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Advancing Sustainability in Latin American Cities: a Study Case on the Urban Metabolism of San Luis Potosí, México

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PRESENTS:

Lucia Elsa Benavides, Mondragón, arch.

CO-DIRECTOR OF THESIS PMPCA

Dr. Alfredo Ávila Galarza

CO-DIRECTOR OF THESIS ITT:

Dr. Johannes Hamhaber

ASSESSOR:

Dr. Carolin Baedeker

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Matri.-Nr. / *N° de matricula*: 11109884 **(CUAS), 0255965 (UASLP)**

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2017

al poder
elemental y dador de vida
del desierto mexicano

a la fuerza
inagotable
de sus caminantes

seamos capaces compañerxs,
de hacer florecer la tierra.

LBM
Colonia, 11.09

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Abbreviations used

BCE	Before current era
CAS	Complex Adaptive System(s)
CSR	Corporate Social Responsability
EEA	European Environmental Agency
EF	Environmental Footprint
EIO	Economic Input Output
EM	Energy Metabolism
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
Ga	Giga annum
GHG	Greenhouse gas
gWh	Giga-watt hour
INECC	Instituto Nacional de Ecología y Cambio Climático
IPCC	Inter-governmental panel on climate change
IUGS	International Union of Geological Sciences
ISO	International Standards Organisation
IUME	Integrated Urban Monitoring European Programme
J	Joule
k	kilogram
kt	kiloton
kWh	kilowatt-hour
LCA	Life cycle assessment
LF	Land footprint
M(E)FA	Materials (and energy) flow accounting
MIT	Massachusetts Institute of Technology
MuSIASEM	Multi-scale Integrated Analysis of Societal Metabolism
mWh	Megawatt-hour
NAFTA	North American Free Trade Agreement

NUP National Urban policy
NEF New Economics Foundation

PJ Petajoule

SAGARPA Secretaría de Agricultura, Ganadería, Desarrollo Rural y Pesca
SEGAM Secretaría de Ecología y Gestión Ambiental
SEMARNAT Secretaria del Medio Ambiente y Recursos Naturales
SENER Secretaría de Energía
SFA Substance Flow Analysis
SGS Soledad de Graciano Sanchez
SLP San Luis Potosí
SR System Robustness

t ton
TMR Total Material Requirement

UM Urban metabolism
UMA Urban metabolism analysis
UN United Nations

WB World Bank
WCO World Customs Organisation
WTO World Trade Organisation

Advancing sustainability in Latin American cities: A study case on the urban metabolism of San Luis Potosí, México

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Summary:

Urbanization is one of the main factors of global environmental change. Contemporary lifestyles have increased the velocity and intensity of resource consumption, while producing enormous volumes of waste and toxics, pervasively altering landscapes and disturbing ecosystem function at different scales, and ultimately posing problems for human health. Much of these consumption patterns are concentrated in cities, where already >50% of the world's population lives. Latin America & the Caribbean (LAC) is a richly biodiverse region, whose wealth in natural assets has long been the basis of its role in the international economy. It is the most urbanized region of the world, with ~80% of its population being urban. While environmental impacts associated with this rapid and large-scale urbanization continue to occur, data about the environmental *status quo* is incomplete or scattered, and is often missing regarding the specific topic of urbanization and its impacts. Fundamental baseline data such as resource consumption for specific cities is rarely collected, and urban sustainability practice in general is still incipient. This thesis explores this situation and possibilities to overcome it. It examines frameworks applied globally to urban sustainability thought and practice, and proposes a prototype tool (Urban Metabolism Analysis with a nexus perspective) to apply to a case-study city in central Mexico. It concludes by reporting on the tool's performance and viability for further use in LAC, as well as on data availability and patterns of natural resource consumption under a nexus a perspective in the city studied.

Keywords: *Cities, urban sustainability, urban metabolism, Latin America, San Luis Potosí, nexus perspective.*

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Resumen:

La urbanización es un factor principal del cambio ambiental global. Los estilos de vida contemporáneos han aumentado la velocidad e intensidad del consumo de recursos naturales, al mismo tiempo que producen enormes volúmenes de desperdicios y tóxicos, alteran paisajes y perturban el funcionamiento ecosistémico en varias escalas, poniendo también en riesgo la salud humana. Estos patrones de consumo se concentran en las ciudades, donde ya habita >50% de la población mundial. La riqueza natural de la región de América Latina y el Caribe (LAC) ha constituido por siglos la base de su inserción en la economía internacional. LAC es la región más urbanizada del mundo, con ~80% de población urbana. Los impactos ambientales asociados a esta rápida y generalizada urbanización continúan, pero los datos sobre el *status quo* ambiental, y en particular sobre la urbanización y sus consecuencias son insuficientes. Datos fundamentales, tales como las tasas de consumo de recursos para ciudades determinadas se generan rara vez, y en general es incipiente el trabajo sobre la sustentabilidad de las ciudades. Esta tesis explora esta situación y maneras para mejorarla. Examina marcos utilizados globalmente para pensar y practicar la sustentabilidad urbana, y propone un prototipo de herramienta (Análisis del Metabolismo Urbano con perspectiva sistémica), aplicándola en un caso de estudio en el centro de México. Concluye analizando el desempeño de la herramienta y su viabilidad para futuros usos en LAC, y reportando sobre la disponibilidad de datos y los patrones de consumo de recursos naturales en la ciudad estudiada.

Palabras claves: *ciudades, sustentabilidad urbana, Latinoamérica, metabolismo urbano, San Luis Potosí, perspectiva nexus*

Chapter 1.

Global environmental change, cities & sustainability.

1.1 Global environmental change

Except for a relatively reduced number of people, advocacy groups and scholars (e.g.[1–7]), it is now mostly a world-wide consensus that the planet is facing unprecedented human-induced environmental change –including but not at all limited to global warming[A]--, which has already began to endanger human activities as well as to perturb other species and all ecosystems on the planet[16–21].

It is true that alteration of the earth occurs normally as a result of its interaction with not only humans but any other species. Ants in their constructive efforts re-model the surface of the soil, translocation minerals and modify edaphic properties in the surroundings of their nests, thus influencing plant diversity at the micro-scale[22], yes. A myriad of such examples can be found. However, the scale and velocity of change attributable to humans, particularly since the second half of the 19th century, seems to be unprecedented [23]. Oxygenic cyanobacteria and plants began changing the chemical composition of the atmosphere during the Archean period 2.45 Ga[B] ago[24]. But their effect, most likely heightened by the escape of excess hydrogen towards outer space and a change in the composition of volcanic emissions[25], nonetheless took between 400 and 700 million years before the difference created was large enough to allow for major change, namely the constitution of an oxygen atmosphere and the emergence of eukaryotic life[26,27]. The difference in time scales is quite eloquent: humans have changed the chemical composition of their local troposphere beginning 2,500 years ago[28] and at a faster pace and at world-scale in the last 200 years[29], a change at least 5 orders of magnitude faster than the Archean oxidation.

It is well established that human activity has altered almost every corner of the earth, from the atmosphere to the deep ocean and the icy poles[30,31]. The human activities driving these changes, as graphed by Steffen et al. (2015) show a dramatic acceleration around the mid 20th century[23]. Although the long term consequences of ecological interactions are known to be, at best, extremely difficult to predict with certainty, and however uncertain global warming could be thought to be, so far the summing up of human ecological alterations appear to be pernicious to the existence and thriving of

[A] Sceptical views on climate change, particularly on global warming, and human´s responsibility therein, have been and are held by various people, scholars and institutions. Investigative journalism has unveiled links of many "sceptics" with coal, oil, agrochemical and other corporations whose profits could be undermined under stricter environmental regulation [8–10]. In the scientific realm, controversies and heated debates around statistical interpretation, credibility of methods and models, and the overall capacity of human action to cause relevant climate change were particularly intense around the turn of the century [11–15]. Although a world consensus seems to be somewhat settled around the IPCC`s reports and a corpus of United Nations-led agreements, these do not remain unchallenged, as sceptics continue to publish and in other ways put forward their arguments. However thick the evidence for anthropogenic climate change (ACC) seems to pile up, it is reasonable to acknowledge that controversy exists, and that the science of climate change may still much improvement ahead. The present work can unfortunately not treat this controversy, as research and opinions on either side are abundant and constantly revised, criticized and mutually un-validated, and the task would be gigantic. The interested reader is advised to consult references 1-17. It must be said that in looking for scientific literature that argued *against* ACC, I ran mostly into newspaper or magazine articles, articles in journals who charge authors a publishing fee or books published by advocacy groups with an evident tendency. In my references for this topic, I have deliberately tried to include as few of these as possible. For a comprehensive list of personalities, institutions and publications who have argued that there is no climate change, that it is an unimportant phenomenon or that it is not human-caused, among similar ideas, the reader may consult the Climate Disinformation Database at www.desmogblog.com.

[B] Ga=*Giga annum*, or 10^9 years. 1 Ga= 1,000 million years.

species –including our own- and ecosystems. Mass extinction of species due to human-induced land cover change[18], loss of primary productivity in various ecosystems[21], degrading of ecosystem services for humans[18,32] and loss of resilience up to quasi-collapse of coastal marine ecosystems due to overfishing [33] are a few examples among probably thousands of well-documented impacts of human activities on Earth system – the comprehensive list of which falls well beyond the scope of this work, although a few cases will be examined.

A recent attempt to quantify environmental change in an illustrative, operational and policy-relevant manner was made by Rockström *et al.* (2009) with the introduction of the Planetary Boundaries framework[34]. Planetary boundaries are calculated limits of modification beyond which abrupt and unpredictable behaviour of the given parameter is likely to occur, ultimately resulting in potential risk to human society[34,35]. PBs were originally established for 9 variables and refined in the 2015 edition of the framework[36] : (i) climate change, (ii) stratospheric ozone depletion, (iii) atmospheric aerosol loading, (iv) ocean acidification, (v) interference of biogeochemical cycles, (vi) global freshwater use, (vii) land-system change, (viii) change in biosphere integrity and (ix) introduction of novel entities. As calculated by the research team, global society has surpassed three of the nine boundaries and is approaching dangerous levels in at least two. Although the consequences of these crossings are not explicitly stated, the authors consider that crossing planetary boundaries is likely to result in functional collapse or ecosystems[34] and therefore of the live-support base of human society.

Because the irruption of earth´s dynamics is so large –indeed, between 75% and 80% of Earth's surface is estimated to be under direct human pressure of some sort[37,38]- some researchers have estimated it will be evident in a geological scale[39]. The term *Anthropocene* was originally proposed by Crutzen and Stoermer (2000) to distinguish our time from the Holocene, the officially recognized name of the geological epoch we are living in, a subdivision of the Quaternary period. The main premise of the *Anthropocene* concept is that during the Holocene, humans evolved their capacity to modify the earth to such a magnitude that the species has become a geological force, comparable to volcanism or erosion, something that, according to the authors had been recognized by scholars since the 19th century. Proponents of the term hold that, because of the large scale consequences of environment-modifying behaviours, traces of the human species on Earth will be clearly distinguishable in sediments, rock strata, tree rings or ice cores millennia from now even in the hypothetical case that we should suddenly disappear tomorrow[40,41,39] and therefore the epoch should bear a name that appropriately reflects its main drivers : humans.

Throughout the years since its initial publication, many scientists and scholars around the world have come together under the momentum created by the broad acceptance of the *Anthropocene* concept. Work and debate have been ongoing : the proposed beginning date for the *Anthropocene* has been suggested to change from the mid 10th century to the early or mid 20th[42,43,23], with other authors presenting the evidence of possibly human-caused pre-historic faunal extinction and ecological change as arguments of a much longer *Anthropocene*, encompassing or even surpassing the Holocene[44,45] and yet others proposing the stratigraphic appearance of anthropogenic soils, or the diachronic increase in the presence of certain materials in stratigraphic columns as more suitable boundaries[46,47]. At the time of writing, debate continues within the International Union of Geological Sciences (IUGS) on whether and under what terms the *Anthropocene* will be officially accepted as a new geological era[48,49].

Patterns of the anthroposphere

« Excess of manpower abetted an excessive belief in the power of man »

- Lewis Mumford
The Natural History of Urbanization, 1956

Regardless of the suitability one may ponder for term *Anthropocene*, or of the exact starting date we choose for it, we can continue forward, stepping on the stones laid by the abundant evidence of human caused environmental change such as we have cited it in the preceding section. That humans have altered early Holocene environmental conditions, including species abundance and distribution, climate at the local scale and likely also at the global scale, numerous abiotic systems of the earth system such as biogeochemical cycles and so on, has been widely demonstrated so as to assume it as a first element of the present work. In this train of thought, I would like to now introduce the work put forward by a team of chemists, working in the fields of environmental science and environmental management, who have tried to outline the general behavioural patterns that cause these very effects.

Baccini and Brunner (1991) introduced the notion of *Anthroposphere*, distinct from, but much in the spirit of Crutzen and Stoermer's later *Anthropocene*, to describe the network of human creations, material and immaterial, that constitute the unique habitat of our species. This network has steadily grown since the advent of human fabrication in prehistory, to now interconnect the most remote corners of the earth: roads and train lines, towns and cities, forestry and agricultural parcels, sailing routes and their ships, water supply pipes, optic fibre lines and the information circulating within are all part of the Anthroposphere. The authors transpose the physiological notion of *metabolism*[C], proceeding from the medical sciences, and propose to analyse the *Metabolism of the Anthroposphere* as the circulation and stocks of materials and energy that keep the anthroposphere running. In their 2012 revision of the original work, they identify seven « *Key phenomena of Modern Anthropogenic metabolism* »[50D].

[C] The terms *« metabolism, urban metabolism, social metabolism »* have been used by other scholars preoccupied with the material flows of human societies, at least since 1960s and likely since the XIXth century. A revision of the use of the term is given in chapter 2.
[D] Baccini and Brunner's publication (2012) presents the seven key phenomena in a different order than is given here, but all have been included. I have also extended their description, enriching the description of each point with contributions from other literature.

1) Increasing material and energy[E] flows

Although consumption is shrinking in some regions of the world, average per capita consumption of materials and energy, also called *material/energy intensity*, is a growing phenomenon. Each individual consumes more energy and materials in his or her daily life than ever before, as do national economies [51,23]. Although growth in material/energy intensity of human life can be assumed to be a trend since early human life, its increase was relatively slow until the mid 20th century, when material consumption grew at unprecedented rates, exceeding doubling between 1950 and 2010[51,52]. During the 20th century, mining of metals was multiplied by 27, the extraction of construction materials such as gravel and sand grew 34 fold and fossil fuel extraction 12 fold[53]. The average per capita material consumption of today's humans is 10.3 ton/year, with great variations from one region to another : 4.5 t/cap/year in Sub Saharan Africa and 14.8 t/cap/year in Western Industrialised countries[52]. As for energy, data from the World bank show a per capita average energy use of 1.92 toe/y in the year 2014[54]. In both cases the trend has been to growth all throughout the 20th century.

The material intensity of a given economy or product is greater when taking into account what Schmidt-Bleek (1994) called *ecological rucksack*, i.e. substances and products not directly consumed by a final consumer but which are used to grow, manufacture or transport a product, and remain anonymous to the consumer[55]. Increasing importance has been given to the rucksack idea, through echoing concepts and measurement methodologies such as *ecological footprint*[56] ; *virtual water* and *water footprinting*[57,58]; *embodied flows*, *embodied carbon* and *carbon footprinting*[59,60] and *hidden flows*[61].

The importance of invisible flow accounting is ever growing in a global economic system where raw material extraction, production and consumption many goods occur in different places, with the participants of each phase having little or no contact or knowledge of other phases in the product's life cycle. The assessment of a product or a country's resource or energy intensity will be flawed, and sometimes greatly, when embodied flows, e.g. embodied carbon, are not considered, and thus apparent advances toward sustainability may not be as much[62]. The New Economics Foundation (NEF) goes so far as to propose the term *carbon laundering*, to refer to the non-accounting of large amounts of greenhouse gas emissions caused by transferring production from developed countries to developing countries[63]. Through this offsetting, although carbon footprints and other sustainability indicators would appear to be improving in some countries, when the whole life cycle of products and the global scale is considered, this is not necessarily so.

[E] Baccini and Brunner (2012) do not include energy flows in their seven key phenomena, although energy is by no means an unimportant part of human living, and the growth of its flows throughout human history has followed trend much like that of material flows[51]. I consider that the study of energy flows is fundamental to understand the evolution and behaviour of the anthroposhere and have thus included them in this point.

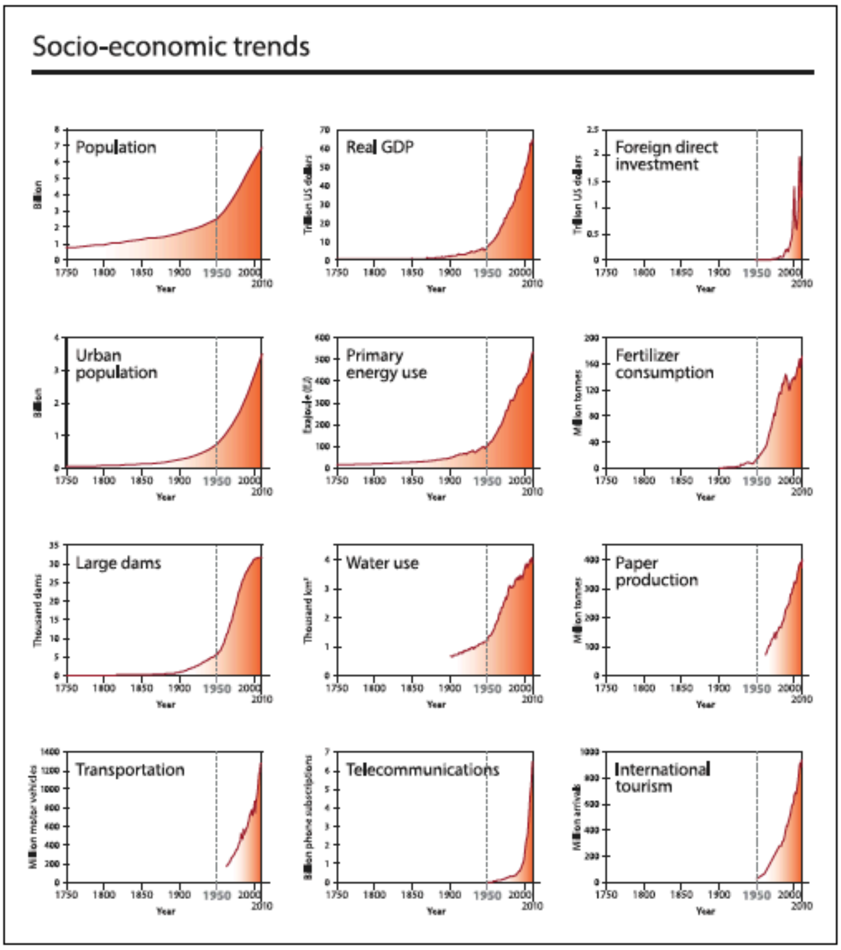

Fig. 1.1. Updated "Great acceleration" charts, showing consumption trends from 1750 to 2010. Taken from Steffen *et al* (2005)

Since the turn of this century, efforts have been launched to decrease the material and energy intensity of industrialised economies[64]. Material intensity has indeed ceased to grow in most of western Europe, and has also done so in Sub-Saharan Africa, although for very different reasons. All other regions, particularly Asia, remain on a growing trend, and the overall material and energy throughput of the world economy, when considered in ensemble, grew drastically during the last half of the 20th century, and though at a slower rate now, continues to grow into the XXIst[51,52]

2) Increasing complexity

A parallel phenomenon of the steadily growing size and material intensity of the metabolism of the anthroposphere is the increasing complexity of its products. According to Baccini and Brunner (2012), 1 million substances are newly identified every year, many of which will be put into the market and used in diverse manufacturing procedures. For the sake of illustration, we shall use the example of a semiconductor –what we commonly know as a microchip. At present technology, a microchip is composed of many different materials (at least in the 10^2 order of magnitude), among which are several synthetic substances whose exact chemical formulas and elaboration procedures are unknown because they are the intellectual property of private enterprises[65]. A chip´s manufacturing process calls for a similarly large number of steps[66,65], which are many times outsourced to different companies and countries, along a dispersed, international assembly line[67]. The long and complex series of steps, composed of hundreds of products of sometimes unknown characteristics, which come together in a series of multinational operations, makes the thorough Life Cycle Analysis of a microchip a task almost impossible to perform with great accuracy[66,68].

As of now, we at least know that the manufacture process is resource-intensive : one single microchip weighing 2 gr., has consumed during its fabrication 800 times its weight in fossil fuels and 36 times in diverse chemical substances[69]. It also known that with the advancement of sophistication in a given technology, there is a tendency for manufacturing process to also become more complex, involving more steps, more energy and more materials –among which some toxic, carcinogenic or potentially harmful to ecosystems[65].

The complexity intrinsic to the product in question reflects upon the overall complexity of today´s anthroposphere -and of the environmental analysis thereof. A last example will be Bull and Kozak's (2014) work on a topic much taken for granted in everyday life: that supplanting printed matter with digital media brings about environmental advantages. In reality, in order to know whether a document has more or less environmental impact when printed than when sent by email, one would have to perform detailed LCAs of both activities. While an LCA for a paper-printed document is quite straight forward, the LCA for sending an email may prove, as we have seen, almost prohibitively difficult, as it is now not only microchips in question, but a whole array of equally under-studied and perhaps opaque components of other electric appliances, global information transmission infrastructure, satellites and so on.

The fastly-growing complexity of human products and their chains of production, with digital electronics being perhaps the *non plus ultra* of all possible examples, appears as quite inapprehensible, moving into unpredictable trends at such a pace that attempts to measure, analyse and reflect on their environmental consequences cannot quite catch up[68].

3) Linear material flows

Today's human made flows of materials mostly follow a linear path: materials are extracted, used and disposed of. Globalized markets and technological sophistication have allowed for (i) successive assembly of products in different parts of the world, with components mined or grown also in different parts of the world, and (ii) chemically complex and highly synthetically products, as we have seen in the previous point. Resulting are a complex de-localisation of resources and materials (e.g. carbon embedded in wood from a Finnish forest sent to Japan as construction wood) and ii) unlikely or difficult reintegration of products to the biosphere (e.g. via decomposition) due to their complex chemical composition or to waste management models.

Where biological reintegration would be possible, as could be the case of many foodstuffs, currently dominant waste management models constitute an obstacle for the re-integration, or circular flow, of nutrients and organic matter. In a pre-modern human settlement –or indeed in envisionable contemporary agroecological food systems- most of the nutrients resulting from locally grown food would be reintegrated into local or nearby soil[70–74]. In contrast, in most present-day human settlements, the waste generated after the consumption of food will go into municipal sewage and solid waste recollection systems. In the sewage system, it will be mixed with other substances and materials such as endocrine disruptors, pharmaceuticals, heavy metals, plastics and an array of chemical compounds, that would render it unsuitable for farm irrigation. Sewage water will then follow one of two possible paths: one, to be treated in a water treatment facility, after which nonetheless it would likely still not be suitable for crop irrigation or for reincorporation into the hydrosphere[75–77], although the latter is standard practice in developed countries. Alternatively, and if this hypothesis were to happen in a less developed country, it may be directly pumped into the hydrosphere or directly on agricultural or otherwise non-urban soil, were it will constitute in all propriety a form of –often quite hazardous- pollution to ecosystems and human communities along the way[78–81]. In any of both alternatives (and of course the globally more infrequent former is preferable albeit not perfect) nitrogen, phosphorus, organic matter and other potentially valuable components originally contained in food waste will be lost into landfill stocks and/or paradoxically (tragically?) transformed into environmental pollution[82–84]. New nitrogen and other nutrients, most likely synthesized, will be brought into the farming system to again follow the same path.

This linear throughput has been the pattern of modern economics : sourcing, producing, selling, using and disposing-[85,86] By definition, at the end of such a process, i.e. after consumption, waste results and accumulates, as materials and products cannot be re-circulated. On the other end, upstream sources of materials may become depleted if they are not managed sustainably. Thus, the ecosystems which provide for human activity – the hinterland – must not only be sources but also sinks to process wastes[50]. As has been discussed above, the capacity of the planet to cope with linear flows, intensive upstream and downstream, and with little or no opportunity to regenerate resources, appears to be nearing its limits.

4) Increasing stocks of materials and substances.

Because net material imports exceed net exports in most human-occupied regions, the latter have increasingly become a sort of gigantic warehouse of diverse materials. Constructed buildings, roads and other infrastructure constitute stocks of asphalt, cement, steel, plastics and so on; landfills or residues left behind after mining or industrial activities are stocks for a large diversity of materials, including economically valuable as well as hazardous substances.

Though there is too little quantitative or qualitative knowledge about human material stocks, they are thought to be both potentially dangerous and economically profitable. In the first case, it is esteemed that stocks of materials can pose a risk in the case of hazardous substances. The weathering of stocks of paint, cement and other building coatings as well as the wear of car brakes and machinery slowly « leaks » out of the stock in the form of pollution and inadvertently increases contamination levels in water and soils. Through a first estimate, Baccini & Brunner (2012) found that there are more hazardous substances embedded in the urban fabric than in a hazardous waste disposal sites[50].

Human material stocks could also hold economic potential : stocks of copper, zinc, silver and other metals « residing » in cities have been calculated to be large enough to allow in the near future for *urban mining* as a substitute measure, perhaps more economical and sustainable (or downright necessary) than the exploitation of deplenished natural ores[87,88,50,89].

5) Anthropogenic material flows are greater than geogenic flows

Since the beginning of its industrious existence, the anthroposphere builder has moved substances and materials from one place to another in order to accomplish his projects or as unintended consequences thereof. By the beginning of the 21st century, ~80% of the Earth is under some type of human influence, mainly through agriculture[37] and ~50% of the Earth's ice free surface has been «*directly modified by human action involving moving Earth or changing sediment flux*es»[90].

Anthropogenic translocations of matter (e.g. nitrogen input into lakes and rivers, excavations and mines, plastic matter input into oceans) have become, in some cases, larger than geogenic translocations (e.g. the natural nitrogen cycle, movement of land as a result of landslides or subsidence, the naturally non-existing plastic flow into oceans), and in some other cases, closely approaching. Already in the early 1980s, Brunner and Baccini had calculated an anthropogenic cadmium flow twice as large as the naturally occurring or geogenic flow[50]. A little over a decade later, Vitousek and colleagues found the Nitrogen human-led flow to be also twice as large as the naturally occurring movement of nitrogen through the N cycle[82].

Fig. 1.2. Adam-Pirie Quarry. Barre, Vermont, USA, 1991. Photograph by Edward Burtynsky. Taken with permission by the author from the site http://www.edwardburtynsky.com/

6) Consumption emissions surpass production emissions

In present-day society and because of advancing environmental regulation regarding industrial and other manufacturing processes, polluting emissions have been reduced. However, according to Baccini & Brunner (2012) emissions linked to the consumption phase of goods have increased, as has consumption itself. Even assuming consumer-end emissions not to be growing, if production-end emissions continue a decreasing trend, eventually they will fall below those on the consumer-end. At any rate attention should also be paid to consumption-end emissions, of which some examples are: greenhouse gas emissions associated with the energy used for the heating of houses, or to move vehicles; particulate matter and heavy metals from zinc on construction steel, paints and impermeable roof coatings on buildings, vehicle's rubber tires and brake linings[91].

7) increasing urbanization

« ...may a city perhaps continue to grow
until a single continuous urban area might
cover half the American continent,
with the rest of the world tributary to this mass?

- L. Mumford
What is a City?, 1937.

Although the boundary between 'rural' and 'urban' settlements is not necessarily a clear one and this has promoted a decades-long debate[92–95], it is today commonplace to quote the United Nations in saying that around half of the world's population lives in 'cities' and that the trend for this century is for that number to increase. Before entering head on into the subject of urbanization, and in the spirit of exercising the critical and cautious spirit which must accompany the entrance into mainstream debates, - as urbanization so clearly is in our day –, I would like to briefly stop at the conceptual question of what a city is and is not, re-visiting the debate and some of its contributors through time.

Etymological definitions of the Latin *civitas* will direct us to political status and rights of inhabitants, to public life and belonging to an organized State. The earlier Greek *urbis* and it relative *urbanus*, hint towards « courteous », « polished » or « polite », itself from *polis* which also gave us « politics ». Forms of *urbanus* are still in use, albeit declining through the 20th century, in for example French (*urbanitê*) and Spanish (*urbanidad)* as referring to being refined, well-mannered or attentive. H.D.F Kitto (1951) has registered for us that in classical literature, 2500 years ago, Plato can be found saying that an ideal city would have enough productive land to feed itself, and hold around 5,000 citizens (males old enough to vote and have property) plus their corresponding wives, children and slaves. The Greek polis was indeed densely built and exhibited walls or other delimiting elements, gates and city doors, and tributary agricultural lands in the periphery[96].

The famed archaeologist Gordon Childe (1938) describes cities succinctly as a multiplication of «*the number of people living together in a single built-up* area» ; while Lewis Mumford (1956) identifies two main traits : «*an organized social core[...] around which the whole community coheres* », and the use of permanent materials and specialized methods to build all sort of buildings and infrastructure such as palaces, temples, roads and sewage lines[97].

Potter (1985), provides a useful synthesis of opinions. Building on the work of Lampard (1965) he proposes three possible, not mutually exclusive, perspectives to define the 'urban': (i)Behavioural, the 'urban' understood as an attitude, way thought life, distinct from the rural (ii)Structural, the 'urban' is a place where the reigning activities are not agricultural, and at the same time made possible precisely because of agricultural surplus in rural environments, and (iii)Demographic, where 'urban' is understood as a concentration of people at a greater density than that found in rural areas. Also cited here we find Danserau (1978), listing as characteristics of the 'urban' : high densities, high cover of built structures, and transformation of wild landscapes ; Wirth (1938), stressing social heterogeneity and Tuan (1978), pointing at a life distanced from food production, from the constraints of nature (night time lack of light) and from the seasons' hardships (cold winters)[98].

Lewis Mumford had also said elsewehere (1937) that a city´s essential physical traits are : a *«fixed site, durable shelter and permanent facilities for assembly, interchange and storage»* but recognizes all of them to be equally likely to occur in a rural setting. He thus proceeds to state the only real difference is really qualitative: «*the city creates drama, the suburb lacks it*»[99]. Renowned author and critic of urban development Jane Jacobs also wrote about the scenic nature of 'good' urban space in her *Death and Life of Great American Cities* (1961). And there is of course the almost metaphysical understanding of what creates urban form, and of the interconnectedness of people and nature that allow for the creation of *natural* vs. *artificial* cities proposed by such scholars as Christopher Alexander[100]. And in this direction we could continue to find many valuable thinkers enriching and pushing the century-old conversation on what makes a city a city.

But we shall go no further, as the point has been made that cities have been an important element of society at least since antiquity, and that the attributes of what 'urban' spaces are considered to be have changed over time and may also continue changing in the future. Today, although no official world-wide definition exists[F], we can agree that what we call urban space' or 'cities' is a distinct agglomeration of traits, punctuating and dissolving back into the urban-rural gradient. These traits tend to include (i) little to no presence of wild ecosystems or primary production systems (agriculture, mining: hence the need to distinguish 'urban' agriculture from 'normal' agriculture); (ii) an observable break on the territory, from a pattern of low density of population and of built structures, to a higher density of both; (iii) an intense cultural and social activity combined with a relatively anonymous social condition : most people don´t know each other ; and (iv) an almost absolute dependence on a provisioning territory outside its bounds – the hinterland[56,50]- for food, water, to sink wastes and most other things vital[G].

Under the comprehensive and multiple definition allowed for by the United Nations[H], urban space occupies 3% of the Earth's surface[103]. Indeed 54% of the world's population inhabit cities of some sort[104], compared to 30% in 1950[105], 13% at the beginning of the 20th century[106], and 2% at the

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[F] In order to count and analyse world urban population, the United Nations recurs to each country's population count according to what is locally understood as "urban" in the legal frame. For example, the 2015 Demographic Yearbook registers that in Georgia 'urban' means : *«Cities and urban-type localities, officially designated as such"*, while in Norway it is : « *A hub of buildings inhabited by at least 200 people and where the distance between the buildings does not exceed 50 metres.»*[101]. There are efforts to standardize definitions. An example is the 2014 European Commission working paper with a new proposal to update the Pan-European understanding of the terms 'urban', 'cities' and 'rural', using a population density criteria[102].
[G] This is only a rough outlining of 'urban' traits that can be experienced empirically and are also often referred to by scholars mentioned that will prove useful further ahead. It is, obviously by no means an attempt to formulate a proper 'theory of the urban'.
[H] See note F

beginning of the 19th century [107]. The world population's urban-rural proportion is still on the rise and expected to reach 66% by 2050, with cities in Asia and Africa estimated to grow at the fastest rates. Asian cities already hold 53% of urban population worldwide[105], although it is the second-to last urbanized region in relation to its total population. The American and European continents will remain the most urbanized[104].

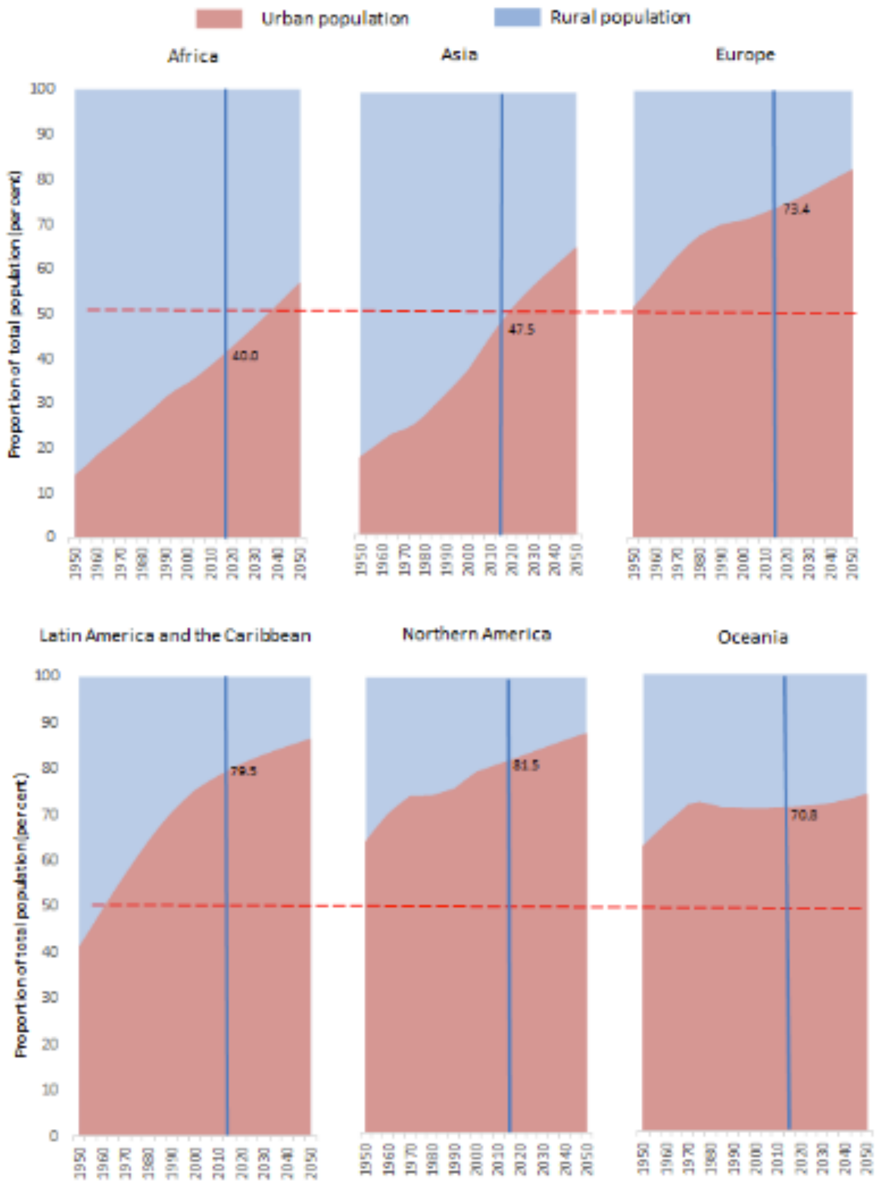


Fig. 1.3. Urban and Rural Population as a Proportion of Total Population.
Taken from : UN/ESA (2014)

Urban areas, with their dense concentrations of people, economic activities and human life in general, are then sorts of *hotspots* of the anthroposphere, places where the anthroposphere's patterns of behaviour can be seen eloquently in full display. Their particular environmental conditions and impacts have long aroused attention: from Dickens and Engels recording the foul air, polluted streets and waste water discharges to rivers in 19th century English cities, to our contemporary natural and social scientists hard at work, there is a solid recognition of the fact that cities' environmental performance are less-than-desirable *vis-à-vis* human health and, as of lately, also ecosystem health and sustainability. Precisely because of cities' *hotspot* or *condenser* condition, they have played a crucial role in global environmental degradation, and they play a crucial role now in reversing it. The moving of cities – and their citizens – towards sustainable behaviours is bound to have large scale impact both locally and globally.

1.2 Cities/citizens and their role in environmental change

Cities, loosely understood as dense agglomeration of people and buildings holding socially-recognised symbolic meaning as well as concentrating economic activity and political power, have existed for around 5,000 years[108]. But they are a product of human cultural evolution, stemming and building on early agricultural villages which had in them the essential elements of the city already[109,110]. Cities are an indivisible part of human expression and creative character, an consequence of the development of our technique and social institutions[109], in short, a natural and integral part of the anthroposphere. We can say that we cannot help but to build cities, as much as we cannot help but to imagine and to create.

And we have built cities which have grown considerably. Today, urban areas, besides holding 54% of the population[104], produce a considerable amount of economic prosperity[I]: the World Bank (2017) finds that 80% of global GDP is generated in urban settlements[111]. The urban concentration of GDP also holds true when looking at the subnational scale, particularly in developing countries: Kinshasa, Kabul and Manila all generate half or more (85% in Kinshasa) of their country's GDP, while hosting less than 20% of the population. Buenos Aires and Santiago de Chile, with around 35% of the population, produce 62% and 52% of GDP, respectively[105]. In contrast, no city in the developed world shares more than 47% of the countries GDP and in most cases, the number is much smaller.

