	7.50	16.00	8.00	16,000.00	8,000.00
11	140.00	70.00	7.50	18.67	9.33	18,666.67	9,333.33
12	150.00	75.00	7.50	20.00	10.00	20,000.00	10,000.00
13	150.00	75.00	7.50	20.00	10.00	20,000.00	10,000.00
14	150.00	75.00	7.50	20.00	10.00	20,000.00	10,000.00
15	150.00	75.00	7.50	20.00	10.00	20,000.00	10,000.00
16	152.00	76.00	10.00	15.20	7.60	15,200.00	7,600.00
17	153.00	76.50	10.00	15.30	7.65	15,300.00	7,650.00
18	153.00	76.50	17.50	8.74	4.37	8,742.86	4,371.43
19	175.00	87.50	5.00	35.00	17.50	35,000.00	17,500.00
20	175.00	87.50	5.00	35.00	17.50	35,000.00	17,500.00
21	175.00	87.50	5.00	35.00	17.50	35,000.00	17,500.00
22	180.00	90.00	7.50	24.00	12.00	24,000.00	12,000.00
23	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
24	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
25	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
26	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
27	200.00	100.00	7.50	28.57	14.29	28,571.43	14,285.71
28	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
29	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
30	200.00	100.00	10.00	20.00	10.00	20,000.00	10,000.00
31	201.00	100.50	15.00	13.40	6.70	13,400.00	6,700.00
32	205.00	102.50	5.00	41.00	20.50	41,000.00	20,500.00
33	230.00	115.00	5.00	46.00	23.00	46,000.00	23,000.00
34	230.00	115.00	5.00	46.00	23.00	46,000.00	23,000.00
35	250.00	125.00	5.00	50.00	25.00	50,000.00	25,000.00
36	260.00	130.00	5.00	52.00	26.00	52,000.00	26,000.00
37	350.00	175.00	5.00	70.00	35.00	70,000.00	35,000.00
38	600.00	300.00	5.00	120.00	60.00	120,000.00	60,000.00
39	700.00	350.00	5.00	140.00	70.00	140,000.00	70,000.00
40	1,920.00	960.00	7.50	256.00	128.00	256,000.00	128,000.00
Average	**230.23**	**115.11**	**7.05**	**35.78**	**17.89**	**35,780.36**	**17,890.18**
Median	**175.00**	**87.50**	**7.50**	**22.00**	**11.00**	**22,000.00**	**11,000.00**

Table C.1. *Water in Households: Estimated Water Consumption per Household in La Pila (L.).*

WATER IN HOUSEHOLDS: ESTIMATED WATER CONSUMPTION IN TYPE A HOUSEHOLDS (L.)							
N	Money spent in Water every two months	Money spent in Water monthly	Cost per liter	M³ spent every two months	M³ spent per month	Liters spent every two months	Liters spent per month
	MXN	MXN	MXN	M³	M³	L	L
1	40.00	20.00	5.00	8.00	4.00	8,000.00	4,000.00
2	40.00	20.00	5.00	8.00	4.00	8,000.00	4,000.00
3	70.00	35.00	5.00	14.00	7.00	14,000.00	7,000.00
4	80.00	40.00	5.00	16.00	8.00	16,000.00	8,000.00
5	100.00	50.00	5.00	20.00	10.00	20,000.00	10,000.00
6	120.00	60.00	5.00	24.00	12.00	24,000.00	12,000.00
7	150.00	75.00	7.50	20.00	10.00	20,000.00	10,000.00
8	150.00	75.00	7.50	20.00	10.00	20,000.00	10,000.00
9	175.00	87.50	7.50	23.33	11.67	23,333.33	11,666.67
10	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
11	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
12	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
13	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
14	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
15	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
16	260.00	130.00	10.00	26.00	13.00	26,000.00	13,000.00
17	600.00	300.00	10.00	60.00	30.00	60,000.00	30,000.00
18	1,920.00	960.00	17.50	109.71	54.86	109,714.29	54,857.14
Average	**272.50**	**136.25**	**7.50**	**28.28**	**14.14**	**28,280.42**	**14,140.21**
Median	**187.50**	**93.75**	**7.50**	**25.00**	**12.50**	**25,000.00**	**12,500.00**

Table C.2. *Water in Households: Estimated Water Consumption in Type A Households in La Pila (L.).*

WATER IN HOUSEHOLDS: ESTIMATED WATER CONSUMPTION IN TYPE B HOUSEHOLDS (L.)							
N	Money spent in Water every two months	Money spent in Water monthly	Cost per liter	M³ spent every two months	M³ spent per month	Liters spent every two months	Liters spent per month
	MXN	MXN	MXN	M³	M³	L	L
1	20.00	10.00	5.00	4.00	2.00	4,000.00	2,000.00
2	120.00	60.00	5.00	24.00	12.00	24,000.00	12,000.00
3	120.00	60.00	5.00	24.00	12.00	24,000.00	12,000.00
4	140.00	70.00	7.50	18.67	9.33	18,666.67	9,333.33
5	150.00	75.00	7.50	20.00	10.00	20,000.00	10,000.00
6	175.00	87.50	7.50	23.33	11.67	23,333.33	11,666.67
7	175.00	87.50	7.50	23.33	11.67	23,333.33	11,666.67
8	180.00	90.00	7.50	24.00	12.00	24,000.00	12,000.00
9	200.00	100.00	7.00	28.57	14.29	28,571.43	14,285.71
10	200.00	100.00	7.50	26.67	13.33	26,666.67	13,333.33
11	205.00	102.50	7.50	27.33	13.67	27,333.33	13,666.67
12	230.00	115.00	10.00	23.00	11.50	23,000.00	11,500.00
13	700.00	350.00	15.00	46.67	23.33	46,666.67	23,333.33
Average	**201.15**	**100.58**	**7.65**	**24.12**	**12.06**	**24,120.88**	**12,060.4**
Median	**175.00**	**87.50**	**7.50**	**24.00**	**12.00**	**24,000.00**	**12,000.0**

Table C.3. *Water in Households: Estimated Water Consumption in Type B Households in La Pila (L.).*

WATER IN HOUSEHOLDS: ESTIMATED WATER CONSUMPTION IN TYPE C HOUSEHOLDS (L.)							
N	**Money spent in Water every two months**	**Money spent in Water monthly**	**Cost per liter**	**M^3 spent every two months**	**M^3 spent per month**	**Liters spent every two months**	**Liters spent per month**
	MXN	**MXN**	**MXN**	**M^3**	**M^3**	**L.**	**L.**
1	50.00	25.00	5.00	10.00	5.00	10,000.00	5,000.00
2	150.00	75.00	5.00	30.00	15.00	30,000.00	15,000.00
3	152.00	76.00	5.00	30.40	15.20	30,400.00	15,200.00
4	153.00	76.50	5.00	30.60	15.30	30,600.00	15,300.00
5	153.00	76.50	5.00	30.60	15.30	30,600.00	15,300.00
6	201.00	100.50	5.00	40.20	20.10	40,200.00	20,100.00
7	230.00	115.00	5.00	46.00	23.00	46,000.00	23,000.00
8	250.00	125.00	5.00	50.00	25.00	50,000.00	25,000.00
9	350.00	175.00	7.50	46.67	23.33	46,666.67	23,333.33
Average	**187.67**	**93.83**	**5.28**	**34.94**	**17.47**	**34,940.70**	**17,470.37**
Median	**153.00**	**76.50**	**5.00**	**30.60**	**15.30**	**30,600.00**	**15,300.00**

Table C.4. *Water in Households: Estimated Water Consumption in Type C Households in La Pila (L.).*

ESTIMATED WATER CONSUMPTION PER CAPITA PER HOUSEHOLD IN LA PILA (L.)			
N	**Water spent monthly**	**Inhabitants in this Household**	**Water spent per Capita**
	L.	**U.**	**L.**
1	2,000.00	5	400.00
2	5,000.00	6	833.33
3	4,000.00	4	1,000.00
4	4,000.00	4	1,000.00
5	9,333.33	5	1,866.67
6	8,000.00	4	2,000.00
7	10,000.00	5	2,000.00
8	15,200.00	7	2,171.43
9	20,100.00	9	2,233.33
10	11,500.00	5	2,300.00
11	11,666.67	5	2,333.33
12	11,666.67	5	2,333.33
13	7,000.00	3	2,333.33
14	12,000.00	5	2,400.00
15	12,000.00	5	2,400.00
16	12,000.00	5	2,400.00
17	10,000.00	4	2,500.00
18	10,000.00	4	2,500.00
19	10,000.00	4	2,500.00
20	15,000.00	6	2,500.00
21	15,300.00	6	2,550.00
22	15,300.00	6	2,550.00
23	13,333.33	5	2,666.67
24	13,666.67	5	2,733.33
25	14,285.71	5	2,857.14
26	11,666.67	4	2,916.67
27	12,000.00	4	3,000.00
28	25,000.00	8	3,125.00
29	13,333.33	4	3,333.33
30	13,333.33	4	3,333.33
31	13,333.33	4	3,333.33
32	13,333.33	4	3,333.33
33	13,333.33	4	3,333.33
34	23,000.00	6	3,833.33
35	23,333.33	6	3,888.89
36	13,000.00	3	4,333.33
37	13,333.33	3	4,444.44
38	23,333.33	5	4,666.67
39	30,000.00	3	10,000.00
40	54,857.14	4	13,714.29
Average	**14,213.57**		**3,098.78**
Median	**13,333.33**		**2,525.00**

Table C.5. *Estimated Water Consumption per Capita per Household in La Pila (L.).*

ESTIMATED WATER CONSUMPTION PER CAPITA IN TYPE A HOUSEHOLDS (L.)			
N	Water spent monthly	Inhabitants in this Household	Water spent per Capita
	L.	U.	L.
1	4,000.00	4	1,000.00
2	4,000.00	4	1,000.00
3	7,000.00	3	2,333.33
4	8,000.00	4	2,000.00
5	10,000.00	4	2,500.00
6	12,000.00	4	3,000.00
7	10,000.00	4	2,500.00
8	10,000.00	4	2,500.00
9	11,666.67	4	2,916.67
10	13,333.33	3	4,444.44
11	13,333.33	4	3,333.33
12	13,333.33	4	3,333.33
13	13,333.33	4	3,333.33
14	13,333.33	4	3,333.33
15	13,333.33	4	3,333.33
16	13,000.00	3	4,333.33
17	30,000.00	3	10,000.00
18	54,857.14	4	13,714.29
Average	**14,140.21**		**3,828.26**
Median	**12,500.00**		**3,166.67**

Table C.6. *Estimated Water Consumption per Capita in Type A Households (L.).*

ESTIMATED WATER CONSUMPTION PER CAPITA IN TYPE B HOUSEHOLDS (L.)			
N	Water spent monthly (L.)	Inhabitants in this Household	Water spent per Capita (L.)
	L.	U.	L.
1	2,000.00	5	400.00
2	12,000.00	5	2,400.00
3	12,000.00	5	2,400.00
4	9,333.33	5	1,866.67
5	10,000.00	5	2,000.00
6	11,666.67	5	2,333.33
7	11,666.67	5	2,333.33
8	12,000.00	5	2,400.00
9	14,285.71	5	2,857.14
10	13,333.33	5	2,666.67
11	13,666.67	5	2,733.33
12	11,500.00	5	2,300.00
13	23,333.33	5	4,666.67
Average	**12,060.44**		**2,412.09**
Median	**12,000.00**		**2,400.00**

Table C.7. *Estimated Water Consumption per Capita in Type B Households (L.).*

ESTIMATED WATER CONSUMPTION PER CAPITA IN TYPE C HOUSEHOLDS (L.)			
N	**Water spent monthly (L.)**	**Inhabitants in this Household**	**Water spent per Capita (L.)**
1	5,000.00	6	833.33
2	15,000.00	6	2,500.00
3	15,200.00	7	2,171.43
4	15,300.00	6	2,550.00
5	15,300.00	6	2,550.00
6	20,100.00	9	2,233.33
7	23,000.00	6	3,833.33
8	25,000.00	8	3,125.00
9	23,333.33	6	3,888.89
Average	**17,470.37**		**2,631.70**
Median	**15,300.00**		**2,550.00**

Table C.8. *Estimated Water Consumption per Capita in Type C Households (L.).*

C.2. Bottled Water in Households and per capita

ESTIMATED BOTTLED WATER CONSUMPTION PER CAPITA PER HOUSEHOLD IN LA PILA (L.)									
N	Weekly Bottled Water Consumption			Monthly Bottled Water Consumption			Inhabitants in this household	Monthly expenditure per capita	
	Carboys	L.	MXN	Carboys	Liters	MXN	U.	L.	MXN
1	0	0	-	0	0	-	3	0	-
2	0	0	-	0	0	-	5	0	-
3	0	0	-	0	0	-	5	0	-
4	0	0	-	0	0	-	5	0	-
5	0	0	-	0	0	-	6	0	-
6	0	0	-	0	0	-	6	0	-
7	0	0	-	0	0	-	9	0	-
8	1	19	20.00	4	76	80.00	3	19	26.67
9	1	19	20.00	4	76	80.00	4	19	20.00
10	1	19	20.00	4	76	80.00	4	19	20.00
11	1	19	20.00	4	76	80.00	4	19	20.00
12	1	19	20.00	4	76	80.00	6	19	13.33
13	1	19	20.00	4	76	80.00	7	19	11.43
14	2	38	40.00	8	152	160.00	3	38	53.33
15	2	38	40.00	8	152	160.00	4	38	40.00
16	2	38	40.00	8	152	160.00	4	38	40.00
17	2	38	40.00	8	152	160.00	4	38	40.00
18	2	38	40.00	8	152	160.00	4	38	40.00
19	2	38	40.00	8	152	160.00	4	38	40.00
20	2	38	40.00	8	152	160.00	5	38	32.00
21	2	38	40.00	8	152	160.00	5	38	32.00
22	2	38	40.00	8	152	160.00	5	38	32.00
23	2	38	40.00	8	152	160.00	5	38	32.00
24	2	38	40.00	8	152	160.00	5	38	32.00
25	2	38	40.00	8	152	160.00	5	38	32.00
26	2	38	40.00	8	152	160.00	6	38	26.67
27	3	57	60.00	12	228	240.00	3	57	80.00
28	3	57	60.00	12	228	240.00	4	57	60.00
29	3	57	60.00	12	228	240.00	4	57	60.00
30	3	57	60.00	12	228	240.00	4	57	60.00
31	3	57	60.00	12	228	240.00	4	57	60.00
32	3	57	60.00	12	228	240.00	4	57	60.00
33	3	57	60.00	12	228	240.00	4	57	60.00
34	3	57	60.00	12	228	240.00	5	57	48.00
35	3	57	60.00	12	228	240.00	5	57	48.00
36	3	57	60.00	12	228	240.00	6	57	40.00
37	4	76	80.00	16	304	320.00	5	76	64.00
38	5	95	100.00	20	380	400.00	5	95	80.00
39	5	95	100.00	20	380	400.00	8	95	50.00
40	10	190	200.00	40	760	800.00	6	190	133.33
Average	**2**	**41**	**43.00**	**9**	**163**	**172.00**		**41**	**37.17**
Median	**2**	**38**	**40.00**	**8**	**152**	**160.00**		**38**	**36.00**

Table C.9. *Estimated Bottled Water Consumption per Capita per Household in La Pila (L.).*

ESTIMATED BOTTLED WATER CONSUMPTION PER CAPITA IN TYPE A HOUSEHOLDS (L.)									
N	Weekly Bottled Water Consumption			Monthly Bottled Water Consumption			Inhabitants in this household	Monthly expenditure per capita	
	Carboys	L.	MXN	Carboys	Liters	MXN	U.	L	MXN
1	2	38	40.00	8	152	160.00	3	38	53.33
2	3	57	60.00	12	228	240.00	3	57	80.00
3	0	0	-	0	0	-	3	0	-
4	1	19	20.00	4	76	80.00	3	19	26.67
5	1	19	20.00	4	76	80.00	4	19	20.00
6	1	19	20.00	4	76	80.00	4	19	20.00
7	2	38	40.00	8	152	160.00	4	38	40.00
8	3	57	60.00	12	228	240.00	4	57	60.00
9	3	57	60.00	12	228	240.00	4	57	60.00
10	3	57	60.00	12	228	240.00	4	57	60.00
11	1	19	20.00	4	76	80.00	4	19	20.00
12	3	57	60.00	12	228	240.00	4	57	60.00
13	2	38	40.00	8	152	160.00	4	38	40.00
14	2	38	40.00	8	152	160.00	4	38	40.00
15	3	57	60.00	12	228	240.00	4	57	60.00
16	2	38	40.00	8	152	160.00	4	38	40.00
17	2	38	40.00	8	152	160.00	4	38	40.00
18	3	57	60.00	12	228	240.00	4	57	60.00
Average	**2**	**39**	**41.11**	**8**	**156**	**164.44**		**39**	**43.33**
Median	**2**	**38**	**40.00**	**8**	**152**	**160.00**		**38**	**40.00**

Table C.10. *Estimated Bottled Water Consumption per Capita in Type A Households (L.).*

ESTIMATED BOTTLED WATER CONSUMPTION PER CAPITA IN TYPE B HOUSEHOLDS (L.)									
N	Weekly Bottled Water Consumption			Monthly Bottled Water Consumption			Inhabitants in this household	Monthly expenditure per capita	
	Carboys	L.	MXN	Carboys	Liters	MXN	U.	L	MXN
1	4	76	80.00	16	304	320.00	5	76	64.00
2	0	0	-	0	0	-	5	0	-
3	5	95	100.00	20	380	400.00	5	95	80.00
4	2	38	40.00	8	152	160.00	5	38	32.00
5	3	57	60.00	12	228	240.00	5	57	48.00
6	2	38	40.00	8	152	160.00	5	38	32.00
7	2	38	40.00	8	152	160.00	5	38	32.00
8	0	0	-	0	0	-	5	0	-
9	3	57	60.00	12	228	240.00	5	57	48.00
10	2	38	40.00	8	152	160.00	5	38	32.00
11	0	0	-	0	0	-	5	0	-
12	2	38	40.00	8	152	160.00	5	38	32.00
13	2	38	40.00	8	152	160.00	5	38	32.00
Average	**2**	**39**	**41.54**	**8**	**158**	**166.15**		**39**	**33.23**
Median	**2**	**38**	**40.00**	**8**	**152**	**160.00**		**38**	**32.00**

Table C.11. *Estimated Bottled Water Consumption per Capita in Type B Households (L.).*

ESTIMATED BOTTLED WATER CONSUMPTION PER CAPITA IN TYPE C HOUSEHOLDS (L.)									
N	Weekly Bottled Water Consumption			Monthly Bottled Water Consumption			Inhabitants in this household	Monthly expenditure per capita	
	Carboys	L.	MXN	Carboys	Liters	MXN	U.	L	MXN
1	0	0	-	0	0	-	6	0	-
2	0	0	-	0	0	-	6	0	-
3	1	19	20.00	4	76	80.00	6	19	13.33
4	2	38	40.00	8	152	160.00	6	38	26.67
5	3	57	60.00	12	228	240.00	6	57	40.00
6	10	190	200.00	40	760	800.00	6	190	133.33
7	1	19	20.00	4	76	80.00	7	19	11.43
8	5	95	100.00	20	380	400.00	8	95	50.00
9	0	0	-	0	0	-	9	0	-
Average	**2**	**46**	**48.89**	**10**	**186**	**195.56**		**46**	**30.53**
Median	**1**	**19**	**20.00**	**4**	**76**	**80.00**		**19**	**13.33**

Table C.12. *Estimated Bottled Water Consumption per Capita in Type C Households (L.).*

C.3. Energy in Households

C.3.1. Gas Consumption in Households

ESTIMATED GAS CONSUMPTION PER HOUSEHOLD IN LA PILA (KG.)		
N	Money spent in Gas per month	Gas spent per month
	MXN	Kg.
1	83.33	4.10
2	87.50	4.30
3	91.67	4.51
4	100.00	4.92
5	100.00	4.92
6	100.00	4.92
7	120.00	5.90
8	125.00	6.15
9	133.33	6.56
10	140.00	6.89
11	150.00	7.38
12	150.00	7.38
13	150.00	7.38
14	150.00	7.38
15	166.67	8.20
16	173.00	8.51
17	183.33	9.02
18	193.33	9.51
19	195.00	9.59
20	200.00	9.84
21	240.00	11.80
22	265.00	13.03
23	266.67	13.11
24	270.00	13.28
25	280.00	13.77
26	287.50	14.14
27	290.00	14.26
28	290.00	14.26
29	300.00	14.75
30	300.00	14.75
31	460.00	22.62
32	480.00	23.61
33	480.00	23.61
34	555.00	27.30
35	560.00	27.54
36	570.00	28.03
37	580.00	28.52
38	580.00	28.52
39	600.00	29.51
40	800.00	39.34
Average	**281.16**	**13.82**
Median	**252.50**	**12.42**

Table C.13. *Energy in Households: Estimated Gas Consumption per Household in La Pila (Kg.).*

ESTIMATED GAS CONSUMPTION IN TYPE A HOUSEHOLDS (KG.)		
N	Money spent in Gas per month	Gas spent per month
	MXN	Kg.
1	100.00	4.92
2	100.00	4.92
3	120.00	5.90
4	125.00	6.15
5	133.33	6.56
6	150.00	7.38
7	150.00	7.38
8	173.00	8.51
9	195.00	9.59
10	240.00	11.80
11	280.00	13.77
12	287.50	14.14
13	290.00	14.26
14	300.00	14.75
15	460.00	22.62
16	555.00	27.30
17	570.00	28.03
18	800.00	39.34
Average	**279.38**	**13.74**
Median	**217.50**	**10.70**

Table C.14. *Energy in Households: Estimated Gas Consumption in Type A Households (Kg.).*

ESTIMATED GAS CONSUMPTION IN TYPE B HOUSEHOLDS (KG.)		
N	Money spent in Gas per month	Gas spent per month
	MXN	Kg.
1	83.33	4.10
2	87.50	4.30
3	91.67	4.51
4	100.00	4.92
5	140.00	6.89
6	150.00	7.38
7	166.67	8.20
8	265.00	13.03
9	266.67	13.11
10	290.00	14.26
11	300.00	14.75
12	480.00	23.61
13	480.00	23.61
Average	**223.14**	**10.97**
Median	**166.67**	**8.20**

Table C.15. *Energy in Households: Estimated Gas Consumption in Type B Households (Kg.).*

ESTIMATED GAS CONSUMPTION IN TYPE C HOUSEHOLDS (KG.)		
N	**Money spent in Gas per month**	**Gas spent per month**
	MXN	**Kg.**
1	150.00	7.38
2	183.33	9.02
3	193.33	9.51
4	200.00	9.84
5	270.00	13.28
6	560.00	27.54
7	580.00	28.52
8	580.00	28.52
9	600.00	29.51
Average	**368.52**	**18.12**
Median	**270.00**	**13.28**

Table C.16. *Energy in Households: Estimated Gas Consumption in Type C Households (Kg.).*

C.3.2. Electricity Consumption in Households

ESTIMATED ELECTRICITY CONSUMPTION PER HOUSEHOLD IN LA PILA (kWh.)										
N	Electricity Cost with Taxes	Taxes	Electricity Cost without Taxes	Basic (Up to 150 kWh)[73]	Money exceeding the Basic Fee[74]	Intermediate (Next 130 kWh)[75]	Money exceeding the Basic Fee[76]	Exceeding (Next kWh spent)[77]	Total Consumption in Two Months	Total Consumption in One Month
	MXN	MXN	MXN	kWh	MXN	kWh	MXN	kWh	kWh	kWh
1	40.00	6.40	33.60	42.37					42.37	21.19
2	60.00	9.60	50.40	63.56					63.56	31.78
3	75.00	12.00	63.00	79.45					79.45	39.72
4	75.00	12.00	63.00	79.45					79.45	39.72
5	80.00	12.80	67.20	84.74					84.74	42.37
6	85.00	13.60	71.40	90.04					90.04	45.02
7	90.00	14.40	75.60	95.33					95.33	47.67
8	90.00	14.40	75.60	95.33					95.33	47.67
9	100.00	16.00	84.00	105.93					105.93	52.96
10	100.00	16.00	84.00	105.93					105.93	52.96
11	100.00	16.00	84.00	105.93					105.93	52.96
12	100.00	16.00	84.00	105.93					105.93	52.96
13	100.00	16.00	84.00	105.93					105.93	52.96
14	115.00	18.40	96.60	121.82					121.82	60.91
15	122.00	19.52	102.48	129.23					129.23	64.62
16	150.00	24.00	126.00	150.00	7.05	7.37			157.37	78.69
17	150.00	24.00	126.00	150.00	7.05	7.37			157.37	78.69
18	150.00	24.00	126.00	150.00	7.05	7.37			157.37	78.69
19	163.00	26.08	136.92	150.00	17.97	18.80			168.80	84.40
20	163.00	26.08	136.92	150.00	17.97	18.80			168.80	84.40
21	163.00	26.08	136.92	150.00	17.97	18.80			168.80	84.40
22	163.00	26.08	136.92	150.00	17.97	18.80			168.80	84.40
23	163.00	26.08	136.92	150.00	17.97	18.80			168.80	84.40
24	175.00	28.00	147.00	150.00	28.05	29.34			179.34	89.67

[73] Calculated by dividing the Electricity Cost without Taxes by MXN 0.793, in order to get kWh spent with the Basic Fee.

[74] Electricity Cost minus MXN 118.95 for the first 150 kWh.

[75] Calculated by dividing the Money exceeding the Basic Fee by MXN 0.956, in order to get kWh spent with the Intermediate Fee.

[76] Electricity Cost minus MXN 118.95 for the first 150 kWh and minus MXN 124.28 for the next 130 kWh.

[77] Calculated by dividing the Money exceeding the Intermediate Fee by MXN 2.802, in order to get kWh spent with the Exceeding Fee.