It is often stressed that city life promotes poverty eradication, job creation, permits access to labour force and markets for enterprises, provides opportunities for resource efficiency and a number other benefits for individuals, including education and access to culture[105]. While this may certainly be so, it is also true that this same city life is a heavy burden on the environment[112–115] and in extreme cases (such as with air or water quality) on people's health. Although the physical expansion of cities in the coming decades *alone* could produce a larger share of GHG emissions than the entire world has generated since 1900[20], the overall environmental burden of city life is not only a consequence of the

[I] GDP is the measure most often used internationally in data on income and wealth. For practicality, it will be used in this section, but recognizing and rather tending to agree with the position that holds it to be a non-comprehensive and unreal measure of wealth.

city *per se*, but rather of the lifestyles of citizens *inside* these cities[J], and of the intensities of material and energy thereof[117].

The true magnitude of cities' environmental footprint is at best, very difficult to estimate and there is uncertainty and debate around, for example, the share of GHG emissions actually allocable to cities[116,118]. The UNEP has suggested 75%[19], UN-HABITAT states 60% on their webpage[119], and some scholars have argued for somewhere between 30 and 40%[116,118].

Material and energy intensity

As for the material and energy intensity of cities, it has been estimated that city life consumes 75% of the world's total resources[53] and 66% of the world's primary energy[120]. As with GHG allocation, global urban material use estimates are also discussed, with claims that results are altered by incorrect allocation or material consumption to manufacturing cities and not to final consumers (not necessarily urban). Cities, particularly very dense ones, can be intensive in their energy and material consumption but not necessarily exceedingly more so than their rural counterparts: in a study of megacities' metabolism, Kennedy et al (2015) found that the 27 global megacities, with 7% of the population, consume 7% of global energy supply, and produce 13% of wastes[121]. Water intensity is generally lower in urban than in rural areas because cities lack agriculture, mining and other water intensive economic activities[121], consequently the 27 megacities studied by Kennedy *et al.*, with 7% of global population, are only responsible for 3% of global water consumption. This example suggests that urban energy intensity is roughly equal to that of non-urban areas, while water intensity is lower and waste production is higher.

Regional and local scale impacts

At the regional and local scale, impacts of cities on their environment and on neighbouring ecosystems are more evident and perhaps easier to grasp. As ecologists continue to study urban settings, the list becomes longer are more refined. A far from comprehensive example of documented ecological change in urban and peri-urban contexts follows:

Physical expansion over adjacent land increases patch fragmentation[113], thus potentially altering horizontal ecological flows[122] and endangering biodiversity[123], the latter already under pressure by the intense loss of native flora and fauna species and dominance of exotic species associated with urban

[J] Dodman (2009) makes the point that not all cities have an equal share of responsibility in GHG emissions, as 20% of the world's population living in the most developed countries make up for almost 50% of emissions. He stresses that blaming the impersonal entity 'cities' for climate change is distracting attention from the fact that it is *people's* consumption patterns in wealthy and middle income nations and cities that are responsible for the largest share of emissions, citing Hardoy *et al.* (2001) in underscoring that low income countries have virtually no net environmental impact. [116].

areas[114,124]. Construction (e.g. roads, infrastructure, housing) often leads to erosion, loss of nutrient-rich topsoils, alteration of local and regional hydrological cycles (through surface sealing, decreased absorption, modified flow directions and increased sedimentation downstream)[122] and of soil nutrient balance in adjacent ecosystems[125]. Deposition of particles and heavy metals from urban transport and industry have been found to increase soil acidity and salinity in ecosystems neighbouring cities[114], with the potential to alter plants' nutrient cycling and thus primary productivty[113]. Water pollution induces eutrophication in close-by water bodies[113], while leaks from waste management systems can change soil and underground water chemistry[82,79,75,80]. Heat islands will alter tropospheric conditions, modifying soil-atmosphere heat and moisture fluxes, with possible impacts on vegetation, local climate and air quality[114,126], local water resources[113], and inhabitants health[126].

Hinterland and global footprint

Unlike early cities, which held productive areas inside or near their grounds[110], most contemporary cities are generally not producers of any primary goods (food, fibres, construction materials, energy carriers) or are so only in very limited proportions. They are heterotrophic systems, heavily or totally dependant on outside supplies of energy and matter[112] and thus forcibly rely on a provisioning area – the hinterland - often spreading far beyond their borders or even into other countries[127,128]. Additionally, because cities have limited space which is normally already under intense use, a hinterland must also support the exporting and sinking of cities' wastes[50]. This (growing) reliance of city life on a (sometimes global)[127] hinterland has been shown to drive land use change at the local, regional and global scales[129-131]. Given that the second law of thermodynamics states that increased growth and internal order of a system can only be realized by increasing disorder (entropy)in higher levels of the systems hierarchy, the anthroposphere's expansion will necessarily degrade ecosystems in its hinterland as long as material imports exceed the « *thermodynamic load bearing capacity of the ecosphere*»[127].

Because of them being anthroposphere hotspots (and not necessarily due to the urban condition per se) cities intensely exhibit the anthroposphere's traits: high metabolic rates, large and often increasing incoming and outgoing flows of materials[50], and therefore a high demand on their hinterlands[128,50]. The degree to which anthropic demand is sustainable -that is, not exceeding the load-bearing capacity of its supporting ecosystems-, constitutes the measure to which cities and ultimately, of human society will be sustainable[K].

[K] « Sustainability" thought and discussion has been around for at least four decades, and actually even more. What sustainability means and when the thought of it began is a fascinating topic, absolutely crosscutting all issues of human life, and maybe causing a sort of revolution ***. For a comprehensive review I have found it delightful to read *****. Discussion around the concept and its applicability of course persists, as some find it to be ambiguous,***, not worth changing policy for***, a conspiracy **, just a trend ***, in-operational, etc… sometimes in the sense much in the sense of what was discussed in foot note B. These discussions evidently fall outside the scope of this thesis, which assumes a priori that there is such a thing as sustainability, broadly and flexibly defined in terms such as"", and that it is at least *likely* that human society can attain it.

1.2.2 Cities are crucial to sustainability

Because city life concentrates people and economic transaction (anthroposphere hotspot), while at the same time concentrating the large shares of knowledge and social capital their role as key point to drive human systems towards sustainable behaviour has long been long recognized:

(i) In science and academia

Apart from pioneering works[L], ecologists had traditionally not worked in cities[113], but became increasingly interested in them towards the decade of 1990 (e.g.[132-134]). Fields of study such as urban ecology and socioecological systems ecology began to grow, and through them, biological sciences and their practitioners have become intensely involved in the global urban sustainability discussion (e.g.[135,136]).

Across other disciplines, scholars suggest that the city scale might be the proper or most efficient scale to manage sustainability, and that «urban authorities and local governments have the potential to implement mitigation programmes effectively, because of the type of responsibilities they hold [...]»[116]. Hoornweg *et al.* (2012) for example, argue that «the global development community is not fully tapping into the capacity of cities to take action with regard to the resource efficiency of business, industries and the population that are concentrated in urban agglomerations»[137]. Yet others suggest that the city/local scale is the only possible scale at which sustainability can actually become a way of life for humanity, and that «the uncoordinated yet globally emerging movement in cities where innovative new sustainable solutions are being experimented with[...] » holds the most promising possibilities to do so at an accelerated rate[138].

(ii) In international institutions

The Population Division at the United Nations publishes reports and projections on urban population since the 19060s[139]. However, it was until 1975 that the UN General Assembly first mandated the creation of an exclusively urban agency – the Habitat and Human Settlements Foundation (UNHHSF)-, under the direction of UNEP[140]. After the first UN meeting on urbanization was held in Vancouver (1976), the precursor of today's UN-HABITAT agency was set up. One of the most remarkable results of this meeting was a joint statement recognizing uncontrolled urbanization as a a cause of pollution and deterioration of living conditions[105]. Two follow up conferences have been held: Habitat II in Istanbul (1996) and Habitat III in Quito (2016)

In 1992, the UN held the « Conference on Environment and Development » in Rio de Janeiro, Brazil, which is considered to be a historical landmark in sustainable development efforts. In Rio, the local

[L] See for example Roblowsky, 1967; Gilbert, 1971; Schmidt, 1975; Sukopp, 1979; H.T.Odum, 1983.

scale gained central recognition as the most appropriate governance level on which to act towards sustainability*. This idea was captured in the *Agenda 21*, which stressed the need for sustainable settlements, participatory processes in governance as central elements of sustainable development[105]. Through the following decades Agenda 21 would influence governance and support the creation of thousands of local-urban sustainability initiatives tailored around it[105,141]. Today, around 1200 member cities adhere to Agenda 21[105].

UN-HABITAT gained full status as a UN programme in 2002, a year after UN Member States had adopted the *Declaration on Cities and Other Human Settlements in the New Millenium*[140]. Finally, in 2016, during the Habitat III conference in 2016 a « New Urban Agenda » was agreed on by UN member states, who « r*ecognized the relevance of sustainable urban development in the development agenda, and have endorsed the New Urban Agenda as a guide for this process »*. To signatories, it represents a commitment to rethinking the planning, design and management of their cities. As for other UN agencies, UNEP has continued to have urban programmes, and UNESCO, UNIDO and others have also joined with programmes under their own particular focus.

Today, the World Bank, the International Development Bank, the OECD and the European Union, to name a few, all have sustainable cities programmes[142], as do many development agencies and large international NGOs such as Greenpeace and The World Wildlife Fund. Specifically urban-focused projects, research and reports carried out by these and other institutions have become quite common in the 21st century.

(iii) In national and sub-national policy

National and subnational policy-making in many countries has responded to global acknowledgement of the urban stakes for sustainability. Many countries, provinces, municipalities and cities are trying to combine their development targets with sustainability goals, often finding not few challenges[143].

Many countries in the developing world tended to infrastructural and social issues in cities through national urban policy (NUP) throughout the 20th century, but with little regard to environmental problems[144,145]. Since the turn of the century, environmentally-minded reforms, laws and projects have begun to be prepared by national governments, most notable in Asia, where Korea seems to be at the forefront [144], and despite considerable structural problems, increasingly in the highly urbanized Latin America[144,146]. In this region, a frequently-cited exception is Brazil, where an urban policy chapter was included in the new post-dictatorship federal constitution in 1988, followed by a series of uncommonly environmentally oriented municipal plans and zoning regulations[147]. Recently, the Mexican federal government introduced 'green mortgage' plans to finance ecological renovation of low-income homes, and also incentives for green building in selected cities. As for the African region, it is still lagging considerably behind in terms of sustainability-oriented NUP in comparison to all other developing regions[148], and innovative environmental programs at the city level are mostly carried out in small scale by NGOs.

In developed countries, strong traditions of spatial planning, particularly in central Europe, had longed turned their attention to the quality of the environment, but not necessarily on environmental performance or what we understand today by "sustainability of cities". In the mid 1980s, urban topics were briefly mentioned in overall environmental programmes, but a first totally urban-focused environmental plan came with the *«Green paper on urban environment»*, published in 1990 by the then Commission on European Communities[149]. In this green paper, the need to find long term solutions to a « deep-seated crisis » manifest in urban development was expressed, along with the recognition that urban environmental solution could much help to improve global environmental concerns[149]. as well as the importance of a national, and in that case supra national, policy to address urban issues.

With the 1997 publication of « *Towards an Urban Agenda in the European Union* », the EU commission continued to call for an urban perspective in EU and national policy on urban environmental issues, and seeking to establish mechanisms to foster the process[150]. National policies started to come forth. Sweden , for example, presented an « Integrated metropolitan Policy » where sustainable growth was considered for the first time in 1998[151]. The beginning 21st century also saw a large array of programmes, plans, declarations and research happening in the region[152]. And while the environmental performance and internal environmental conditions of European cities tend to be much better than in global South cities, a 2014 communication[153] however still recognized « piecemeal » advance in national level urban policy and a persistently « problematic » situation, and insisted on the past appeals for a EU Urban Agenda. The Pact of Amsterdam sealed this process recently, with the Urban Agenda being agreed on at the end of 2016[154].

Also around the turn of the century, municipalities and local governments throughout the world have recognized the fundamental need for sustainability action at the city scale and undertaken action, with varying degrees of depth, strength and sucess[105]. This shift of scales for action –from the more traditional centralised planning schemes to localised, smaller scale planning that allows for tailor made actions - has been facilitated by trends of decentralization and inclusive and multi scale governance occurring in parallel, surely to different degrees, but in all regions of the world[105].

An early pioneer in the Latin American region was then Brazilian city of Curitiba, now well known for its avant-garde urban planning schemes, much tinted with environmental conservation and social equity issues, which were by 1990 becoming a tangible reality[155]. In the developed world, many cities (Copenhagen, Helsinki, Amsterdam, and many more) had designed and implemented sustainability-oriented urban policy since at least the 1960s, and perhaps earlier. But the general turning point for the world appears to be the *Agenda 21*, which as discussed earlier, emerged from the Rio 1992 conference. *Agenda 21* gave momentum to the creation of many local-scale initiatives, much aided by the International Council for Local Environmental Initiatives (ICLEI) has worked over 1,500 member cities and towns to develop local plans for sustainability in a wide variety of topics[156].

Despite considerable advances, many cities continue to encounter difficulties in the transition towards more sustainable lifestyles, or to feel that the improvement may not be enough. To better the process, early in the 21st century cities in the Netherlands started «managing the transition» through experimental programmes at the urban scale[138]. Other cities in different regions have also begun to organise «labs» or other such experiments around urban sustainability, citizen engagement, and multilevel governance[141], sometimes aided by multi lateral organizations such as the International Development Bank, who has sponsored urban labs in Latin America, or the Ibero American General Secretariat, who sponsors the Ibero American LabIc.

***

All throughout the world, in organizations of many different sizes and types, in national and subnational government and in research and academia, there appears to be a solid and yet still growing interest in making cities «sustainable». Much of this concern may stem from the acknowledgement of the contribution that cities make to environmental degradation, of an the understanding of their advantageous position in terms of agglomeration economies, innovation, entrepreneurship and development opportunities, as well as of the fact that cities need to be better planned, regulated and managed in order to actually benefit from this potential[144]

Indeed, cities are potential hubs for innovation and creativity, possible drivers of change both in everyday *modus operandi* and in policy[138] and many have shown admirable leadership in embracing responsibility to face and change human´s pernicious impact on the Earth system. And yet, when looked at globally, it appears as though we have not been as effective as necessary: despite decades of global efforts, consumption patterns not only continue to demand large amount of materials and energy, but do so in an *increasing* way[138,157]. The associated environmental burdens are thus not significantly diminished (despite decoupling efforts, for example), and pollution levels, habitat loss and other large scale and dangerous human impacts on the environment also continue to rise[131]

Some argue that policy has simply been slow to adapt to real environmental challenges and to the technological innovations that are happening so quickly around the topic of sustainability[141], and that the links between scientific research and policy making are insufficient[158]. Among them, some have made a clear appeal to drastically reform national and international institutions in order to improve the governance of natural resources[159]. Yet others, on a more radical tone, see the only solution in fundamental changes in civilization's paradigm and a transition away from a culture and economic structure that appear to be inherently unsustainable[138]: the point has been made that, for example, despite sophisticated pollution control mechanisms being put in place, the weathering of goods used in our everyday life, such as cars or buildings (erosion of car brake linings, of building façades materials) would continue, however slowly, to increase the amounts of trace pollutants in water, soils and air[50].

1.2.3 Urban-based planetary stewardship

« The city is a natural pattern for the organizing of cultural life, just like anything else about us can be natural. If it is correctly built [...], the city can be an excellent tool to harmonize culture and nature. What happens is that nobody has bothered to design and build the city in such a way ... »

- Richard register. Ecocities, 2000.

« Cities are a product of the Earth. They reflect the peasant's cunning in dominating the earth ; technically they but carry his skill in turning the soil to productive uses, in enfolding his cattle to safety, in regulating the waters that moisten his fields... »

Lewis Mumford
-The culture of cities, 1938

A comparative sectorial analysis of GHG emissions conducted by Dodman (2009) showed that the share of urban residents tends to be smaller than the country average and that those of residents elsewhere within the same country[116]. This holds true in compact, service oriented cities whose metabolic systems(water and energy provision, waste management, etc.) are thoughtfully planned to be sustainable. It is however untrue for cities such as Mexico City, New Delhi or Manila[105].

It is also true that cities and countries who have evolved form industry-based economies into service-based economies have done so by offsetting their sources and sinks demands to other regions. Not only GHG emissions, but polluting discharges into water and air, as well as natural resource consumption (depletion?) are shifted, and while ecosystem health and overall environmental footprint seem to diminish in some regions, they grow in others. A 2015 compilation of footprinting studies[158] reports, for instance, that Europe's reliance on foreign cropland is equal to between 1/3 and 1/4 of its own agricultural surface, with the proportion increasing throughout the first decade of the 21st century. 50% of the total land use demand for the EU occurs outside its borders. Country wide studies show that, for example, Austria and Japan are increasingly appropriating foreign forest ecosystems and arable land, and that Australians have the largest land footprint in the world, 150 time larger than that of Bangladeshis, who have the smallest.

Evidently, world trade between regions with different resource endowments is not only unavoidable, but necessary and natural. It is impossible for each country (or city, for that matter) to meet all of its material needs within its own boundaries. However, more equitable, fair, and scientifically sound[158] schemes must be found, as simply exporting the environmental externalities of our economies and consumption patterns to regions with less strict environmental regulations will not suffice. From studies showing that the higher-income 30% of the world population appropriates 70% of all resources[158], and that the 20% high income urban population produce 50% of all urban GHG emissions[116], it follows that consumption patterns in the most developed regions of the world must adapt and change. This includes higher-income cities in developing countries as well.

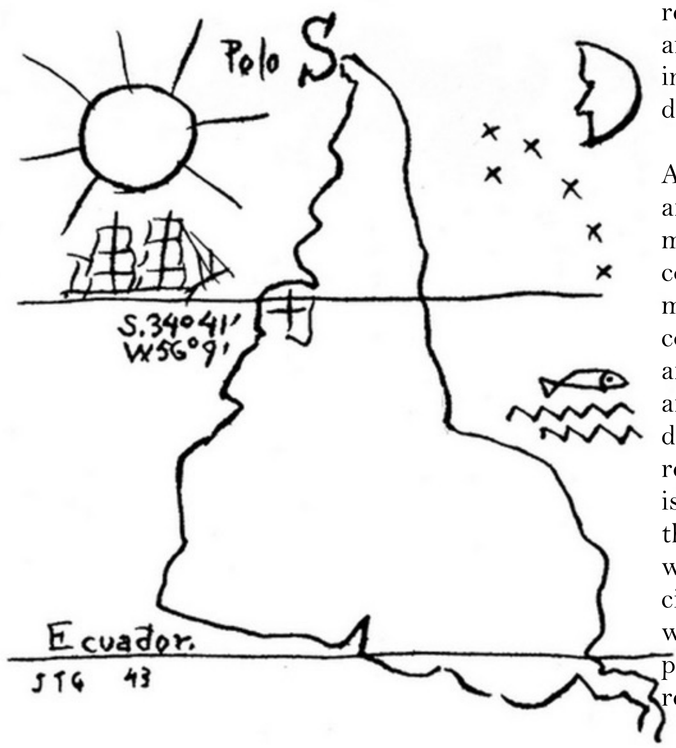
City life, with its innovative, creative and lively environment as well as its physical advantages (density, proximity, compactness, connectivity) offers a huge opportunity to achieve global sustainability goals[105,116,117] through more efficient energy consumption, reutilization of wastes (waste-to energy schemes, composting, etc.) and a heightened consciousness over consumption patters. Because most people live in cities now and will increasingly continue to do so in the future, urban metabolism patterns are perhaps the largest driver of environmental degradation (occurring for the most part in non urban areas!). The urban realm has then clearly become a bastion of sustainability[105] and planetary stewardship[160], understood as "an action oriented framework intended to foster the socio-ecological sustinability"[161], where profound responsibility, interconnected dialogue and a proactive attitude is taken by stakeholders including citizens, scientists and policy makers. In this sense, it is clear that true city sustainability can only be achieved in the context of planetary-wide awareness and a global accord between cities and their provisioning areas[160].

Botafogo beach and the Pão de açúcar from the Dona Marta lookout
Rio de Janeiro, Brasil

Photographer: Higor de Padua Vieira Neto
Taken on a Creative Commons License from:

Chapter 2

Latin American cities, Mexican cities: common problems and a motivation



Joaquín Torres García
(Montevideo, Uruguay, 1874- 1949)
América Invertida, 1943
Tinta sobre papel
22 x 16 cm
Fundación Joaquín Torres García, Montevideo

An initial note

Although the Latin American region is of course quite diverse, with economies and territories of different sizes, there are many similarities among countries, besides the already evident, such as language and cultural heritage. Severe structural problems in policy and public administration, corruption, violence, insufficient support for research, lack of data, lack of coordination among stakeholders and lack of a long term integrative vision for sustainable development are a shared situation.

Acknowledging that no solution is a panacea and every place has delicate specificities that must be expressly dealt with, I nonetheless consider that, due to the strong resemblance mentioned, the specific experience of one country can be useful for application to another in the region, without only minor and certainly surmountable "translation" difficulties. Therefore, and also because a review of every single country in the region is not possible to do in the occasion of this thesis, the following sections and chapters will dive deeper into the case of Mexican cities, parting then from this premise: that whatever solutions we may find could be potentially useful for other countries in the region.

I furthermore believe, and indeed this is a personal motivation, that Mexico has been a sort of outsider within the Latin American community, due to historical and also geographical reasons, and has become better integrated with the Anglophone north than with the more culturally and historically similar south. While that would not necessarily have be a problem, given that the conditions of such integration were different, it is my opinion that Mexico and also the rest of Latin America would greatly benefit from the tightening of Mexico's integration in the region. I therefore would like to profit from this thesis to turn a Mexican glance to the south, and propose to step towards integration through the sharing of our knowledge and efforts in the very relevant goal of environmental protection and sustainable development.

2.1 The Latin American region, its cities and the environment

The Latin America & Caribbean region (LAC) holds 8.6% of the world population[162] on 16% of the earth's surface[52], distributed in 33 countries[21]. Brazil and Mexico, the two largest economies, together host half the population of the region[163]. Despite high indices of environmental deterioration (the world's highest deforestation rates[164] and 50% soil degradation[165],for instance) it still holds 23% of the world's forests, 31% of fresh water resources and hosts ~70% of all species, with high degrees of endemism[21] and six of the seventeen megadiverse countries[166].

LAC provides 12% of global material use[52], with its largest export destination being the United States and China[167]. It is the largest net exporter of food products[168], and one of the largest world providers of minerals: ~50% of world copper, ~33% of silver and ~20% of iron are obtained in the region[52]. Fuels account for around ~15% and food and agricultural products ~17%[167] of the regions' exports. Domestic material extraction (DMC) in 2010 was 14.3. ton/cap/y, the world's second highest extraction rate when measured per capita[52]. This seemingly large share is associated with the export-oriented extractive nature of the region's economy (exacerbated since the turn away from import substitution and state-led industrialisation policies in the 1980s[169]) as global material flow accounting methodologies normally allocate extraction and other environmental burdens to the producers, and not to the final consumers[52]. Asia's accelerated growth in the last decades has indeed left its mark in Latin America's material extraction, as have the expansion of European economies in the 16-19th centuries. Overall the region can be said to be an "*extended hinterland of external economies*", providing mainly primary products to international consumers[169].

LAC is the most urbanized region in the world, product of a relatively quick rural-urban shift between 1950 and 1990[163]. Although the change rate has now diminished, with urban growth almost equalling the natural population growth rate[163], 80% of Latin Americans now live in cities[105], generating up to 70% of the regional GDP[163]. There are considerable variations among countries: Antigua and Barbuda is only 30% urban, while the Cayman islands are 100% urban[163]. Almost 50% of the total population lives in coastal areas[163].

Latin American cities in general are of medium-high density and large surface, which continues to expand despite the fact that their population is no longer significantly growing[163]. They experience housing shortages both in quality and quantity, a tendency to congestion and poor mobility, and a lack of infrastructure and public spaces even in the most advanced cities[105]. This is perhaps illustrated by the fact that the region's consumption of construction materials is relatively low compared to other developing regions, at around 2.3.ton/cap/y[52].

Metropolitan areas are common in LAC, where there is a historical legacy of very strong single power centres. Around 20% of the total population live in large cities of more than 5 million inhabitants[170]. On the other hand, it is also true that intermediate-size cities throughout the region have grown in number and size, and have become more popular as places to live and work, and also as places of investment of large scale national and foreign industrial, manufacturing and in some cases, agricultural enterprise[163,170]. Notwithstanding the economic opportunity this represents, there is also now an added pressure on these cities' infrastructure and provisioning ecosystems that local authorities are on the whole not prepared to face.[163]

Latin America is the most unequal region in the world, when inequality is measured with the Gini coefficient[105,163]. The richest 20% income is 20 times larger than the poorest 20%. This translates into a highly contrasting urban space: gated communities, private urban highways and high-end privatized urban spaces many times in the form of exclusive shopping malls, are common throughout the region's cities[105], intertwined with slums, low-quality urban infrastructure and deteriorated pubic and green space. UN-HABITAT[105] reports 33% of households on or below the poverty line and 21% of the urban population, around 111 million people, living in slums[163] (*favelas, ciudades perdidas, asentamientos de paracaidistas*). A large fraction, between 30% and 60% of urban workers are "informal" but vital, as they generate anywhere from 1/4 to 1/2 of the national GDP[170]. At the same time, LAC cities are insecure and violent, classified as the world's most dangerous, with the highest homicide and gender violence rates, to a degree equal to or even higher than those where a war situation is formally declared[163]. In Mexico, for example, the economic costs of violence have been calculated at 15% of the GDP[171].

When intra-city conditions are examined, great disparities prevail between different income households in terms of, for instance, water access in sufficient quantity, quality and temporality[163]. Many cities experience trouble in servicing its urban population with basic commodities[21]. However, when the region is looked at as a whole, water, sanitation and electricity provision shows a fair, if not excellent, coverage, with the exception of waste water treatment, which is infrequent, and has effects beyond the urban surface: around 25 million rural inhabitants in LAC are in classified as having dangerous contact with urban-originated pollution in rural water bodies[165].

The economic growth and development of the LAC e entails considerable environmental impacts, largely due to its export oriented activities, which demand large scale resource extraction[169]. Increase in environmental impacts is to be expected, due to ongoing conversion of natural environments to productive lands[21] and also due to growing populations' growing aspirations for "development"[169] understood in the western, intensive consumption style. Because increasing inequality has been found to be correlated with extractive economies (Bunker and Ciccantell, cited in[169]), a growing rich-poor breach is also to be expected.

Despite great economic and social constraints and an adverse political atmosphere, creative industries are growing in many cities in the Latin America and Caribbean region[170], and it is gaining recognition as a hub for urban creativity and innovation, influencing city governance and citizen's involvement[163,171].

LAC cities & the environment

City and regional scale studies exist for selected of urban environmental topics, but they are not abundant. According to UN-HABITAT, urban-based environmental information is quite limited at the city scale, with most measurements being made nation-wide, creating aggregated indicators[163]. Furthermore, a literature review or compilation reporting urban environmental research in LAC does seem to be lacking[M]. It is therefore difficult to understand the contribution of cities in the region to environmental problems in a precise manner[163]. Main areas of regional research, where more data is at hand, appear to be air quality, GHG emissions and water supply systems. Available information in those areas shows that air quality in all of the regions' large cities tends to be bad, with particulate matter concentration well above the WHO recommendation in most cities[172]. The principal source of air pollution is transport, with industry and energy generation in the second position, though much farther behind.[163] Lima, Bogotá, Santiago de Chile, Mexico City are all infamous for their unacceptable indicators of air quality. As for GHG emissions, the largest share is due to land use change[163], linked to the fact that LAC's deforestation rate is among the highest in the world. Although the role of physical city expansion in deforestation is minimal[163], forests clearance for agriculture, farming, mining and other productive activities are clearly linked to urban life, as discussed in chapter one.

At least two cities in the region have carried out environmental footprint analyses (Bogotá and Quito), all obtaining above-national average results, meaning their pressure n the environment tends to be larger than those of other settlements in the country[163]. UNEP (2010) finds that overall, LAC cities are responsible for an important degree of water and air pollution, and pressure of marine and terrestrial ecosystems in the region[21], while UN-HABITAT (2012) observed that the continuing expansion of LAC cities over adjacent territories is a major challenge to their possibilities of developing sustainably, although there are opportunities to be exploited in the increasing concentration of

[M] This statement by the UN refers to *regional* aggregate data. But as world-wide interest for urban environmental research has grown since the end of the 20th century (as shown by ref.[132–134] and discussed in chapter one), it has also done so in the LAC region. At least in Mexico, we have witnessed a growing inclination to study urban-related environments and environmental impacts, interestingly going beyond traditional studies (GHG accounting), and deeper into ecological and inter-disciplinary questions, at both city and regional scales. I am confident the same is true in many countries throughout our region, as suggested by existing research compilations on selected topics in Chile (Cursach *et al.*, 2012) and Colombia (Delgado and Correa, 2013) and a full review of Latin American knowledge on urban ornithology Ortega and MacGregor, 2011). There is also a good amount of research to be found on on specific issues, such as indicators on sustainable urban development (Moreno-Sanchez, 2014), nature appropriation by urban growth in Brazil (Barbosa and DaCosta, 2012), among many others. However, tracking, compilation and data aggregation of such studies indeed seems to be lacking, judging from the searches in scholarly databases that were performed in the context of this thesis. I consider the detailed examination of the *status quo* of urban environmental research in LAC, its compilation and aggregate analysis to be a very important but pending item in our to-do list. Despite the importance of the subject, carrying out such revision would have proved impossible within the frame of this thesis. A regional literature review focusing specifically on urban metabolism studies was nonetheless made, and its results are presented in chapter 3.

population[163]. On the whole, urban regions in the region are mostly classified as 'very vulnerable' or 'vulnerable' to climate change and natural disaster[163].

2.2 Mexico and its cities

Mexico is one of the countries with largest diasporas in the world: 12 million Mexicans are estimated to live abroad[163]. As of 2015, the national population slightly surpassed 127 million, making it the 10th most populated country in the world[173]. Richly endowed with natural resources, it is one of the 17 megadiverse countries[166], with a registry of over 19,000 endemic species throughout its 20 biogeographical regions[174]. Among these many different types of ecosystems present in Mexico, some of the last surviving patches of the globally disappearing Tropical Montane Cloud Forest can be found[175]. It is also socially and cultural diverse, globally ranked as the fifth country with the most living native languages, 89 plus dialects, 291 in total[174]. An estimated 6% of the country's population speaks a native language[176], but sadly, over 75% of them live below the poverty line[177]. Poverty is an unresolved problem in Mexico: 46% of people are officially recognized as 'poor', ~20% of which are in extreme poverty[178]. Neither proportion fluctuates significantly since the 1960s[179]. At the same time, Mexico boasts the world's 15th largest GDP[180] and three of its nationals, owners of large corporation firms in the country, are listed among the 150 richest people in the world[181]. It follows that inequality indicators are comparable to those of other countries in the LAC region, being ranked among the 25% most unequal countries[182].

Within the LAC region, Mexico is the second largest economy[180]. Its economic activity is less based on raw natural resources exports than that of some of its regional counterparts[179], roughly divided in a 62% share of services, 24% of industry and 13% of agriculture. Remittances from Mexicans abroad, mainly in the USA, make up for 2.3% of the GDP[54]. In monetary terms, cars and car parts are the most important single export items, followed by crude oil[183]. Natural resources make up for ~20% of exports[183].

The country's economy has grown continuously, albeit modestly, in the past 40 years, very closely coupled with that of the USA, its biggest trade partner[179] and historical receptor of the vast majority of Mexican migrants. Economic liberalisation in the 1980s brought an unprecedented opening of manufacturing facilities delivering finished and semi-finished products to international markets[179,184]. During the same period, and linked to the demands of export-oriented manufacturing, national material consumption grew threefold[179], inducing a material intensity of the economy that, despite decades having gone by and dematerialisation being encouraged world-wide, has not substantially decreased, mainly because of inefficient production processes and the lack of technological innovation[179]. The new manufacturing facilities were mostly installed in small and medium cities in the northern and central regions of the country, attracting the migration of workers and boosting economical and physical growth in these newly industrialised cities[184]. Gonzalez and Shandl (2008) find that this period effectively coincides with a fast growth in the consumption of construction materials, which by 2003 were 47% of the total Domestic Material Consumption (DMC)[179]. The northern regions, which received most of this industrial boom remain to this day the best positioned in terms of Human Development Index, GDP and Gender-related development Index[185]

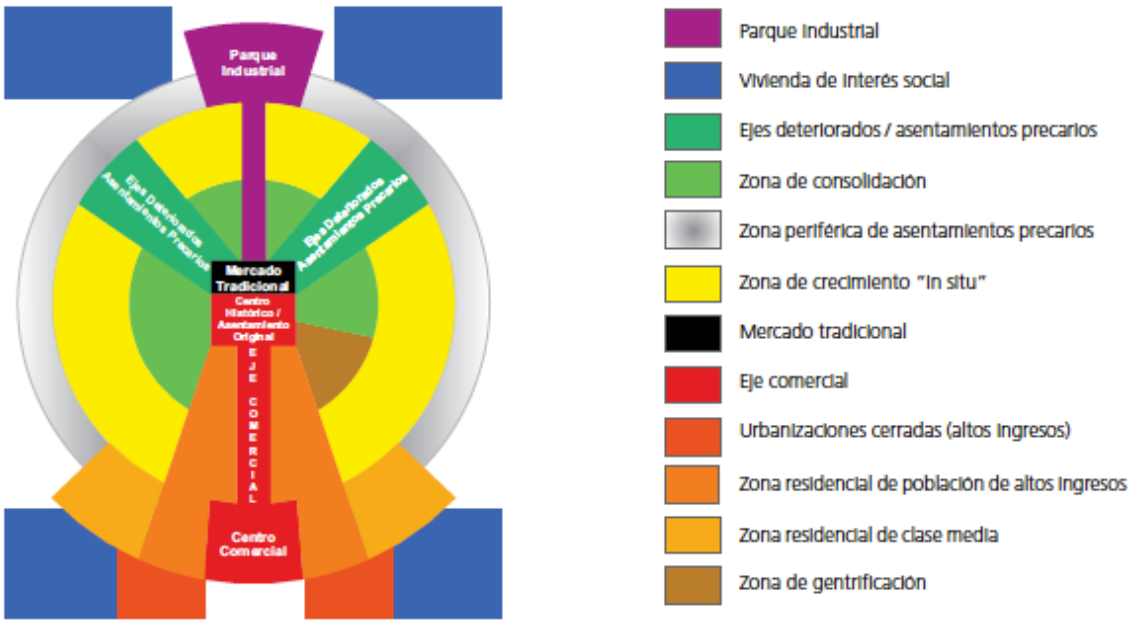


Fig. 2.1 A schematic model of city structure in Mexico.
Taken from: CONAPO/SEDESOL, 2012.

After the 1980s, Mexico City, the capital, saw a diminishing of its central role in industry and a shift into a service-oriented economy, marked by informality and low-skilled labour[163,184]. Although the capital's main core ceased to grow and even became depopulated, the city continued to attract workers, who settled on cheaper periphery land, first within the limits of the federal capital (DF, Distrito Federal) and then on the municipalities of the neighbouring Estado de México (State of Mexico). Today 52% of the metropolitan population lives outside DF borders, in the adjacent Estado de México, although ~42% of them must commute into the city to work and study[186]. Aguilar (2002) argues that similar patterns of urban dynamics (capital city shifting into low-skill services and metropolisation, booming of intermediate industrial towns, fast and uncontrolled growth of urban peripheries) of 1980s neo-liberal reforms are observable in Brazil and Argentina[184] who followed similar macro-economic trends during that period. This pattern of economic growth has also been found to be correlated to (and perhaps favoured by) an even faster increase in informal economy[105].

Like their regional peers, Mexican cities are extensive and tending to sprawl. Sprawl in Mexico is perhaps encouraged by a favourable topography, as most Mexican cities are on the central plateau or on the coasts, with very few on areas mountainous enough to be prohibitive[186]. The average city surface has grown 3 times faster than its population[163], bringing associated high transport costs, low labour productivity and high marginalisation of periphery dwellers[105]. Real estate speculation allowed by an incomplete and insufficiently planned regulatory frame, led to an immoderate transformation of rural areas on the far periphery of many cities, building low and middle income housing with insufficient services provision and obligated long commute times[187]. The result is a paradoxical situation where between 14% and 18% of built houses are unoccupied but housing shortage persists[171] and 11% of urban population live in slums[105]. Furthermore, through this process of extensive growth, cities in Mexico, like others in the region, tend to exhibit the surge of peripheral high-end, car-oriented settlements, characterised by gated communities, shopping malls, country clubs and other private recreational spaces, that become clear spatial segregators between income groups, a phenomenon which Aguilar (2002) and others suggest is linked to the city growth that came with neoliberal economic policies and major growth in foreign investments[184]. *Megalópolis, city-region, mega-urban region, expanded metropolis, disperse city* are some of the names that Latin American spatial researchers have used to describe this phenomenon[184].