25	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
26	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
27	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
28	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
29	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
30	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
31	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
32	200.00	32.00	168.00	150.00	49.05	51.31			201.31	100.65
33	200.00	32.00	168.00	150.00	49.05	51.31			201.31	100.65
34	300.00	48.00	252.00	150.00	133.05	130.00	8.77	3.13	283.13	141.56
35	408.00	65.28	342.72	150.00	223.77	130.00	99.49	35.51	315.51	157.75
36	408.00	65.28	342.72	150.00	223.77	130.00	99.49	35.51	315.51	157.75
37	408.00	65.28	342.72	150.00	223.77	130.00	99.49	35.51	315.51	157.75
38	435.00	69.60	365.40	150.00	246.45	130.00	122.17	43.60	323.60	161.80
39	750.00	120.00	630.00	150.00	511.05	130.00	386.77	138.03	418.03	209.02
40	1,900.00	304.00	1,596.00	150.00	1,477.05	130.00	1,352.77	482.79	762.79	381.39
		Average	**192.07**						**185.54**	**92.77**
		Median	**136.92**						**168.80**	**84.40**

Table C.17. *Estimated Electricity Consumption per Household in La Pila (kWh).*

ESTIMATED ELECTRICITY CONSUMPTION IN TYPE A HOUSEHOLDS (kWh.)										
N	**Electricity Cost with Taxes**	**Taxes**	**Electricity Cost without Taxes**	**Basic (Up to 150 kWh)[78]**	**Money exceeding the Basic Fee [79]**	**Intermediate (Next 130 kWh)[80]**	**Money exceeding the Basic Fee [81]**	**Exceeding (Next kWh spent)[82]**	**Total Consumption in Two Months**	**Total Consumption in One Month**
	MXN	**MXN**	**MXN**	**kWh**	**MXN**	**kWh**	**MXN**	**kWh**	**kWh**	**kWh**
1	75.00	12.00	63.00	79.45					79.45	39.72
2	75.00	12.00	63.00	79.45					79.45	39.72
3	80.00	12.80	67.20	84.74					84.74	42.37
4	85.00	13.60	71.40	90.04					90.04	45.02
5	90.00	14.40	75.60	95.33					95.33	47.67
6	100.00	16.00	84.00	105.93					105.93	52.96
7	100.00	16.00	84.00	105.93					105.93	52.96
8	100.00	16.00	84.00	105.93					105.93	52.96
9	100.00	16.00	84.00	105.93					105.93	52.96
10	122.00	19.52	102.48	129.23					129.23	64.62
11	150.00	24.00	126.00	150.00	7.05	7.37			157.37	78.69
12	163.00	26.08	136.92	150.00	17.97	18.80			168.80	84.40
13	163.00	26.08	136.92	150.00	17.97	18.80			168.80	84.40
14	163.00	26.08	136.92	150.00	17.97	18.80			168.80	84.40
15	163.00	26.08	136.92	150.00	17.97	18.80			168.80	84.40
16	163.00	26.08	136.92	150.00	17.97	18.80			168.80	84.40
17	300.00	48.00	252.00	150.00	133.05	130.00	8.77	3.13	283.13	141.56
18	750.00	120.00	630.00	150.00	511.05	130.00	386.77	138.03	418.03	209.02
		Average	**137.29**						**149.14**	**74.57**
		Median	**93.24**						**117.58**	**58.79**

Table C.18. *Estimated Electricity Consumption in Type A Households (kWh).*

[78] Calculated by dividing the Electricity Cost without Taxes by MXN 0.793, in order to get kWh spent with the Basic Fee.

[79] Electricity Cost minus MXN 118.95 for the first 150 kWh.

[80] Calculated by dividing the Money exceeding the Basic Fee by MXN 0.956, in order to get kWh spent with the Intermediate Fee.

[81] Electricity Cost minus MXN 118.95 for the first 150 kWh and minus MXN 124.28 for the next 130 kWh.

[82] Calculated by dividing the Money exceeding the Intermediate Fee by MXN 2.802, in order to get kWh spent with the Exceeding Fee.

ESTIMATED ELECTRICITY CONSUMPTION IN TYPE B HOUSEHOLDS (kWh.)										
N	Electricity Cost with Taxes	Taxes	Electricity Cost without Taxes	Basic (Up to 150 kWh)[83]	Money exceeding the Basic Fee[84]	Intermediate (Next 130 kWh)[85]	Money exceeding the Basic Fee [86]	Exceeding (Next kWh spent)[87]	Total Consumption in Two Months	Total Consumption in One Month
	MXN	MXN	MXN	kWh	MXN	kWh	MXN	kWh	kWh	kWh
1	90.00	14.40	75.60	95.33					95.33	47.67
2	115.00	18.40	96.60	121.82					121.82	60.91
3	150.00	24.00	126.00	150.00	7.05	7.37			157.37	78.69
4	175.00	28.00	147.00	150.00	28.05	29.34			179.34	89.67
5	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
6	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
7	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
8	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
9	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
10	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
11	195.00	31.20	163.80	150.00	44.85	46.91			196.91	98.46
12	200.00	32.00	168.00	150.00	49.05	51.31			201.31	100.65
13	435.00	69.60	365.40	150.00	246.45	130.00	122.17	43.60	323.60	161.80
		Average	**163.48**						**189.01**	**94.51**
		Median	**163.80**						**196.91**	**98.46**

Table C.19. *Estimated Electricity Consumption in Type B Households (kWh).*

[83] Calculated by dividing the Electricity Cost without Taxes by MXN 0.793, in order to get kWh spent with the Basic Fee.

[84] Electricity Cost minus MXN 118.95 for the first 150 kWh.

[85] Calculated by dividing the Money exceeding the Basic Fee by MXN 0.956, in order to get kWh spent with the Intermediate Fee.

[86] Electricity Cost minus MXN 118.95 for the first 150 kWh and minus MXN 124.28 for the next 130 kWh.

[87] Calculated by dividing the Money exceeding the Intermediate Fee by MXN 2.802, in order to get kWh spent with the Exceeding Fee.

ESTIMATED ELECTRICITY CONSUMPTION IN TYPE C HOUSEHOLDS (kWh.)										
N	Electricity Cost with Taxes	Taxes	Electricity Cost without Taxes	Basic (Up to 150 kWh)[88]	Money exceeding the Basic Fee[89]	Intermediate (Next 130 kWh)[90]	Money exceeding the Basic Fee[91]	Exceeding (Next kWh spent)[92]	Total Consumption in Two Months	Total Consumption in One Month
	MXN	MXN	MXN	kWh	MXN	kWh	MXN	kWh	kWh	kWh
1	40.00	6.40	33.60	42.37					42.37	21.19
2	60.00	9.60	50.40	63.56					63.56	31.78
3	100.00	16.00	84.00	105.93					105.93	52.96
4	150.00	24.00	126.00	150.00	7.05	7.37			157.37	78.69
5	200.00	32.00	168.00	150.00	49.05	51.31			201.31	100.65
6	408.00	65.28	342.72	150.00	223.77	130.00	99.49	35.51	315.51	157.75
7	408.00	65.28	342.72	150.00	223.77	130.00	99.49	35.51	315.51	157.75
8	408.00	65.28	342.72	150.00	223.77	130.00	99.49	35.51	315.51	157.75
9	1,900.00	304.00	1,596.00	150.00	1,477.05	130.00	1,352.77	482.79	762.79	381.39
		Average	**342.91**						**253.32**	**126.66**
		Median	**168.00**						**201.31**	**100.65**

Table C.20. *Estimated Electricity Consumption in Type C Households (kWh).*

[88] Calculated by dividing the Electricity Cost without Taxes by MXN 0.793, in order to get kWh spent with the Basic Fee.

[89] Electricity Cost minus MXN 118.95 for the first 150 kWh.

[90] Calculated by dividing the Money exceeding the Basic Fee by MXN 0.956, in order to get kWh spent with the Intermediate Fee.

[91] Electricity Cost minus MXN 118.95 for the first 150 kWh and minus MXN124.28 for the next 130 kWh.

[92] Calculated by dividing the Money exceeding the Intermediate Fee by MXN 2.802, in order to get kWh spent with the Exceeding Fee.

C.3.3. Fossil Fuel Consumption in Households

ESTIMATED FUEL CONSUMPTION PER HOUSEHOLD IN LA PILA (L.)		
N	Money spent in fuel monthly	Fuel liters spent monthly
	MXN	L.
1	-	0.00
2	-	0.00
3	-	0.00
4	-	0.00
5	-	0.00
6	-	0.00
7	-	0.00
8	-	0.00
9	-	0.00
10	-	0.00
11	-	0.00
12	-	0.00
13	-	0.00
14	-	0.00
15	-	0.00
16	-	0.00
17	-	0.00
18	400.00	22.16
19	800.00	44.32
20	800.00	44.32
21	800.00	44.32
22	800.00	44.32
23	800.00	44.32
24	800.00	44.32
25	800.00	44.32
26	1,200.00	66.48
27	1,200.00	66.48
28	1,200.00	66.48
29	1,200.00	66.48
30	1,200.00	66.48
31	1,200.00	66.48
32	1,200.00	66.48
33	1,200.00	66.48
34	1,600.00	88.64
35	1,600.00	88.64
36	2,000.00	110.80
37	2,400.00	132.96
38	2,400.00	132.96
39	2,400.00	132.96
40	3,200.00	177.29
Average	**780.00**	**43.21**
Median	**800.00**	**44.32**

Table C.21. *Estimated Fuel Consumption per Household in La Pila (L.).*

ESTIMATED FUEL CONSUMPTION IN TYPE A HOUSEHOLDS (L.)		
N	**Money spent in fuel monthly**	**Fuel liters spent monthly**
	MXN	**L.**
1	-	0.00
2	-	0.00
3	-	0.00
4	-	0.00
5	-	0.00
6	-	0.00
7	800.00	44.32
8	800.00	44.32
9	800.00	44.32
10	800.00	44.32
11	1,200.00	66.48
12	1,200.00	66.48
13	1,200.00	66.48
14	1,200.00	66.48
15	2,000.00	110.80
16	2,400.00	132.96
17	2,400.00	132.96
18	2,400.00	132.96
Average	**955.56**	**52.94**
Median	**800.00**	**44.32**

Table C.22. *Estimated Fuel Consumption in Type A Households in La Pila (L.).*

ESTIMATED FUEL CONSUMPTION IN TYPE B HOUSEHOLDS (L.)		
N	**Money spent in fuel monthly**	**Fuel liters spent monthly**
	MXN	**U.**
1	-	0.00
2	-	0.00
3	-	0.00
4	-	0.00
5	-	0.00
6	400.00	22.16
7	800.00	44.32
8	800.00	44.32
9	800.00	44.32
10	1,200.00	66.48
11	1,200.00	66.48
12	1,600.00	88.64
13	3,200.00	177.29
Average	**769.23**	**42.62**
Median	**800.00**	**44.32**

Table C.23. *Estimated Fuel Consumption in Type B Households in La Pila (L.).*

ESTIMATED FUEL CONSUMPTION IN TYPE C HOUSEHOLDS (L.)		
N	Money spent in fuel monthly	Fuel liters spent monthly
	MXN	L.
1	-	0.00
2	-	0.00
3	-	0.00
4	-	0.00
5	-	0.00
6	-	0.00
7	1,200.00	66.48
8	1,200.00	66.48
9	1,600.00	88.64
Average	**444.44**	**24.62**
Median	**-**	**0.00**

Table C.24. *Estimated Fuel Consumption in Type C Households in La Pila (L.).*

C.4. Energy per Capita

C.4.1. Gas Consumption per Capita

ESTIMATED GAS CONSUMPTION PER CAPITA AND HOUSEHOLD IN LA PILA (KG.)			
N	Gas consumed per Household	Inhabitants in this Household	Gas Consumption per Capita
	Kg.	U.	Kg.
1	4.10	5	0.820
2	4.30	5	0.861
3	4.51	5	0.902
4	4.92	3	1.639
5	4.92	4	1.230
6	4.92	5	0.984
7	5.90	4	1.475
8	6.15	4	1.538
9	6.56	3	2.187
10	6.89	5	1.377
11	7.38	4	1.844
12	7.38	4	1.844
13	7.38	5	1.476
14	7.38	6	1.230
15	8.20	5	1.639
16	8.51	4	2.128
17	9.02	6	1.503
18	9.51	6	1.585
19	9.59	4	2.398
20	9.84	6	1.639
21	11.80	4	2.950
22	13.03	5	2.607
23	13.11	5	2.623
24	13.28	6	2.213
25	13.77	4	3.443
26	14.14	4	3.535
27	14.26	4	3.565
28	14.26	5	2.852
29	14.75	4	3.688
30	14.75	5	2.951
31	22.62	3	7.540
32	23.61	5	4.721
33	23.61	5	4.721
34	27.30	4	6.825
35	27.54	7	3.934
36	28.03	4	7.008
37	28.52	6	4.753
38	28.52	9	3.169
39	29.51	8	3.689
40	39.34	3	13.113
Average	**13.82**		**3.005**
Median	**12.42**		**2.502**

Table C.25. *Estimated Gas Consumption per Capita and Household in La Pila (Kg.).*

ESTIMATED GAS CONSUMPTION PER CAPITA IN TYPE A HOUSEHOLDS (KG.)			
N	Gas consumed per Household	Inhabitants in this Household	Gas Consumption per Capita
	Kg.	U.	Kg.
1	4.92	3	1.640
2	4.92	4	1.230
3	5.90	4	1.475
4	6.15	4	1.538
5	6.56	3	2.187
6	7.38	4	1.845
7	7.38	4	1.845
8	8.51	4	2.128
9	9.59	4	2.398
10	11.80	4	2.950
11	13.77	4	3.443
12	14.14	4	3.535
13	14.26	4	3.565
14	14.75	4	3.688
15	22.62	3	7.540
16	27.30	4	6.825
17	28.03	4	7.008
18	39.34	3	13.113
Average	**13.74**		**3.775**
Median	**10.70**		**2.674**

Table C.26. *Estimated Gas Consumption per Capita in Type A Households (Kg.).*

ESTIMATED GAS CONSUMPTION PER CAPITA IN TYPE B HOUSEHOLDS (KG.)			
N	Gas consumed per Household	Inhabitants in this Household	Gas Consumption per Capita
	Kg.	U.	Kg.
1	4.10	5	0.820
2	4.30	5	0.861
3	4.51	5	0.902
4	4.92	5	0.984
5	6.89	5	1.377
6	7.38	5	1.475
7	8.20	5	1.639
8	13.03	5	2.607
9	13.11	5	2.623
10	14.26	5	2.852
11	14.75	5	2.951
12	23.61	5	4.721
13	23.61	5	4.721
Average	**10.97**		**2.195**
Median	**8.20**		**1.639**