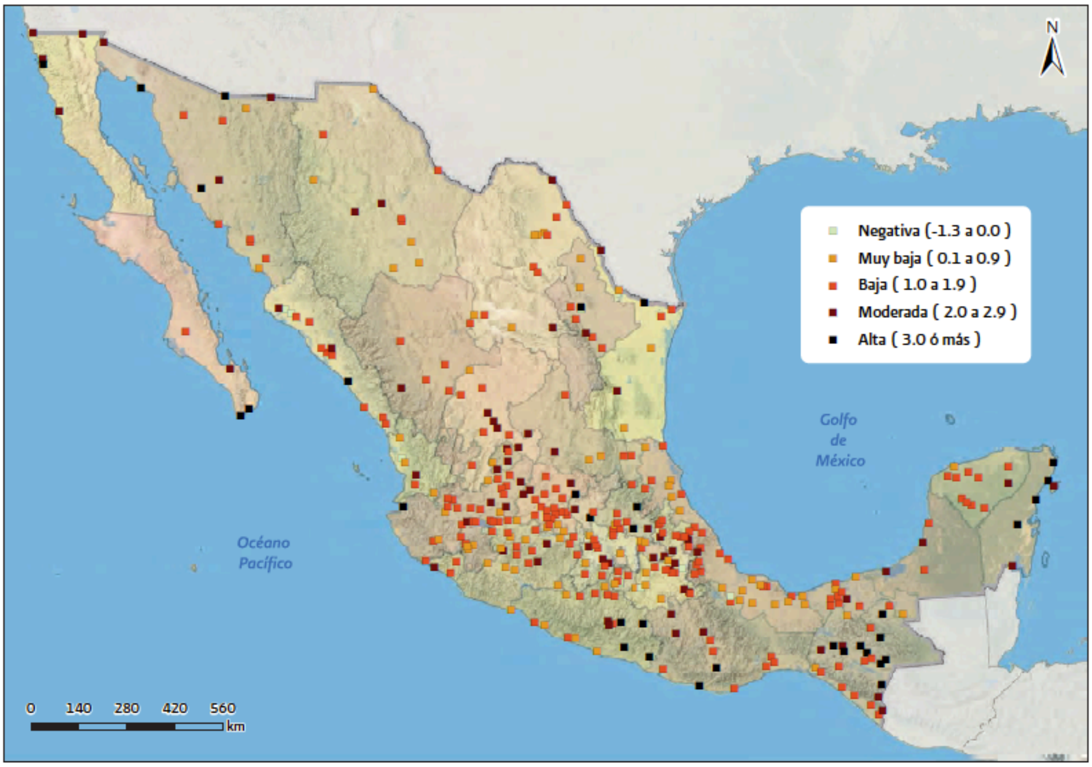


Fig. 2.2 Mexican cities and their growth rate (in %, right hand legend).
Taken from: CONAPO/SEDESOL, 2012.

80% of Mexico's population is urban[54], and most of it, metropolitan[N,188], and consequently, metropolitan areas have been recognized as a national policy priority. Apart from Mexico City, the world's 4th most populous in 2014[139], the remaining 58 metropolitan areas concentrate ~57% of the

[N] In the Mexican regulation frame, 'metropolitan' refers to one of the following conditions: a) the grouping of two or more entire municipalities in one single functional and physical unit; b) urban centres over a million inhabitants, even when contained in a single municipality, c) settlements over 250,000 inhabitants that go over international borders.[186]

national population[186O]. Out of a total 384 cities identified in the National Urban System (Sistema Urbano Nacional), 59 are the mentioned metropolitan areas, and the remaining 325 are classified either an 'urban centre' or 'conurbation'[186]. Within their regions, all these cities replicate a centralised model of development, concentrating economic activity, job creation, public services, and recreation and cultural facilities within their urban cores and industrial zones, leaving the rest of the region, including the urbanized periphery, relatively underserviced[171], with a perceivable abandonment of rural activities such as agriculture and forestry.

2.2.1 Environmental urban policy & planning in Mexico

In resonance with the global trend, countries in the LAC region have mostly subscribed to all major international agreements on environmental issues[165]. From this, a considerable amount of environmentally-oriented policy at all levels has stemmed[21], but in general, countries and cities have lacked institutional strength, will or capacity to enforce it. This is also the case in Mexico, where a framework of weak and uncoordinated institutions, corruption, lack of long-term planning and unprepared public servants[P] has prevented cities from developing sustainably[171].

Despite some commendable advances, ambitious policy remains unrealized and most projects rather focalised and palliative. According to Sobrino *et al.* (2015) public management of environmental affairs in Mexico has been characterized by a *"...disjoint and hierarchical administrative structure, not suitable for integrating society and different stakeholders in problem resolution and unable, within power struggles, to implement consistent and long term programs for sustainable development"*[171]. Similarly, in a UN-HABITAT commissioned study, Turok (2014) finds that inflexible and outdated institutions and legislation, lack of integrative work to achieve a shared vision among stakeholders, weak governments with no capacity to establish long-term plans, and social uncertainty are obstacles to overcome in achieving coherence and sustainability in urban planning[144]. All of which seems consistent with UN-HABITAT's (2016) observation that despite important breakthroughs in urban policy, showing more advance than other developing regions and having some of the world's referents for innovation in urban management, the overall progress of planning and physical control over LAC cities remain "*remarkably low*"[105]. Indeed, Castro Ramírez (2010), in analysing the history of urban planning in the country, finds that no "*serious environmental consideration*" has been taken in urban planning in Mexico since major urban planning

[O] The 11th largest in terms of population[188], with ~1.2 million people, an intermediate city by Mexican standards, will be our study case in chapter 4.
[P] Arellano *et al.* (2011) report that only 38% of the civil servants elected to lead municipalities (*presidente municipal*) had a university degree, and 24% only finished primary school. The average head staff (*jefe de área)*, who would typically be leading departments such as municipal commerce, municipal ecology, municipal security, rural development, and so on, had in average only six years of schooling, meaning that they stopped attending school at the age of twelve or thirteen. Furthermore, due to political habits, it is common practice for the whole head staff to be removed once a new *presidente municipal* comes into office, resulting in the impossibility of following through with plans or programmes for more than 3, and more often 2 years, and thus a high degree of improvisation. In Mexico, the amount and degree of the challenges at the municipal scale -arguably a fundamental one to sustainability in cities-, are quite considerable. For a thorough revision, the interested reader can consult Cabrera and Arellano (2011)[189]

began in the 1970s, and states that "*urbanization via destruction*" generally substitutes "*urban planning*" in Mexico[190].

In recent times, and probably linked to Mexico's enthusiast participation in international agreements and to the general world-wide tendency towards "green" and "sustainable" solutions, environmental considerations appear to be entering urban planning and infrastructure building policy, or at least the discourse around them. In the following paragraphs I will contend that these are not necessarily delivering the results needed for a truly sustainable development, and that the labels "sustainable", "eco" and so forth, with which housing programmes and even policy instruments are being marketed are misleading, if not in all cases, certainly in some, and likely in most.

The marketing of a product under false premises claiming "sustainable", "green" attributes is know as *greenwashing* and is equally pernicious be it a conscious or an unconscious act. This concept is generally used in circles thinking about corporate social responsibility and product marketing, but it is applicable beyond these spheres. Therefore, it will be briefly revised in the coming section, as it would appear to be a useful element in assessing current practice in sustainable urban development in Mexico.

2.2.2 Greenwashing

" No important change in ethics was ever accomplished without an internal change in our intellectual emphasis, loyalties, affections, and convictions. [...] In our attempt to make conservation easy, we have made it trivial."

-Aldo Leopold
A Sand County Almanac, 1949

The term *Greenwashing* refers to the action of adorning something (a product, a company, an action) to make it appear to be sustainable, and marketing it as such[191,192]. Different strategies for *greenwashing* have been identified[191,193], but in general terms the practice consists on a change in communication strategies or their content, without substantial change in activities, processes or goals. An entity (brand, corporation, state) will project an (un-founded) image of sustainability engagement through vague, misleading or inaccurate communications (text, imagery, etc.), or through self proclaimed sustainability standards, such as corporate, ready-made eco-labels. In more extreme cases, deceiving, false reports of having action will be made[191,194]. Sponsored NGOs or think tanks might also be funded to support the entity's 'greenness', or donations be give to well-knows environmental causes, such as reforestation, etc.

Greenwashing hinders the advance towards sustainability in various ways. Frist, falsely communicating that solutions are being implemented for a certain situation will relax efforts to solve it, while in reality it may be the same (or worse), and those efforts still urgently needed. *Greenwashing* may also deviate attention from substantial, structural matters, by focusing advertising on superficial aspects –e.g. "green" products using 20% less packaging but whose contents and fabrication procedures are still environmentally dangerous). Finally, *greenwashing* may obstruct accountability, as actors may carry on with harmful activities as long as they manage to create a "green" impression in society and government authorities who would otherwise may be alarmed by their actions and try to for example shut down their activities or make them pay fines, etc.[192] Finally, as scams or fraud is discovered and scandal is created (e.g. the Volkswagen software case[191]) or as critical audiences are disappointed by the evidently insufficient "greenness" of products offered, markets, support and enthusiasm for environmentally aware products and causes is also eroded[193], reinforcing skepticism and helplessness or conformity in the public.

Greenwashing has been and remains a recurring and wide-spread practice since the talk about sustainability ever started (some[193] would even say that it has 'skyrocketed') among businesses, corporations and even governments. Motivations to *greenwash* instead of taking decisive action are many:

i) Firms or other entities (governments, for example) perceive and may effectively gain advantages (e.g. market opportunities, customer loyalty, profit, votes) in appearing to be sustainable, because demand for green products is increasingly growing[193] as concern about the environment becomes more and more widespread, and improved environmental performance is considered to be a key component of a "socially responsible" entity[193].

ii) Assessing sustainability on an entity, and adjusting its structure, products or practices to improve environmental performance may be expensive, time consuming and demand to hire external technical expertise. (Although better environmental performance can sometimes be attained with small and not necessarily expensive changes, or may even bring savings to an entity, doing *something* will normally be perceived as costlier than doing *nothing*).

iii) Audiences tend to be passive consumers[191] and in general, are not prepared to undertake scientific or technical examination of an entity's statements. Even in the infrequent case that costumers exercise environmentally-informed and sound choices and through them try to exert pressure on firms , the real strength of this "consumer power" remains to be evaluated, and is virtually non-existent in periphery countries[192].

iv) Regulations on environmental reporting are few and not robust[193], and little to no external auditing is normally performed on, for example, Corporate Social Responsibility (CSR) reports[194]. Although independent auditors are increasingly being called on, their 'independence' is by no means assured, specially in the frequent case that their services come together with "reputation management" packages[194].

The result is that, when compared to effectively taking action, *greenwashing* is easier, faster, less costly and virtually risk-free, and provides sound advantages, such as reducing negative publicity and liability, improving reputation and therein the possibility of profit growth[192]. 'Green' advertising has multiplied by at least 10 since the early 1990s[193], but overall environmental impacts of human activities, as was discussed in the preceding chapter, have not ceased to grow., suggesting that environmental reporting by corporations and other entities can be considered business and communication strategies[194] more than real indicators of substantial change.

Examples of *greenwashing* abound[Q]. To name only one: Siano *et al.* (2017) bring forward the British Petroleum (BP) oil spill in the Gulf of Mexico in 2010[191]. When it happened, BP was already recognised as a "world leader" in sustainability, as it had successfully projected an image of being committed to, for example, renewable energy research and development. Its CEO had received an international award for environmental leadership in the late 1990s. Taking into consideration the oil spill and its overwhelming consequences, BP can be better considered a world leader in "sustainability communication", as it made successful efforts in changing its communications strategies to project itself as 'green', but at the same time managed to cause an world-class environmental catastrophe through the non-change of its internal operations, processes and goals.

Although *greenwashing* is more often associated with corporations and firms, I would like to argue that it (or something much like it) has become standard practice in the context of environmental performance assessment and urban sustainability in Mexico. 'Eco', 'green', 'sustainable' and other such labels are liberally assigned to projects all across the public and private sector, with no disclosed evidence or data as to their real environmental performance. This includes building and infrastructure projects, urban developments, and policy at all levels. The specific situation of what could be called *greenwashed urban development* will be illustrated with the following example.

Greenwashed urbanism?: a review of the NAMA Sustainable Housing programme

The 2009 "green mortgage"[R] programme, and the 2013 NAMA efficient housing programme introduced efficiency devices for gas, water and electric installations, as well as insulation techniques and materials in newly built social housing. A retrofitting programme was also proposed, to improve the environmental performance of some of the existing housing stock. At least 65,000 new houses have

[Q] NGOs and universities have made large efforts to track and document *greenwashing* practices. Besides abundant scholarly literature and regular media coverage on specific cases, comprehensive examples are The University of Oregon-sponsored *Greenwashing Index* database: greenwashingindex.com and *Greenpeace's Stop Greenwash* at stopgreenwash.org.

[R] It is a financial instrument (loan) to equip houses with efficiency devices (water and for energy). The program is run by a federal institute who funds to purchase of remodel social housing (INFONAVIT). These credits are only accessible to workers who have access to social security through their employment. 60% of Mexican workers are informally employed and thus have no access to social security[195].

been equipped with saving devices[196], and built on at least three sites. According to the ministry of Territorial Development (SEDATU), NAMA houses "mitigate 20% of GHG, in comparison to traditional housing"[197]. The results of the programme are marketed as a very successful strategy through the websites of the involved ministries (CONAVI, SEDATU), and the programme itself is called "sustainable housing".

After analysing the available documentation and interviewing an architect who was closely involved with the development of one of the pilot projects, I contend that, although energy savings may have been reached in some cases, there is insufficient evidence and knowledge to provide support for enthusiastic statements made by ministries, which can be quite misleading. There are two main supporting arguments for this contention:

1) Efficiency is not equal to sustainability

> Saving devices renders the houses "potentially more efficient, but this is far from being totally "sustainable". The installation of efficiency equipment does not alone guarantee reduction in consumption or emissions, which are largely influenced by user behaviour[198,199]. While efficiency equipment indeed enhances the potential for consumption reduction, if the user consumes more, the potential savings are lost. In ecological economics this is called the Jevons Paradox[200]: when technological efficiency gains are achieved, consumption tends to rise. Because no monitoring information is available, it can be assumed that the alleged 20% is a *potential reduction*, not a *measured* reduction or even an *estimated* reduction based on consumer behaviour tracking[S]. It would be more exact to state that these measures *may* help mitigate emissions, and that the savings are potential. Furthermore, nothing is stated in the programme documentation[201] as to, for example, the eco-balancing of construction materials or of the construction process. There is no way of knowing if the devices installed are imported and have a carbon footprint that will override whatever emissions they are meant to mitigate during in-house consumption, or if installation of additional insulation required an extra expenditure of fuel for machinery, and so on.

2) There are structural gaps in policy a lack of adequate zoning, and insufficient knowledge to fill those gaps

> Two of the main framing national policies for the NAMA housing programme are: the *Sectorial Programme for Agrarian, Territorial and Urban Development* 2013-2018 (SPD)[195] and the *National Programme for Urban Development* 2014-2018[T] (NPUD)[203]. They both include land use planning as objectives, and the NPUD also makes mention of hydrological cycles and availability of natural resources, but only in general terms. Neither SPD and NPUD make any mention of, for instance, ecosystem carrying capacity, hydrological balance, material and energy flow accounting, waste management, or degradation or loss ecosystems due to urban expansion. Only GHG emissions are

[S] Although a monitoring programme is mentioned in the documentation and the way it should be carried out is detailed[201], no monitoring results seem to be publically available. In 2015, the Social Research Institute at the National University of Mexico (UNAM) was commissioned by SEDATU, CONAVI and GIZ to perform a monitoring study on a small sample of houses (38 NAMA vs. 63 conventional, 101 in total) in two NAMA sites[202]. The study is not published on the internet and was obtained through an interview. It concludes that there are energy and gas savings (between 10 and 40% for electricity, and up to 50% in gas) in the 38 NAMA houses as compared to conventional houses, and no significant water savings. The study acknowledges that the sample was very small and only basic statistical analysis could be performed because conditions to monitor are not easy (e.g. users unwilling to participate) and data is insufficient (e.g. no water meters installed in many cities, absence of data, experience in energy efficiency monitoring in Mexico is not abundant).

[T] *Programa Sectorial de Desarrollo Agrario, Territorial y Urbano*[195] (from now on SPD); and *Programa Nacional de Desarrollo Urbano*[203] (from now on NPUD).

mentioned, but mostly in relation to mobility objectives and never in reference to, for example, soil degradation or loss of biomass.

"Sustainability" in these two policies is defined along the lines of the *Brundtland* Report, as "*developing without compromising natural resources for future generations*" (NPUD, p.17) or also as "*developing without compromising ecological equilibrium*" (SPD, p.46). However, how 'ecological equilibrium' is to be measured, or what the resource requirements of 'future generations' are considered to be, is not disclosed, nor are methods of evaluating them mentioned or referred to. It could be that these terms are thoroughly described in the General Law of Ecological Equilibrium (1988) or the General Law of Human Settlements (1993), but the policies we are examining make no reference thereto. Furthermore, an external evaluation of the SPD programme done by CONEVAL (2016)[204], concludes that it has no clear indicators to give account of whether sustainability is or is not achieved (p.141), and that, in general, proposals made in the programme "do not guarantee concrete results that directly contribute to transform land use problems"(p.137).

One reason why it is hard to meet sustainability targets included in policy is that ecological carrying capacity of Mexican ecosystems is in general poorly known, with aquifer availability estimations being perhaps the most researched and nonetheless being quite understudied. Land zoning plans can then rarely be made on the basis of sound scientific information regarding ecosystem health and sustaining capacity, and most frequently altogether fail to include such considerations, even in the case where some information may be available[205]. Furthermore, only 71 of the 2,473 (<3%) Mexican municipalities have a land use zoning document[206], and only 36% of urbanized municipalities have a planning office or appointed official[207]. Where they do exist, law mandates that the zoning plan be made through a participatory process, and may then be heavily influenced by participating civil society, which unfortunately is usually not the whole of society but representatives of social sectors which tend to "*have interests opposed to natural resource conservation*"[205].

No increase in the number of municipal zoning plans is reported through the National Commission for Evaluation of Social Development Policy (CONEVAL)[U] as of 2017[208], which would suggest that land use regulations are still not applied in the vast majority of the Mexican territory, and therefore probability is that NAMA developments are being built in municipalities with no zoning regulations and where ecological baselines and carrying capacity in poorly studied, when not absolutely unknown. It is therefore also virtually impossible to know what environmental impacts these new developments cause on adjacent and supporting ecosystems.

These two arguments are intended to point out that fundamental criteria to make claims for sustainability are missing in the public communications of the NAMA programme, whose label "sustainable housing" may be misleading. On the one hand, the evidence available is quite insufficient to claim that the insulation and efficiency equipment is rendering the houses sustainable. On the other, because baseline data (i.e. the present state of the environment), an ecosystems perspective, the use of sustainability assessment tools and adequate monitoring are not properly integrated (e.g.[208]), the term "sustainability" lacks substantial meaning in the three programmes analysed (NAMA, NPUD, SPLD). The National Population Council (CONAPO) estimates that around 10.8 million housing solutions will be needed to meet the demand in 2030[195]. Only around 40% of Mexican workers are potential recipients of the type of credit needed to purchase a NAMA house (see footnote D), 90,000 illegal lots

[U] The National Commission for the Evaluation of Social Development Policy (CONEVAL), an autonomous government body in charge of evaluating all social and development related policy, supports an online system where indicator progress and evaluations reports can be found. See ref.[208]

are fractioned each year to cater to those not having access to the formal housing market[195], and about 1/3 of housing is self-built[195]. Adding this to the already mentioned deficiencies and pending issues in land zoning and land use planning, it is clear that a much deeper, comprehensive, and scientifically robust strategy that can linking researchers in academia with policy making and civil society, is needed to be able to make any honest claims about sustainability in the housing or urban developments sector.

These claims of 'sustainability' are at best, a product of incoordination among institutions and their technical advisors in the process of policy making and programme evaluation, or of lack of clarity and reflection about concepts and their implications. At worst, they are deliberately deflection attention from the substantial deficiencies built into policy, from the national level down, and the inexistence of an effective strategy to tackle sustainability issues across sectors and scales[V].

Figure 2.3 NAMA housing development in Monterrey, a regional capital of north-eastern Mexico.
Taken from: www.nama-facility.org.

[V] Many efforts are nonetheless put into overcoming such a situation specially in academia, as illustrates the work by Sobrino *et al.* (2015)[171] who have provide an extensive and well-documented set of conceptual frameworks and most importantly, practical and technical recommendations for Mexican policy makers and other stakeholders to improve on a wide array of issues, such as institutional capacity, regulatory frameworks, planning, finance and governance, to move Mexican cities into a sustainable development path. How these efforts manage to actually exert influence and counterweigh other pressures made on policy makers and public officials is perhaps the biggest challenge.

2.2.3 State of the urban environment and its reporting

In line with what was discussed in the previous section, the Ministry for Social Development (SEDESOL) and the Institute of Geography and Statistics (INEGI) (2010) acknowledge that urban development in Mexico is often "carried out without considering land vocation, availability of water resources or vulnerability to risks"[188]. Additionally, in 2016 UN-HABITAT and the National Institute for Workers' Housing Funding (INFONAVIT) conducted a study on the City Prosperity Index of 152 cities[209], in which among the 28 pages of recommendations and strategy proposals, the need to improve environmental conditions in cities and data availability about them, make repeated appearances.

It would be expected then, that a reasonable amount of information, research and diagnostic about urban environmental topics was available. While information is indeed reachable if not abundant for discrete topics in different cities, ideally, a comprehensive, multiple-city report would have to exist to synthetize the general panorama of urban environmental knowledge in Mexico, comparing cities and making regional and nationally relevant analysis, for example. This sort of report is necessary for a research project such as this thesis, where a an *ex profeso* compilation of urban environmental information that surveyed availability one city at a time would have been impossible within the limits of time and objectives (albeit most interesting!). A brief survey of urban-environmental research that collected multiple cities' data was therefore conducted to examine whether there exists such compendium or overall diagnosis of the state of the urban and urban-related environment (see Table 2.1). This survey was non-exhaustive, but rather, exploratory. It certainly cannot replace a true literature review, as it is more likely than not that a number of results will have been missed. Nonetheless, its results are useful to obtain a general idea as to the state of the environment both within cities and as result of their activity.

No single comprehensive, exclusively urban-environmental report comprising several cities (our "ideal" type) was found, as were not reports from the academia or NGO sector (although in all cases members of both participated, but they were neither lead authors of the project, nor the commissioners or the publishers). Comprehensive reports for single cities (e.g. an "environmental atlas" for a city) were also missing [W]. All four reports analyse a general spectrum of urban issues (e.g. economics, social topics, physical growth) and within those, include an environmental component. All reports but one state a lack of data or complications to access data. Banamex states that the availability of data was for them a key factor in choosing indicators, as data was not available for all the questions they would have liked to survey. Report 1 does recognize that data is disperse and not comparable, and that limited

[W] For the purpose of this thesis, a direct inquiry and information request on one particular city (San Luis Potosí) was made into federal, state and municipal environmental government offices as well as with research departments at the local university. No compilation of environmental data had ever been made. Details are given in chapter four.

data is available on the topic of precarious urbanization. These findings suggest that lack, dispersal, un-compilation and quality of data are indeed pervading problems.

Table 2.1 Comparison of four studies containing urban environmental data

		type of study				variables considered										researcher					other contents		
		number of cities	Es	Us	UE	water use, quality	energy use	air, emissions	solid waste	waste water	biodiversity	green space	impacts outside city	ecosystem services	material use	public study	private study	academia	NGO	International organization	policy recommendations	mentions lack of data	Publisher, commissioner
1	Estado de las ciudades de México, 2011	58		■		■	■	■	■	■						■				■	■	▥	UN HABITAT / SEDESOL
2	Ciudades Competitivas Sustentable, 2014	78		■		■	■	■	■			■				■	■				■	■	Banamex, BANOBRAS, INFONAVIT
3	Ciudades Competitivas Sustentable, 2015	78		■		■	■	■	■		■	■				■	■				■	■	Banamex, BANOBRAS, INFONAVIT
4	City Prosperity Index, 2016	152		■			■	■	■											■	■	■	UN HABITAT

Es= Mainly an environmental study containing urban information
Us= Mainly an urban study containing Environmental Information
UE= Urban environmental study (the ideal type)
NGO = Non Governmental Organization
I = International or multilateral organization

Report 1 was carried out by the Ministry of Social Development and the United Nations Human Settlement Programme (UN HABITAT and SEDESOL, 2011)[185]. It gives no numerical pondering, quantitative evaluation or index of any type, and is rather an narrated compilation of selected data on metropolitan zones provided mostly by INEGI, accompanied by series of thoughts and recommendations for policy and government.

Reports 2 and 3 (Banamex, 2014 and 2015)[210,211] are a series. They were commissioned and published by one of the largest banking institutions in the country, and carried out with collaboration of the public and NGO sectors. Their ambition is noteworthy: they attempt the construction of an index (ICCS) that, in their view, is appropriate for the urban conditions of Mexico. They refer to other urban sustainability indexes around the world and proceed to their own proposal of indices, their indexing and calculations. Also notable is that from the 2014 to the 2105 editions, considerable progress was made: many more institutions came on board, and methodology and the choice of indicators was refined. Report 3 is the only one among the four that mentions urban growth on 'ecologically valuable land', biodiversity and pollution of water bodies. Each city receives a grade on five environmental indicators, which are added to ten economic and social indicators, to obtain the ICCS.

Ciudad							IDA	Posición
Salamanca	70.18	59.33	52.62	46.33	51.18	58.78	55.91	3
Tehuacán	48.51	50.75	62.39	50.84	58.18	53.31	53.79	8
Tepic	51.73	53.71	55.88	50.03	51.63	54.81	52.93	10
San Francisco del Rincón	55	49.55	45.17	47.66	69.03	52.66	52.66	11
Cuautla	45.92	54.21	51.61	48.21	63.73	50.61	52.09	14
Guanajuato	50.46	59.34	46.79	55.61	53.99	46.19	51.85	15
Moroleón-Uriangato	52.4	57.16	50.12	44.12	60.57	45.12	51.24	19
Zacatecas-Guadalupe	47	52.81	48.99	49.86	53.09	54.03	50.9	21
La Piedad-Pénjamo	47.96	49.47	54.09	46.68	54.43	52.9	50.83	22
Chilpancingo	46.2	58.17	67.02	47.25	51.44	38.96	50.74	24
Uruapan	46.49	49.04	61.71	46.32	47.57	54.87	50.71	26
Ocotlán	48.33	47.96	50.88	51.67	55.38	49.53	50.56	28
San Juan del Río	47.07	58.04	45.34	51.79	52.84	48.54	50.43	29
Rioverde-Cd Fernández	44.65	49.83	62.39	43.88	54.37	46.94	49.96	34
Colima-Villa de Álvarez	42.49	47.04	47.21	49.69	54.59	60.38	49.91	37
Tulancingo	44.58	53.83	59.83	46.15	54.14	41.53	49.6	39
Tapachula	48.07	43.29	57.1	43.26	60.12	47.37	49.48	40
Puerto Vallarta	45.16	50.04	44.05	55.98	56.4	45.92	49.34	41
Monclova-Frontera	48.75	54.75	38.16	50.89	48.04	56.81	49.18	42
Minatitlán	48.74	47.52	52.55	44.36	54.13	47.92	49.1	43
Córdoba	47.4	41.44	59.81	45.8	50.69	49.94	48.87	47
Coatzacoalcos	47.4	54.56	44.98	48.86	46.74	48.89	48.48	49
Orizaba	47.56	44.82	54.18	42.7	53.92	48.26	48.38	51
Ciudad Victoria	47.4	42.42	47.23	47.27	55.24	50.47	48.18	54
Tula	50.9	48.49	45.89	45.89	53.05	43.43	47.83	58
Piedras Negras	48.75	47.99	37.97	50.31	50.28	51.8	47.61	60
Chetumal	49.42	42.4	51.2	49.59	51.3	42.37	47.56	62
Ciudad del Carmen	43.14	48.74	51.6	46.81	48.54	46.21	47.43	64
Los Mochis	40.57	49.4	47.32	50.61	49.83	46.85	47.3	65
Tecomán	41.15	39.52	51.28	45.35	56.81	49.88	46.96	66
Mazatlán	40.57	50.2	44.96	50.53	46.37	49.18	46.83	67
Tehuantepec-Salina Cruz	43.81	41.9	59.81	34.91	66.51	40.76	46.71	68
Zamora-Jacona	46.49	29.39	57.38	49.11	51.56	51.71	46.59	69
Nuevo Laredo	47.4	47.49	41.02	51.57	43.29	47.77	46.3	70
Ciudad Obregón	45.11	50.84	44.32	46.3	48.16	43.29	46.27	71
Guaymas	46.34	42.1	43.89	50.1	56.43	38.54	45.88	72
Cárdenas	47.6	41.45	49.31	39.67	57.48	41.44	45.77	73
Campeche	44.37	39.64	47.35	46.72	51.73	44.58	45.55	75
La Paz	46.93	48.75	41.55	48.05	45.38	41.76	45.28	76
Manzanillo	41.15	47.36	37.99	48.61	49.82	46.28	45	77
Los Cabos	45.89	41.55	40.36	47.62	47.12	39.31	43.51	78

Fig. 2.4 Banamex urban sustainability indicators for selected cities, before they are grouped into the ICCS. Taken from: Banamex, 2015.

Report 4 (UN-HABITAT, 2016)[209] is the only to attempt to attempt an exclusively environmental index of urban conditions. This index is part of the City Prosperity Index (CPI), developed by United Nations and composed of 6 'dimensions'. Three environmental variables are calculated into it: air quality, renewable electricity consumption and waste management. The "sustainable dimension" obtains a score of 46.7/100 when all 157 cities are aggregated. INEGI and other nationally collected public data was used.

As shown in Table 2.1, these environmental reports focus on supply and consumption of selected natural resource-based commodities (water, energy), as well as on waste disposal and air quality control, but with no mention of such things as urban heat island, stress on biota, irruption of biogeochemical cycles, changes in biodiversity (report 3 makes only a brief mention but does not report anything specific), ecological relations between the city and its provisioning ecosystems (except when groundwater depletion is mentioned), material extraction, or other indicators of ecological relations that are necessary to understand the ecology of a city.

Finally, it is also clear that these reports are not comparable in a quantitative manner, as they do not share methodologies, choice of variables, or data sources (reports 2 and 3 do not disclose their sources). Furthermore, the reliability of the proposed indices remains to be validated, as the methodology for aggregation is quite unclear (e.g. the Banamex index includes water treatment, measurement of water body quality, water supply per capita and aquifer over exploitation all in the same index, with no explanation as to the relative weights of each and how the final number is come up with).

Despite these limitations, the review of the reports was able to provide general information and a sense of the broad panorama around the topic of urban environmental conditions (inside cities and related to them). The reviews showed many commonalities and some interesting coincidences (for instance, reports 1-3 all found that intermediate cities tend to performance worse than small or large ones). The following paragraphs collect the information distilled from the review, taking special consideration of common or recurring points among the four reports:

Territory

i. Population dispersal is often mentioned as a problem for services provision, for transport and therefore is found to be connected to GHG emissions. Risk reduction also appears to be made harder by population dispersion and often by this dispersion occurring in irregular settlements of urban peripheries.

ii. Report 3 was the only one to name city expansion over adjacent ecosystems. Data is available (the report used public satellite images and GIS data, and there are quite continues series of land cover change data in universities, for example) and a country wide evaluation of ecosystems and ecosystems services lost to urban expansion would not be prohibitive to make. Partial assessments have likely been made for some cities.

Water

i. In 2009, 30% - 50% of the total water input into urban systems was either lost through leakage or not paid for[185]. In more recent years, the water authorities of San Luis Potosí (2015)[212] and Mexico city (2017 report similar numbers.

ii. Intensive and inefficient use of water by all types users even in water-scarce areas is common throughout the country. Over extraction of groundwater is common, and supply through trans boundary exported increasingly becoming so. There seems to be a persistent inability to charge users who do not pay, and to lower per capita supply, which in arid, hot climates of the water-scarce Sonoran desert can still reaches more than 400 l/cap/d.

iii. Some degree of water pollution is to be found in most major cities' water bodies (lakes, mangroves, rivers, creeks and aquifers)

Sanitation

i. Only ~50% of urban waste water of any given city is treated, with very few exceptions: Salamanca, nearing 100%, Aguascalientes 90% and Monterrey, 81%.

ii. Around 1/3 of solid wastes are not disposed of in a proper way, going to illegal dumps, or straying in abandoned grounds. The most common form of disposal is landfilling, ~10% of which still occurs in earth landfills with no protection for groundwater.

iii. Recycling or reuse of waste is quite uncommon. Urban waste to energy facilities are only starting to be installed: in 2014 there were less than five. Recycling of any type also is low, at <5%.

Energy

i. Energy use efficiency by consumers falls within acceptable standards. In general, the reports seem to support what Sobrino *et al. (*2015) report, as to the fact that larger cities tend to be less energy intensive than their smaller counterparts, but their citizens consume more energy per capita due to their lifestyles and the need for intensive transportation in congested city space[171]. Likewise, the more competitive a city is ranked to be, the greater its energy usage per capita and the energy intensity of its economy. This data suggests that no decoupling of the economy and energy consumption is being taking place[171]

ii. Renewable generation has taken off, specially in the northern arid weathers where at least three cities are generating significant amounts on electricity through solar PV systems. Several other cities towards in central and and north-central regions, have a smaller and/or pilot solar systems.

Air quality, emissions and climate change	i. 40 cities were part of the Carbonn initiative in 2011. Carbonn is a global reporting platform for cities to make their emissions and GHG accounting information public. There is then a fairly wide network of monitoring facilities and reporting of GHG emissions and air quality is quite constant although a few intermediate cities are lagging behind. ii. Air quality tends to be medium to bad in all major cities. iii. Air quality is perhaps the best studied field, as detailed studies have been conducted for major cities by the National Institute for Climate Change and Ecology (INECC), who has also put together the National Inventory of GHG emissions, with public data from all municipalities.
Natural disaster & risk	i. A majority (~70%) of urban dwellers face some type of risk to natural disasters.
Green urban space	i. Most cities have very few to practically no urban green spaces. ii. Public space in general tends to be deteriorated or perceived as unsafe.
Ecological/ ecosystems	i. There is no information in any of the reports about fragmentation of adjacent habitats, ecosystem services or urban ecosystems. It is not unreasonable to believe that ecosystem-related topics have not entered the urban sustainability discussion in Mexico, or they have done so marginally.
"Sustainability"	i. The term "sustainability" is in general used rather lightly. For instance, the Bus Rapid Transit System is qualified as a sustainable solution, and insisted upon as such throughout a text. But it is never disclosed why this is held to be true –i.e. compared to what other solution. Clearly, something is not sustainable *per se*, and no BRT or something instead of the BRT may prove more sustainable under a detailed analysis such as a LCA or a Sustainability Assessment, none of which are cited to support the 'fact' that BRTs are or have been sustainable to install in one particular city. Lightness of the trendy sustainability speech puts us at risk of uncritically choosing ready-made solutions.
Data, scattered research	i. The two Banamex reports do not clearly disclose their sources. ii. The reports relied mostly on INEGI and other public data available through government environmental institutions (SAGARPA, SEMARNAT, INECC). None cited any scholarly research. Indeed, public statistics, perhaps enhanced through surveying, measuring or calculating specific elements, can be sufficient to study certain topics in urban sustainability, urban impacts on ecosystems, and so on. But there is also a number of information available on scholarly databases that would appear not to be taken advantage of. During the survey, city-specific literature was found, reporting on a great variety of topics, some of them with a very rich urban-ecological perspective (e.g. ecological conditions of urban rivers, multiple ornithological studies, biodiversity studies along rural-urban gradients, ecosystem service assessments and a few material and energy flow assessments). It is clear that, for any given city, it is quite possible to find an assortment of individual studies, conducted by governmental institutions, research facilities, universities and non-governmental organizations on a variety of topics. Having research and data scattered about in this quite inaccessible fashion, with government data on various locations, very often not straightforward to access, and scholarly research on different databases throughout the academic world, far from where decision makers and other civil servants can access them, and everything untracked and without compiling, represents the loss of an enormous opportunity to

> learn about our urban (eco)systems, their supporting ecosystems and the relationship between. Moreover, the interrelation of all this knowledge across disciplines is fundamental to walk towards sustainability, as it is not only a matter of knowing how much waste is generated and how much recycled (current status of environmental reporting, when existing), but to understand the patterns and drivers, and the interconnectedness of them all.

2.3 Appropriate tools for urban sustainability in Latin American cities: motivation and objectives of this thesis

2.3.1 Justification

Urban sustainability is an increasingly important field in today's research and action agenda. As the world becomes increasingly urbanized and contemporary urban lifestyle, particularly of middle and high income groups[118], demands unprecedented amounts of materials and energy, and to emit more pollutants and toxics, cities clearly emerged as crucial, yet understudied[137], leverage points to drive our societies sustainably.

Although responsible for the world's largest shares of resource consumption, GHG emissions and waste generation, and of protecting its internal environment by offsetting/externalising environmental problems to other regions[56,213], the global north has made commendable advances in measuring and planning for resource efficiency, land management, improved intra-city environmental amenities, pollution control and other aspects important to environmental performance and urban sustainability. In the U.S.A., regional ecologists concerned with cities, such as the Odum brothers, were thinking about the ecology of cities early in the 1950s. Also around the time, H. Sukopp and other urban ecologists were at work in German cities. Regional metabolism data was being collected for Switzerland through field measurements in the 1980s by researchers like P. Brunner, and P. Baccini. Today, many cities in Europe, North America and Australia keep a very accurate tracking of their consumption patterns and environmental externalities, have opened sustainability offices within government structures, and continue to invest in research and development to improve their environmental performance and quality. Accordingly, most of the literature, methods and research around the topic of urban sustainability comes from global north countries.

The reality for most countries in the global South is different. We have examined the case of the Latin America and Caribbean (LAC) region through the specific situation of Mexico and noted that, despite some significant advances, (e.g. water provision coverage is fairly good) there continues to be important gaps in issues such as resource use efficiency, land planning and ecosystem surveillance (e.g. up to 50% of municipal water is lost or poorly managed, lack of zoning and ecological restrictions place aquifer catchment areas under stress due to city and industry expansion, infrastructure building, etc., knowledge about ecosystem and in this case, aquifer carrying capacity is very limited). Particularly urgent is lack of data at the city scale. Despite the clear, and often alarming, indications that urban-environmental issues are needing attention in Mexico, there appears not to be a single, comprehensive compendium of environmental data for all cities, even for just the major ones, and it also likely that there is not such a database or compendium for any one single city[X].

Making precise statements about the environment within and/or as consequence of urban life in Mexico, is then possible only in very general terms, such as those presented in section 2.2.3. While Mexico has some robust databases at the national scale for a good number of topics, little is known about conditions in the municipal, city and city-region scales. Our survey pointed to the existence of a large stock of scholarly data that appears not to be compiled (e.g. journal articles, symposium papers, thesis, university research) and therefore is likely not be profited from in policy and public administration (see sections 2.1 and 2.2.3).