Table C.27. *Estimated Gas Consumption per Capita in Type B Households (Kg.).*

ESTIMATED GAS CONSUMPTION PER CAPITA IN TYPE C HOUSEHOLDS (KG.)			
N	**Gas consumed per Household**	**Inhabitants in this Household**	**Gas Consumption per Capita**
	Kg.	**U.**	**Kg.**
1	7.38	6	1.230
2	9.02	6	1.503
3	9.51	6	1.585
4	9.84	6	1.639
5	13.28	6	2.213
6	27.54	7	3.934
7	28.52	6	4.753
8	28.52	9	3.169
9	29.51	8	3.689
Average	**18.12**		**2.635**
Median	**13.28**		**2.213**

Table C.28. *Estimated Gas Consumption per Capita in Type C Households (Kg.).*

C.4.2. Electricity Consumption per Capita

ESTIMATED ELECTRIITY CONSUMPTION PER CAPITA PER HOUSEHOLD IN LA PILA (kWh)			
N	Total Consumption in One Month	Inhabitants in this Household	Monthly Electricity Consumption per Capita
	kWh.	U.	kWh.
1	21.185	6	3.531
2	31.778	6	5.296
3	39.723	4	9.931
4	39.723	4	9.931
5	42.371	4	10.593
6	45.019	4	11.255
7	47.667	4	11.917
8	47.667	5	9.533
9	52.963	3	17.654
10	52.963	3	17.654
11	52.963	4	13.241
12	52.963	4	13.241
13	52.963	6	8.827
14	60.908	5	12.182
15	64.615	4	16.154
16	78.687	4	19.672
17	78.687	5	15.737
18	78.687	6	13.115
19	84.399	3	28.133
20	84.399	4	21.100
21	84.399	4	21.100
22	84.399	4	21.100
23	84.399	4	21.100
24	89.671	5	17.934
25	98.457	5	19.691
26	98.457	5	19.691
27	98.457	5	19.691
28	98.457	5	19.691
29	98.457	5	19.691
30	98.457	5	19.691
31	98.457	5	19.691
32	100.654	5	20.131
33	100.654	7	14.379
34	141.565	3	47.188
35	157.753	6	26.292
36	157.753	6	26.292
37	157.753	8	19.719
38	161.800	5	32.360
39	209.017	4	52.254
40	381.394	9	42.377
Average	**74.568**		**20.179**
Median	**58.789**		**17.654**

Table C.29. *Estimated Electricity Consumption per Capita and Household in La Pila (kWh.).*

ESTIMATED ELECTRIITY CONSUMPTION PER CAPITA IN TYPE A HOUSEHOLDS (kWh)			
N	Total Consumption in One Month	Inhabitants in this Household	Monthly Electricity Consumption per Capita
	kWh.	U.	kWh.
1	39.723	4	9.931
2	39.723	4	9.931
3	42.371	4	10.593
4	45.019	4	11.255
5	47.667	4	11.917
6	52.963	3	17.654
7	52.963	3	17.654
8	52.963	4	13.241
9	52.963	4	13.241
10	64.615	4	16.154
11	78.687	4	19.672
12	84.399	3	28.133
13	84.399	4	21.100
14	84.399	4	21.100
15	84.399	4	21.100
16	84.399	4	21.100
17	141.565	3	47.188
18	209.017	4	52.254
Average	**74.568**		**20.179**
Median	**58.789**		**17.654**

Table C.30. *Estimated Electricity Consumption per Capita in Type A Households (kWh.).*

ESTIMATED ELECTRIITY CONSUMPTION PER CAPITA IN TYPE B HOUSEHOLDS (kWh)			
N	Total Consumption in One Month	Inhabitants in this Household	Monthly Electricity Consumption per Capita
	kWh.	U.	kWh.
1	47.667	5	9.533
2	60.908	5	12.182
3	78.687	5	15.737
4	89.671	5	17.934
5	98.457	5	19.691
6	98.457	5	19.691
7	98.457	5	19.691
8	98.457	5	19.691
9	98.457	5	19.691
10	98.457	5	19.691
11	98.457	5	19.691
12	100.654	5	20.131
13	161.800	5	32.360
Average	**94.507**		**18.901**
Median	**98.457**		**19.691**

Table C.31. *Estimated Electricity Consumption per Capita in Type B Households (kWh.).*

ESTIMATED ELECTRIITY CONSUMPTION PER CAPITA IN TYPE C HOUSEHOLDS (kWh)			
N	Total Consumption in One Month	Inhabitants in this Household	Monthly Electricity Consumption per Capita
	kWh.	U.	kWh.
1	21.185	6	3.531
2	31.778	6	5.296
3	52.963	6	8.827
4	78.687	6	13.115
5	100.654	7	14.379
6	157.753	6	26.292
7	157.753	6	26.292
8	157.753	8	19.719
9	381.394	9	42.377
Average	**126.658**		**17.759**
Median	**100.654**		**14.379**

Table C.32. *Estimated Electricity Consumption per Capita in Type C Households (kWh.).*

C.4.3. Fossil Fuel Consumption per Capita

ESTIMATED FUEL CONSUMPTION PER CAPITA PER HOUSEHOLD IN LA PILA (L.)			
N	Monthly Fuel Consumption	Inhabitants in this Household	Monthly Fuel Consumption per Capita
	L.	U.	L.
1	0.000	3	0.000
2	0.000	3	0.000
3	0.000	4	0.000
4	0.000	4	0.000
5	0.000	4	0.000
6	0.000	4	0.000
7	0.000	5	0.000
8	0.000	5	0.000
9	0.000	5	0.000
10	0.000	5	0.000
11	0.000	5	0.000
12	0.000	6	0.000
13	0.000	6	0.000
14	0.000	6	0.000
15	0.000	6	0.000
16	0.000	7	0.000
17	0.000	9	0.000
18	22.161	5	4.432
19	44.321	4	11.080
20	44.321	4	11.080
21	44.321	4	11.080
22	44.321	4	11.080
23	44.321	5	8.864
24	44.321	5	8.864
25	44.321	5	8.864
26	66.482	3	22.161
27	66.482	4	16.620
28	66.482	4	16.620
29	66.482	4	16.620
30	66.482	5	13.296
31	66.482	5	13.296
32	66.482	6	11.080
33	66.482	8	8.310
34	88.643	5	17.729
35	88.643	6	14.774
36	110.803	3	36.934
37	132.964	4	33.241
38	132.964	4	33.241
39	132.964	4	33.241
40	177.285	5	35.457
Average	**43.213**		**9.949**
Median	**44.321**		**8.864**

Table C.33. *Estimated Fuel Consumption per Capita in per Household in La Pila (L.).*

ESTIMATED FUEL CONSUMPTION PER CAPITA IN TYPE A HOUSEHOLDS (L.)			
N	Monthly Fuel Consumption	Inhabitants in this Household	Monthly Fuel Consumption per Capita
	L.	U.	L.
1	0.000	3	0.000
2	0.000	3	0.000
3	0.000	4	0.000
4	0.000	4	0.000
5	0.000	4	0.000
6	0.000	4	0.000
7	44.321	4	11.080
8	44.321	4	11.080
9	44.321	4	11.080
10	44.321	4	11.080
11	66.482	3	22.161
12	66.482	4	16.620
13	66.482	4	16.620
14	66.482	4	16.620
15	110.803	3	36.934
16	132.964	4	33.241
17	132.964	4	33.241
18	132.964	4	33.241
Average	**52.939**		**14.056**
Median	**44.321**		**11.080**

Table C.34. *Estimated Fuel Consumption per Capita in Type A Households (L.).*

ESTIMATED FUEL CONSUMPTION PER CAPITA IN TYPE B HOUSEHOLDS (L.)			
N	Monthly Fuel Consumption	Inhabitants in this Household	Monthly Fuel Consumption per Capita
	L.	U.	L.
1	0.000	5	0.000
2	0.000	5	0.000
3	0.000	5	0.000
4	0.000	5	0.000
5	0.000	5	0.000
6	22.161	5	4.432
7	44.321	5	8.864
8	44.321	5	8.864
9	44.321	5	8.864
10	66.482	5	13.296
11	66.482	5	13.296
12	88.643	5	17.729
13	177.285	5	35.457
Average	**42.617**		**8.523**
Median	**44.321**		**8.864**

Table C.35. *Estimated Fuel Consumption per Capita in Type B Households (L.).*

ESTIMATED FUEL CONSUMPTION PER CAPITA IN TYPE C HOUSEHOLDS (L.)			
N	**Monthly Fuel Consumption**	**Inhabitants in this Household**	**Monthly Fuel Consumption per Capita**
	L.	**U.**	**L.**
1	0.000	6	0.000
2	0.000	6	0.000
3	0.000	6	0.000
4	0.000	6	0.000
5	0.000	7	0.000
6	0.000	9	0.000
7	66.482	6	11.080
8	66.482	8	8.310
9	88.643	6	14.774
Average	**24.623**		**3.796**
Median	**0.000**		**0.000**

Table C.36. *Estimated Fuel Consumption per Capita in Type C Households (L.).*

C.5. Food in Households and Per Capita

ESTIMATED FOOD EXPENDITURE PER HOUSEHOLD AND PER CAPITA IN LA PILA					
N	**Estimated Monthly Income**	**Estimated Monthly Food Expenditure**	**Income spent on Food**	**Inhabitants in this Household**	**Estimated Monthly Food Expenditure per Capita**
	MXN	**MXN**	**%**	**N**	**MXN**
1	5,545.00	1,600.00	28.85	4	400.00
2	4,355.00	1,600.00	36.74	4	400.00
3	4,966.67	2,000.00	40.27	4	500.00
4	9,817.67	4,000.00	40.74	9	444.44
5	5,700.00	2,400.00	42.11	3	800.00
6	5,170.00	2,400.00	46.42	6	400.00
7	7,499.66	3,600.00	48.00	3	1,200.00
8	6,550.00	3,200.00	48.85	4	800.00
9	2,010.00	1,000.00	49.75	5	200.00
10	5,176.67	2,600.00	50.23	5	520.00
11	5,425.00	2,900.00	53.46	3	966.67
12	5,425.00	2,900.00	53.46	4	725.00
13	5,425.00	2,900.00	53.46	4	725.00
14	5,425.00	2,900.00	53.46	4	725.00
15	5,425.00	2,900.00	53.46	4	725.00
16	7,440.00	4,000.00	53.76	4	1,000.00
17	10,331.67	6,000.00	58.07	5	1,200.00
18	10,216.67	6,000.00	58.73	6	1,000.00
19	7,200.00	4,270.00	59.31	8	533.75
20	7,200.00	4,270.00	59.31	6	711.67
21	7,200.00	4,270.00	59.31	6	711.67
22	5,260.00	3,200.00	60.84	5	640.00
23	6,500.00	4,066.00	62.55	5	813.20
24	6,500.00	4,066.00	62.55	5	813.20
25	6,500.00	4,066.00	62.55	5	813.20
26	6,500.00	4,066.00	62.55	5	813.20
27	6,500.00	4,066.00	62.55	5	813.20
28	6,500.00	4,066.00	62.55	5	813.20
29	6,500.00	4,066.00	62.55	5	813.20
30	8,808.33	5,600.00	63.58	5	1,120.00
31	4,400.00	2,800.00	63.64	4	700.00
32	3,700.00	2,400.00	64.86	4	600.00
33	6,094.33	4,000.00	65.63	4	1,000.00
34	7,125.00	4,800.00	67.37	7	685.71
35	5,150.00	3,600.00	69.90	4	900.00
36	6,343.67	4,500.00	70.94	4	1,125.00
37	2,780.00	2,000.00	71.94	3	666.67
38	7,170.00	5,200.00	72.52	6	866.67
39	7,731.67	6,000.00	77.60	5	1,200.00
40	3,591.66	3,200.00	89.10	6	533.33
Average	**6,178.97**	**3,586.80**	**58.09**		**760.45**
Median	**6,421.83**	**3,800.00**	**59.31**		**762.50**

Table C.37. *Estimated Food Expenditure per Household and per Capita in La Pila.*

ESTIMATED FOOD EXPENDITURE IN TYPE A HOUSEHOLDS					
N	Estimated Monthly Income	Estimated Monthly Food Expenditure	Percentage of Income spent on Food	Inhabitants in this Household	Estimated Monthly Food Expenditure per Capita
	MXN	MXN	%	N	MXN
1	4,355.00	1,600.00	36.74	4	400.00
2	5,545.00	1,600.00	28.85	4	400.00
3	4,966.67	2,000.00	40.27	4	500.00
4	2,780.00	2,000.00	71.94	3	666.67
5	3,700.00	2,400.00	64.86	4	600.00
6	5,700.00	2,400.00	42.11	3	800.00
7	4,400.00	2,800.00	63.64	4	700.00
8	5,425.00	2,900.00	53.46	3	966.67
9	5,425.00	2,900.00	53.46	4	725.00
10	5,425.00	2,900.00	53.46	4	725.00
11	5,425.00	2,900.00	53.46	4	725.00
12	5,425.00	2,900.00	53.46	4	725.00
13	6,550.00	3,200.00	48.85	4	800.00
14	7,499.66	3,600.00	48.00	3	1,200.00
15	5,150.00	3,600.00	69.90	4	900.00
16	7,440.00	4,000.00	53.76	4	1,000.00
17	6,094.33	4,000.00	65.63	4	1,000.00
18	6,343.67	4,500.00	70.94	4	1,125.00
Average	**5,424.96**	**2,900.00**	**54.04**		**775.46**
Median	**5,425.00**	**2,900.00**	**53.46**		**725.00**

Table C.38. *Estimated Food Expenditure in Type A Households.*

ESTIMATED FOOD EXPENDITURE IN TYPE B HOUSEHOLDS					
N	Estimated Monthly Income	Estimated Monthly Food Expenditure	Percentage of Income spent on Food	Inhabitants in this Household	Estimated Monthly Food Expenditure per Capita
	MXN	MXN	%	N	MXN
1	2,010.00	1,000.00	49.75	5	200.00
2	5,176.67	2,600.00	50.23	5	520.00
3	5,260.00	3,200.00	60.84	5	640.00
4	6,500.00	4,066.00	62.55	5	813.20
5	6,500.00	4,066.00	62.55	5	813.20
6	6,500.00	4,066.00	62.55	5	813.20
7	6,500.00	4,066.00	62.55	5	813.20
8	6,500.00	4,066.00	62.55	5	813.20
9	6,500.00	4,066.00	62.55	5	813.20
10	6,500.00	4,066.00	62.55	5	813.20
11	8,808.33	5,600.00	63.58	5	1,120.00
12	7,731.67	6,000.00	77.60	5	1,200.00
13	10,331.67	6,000.00	58.07	5	1,200.00
Average	**6,524.49**	**4,066.31**	**61.38**		**813.26**
Median	**6,500.00**	**4,066.00**	**62.55**		**813.20**

Table C.39. *Estimated Food Expenditure in Type B Households.*

ESTIMATED FOOD EXPENDITURE IN TYPE C HOUSEHOLDS					
N	**Estimated Monthly Income**	**Estimated Monthly Food Expenditure**	**Percentage of Income spent on Food**	**Inhabitants in this Household**	**Estimated Monthly Food Expenditure per Capita**
	MXN	**MXN**	**%**	**N**	**MXN**
1	3,591.66	3,200.00	89.10	6	533.33
2	5,170.00	2,400.00	46.42	6	400.00
3	7,125.00	4,800.00	67.37	7	685.71
4	7,170.00	5,200.00	72.52	6	866.67
5	7,200.00	4,270.00	59.31	8	533.75
6	7,200.00	4,270.00	59.31	6	711.67
7	7,200.00	4,270.00	59.31	6	711.67
8	9,817.67	4,000.00	40.74	9	444.44
9	10,216.67	6,000.00	58.73	6	1,000.00
Average	**7,187.89**	**4,267.78**	**61.42**		**654.14**
Median	**7,200.00**	**4,270.00**	**59.31**		**685.71**

Table C.40. *Estimated Food Expenditure in Type C Households.*

References

Adriaanse, A., Bringezu, S., Hammond, A., Moriguchi, Y., Rodenburg, E., Rogich, D. and Schütz, H. (1997) *Resource Flows: The Material Base of Industrial Economies*, *World Resources Institute Wuppertal Institute Netherlands Ministry of Housing Spatial Planning and Environment Japans National Institute for Environmental Studies Washington DC World Resources Institute Report*. Available at: http://pdf.wri.org/resourceflows_bw.pdf.

Adriana Gracia, C., Rangel-Buitrago, N., Oakley, J. A. and Williams, A. (2017) 'Use of ecosystems in coastal erosion management', *Ocean and Coastal Management*, pp. 1–13. doi: 10.1016/j.ocecoaman.2017.07.009.

Alawadi, K. (2017) 'Rethinking Dubai's urbanism: Generating sustainable form-based urban design strategies for an integrated neighborhood', *Cities*, 60, pp. 353–366. Available at: http://ac.els-cdn.com/S0264275116301433/1-s2.0-S0264275116301433-main.pdf?_tid=6ccab224-48de-11e7-b252-00000aacb362&acdnat=1496550760_3ebaa1916db9548e4c1d3270fa710347 (Accessed: 3 June 2017).

Altvater, E. (2006) '¿Existe un marxismo ecológico?', *La teoría marxista hoy.*, pp. 341–364.

Antoni, C. D., Huber-Sannwald, E., Reyes Hernández, H. and Van't Hooft, A. (2017) 'Condition, Tendency, and Dynamic Interactions in a Resilience Context of a Social-Ecological System', *Natural Resources and Development*, 7, pp. 12–21.

Aptikar, D. (2005) 'Risk Matrix', *Technical Review*. Available at: http://www.mtpinnacle.com/pdfs/RiskMatrix.pdf (Accessed: 9 August 2018).

Arnold, R. D. and Wade, J. P. (2015) 'A definition of systems thinking: A systems approach', *Procedia Computer Science*. Elsevier Masson SAS, 44(C), pp. 669–678. doi: 10.1016/j.procs.2015.03.050.

ARUP (2015) *City Resilience Framework*. Available at: https://assets.rockefellerfoundation.org/app/uploads/20160105134829/100RC-City-Resilience-Framework.pdf (Accessed: 4 June 2017).

Ashby, W. R. (1956) *An Introduction to Cybernetics*. Methuen, London.

Asian Development Bank (2013) *Moving from Risk to Resilience Sustainable Urban Development in the Pacific Studies Series*.

Baptista, P., Pina, A., Duarte, G., Rolim, C., Pereira, G., Silva, C. and Farias, T. (2015) 'From on-road trial evaluation of electric and conventional bicycles to comparison with other urban transport modes: Case study in the city of Lisbon, Portugal', *Energy Conversion and Management*, 92, pp. 10–18. Available at: http://ac.els-cdn.com/S0196890414010826/1-s2.0-S0196890414010826-main.pdf?_tid=3b9a9550-48e0-11e7-bbf4-00000aab0f02&acdnat=1496551536_5bb0668c19775684ef26dfba35321216 (Accessed: 4 June 2017).

Barkin, D. (2010) 'The Struggle for Local Autonomy in a Multiethnic Society Constructing Alternatives with Indigenous Epistemologies', *Capabilities, Power and Institutions. Towards a more critical development ethics*, (January), pp. 142–162.

Barkin, D., Fuente, M. E. and Rosas, M. (2009) 'Tradición e innovación. Aportaciones campesinas en la orientación de la innovación', *Trayectorias*, 11(29), pp. 39–54.

Beilin, R. and Wilkinson, C. (2015) 'Special issue: Governing for urban resilience', *Urban Studies Urban Studies Journal Limited*, 52(7), pp. 1205–1217. doi: 10.1177/0042098015574955.

Benavides Mondragón, L. E. (2017) *Advancing Sustainability in Latin American Cities: A Study Case on the Urban Metabolism of San Luis Potosí, México*. TH Köln University of Applied Sciences / Universidad Autónoma de San Luis Potosí.

Berkes, F., Colding, J. and Folke, C. (2003) *Navigating Social-ecological Systems: Building Resilience for Complexity and Change*. Edited by F. Berkes, J. Colding, and C. Folke. Cambridge University Press, Cambridge.

Von Bertalanffy, L. (1968) 'General System Theory', *Georg. Braziller New York*, 1, p. 289. Available at: http://books.google.es/books?id=N6k2mILtPYIC.

Bevacqua, A., Yu, D. and Zhang, Y. (2018) 'Coastal vulnerability: Evolving concepts in understanding vulnerable people and places', *Environmental Science & Policy*. Elsevier, 82(November 2017), pp. 19–29. doi: 10.1016/j.envsci.2018.01.006.

Bhowmik, C., Bhowmik, S., Ray, A. and Pandey, K. M. (2017) 'Optimal green energy planning for sustainable development: A review', *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, 71(December 2015), pp. 796–813. doi: 10.1016/j.rser.2016.12.105.

Biggs, R., Schlüter M. and Schoon M.L. (2015) *Principles for building resilience: Sustaining ecosystem services in social-ecological systems - Stockholm Resilience Centre*. Edited by R. Biggs, Schlüter M., and Schoon M.L. Cambridge: Cambridge University Press. Available at: http://www.stockholmresilience.org/publications/artiklar/2016-02-02-principles-for-building-resilience-sustaining-ecosystem-services-in-social-ecological-systems.html (Accessed: 15 May 2018).

Bonaiuto, M., Alves, S., De Dominicis, S. and Petruccelli, I. (2016) 'Place attachment and natural environmental risk: Research review and agenda', *Journal of Environmental Psychology*. Elsevier Ltd, 48, pp. 33–53. doi: 10.1016/j.jenvp.2016.07.007.

Bonilla Moheno, M. (2011) *Criterios alternativos de delimitación de área urbano y rural*.

Boyd, E. and Juhola, S. (2015) 'Adaptive climate change governance for urban resilience', *Urban Studies*, 52(7), pp. 1234–1264. doi: 10.1177/0042098014527483.

Broto, V. C., Allen, A. and Rapoport, E. (2012) 'Interdisciplinary Perspectives on Urban Metabolism', *Journal of Industrial Ecology*, 16, pp. 851–861. doi: 10.1111/j.1530-9290.2012.00556.x.

Brunner, P. H. and Rechberger, H. (2004) *Practical Handbook of Material Flow Analysis: Advanced Methods in Resource and Waste Management*. Boca Raton, London, New York, Washington, D.C.: CRC Press LLC. Available at: https://thecitywasteproject.files.wordpress.com/2013/03/practical_handbook-of-material-flow-analysis.pdf (Accessed: 9 August 2018).

Burg, J. (2008) 'Measuring populations' vulnerabilities for famine and food security interventions: the case of Ethiopia's Chronic Vulnerability Index', *Disasters*, 32(4), pp. 609–630.

Cardona, O. D. (1990) 'Terminología de Uso Común en Manejo de Riesgos', *AGID Reporte No. 13, Escuela de Administración, Finanzas, y Tecnología, Medellín, Colombia*.

Cardona, O. D. (2012) *Determinants of Risk: Exposure and Vulnerability*, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK, and New York, NY, USA: Cambridge University Press.

Cardona, O. D., M.K. van Aalst, Birkmann, J., Fordham, M., McGregor, G., Perez, R., Pulwarty, R. S., Schipper, E. L. F. and Sinh, B. T. (2012) 'Determinants of risk: exposure and vulnerability', in *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge, UK, and New York, NY, USA: Cambridge University Press, pp. 65–108. Available at: https://www.ipcc.ch/pdf/special-reports/srex/SREX-Chap2_FINAL.pdf (Accessed: 13 March 2018).

Carpenter, S., Walker, B., Anderies, J. M. and Abel, N. (2001) 'From Metaphor to Measurement : Resilience of What to What ?', pp. 765–781. doi: 10.1007/s10021-001-0045-9.

Chapin, F. S., Carpenter, S. R., Kofinas, G. P., Folke, C., Abel, N., Clark, W. C., Olsson, P., Smith, D. M. S., Walker, B., Young, O. R., Berkes, F., Biggs, R., Grove, J. M., Naylor, R. L., Pinkerton, E., Steffen, W. and Swanson, F. J. (2009) 'Ecosystem stewardship: sustainability strategies for a rapidly changing planet', *Trends in Ecology and Evolution*. Elsevier Ltd, 25(4), pp. 241–249. doi: 10.1016/j.tree.2009.10.008.

Chapin, F. S., Kofinas, G. P. and Folke, C. (2009) *Principles of Ecosystem Stewardship, Resilience-Based Natural Resource Management in a Changing World*. New York, N.Y.: Springer.

Checkland, P. B. (1981) *Systems Thinking, Systems Practice*. Chichester, UK: John Wiley & Sons.

Chen, S. and Chen, B. (2015a) 'Sustainable Urban Metabolism', *Encyclopedia of Environmental Management*, (August), pp. 1–8. doi: 10.1081/E-EEM-120053897.

Chen, S. and Chen, B. (2015b) 'Sustainable Urban Metabolism', pp. 1–6.

Chen, S. Q., Chen, B. and Fath, B. D. (2014) 'Urban ecosystem modeling and global change: Potential for rational urban management and emissions mitigation', *Environmental Pollution*, 190, pp. 139–149.

Climate Energy and Tenure Division and Food and Agriculture Organization of the United Nations (2014) *Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus in the Context of the Sustainable Energy for All Initiative*. Edited by A. Flammini, M. Puri, L. PLuschke, and O. Dubois. FAO. doi: 978-92-5-108488-5.

Codoban, N. and Kennedy, C. A. (2008) 'Metabolism of Neighborhoods', *Journal of Urban Planning and Development*, 134(1), pp. 21–31. doi: 10.1061/(ASCE)0733-9488(2008)134:1(21).

Comisión Estatal del Agua (2014) 'Caudal', *Acueducto 'El Realito', Proyecto de Ingeniería Hídrica*, pp. 11–15.

Comisión Estatal del Agua (2015) *Agua y Reservas Hidrológicas*, *Plan Estatal de Desarrollo 2015-2021*. San Luis Potosí. Available at: http://www.slp.gob.mx/plan2015-2021/assets/eje3_2.pdf (Accessed: 17 July 2018).

Comisión Estatal del Agua de San Luis Potosí (2018) *Comisión Estatal del Agua de San Luis Potosí*, *Objetivos*. Available at: http://www.ceaslp.gob.mx/objetivos.html (Accessed: 12 July 2018).

Comisión Federal de Electricidad (2018) *Comisión Federal de Electricidad*, *Tarifas 2018*. Available at: https://app.cfe.mx/aplicaciones/ccfe/tarifas/tarifas/Tarifas_casa.asp?Tarifa=DACTAR1&anio=2018 (Accessed: 3 August 2018).