Where data is available, it does not show favourable situations, with 30% of urban dwellers, who account for 80% of the population, living under natural disaster risk, prevailing urban poverty and inequality, and great challenges in waste management and pollution control (see section 2.2.3). Perhaps due to the chronic lack of data, and certainly in combination with many other factors, programmes and projects can be superficial and do not tackle the structural issues that keep systems in unsustainable conditions. Methods and tools from developed countries are many times applied uncritically and without an adaptation process. Other times, no action or actions of marginal significance are *greenwashed* to appear as ground-breaking sustainable solutions (see section 2.2.2). Moreover, institutions and policy makers seem to be uncoordinated and to lack capacity to establish encompassing and inclusive long-term visions and join in sustained efforts. Notably, institution in charge of urban and land planning have been unsuccessful in for example, establishing land management and zoning regulations to order urban growth and resource exploitation, protect ecologically sensitive areas and assure ecosystem health and ecosystem services provision (see section 2.2.1). Accordingly, Mexico has severe erosion, pollution and ecosystem loss problems.

I would contend that to advance in bringing the global South, and in this case particularly Latin America, into the urban sustainability scenario as a serious actor and not only as recipient of development aid that seems to vanish into thin air or perpetuate its own need, solutions must be found that are relevant to the context and that enable the endogenous development of solutions and strategies, enabling local creativity and intellect to act. These solutions, I believe, are not necessarily high-tech or very sophisticated (e.g. smart cities), but rather are sensitive to underlying structural issues, can take advantage of local strengths and experience, and are capable of working with local conditions, under local cultural assumptions (as much as some of these cultural assumptions may need to change –i.e. corruption, for the time being they are the real framing of things). In reality, of course,

[X] For the purpose of this thesis, a direct inquiry and information request on one particular city (San Luis Potosí) was made into federal, state and municipal environmental government offices as well as with research departments at the local university. No compilation of environmental data had ever been made. Details are given in chapter four.

any long-term and thorough solution would have to include some serious work into the political –e.g. no sustainability planning can be effective when a powerful (and unreasonable) demand for resources with great purchasing capacity and backed up by political interventionism is driving local environmental catastrophes from abroad. But that is another story.

This thesis then, is driven by

a) the desire to contribute to the urgent task of developing and applying appropriate and relevant tools, that can support local talent to continue walking towards the sustainability of cities and regions of Latin America. Specifically, tools that can deal with basic impediments, such as data availability, baseline setting, basic ecosystem surveillance, land zoning and adequate policy.

b) the need to fill in data gaps for Latin American cities and gain insight into baseline –i.e. current, urban environmental conditions, coupled with the confirmation that there is enormous amounts of data "laying about", and the certainty that the review, compilation and classification of this data will be highly beneficial for sustainability efforts.

According to the prevailing conditions in the region, that we examined in sections 2.1 and 2.2, such a tool would ideally comply with all of the following **context criteria**:

i. Should help set up a starting point. It should able to provide comprehensive panorama of the urban system and its environmental performance –i.e. a baseline, if not at great detail, at least in an overall manner that would at the same time allow for later refinement. Ideally, it would allow for the inclusion of cultural, social and political specificities.

ii. Should not be data intensive, and be able to work with the possibility of having large amounts of data for one topic and little for another. Ideally, it would at the same time be able to gather and compile whatever data is available, and report on availability and *status quo* of data.

iii. Relatively quick, simple and inexpensive, not requiring important inter-institutional collaboration, for instance, or extensive research staff or large funding sums.

iv. Be applicable through local experience –i.e. not requiring intensive training or learning curves, or large technological imports, and be able to profit from local experience that is already well established.

v. Have pragmatic, applicable results, easily "translatable" into policy-maker language, so as to inform decision makers and public officials in a straight-forward manner.

Because medium-sized cities in Mexico are the worst environmental performers according to environmental information reviewed in section 2.2.3, while at the same time they are currently experiencing increasing investment and accelerated physical expansion (mid size cities will be the ones to grow most in the coming 10 years[185]), San Luis Potosí, a medium sized, industrial and rapidly growing city in central Mexico is chosen as a case study. San Luis Potosí is also a metropolitan area, offering the advantage of also dealing with the topic of metropolitan areas, which is an issue of high priority in Mexican policy as discussed in section 2.2.

2.3.2 Objectives

1. To review major frameworks applied to study urban sustainability, as well as their tools and methods, and identify a framework and/or a toolkit that fulfils all or most of the 6 context criteria.

2. Perform any necessary adjustments to the framework chosen and define a methodology to apply it to the study of the environmental performance of San Luis Potosí.

3. Execute a "trial run" of the method. Report findings on the environmental performance of SLP. Based on the results, and if applicable, outline policy recommendations and/relevant future research lines.

4. Report on environmental data availability as experienced through the case study. Ideally, report on such issues as data sources and banks, relevant actors related to data generation, and gathering, data gaps, future research needs, and desirable future research lines.

5. Evaluate the usefulness, limitations and perspectives of future use of the method itself, reporting on its performance in relation to the context criteria. If applicable, to report on the possibility of applying other related tools and/or frameworks that emerge from the initial searches and reviews.

2.3.3 Method

1. A comparative, analytical review of urban sustainability conceptual frameworks was made, and one among them chosen and further examined for compatibility with the selection criteria (chapter 3).

2. The current status and/or experience with the framework in the LAC region is examined through a specific literature review (in annex 2).

3. The methods and tools available worldwide for the chosen framework are reviewed through an extensive literature review (chapter 3). The methods and tools are discussed and analysed, classified

into categories and its applicability to the case study then assessed through a decision matrix regarding the selection criteria established in this chapter (chapter 3). A final toolset is chosen for application in the case study.

4. The chosen tools are integrated into a method for urban metabolism analysis (UMA) (chapter 3.4).

5. The "trial run" of this UMA method is performed (chapters 4 and 5). The way the steps of the method are carried out is reported in detail, including software used and limitations encountered. Results on the environmental performance of San Luis Potosí according to the UMA, and data gaps found applied are also reported.

6. Based on the results of the UMA, an outline of policy recommendations and desirable future research lines found through the trial test is made (chapter 5).

7. According to the selection criteria and the expectations stated in the justification above, the performance and suitability of the tool, as well as of the method and protocols applied, are evaluated and reported on (chapter 6).

Chapter 3

Environmentally-aware urbanism: thought and tools

3.1 Thinkers, critics, designers

The introductory chapter of this thesis dealt with the evidence of undesirable and dangerous global environmental change, and how the operation of the anthroposphere – the human habitat – has a crucial responsibility in it. It was argued that cities (*anthroposphere hotspots*) and city life play a central role in improving the environmental performance of humans and in facilitating a shift towards a sustainable society.

The point has been made in philosophy and sociology that current environmental problems are closely linked to a western industrial-capitalist vision of the world, with roots in classic antiquity, and accompanied by concepts like "domination" or "taming" of nature and other such precepts that led eventually to objectification of all that is not human[214,215]. An opposite view, one of integration and co-existences of humans and the rest of the natural world has been a trait of several cultures throughout the world. While it is true that the overshooting of ecological load-bearing capacity occurred among human groups since prehistory[44,45], through the neolithic[216] and in antiquity[217], other groups have historically been able to preserve their ecosystems through an earth-based ethic and cosmogony, based on principles such as the belonging of humans to the natural world (a sort of one-ness), a vital dependency and even sub-ordination of humans to nature, a responsibility to take care it, and a sense of the undesirability of damaging the exterior natural world, which is seen as the elemental support of human life. Anthropologists have documented such cosmogonies and their spatial expression in communities still in our present time[218–221]. In other words, degradation of landscapes and ecosystems have not been the only mode of human development, and do not have to be today.

3.1.1 Thinkers and designers in urban sustainability

"...Forget the damned motor car
and build the city for lovers and friends!"
-L. Mumford
My works and days, 1979

In modern western culture, and despite the dominance of anthropocentric values, by the first half of the 19th century, Karl Marx and Friedrich Engels pointed to the appropriation of nature as a means of enlarging private wealth (original appropriation), with detrimental consequences to the environment, such as the loss of soil fertility through the importing of its nutrients, deforestation and changes in local climate[222]. Throughout that same century, and motivated by those same degraded

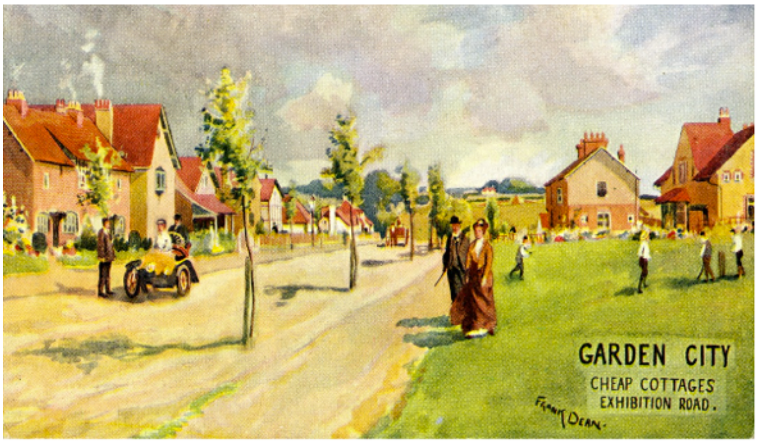


Figure 3.1 Above: a 1905 postcard of Letchchworth Garden City. © Garden City Collection. Used with permission.
Below: Richard Register's 2010 idea for the Ecocity New Orleans.

landscapes, John Ruskin, William Morris, Henry David Thoreau and John Muir were among those who produced influential writings and art, portraying the necessity and possibility of reintegrating nature and humans. Although often much more ideological than practical, these were the works that would propel 20th century environmentally-aware city, landscape and architectural design[223].

Thinkers, critics and designers in the first half of the 20th century continued to make attempts to call the public's attention to the deplorable environmental conditions, consequence of the workings of the economy. Planners Ebenezer Howard and Patrick Geddes in England, along with architects Frederick L. Olmstead and Frank Lloyd Wright and scholar Lewis Mumford in the USA, envisioned new cities as products of social and political reform, with ample green spaces in idyllic rural-like settings, and this was called the 'Garden City' (see fig. 3.1). Theoretical work was prolific, ample plans were laid, prototypes ere constructed, up to the size of real cities, such as the pioneer Letchworth Garden City in England[224] (Howard, 1903) and the Australian Canberra[50]. Building of 'green' settlement prototypes became more common after the 1960s and its upheaval of environmental concerns, and today many, perhaps hundreds, *ecocities*, *ecovillages*, *ecotowns* or other such settlements can be found in several countries around the world. Intellectual production around 'green', 'sustainable' or 'ecological' cities also becomes abundant from around the time of Carson's *Silent Spring* (1962) and into the 21st century. Anne Spirn's six principles for Ecological Urbanism (1984, 2012), the New

Urbanism movement and its charter (1993), and Richard Register's *Ecocities* criteria (1992, 2010, see fig 3.1) are only a few examples among many[Y].

Most of the proposals we have revisited have been utopian and only roughly programmatic in nature –i.e., they propose a (sometimes radical) vision of the future and a general plan of how to get there, sometimes building physical prototypes to illustrate the point. But they are not necessarily built upon robust comprehension of life systems or natural or earth science. Pickett *et al.* (2001)[114] observe that much of contemporary ecological planning has no sound scientific base, while Alberti (2008)[136] finds that urban designers attempting to practice ecological design often act on an incomplete understanding of ecological systems. Finally, Baccini and Brunner (2012) observe that "*in the traditional planning process of new settlements, the design of its metabolic process is of secondary importance. Thomas More did not waste any sentence on the metabolism of his Utopia.*"[50] While visions and utopia are quite valuable components of social change, inasmuch as they can and they do trigger society's mobilizing towards positive change[225], a scientific base is by no means dispensable. For instance, it is clear that the Ecological Urbanism principles, as proposed by Spirn (2012)[226], which propose that cities are to be considered ecosystems and be designed as wholesome entities that emulate ecosystem behaviour[226], are impossible to realize without knowing precisely what these ecosystem rules are –i.e.. how ecosystems evolve, what their components, interrelations and underlying rules for behaviour are, etc. This knowledge is the domain of the natural sciences, which must at any rate be integrated into the design and operation of the anthroposphere, if we wish to steer ourselves into sustainability.

This has however, generally not been the case. Perhaps due largely to the distancing of disciplines, typical of the compartmentalisation of modern science, and perhaps also because evidence of environmental degradation was not as conspicuous as it is now at the time when Ebenezer Howard and of course Thomas More wrote, urban planners and designers, albeit many of them certainly well-intentioned, produced and continue to do so, ideas of 'sustainable architecture' or 'green cities' that in reality may be very distant from being so. It would appear to be self evident that the mere inclusion of green spaces does not render a city sustainable: as was discussed in the previous chapter, prosperous cities in the developed world normally have vast amounts of greenery, and are nonetheless the most unsustainable when their material and energy uses, or their carbon footprints are considered. However, interventions along the lines of building new urban parks or installing green roofs are continuously marketed and thought of as sustainable solutions (see *Greenwashing* section in chapter 2). The vision for a sustainable city should include the vision of its hinterland, taking care to profit from it in a way that assures that its ecosystems stay healthy, are not-over exploited and so on. Ensuring high quality local environmental amenities (increasing park space, tightening water quality regulations, recovering degraded surrounding landscapes, locally improving air quality) while increasing environmental

[Y] It is not within the objectives of this work to present a comprehensive history of the ideas and projects of environmentally aware urban design. Committed compilations have provided us with such material, as the reader can consult in references [223–226], among other abundant literature.

burdens elsewhere, -i.e. *shifting the problem*[213]- makes no sense in an interconnected world, but is the case rather often and is altogether unavoidable if our city sustainability ideas don't consider lifestyle patterns in relation to the (global) hinterland. In this sense, thinking about "greening cities" obliges us to think about, basically, "greening everything", indeed perhaps our priorities, but particularly, and to stick to the topic, our consumption patterns, the quantities and qualities of them, where they comes from and where they go, and how that translates to helping other ecosystems thrive and prosper, or not.

3.1.3 Moving forward

The difficulties in moving toward sustainable lifestyles likely have more than one explanation. One is, perhaps, that objectively assessing whether and to what degree a product, process or programme is sustainable is not a straight forward or uncomplicated task[227,228]. Defining sustainability is still a current debate, and a universal definition may never be reached, opening up a crevice for many things to be claimed 'sustainable'. Another answer could be that we are still within the transition period for these notions to enter policy-making and the *quotidien*,. But whatever the case, it is key to acknowledge the real state of things and exercise critical inconformity. As argued by Delmas and Burbano (2011)[193], *greenwashing* may erode the support for "deeply green" options by setting the baseline at very low standards. In other words, an uninformed society will "settle for less", as less is the common norm[Z].

Urban development in many places throughout the world has generally been conducted with an almost total disregard for issues such as environmental quality, ecosystem health or sustainable provision of natural resources12/09/2017 16:15. In LAC, little to no measurement of environmental impact is as of now carried out, and in not few occasions, proposed 'sustainability' measures strongly resemble *greenwashing* behaviour. Urban planners are ill-equipped to think about environmental problems, as their training stems mostly from the humanities and the social sciences[235], which by a twist of 19th century century ill-fate, were distanced from the sciences. Eventually, through the 20th century interdisciplinary dialogue faded and hyper-specialization grew, resulting in disciplines losing connection to each other, and in the limited ability of most professionals "brought up" in one discipline to tackle complex and interweaved problems such as those of sustainability[235]. But the solutions to the complex problems of social-ecological relations are not likely to be simple, uni-disciplinary, or be easily reached through ready-made panaceas[236] prepared by any discipline.

[Z] This is true in for example, Mexico City receiving a "sustainable city" prize (2013) and city environment staff taking pride in it (along with some citizens too!)[229]. Naming Mexico City the "most sustainable Mexican city of the year" is quite outrageous (when not suspicious): despite some progress in air quality standards, it continues to continuously fall below all national and international standards[230,231] (the city has the worst levels of O_3 atmospheric pollution and fourth worst in suspended particles)[232]. A city whose local aquifers are completely abated[233], where the wastewater produced by 20 million people is pumped untreated practically 24 hours a day, using electricity, out of the watershed and into neighbouring regions where it causes severe health problems, and who has been uncontrollably growing over lakes, forests and marshes for hundreds of years[234] is quite plainly, impossible to consider sustainable.

Urbanism has to go beyond poetic vision, political discourse and commonplace, fashionable and unverifiable 'green' strategies, towards an urbanism with a solid scientific base, a built-in ecological focus, an ample capability of working at multiple scales and of an array of natural-science based disciplines[136]. Such an urbanism would be based on a thorough understanding of the city's demands for resources, and of the ways that mechanisms of provision, consumption and disposal (metabolism), interact with and exert pressure on supporting ecosystems and surrounding landscapes. With the purpose of narrowing down perspectives useful for application in the context of Mexican and Latin-American cities, I will now explore the theoretical and conceptual baggage of three frameworks from the natural and social sciences, notorious in our time for their prolific thinking and acting about urban sustainability.

3.2 Frameworks from the natural and social sciences

To successfully integrate environmental concerns into the planning, building and management of cities, a conceptual framework must be found, in which environmental criteria are assimilated *structurally*, and not only *superficially*[50,237,238]. Such a framework should be operational, in the sense that it must include a set of tools that allow for objective assessment of the current state, for action to be designed and undertaken, and for *a posteriori* evaluation of results that are comparable to initial assessments. The framework should also be locally relevant, and applicable under the particular conditions of Mexican cities, as we have outlined them in the preceding chapter, with its particular social and economic conditions and where, as has been discussed, urban environmental data generating and reporting is quite deficient, and where *greenwashed* solutions often go by unnoticed or even praised.

There are several possibilities of useful frameworks that could fulfil these criteria. I contend that particularly well suited are frameworks derived from the science of ecology, such as the urban ecology and socioecological systems approaches, as well as societal metabolism approaches used to examine socio-economic entities. In this section, the main features of these frameworks will be reviewed.

3.2.1 Urban ecology

Ecology is the branch of biology that studies the interactions between living organisms and their environment, and the driving factors of those interactions. It is a fairly new discipline (compared to, for example, physics or chemistry), stemming from biology late in the 19th century[112,] when the German biologist E. Haeckel coined the term *Ökologie*[239]. It is an inherently synthetic discipline[135], bringing together knowledge from different fields (e.g. soil science, hydrology, organism biology, geography) and dealing with complexity and interaction in and among systems.

One of the cornerstone concepts of ecology is that of 'ecosystem', coined by the English botanist A.G. Tansley in 1935, to refer to the interacting ensemble of an organism and its physical *"habitat factors in the widest sense"*, which are inextricably linked to form a whole. According to Tansley, an ecosystem can be of "*the most various kinds and sizes*" and is, like all other isolations in science, an artificial delimitation, useful for study but ultimately not perfectly real, because all systems in the world overlap, collide and interact[240].

It follows that ecosystem ecology studies the interactions between elements within an ecosystem and of the ecosystem itself -considered as a unitary, complex entity- with other ecosystems and entities. At first, ecosystems ecology (along with other areas of the discipline) was primarily concerned with pristine ecosystems[112], and modelled the environment as if it were human free[136]. But by the 1960s scholars were starting to apply the tools of ecological science in urban settings[241], and conceptualising cities as 'urban ecosystems'[114,136]. E.P. Odum's 1975 classic *Ecology: the link between the Natural and the Social Sciences* features a chapter on "urban ecosystems" and includes "fuel-driven ecosystems" within the ecosystem categories[239]. His brother, H.T. Odum, pioneered work in assessing biogeochemical and energetic budgets in cities[114].

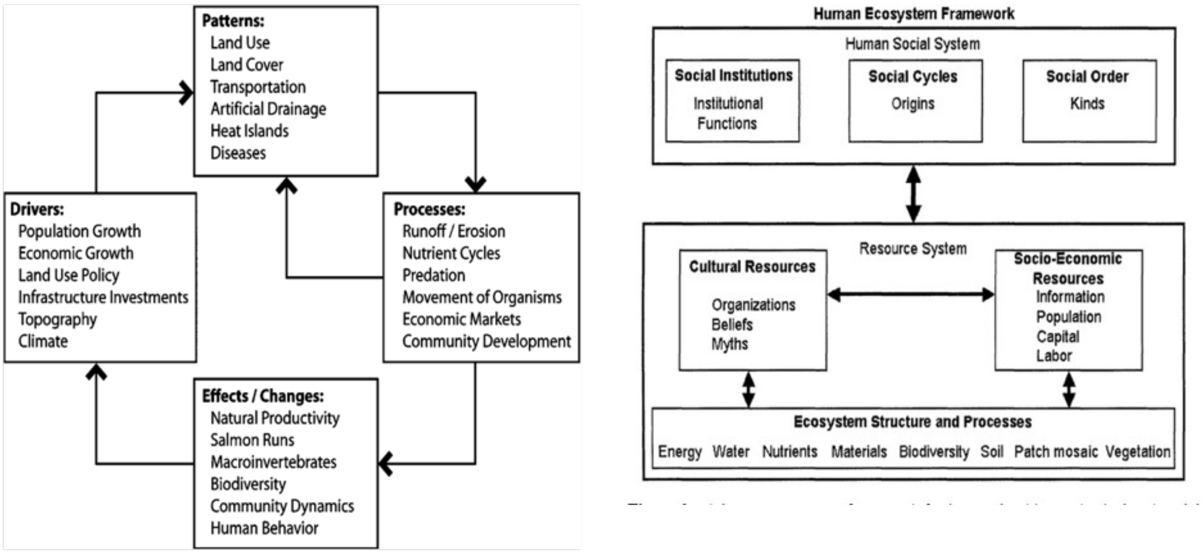


Figure 3.2 Left: Human ecosystem framework. Pickett *et al.*, 2001
Right: Urban ecology conceptual framework. Alberti, 2008

Thus, the distinct field of urban ecology[AA], began to be shaped in its actual form around the mid 20th century. Through the last four decades of the 20th century, numerous scholars around the world added to the urban ecosystem corpus, studying specific aspects of urban ecosystems, including species composition (Sukkopp, 1995), fauna (Beissinger and Osborne, 1982), and energy and material balances (Wolman, 1965; Boyden, 1981). These studies were mostly still within the traditional disciplinary bounds of ecology, but an integration between social and natural sciences was already nacent[136]. In the late 20th and early 21st centuries[BB], urban ecology has become far more interdisciplinary through the work of several teams, a very incomplete list of which would include Pickett *et al.*, (1997[133], 2011[238]), Alberti *et al.* (2003[237], 2008[136]), Grimm *et al.* (2000[244], 2004[245],2008[113]), Groffman *et al.* (2017[246]). Building on the legacy of early ecologists, urbanists and planners (E. Odum, H. Odum, H. Sukopp, L.

[AA] Early 20th century Chicago School sociologists such as R. Park and E. Burgess proposed models of urban expansion built on precepts roughly and rather metaphorically transposed from ecology (e.g. succession, competition, dominance)[235,242]. Their work was then known as 'human ecology' and also 'urban ecology', although their use of ecological concepts was metaphorical and their aim was not to understand ecological systems but to explain social and spatial characteristics observed in cities[136]. Furthermore, the paradigms and concepts of ecology evolved rapidly within a few decades and the ecological theories on which the Chicago School drew inspiration are outdated[114]. While Park and Burgess' theoretical elaborations are still taught in planning schools and may result useful to understand some aspects of urban development, they cannot be recognized as either human or urban ecology in the contemporary sense of the terms.

[BB] A more detailed revision of the development of urban ecology is provided Alberti (2008)[136]. McGregor et al (2013)[243], include evidence of the existence and evolution of urban ecology research since the mid-20th century in Latin America.

Mumford, K. Lynch, I. McHarg, A. Spirn, among many others) these teams are pushing forward the frontiers of ecology into a deeper understanding of cities as ecological systems. In their frameworks, different attempts are made to bring together and correctly ponder both the human and 'natural' components of systems (see figure 3.2). The tools of ecology (e.g. ecological network analysis, matter and energy budgeting, patch dynamics[244], watersheds as study units[133,244], biodiversity assessments) are seen as fundamental, -if perhaps not on their own absolutely sufficient- to study, understand and manage cities[114].

Although laborious and not straight-forward to accomplish, integrating knowledge across fields, particularly with the social sciences and also with engineering and architecture, is recognized to be fundamental for urban ecology to be a successful tool for urban sustainability[112,114,133,135,136]. Contemporary urban ecology "*integrates the theory and methods of both natural and social sciences to study the patterns and processes of urban ecosystems*"[113], and to understand and analyse the city as both a driver and a responder to global environmental change[113]. Collins *et al.* (2000) [112] assert that the urban ecosystems approach is part of a 'New Ecological Paradigm', emerging late in the 20th century, inasumuch as it acknowledges the dependence of human-urban systems on natural assets.

Urban ecology sees urban ecosystems as heterotrophic[112], human dominated[136], and highly heterogeneous[112,114]. Because contemporary ecology draws largely on the theories of complex adaptive systems[CC], cities are also understood as dynamic, complex, adaptive (or living) systems where humans are usually the main driver[113,136]. Urban ecosystems show, like other complex adaptive systems, traits such as openness and non-clear, shifting boundaries, multiple equilibrium points, non linear behaviour, high unpredictability, partially legacy-determined pathways, autonomous agents acting independently and simultaneously, decentralized control and self organization[136,247] (see Box. 2.1).

Ecology *in* cities and ecology *of* cities

There are two main approaches to the study of urban ecology: ecology in cities and of cities[114]. The first, recognized as the pioneer and most common approach[114,135], focuses on ecological patterns and interactions within the urban condition. Examples are: species composition in urban green patches, patterns of succession in vacant lots, effects of the heat island on flowering times, precipitation patterns associated with air pollution, diversity of birds in city parks, local hydrological conditions as affected by the built environment.

[CC] For several decades now, systems theory has been enriched and energetically moved forward by many thinkers. It is by no means a settled field, and although generally accepted foundation exist (General Systems Theory), interpretations, variants and applications are numerous. The terms 'complex adaptive systems' (CAS), 'living systems', 'auto-poetic systems', among others, are current in contemporary systems jargon and point to roughly the same thing: self-organizing, living systemic entities such as bacteria or tundra ecosystems. Systems thinking is already very widely applied across fields from business administration to biology. In the fields of social-ecological thought it is corner-stone relevant, *vis-à-vis* the wicked problems that humanity faces on the road to sustainability. Scholars normally recognize systems thinking as a base for studying ecological issues in general, and urban issues in particular (e.g.[135,136,247] and also pioneer urban systems thinker, C. Alexander, 1966). Throughout this section, mention to systems thinking will be recurrent, but a thorough revision of what systems thinking is can evidently not be made within the bounds of this work. Systems thinkers that are key in the context of CAS and social-ecological theory are: von Bertalanffy (1968), H. Odum (1971, 1996), Nicolis and Prigogigne (1977, 1989), Maturana and Varela (1998), Cilliers (1998); Portugali (2000), E. Morin, Holland (2006) and the classic Meadows (1966/2008).

Box 3.1 Characteristics of urban ecosystems

Human dominated / Organized by human processes
Alberti, 2008[136]; Chen, 2015[248]

Profoundly altered original setting / Modified disturbance and succession regimes
Chen, 2015[248]; Collins *et al.,* 2000[112]

Composed of human and non human organisms, naturally present abiotic elements, human-made abiotic elements and information

Spatially and temporally heterogeneous
Collins *et al.*, 2000[112]; Alberti 2003[237], 2008[18]

Heterotrophic / High dependence on their fringe environments
Odum, 1983[249]; Collins *et a*l., 2000[112]; Alberti, 2008; Chen, 2015[248]

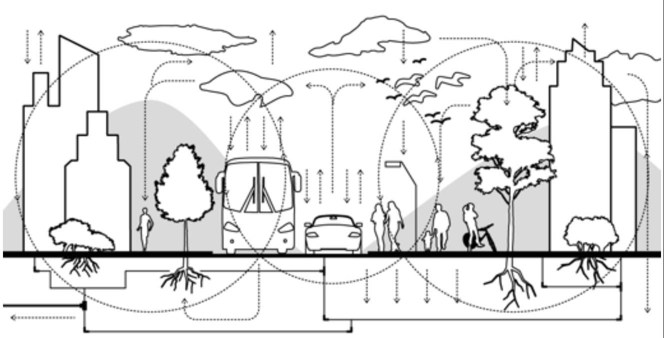
Linear metabolism
Collins *et a*l., 2000[112]

Energy-intensive
Collins *et al.*, 2000[112]

Complex dynamic adaptive systems
Tjallingli, 1993, Collins 2000[112]

-- showing properties such as: --

Open / Non-isochronous boundaries
Alberti, 2008; Golubieswky, 2012[250]) / Chen, 2015[248]
Highly interconnected parts
**
Autonomous agents / Decentralized control
Alberti, 20008[136]
Non-equilibrium state, multiple equilibrium points
Alberti, 20008[136]
Non-linear behaviour
Nicolis and Prigogine, 1977, cited in18[136]
Self-organizing
Nicolis and Prigogine, 1977, cited in18[136]
Emergent properties
Odum, 1983; Alberti, et al. 2003[237], 2008[136]



The study of ecology in the city of, allows for the understanding of how local ecosystems work and how its elements are interconnected or potentially affected by human action, all of which is central to the proper management of local environmental amenities and ecosystem services[135], and thus vital in ensuring both quality of life and environmental performance. Furthermore, the unique and unprecedented conditions created by human-dominated urban systems offer a "life–sized laboratory" of the behaviour, function and evolution of ecosystems in interaction with social systems, insights which could prove useful as future earth's conditions are likely to resemble those of human urbanized regions[113,246]. Thus, the study and tracking of urban ecological conditions, and the evaluation of the outcomes of locally implemented environmental solutions, may help discover and understand general patterns of ecological interactions in human dominated ecosystems, and help predict probable future states of other human-intervened ecosystems and even of the earth system as a whole. These insights can inform urban practitioners for better planning, design, management and problem solving[113,135].

The different but complementary approach of ecology of the city studies the city *itself* as an entity (an ecosystem), analysing its dynamics (e.g. matter and energy flows) and drivers (e.g. resource demands of its inhabitants). This approach is a broader, systems-oriented deviation from the traditional way of studying urban ecology (in cities)[114,135,] including physical attributes (built environment, natural assets) and social elements (institutions, political processes, cultural values), to understand city-region relations.

A large array of tools, models and approaches could be listed as part of the ecology of cities approach to city sustainability[251]. Within them, a notoriously present approach is landscape ecology, which applies patch dynamics theory and modelling tools to research into topics such as: the relations between present and projected land use patterns, habitat fragmentation, ecosystem function and biodiversity[136,244,252]; the effects of urban development regulations in overall resource demand and of that demand on the hinterland; the biogeochemical or energy flows in, through, and out of the city system[245]; effects of the city on climate at the regional scale[245], and ecosystem services provision[248].

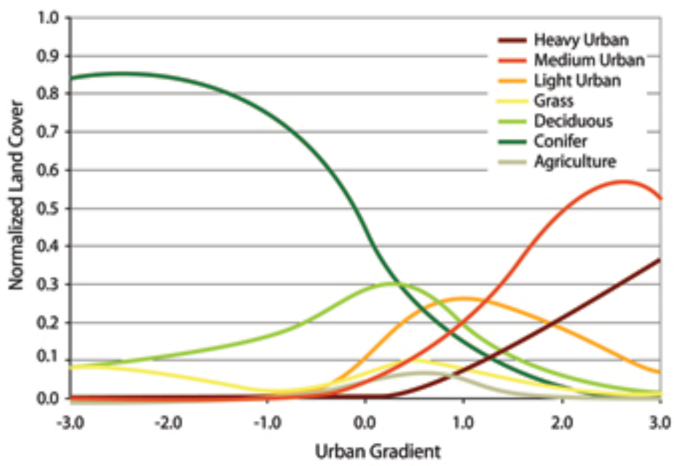


Figure 3.3 Ecological signatures", a recent undertaking of the Urban Ecology lab led by M. Alberti at the University of Washington. It aims at understanding the real ecological effects of given land use types, with the aim of eventually devising low-impact urban development patterns, it is argued that the common bias towards dense urban development is little more than a myth, as in reality too little is know about the ways human settlements interact with their surroundings at the ecological scale.
Taken from: Alberti, 2007.
Available at: escholarship.org

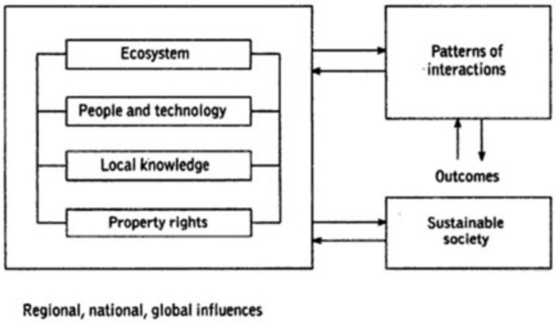
Ecology of cities demands the tight integration of not only the scientific disciplines present in ecology in cities, but of a much broader set of fields (McPhearson *et al.*, (2016) identify at least twenty-three[135]) to come together in a perspective where no one is more important than another[135], but rather all contribute with their own tools to the common goal of understanding the city in its socio-ecological complexity. This jump into trans-disciplinarity[135] is of course a challenge in itself, as it requires scholars to "learn other languages", loosen their own paradigms and break the comfort zones of familiar assumptions, terminology and approaches into a communication with unfamiliar ideas and languages. Furthermore, for an ecology of cities to correctly apprehend to multiple components of the urban ecosystem and influence the state of things, researchers will need not only to communicate amongst themselves, but also with non-academic actors[135,246] traditionally "out of the picture" of ecological research, such as urban practitioners in city offices, private stakeholders such as the real estate industry, social entities such as community associations, and public agents such as legislators and ministries. Ecology of cities may then potentially also be a tool for social transformation, if it achieves the bringing together of top-down and bottom-up approaches, and the involving of a broader community in the study, comprehension and transformation of reality[135]. This transformative and socially engaged ecology would then be an ecology <u>for</u> cities, where knowledge turns to active involvement in make cities sustainable and better for humans well being [135,253].

Although with a more or less consistent identity since the 1990s[246] and showing rapid growth all over the world[135], urban ecology is not yet a settled discipline: it does not have a grounding, generally-accepted theory or set of concepts, nor standardised methodologies or frameworks[135,251], and it continues to define itself through praxis and continued interdisciplinary entwinement. It has however already managed to formulate relevant management and policy proposals plausible for immediate application and is well poised to increasingly continue to do so[135,136,251,252]. Urban ecology can thus be considered a promising field, likely a crucial one, in the building of humanity's sustainable future[135,244,251,].

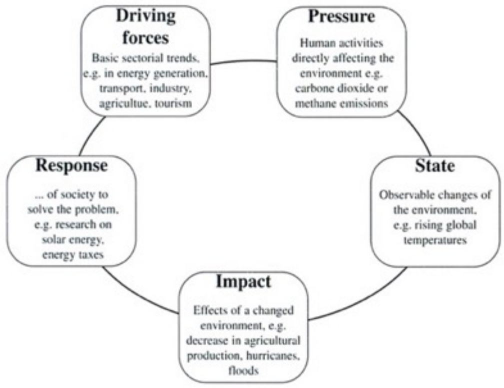
3.2.2 Social-ecological systems

In the late 1990s, the notion of "*social-ecological systems*" (SES) was introduced as a framework to study and think about the interactions of humans with nature[254]. The concept came as a result of the acknowledgement that the complexity of environmental problems called for interdisciplinary approaches that could consider both human and ecological systems[236,255,256]. A pioneer work edited by Berkes and Folke (1998)[255] introduces SES in the context of proposals for improved natural resource management through local/indigenous knowledge, systems thinking and a shifting away from an anthropocentric view of nature. In the volume, Holling *et al.* (1998) posit that "*[natural and social systems] are in fact one system...*".

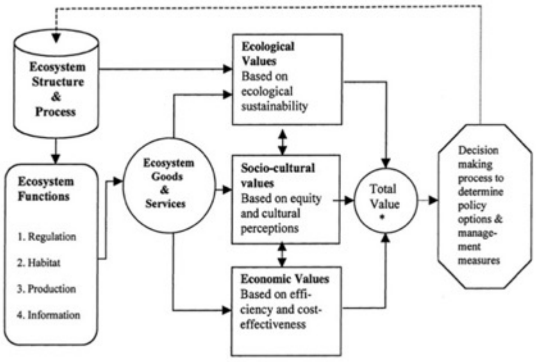
Although at the time when the work was published, a mere 20 years ago, the idea that social and ecological systems are functionally linked and much less one same system, was *"not yet accepted in conventional ecology and social science"*[255], the social-ecological systems concept (also referred to as 'socio-ecological systems', 'linked social-ecological systems', or 'coupled human-environment system) was, much like that of 'urban ecosystem', fast to catch on. In only a couple of decades, SES thinking has gone around the world, and frameworks have multiplied into a variety of approaches and working groups, each emphasizing different aspects of the system[59]. Binder *et al.* (2013)[257] found at least 10 different frameworks for SES analysis, all showing significant differences in, for example, definitions of basic concepts, goals and scales examined. It would appear that, again like urban ecology, SES thinking is entering a "consolidation" phase, as its scholars begin to acknowledge vagueness of terminology[256,257], to attempt the construction of a unified theory[258], and to search for shared languages, models and research agendas that allow for result comparison and integration among different teams, for example[257].



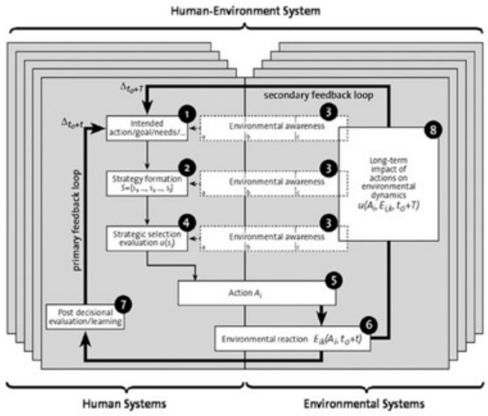
A framework for analysing the link between social and ecological systems
Berkes & Folke, 1998



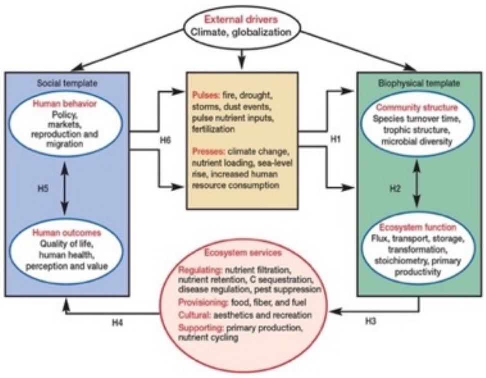
Driver, Pressure, State, Impact, Response (DPSIR) framework
Eurostat, 1999



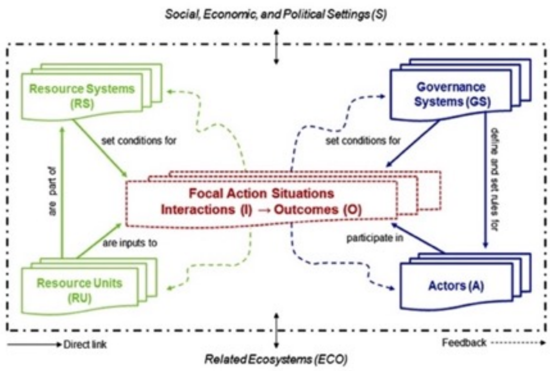
Framework for integrated assessment and valuation of ecosystem function, goods and services.
De Groot *et al.*, 2002



A structure - process model of Human-Environment Systems
Scholz & Binder, 2003



The "Press-Pulse Dynamics" (PPD) framework for long-term social-ecological research
Collins *et al.*, 2011



Social Ecological Systems framework
McGinis & Ostrom, 2014

Figure 3.4 Social-ecological systems frameworks

"...*people depend on resources and services provided by ecosystems, and ecosystem dynamics are influenced, to varying degrees, by human activities.*"[259,DD]

"...*people, communities, economies, societies, cultures, are embedded parts of the biosphere and shape it, from local to global scale. At the same time people, communities, economies, societies, cultures, are shaped by, dependent on, and evolving with the biosphere*"[254]

SES are "*nested, multilevel systems that provide essential services to society, such as supply of food, fibre, energy and drinking water*"[255]

SES thinking draws on complex systems theory, recognizing that SES are complex adaptive systems[EE,254]. Ecology and multiple social science platforms are also important pillars of SES[258,259]. From the interaction among these fields, key SES concepts, such as *ecosystem services*[260] and *resilience*[255] have stemmed, and are now an everyday component of sustainability-related language. Also crucial in SES are the ideas of economy and society as subsystems of the biosphere, of the essential dependency of humankind on the biosphere and the services and goods it provides, of co-evolution between biosphere and humankind, and of a necessary human stewardship of the planet if we are to live sustainably [254,261] (see chapter 1).

The close resemblance of essential postulates of UE and SES jumps to sight. Both fields draw on systems theory, both acknowledge that human and ecosystem dynamics are inescapably intertwined and both are being worked on by multidisciplinary groups with a dominant natural science component, who are trying to create an integrated, trans-disciplinary field. Although Urban Ecology has a longer historical root, both fields emerged into their current form around the same time (late 1990s), and have evolved in similar ways during similar periods, to such an extent that they are both facing very similar disciplinary challenges at present, such as the consolidation phase suggested above. Furthermore, both fields are regarded by their practitioners as effective and necessary tools to reach a more sustainable future (cf.[113,135,258,261]).

Perhaps the two greatest differences between both frameworks is that SES has a far broader scope and is much more strongly linked to applied resource governance and management solutions. Any given urban ecosystem is of course an SES[262], but not all SES are urban ecosystems. SES are any agricultural, forestry or fishing community, any resource-extraction activity and the social-economical framework that drives it, or the landscape-related ritual corpus of indigenous peoples. They are all systems where a strong human-ecosystem relation is taking place, but the human context is not necessarily -and in the development of SES theory has seldom been- urban. Tools such as the SES framework (McGinnis and Ostrom, 2014[263], see 3.4) and the Institutional Analysis and Development Framework (Ostrom, 2011, cited in[263]) have been applied to study natural resource management and governance systems,

[DD] Berkes *et al.* 2003, Turner *et al.* (2003), Steffen *et al.* (2004), cited in Chapin *et al.* (2009)[259].
[EE] See note J.

most often in rural contexts (see for example[236,264,265]). Qualitative methods (interviews, historical sources analysis and other methods from the social sciences), as well as mathematical modelling, have also been applied to understand the complex and dynamic interactions within SES: change regimes, thresholds and mechanisms of resilience[266,267], as well as to understand the conditions that allow for stewardship, sustainable resource management and maintenance of ecosystem services[268]. Material and energy flow accounting with the more traditional methods (e.g. Baccini and Brunner[269]) have been applied within an SES frame[270], and also with MuSIASEM, a more complex societal metabolism study tool, strongly focused on the socio-economic driving structures of a society's materials metabolism[271,272]. In recent decades, and in the context of global environmental change and sustainability thought, SES scholars have began to focus on the management and governance of the planetary-scale social-ecological system (humanity-planet), proposing *planetary stewardship*, i.e. a conscious and pro-active change in attitudes and policy to change undesirable trajectories and conduct society in a way that preserves ecosystem services for the well being of humanity, embracing uncertainty and fostering resilience[261].

Despite the resemblance of conceptual foundations, aims and interests of SES and UE, communication among both fields is not pervasive. Some urban ecologists are thoroughly identified with SES (e.g. Grimm *et al.*, 2013, cited in[135], Pickett *et al.*, 2011), but on the whole it appears as though the two were still separate fields. Recently, SES scholars have touched on the subject of urban areas, pointing to urban lifestyles and globalized urban-based power structures as drivers of land-use change and biosphere shaping, and thus crucial for global sustainability (e.g.[254,256,262]), often along the lines of what was discussed in chapter 1 around the Anthropocene and the *stewardship* concept (e.g.[254,259]). Likewise, UE scholars are beginning to look at the SES approach to enhance urban ecology's understanding of, for example, ecosystem services, resilience and ecosystem management[135].

3.2.3 Societal metabolism

Societal metabolism (SM) is a school of thought committed to the study of society-nature relations, with a strong emphasis on the flows of materials and energy[74]. Fisher Kowalski (1998), for example, uses 'material flow analysis' as an equivalent of 'society's metabolism' (cf.[273]), but Giampietro (2014)[247] emphatically states that not every accounting exercise is equal to a metabolic analysis, which should be considered as *"the set of relations between the identity of the system reproducing itself and the identity of the network of flows required for this purpose"*. Baccini and Brunner's (1991)[50] work, which we have revised in the preceding chapter, can be placed into this category of frameworks, although instead of the term 'societal metabolism', they employ 'metabolism of the anthroposphere'.

When analysing SM one tries to (i) characterize the system, its components, the relations between them and of them as a whole system with "exterior" systems (the *identity* of the system in

Giampietro[274]), and (ii) quantify all material and/or energy flows into, through and out of the given socio-economic system (a city, a nation, a region, etc.). These flows proceed from and flow out into surrounding ecosystems, and therefore the socio-economic unit of analysis should always embedded within an ecosystemic understanding[273]. This accounting of flows is known as Material and Energy Flow Analysis[FF] (MEFA), and it has been applied in all scales, from the global to the very local, meaning that SM's unit of analysis can be a national economy, a city, a small fishing village or an industrial enterprise[213,273.] The flows analysed can also vary largely; from the total amount of materials used (total material requirement, TMR) of a whole nation, to the flow of a single substance (e.g. cadmium or hydrocarbons) in a limited region. MEFA is then a flexible tool applicable in many scales and situations, and its results are a useful indicator of an entity's overall environmental performance[273]. When applying MEFA methodology to know, for example, the TMR of a nation or region[213,275], it will clearly unveil the pathways through which that entity exerts pressure on the environment by making explicit evident and the hidden quantities of materials consumed, and the ways in which they are sourced, used and disposed of. Preciseness will vary depending on the number of variables analysed, the availability of information and the amount of detail of the base model used to represent the system (entity), but even when applied with gross data or a general, coarse model, MEFA can prove useful to obtain an overall, if perhaps 'fuzzy', image of an entity's metabolism.

The first attempts to carry out an empirical accounting of material flows through an economy were done by T. Weyl in the 1890s (at an urban scale) and by P. Geddes in the early 1920s (at a macroeconomic scale)[273], but SM has a longer conceptual tradition. 'Metabolism', understood as the exchange of substances and matter between a human/social entity and its natural surroundings was used already in the 1850s in K. Marx's *Stoffwechsel*[74,273] concept, which he uses to build the idea that flows of matter from nature are the primary base of man's work and therefore of value-creation (Schmidt, 1971, cited in[74]).

A century later, and in the context of the 1960's environmental movements, the exchanges nature-society became a main theme again, notably in Europe and the USA, and in the fields of economics (e.g. Boulding, 1966; Ayres and Kneese, 1969), geography (e.g. Neef, 1969), engineering (Wolman, 1965)[273]. A pioneering first impulse came from the works of ecologists H.T. and E.P. Odum working since the 1950 on the metabolism of large scale systems[50]. The work in this couple of decades was arguably the land-marking start to a 'new research tradition', as it focused on flow analysis from the perspective of environmental concerns[273], in contrast to, for example, Marx's more political and

[FF] Flow Analysis can include materials *and* energy (MEFA), be limited to one substance (SFA) or be exclusively focused on energy flows (most often called Energy Metabolism, EM). Fischer-Kowalski (1998) notes that EM research was so wide (already 20 years ago) that she excluded it from her review because the amount of research was too vast and was better studied and reviewed than MFA. Likewise, today's research is abundant, and very diverse. To note every exception would be unpractical, and thus for brevity's sake in this text we shall only use the term 'MEFA', but keeping in mind that this can also mean MFA, EM, or even SFA.

economics-oriented studies. The period since the 1960s was labelled by Fischer-Kowalski (1998) the "first wave" of societal metabolism studies[273].

Arguably because disciplinary divisions had grown stronger than they were in the preceding century[74,273], this time the use of the term 'metabolism' was challenged, through arguments such as early 20th century sociologists' (e.g. M. Weber, E. Durkheim) that society can only be explained in social terms, claiming as invalid any biology-based arguments about social systems, because these do not show the organizational properties and regulatory mechanisms of the organismic metabolism[273]. Thus the term 'metabolism' was thought by critics to be only applicable in the focus of the biological or medical sciences, as an ensemble of chemical processes leading to vital energy in living *individuals*, and therefore its application to higher levels or organizations (e.g. ecosystems or societies) was deemed unacceptable. This was eventually contested[GG] by environmental sociologists (e.g. Catton and Dunlap, 1978)[74] and ecologists (e.g. H. Odum, 1956; E. Odum, 1969[276]) who had worked with, for example, the information networks and emergent properties of ecological systems, and argued, that because ecosystems are not organisms, their metabolisms are indeed not governed by the same laws, but that does not mean they do not have a metabolism (E. Odum, 1959, 1975). The advancement of systems thinking helped push these ideas forward, and cut the disciplinary boundaries laid in the preceding century[50]. Thus, the need was recognized to expand the concept of metabolism to include other processes besides cells' anabolism and catabolism[247,273] and encompass the exchange and flows of materials and energy between any entity/system and its environment, and the set of relations that define these exchanges.

By the 1990s, the use of the term was well established at least in the fields of SM and MEFA, as show Baccini and Brunner's frugal introduction to and non-apologetic use of the term in their *Metabolism of the Anthroposphere*[269]. This "second wave of socioeconomic metabolism studies"[273], continues to be on a healthy run, as is testified by the increasing number of SM-related publications found in a literature review by Infante *et al.* (2014)[74], who also found the number of publications in Spanish and Portuguese to be increasing at a fast rate, suggesting increased experience in SM analysis in Latin America[74].

Today, SM is closely associated with sustainability thought and science as a basic framework to bring together findings across disciplines in the context of human-nature relations[74], and its tool are commonly used for the study of human-induced environmental change[273]. Distinct fields studying fractions of SM – such as industrial metabolism, regional metabolism, urban metabolism, hydraulic metabolism – have in this time stemmed from the main core of SM, though in some of them (e.g. urban metabolism), debate about the use of the term metabolism is not quite over, as will be discussed in the next section.

[GG] The historical debate is briefly summarized by Fischer-Kowalski (1998). See Box 2.1 for further comment on the debate over the term 'metabolism'

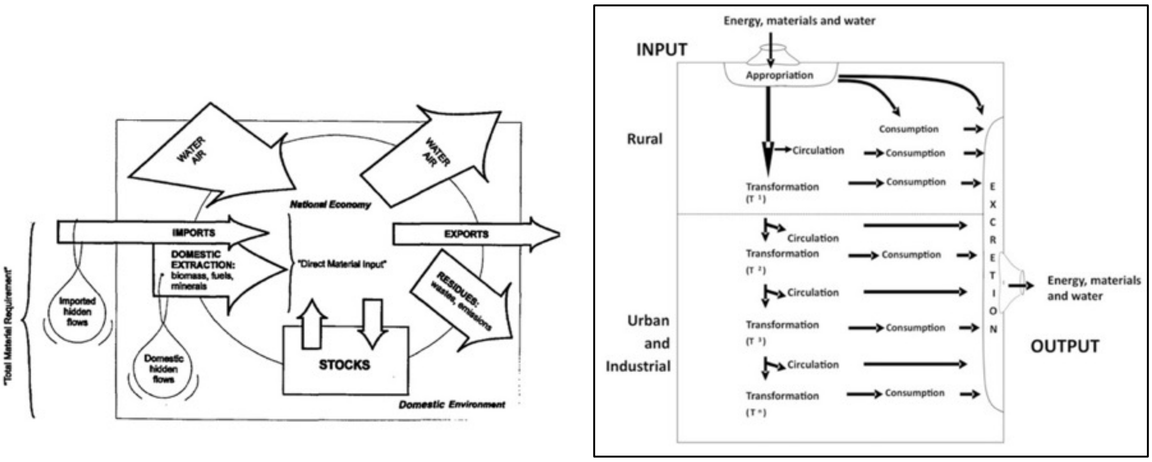


Figure 3.5 Left: Material flows at the national level. Fischer-Kowalski, 1998
Right: Diagram showing the relations of the five main functions of social metabolism in rural, urban and industrial sectors.
González de Molina and Toledo, 2014

As in the other frameworks we have analysed, some contemporary practitioners of SM analysis also draw heavily on complex adaptive systems theory[HH]. Giampietro *el al.* (2014) propose, for example, a method to go beyond MEFA through the viewing of the entity analysed as a complex adaptive system (CAS), thus seeking to work with its undefined boundaries, understanding the multiple scales and hierarchies in which it is organized[247]. They furthermore stress that a metabolic analysis cannot be complete by only looking at MEFA but that the analyst should begin by 'defining the identity of the system', looking at what they call *fund elements*, which are traits such as organization of labour, major economic activities, size of the population and relative size of population employed per economic sector. To this end, the team, based at the ICTA in Barcelona, has spent almost 20 years developing the method MuSIASEM.

SM poses advantages in the pragmatic terrain, perhaps more so than other methods used for sustainability analysis. Fischer-Kowalski (1998) [273] argues that MEFA results are relatively easy to communicate to decision makers, managers and technicians, because they are familiar with for example, national accounting, economic input-output tables and process charting and thus can relate to MEFA process and output. Furthermore, she argues that because elementary concepts of MEFA are fairly straight forward to grasp, they can be easily shared between academic disciplines and other actors, while at the same time allowing themselves to be blended into other methods as parts of more complex analysis.

[HH] See note J.

3.2.4 Urban metabolism: a synthetic framework appropriate to study cities in Mexico and Latin America

"Natural science will in time incorporate into itself the science of man, just as the science of man will incorporate into itself natural science."

-K. Marx, Economic and philosophic manuscripts of 1884.

Table 3.1 summarizes remarks made throughout the text about the resemblances in grounding concepts, relation to system thinking and toolkits shared by the three frameworks analysed. Recognizing in these proximities the large potential of working together, scholars from the three fields are increasingly calling for integration and synthesis in the context of sustainability science[277,278]. Dialogue is however only beginning to happen, and it is not clear how integration could occur, with urban ecology having a sturdy legacy of concepts and techniques, and being related more to SES than to SM, while keeping a bit at a distance from it all. In looking at the summary table (3.1) it is clear that the tools of complex system modelling, and of material/energy flow analysis (MEFA), are a methodological bridge linking all three. Systems thinking and MEFA are both strongly associated with metabolism thinking, which at the same time has solid roots in the social sciences, particularly in environmental sociology[74,247,273] and political economy[279]. In thinking about cities, which all three frameworks indeed do, I find they meet conceptually at the same crossroads where MEFA and a systems thinking meet: at the frontiers of urban metabolism.

Ideas of urban metabolism are currently lively in SM and also to a lesser degree, also in urban ecology, where the focus there has been that of 'urban ecosystems', keeping at a distance from the seemingly polemic 'metabolism' concepts[280] (see following section). Despite different degrees of acceptance, and some very well-rounded criticism (particularly in the realm of contemporary political ecology, see for example Gandy (2004)[281]; Swyngedouw (2006)[282]; Wachsmuth (2012)[283]) work around urban metabolism (UM) has increased steadily in many disciplines. UM has been suggested to be well placed to contribute to sustainability challenges in important ways[142,277,284,285] and it seems to be able to cross-cut disciplines in a quite contemporary fashion, in the sense that it can draw at the same time, from several different legacies and deep histories, managing to synthesize original contributions to sustainability.

UM thinking is being configured as a middle ground, where rich, multi-disciplinary urban sustainability experiences can take root, using the urban ecosystem as a real scale "experimenting ground" for advancing research[112]. Additionally, and despite it being true that a common ground will be convenient to delimit for a clear exchange, Castán *et al.* (2012)[84] make the case that there is no need for each discipline to abandon their own models and try to homogenise them into one single framework, but rather each discipline could bring their own lens into the discussion, and produce more holistic and useful UM studies[280,286]. Such an eclectic or hybrid UM framework will certainly have at hand a very interesting and ample set of conceptual and methodological tools.

Table 3.1 Comparison of three frameworks concerned with urban sustainability

	Urban Ecology	Social-Ecological Systems	Societal Metabolism
some lead authors (+ *et alia*)	H.T. Odum, S.T. Pickett M. Cadenasso, M. Alberti, N. Grimm, N. Golubwieski, T. McPhearson	C. Folke, G.S. Cumming, C. Binder, S. Birkes, F.S. Chapin E. Ostrom, S. Holling	F. Kowalski P. Gonzalez de Molina V.Toledo, M. Giampetro P. Baccini, P.Brunner, S.Bringezu
time developed	roots in early 20th century first studies in the 1960s booming since the 1990s	since the 1990s at a steady pace	roots in the mid 19th century "first wave" in the 1960s "second wave" in the 1990s
highlights	urban ecosystems are coupled human- natural entities present city conditions are novel and likely to replicate in the future ecology **of and** ecology **in** cities	human-nature is a coupled system: the social and the natural are reciprocally shaped focus on resource management and governance	society exchanges flows with nature, and these flows are basal for society's existence socio-economical organization drives resource consumption
aims	understand urban ecosystem dynamics	achieving resilience	identify, measure & analyse material and energy flows entity-environment
	transformational potential through community involvement and action	fostering stewardship	resource efficiency
tools (ordered by apparent frequency of use)	Complex System Analysis** Patch Dynamics, System Dynamics* Ecological Network Analysis* Energy And Materials Budgets**	SES & IAD frameworks MEFA / MuSIASEM** Qualitative Analysis Anthropology, Social Science Complex Systems Analysis**	MEFA/ MuSIASEM ** eMergy Analysis* Ecological Network Analysis* Complex Systems Analysis** System Dynamics*
experience en Latin America	only with ecology in cities	yes, wide	yes, recent but increasing See Infante et al. 2014, Toledo,
scale of application	cities, city surroundings	rural settings mostly, sometimes cities	all scales from the globe to cities, regions and very small communities
systems perspective	yes	yes	yes
City	City= ecological system where humans dominate	City= social-ecological system	City = metabolic entity shaped by socio-economical drivers

*tool shared by at least two fields **tool shared by all three fields

The environmental problems of Latin America, like those of mostly any other place n the global South, cannot be solved by purely technical means, and neither by purely political ones. UM seems to be able to bring together scientific tradition, rigour and technical tools for operating sustainability assessment and planning, while at the same time widening technical scope by a rich theoretical discussion that includes a sharp and critical - indeed political - perspective of social critique and awareness, managing to –at last- "sit everybody together at the table". UM seems well positioned to be a useful framework to operate sustainability transitions in Latin America. A literature review on the status of UM research in the region was made (annex 1), revealing incipient first explorations mainly in Brazil, Colombia and Mexico, that outside of an exceptional case in Brasil[287], show little technical detail and are currently still schematical approximations , although well laden with theoretical baggage.

3.2.5 History

Urban metabolism (UM) is a distinct field within metabolic approaches, very close to industrial metabolism or industrial ecology, but specifically studying cities. The now famous publication of Abel Wolman's *The Metabolism of cities* (1965), where some of the material inputs and waste outputs of a hypothetical U.S. city of one million inhabitants were quantified and analysed, seeking to understand the prototypical US urban metabolism[288], seems to have been the first in the English language to use the term 'metabolism of cities'[285]. A much earlier study[II] by the German Theodor Weyl was published in 1894, analysing the metabolism of Berlin (*Stoffwechsel Berlins)*[289], where the term 'Stoffwechsel' was employed much in the sense that K. Marx had used it a few decades earlier, as an exchange and throughput of matter between a society and nature. Moved by concerns about nutrition and sewage managment[289], Weyl analysed Berlin's metabolism in terms of inputs (food, water and nutrients) and outputs (sewage), making thus the first known quantitative urban metabolism excercise[289]. To do so, he gathered and analysed available data on sewage flow, and also generated primary data on food consumption, through consumption surveys[289].

Wyle's main motivation was to study nutrition and public access to basic commodities, with emphasis on the health of the working classes[289]. In this sense, it is clear that this German school of *Stoffwechsel* thought, as Marx and Weyl employed it, falls in the realm of what today we would call Political Ecology[289]. But literature with this perspective was not to be abundant in that period, and since

[II] Lederer and Kral (2015) acknowledge the prior or contemporary (1881, 1899, 1921) publication of other similar studies in Germany and the USA, where flows of materials through cities where analysed, but where the term 'metabolism' (or the German translation 'Stoffwechsel') was not used[289]. Thus, these authors propose to consider Wyle as the pioneer in applying the term 'metabolism' in an urban analysis. The discussion of when and by whom the term 'urban/city metabolism' was used for the first time has been sparked not long ago (see for example Kennedy *et al.*, 2011[285]; Lin et al., 2012[290]; Lederer and Kral, 2015[289]) with claims for A. Wolman and E. Burgess, along with that for T. Wyle. This is evidently a tricky subject, because there has not been an extensive review of literature in all languages, let alone all epochs. English and German have been more extensively reviewed down to the 19th century (for English see Fisher-Kowalski, 1998; Kennedy *et al.*, 2011; Holmes and Pincetl, 2012; Dinarès, 2014. For German: Fisher-Kowalski, 1998; Lederer and Kral, 2015), and Spanish and Portuguese to a lesser extent (within a shorter time frame and not looking specifically at 'urban metabolism', but rather at 'metabolism' in general, see Gonzalez de Molina and Toledo, 2014). Pre-19th century material is practically untouched. Much of any claim would maybe rely on the translations employed, or even on hermeneutics if we were to recur to ancient texts. Indeed, it could well be possible to find the Greek μεταβολή (metabolé) in some ancient text, used in a sense that could be interpreted as an urban metabolic flow. Furthermore, it can of course be argued that a specific piece research touching on the subject but not using a specific wording should be classified in the "metabolic school" when its contents match the "metabolic criteria", even if the specific term is not used, etc. Finally, it appears as if the societal metabolists who focus on MEFA (Toledo, Martínez Alier, Ayres, Fischer-Kowalski) have been researching the origins of the term 'metabolism' in separation from architecture/planning oriented urban metabolists (e.g. Kennedy, Decker, Pincetl, Holmes) and from urban ecologists who employ the term 'metabolism' (Alberti, Golubiwesky, Grimm). There is furthermore an incipient Latin American school (Delgado, Díaz, Conke, Ferreira) who only seldom appears to take part in the global discussion, and a very robust Asian school, intensely dedicated to systems thinking, and who is indeed present when its results are translated into English, but whose findings must surely be much more prolific than the fraction that reaches translation. It could be that when brought together, all these separate findings shed new light on the precise history of the urban application of metabolic approaches, along with many other important topics. Although an interesting disgression, the detail of the whos and wheres of the term, does not appeal to me as central, and will not be discussed beyond what has already been said. In any case, the reflection contained in this footnote does certainly underscore the importance of integrating knowledge across continents, epochs, languages and disciplines.

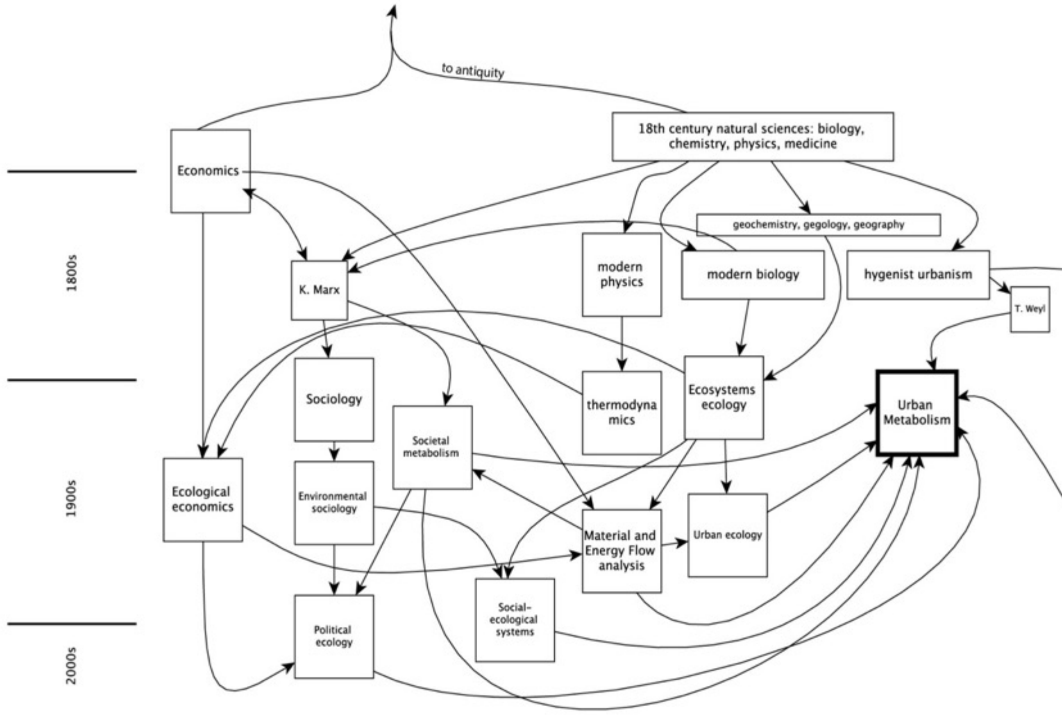


Figure 3.6 The Conceptual lineage of UM

Wolman's paper (1965), the main concerns of most urban metabolists, with some exceptions, are related more to general resource consumption and efficiency in the context of environmental concerns, and much less to the distributive problems of political economy and political ecology[81,86].

In general, UM analysis is the application, in an urban setting, of some variation of the metabolic approaches described in the preceding section. Definitions for 'urban metabolism' include:

> "*The metabolic requirements of a city can be defined as the materials and commodities needed to sustain the city's inhabitants at home, at work, and at play.*" (Wolman, 1965[288])
>
> "*Urban metabolism may be defined as the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste.*" (Kennedy, 2011[285]).
>
> "*The ultimate purpose of UM research is to describe and understand those sociometabolic regimes such that reductions in the use of resources and associated environmental impacts can be achieved. We add to those the importance of equity considerations. Thus, one goal of establishing a regions' metabolism is to quantify the material substrate on which a city depends and to unravel the policy and behavioral drivers as well as the differences that that might exit among socio economic groups...*" (Holmes *et al.*, 2014)[291]

Some authors use 'UM' and 'UM analysis/study' as synonyms[JJ].

> "*Urban metabolism is the study of material and energy flows arising from urban socioeconomic activities and regional and global biogeochemical processes... [urban metabolism] is therefore a deeply multi-disciplinary research domain...*" (Ferrão and Fernandez, 2017)

Based on the mass conservation principle[284], the first practical approaches to UMA were input-output schemes where the city remained mostly a blackbox[292,293] (e.g Wolman, 1965[288]). Subsequently, efforts were made to at least identify some internal processes or drivers, although without measuring or calculating them (e.g. Newman, 1999[142]; Costa, 2008[293]; Barles, 2009[294]), and also to "open the black box", detailing some of those internal processes and feedbacks, such as household metabolism[295], metabolism of single substances[50], or the relations between building densities and energy demand[296]. (See fig.3.7).

3.2.6 Variants

Castán *et al.* (2012)[286] identified six main themes running across UM literature:

i) the city as an ecosystem
ii) material and energy flows in the city
iii) the material basis of the economy
iv) economic drivers or rural-urban relations
v) the reproduction of urban inequality
vi) re-significance of social-ecological relations

Each of these themes is emphasized in different ways by different disciplines: urban ecology, industrial ecology, ecological economics, political ecology, political geography[278,286]. Technical approaches also vary: Holmes and Pincetl (2012)[277] identify two main currents: what they call the *engineering* approach, with MEFA and LCA as main tools, and the *ecological* approach, using mainly H.T. Odum's *Emergy* concept. Other methodological approaches have been -and continue to be- attempted, such as Process Analysis[292], Ecological Network Analysis [292,297] and System Dynamics[298–300,KK]. UMA has been basic in a wide variety of studies, including environmental impact assessment[121], consumption patterns[292], spatial distribution of resource consumption, environmental governance[278] and policy analysis[299].

[JJ] I believe the semantically correct is to understand 'urban metabolism' (UM) as the phenomenon, which exists independently of our studies, and' urban metabolism analysis' (UMA) as the study of these phenomena. The flow of materials through a city (metabolism) exists independent of our studying it: the thing and the study of the thing are not equal. Thinking that 'UM' is the same as 'UMA' would be equal to thinking that society is the same as sociology. 'UM' and 'UMA' will then be used distinctly throughout the text.

[KK] The UM literature corpus appears to be growing fast[285]. Kennedy *et al.* (2011), Castán *et al.* (2012), Holmes and Pincetl (2012), Zhang (2013) and Dinarès (2014) have all made interesting attempts to review, classify and find commonalities and discrepancies among UM literature, but their efforts are not comparable as they did not use the same criteria for inclusion, classification or review (except for Dinarès and Castán *et al.*, with the former building on the latter). Furthermore, after reviewing these reviews, it appears to me that none of them are fully comprehensive. It is clear that the task is large, as the gathering literature in other languages is pending, as is perhaps a finer search in studies who might really be a form of UMA without being called so (see note L). As for tools, I also find that none of these reviews exhaust the wide variation of tools being applied, but I also concede that the tracking of the highly dynamic field of UMA, occurring quickly in many languages and countries, is a gigantic task. Further comment on methods and tools of UMA is given in section 3.3.

BOX 3.2 : metabolism or no metabolism?

In her influential 1998 paper, Fischer-Kowalski suggests that, to analyse its metabolism, an economy or society can be looked at *"...in the way biology looks at an organism."*[273]

Haberl et al. (2006) assert that when considering the chemical processes of the metabolism of a living organism, *"[t]he analogy to social systems is obvious."*[108]

"*The notion of urban metabolism is loosely based on an analogy with the metabolism of organisms, although in other respects parallels can also be made between cities and ecosystems...*" (Kennedy et al. 2011)[85285]

This city-organism analogy, in use since T. Weyl's 1894 *Stoffwechseln Berlins*[91289] motivated N. Golubiewsky's (2012)[250] questioning of the concept 'Urban Metabolism', by highlighting that 'metabolism', understood as an organismic property is of little use when applied to a city, because a (city) ecosystem differs largely from an organism (e.g. no clear boundaries, changing circulatory system, enduring beyond individual's life spans). She argues that UM studies fall short "...with their macroscopic black box approach, which does not make the city a part of the ecosystem", and fail to recognize ecosystem properties of cities. She furthermore criticizes the misapplication of ecology, both in theory and in practice, as exemplified by the common use in UM literature of the terms 'ecosystem' and 'organism' as if they were synonyms. She emphasizes that cities are not comparable to organisms, but that, being ecosystems, must be studied through an ecosystem approach, which should go beyond input-output accounting of black box models to include internal feedbacks, organism respiration and primary production, etc. (opening the black box). She finally argues for "material flow analysis" as a more suitable term.

It is simple to see that cities are hardly like organisms and indeed should be considered ecosystems, and one can readily agree with the idea that the misapplication of terms and ideas hinders the progress of urban sustainability studies. However, on the matter of metabolism it should be stressed that ecology itself has long spoken about –and measured– ecosystem metabolism, i.e. the pathways along which energy and material flow to support ecosystem processes. In the 1950s, H.T. Odum pioneered methods for estimating aquatic ecosystem metabolic rates which are still in use today[109,110], and ecosystem metabolism continues to be an active part of ecosystem ecology field[103–106.]

Furthermore, Giampetro et al. (2014)[247] find that:

"... the use of the concept of metabolism to describe both ecosystems and socio-economic systems is backed up by a robust theoretical work in the field of non-equilibrium thermodynamics, complex systems theory, theoretical discussions about the foundations of life, theoretical ecology, bioeconomics, and a long tradition of social sciences." (p.23)

"[the term] can be applied to any integrated set of functions expressed by a complex self-organizing system capable of gathering energy and material inputs and dumpling wastes into the environment in order to reproduce itself according to information stored in the system. Interpreted in this broader sense, [metabolism] can be applied to the study of [...] the interface between societal and ecosystem metabolism and more in general, to socio-economic systems..." (p.24)

The use of the term seems to be booming, but with little reflection and discussion as to the epistemological implications of it, and still without consensus as to what it is supposed to mean[247]. Indeed, further integration of the sciences and refinement of both theories and methods awaits, but it is already apparent that, as long as we consider a city to be an ecosystem and/or a social-ecological system, we shall also recognize in it such thing as a metabolism.

In all cases, some form of accounting of material and energy flows (such as MEFA) is a substantial part of the work. This procedure is also one of the tools of ecosystem analysis and therefore UMA could be thought to belong as much to the urban ecology school as to that of societal metabolism. But the use of the term 'urban metabolism' is not at all frequent among ecologists. Pickett *et al.*, (1997), for example, propose that one way to study urban ecosystems is:

"...the classical ecosystem approach, which focuses on fluxes of matter and energy[...] Under this paradigm, a major concern would be with the magnitude and control of the flows of nutrients, toxins, wastes, and assimilated and thermal energy in urban systems"[133]

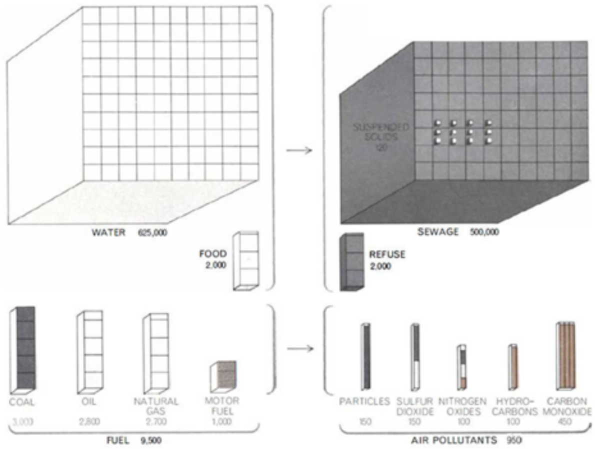
However close they come to it, Pickett and his colleagues never use the specific term 'urban metabolism'; as nor do Alberti *et al.* (2003[237], 2008[136]) or Grimm *et al.* (2000[244], 2014[305]), all of which can be classified as leading researchers in the field of urban ecology. Other ecologists do employ it sometimes, either centrally (e.g. Pataki *et al.*, 2008[306]) or, more often, marginally (Collins *et al.*, 2000[112]; Grimm *et al.*, 2008[113]; McPhearson *et al.*, 2016[135]). The statements made here are of course not to be taken as a comprehensive review of the reception of the term within the field of urban ecology, but are nonetheless useful to suggest that the acceptance is, at least, far from homogeneous. Certainly most, practitioners of urban ecology appear to be carrying on well enough without the term.

I consider this issue to be more than a subtlety, because it would be misleading to simply connect the growingly ubiquitous (and catchy) term 'urban metabolism' to the quite robust field of 'urban ecology', both of which seem to be today in vogue and could be (and are) easily thought of as interconnected or even inter-changeable (as do González and Benavides, 2012[307]). I have argued above that *greenwashing* is an obstacle in the quest for sustainability, and lack of clarity in concepts is indeed one step in that direction. Urban ecology does not as a whole endorse UM, nor are metabolic approaches they the sole tool that urban ecology has to approach urban settings. In fact, the perhaps most severe critique of the term 'urban metabolism' came precisely from an ecologist: Golubiewsky (2012)[250] argued that the use of the term is misleading, limiting analysis, preventing interdisciplinary problem solving, and is based on a superficial understanding of the ecological science. (See Box 1).

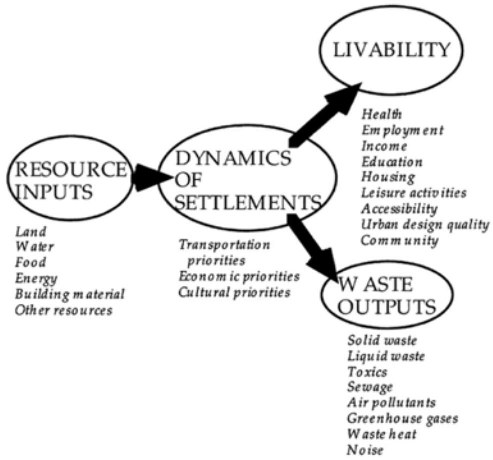
How much this controversy really influences ecologists' choices of terms is not clear, but UM does appear to be less frequently used in literature written by urban ecologists than by, for example, urban planners or designers (e.g. Girardet, 1996[308], 2015[309]; Kennedy et al. 2011[285]; Pincetl *et al.* 2012[284]). Perhaps architects and urbanists are more flexible (less scrupulous?) about adopting innovative (catchy?) terms, or perhaps it is a matter of disciplinary inertia, with ecologists being at ease with the terms they traditionally use and and/or seeing no need to adopt UM. Whatever the case, and despite reluctance on one side and possible over-use on another, if cities are ecosystems, they indeed have a metabolism (Box 1) and it is consequently also true the organismic metaphor (i.e. thinking of the city as an organisms and to its metabolism as "that of a human being") is not necessary and may even be counterproductive[250], to understand urban metabolism. The city is not *like* and ecosystem, it *is* an ecosystem, and therefore part of its study toolset lies in ecosystem ecology[250]. Furthermore, it seems clear that the city is neither an organism nor is it *like* an organism[250]. The city is a coupled human-ecological system[136], and therefore a complex, adaptive system[113,238,251,] and from this perspective part of its study tool set is in complex systems theory and social-ecological systems frameworks[135].