Comisión Nacional del Agua (2007) *Manual de Agua*

Potable, Alcantarillado y Saneamiento. Coyoacán, México, D.F. Available at: ftp://ftp.conagua.gob.mx/Mapas/libros pdf 2007/Datos B%E1sicos.pdf (Accessed: 17 July 2018).

Comisión Reguladora de Energía (2018) *Consulta de precios vigentes de gas LP mediante planta de distribución reportados por los permisionarios*, *Precios al Público*. Available at: http://www.cre.gob.mx/ConsultaPrecios/GasLP/PlantaDistribucion.html?idiom=es (Accessed: 4 August 2018).

Crowe, P. R., Foley, K. and Collier, M. J. (2016) 'Operationalizing urban resilience through a framework for adaptive co-management and design: Five experiments in urban planning practice and policy', *Environmental Science & Policy*, 62, pp. 112–119. doi: 10.1016/j.envsci.2016.04.007.

Davoudi, S. and Sturzaker, J. (2017) 'Resources, Conservation and Recycling Urban form, policy packaging and sustainable urban metabolism', *'Resources, Conservation & Recycling'*, 120, pp. 55–64. doi: 10.1016/j.resconrec.2017.01.011.

Decker, E. H., Elliott, S., Smith, F. A., Blake, D. R. and Rowland, F. S. (2000) 'Energy and Material Flow through the Urban Ecosystem', *Annual Review of Energy and the Environment*, 25, pp. 685–740.

DeFries, R., Mondal, P., Singh, D., Agrawal, I., Fanzo, J., Remans, R. and Wood, S. (2016) 'Synergies and trade-offs for sustainable agriculture: Nutritional yields and climate-resilience for cereal crops in Central India', *Global Food Security*. Elsevier, 11, pp. 44–53. doi: 10.1016/j.gfs.2016.07.001.

Deressa, T. T. (2010) 'Assessment of the vulnerability of Ethiopian agriculture to climate change and farmers' adaptation strategies', *Department of Agricultural Economics, Extension and Rural Development*. *University of Pretoria, Pretoria*. Available at: http://upetd.up.ac.za/thesis/available/etd-10232010-165854/unrestricted/thesis.pdf.

Díaz Álvarez, C. J. (2014) 'Metabolismo urbano: herramienta para la sustentabilidad de las ciudades', *INTERdisciplina*, pp. 51–70. doi: http://dx.doi.org/10.22201/ceiich.24485705e.2014.2.46524.

Dinarès, M. (2014) 'Urban Metabolism: A review of recent literature on the subject', *Documents d'Anàlisi Geogràfica*, 60(3), pp. 551–571. Available at: http://dag.revista.uab.es/article/view/v60-n3-dinares.

Dobbs, R., Remes, J., Manyika, J., Roxburgh, C., Smit, S. and Schaer, F. (2012) *Urban world: Cities and the rise of the consuming class*, *McKinsey Global Institute*. Available at: http://www.mckinsey.com/insights/mgi/research/urbanization/urban_world_cities_and_the_rise_of_the_consuming_class%5Cnpapers2://publication/uuid/C1BBC14A-B51F-43FC-AE92-CAC2DB6E346E.

El Precio de La Gasolina 2018 (2018) 'La Economía'. Available at: http://laeconomia.com.mx/el-precio-de-la-gasolina/ (Accessed: 3 August 2018).

Elliott, M., Cutts, N. D. and Trono, A. (2014) 'A typology of marine and estuarine hazards and risks as vectors of change: A review for vulnerable coasts and their management', *Ocean and Coastal Management*. Elsevier Ltd, 93, pp. 88–99. doi: 10.1016/j.ocecoaman.2014.03.014.

Elliott, M., Trono, A. and Cutts, N. D. (2010) 'Chapter 17: Coastal hazards and risk', in Green, D. R. (ed.) *Coastal Zone Management*. London: Thomas Telford, pp. 396–432.

Faivre, N., Sgobbi, A., Happaerts, S., Raynal, J. and Schmidt, L. (2017) 'Translating the Sendai Framework into action: the EU approach to ecosystem-based disaster risk reduction', *International Journal of Disaster Risk Reduction*. Elsevier Ltd. doi: 10.1016/j.ijdrr.2017.12.015.

FAO (2018) *Food and Agriculture Organization of the United Nations*, *Water-Energy-Food Nexus*. Available at: http://www.fao.org/energy/water-food-energy-nexus/en/ (Accessed: 5 February 2018).

Ferrão, P. and Fernandez, J. E. (2013) *Sustainable Urban Metabolism*. Cambridge: MIT Press.

Fischer-Kowalski, M. (1998) 'Society's Metabolism. The Intellectual History of Materials Flow Analysis, Part I, 1860-1970', *Journal of Industrial Ecology*, 2(1), pp. 61–78.

Folke, C. (2017) *Resilience thinking for global development*, *Why Resilience?* Available at: https://courses.sdgacademy.org/courses/6351/learn#/posts?contextId=e3b07e2e6b3e4ca1a599ce553603d6f0-2b90ab83c185434d9c8a61ad3a001f66-undefined (Accessed: 15 May 2018).

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chappin, T. and Rockstrom, J. (2010) 'Resilience thinking: integrating resilience, adaptability and transformability', *Ecology and Society*. doi: 15. https://doi.org/10.5751/ES-03610-150420.

Folke, C., Hahn, T. and Olsson, P. (2005) 'Adaptive governance of socio-ecological systems', *Annual Review of Environment and Resources*, 30, pp. 441–473.

Forman, R. T. T. (2008) *Urban regions: Ecology and planning beyond the city*. Cambridge: Cambridge University Press.

Foster, J. B. (1999) 'Marx's Theory of Metabolic Rift: Classical Foundations for Environmental Sociology', *American Journal of Sociology*, 105(2), pp. 366–405.

Frank, B., Delano, D. and Caniglia, B. S. (2017) 'Urban

Systems : A Socio-Ecological System Perspective', *Sociology Intenational Journal*, 1(1), pp. 1–9. doi: 10.15406/sij.2017.01.00001.

Fraser, A., Leck, H., Parnell, S., Pelling, M., Brown, D. and Lwasa, S. (2017) 'Meeting the challenge of risk-sensitive and resilient urban development in sub-Saharan Africa: Directions for future research and practice', *International Journal of Disaster Risk Reduction*. Elsevier Ltd, 26(October), pp. 106–109. doi: 10.1016/j.ijdrr.2017.10.001.

Gallopin, G. (2003) *A systems approach to sustainability and sustainable development*, *Sustainable Development and Human Settlements Division*. doi: 1680-8886.

Georgescu-Roegen, N. (1989) 'La Ley de la Entropía y el Problema Económico', *Economía, ecología y ética. Ensayos hacia una economía en estado estacionario*, pp. 61–72.

Global Initiative for Resource Efficient Cities (2018) 'Metabolism of Cities (Massive Online Open Courses)'.

Gordon, W. F. D. (2018) *Britannica*, *Thermodynamics*. Available at: https://www.britannica.com/science/thermodynamics (Accessed: 9 August 2018).

Grove, J. M. (2009) 'Cities: Managing Densely Settled Social-Ecological Systems', in Chapin III, F. S., Folke, C., and Kofinas, G. P. (eds) *Principles of Ecosystem Stewardship*. New York: Springer New York.

Hallegatte, S. and Corfee-Morlot, J. (2011) 'Understanding climate change impacts, vulnerability and adaptation at city scale: An introduction', *Climatic Change*, 104, pp. 1–12. doi: 10.1007/s10584-010-9981-8.

Harvey, D. (1989) 'Capitalism FROM MANAGERIALISM TO THE ENTREPRENEURIALISM : IN URBAN GOVERNANCE TRANSFORMATION', *Geografiska Annaler. Series B, Human Geography*, 71(1), pp. 3–17. doi: 10.2307/490503.

Harvey, D. (1989) 'From Managerialism to Entrepreneurialism : The Transformation in Urban Governance in Late Capitalism', *Geografiska Annaler, Series B, Human Geography*, 71(1), p. 82.

Hester, P. T. and MacG. Adams, K. (2013) 'Thinking systemically about complex systems', *Procedia Computer Science*, 20, pp. 312–317. doi: 10.1016/j.procs.2013.09.278.

Hitchins, D. K. (2007) *Systems engineering: A 21st century systems methodology*. Chichester, UK: Wiley.

Holling, C. S. (1973) 'Resilience and stability of ecological systems', *Annual Review of Ecology and Systematics*, 4, pp. 1–23.

INEGI (1997) *San Luis Potosí: Datos por Ejido y Comunidad Agraria*. Available at: http://internet.contenidos.inegi.org.mx/contenidos/productos/prod_serv/contenidos/espanol/bvinegi/productos/historicos/1329/702825116828/702825116828_2.pdf (Accessed: 10 July 2018).

INEGI (2005) *II Conteo de Población y Vivienda 2005. Principales resultados por localidad (ITER)*.

INEGI (2010a) *Censo de Población Vivienda 2010. Principales resultados por localidad (ITER)*.

INEGI (2010b) *Cuéntame INEGI*, *Población Rural y Urbana*. Available at: http://cuentame.inegi.org.mx/poblacion/rur_urb.aspx?tema=P (Accessed: 10 July 2018).

INEGI (2014) *Perspectiva Estadística: San Luis Potosí*. San Luis Potosí. Available at: www.inegi.org.mx (Accessed: 6 August 2018).

INEGI (2015a) *Catálogo de claves de entidades federativas, municipios y localidades, Octubre 2015*. Available at: http://geoweb.inegi.org.mx/mgn2k/catalogo.jsp.

INEGI (2015b) *Marco Geoestadístico Nacional*, *Catálogo Único de Claves de Áreas Geoestadísticas Estatales, Municipales y Localidades*. Available at: http://www.inegi.org.mx/geo/contenidos/geoestadistica/catalogoclaves.aspx (Accessed: 11 July 2018).

INEGI (2018) *INEGI*, *Espacio y datos de México*. Instituto Nacional de Estadística y Geografía. INEGI. Available at: http://www.beta.inegi.org.mx/app/mapa/espacioydatos/default.aspx?ag=240280264 (Accessed: 15 July 2018).

INEGI and Gobierno del Estado de San Luis Potosí (2002) *Estudio Hidrológico del Estado de San Luis Potosí*. San Luis Potosí. Available at: www.inegi.gob.mx (Accessed: 17 July 2018).

INEGI through Google Maps (2018) *La Pila, San Luis Potosí, San Luis Potosí*, *Espacio y datos de México*. Instituto Nacional de Estadística y Geografía. INEGI. Available at: http://www.beta.inegi.org.mx/app/mapa/espacioydatos/default.aspx?ag=240280264 (Accessed: 12 July 2018).

Interapas (2005) *Estudio de Diagnóstico y Planeación Integral*.

Jabareen, Y. (2013) 'Planning the resilient city: Concepts and strategies for coping with climate change and environmental risk', *Cities*, 31, pp. 220–229. doi: 10.1016/j.cities.2012.05.004.

Jackson, M. C. (2003) *Systems Thinking: Creative Holism for Managers*. London: John Wiley & Sons, Ltd. doi: 10.1002/sres.

Jiang, Y., Zevenbergen, C. and Ma, Y. (2018) 'Urban pluvial flooding and stormwater management: A contemporary review of China's challenges and "sponge cities" strategy', *Environmental Science and Policy*. Elsevier, 80(June 2017), pp. 132–143. doi: 10.1016/j.envsci.2017.11.016.

Johnson, C. and Blackburn, S. (2014) 'Advocacy for urban resilience: UNISDR's Making Cities Resilient Campaign', *and Development (IIED). Vol*, 26(1), pp. 29–52. doi: 10.1177/0956247813518684.

Juan-García, P., Butler, D., Comas, J., Darch, G., Sweetapple, C., Thornton, A. and Corominas, L. (2017) 'Resilience theory incorporated into urban wastewater systems management. State of the art', *Water Research Elsevier Ltd.* , 115, pp. 149–161. Available at: http://ac.els-cdn.com/S0043135417301392/1-s2.0-S0043135417301392-main.pdf?_tid=989b7456-44ba-11e7-bdcf-00000aab0f27&acdnat=1496095567_2df008c90c7968d6b4174655bcc0688b (Accessed: 29 May 2017).

Kennedy, C., Cuddihy, J. and Engel-Yan, J. (2007) 'The changing metabolism of cities', *Industrial Ecology*, 11(2), pp. 43–59.

Kennedy, C., Cuddihy, J. and Engel-Yan, J. (2007) 'The Changing Metabolism of Cities', *Journal of Industrial Ecology*, 11(2), pp. 43–59.

Kennedy, C., Pincetl, S. and Bunje, P. (2011) 'The study of urban metabolism and its applications to urban planning and design', *Environmental Pollution*. Elsevier Ltd, 159(8–9), pp. 1965–1973. doi: 10.1016/j.envpol.2010.10.022.

Kenny, D. C. (2017) 'Modeling of natural and social capital on farms: Toward useable integration', *Ecological Modelling*. Elsevier B.V., 356, pp. 1–13. doi: 10.1016/j.ecolmodel.2017.04.010.

Keys W., P. (2018) *Resilience thinking for global development*, *Global gambles in the Age of Humans*. Available at: https://rethink.earth/global-gambles-in-the-age-of-humans/.

Kim, D. H. (1999) 'Introduction to Systems Thinking', *Most*, (September 2010), p. 16. Available at: http://www.thinking.net/Systems_Thinking/Intro_to_ST/intro_to_st.html.