It is then unfortunate that many writing about UM continue to use the organismic metaphor (e.g.; Conke and Ferreira, 2015[287]; Díaz, 2014[310]) or even seeming to confuse 'ecosystem' with 'organism' by using them interchangeably (e.g. Kennedy *et al.*, 2011[285]; Zhang, 2013[292]). A solid understanding of basic concepts in ecological science is needed for the advance of sustainability science[250] and shallow assumptions or overuse of poorly understood concepts, may give place to ill-founded analyses and projects. Because the exchange between "multilingual" scholars who move from a solid background in a certain field into a diverse discussion table, is fundamental for urban sustainability[136,135,244], and it in turn is a pressing contemporary topic (chapter 1), this discussion is timely.

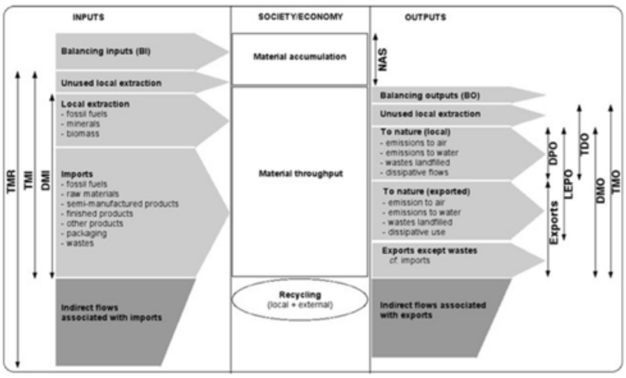
Despite the polemic and the distance they have kept, urban ecology and urban metabolism are actually share many concerns, focal points and approaches, under the already common goal of urban sustainability[280]. Moreover, it is clear in sustainability through that sciences must inform one another and become well integrated and able to exchange knowledge in order to reach sustainability goals[112,135,244,246]. Black boxes in urban metabolic studies must be open in order to better understand drivers, consequences and internal working of societal metabolism. Both the social and the natural sciences are well equipped to do so. Sometimes each one will be required in different parts of the box, and frequently, also together.



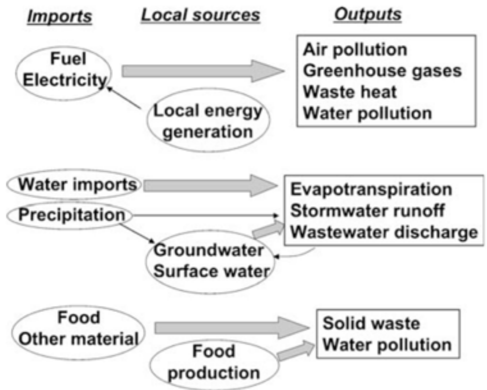
Wolman, 1965



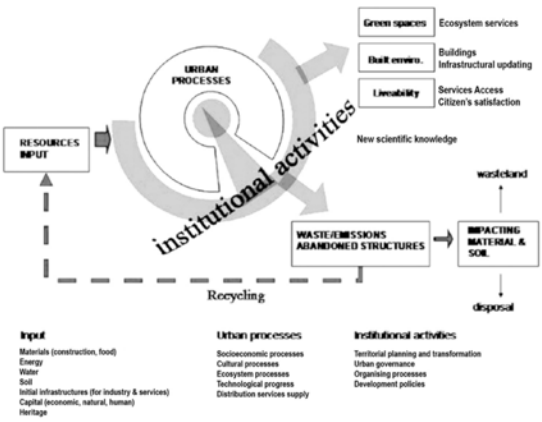
Newman, 1999



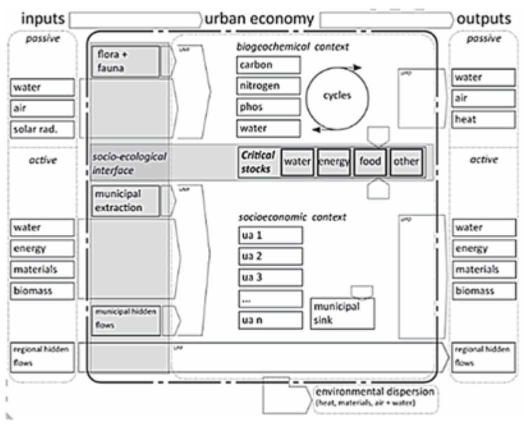
Barles, 2007



Ngo & Pataki, 2008



Costa, 2008



Ferrão & Fernandez, 2013

Figure 3.7 Evolution of metabolic models since Wolman

3.2.7 Usefulness and limitations

I. Understand gross resource demands, show pressures on the environment

Quantifying the amount of resources an entity uses is a basic starting point to know what that entities' demands on the environments are, and therefore a first step to unveil the degree of pressure those demands exert on the environment[137]. UMA can be a powerful tool to accurately portray the magnitude and nature of the flows into, through and out of a city[296,311], capable of displaying the complexity of multiple, simultaneous flows and their interconections[293] and is thus key to understanding the relationship between the city and the environment[312] and useful in establishing sustainability indicators[277]. Metabolic analyses of future scenarios can also be made to look into and decide between different options for development, policy, etc.[299]

II. Allocate flows and find drivers, understand resource distribution

Besides identifying the flows, themselves, a finer-grained UM study can visualize the relative contribution of different sectors to the city's resource demand. Although not yet widely used due to the difficulties of obtaining finer resolution data[284], it is possible to begin to understand what and who the drivers of resource demand are by looking at the internal distribution of the city's resources through geo-referenced data. A UMA can be tailored to show differentiated energy demands according to urban typologies[296], or areas of the city or sectors of the economy produce the most or the least GHG emissions[118], thus opening up possibilities for identifying the most urgent concerns, key actors, and possible intervention points[118,137]. Work in this direction will be able to disclose issues of environmental justice such as, for instance, equity in access to resources.

III. Determine the feasibility of the system

A solid knowledge of the magnitude and nature of flows in required to ensure resource provisions are not overshot, and sink saturations stays within acceptable limits[50].. In the case of cities, besides defining flows and their magnitudes, UMA can help identify the locations of the city's sources and sinks[284]. Coupling this information with, for example, sink capacities, renewal rates, current saturation, trends of demand etc., it will be possible to assess whether and for how long the city in question can be sustained by the available resource base, without it suffering considerable deterioration[247]. Visualizing the identity of the hinterland of a city is not straight forward in a globalised world where resources many times flow into a city from a 'global hinterland'[127], made possible by the impressive network of human telecommunications.

There are several effects to this amplification of a city's resource base: First, a considerable amount of flows are hidden, as resources come in with an invisible 'ecological rucksack'[55] that can easily go unaccounted for[55,247]. Secondly, as the resource base appears to enlarge, the carrying capacity of local ecosystems is no longer deemed as a limitation to growth, because other resources can be brought in. Thus, overshooting local carrying capacities becomes more likely, as does the appropriation of far away resources, whose ecosystem base may evidently also be easily overshot under this *modus operando.* The same occurs with sinks, as long distance shipping of wastes or other forms of offsetting become easier. Third, as very well known in military theory, long supply lines make for vulnerability. The more a city's dependence is based on imports from distant locations, the more it is more vulnerable to situations well beyond its control. This is of course particularly true for less powerful nations and regions who have lost their capacity to provide for themselves and who will have less capacity to react or power to negotiate under unfavourable circumstances. UM comes in as a useful tool to visualize a city and its region's resource dependencies, and to then assess the feasibility of the system considering availability and access to regional and global resource stocks[50,247].

IV. Design and evaluate solutions

Metabolic analysis is much like general check up, helpful in understanding the overall status and behaviour of a city system, and in revealing unsustainable patterns linked to the quality and quantity of incoming or outgoing flows[213]. Coupling UMA with information about hinterland capacities, improved management strategies or technological solutions can be envisioned[142]. Decoupling strategies, whose aim is to *de-materialise* the economy, for example, need a prior evaluation of current patterns of resource flows[53,277]. Urban planning, design and management can also benefit from UM knowledge, by providing insight on present city-environment relations and consumption patterns, and informing on future design and policy needs[285]. Finally, when UMAs are updated periodically, their comparison will provide quantitative evidence of the progress made towards set sustainability goals[137]. UMA is thus an effective tool to evaluate the success and/or relevance of given policies, programmes and other action undertaken by stakeholders aiming at improving environmental performance[137,169,277]

As any other tool, UMA cannot provide explanations for every single topic linked to city sustainability. There are practical limitations to the information that any UMA can provide about a given city, and it is best used in combination with other tools. Main limitations, and some proposals to overcome them are discussed below.

I. Not informant of ecosystem health

Clearly, an urban metabolic study cannot inform on topics such as the provisioning ecosystem's carrying capacity or resource availability[284]. This is the realm of for example, ecosystem ecology and biogeography, whose expertise is needed to understand the implication of a city's metabolism. As for ecosystem services and function *within* city bounds, which are also important to understand, to better manage local ecosystems with actual potential value for sustainability, they are only recently beginning to be studied in the field on urban ecology[135].

II. Not easily informant on systemic properties

UMA is not necessarily a system analysis tool. While it does work by outlining basic definitions of the system components and their interrelations, its focus is not to understand systemic behaviour in detail, but to quantify and allocate the resources used by the system. Emergent properties, for instance, a known characteristic of complex adaptive systems (CAS), are not unveiled by UMA, as are not non-linear behaviour or dynamics, given that UMA is essentially a rigid, one-moment snapshot of the metabolism of a given entity.

Steps are being made in this direction because it is clear that finer understanding of systemic behaviour will lead to better UM models and management[284]. Ecological System Analysis (ENA), Systems Dynamics (SD), and other complex system modelling tools are being used[292,297–300]. Another example is MuSIASEM, a metabolism analysis tool whose theoretical development relies heavily on CAS theory and look to incorporate such criteria as nested hierarchies, impredicative loops, multiple agents and multiple scale operation into the definition of the metabolic system[247,274,313]. SES scholars have been working with complex systems models for a time now[135,136,314–316], and their input to the UM community may soon prove useful

III. Multiple frameworks, multiple procedures

Because UMA is being practiced by scholars from very diverse backgrounds, a multiplicity of frameworks, conceptual understandings and methods exists[278,317], resulting in very limited comparability of studies[137,311,] which hinders the possibilities of making general statements, finding common patterns and establishing theory[317]. If common UMA conceptual framework and methodology were adopted, experiences in different cities could be compared, facilitating exchange of information and joint learning processes[137,311]. At least two proposals for a unified method have been made: Hoornweg *et al.*, 2012[137] and Rosado *et al.*, 2014[317], more details further below).

IV. Social and political factors

Critiques to UM include that they are ill-suited to find the underlying drivers of metabolic patters[306], or that it is a-historical and a-political, technocratic and failing to provide explanations on the relations of urbanism, biophysical environment, social/economical factors such as culture and power[77,78,80,84,125], and in general incapable of assessing qualitative issues[277]. "*The city is not an ecosystem, but a specific form of human association made possible only by the sub-ordination of territorial space beyond the periphery*" has written Delgado (2015)[319]. It is argued that UMA's focus on politically-neutral quantitative exercises, deviates attention from the power struggles that shape patterns of resource distribution and use (the right to metabolism[282]), fails to theorize on the social production of urban space[279] and either explain or provide solutions to prevailing inequalities of access to resources[283,320].

Indeed, an exclusively quantitative approach focusing only on the nature of flows and perhaps on reducing them or making consumption more efficient, will not underscore that resource efficiency is not necessarily the only or the best answer to sustainability problems, that flows may be being driven by unequal access to power, or that resources might are unevenly allocated, particularly in very unequal regions like Latin America[320].

But as much as it is a product of history and a political arena the city *is* an ecosystem, and we will do good in -at least- striving to consider this multiplicity and complexity. While bringing distributive and environmental justice issues into the global discussion is clearly fundamental for sustainability, it is also true that without accurate and thorough biophysical understanding and metabolic accounting, political arguments will lack substance and, and proposals for solutions will likely lack viability when made without a scientific base. The objectives of UMA are not to unveil social and historical phenomena, but to account for material flows. On that base, it can extremely useful in informing other studies[137].Because UMA can evidently not be by itself a comprehensive tool to explain *every* issue related to the city or to the ecosystems that support it, multi and interdisciplinary should be recurred to. This of course needs for social scientists to be open towards and willing to communicate with the natural sciences, and vice versa. Fortunately, this awareness seems to be present and growing in the fields of urban ecology and urban metabolism, with scholars arguing for a closer integration with the social sciences, and calling attention to the transformative potential of an urban ecology that is politically sensitive and manages to highlight equity issues and include voices and needs across social sectors (e.g. Pincetl *et al.*, 2014[74]; Tanner *et al.*, 2014[305]; Grove *et al.*, 2015[321]; Mcphearson *et al.*, 2016[135])

V. Cooperation with other disciplines

Precisely because UM need to cooperate with other disciplines (ecology, political ecology, political economy, sociology, economics, geography, anthropology)[284] in order to fully contextualize and understand the implications of any metabolic study, integration is a pressing need, but a challenging one to realize as different disciplines understand concepts and terms in different ways, and have different priorities and research agendas[135,250,284]. Responding to this evident desirability of interdisciplinary work, Pincetl *et al.* (2012)[284] have proposed an "expanded metabolism framework", which, starting from the base of a traditional MEFA analysis, would add to it Life Cycle Analysis detailing the behaviour of major resource consumers and waste producers; geographical specificity to analyse internal distribution of resource flows, and identify major drivers of resource consumption; political ecology approaches to analyse environmental justice and governance issues; and urban ecology analysis on ecosystem services provision and internal ecological conditions. The result, according to the authors is an encompassing, holistic UMA that would reduce unintended consequences and amplify societal relevance through the incorporation of several perspectives in one same study. There are however severe limitations to the possibilities of applying such a large framework, due to the inherent difficulties on inter-disciplinary communication, and also, as acknowledged by the authors themselves, due to important logistical, institutional and budgetary requirements needed to operate such encompassing research efforts.

VI. Data availability

A last limitation to UMA is that it requires considerable amounts of data, many times difficult to obtain, if at all existing[277,294,306]. Sources of data include direct measurements and interviews, as well files held by government facilities and research institutions[269]. While national-wide information tends to be readily available, and be in standardised formats that allow for comparison between countries (e.g. Europe's EUROSTAT), data at the urban scale is very often dispersed among different actors, is of unreliable quality or is plainly not collected. Differences in units and in measurement protocols among sources are quite common and force researchers to work with estimates, proxies and black boxes, making the final outcome less likely to be accurate[277,311]. Because the data available to each research team varies so much, and each research team sources, processess, estimates and prioritises data differently, comparison between cities are difficult to carry[137,311].

3.3 Urban Metabolism Methods and Tools

An enormous amount of methods and tools (and their particular adaptations) exist and are used for working with different aspect of urban sustainability around the world. Section 3.2 has provided a non-extensive overview of tools used in in the fields of Urban Ecology, Social Ecological Systems and Societal Metabolism. A deeper revision of the tools used for urban metabolism analysis (UMA) will be provided in this section, making a critical review with the perspective of finding applicable tools that fulfil the criteria for application in the Mexican/Latin American context as outlined in the conclusions of chapter 2.

Tools available for urban metabolism analysis (UMA) can be coarsely classified in three major types: (i) measuring tools, (ii) system analysis tools, and (iii) environmental impact assessment tools (See Fig. 3.6). As will be discussed at the end of this section, any metabolic system is thoroughly analysed only when a multidisciplinary approach is used, linking social, economic and political analysis to that of the material base of the economy[50,247,284]. An ambitious metabolic study aiming at understanding the whole of a given societal metabolism, its drivers and consequences, would need to use several tools, probably at least one from each different tool set, and would certainly need to be linked to other studies not dealing specifically with metabolism, but which would explain important components of it, such as basic geographical and ecological studies, anthropological and cultural factors, policies and institutions, and so on. Such a study would evidently be a gigantic task, and require a linking between disciplines that is only starting to be worked on.

In practice, "metabolists" focus on a certain part of the metabolic system, such as throughput of energy and materials, or on the way the system is structured, or on the environmental impacts of those accounted metabolic processes. While the complex integrated studies described before are a future horizon that many in the UM and adjacent disciplines are walking towards[246,284,322,323], the basic, quantitative knowledge about a system that material accounting can provide is in itself a crucial milestone to attain in the path towards sustainability – and not necessarily an easy one to arrive to.

3.3.1 UM measuring tools

They answer questions such as "*how much?*" or "*at what rates?*". They are then the basic tools for UM, used to quantify amount of materials running into, through and out of the system. Regarding measuring units, two distinct procedures in metabolism accounting exist: that of eMergy, which is a solar equivalence unit, proposed by H.T. Odum in the 1950s, to convert all units, including volume and weight into an energy unit, based on solar radiance (solar-eMergy joules, seJ). Conversions are done with constants and tables, the validity of which is not entirely agreed on[277]. Despite these difficulties, the eMergy approach is still used, although less frequently than the Standard Units

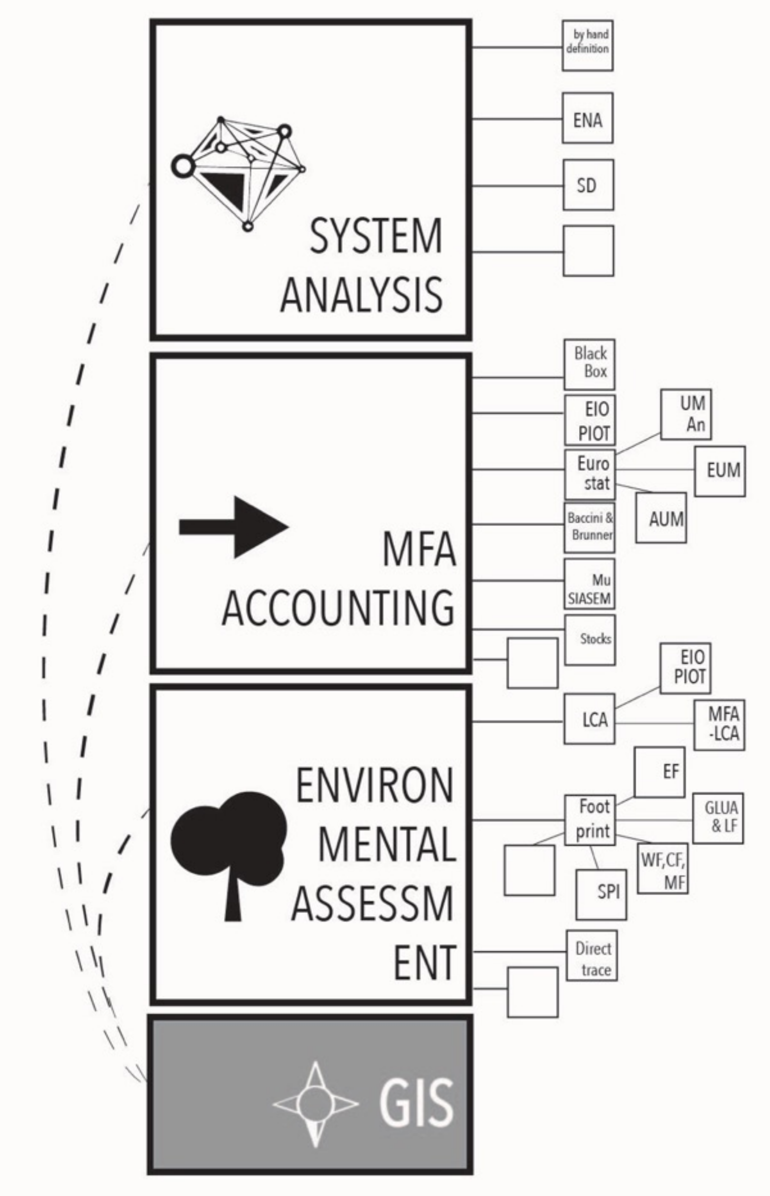


Figure 3.8 The UM toolbox as presented in this thesis. Each large box is a category of tools, discussed throughout the text. GIS is an overarching method, "sharing" its tools with every category. Blank boxes are intentionally left to represent tools not covered in this review.

approach, where "everyday" units are used (joules, MW, tons, etc.). The use of standard units is more practical because there is no polemic as to the conversion values (e.g. from KW to J) and thus data available can be readily used and communicated.

Material and Energy Flow Analysis (MEFA), is the fundamental tool of any metabolic measurement[50,277]. Material and energy accounting are often done separately (MFA separate from EA), although they can also be treated together as MEFA. MFA tools range from the accounting of one single substance (Substance Flow Analysis, SFA) which can be done at the level of a small region or of the entire planet, to the accounting of the total material flow of a whole city, region, or national economy (or the planetary economy, if desired). Intermediate MFAs can look at the material and energy flows of specific products (Material System Analysis, MSA) or the material flow of individual businesses, factories or entire production sectors (e.g. construction industry) through the method of Input-Output Analysis[324]. Although not looking at the city in its entirety, these methods can help understand certain desired sectors in more detail and are thus useful to consider when carrying out a city-wide MEFA. There are several methods for Material and Energy Flow Analysis at the urban or regional scale:

1. Black box accounting

The most basic form of M(E)FA are simple input-output accounting schemes, such as those used by early metabolists like T. Weyl (1894)[289], P. Geddes[273] (1920s) and A.Wolman[288] (1965), and similar to the approaches used by ecosystems ecologists in the 1960s-70s[262] . In them, material and/or energy flows into and out of the (urban) system are accounted for, without detailing any internal process, considering the city a "black box" (see fig 3.8). When inputs and outputs are known, stocks can be inferred. Data for such a basic scheme can come from government offices and chambers of commerce or be generated through surveys, interviews, and measurements. Examples of contemporary studies using such an approach is Ngo and Pataki (2008)[306], on the material and energy budget for Los Angeles County, and Delgado *et al.* (2012)[132] on the resource consumption of four Latin American cities.

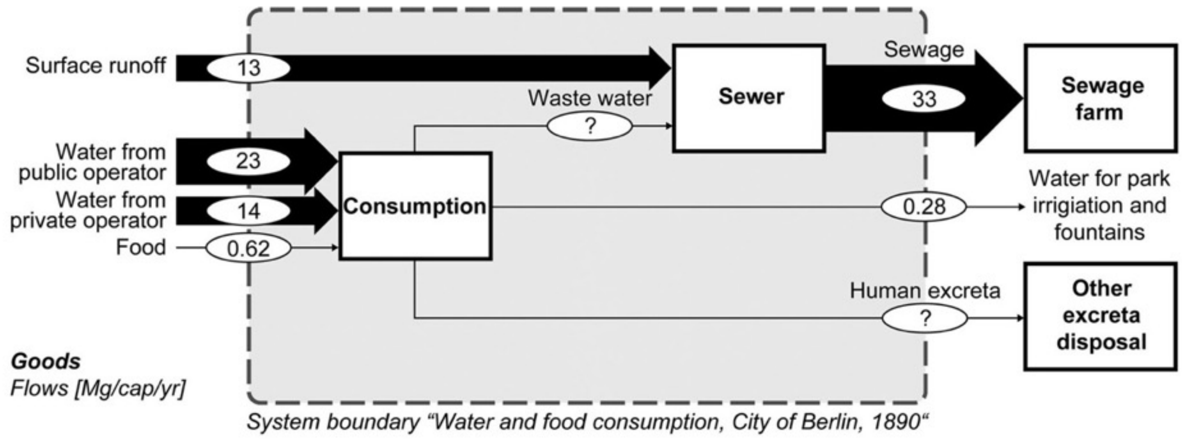


Figure 3.9 T. Weyl's input-output metabolic data for Berlin, represented with a Sankey diagram by Lederer and Kral (2015)

Black box accounting results can also be translated into indicators by aggregating different flows and/or combining flow quantities with socioeconomic information such as GDP or population size, to provide convenient metrics on gross material throughput, material intensity of the economy, and others (see indicators section 3.3.4). Because no detailing of internal processes is done, black box analyses are relatively simpler to carry out in comparison to other methods, and useful to establish first approximations and provide gross numbers on the metabolic behaviour of a system, and especially useful in situations of little data availability, or when there is a need to quickly produce an approximation to resource consumption and output generation. However, the approach implicitly treats all processes within the box as homogeneous in weight and ecological importance[262], making it impossible to understand internal distribution of flows, drivers, equity in access to resources, or spatial issues[238]. There are other, more detailed variants of MEFA, which try to open the black box, or at least divide it into smaller black boxes, to come closer to understanding how fluxes behave within the city:

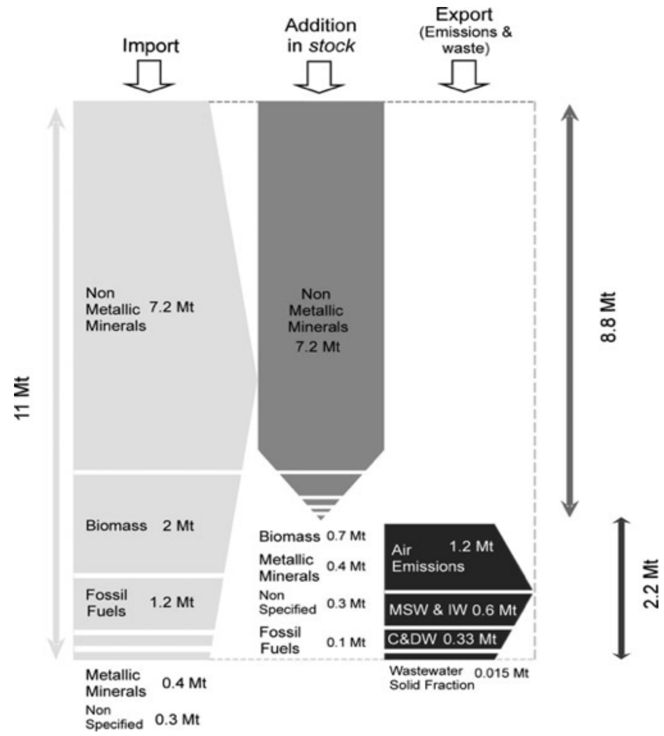


Figure 3.10 2004 Lisbon material balance, using an adapted EW-MFA. Taken from Niza *et al.* (2014)

2. EIO-PIOT

Accounting methods used in economics, such as Leontief's Economic Input-Output tables (EIO) have been also applied to resource accounting for urban metabolism analysis purposes[284,322]. EIO tables are constructed to describe the monetary exchanges and thus interdependence between the sectors of an economy. A related method, Physical Input-Output tables (PIOT) register the physical flows (of materials) occurring in an economy, illustrating how one sector's output becomes the input for another, for example[326]. Both EIO and PIO tables can be applied at a sectorial, local or national scale to quantify material flows (or economic flows that then have to be converted, in the case of EIO) and are current and common form of national accounting, kept by most of the world's countries, making them a readily accessible instrument[322]. Both of them have also been further extended to be able to account for environmental impacts associated with the monetary/material flows (see environmental assessment 3.3.3).

3. Eurostat method

The *economy-wide material flow analysis* (EW-MFA) also known as the Eurostat method, has been developed jointly by several European research institutions and is one of the three officially used methods for environmental accounting and reporting in European nations since the late 1990s[327] (the other two are PIOTs, discussed above, and Material Balances, which will not be discussed here). EW-MFA uses a variety of indicators (see indicators section, 3.3.4) and standardised European Union databases to describe the material flows of economies. A Eurostat method analysis is therefore possible because harmonised, nation-wide databases exist, to which countries report their data back to. The method relies on the mass balance principle, where outputs should be equal to inputs minus stocks. The indicators developed for EW-MFA are straight forward and not exceedingly difficult to calculate, given the necessary data is available. They can be further expanded when considering other databases, such as the Harmonised Commodity Description and Coding System (HS), developed by the World Customs Organisation, which reports raw materials used for product fabrication, or databases held by research institutions. Using these sorts of databases for example, Total Material Requirement (TMR),

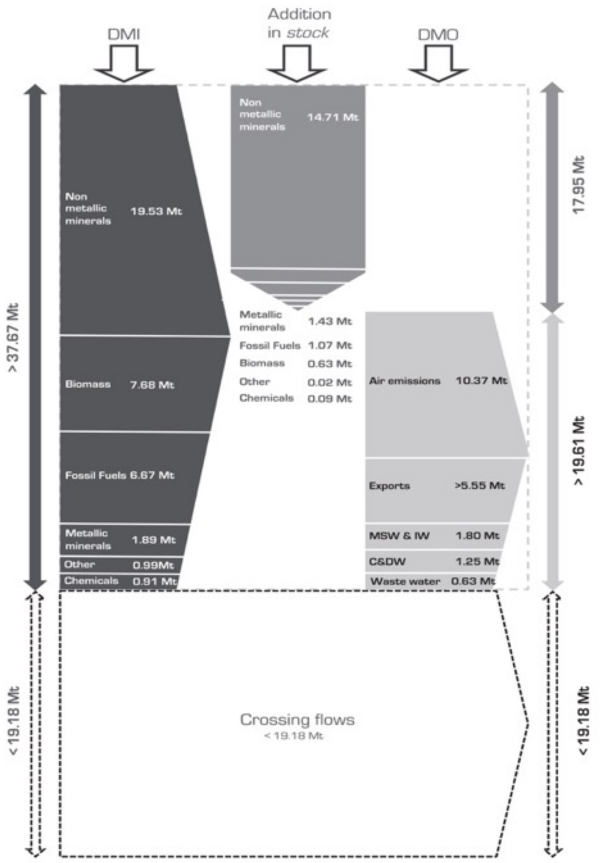


Figure 3.11 2005 Metropolitan material flows in Lisbon, using the UMAn model. Taken from Rosado *et al.,* (2014)

an indicator developed at the Wuppertal Institute to report more thoroughly on the ecological rucksacks of flows, can be calaculated[213,328] (see indicator sections, 3.3.4).

Because EW-MFA is originally designed to account for national-level material flows, several adaptations have been done to work with cities and regions (e.g. Hammer *et al.*, 2003, for Hamburg[329]; Barles, 2009, for Paris[294]; Nia *et al.*, 2009, for Lisbon[330]; Voskamp *et al.*, 2017, for Amsterdam[331]) with each research group tailoring the method as needed, which has resulted in the existence of several, slightly different, adapted urban MEFA Eurostat methods, each one using different indicator sets and methodology, and also structuring the system differently[331]. At least two proposals for a unified method have been made: Hoornweg *et al.*, 2012[137] and Rosado *et al.*, 2014[317]. More details on these methods are given further below.

4. UMAn Model[317]

The Urban Metabolism Analyst (UMAn) Model was developed by Rosado, Niza, and Ferrão (2014)[317] at the university of Lisbon (see fig 3.11). It is presented as a good option to bridge the variety of UM methods, for application in Europe. UMAn adjusts Eurostat data using other data sets, including, among others, the European Standard Goods Classification for Transport Statistics (NST), which provides data on the origin and destination of products down to the regional or sometimes municipal level, which allows for urban or metropolitan scale quantification. A second source of data was Eurostat's Industrial Production Statistics (IPS), providing information about non-final goods processed by local industry. A set of equations allows for the information in these datasets to be crossed with a finer disaggregation of Eurostat material categories (e.g. the bulk category "metals" in Eurostat into six smaller categories such as ferrous, non-ferrous, precious and so on), and with data bases created specifically for UMAn (called *plugins*), where material composition, lifespan and lifecycle state of products as they enter the urban economy is specified.

UMAn allows for the tracing of material consumption and origin of outputs to specific sectors of the economy, "opening up the black box" into several consumption and transformation boxes (for materials that are not directly consumed but undergo further process within the city), as well as a box for what they call *crossing flows* –i.e. flows associated with floating population, such as commuters, who participate in the city's economy but do not live in it. It also allows for a finer division of the composition of material stocks. Considerations for application elsewhere would have to include the fact that UMAn is tailored around the data availability of the European Union, and thus any adaptation would have to look into whether data is available to disaggregate national accounting categories and trace the origin of materials. Also, Rosado and colleagues created their own databases (much like LCA databases) to be able to detail the composition of products entering the metropolitan economy, a task that would be time-intensive, but that could be perhaps covered by existing local LCA databases.

5. Extended Urban Metabolism for European cities[332]

The Extended Urban Metabolism (EUM) method was developed at the Technical University of Berlin and the Stockholm Environmental Institute in 2011, also with the purpose of exploring more precise and thorough options for UMA than EW- MFA[332]. It accounts for flows, but goes beyond the accounting, to try to understand how framing conditions (urban patterns, policy or lifestyles) shape flows of matter and energy, and how environmental quality within and beyond the city is affected as a result of those flows. The extensions to traditional UMA methods are made in three aspects (See Fig.3.12): 14 indicators for environmental quality (e.g. air pollution, noise, green space), 16 indicators urban drivers (e.g. population size, number of households, policy) and 10 indicators urban patterns (e.g. city size and form, transportation networks).

Because a main concern is practical applicability, the method focuses on being pragmatic, and was built only after a survey of easily available data sources. The authors constructed an initial table of "ideal" or *desired* indicators, and proceeded to check on the availability of that information. With the results of such cross-checking, a list of *possible* indicators indicators is distilled, with the idea of furthering data availability in the future in order to be able to add the rest of the ideal indicators. Data comes from standardised surveys carried out by the European Environmental Agency (EEA), such as the Urban Audit and Integrated Urban Monitoring Europe programme (IUME), which are publically available; and from direct requests to city officials. Although not used for the development of the method, research from universities and other institutions are mentioned as possible data sources as well.

The proposed indicator set (40 indicators) is quantified for a sample set of five cities: Sofia, Malmö, Freiburg, Lille and Barcelona. With the results from this initial quantification, they outline future research lines and gain insight into the possibilities and refining requirements for further use of the model. A summary method is also proposed (Fig. 3.13) using 15 from the 40 indicators represented in a spider web diagram, useful to provide an overview of the environmental performance of the city.

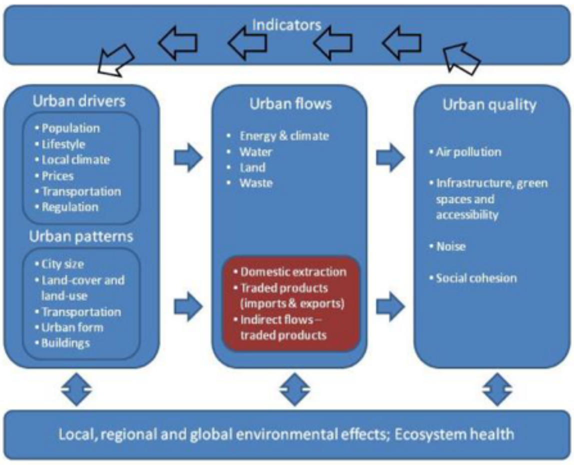


Figure 3.12 The extended urban metabolism framework, including drivers, patters and environmental quality within the city and beyond. Taken from Minx et al. (2011).

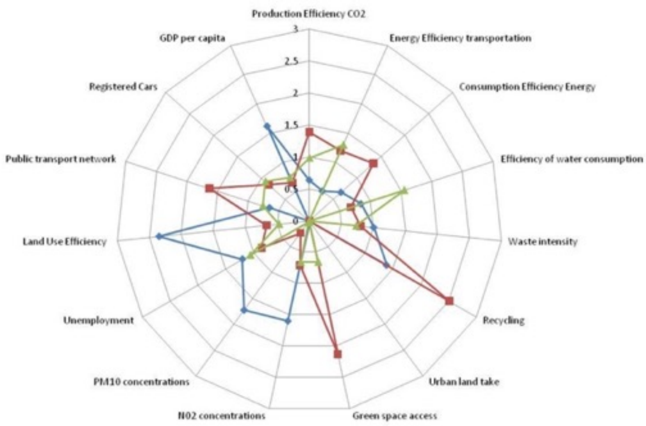


Figure 3.13 Headline indicator set in a spiderweb diagram, the summary version of Minx et al's Urban Metabolism study for European cities using the EMU.Taken from Minx *et al.* (2011)

Urban resilience and wide-context sustainability are also an important concern for Minx and colleagues, who begin an attempt to link local flows to the wider context of provisioning areas, sources and sinks and ecosystem services. While they acknowledge that quantitatively linking ecosystem services such as sources and sinks with urban metabolic flows is a great technical challenge, they nonetheless insist on the importance of it, and stress the need of furthering research to be able to finally include such considerations. Within the frame of this study, they attempt a first approximation, through the making of the conceptual links clear (Fig. 3.12), and also by developing a consumption-based GHG emissions accounting exercise for five cities in the UK, which reflects the contribution of beef consumption in these cities to emissions, but also to changes in land cover abroad. This is accomplished with a top-down approach, by relating material and monetary flows between world regions as captured by global input-output trade accounts, with standard criteria for emissions per monetary unit traded and geodemographical data of consumption patterns for these cities, which allow an approximate of amounts of beef consumed. They then are able to calculate the quantities of GHG emissions directly linked to consumption.

The authors report having found data gathering problems similar to those encountered in the other methods examined in this section (AUM, UMAn), and stress the need for cities to generate, collect and report data in a standardised fashion that allows for finer-scale urban metabolism studies using this EMU method and others, and also for the comparability and replicability of studies.

6. Abbreviated urban metabolism[137]

The Abbreviated Urban Metabolism method was developed in 2010 at the Massachusetts Institute of Technology (MIT) and has been standardised and tested by the World Bank[137]. AUM calls for information on 28 indicators of inputs, internal flows and outputs, most of which are, or should be, already being collected by city officials, as they are part of standard GHG accounting procedures that most cities are engaged with[137]. Although the detail it provides is not very fine, AUM is not absolutely a black box approach, as its application can provide some detail about the distribution of flows and stocks inside the system, such as the differences in fuel or electricity consumption per sector (see Fig 3.14). The resolution of these internal flows and stocks will always depend on the data available, but AUM does not attempt to go further into the detail of, for example, differentiated access to resources within city space. The method is simple and flexible, can be adapted if needed.

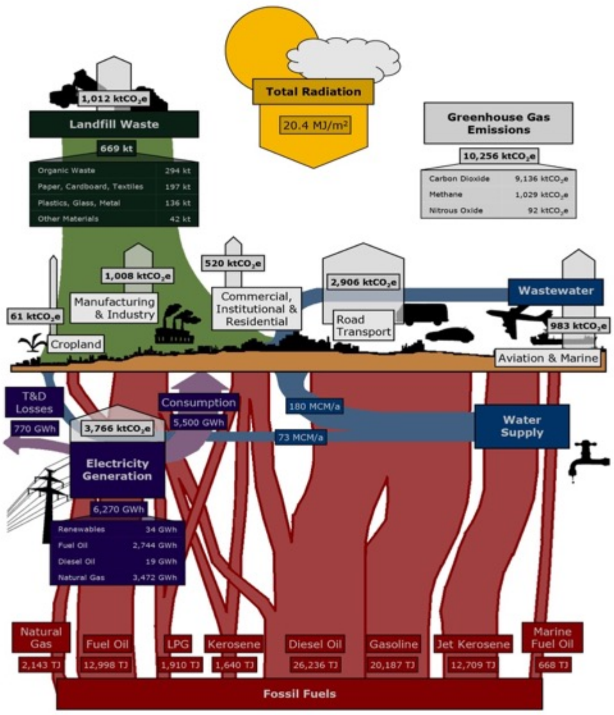


Figure 3.14 The results of an abbreviated urban metabolism analysis for Amman, Jordan. Lorraine Sugar, 2010. Taken from Hoornweg *et al.*, 2012

AUM is also explicitly proposed as a synthetic UMA method, that could replace the variety of adaptations currently available. According to Hoornweg *et al.* (2012)[137], who describe its pilot application in seven cities, it contains the minimum set of indicators that should be collected to gain a sufficient overall perspective as to the city's environmental performance, and it is carried out through a simple methodology that city officials, often acting with limited resources, can carry out with current infrastructure and personnel, or perhaps with adjustments that would not be, in general, strenuous. Thus, its authors propose it as an appropriate standard UM procedure that, if adopted would provide elements to strengthen local environmental knowledge and inform policy and public administration in a straight forward manner, and also allow tracking of progress over time, and for inter city comparisons and experience sharing.

AUM has been used in at least four Latin American cities: Buenos Aires, Río de Janeiro, São Paulo were studied by the World Bank[137] and Curitiba by a team at the University of Brasilia[287]. The first study is a basic accounting exercise, made with a variety of data sources:, the main one being primary information generated by government facilities, who were contacted by World Bank personnel to obtain access in the frequent case that data was not publicly available. The willingness of city officials to cooperate and the degree to which they themselves had data, was of course crucial. Another common source was data contained in previous thematic studies done by local researchers in universities. The study found, in general, a great fragmentation and dispersion of the data. While some of it was publicly available, most had to be collected through contacting and interviewing different city officials, sometimes relying heavily on the personal links and the intervention of contact people within the city's administrative structure.

The Curitiba study also obtained its data from different set of sources and faced similar difficulties, albeit the fact that Curitiba has a central official database made it easier in general. Once having described the quantitative aspects of the urban metabolism through the 28 indicators of AUM, the Curitiba study goes a step further, considering the provisioning capacity of local hinterland and the actual and potential degrees of self-sufficiency of the city, as well as liveability and issues of resource distribution and access. This study shows that as long as the minimum data can be collected to quantitatively assess basic aspects of UM, interesting studies beyond the quantitative can be made. Also, that cooperation and intense communication between stakeholders and the research team seems to be crucial in the LAC context.

7. Baccini-Rechberger-Brunner method[50,128,269]

This method parts from the idea that a society's metabolic system is shaped by human needs, which translated into activities and series of them, ultimately shape consumption systems. Human activity is classified in 4 categories: "TO NOURISH", "TO RESIDE&WORK", "TO TRANSPORT & COMMUNICATE". Each category consists of sub categories – i.e. "TO NOURISH" includes agriculture, chemical fertilizer manufacturing, food processing, eating, and so on. To analyse the metabolism of a region, the material and energy flows needed to operate each of those activities should be quantified. For "TO NOURISH", one would account for all edible crops, vegetables and fruits, as well as processed and packaged foods, drinking water, bottled beverages and also all flows of materials associated with those goods, such as cans, bottles, plastic bags, dishes used for eating, cutlery, etc. Other associated materials would include tractors, barns, warehouses, etc. Once activities within each category are established, substance and energetic flows can be associated as well (fig 3.15). The mass balance principle is applied once the quantities are known, to assure that all flows are accounted. This means of course that at least one end of the flow (inputs or outputs) must be known with certainty – i.e., it should ideally be measured or very closely estimated. When either end of the flow (input or

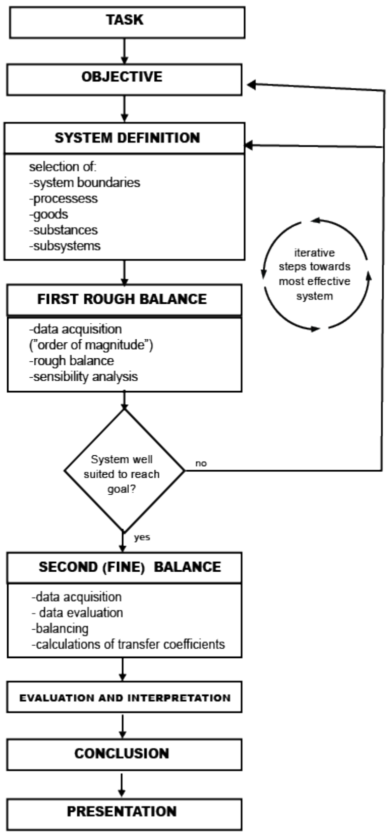


Figure 3.16 Baccini & Brunner's general procedure guide for performing Material Flow Analysis. It will guide the shaping of the method to apply in the study case. See section 3.4 and chapter 4.
Redrawn from the original in Baccini and Brunner, 2012

output) is unknown, it can be calculated on the base of the other end, and a detailed knowledge of the process steps plus the application of transfer coefficients, and then mass balance could be performed.

This method is quite powerful to understand not only the overall metabolic requirement of a society, but also the drivers and feedbacks of the system, given that data is available at fine scales. For the method to fully display its capacities, there must be information about, for instance the proportion of water destined to separate cleaning activities within the household, or the proportions of types of waste among different sectors of society. To describe the activity "TO CLEAN", for instance, knowledge about the types and amounts of cleansers used would be needed, etc. This fine granularity of information is often only accessible through field work, measurements and surveys. In studying Paris, Barles (2009)[294] finds that fine scaled data that is needed to run this method is not available, which is very likely also the case in most Latin American cities. Furthermore, Barles also observes that the social system being predefined through the four activities, the method leaves little chance to describe the particulars of other local systems, but the authors argue that the four activities are encompassing and flexible enough to allow for adaptation[50].

Although the intense data requirements in this MEFA method render it inoperable for the purpose of our case study, in the 2012 edition of *Metabolism of the Anthroposphere*, Baccini and Brunner propose a guiding procedure to perform an MFA, with a logical sequence of steps that the analyst may follow from the initial stages of planning and deciding the system boundary, to the communication of results. It is an iterative process where results of the first steps are communicated back to the beginning to re-adjust the process (Fig. 3.16). This sequence could be slightly adjusted for application to the general organization of any MFA, regardless of the method, and will be used as a guide in shaping the method present at the end of this chapter.

8. MuSIASEM[247,274]

Multi-scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), has been developed by M. Giampietro and collaborators through 20 years of research, at various institutions throughout Europe, with operations headquartered at the ICTA in Barcelona. One of the core objectives of MuSIASEM is to capture the true complexity of metabolic patterns, by analysing the system at multiple dimensions and scales. MuSIASEM has a dense and multi-disciplinary theoretical baggage, drawing from Georgescu Roegen's flow-fund bioeconomic analysis, thermodynamics as applied to ecosystem theory in the work of the Odum brothers, and on complex system theory[274]. It builds on the premise of the dynamic nature of metabolic systems, which are always "becoming", -i.e. in constant change, iteratively inter-determined by their internal structure, their legacy and the interaction with other systems, having simultaneous processes at multiple scales and dimensions.

In MuSIASEM, the system is first empirically analysed to determine "what the system is" and "what the system does", and *flow elements* (water, food, energy, etc.) are allocated to *fund elements* (human activities, households), which consume the flows. This characterisation of the system (*internal view*) is subject to be proven wrong when the method is applied, and is then in itself also part of the iterative process of studying and understanding the system. *Fund* elements are divided into typologies (capital, people, activities), and their required material flows calculated or estimated according to available data on resource consumption. The consumption pattern of the *fund* determines its identity. The *flow-fund ratio* is central to MuSIASEM, and it represents the metabolic rate of the entity examined (a society or a compartment of it). To calculate this metabolic rate, human activity is analysed in extreme detail, accounting the number of hours allocated to paid work, to leisure, to household activities, etc. A hierarchy analysis then nests individual's paid worked hours into larger categories, called *functional compartments*, such as economic sectors (e.g. paid hours worked in agriculture, mining, etc.), and these into total hours worked by the society, giving the indicator Total Human Activity, THA.

The hierarchical structure of ecosystems and their metabolism is also considered and analysed, in what is called the *external view*, where a given metabolic system is looked at "from the outside", and its feasibility can be determined, i.e. whether its resource demands are sustainable within the limits of available resources. Social-ecological systems are defined as the crossing point of the two metabolic patterns, ecological and social (see fig. 3.18). This fine-grained analysis of the nested categories of activities and processes within the structure of a society or an ecosystem is fundamental to MuSIASEM, as its authors point out that, because societies are complex systems, emergent properties arise when the individual parts interact. Metabolic analyses that only add up the consumption of individual to obtain the whole (i.e. addition of local scales to obtain the macro scale) will miss flows caused by these emergent properties. Hence, MuSIASEM insists on the need for a multi scalar approach (in Fig. 3.10: n, n+1, e, e+1, etc.,). Thus, different levels of ecosystem organisation (e, e+1, etc.), social-local (e.g., rural, household), meso (country) and large scales (international markets) must be analysed individually and then in ensemble to understand the entire system. Accordingly, MuSIASEM consists, besides the human activity *fund element*, also of water, energy and food flow *grammars*, each with their own set of rules to analyse, describe and quantify the according flows. While they can be used in conjunction, it is also possible to analyse only one.

MuSIASEM can allegedly provide very accurate analyses of the metabolic patterns of a society, as well as of its viability and feasibility –i.e., the congruence between the system's goals and internal structure, and between the system's metabolic pattern and the resources available to it. According to the authors, one of its main strengths compared to other metabolism analysis tools, is that it can quantitatively describe discrete socio-economic drivers of unsustainability, thus shedding concise light on possible intervention points. MuSIASEM has been applied to analyse the ecological feasibility of economic sectors and of energy metabolism patterns of countries and regions[333], to address water scarcity issues at the watershed scale[272], and to assess the role of human labour in Beijing's metabolism[334].

The theoretical loading and discourse of MuSIASEM is round, timely and interesting. The method itself is however not straight forward to apply, seems to be rigid and is highly data demanding. For instance, to define the *fund* element "Human Activity", it needs calculation of total paid hours worked by the adult population, which is already something quite difficult to know, and additionally, calls for per economic sector work hours and the efficiency or productivity in monetary of those working hours.

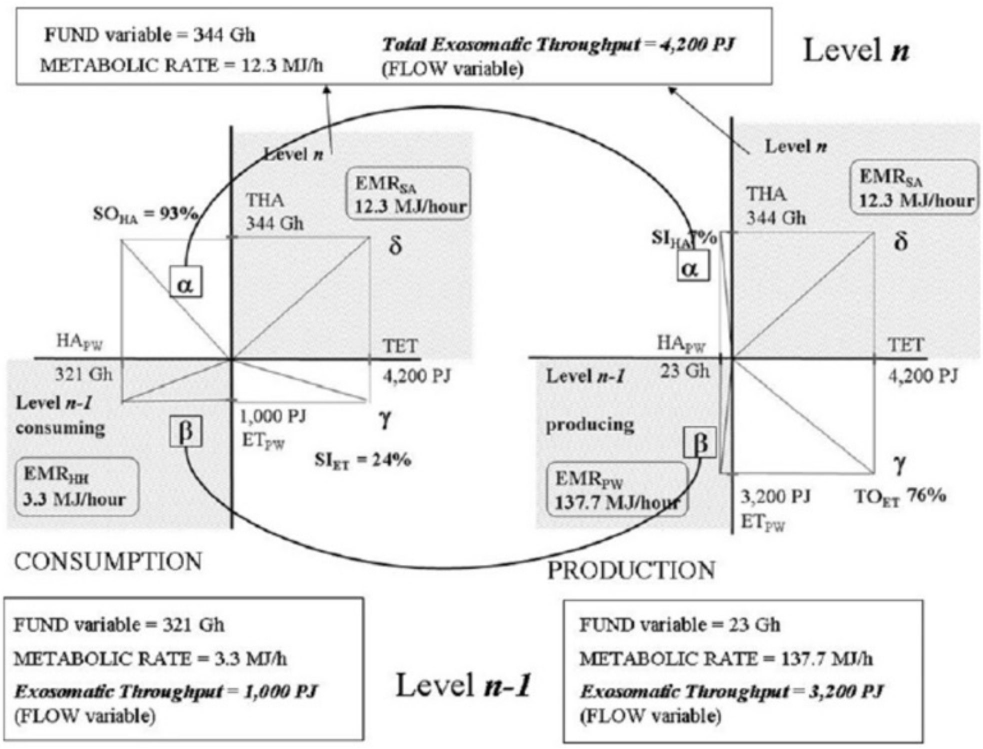


Figure 3.18 A MUSIASEM diagram showing the metabolic rates and patterns of consumption and production in an economy (called level n). Level n-1 is the household level, and the diagram represents the consumption and production sides of households, with different combinations of age groups (adult couple, adult couple + two children, elderly couple) represented by the greek characters. "Exosomatic metabolic rate" (EMR) of each age cohort is shown, as well as human activity counted as paid work hors (HA). In this case the economy is a fictitious entity, used to explain the concepts and methodology of MuSIASEM.
Taken from Giampietro *et al.,* 2009

MuSIASEM also calls for the calculation of the hours dedicated to nourishment, personal care and so on (referred to as *physiological overhead*). To operate, it makes a series of assumptions, such as the number of hours that are effectively worked, and the way that families are composed (2 adults+2 children etc.). National statistics on family composition, labour and average working hours in LAC countries certainly exist, but family dynamics are so changing, and in LAC the informal sector is so large (in certain cities it is estimated to be around 50%, see chapter 2) that the accounting of the number of hours and their monetary yield seems almost impossible.

Furthermore, MuSIASEM has developed a set of unique jargon, assumptions and self-references, that have to be constantly referred to until they are memorized. To fully run the method, the series of steps to follow seems long and confusing. Although the authors many times describe MuSIASEM as "simple", in practice it is evident it cannot be applied made without assistance from the developers themselves, or at least through a considerable learning curve.

Finally, the output possibilities of the tools (charts, graphs, etc.) require extensive reading of the text for their understanding and –although they are indeed a noteworthy effort to portray complexity and interconnection between levels and elements of a system, something that is never easy–, are simply not easy to grasp without having invested time to understand the general concept and procedure of MuSIASEM (See fig. 3.18). Such a graphic output does not seem like a practical communication tool for a non-expert audience as would be decision makers, civic organizations and so on. Communicability is one of the basic criteria looked for in this tool survey. For these reasons, although MuSIASEM seems to contain much substance and may be very interesting to try in the future, it is discarded for the trial test in the case study of this thesis.

9. A visualization proposal

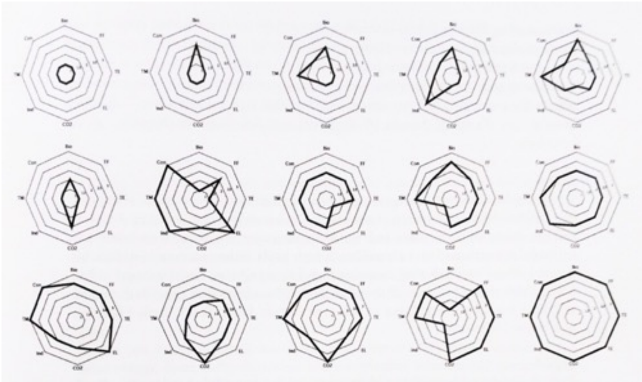


Figure 3.19 The 15 categories of the Saldivar-Sali (2010) global city typology. 7 resource consumption flows + 1 emissions flow are classified in low, medium or high consumption for 155 cities, which are categorized in the 15 types showed here. The aim of this typology is to provide a general overview of metabolic behaviour and explore methods to compare the metabolisms of different cities. Taken from Ferrão and Fernandez (2013).

As can be seen from the method reviews presented so far, urban metabolism accounting is normally communicated with Sankey diagrams or with conventional tables and pie charts. While a graduate student at MIT, Saldívar-Sali (2010[335]; and cited in[322]) has proposed a slightly different approach, through her global typology of urban metabolic profiles (Fig. 3.19). In her study, 155 cities are categorized into 15 typologies by accounting for per capita consumption of eight flows (biomass, fossil fuels, total energy, electricity, CO2 emissions, industrial minerals, total materials, construction minerals). The consumption of the city is classified as low, medium or high. Because of limitations in data availability and comparability, the flow estimations were made by downscaling available national level consumption data with GDP and population size data, through a downscaling function taken from the literature[335]. The results are most likely, as acknowledged by Saldívar herself, quite a rough approximation to reality. The categorization itself (low-medium-high) might also be deemed arbitrary. Likewise, the typology itself does not inform on cities' spatial attributes or socio-economic particularities (although these considerations are examined in a different part of the study). However, the author herself states that the typology proposal is a first exploration into the possibilities of unifying urban resource consumption accounting, and that its value resides more in this exploration of possibilities and communication strategies than in the accuracy of the calculations. Minx *et al.* (2011) have used a similar approach to communicate the abbreviated results of their Extended Urban Metabolism analysis of European cities, which was carried out with much more reliable data and procedures (see EUM in section 3.3.1). The simple graphical output seems certainly straight forward and useful to grasp the overall environmental performance of the city, and can be used not only to compare cities among each other, but also one single city against its own targets or historical development. Furthermore, if the calculations are done with more precise data and methods, the diagrams could be a truly reliable communication tool.

10. Stock analysis

Most UMA focus on the flows in, through and out of a city. The quantification of stocks (e.g. materials embedded in buildings and infrastructure, nutrients and other compounds stored in soil or water within the city system, materials contained in landfill sites) is a relatively recent field of study[336], and is an important one, be it to understand environmental consequences of the stock itself, or to analyse its potential for future use (urban mining)[88,296]. Although most cities keep data records that can help estimate changes in the building stock (e.g. construction permits can provide fine details on surface and materials used in every building constructed), material stocks are hardly investigated in many cities in the global south ([337], cf. [88,336]).

Stocks can be calculated or estimated in a variety of ways, depending on the material in question and the aim of the study. Lichtensteiger and Baccini (2008)[88] use a dynamic MFA model considering historical and statistical data on city growth, as well as concentration quantities of certain substances and standard traits of Swiss constructive systems to estimate availability of several materials in the building stock, including wood, copper, cement, clay and gravel. Oezdemir *et al.* (2017)[338] used a similar method, adding to field and historical data, the use of GIS tools (see also GIS section, 3.3.3), to estimate the material stocks available in the Rhine-Ruhr region in western Germany, including additional materials, such as adhesives, plasters and textiles. These two studies are examples of urban mining surveys, aimed at assessing resource availability for future use, under the premise that it is a better alternative to transform the built environment with *in situ* existing materials, than to expand the city bringing in additional new materials. In this sense, urban material stock reuse (urban mining) is closely associated with the ideas of the "circular economy"[338], where the analysis or urban stocks is a fundamental step.

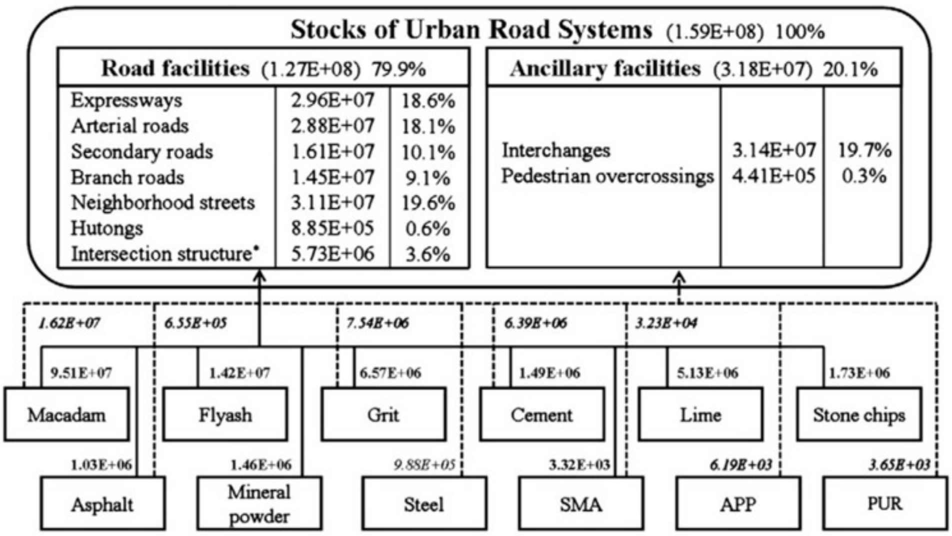


Figure 3.21 The material stock in Beijing's road system as calculated by a GIS-adjusted mathematical model. Taken from: Guo *et al.* (2014)

With a different aim, Deilmann (2009)[296] also used advanced GIS tools, along with a typology of building structures, to quantify the material stock of three east German cities (including total building surface and footprint, street surface and green surface). Once the stock was quantified for each of the typologies, current population growth and construction industry trends were used to predict changes in stock, and on that basis, estimate future required flows of energy, construction materials and waste. Guo *et al.* (2014)[336] used road typologies, GIS information on surface cover, knowledge about locally used structural engineering and road construction processes, and built a model to quantify the stock of five materials in Beijing's road system, and also to find key parameters of environmental impact linked to road construction[LL]. Inostroza (2014)[339] quantified the material stocks in Bogotá through GIS tools and the concept of *Technomass*, (i.e. the amount of anthropogenic material accumulated in a region. See indicators section, 3.3.4).

3.3.2 UM system description/ system analysis tools

A comprehensive study of the urban metabolism would entail looking inside the black box, to understand the structure of the system itself[340]. This means unveiling the "building blocks" or nodes of the system (*fund* elements in Georgescu Roegen's bioeconomics[247], used in the MuSIASEM method), as well as the nature of the processes that connect these nodes (*flow* elements), and the rules of their relations, including the feedbacks reinforcing or dissipating the structure of the system. To carry out such a description, an empirical ("by hand") analysis is always fundamental, and it can be sufficient in many cases. The analyst decides what is connected to what, and proceeds to try and quantify those connections. For instance, one can empirically know that water consuming activities (households, factories) are linked to the city's water supply system, and this system has an input such as a dam or a river, and an output in the sewage system, which may go to treatment plants and then back to the river. The analyst would name these nodes and connect the flows and then try to find the data for the magnitude of each, and try to make the best possible calculations to fill in any gaps. This sort of procedure can be sufficient in many cases, and can provide with useful results. In MuSIASEM, a method based on complex systems theory, the initial definition of the system is done by the analyst following his/her own experience and thought, in an iterative process where many runs, or calibrations, of the processes may be needed to come to a description of the system that approximates well enough to the behaviour of the system in the real world. H.T. Odum worked on ecosystem and urban metabolism assessment models with only basic computing tools, for example, and early metabolists such as T. Weyl and A. Wolman, with no computing tools whatsoever.

However, when it is desired to dive deeper into the the complexity of the system –and this desire indeed seems to be a sign of our time–, many other nodes and flow must appear. In reality, the input-output behaviour of the water supply system is affected by many factors besides the demand of consumers. Hydrological factors such as evaporation in the dam or the ability of soils within the catchment area to retain and infiltrate water; infrastructural issues such as the quality of pipes and the

[LL] This same study provides a brief review of other GIS-based stock analysis studies.

efficiency of pumps; and socio-economic issues such as water tariffs, consumer preferences, and so on, intervene. Management solutions that are based on an oversimplified view of the system (e.g. one where only four elements connected in a linear way exist: dam-pipe-house-drain) may miss possible solutions for improved management (e.g. maybe there is no need to build a new dam to have more water, but to improve the quality of the catchment area by avoiding further urban growth, etc.).

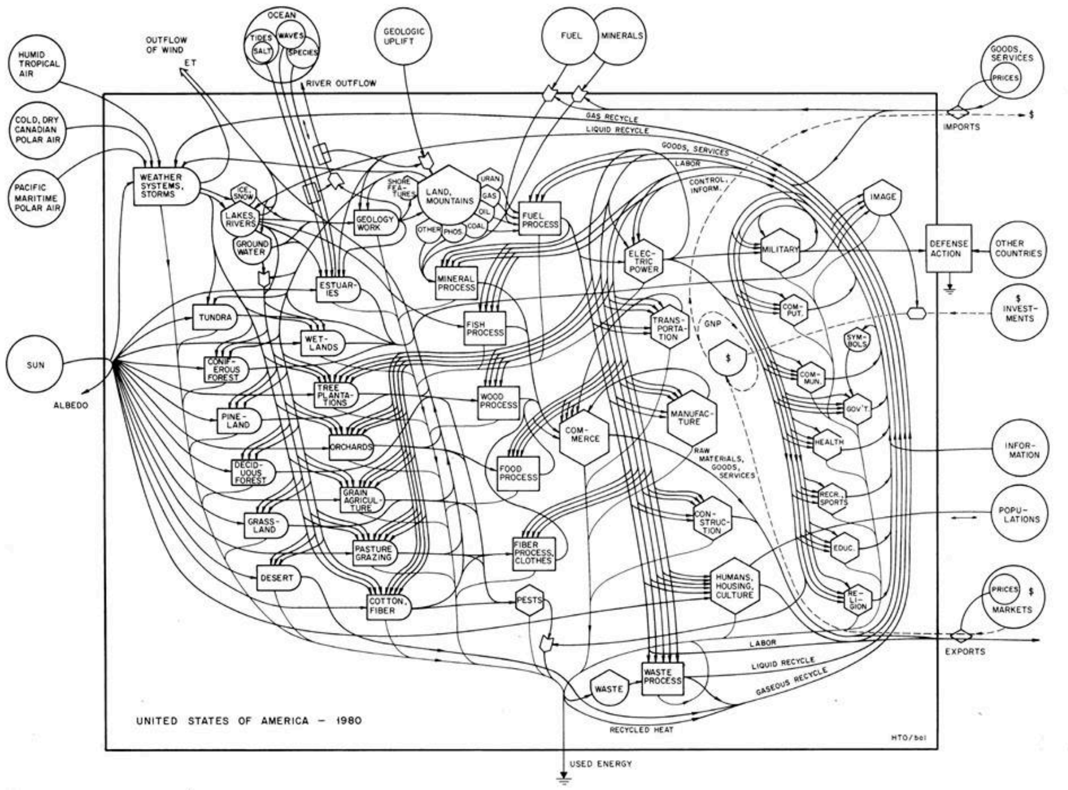


Figure 3.20 Odum and Odum's (1980) empirical system description of the United States economy. Sectors are arranged from left to right, in order of increasing energy quality.
Taken from Odum,1983 (1994).

Notwithstanding its importance and appeal, grasping this complexity is a formidable task. Systems thinkers have been attempting to model complexity for decades, more or less successfully depending on the field. In urban metabolism, attempts have started only recently, with the transfer of methodologies from ecological science and systems modelling[340], with a predominant presence of Chinese researchers in the UM-systems literature. The main objective of systemic analysis attempts in UMA are centred around understanding the composition of the black box, attempting to answer such questions as*: what are the nodes or compartments of the system? What is the relative weight of each? How are they interconnected and how do they influence each other? How are they influences by outside factors?* etc. The following section will provide an overview of what, after reviewing available literature, appear to be the two most commonly found systems approaches in UMA.

1. System Dynamics (SD)

Systems dynamics is a well established computer-based method for the analysis of complex systems, with a strong emphasis on causality and feedback loops[341]. It was introduced in the 1960s through the work of MIT engineer Jay Forrester, who linked SD to urban systems analysis from the beginning, in his book *Urban dynamics* (1969), and was used to obtain the results in the famous *Limits to Growth* 1972 report. In very broad terms, SD consists of sets of non-linear differential equations whose solution is approximated by dividing them in time intervals (called *time steps*). SD aims at to find underlying patterns in system behaviour, seeing events and phenomena as expressions of the system structure and governing rules[341]. SD has found wide application in environmental issues, and also in social and economical matters, including management and policy analysis[299,341]. In urban sustainability and UMA, SD has been applied to describe the system components, behaviour drivers and feedbacks, mainly with the aim of finding resource efficient strategies for the future development of cities or exploring the environmental effects of policy options through the modelling of different scenarios[299,300,315]. SD has also been used to attempt to find the key components that define resilience of urban and other social-ecological systems[298] (See Fig. 3.22). For example, Song *et al.* (2013) applied SD with eMergy units to describe the relations and feedback loops of city drivers (population growth, GDP, proportion of participation of different economic sectors) with flows of resources (divided into 'local' and 'imported', including for example cement, steel, fertilizer, coal) and patterns of consumption. The model was used to understand the current pattern of resource consumption, and the resource intensity of Beijing's economy, as well as to model the possible impacts on resource consumption and environmental pressure of different policy scenarios for future development. Guan *et al.* (2011)[315] extend the possibilities of SD by combining it with GIS based spatial analysis of resource consumption and ecosystem degradation, to evaluate policy options that would allow Chongqing city to overcome resource depletion and environmental pollution problems.

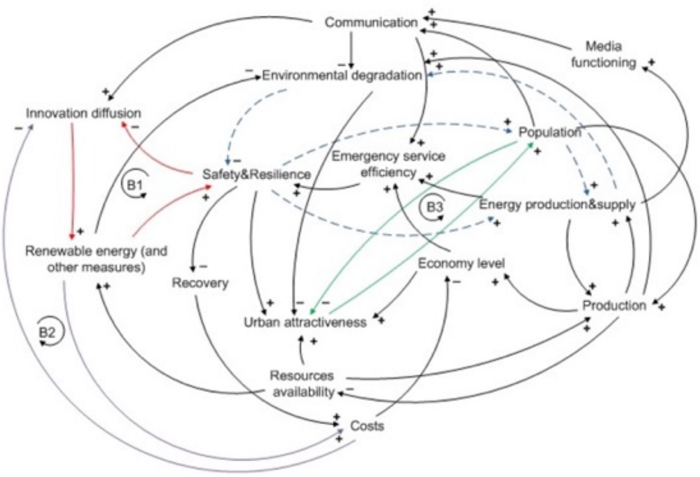


Figure 3.22 A System Dynamics model of the dynamics of resilience factors in an urban system. Taken from Kuznecova *et al.*, 2014.

2. Ecological Network Analysis (ENA)

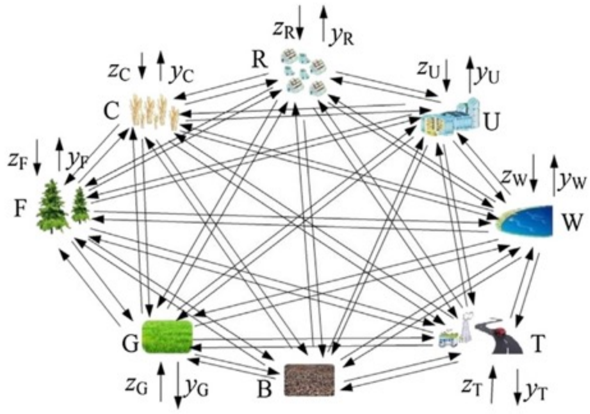


Figure 3.23 The conceptual model of Beijing's carbon metabolism, showing different land types and the carbon exchange relations between them. This model is the base for subsequent ENA. Taken from Zhang *et al.*, 2016.

ENA is a method used to understand the distribution in space of the components of a system and of their relations, and is frequently used in ecological studies to gain insight into how ecosystem structure is linked to its function[297,342]. For example, in landscape ecology, ENA is used to study how nutrient flows are shaped by available corridors and the structure of patches. It has also been used in urban and regional planning to plan the optimal distribution of green space[343]. Applications in urban metabolism include Zhang *et al.* (2010)[342]; Chen *et al.* (2010)[340]; Chen and Chen, 2015[344]; and Zhang *et al.* (2016)[297]. They all have used ENA to understand what the important nodes in the city's material and energy flows are, how they are related and how they influence each other in the context of material and energy demands, distribution and exchange. Zhang *et al.* 2016[297], for example, analyse the structure of the urban system of Beijing in the context of carbon flows. An analytical description of the components of the system and their relations if first made (i.e. the analysts decide what the parts of the system are and how they are interconnected, and this process is done "by hand", as was discussed above. See fig. 3.13), and the carbon emission and release capacities of each component determined through empirical coefficients. Using time series of land use and cover, the study determined how the spatial patterns of carbon flows changed over time, and what the key drivers of increased carbon release are.

As can be seen from this short description, applications of complex system modelling to UM are only beginning, but they hold great promise to inform with detail about the dynamics of urban metabolism. Modelling systems with these methods requires the writing of equation sets, and although some SD software provides friendly interfaces that are more or less accessible to any user, these are limited. While it is true that intuition and observations are fundamental to access complex systems and thus, as stated, careful "by hand" definitions of the system are basic, without the ability to produce their own equations, a research team will likely not be able to benefit from the power of SD, ENA or other complex system modelling computer-based tools.

3.3.3 UM environmental assessment tools

Environmental impacts happen in various forms, and through the complex interaction of many factors. In the context of current resource use, which occurs in intricate chains of global processes, total environmental impacts of even one single process are often extremely difficult to estimate entirely[213,324], let alone those of a large metabolic entity such as a city. Furthermore, each metabolic pattern has its own specificities beyond quantities and qualities, such as the context it occurs in, or the regulations around it. It is thus clear that no single tool or method can assess the entirety of the environmental impact of a given metabolic pattern, and each case should be looked at specifically to find the right combination of tools and indicators to work with in the assessment of its environmental impacts[213,324]. But in all cases, quantitative knowledge provided by MFA (section 3.3.1), along with qualitative and contextual knowledge, are fundamental to proceed to environmental assessment (EA).

In practice, EA does not attempt to quantify every single environmental impact of a metabolic system, but rather looks at specific flows or aspects that are deemed key, because of their great volume, their high impacting potential or other. Integrated tool sets, using combinations of tools are also often used. A review of EA tools found among the UM literature is given in the following paragraphs.

1. Life Cycle Analysis (LCA)

Life Cycle Analysis is widely used throughout the world, in many different situations and fields. The process to carry it out has been standardised by the International Standards Organization through the ISO 14040 / 14044 norms. It is a well-performing tool to assess the environmental implications of a product, activity or system, from "cradle to grave", meaning that it can inform on the impacts of every stage in the unit's life, from the sourcing of raw materials required to fabricate it, to the impacts linked to its manufacture, transport, assembly and so on, up to the consequences it will have at the end of its useful life. LCA can be applied to small individual items (a coffee-maker), more elaborated goods (a bridge over a river), or to much more complex processes (the waste management system of a city).

The practice of LCA is automatized, through the use of software and databases gathered by private enterprises, research institutions and governments, where information on the impacts of millions of activities and processes is concentrated. LCA software permits for the user to add additional processes, making it an adaptable tool for every situation. Although it may be data and time intensive, it has found many useful applications across fields and disciplines, including urban issues, where it is normally used to describe the impacts of singleprocesses[345] (road construction, for instance). New methods have however emerged for more widely using LCA to give approximations of the city's overall impacts. In the context of UM studies, LCA offers the advantage of being able to inform in a detailed manner about upstream and downstream impacts of urban consumptive flows, something that UM accounting cannot necessarily do by itself[345], unless it is extended otherwise, e.g. through the use and analysis of hidden flow indicators. LCA methods applied to UMA in this broad manner will be discussed in the following paragraphs.

1.I EIO/PIOT-LCA

LCA can be integrated into an UMA using Economic or Physical Input Output (EIO/PIO) tables (see section 3.3.1). In the method known as known as Environmentally Extended Input-Output Analysis, (EEIOA), the monetary flows per economic sector are associated with environmental impacts through the use of a model developed at the Carnegie Mellon University[284,346,MM]. Because EIO groups together several economic activities (plastics industry including all its sub-processes, for instance), EEIAO studies tend to be highly aggregated, giving the environmental impact of a given sector as an average of the many subsectors it contains, and thus not permitting to see specific flows[346]. To overcome this problem, an alternative method of has been developed by Hoekstra and van den Bergh (2006)[326], using PIOTs, which describe material flows in a more disaggregated manner, to find environmentally sensitive flows, including those related to packaging, residuals, landfilling, incineration and others not often taken into account in more general EIO tables, and associate them to environmental impacts using a variety of already available indicators and empirical measurements[326].

1.II BLACK BOX MFA- LCA

Goldstein *et al.* (2013)[345] and Kalmykova and Rosado (2015)[346] both make the case for expanding MFA/UMA through LCA, under the argument that UMA is weak in establishing environmental impacts, and that it can largely profit from the very wide array of databases that LCA now has. They contend that in order to do so, LCA must be applied not only on specific processes, but rather be performed on the entire metabolic model of the city, or at least its major points. The latter authors perform a test run of an UMA using material flow analysis and life cycle analysis (MFA-LCA) on five cities, in a first attempt to assess complete urban metabolic flows (from source to sink) through LCA. They worked with flows calculated in black box accounting models (see section 3.3.1), previously done by other researches, in which the city is viewed as a gross consumer, with no detailing of the processes inside the city are. LCA was performed on eight metabolic flows (water, electronics, certain foodstuffs, plastics, metals and others) through the software GaBi and according to ISO 2006 standards. Results indicate, for instance, that upstream (embedded) flows are a very significant part of the material consumption (50% or more in 4 out of 5 cases) and that global warming potential (GWP) and GHG emissions per capita tend to be slightly higher when calculate with LCA than with traditional GHG accounting methods. The study found that environmental impacts of wealthier cities tend to be linked with private consumption and transport, whereas those of poorer cities tend to be linked with inefficient energy and industrial infrastructure powered by "dirty" fuels such as coal. The amount of

[MM] Available at: www.eiolca.net

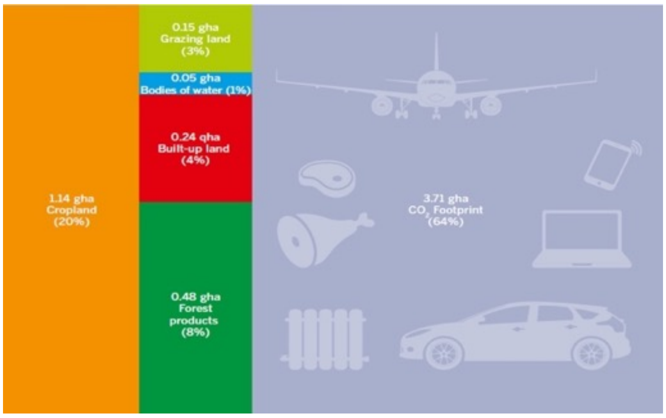


Figure 3.24 The per capita footprint of the German State of Nord-Rhein Westphalia, shown by land-use category. These results come from a 2017 EF study presented by the State's environment minister. Taken from www.footprintnetwork.org

agricultural land "occupied" by each city for its supply was also calculated, with findings consistent with other studies, as to the fact that wealthier cities tend to export their environmental burdens.