Kita, S. M. (2017) 'Urban vulnerability, disaster risk reduction and resettlement in Mzuzu city, Malawi'. doi: 10.1016/j.ijdrr.2017.03.010.

Larson, B. (2011) *Metaphors for environmental sustainability: Redefining our relationship with nature*. New Haven: Yale University Press.

Lavorel, S., Bayer, A., Bondeau, A., Lautenbach, S., Ruiz-Frau, A., Schulp, N., Seppelt, R., Verburg, P., Teeffelen, A. van, Vannier, C., Arneth, A., Cramer, W. and Marba, N. (2017) 'Pathways to bridge the biophysical realism gap in ecosystem services mapping approaches', *Ecological Indicators*. Elsevier Ltd, 74, pp. 241–260. doi: 10.1016/j.ecolind.2016.11.015.

LeTourneau, C., Armstrong, A., Nelson, P., Berkowitz, M., Salkin, A., Flax, L., Laberenne, R., Brenner, A. and Lipper, B. (2016) 'Resilience Strategy. A plan to advance preparedness and equity in Berkeley, a community known for inclussiveness and innovation', *100 Resilient Cities*. Available at: http://lghttp.60358.nexcesscdn.net/8046264/images/page/-/100rc/Berkeley_Resilience_Strategy-LowRes.pdf (Accessed: 24 April 2017).

Linnenluecke, M. and Griffiths, A. (2010) 'Beyond adaptation: Resilience for business in light of climate change and weather extremes', *Business and Society*, 49(3), pp. 477–511.

Lu, P. and Stead, D. (2013) 'Understanding the notion of resilience in spatial planning: A case study of Rotterdam, The Netherlands', *Cities*, 35, pp. 200–212. Available at: https://ac.els-cdn.com/S0264275113000851/1-s2.0-S0264275113000851-main.pdf?_tid=7bf334f8-d383-11e7-8b66-00000aacb35d&acdnat=1511794913_e38f65af9ac7245be9017df94e95cd85 (Accessed: 27 November 2017).

Lucas, E. B. (2006) 'Migration and Economic Development in Africa: A Review of Evidence', *African Journal of Economics*, 15(2), pp. 337–395. Available at: doi:10.1093/jafeco/ejl032.

Luck, M., Jenrette, G. D., Wu, J. and Grimm, N. B. (2001) 'The urban funnel model and spatially explicit ecological footprint', *Ecosystems*, 4, pp. 782–796.

Marcus, J., Kurucz, E. C. and Colbert, B. A. (2010) 'Conceptions of the Business-Society-Nature Interface: Implications for Management Scholarship', *Business & Society*, 49(3), pp. 402–438.

Martínez-Alier, J. (2003) 'Ecología industrial y metabolismo socioeconómico: concepto y evolución histórica.', *Economía Industrial*, 351(III), pp. 15–26. Available at: http://www.minetad.gob.es/Publicaciones/Publicacionesperiodicas/EconomiaIndustrial/RevistaEconomiaIndustrial/352/Economia02.pdf.

Martínez-Alier, J. (2006) 'Los conflictos ecológico-distributivos y los indicadores de sustentablidad', *Polis, Revista de la Universidad Bolivariana*, 5(13), pp. 1–14. Available at: http://www.redalyc.org/articulo.oa?id=30551307.

Martinez, S., Escolero, O. and Kralisch, S. (2010) 'Water management in San Luis Potosí Metropolitan Area, Mexico', *International Journal of Water Resources Development*, 26(3), pp. 459–475. doi: 10.1080/07900627.2010.489292.

McBean, G. and Ajibade, I. (2009) 'Climate change, related hazards and human settlements', *Current Opinion in Environmental Sustainability*, 1(2), pp. 179–186. doi: 10.1016/j.cosust.2009.10.006.

McGrath, B. (2013) *Slow, moderate, fast: Urban adaptation and change.*, *Resilience in ecology and urban design: Linking theory and practice for sustainable cities*. Edited by S. T. A. Pickett, M. L. Cadenasso, and B. McGrath. New York: Springer.

McPhearson, T. (2013) *The Nature of Cities*, *Wicked Problems , Social-ecological Systems , and the Utility of Systems Thinking*. Available at: http://www.thenatureofcities.com/2013/01/20/wicked-problems-social-ecological-systems-and-the-utility-of-systems-thinking/ (Accessed: 21 May 2018).

Meadows, D. H. (2008) *Thinking in Systems*. USA.

Meadows, D. H. (2009) *Thinking in Systems*.

Mersal, A. (2016) 'Sustainable Urban Futures: Environmental Planning for Sustainable Urban Development', *Procedia Environmental Sciences*, 34, pp. 49–61. doi: 10.1016/j.proenv.2016.04.005.

Michael, F. L., Noor, Z. Z. and Figueroa, M. J. (2014) 'Review of urban sustainability indicators assessment - Case study between Asian countries', *Habitat International*. Elsevier Ltd, 44, pp. 491–500. doi: 10.1016/j.habitatint.2014.09.006.

Middleton, N. J. and Sternberg, T. (2013) 'Climate hazards in drylands: A review', *Earth-Science Reviews*. Elsevier B.V., 126, pp. 48–57. doi: 10.1016/j.earscirev.2013.07.008.

Minx, J., Ziegler, T. and Owen, A. (2010) 'Developing a Pragmatic Approach To Assess Urban Metabolism in Europe', *Quality*, p. 82.

Miser, H. J. and Quade, E. S. (1985) *Handbook of Systems Analysis: Overview ofUses, Procedures, Applications and Practice*. North Holland, New York.

Mochizuki, J., Mechler, R., Hochrainer-Stigler, S., Keating, A. and Williges, K. (2014) 'Revisiting the "disaster and development" debate - Toward a broader understanding of macroeconomic risk and resilience', *Climate Risk Management*. Elsevier B.V., 3, pp. 39–54. doi: 10.1016/j.crm.2014.05.002.

Moore, J., Kissinger, M. and Rees, W. E. (2013) 'An urban metabolism and ecological footprint assessment of Metro Vancouver', *Journal of Environmental Management*, 124, pp. 51–61. doi: 10.1016/j.jenvman.2013.03.009.

Morin, E. (2008) *On complexity*. New Jersey, USA: Hampton Press.

Nazari, S., Rad, G. P., Sedighi, H. and Azadi, H. (2015) 'Vulnerability of wheat farmers: Toward a conceptual framework', *Ecological Indicators*. Elsevier Ltd, 52, pp. 517–532. doi: 10.1016/j.ecolind.2015.01.006.

Nourhan, M. (2014) 'Analysis of Egyptian Cities towards Sustainable Urban Metabolism', in Bilec, M. and Choi, J.-K. (eds) *International Symposium on Sustainable Systems ad Technologies*. Sustainable Conoscente Network, pp. 1–9.

Odum, E. P. (1984) 'Properties of Agroecosystems', in Lowrance, R., Stinner, B. R., and House, G. J. (eds) *Agricultural Ecosystems. Unifying Concepts*. New York. EE.UU.: John Wiley and Sons, pp. 5–11.

OECD (2008) 'Measuring Material Flows and Resource Productivity', *Volume 1*, III, pp. 1–164. Available at: http://www.oecd.org/dataoecd/46/48/40485853.pdf%5Cnpapers2://publication/uuid/686D0BB7-44D3-454F-8D23-02FE7A24E1E8.

Oxford Business Group (2017) *Industrial growth to continue in San Luis Potosí*, *The Report: Mexico 2017*. Available at: https://oxfordbusinessgroup.com/overview/regional-powerhouse-industrial-growth-set-continue-region (Accessed: 16 July 2018).

Oxford Business Group (2018) *Oxford Business Group*, *San Luis Potosí Agricultural sector analysis*. Available at: https://oxfordbusinessgroup.com/analysis/key-area-potential-officials-look-ways-streamline-and-add-value-agriculture (Accessed: 6 August 2018).

Parnell, S. (2016) 'Defining a Global Urban Development Agenda', *World Development*. Elsevier Ltd, 78, pp. 529–540. doi: 10.1016/j.worlddev.2015.10.028.

Penn, H. J. F., Loring, P. A. and Schnabel, W. E. (2017) 'Diagnosing water security in the rural North with an environmental security framework', *Journal of Environmental Management*, 199, pp. 91–98. Available at: https://ac.els-cdn.com/S0301479717304437/1-s2.0-S0301479717304437-main.pdf?_tid=c0466b6e-ff59-11e7-88a5-00000aacb361&acdnat=1516614840_37a805f3c57d571a195226dd6bc067e2 (Accessed: 22 January 2018).

Peters, T. (1988) *Thriving on Chaos: Handbook for a Management Revolution*. Edited by HarperCollins.

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Groffman, P. M., Band, L. E., Boone, C. G. and Wilson, M. A. (2008) 'Beyond urban legends: An emerging framework of urban ecology, as illustrated by the Baltimore Ecosystem Study', *BioScience*, 58, pp. 139–150.

Pickett, S. T. A., Boone, C. G., McGrath, B. P., Cadenasso, M. L., Childers, D. L., Ogden, L. A., McHale, M. and Grove, J. M. (2013) 'Ecological science and transformation to the sustainable city', *Cities*. Elsevier Ltd, 32, pp. S10–S20. doi: 10.1016/j.cities.2013.02.008.

Pickett, S. T. A. and Cadenasso, M. L. (2002) 'Ecosystem as a multidi-mensional concept: meaning, model and metaphor', *Ecosystems*, 5, pp. 1–10.

Pickett, S. T. A., Cadenasso, M. L. and Grove, J. M. (2011) 'Urban Ecological Systems: Scientific Foundations and a Decade of Progress', *Journal of Environmental Management*, 92, pp. 331–362.

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Boone, C. G., Groffman, P. M., Irwin, E. and Warren, P. (2011) 'Urban ecological systems: Scientific foundations and a decade of progress', *Journal of Environmental Management*, 92, pp. 331–362.

Pickett, S. T. A., McGrath, B., Cadenasso, M. L. and Felson, A. J. (2014) 'Ecological resilience and resilient cities', *Building Research & Information*, 42(2), pp. 143–157. doi: 10.1080/09613218.2014.850600.

Pincetl, S. (2012) 'Nature, urban development and sustainability – what new elements are needed for a more comprehensive understanding?', *Cities*, 29(2), pp. 32–37.

Population Division, Department of Economic and Social Affairs and United Nations Secretariat (2001) *The Components of Urban Growth in Developing Countries*. Available at: https://esa.un.org/unpd/wup/Archive/Files/studies/United Nations (2001) - The Components of Urban Growth in Developing Countries.pdf (Accessed: 13 December 2016).

Ramos-Martin, J., Mayumi, K. and Giampietro, M. (2007) 'On China's exosomatic energy metabolism: An application of multi-scale integrated analysis of societal metabolism (MSIASM)', *Ecological Economics*, 63(1), pp. 174–191.

Redman, C. L., Grove, J. M. and Kuby, L. H. (2004) 'Integrating Social Science into the Long-Term Ecological Research (LTER) Network: Social Dimensions of Ecological Change and Ecological Dimensions of Social Change', *Ecosystems*, 7(2), pp. 161–171. doi: 10.1007/s10021-003-0215-z.

Renaud, F. G., Syvitski, J. P. M., Sebesvari, Z., Werners, S. E., Kremer, H., Kuenzer, C., Ramesh, R., Jeuken, A. D. and Friedrich, J. (2013) 'Tipping from the Holocene to the Anthropocene: How threatened are major world deltas?', *Current Opinion in Environmental Sustainability*. Elsevier B.V., 5(6), pp. 644–654. doi: 10.1016/j.cosust.2013.11.007.

Resilience Alliance (2007) *Assessing and managing resilience in social-ecological systems: A practitioners workbook. Version 1.0.* Available at: www.resalliance.org. (Accessed: 8 August 2018).

Resilience Alliance (2010) *Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners. Vesion 2.0.* Available at: http://www.resalliance.org/3871.php%0A2.

Resilience Alliance (2018) *Resilience Alliance*, *About*. Available at: https://www.resalliance.org/about (Accessed: 7 August 2018).

Revi, A. and Rosenzweig, C. (2013) 'The Urban Opportunity : Enabling Transformative and Sustainable Development', *Background research paper submitted to the High-level Panel on the Post-2015 Agenda*, pp. 1–47. Available at: https://www.researchgate.net/profile/Aromar_Revi/publication/261697339_The_urban_opportunity_Enabling_transformative_and_sustainable_development/links/0046353520e481787f000000.pdf.

Reyers, B. and Lee Moore, M. (2017) *Resilience thinking for global development*, *We all want to b resilient. Or do we?* Available at: https://courses.sdgacademy.org/courses/6351/learn#/posts (Accessed: 15 May 2018).

Richmond, B. (1994) 'System Dynamics/Systems Thinking: Let's Just Get On With It', *International Systems Dynamics Conference*. Sterling, Scotland, pp. 1–24. Available at: https://www.colorado.edu/mcedc/sites/default/files/attached-files/sdstletsjustgetonwithit.pdf (Accessed: 24 April 2018).

Robins, N. and Kumar, R. (1999) 'Producing, providing, trading: manufacturing industry and sustainable cities', *Environment&Urbanization*, 11(2), pp. 75–94. Available at: http://journals.sagepub.com/doi/pdf/10.1177/095624789901100208 (Accessed: 4 June 2017).

Rogers, K. H., Luton, R., Biggs, H., Biggs, R., Blignaut, S., Choles, A. G., Palmer, C. G. and Tangwe, P. (2013) 'Fostering Complexity Thinking in Action Research for Change in Social– Ecological Systems', *Ecology and Society*, 18(2), p. 31. doi: 10.5751/ES-05330-180231.

Romero-Lankao, P. and Dodman, D. (2011) 'Cities in transition: Transforming urban centers from hotbeds of GHG emissions and vulnerability to seedbeds of sustainability and resilience. Introduction and Editorial overview', *Current Opinion in Environmental Sustainability*, 3(3), pp. 113–120. doi: 10.1016/j.cosust.2011.02.002.

Romero-Lankao, P. and Gnatz, D. M. (2013) 'Exploring urban transformations in Latin America', *Current Opinion in Environmental Sustainability*. Elsevier B.V., 5(3–4), pp. 358–367. doi: 10.1016/j.cosust.2013.07.008.

Romero Lankao, P. and Qin, H. (2011) 'Conceptualizing urban vulnerability to global climate and environmental change', *Current Opinion in Environmental Sustainability*, 3(3), pp. 142–149. doi: 10.1016/j.cosust.2010.12.016.

Satterthwaite, D. (2007) 'The transition to a predominantly urban world and its underpinnings', *Human Settlements Discussion Paper Series: Urban change -4*, pp. 1–91. doi: 1 84369 560 X.

Scheiner, S. M. and Willig, M. R. (2011) *The theory of ecology*. Chicag: University of Chicago Press.

Secretaría del Trabajo y Previsión Social (2011) *Norma Oficial Mexicana NOM-031-STPS-2011*, *NOM-031-STPS-2011*. Diario Oficial de la Nación. Available at: http://www.stps.gob.mx/bp/secciones/dgsst/normatividad/normas/Nom-031.pdf (Accessed: 5 August 2018).

Secretaría General de Gobierno (2016) *Plan de San Luis: Periódico Oficial del Gobierno del Estado*. San Luis Potosí, S.L.P, México.

SEDESOL (2013a) *Indicadores de Carencia en la Vivienda*, *Sistema de Apoyo para la Planeación del PDZP*. Available at: http://www.microrregiones.gob.mx/catloc/IndRezViv.aspx?refn=240280264 (Accessed: 26 January 2018).

SEDESOL (2013b) *Indicadores de Marginación*, *Sistema de Apoyo para la Planeación del PDZP*. Available at: http://www.microrregiones.gob.mx/catloc/indiMarginacLoc.aspx?refnac=240280264 (Accessed: 26 January 2018).

SEDESOL (2013c) *Indicadores de Rezago Social*, *Sistema de Apoyo para la Planeación del PDZP*. Available at: http://www.microrregiones.gob.mx/catloc/indRezSocial.aspx?ent=24&mun=028&loc=0264&refn=240280264 (Accessed: 26 January 2018).

SEDESOL (2013d) *Microrregiones*, *Catálogo de Localidades: Sistema de Apoyo para la Planeación del PDZP*. Available at: http://www.microrregiones.gob.mx/catloc/contenido.aspx?refnac=240280554 (Accessed: 11 July 2018).

Sellberg, M. M., Ryan, P., Borgström, S. T., Norström, A. V. and Peterson, G. D. (2018) 'From Resilience Thinking to Resilience Planning: Lessons from Practice', *Journal of Environmental Management*, 217, pp. 906–918.

SENER (2017) *Evaluación Rápida del Uso de la Energía*. San Luis Potosí. Available at: https://www.gob.mx/cms/uploads/attachment/file/170903/28__San_Luis_Potos_.pdf (Accessed: 14 August 2018).

Seto, K. C., Reenberg, A., Boone, C. G., Fragkias, M., Haase, D., Langanke, T. and Simon, D. (2012) 'Urban land teleconnections and sustainability', *Proceedings of the National Academy of Sciences of the United States of America*, 109(20), pp. 7687–7692.

Shane, D. G. (2013) 'Urban patch dynamics and resilience: Three London urban design ecologies', in Pickett, S. T. A., Cadenasso, M. L., and McGrath, B. (eds) *Resilience in ecology and urban design: Linking theory and practice for sustainable cities*. New York: Springer, pp. 131–161.

Sharifi, A. and Yamagata, Y. (2016) 'Principles and criteria for assessing urban energy resilience: A literature review', *Renewable and Sustainable Energy Reviews*, 60, pp. 1654–1677. doi: 10.1016/j.rser.2016.03.028.

Simelane, T. (2012) 'To What Extent Are Cities Influenced by Rural Urban Relationships in Africa', *Natural Resources*, 3, pp. 240–247. doi: 10.4236/nr.2012.34031.

Sonwa, D. J., Somorin, O. A., Jum, C., Bele, M. Y. and Nkem, J. N. (2012) 'Vulnerability, forest-related sectors and climate change adaptation: The case of Cameroon', *Forest Policy and Economics*. Elsevier B.V., 23, pp. 1–9. doi: 10.1016/j.forpol.2012.06.009.

Spaans, M. and Waterhout, B. (2017) 'Building up resilience in cities worldwide – Rotterdam as participant in the 100 Resilient Cities Programme ☆', *JCIT*, 61, pp. 109–116. doi: 10.1016/j.cities.2016.05.011.

Steiner, F. R. (2002) *Human ecology: Following nature's lead*. Washington, DC: Island Press.

Sukamdi (2005) *Rural-Urban Population Mobility and Strengthening of Rural-Urban Linkages*, *Urban and Peri Urban Developments - Structures, Processes annd Solutions. Southeast Asian-German Summer School Programme 2005 in Cologne/Germany*. Edited by C. Knie.

Tatebe, J. and Mutch, C. (2015) 'Perspectives on education, children and young people in disaster risk reduction', *International Journal of Disaster Risk Reduction*. Elsevier, 14, pp. 108–114. doi: 10.1016/j.ijdrr.2015.06.011.

The Rockefeller Foundation (2017) *100 Resilient Cities*. Available at: http://www.100resilientcities.org/resources/#section-1 (Accessed: 6 December 2017).

The Rockefeller Foundation (2018) *Rockefeller Foundation*, *City Resilience Index*. Available at: https://www.rockefellerfoundation.org/report/city-resilience-index/ (Accessed: 7 June 2018).

The Rockefeller Foundation and ARUP (2015a) 'City Resilience Index', (December), p. 16. doi: London, United Kingdom.

The Rockefeller Foundation and ARUP (2015b) 'City Resilience Framework'. Available at: https://assets.rockefellerfoundation.org/app/uploads/20140410162455/City-Resilience-Framework-2015.pdf (Accessed: 6 December 2017).

Toledo, V. M. (2008) 'Metabolismos rurales : hacia una teoría económico-ecológica de la apropiación de la naturaleza', *Revista Iberoamericana de Economía Ecológica*, 7, pp. 1–26.

Toledo, V. M. (2008) 'Metabolismos rurales: hacia una teoría económico-ecológica de la apropiación de la naturaleza', *Revista Iberoamericana de Economía Ecológica*, 7, pp. 1–26.

Tong Keng Yam, T., Clos, J., Rodas, M. and Chan, M. (2016) *Urban solutions: Making cities strong, smart, sustainable*. Nairobi, Kenya.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L. and Schiller, A. (2003) 'A framework for vulnerability analysis in sustainability science', 100(14), pp. 8074–8079. Available at: www.pnas.org/cgi/doi/10.1073/pnas.1231335100.

Úbeda, X. and Sarricolea, P. (2016) 'Wildfires in Chile: A review', *Global and Planetary Change*, 146, pp. 152–161. doi: 10.1016/j.gloplacha.2016.10.004.

UCLG (2014) *Basic Services for All in an Urbanizing World: Third Global Report on Local Democracy and Decentralisation*.

UNDRO (1980) 'Natural Disasters and Vulnerability Analysis', *Report of Experts Group Meeting of 9-12 July 1979, UNDRO, Geneva, Switzerland*.

UNISDR (2004) 'Living With Risk', in *United Nations International Strategy for Disaster Reduction*. Geneva, Switzerland.

UNISDR (2009) 'Terminology on Disaster Risk Reduction', in *United Nations International Strategy for Disaster Reduction*. Geneva, Switzerland. Available at: unisdr.org/eng/library/lib-terminology-eng.htm.

UNISDR (2017) *Terminology*. Available at: https://www.unisdr.org/we/inform/terminology (Accessed: 11 February 2018).

United Nations (2005) *Definition of 'Urban', Demographic Yearbook 2005*. Available at: http://unstats.un.org/unsd/demographic/sconcerns/densurb/Defintion_of Urban.pdf.

United Nations (2012) *'Our Struggle for Global Sustainability Will Be Won or Lost in Cities,' Says Secretary-General, at New York Event | Meetings Coverage and Press Releases*. Available at: https://www.un.org/press/en/2012/sgsm14249.doc.htm (Accessed: 23 June 2018).

United Nations (2014a) *World City Populations Interactive Map 1950-2030*. Available at: http://luminocity3d.org/WorldCity/#4/27.92/-79.45 (Accessed: 10 February 2018).

United Nations (2014b) *World Urbanization Prospects*. New York. Available at: https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.Pdf (Accessed: 29 May 2017).

United Nations (2015) 'Transforming our world: the 2030 Agenda for Sustainable Development', *General Assembley 70 session*, 16301(October), pp. 1–35. doi: 10.1007/s13398-014-0173-7.2.

United Nations (2016) *Sustainable Cities: Why they matter*. Available at: http://www.un.org/sustainabledevelopment/wp-content/uploads/2016/08/16-00055K_Why-it-Matters_Goal-11_Cities_2p.pdf (Accessed: 15 December 2016).

United Nations Habitat (2015) *International Guidelines on Urban and Territorial Planning*.

Vakilifard, N., Anda, Martin, Bahri, P. A. and Ho, G. (2018) 'The role of water-energy nexus in optimising water supply systems – Review of techniques and approaches', *Renewable and Sustainable Energy Reviews*, pp. 1424–1432. Available at: https://ac.els-cdn.com/S1364032117307621/1-s2.0-S1364032117307621-main.pdf?_tid=2ecbad1e-feed-11e7-9c58-00000aacb35e&acdnat=1516568210_3e0eb95af23a7836e23132c47ce05402 (Accessed: 21 January 2018).

Vastag G, K. S. (1996) 'Evaluation of corporate environmental management approaches: a framework and application', *Rondinelli DA*, 43, pp. 193–211.

Vlahov, D., Freudenberg, N., Proietti, F., Ompad, D., Quinn, A., Nandi, V. and Galea, S. (2007) 'Urban as a Determinant of Health', *Journal of Urban Health*, 84(1), pp. 16–26. doi: 10.1007/s11524-007-9169-3.

Vuille, M., Carey, M., Huggel, C., Buytaert, W., Rabatel, A., Jacobsen, D., Soruco, A., Villacis, M., Yarleque, C., Elison Timm, O., Condom, T., Salzmann, N. and Sicart, J. E. (2018) 'Rapid decline of snow and ice in the tropical Andes – Impacts, uncertainties and challenges ahead', *Earth-Science Reviews*. Elsevier, 176(October 2017), pp. 195–213. doi: 10.1016/j.earscirev.2017.09.019.

Wachsmuth, D. (2012) 'Three Ecologies: Urban Metabolism and the Society- Nature Opposition', *The Sociological Quarterly*, 53, pp. 506–523.

Wagner, I. and Breil, P. (2013) 'The role of ecohydrology in creating more resilient cities', *Integrative Medicine Research*, 13, pp. 113–134. doi: 10.1016/j.ecohyd.2013.06.002.

Warren-Rhodes, K. and Koenig, A. (2001) 'Escalating trends in the urban metabolism of Hong Kong: 1971–1997', *AMBIO*, 30(7), pp. 429–438.

Whiteman, G., Walker, B. and Perego, P. (2013) 'Planetary Boundaries: Ecological Foundations for Corporate Sustainability', *Journal of Management Studies*, 50(2), pp. 307–336. doi: 10.1111/j.1467-6486.2012.01073.x.

Wiener, N. (1948) *Cybernetics Or Control and*

Communication in the Animal and the Machine. MIT Press.

Wilkinson, C. (2012) 'Social-ecological resilience: Insights and issues for planning theory', *Planning Theory*, 11(2), pp. 148–169.

Williams, A., Kennedy, S., Philipp, F. and Whiteman, G. (2017) 'Systems thinking: A review of sustainability management research', *Journal of Cleaner Production*. Elsevier Ltd, 148, pp. 866–881. doi: 10.1016/j.jclepro.2017.02.002.

Wolman, A. (1965) 'The Metabolism of Cities', *Cities*, pp. 156–174. Available at: http://www.irows.ucr.edu/cd/courses/10/wolman.pdf (Accessed: 4 June 2017).

World Bank and International Monetary Fund (2013) *Global Monitoring Report 2013: Rural-Urban Dynamics and the Millennium Development Goals*. doi: 10.1596/978-0-8213-9806-7.

World Commission on Environment and Development (1987) *Our Common Future: Report of the World Commission on Environment and Development*. Available at: http://www.un-documents.net/our-common-future.pdf (Accessed: 13 March 2018).

Yohe, G. and Tol, R. S. J. (2002) 'Indicators for social and economic coping capacity – moving toward a working definition of adaptive capacity', *Global Environmental Change*, 12, pp. 25–40.

Ziervogel, G., Pelling, M., Cartwright, A., Chu, E., Deshpande, T., Harris, L., Hyams, K., Kaunda, J., Klaus, B., Michael, K., Pasquini, L., Pharoah, R., Rodina, L., Scott, D. and Zweig, P. (2017) 'Inserting rights and justice into urban resilience: a focus on everyday risk', *International Institute for and Development (IIED)*, 29(1), pp. 123–138. doi: 10.1177/0956247816686905.