The study was rough, using many proxies and adjusted data, but was able to nonetheless settle that in fact UM-LCA is a good choice of method to expand and strengthen UMA, specially in tasks such as the calculation of upstream impacts, or pointing to key flows contributing to environmental pressure, something that UMA could do, but with a (very) open box approach and enough detail about internal processes. But for example, in the case that a research team can only perform a black box MFA, which is normally easier and faster, UM-LCA could be a good option to amplify the power of the UMA and describe environmental impacts of the city's metabolism.

2. *Footprinting*

2.1 Ecological Footprint

The *ecological footprint* is a well-known concept introduced by W. Rees in the early1990s[56], and with a long historical root[347]. The measure of EF answers to the question "*how much of the biosphere's production and land is needed to support the population of a region (i) indefinitely and (ii) ideally, without impairing ecosystem integrity*?"[56]. EF is closely related to the ecological concepts of ecosystem carrying capacity and human appropriation of primary productivity[56]. A measure of the (un)sustainability of a given entity can be given by the ratio of its EF to the available carrying capacity (CC) of the biosphere for that given entity, where an EF>CC would be deemed unsustainable (and called *overshoot* in the EF framework).

EF has been since it introduction inherently linked to the quantifying of material flows and to the notion of urban metabolism. In what can be considered the second foundational paper, Rees and Wackernagel (1996)[127] touch upon the notion of industrial metabolism, and state that EF is a method to assess the land surface needed to support it. Later, Wackernagel *et al.* (2006)[348] propose that EF is an accurate tool for understanding and managing regional or urban metabolism. Through the years, EF has been revised and refined: in the most recent version, distinction is made between production, consumption and trade footprints, for instance[349]. At the urban scale, it has recently been applied to analyse the sustainability of Chinese agglomerations[350], of an Irish city-region[351], and of two Japanese cities[352].

Ecological footprints of many nations and cities have been calculated[348,NN] and EF has become popular both as a method and as a concept, giving way to other footprints: carbon footprint, water footprint, etc. Indeed, after the clear idea of a foot stepping on the earth as a sign of pressure, perhaps the second main advantages of EF is that it is one single, straight forward indicator, useful in quickly communicating something quite concrete about the impacts of the entity examined[347]. EF is a good first approximation to metabolic notions, as it highlights that humans need a flow of resources that comes from natural spaces beyond the city borders, something that is sometimes "forgotten" in the much de-sensitized contemporary urban society[308,347]. Also, by stressing the "fair share" of resources (i.e. the amount of resources that would fairly belong to every person, when all resources are equally distributed), EF enforces ideas about equity and environmental justice[117,347].

Since its introduction, EF has been examined and analysed by several scholars, some of which openly criticize it and some of which have proposed methods to refine it and improve its capacity and accuracy as a metric for sustainability[347]. Criticism includes that, because of the high level of aggregation needed to convey information on multiple and complex impacts in one single indicator, EF forcibly oversimplifies or hides many sides of any environmental problem, such as toxicity, differentiated risk of population sectors and exposure to impacts, boundaries, and others[117,347]. Baccini and Brunner (2012) have pointed out that one single indicator can never fully look into real-world environmental concerns in a way that offers concrete solutions, making EF an attractive tool for communicating with non-expert audiences, but by no means a sufficient tool for deep understanding of human's metabolic systems[50]. Furthermore, it has been observed the "productive land" or "biosphere" estimated in EF is an abstract: it is everywhere and nowhere, missing all nuance as to ecological specificities, priorities for land conservation, different levels of sensitivity to appropriation and so on. In other words, it "forgets" that it is ecologically not equivalent to appropriate hectares of already existing pasture land than to appropriate hectares of forest to turn it into grazing land[347]. It has also been argued that EF being a single, highly aggregated indicator, it cannot by itself point to drivers[347], or highlight priority areas to work on or appropriate policy directions[117]. McManus and Haughton (2006)[347] find that, due to its conceptual ambiguity and rough science, EF has been easily co-opted as an instrument for lobbying and achieving political goals by groups pursuing personal agendas under a "green" banner that hides a narrow understanding of sustainability and the science around it.

[NN] For a comprehensive compilation, see the Global Footprint Network's webpage at www.footprintnetwork.org. Also, a good compilation and regularly updated compilation of all five footprint studies linked to UM, is provided by the excellent database at www.metabolismofcities.org Reviews of urban footprinting studies is also provided by Best *et al.* (2008)[353].

Different efforts have been made to refine the method (e.g. Wackernagel *et al.* (2004)[354]; Bagliani *et al*, (2008)[355]; Jin *et al.*, (2009)[356]; Dakia and Berezzowksa (2010)[357]), while others have worked with the notions of "footprint", "environmental pressure" and so on, and tailored different methods around these concepts. The following paragraphs will provide a brief overview of these, which can surely be classified as "footprinting" methods, although they do not draw on the work of Rees and Wackernagel.

2.II The four footprints

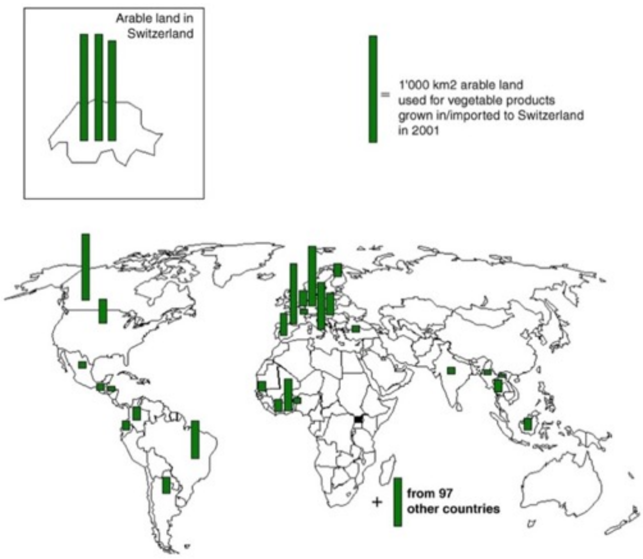


Figure 3.25 The geographical distribution of land use for vegetable product imports into Switzerland in the year 2001. Taken from Würtenberg *et al.* 2006.

Land, water, carbon and materials footprint[OO] – known as the "four footprints"[158]– are a class different from EF in that they quantify the actual amount of a resource being used (or pollution emitted, in the case of the carbon footprint) in the consumption of a certain flow of goods or materials, and often also point to the location of the impacts[PP]. In contrast, EF calculates an amount of abstract land/water that would theoretically be needed to support a given production process, or resource flow, including the sinking of its emissions[158]. Put another way, EF is production-based and points to abstract land, while the four footprints are consumption-based and point to real land.

Global Land Use Accounting (GLUA) developed at the Wuppertal Institut in the early 2000, belongs to this class of footprinting methods. It is focused on agricultural goods, but other similar methods look at other flows, and also at whole sectors or even whole economies[QQ]. GLUA quantifies the amount of land needed to produce a certain agricultural good on a consumption-base, meaning that it accounts for resource use (in this case land), based on the real consumption of products requiring such land for

[OO] There is also the "foodprint", accounting for food consumed, and its impacts. Still, in definition, sometimes it is used *en lieu* of materials footprint, or also can be considered a subclass of MF. Sometimes it is also estimated as an EF. See, for example, Goldstein *et al.* (2017)[345] for a review.

[PP] The shortcomings of EF have been discussed in the preceding section, but the inconvenience of aggregating many factors in one indicator which in turn points to a non-existing place, and assigns equal value to different land cover types, shall be recalled now, as authors of methods for the four footprints emphatically highlight the conceptual and methodological differences that set them apart from the EF school (cf.[158,213,358]). Nonetheless, the 'footprint' concept is well placed on the global discussion table and indeed is so straight forward to grasp, that these same methods in fact benefit from its use a clear communication label. In my view, GLUA and other methods discussed in this section should be considered footprinting methods.

[QQ] See O'Brien *et al.*, (2015)[158] for a comprehensive review of LF studies and Tukker *et al.* (2014)[359] for results on all four footprints of several countries.

their production. It is an indicator of environmental pressure insofar as it is assumed that increased consumption leads in general to increased environmental degradation[158].

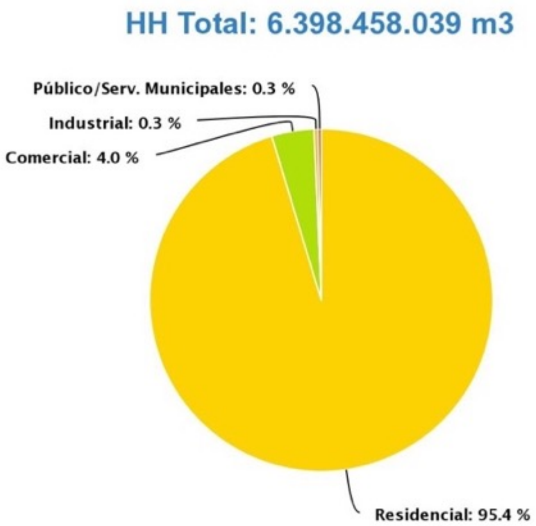


Figure 3.26 The "Water Footprint" of Lima, Peru, as measured by the *Huella de Ciudades* programme in 2012. From these results, it can be inferred that the method deployed by the programme is not considering any embedded flows, and that the alleged "footprint", is really only an accounting of the *blue* water input into the municipal system. Taken from www.huelladeciudades.com

To calculate global land use, GLUA traces the origins of imports and considers domestic production through trade and production statistics from Eurostat and/or other databases. It uses yet other statistical databases, such as FAO, those at Wuppertal Institut, national databases, and LCA, to obtain land use requirements and yields for crops, and then calculates the *gross production land* used in growing and raising the agricultural consumption of the studied entity[158,213].

One of the virtues of this method, and other similar to it, is that it accurately accounts for hidden flows of land (also called *virtual land*[358], see Fig 3:25). In contrast, it is recognized that neither GLUA nor other methods in its class can be used to assess other phenomena linked to land use and land use cover change, such as biodiversity loss, erosion and ecosystem health. However, they can point to pressures in those directions[158], and be furthermore useful in, for instance, anticipating environmental consequences of trade agreements[358], being potentially informant for the design of policies of countries who wish to improve their environmental performances, both domestically and in relation to hidden flows. Moreover, footprinting techniques can be combined with other methods to improve the accuracy of insights into the environmental impacts of resource flows.

Surely, because land footprinting (LF) methods are fairly new, much refinement is to be expected, in methodology as well as in data availability and aggregation techniques[358]. All footprinting studies reviewed recognize difficulties for data gathering, even at the national scale, although for European countries the problem seems smaller, as there are at least three reliable data sources: (i) international databases such as those at FAO or the WCO; (ii) national accounting data reported in Eurostat, and (iii) data gathered by research institutions, notably the well-established data base on global material flows at the Wuppertal Institut.

The methods for materials, carbon and water footprint (MF, CF, WF) assessment are much better established than those of LF[158], at least for the national scale. The most commonly used method for water footprint (WF) assessment is that proposed by Hoekstra et al. (2009)[360] and the Water Footprint Network (WFN). It has been implemented in a variety of scales, from the global[361] to economic sectors[362], production processess[363] and also cities. Although it would appear that the methods applied need to be refined (see Fig. 3.27), urban WF and CF have received increasing attention in Latin America. Quito and Bogotá have assessed their WF, and further cities are on the way, through *Huella de Ciudades*, a partner alliance including the WFN, governments, consultants and the Latin American Development Bank (CAF), who since 2014 are implementing a WF and CF measurement and management programme in eight cities[RR].

As for CF, its assessment is approached in different ways. GHG accounting are a common but incomplete approach[364], as a GHG emissions inventory does not account for the hidden carbon flows linked to urban consumption[365]. EIO and LCA, discussed before, are also approaches used in CF[364]. Minx *et al.* (2011)[332] demonstrate a simple carbon footprint of beef consumption in selected UK cities, and discuss its association to land cover change in Brazil. However, they acknowledge that more detail, e.g. including flows hidden in beef production and consumption, is a methodological challenge. The matter is certainly not simple, as any flow, for example a food flow, which would strictly be a material flow, has a carbon and water flow embedded, and vice versa. As a result of the growing complexity globalised production chains, which have been discussed elsewhere in this thesis, there challenges are great for any EA to be thorough[SS]. Discussion is ongoing as to how to better proceed in CF and other footprint analysis[364].

It is clear that, perhaps due to the limitations inherent to their early stage of their development, CF, MF, and WF are not yet fully ready to be considered comprehensive measures of environmental impact, although they are already useful for pointing at occurring pressures and act as early alarms[158,324], and will be likely developed in the future into fully informative instruments of the environmental impact of urban metabolic patterns.

2.III Sustainable Process Index (SPI)[366]

SPI has been developed since the 1990s at the University of Graz. It is similar to EF, in that it evaluates the ecological pressure of a given process or service, or system, on the planet in surface units. SPI evaluates the area needed to provide sources and sinks for the process, and compares it to the total available area per capita in the planet (how the latter is calculated is not clear), giving insight into the

[RR] http://www.huelladeciudades.com

[SS] For this reason, Ramaswami *et al.* (2012)[364] propose the footprinting and the GHG accounting communities share insights and thoughts, to agree on questions such as what flows are really relevant to account for and what we intend to do with such information. Such considerations must precede further technical efforts aimed at "counting everything", which is, really, perhaps not technically possible.

« expensiveness » of a given process in relation to the total available resources. SPI has not been used at the urban scale, as it is oriented to the evaluation of single processes, but it could be a potential tool to fill gaps in certain or carry out rapid assessments of major environmentally important factors. A free web version of the tool, similar in function and possibilities to LCA software, is available at spionweb.tugraz.at

III. Manually tracing impacts through flow origins

A useful method to provide accurate insights into the environmental impacts of resource flows has been demonstrated by Arto (2009)[328]. Using Total Material Requirement[TT] of a region (the Basque Country), and its methodology for calculating hidden flows (HF), Potentially Environmentally Relevant Flows (PERF) are identified among the activities with the highest HF. Once the PERFs are selected (in the study, the international flow of tin is chosen), their origins can be traced through trade statistics provided by national accounting databases. When the quantity and quality of the flow is localised (in this case in four Asian and three Latin American countries), the environmental impacts of the flow are inspected at the local scale. This entails a labour-intensive procedure of analysing a variety of data sources, which can include fieldwork, local NGO reports, scholarly research and international studies. Although not mentioned in this particular study them, EIA reports to local government facilities could also be a data source. Arto concludes that tin industry in the Basque Country "*...involves several social and environmental impacts such as waste generation, soil, water, and air pollution affecting biodiversity and human health, and child labour. These impacts are located in Indonesia, China, Peru, Bolivia, Brazil, Malaysia, and Thailand.*" (p.13), and that these impacts would normally be ignored by common metrics and indicators, thus suggesting that the environmental dimension must be deepened in MFA.

The method is interesting in that it offers a more accurate approximation to a given flow's real, on the ground, environmental impacts by linking local studies and research to macro-scale indicators such as TMR. It is however data, labour and time intensive, as tracing local environmental damage reports, and certainly field work would certainly be time and resource demanding. Also, it was demonstrated at the regional scale, where data is not abundant but is indeed more so than at the urban scale. The method seems reasonably well fitted to adapt and try at the regional scale in a Latin American context, but the urban scale may pose prohibitive difficulties. To give an example, knowing the exact origin of the flow of steel into a given city might prove almost impossible, due to the fact that the origins of incoming international and domestic steel flows might be registered at the national scale, but they are atomized and mixed once they enter local commerce, and it is highly likely that local government facilities in charge of commerce are not tracking where their steel is coming from, mainly because it is

[TT] TMR, see sections 3.2.3, 3.3.1 and indicators table in Annex 1 not among their assigned tasks. Tracking steel origin would then require intensive field-work among actors in the city, combined with analysis of national trade statistics.

Indeed, it seems clear that in general, establishing direct links between urban-scale flows, their sources and the environmental impacts is one of the greatest challenge for UM research. In a reflection about these methodological difficulties, Minx *et al.* (2011)[332] propose that every case should be considered individually, as a resource flow important to one city may not necessarily be environmentally relevant at the local scale where the extraction is happening, or that the issue of a given flow might be too difficult to address in a given city's political agenda and research efforts would then be better invested in topics more likely to be influenced.

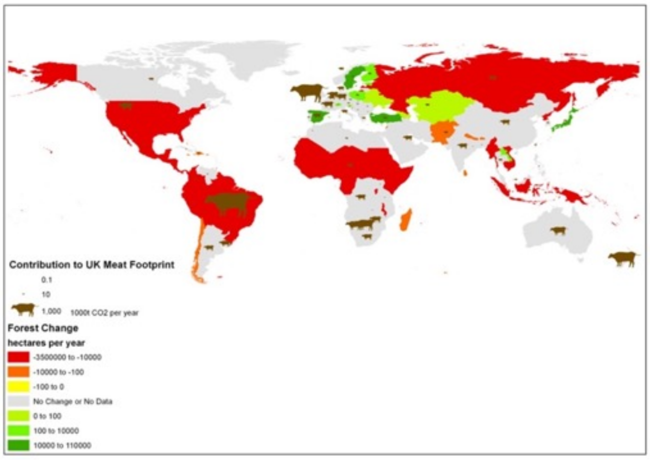


Figure 3.27 The GHG emissions and participation in land cover change of five British cities. Taken from Minx *et al.* (2011).

3.3.4 GIS methods

A common critique to UMA is that it cannot disclose spatial issues, such as the intra-urban patterns of flows or the localised consequences of metabolic patterns. This is true when black box analyses are performed, but the possibilities of expanding UMA through geographical information systems are large, depending of course on the data available. The use of GIS in UMA is not yet widespread except in some topics. They are however a very promising alternative to explore in the coming years.

Within UM studies, GIS tools appear to have been up to now mostly applied to carbon emissions and flows. For example, high resolution remote sensing data sets have been used by Christen *et al.* (2010)[367] to relate carbon flows with urban form and green space availability at the neighbourhood scale in Vancouver. Although only analysing one metabolic flow (carbon mass balance), the authors find the approach promising for expansion. On a similar note, Minx *et al.* (2011)[332] provide an example of GIS-based analysis of the relation between urban form, patterns and population consumption with resource flows and GHG emissions. Another example is Zheng *et al.* (2016)[297], who used ENA and a historical series of GIS land cover data to model the spatial behaviour of carbon flows for Beijing, evaluating the role of different land use types in the metabolic pattern of carbon.

MuSIASEM (see section 3.3.1) also works with GIS protocols to define the boundaries, extents and uses of its *fund* element "land". Through the use of GIS, MuSIASEM can then relate metabolic intensities to specific areas, explore the effects of different land uses in metabolic patterns and vice versa, explore the possible outcomes of different policy or development scenarios through simulation, and communicate the results of such explorations through maps[333,368].

These examples are somewhat of an exception, as GIS has not been a part of UMA (practically all of the methods discussed in section 3.3.1 are barely beginning to use GIS, or do not use it at all). But one aspect of UMA that does rely on GIS tools is material stocks analysis (section 3.3.1). Deilmann (2009)[296] has provided an excellent example of the use of cadastral data to analyse neighbourhood typologies and quantify the material stock of cities in East Germany. There are several other in European countries, such as Oezdemir *et al.* (2017)[338] study on the Ruhrgebiet, also discussed in the preceding section. Guo *et al.* (2014)[336] quantified the stock of several material types contained in the urban roads of Beijing through GIS data[UU]. Inostroza (2014)[339] used GIS tools to quantify the *Technomass* (i.e. the amount of anthropogenic material, see indicators section below) of the Colombian city of Bogotá.

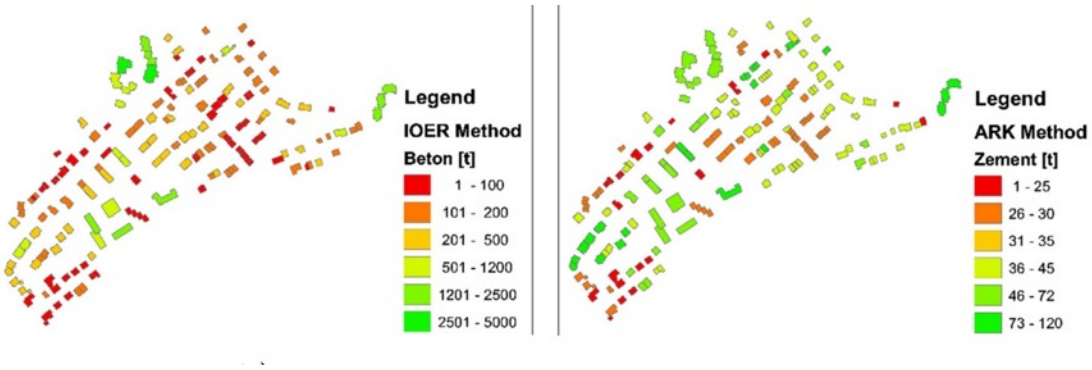


Figure 3.28 The results of GIS-based material stock analysis in the Ruhr region of west Germany. Taken from Oezdemir *et al.*, 2017.

A final example, and one who has attempted to consider several aspects of urban metabolism at the same time, while also trying to offer practical, applicable tools to decision making, will be the BRIDGE project, developed by a multinational research team in Europe in 2013[369]. It aimed at integrating scientific knowledge into urban planning, bringing support to the tasks of city officials through a computerized Decision Support System (DSS). The BRIDGE DSS would aid urban decision makers in assessing the environmental implications of different possibilities of urban policy and planning. It relates socio-economic variables in urban development (housing needs, land costs, employment) to metabolic flows of water, energy, carbon and pollutants. The tool models the change of these flows when different urban development possibilities are chosen, and provides geographically-explicit rendering –i.e. where the changes in flows occur. The BRDIGE tool was built and tested with data collected from five European cities, in which different developing scenarios were evaluated. BRDIGE

[UU] This same study provides a brief review of other GIS-based stock analysis studies.

continues to be under development and is proposed by the authors to be a helpful tool in dealing with the complexity of including environmental issues in urban planning.

Although GIS is only beginning to make its way into urban metabolism studies, and its development appears for the moment to be heavily concentrated on a few particular aspects of the UM phenomenon, research seems to be intense and ongoing to bring further use of GIS into UMA. Furthermore, the heavily-GIS reliant methods of patch dynamics in landscape ecology are starting to percolate into urban studies (see for example Mörtberg *et al.* 2012[252]) to assess environmental quality inside the city. It is reasonable to believe that it will not be long before GIS tools are fully integrated into a wider and more comprehensive spectrum of urban metabolism aspects.

3.3.5 Others: indicators, indexes, models and assessments

1. Indicators, indexes

Besides the methods discussed above, there is a very wide array of other indicator sets and indices proposed to assess sustainability and environmental impact in general. Creation and development of environmental indicators and indices is a dynamic and heatedly discussed topic, moving forward with great momentum[370]. In sustainability science and sustainable development thought, perhaps thousands of indicators and have already been proposed[370] and dozens of indices as well, and while not expressly formulated within an urban framework, many of them could be adapted to serve the purpose of environmental assessment of the UM (see for example [312,329,331] for urban version of EW-MFA).

Because of this great diversity, throughout this section I have tried to focus only on methods that appear in UM literature, but have not deemed it convenient to simply dismiss the great diversity of potentially helpful tools that lie in neighbouring fields. It is however clear that a comprehensive review of all indicators potentially suitable to address urban metabolism issues cannot possibly be compiled within the frame of this thesis, but fortunately, many good compilations exist: Pintér *et al.* (2012)[370] review criteria for "good" indicator building, while Wu and Wu (2012)[227] and Best *et al.* (2008)[353] provide compilations of general sustainability indicators; FAO (2013)[371] compiles methods to unveil and estimate resource flow inter-linkages (water-food- energy-socioeconomic factors); Bringezu *et al.* (2009)[324] cite some environmental indicators of macro-scale material flows, Giljum *et al.* (2013)[372] compile methods and experiences for consumption-based estimation of the "four footprints". The table in Annex 1 compiles the indicators that have been discussed in this chapter.

Two other considerations are worth noting: one, that there are some well-established fields with solid experience who are currently not participating in the UM discussion, and might have a good say. For example, Environmental Impact Assessment (EIA) has not been reviewed here, as it does not appear in UM literature, but it is very likely that it could offer useful techniques and indicators, due to its decades of development world-wide[VV]. Second, the field of UMA in its quite young life has no definite established methods and evidently has no fixed indicator sets. This means on the one hand, that UM research has few exactly matching choices of methods and indicators, and must work by adapting those of other closely-related fields, or by developing their own. On the other hand, it means that there is an exciting opportunity to experiment with methods old and new, and to develop insight that is at the same time place-based, locally relevant, and globally useful. As will be discussed in the following section, recent research and thought on UM point to the need for hybrid methodologies.

2. Mathematical and computer-based models

Mathematical and computer based modelling tools to estimate environmental impacts are abundant, but applications to UM are only emerging. System Dynamics and Ecological Network analysis have been discussed in section 3.3.2 as options to create models of a city's metabolism, given that the research team has the technical capacities required. A compilation of current example of mathematical modelling applied specifically to the study of UM is presented by Chen(2015)[248].

There are also a number of "pre-fabricated" models or simulators that allow users to input information about a certain city's metabolic flows, with impacts being estimated on the base of pre-programmed algorithms and data. One such example is the BRIDGE DSS programme, discussed already in the GIS section, as it is a GIS-based tool. Another example is the Integrated Urban Metabolism Analysis Tool (IUMAT), developed at the University of Massachusetts in recent years[373]. It consists of a series of algorithm sets that describe interrelations between social, economical and physical factors and environmental issues. The individual building is the central unit of analysis, and the model acts according to the changes occurring in the building fabric of the city, such as changes in GDP of occupants, construction materials in new buildings, or demolition. The algorithms are tailored to estimate the impact of those changes on transportation networks, carbon storage capacity of land cover, and materials/energy resources use, among others. IUMAT has only been used by the developing team, and it is unclear whether it can be modified to suit other city's needs and patterns, making it then also unclear how applicable it it is to outside users. This is likely to be often the case with any model which has been developed to address a particular city's. Learning curves and time needed to adapt any given model are factors to consider when deciding to work with an already developed model. On the other hand, precisely because many research institutions develop their own mathematical models, it will likely prove convenient to be in contact with local research communities who might have already developed models for the context in question.

[VV] At the time of writing this chapter, a study by Fernandes and Batista at the University of Porto, aiming at linking UM with Strategic Environmental Assessment to develop a Metabolic Impact Assessment was announced, with aim of completion in 2019. Further details at https://metabolismofcities.org/research/23.

3.3.6 An ideal tool set is a hybrid one

This review has tried to be extensive but precise, looking into the tools often cited in UM literature reviewed and classifying them in three categories (Fig.3.6). It has become clear that:

(i) Despite its relatively recent appearance, UMA already has an ample toolset, notably in the category of accounting where much adjusting and downscaling is going on. Tools for environmental assessment exist but adjustment to the urban scale is also still underway, and system analysis tools, which do not need downscaling, are starting to percolate from other disciplines. The broad choice of tool posibilities is also related to the lack of a unified method, often mentioned in literature as an obstacle to overcome.

(ii) Although a considerable effort was made to cover as many tools as possible, the dynamism of the urban sustainability field, to which UMA belongs, made it impossible to cover the totality of tools, especially when trying to consider the ones potentially available –i.e. those not currently used which could be adapted to perform UMA. Fields like EIA, social-ecological systems and ecology seem particularly well poised to offer new options. Fig. 3.6 illustrates the most currently used tools, only in the UMA field. If tools from EIA, urban ecology or SES would have been considered, and indeed they could be, given the conceptual proximity they share, the graphic would have had to contain many more boxes.

(iii) No matter where an UMA is being carried out, the appropriate way to do it seems to be by composing a hybrid method out of the tool array available, creating a multi layer or integrated method[284,322]. The choosing of tools would be distilled from an initial process of scoping and goal-defining[324], as well as of overviewing available data[50]. Fig. 3.29 illustrates hypothetical toolsets that could be chosen according to the objectives and real possibilities of different type of studies. The first combination illustrates a simple, black box accounting exercise, as discussed at the beginning of section 3.1. The second one represents a more sophisticated combination, yet relatively simple to perform, where the system is described in an empirical manner, and major flows accounted for with a simple accounting method (AUM). A combination similar is proposed in the case study. The third one is similar to a typical current European approach. The tool choices basically depend on the availability of data and the technical expertise of the research team to handle techniques and software. The case study in the following chapter will try to join the global discussion by using common toolsets, while caring for applicability and relevance in the local context.

(iv) No methods or tools seem to have been developed in the LAC region. The studies dealing with Latin American cities have all used some sort of adaptation of tools developed in Europe or the USA. (Besides what has been stated throughout the chapter, the reader may refer to Annex 2, where the literature review for UM in Latin America is presented).

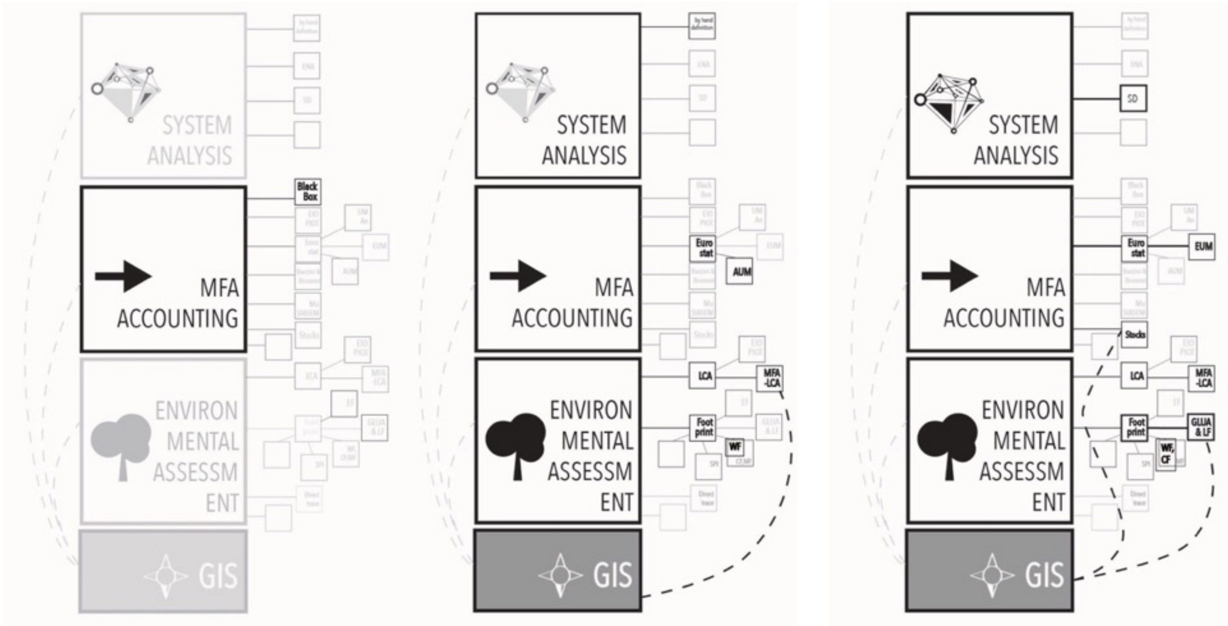


Figure 3.29 Three hypothetical combinations of tools from the UM toolkit, to be compared with the full toolkit in Fig. 3.6. The first combination to the left illustrates a simple, black box accounting exercise, as discussed at the beginning of section 3.1. The second one represents a more sophisticated combination, yet relatively simple to perform, where the system is described in an empirical manner, and major flows accounted for with a simple accounting method (AUM). More detail can nonetheless be given on the environmental impact category, where GIS is used to localise impacts detected through a black box LCA. A combination similar to this may be applicable in Latin America, and is proposed in the case study. The third one represents, except for the inclusion of System Dynamics, which would be a sort of cherry on the cake, a typical current European approach. It uses a Eurostat statics set through the EUM method, and stock accounting, with which there is already fair experience in central and northern Europe. Environmental impact in this combination is assessed through a black box LCA, that could then be furthered detailed through the Wuppertal Institut's GLUA, and a choice of the four footprints, with which there is also growing experience. The tool choices basically depends on the availability of data and the technical expertise of the research team to handle techniques and software.

3.4 An urban metabolism analysis method for Mexican cities

As stated in chapter 2, the objective of the review presented in this chapter was to find suitable frameworks and tools that would comply with and be "proof-run" to assess viability to inform on environmental performance in Mexican cities, and do so in a relevant way, taking into consideration needs and the applicability criteria stated in chapter 2.

The theoretical and conceptual issues have been settled in section 3.2, where the legacies and current extents of the urban metabolism framework are discussed, within the theoretical framing of Societal Metabolism, urban ecology and Social-Ecological Systems. As to the methodological approach, section 3.3 has made it clear that the options for tools are many, as UM has not yet settled fixed methodological guidelines. But because the most robust methodologies are set within a European context, where institutional conditions, data reporting regulations and data availability are quite different than in the context we are aiming to work in, the choice seems to be reduced.

3.4.1 Finding an appropriate UM toolkit

A decision matrix relating the methodological options to selection criteria as stated in chapter 2.3 was carried out to make the soundest choice. The final table was rather long, and here only an extract is included (Table 3.2) to showing the evaluation process for the first criterion.

In the decision matrix, 2 out of the 9 original accounting methods were discarded (Baccini-Rechberger and MuSIASEM) because of the evident impossibility of their application within pre-surveyed data conditions and available time frames. Mathematical modelling was excluded for the same reasons. The two systems modelling tools (ENA and SD) were merged into one category, as were all three footprinting methods (EF, 4 Footprints and SPI). GIS methods are not examined because they are considered to be a crosscutting and highly useful tool that should be used whenever possible. Data availability was quickly surveyed while filling the decision matrix. There remain open questions, particularly regarding MFA indicators under the Eurostat framework. It is not clear whether the procedures for gathering, calculating and reporting to the national accounting system kept by Mexican federal facilities (namely INEGI) are compatible to account for the indicators calculated by these methods (DMI, DMC, TMR, TPO, etc.). A brief revision of the national accounts publically available was made, but these doubts could not be cleared. The revision did however make it clear that, in order to work with the national accounting reported by INEGI[ww], further collaboration with an economics specialist would be needed, as the contents of the databases are not easily navigated, and little guidance is provided by INEGI itself. For the time being, the Eurostat indicators are kept in the background,

[ww] At http://www.inegi.org.mx/sistemas/bie/default.aspx for national accouting, for example, and at http://www.beta.inegi.org.mx/ for a wide array of indicators

because they seem to be quite useful and the calculations for most of them do not seem to be exceedingly complicated, given the data is available at the correct resolution. Furthermore, I do not believe they should be discarded, as the idea discussed in preceding sections, that it is convenient to harmonise accounting systems, data collection and reporting methods in order to facilitate comparability seems completely reasonable, and being that these indicators have such a long trajectory and are well developed, it makes sense to pursue integration with them.

Table 3.2 (extract) Decision Matrix: Finding the right tools according to selection criteria

	Criteria (as stated in chapter 2.3)	Tools	Notes/reasoning	Suitability 2	1	0
1	Should help set up a starting point. It should be able to provide comprehensive panorama of environmental performance of city –i.e. a baseline, if not at great detail, at least in an overall manner that would at the same time allow for later refinement. Ideally, it would allow for the inclusion of cultural, social and political specificities.	System definition/ empirical	Not necessary, but a general characterisation of the SLP environmental system could prove useful for context, and for further expansion of studies		■	
		System analysis/ model	Too complex to use in baseline setting, not possible for this particular study.			■
		Black box	Very general overview, but not allowing for inside the box views or social factors.		■	
		EIO-PIOT	Not suitable for setting up a starting point or environmental data. Uncertainties as the whether appropriate scale is available, and time/data requirements of downscaling may be prohibitive.			■
		EUROSTAT	Eurostat indicators are not totally discarded, but it is unclear whether national accounting in Mexico follows the same guidelines for aggregation and reporting. The possibility of their use or adaptation should be kept in mind because it is a globally relevant and robust method.			■
		UMAN/EUM				■
		AUM	Minimum indicator set. Accessible as SLP has a GHG inventory. Allows for further detailing (looking into the black box), as much as data allows	■		
		Stocks	Stocks are not a priority for a baseline study, but could be considered for a second phase if data allows.		■	
		LCA	Not suitable for a baseline, but could be useful for future expansion of the study, especially through MFA-LCA.		■	
		Footprinting	Uncertainties about data availability for consumption-base footprints. EF may be a simpler option.	■		
		Manual trace	Its fundamental to scope locally available data to establish the baseline. Manual tracing would be indispensable for this criterion.	■		
	Best options:		**AUM, Footprinting and Manual trace.**			

Once a suitability grade was given to each method for each criterion, the best "competitors" to fulfil each criterion were identified (highlighted with bold borders and also listed at the end of each criterion block in the table). The decision matrix led to the choice of tools illustrated in Fig. 3.30. This tool set can be deemed an initial toolset to approach UMA in Mexican cities. It is by no means the only possible option, but rather the results of my own ponderation of the possibilities versus the desired outcomes. Further developments and additions would have to be encouraged (e.g. passing from an empirical system description to a modelled ecological network analysis).

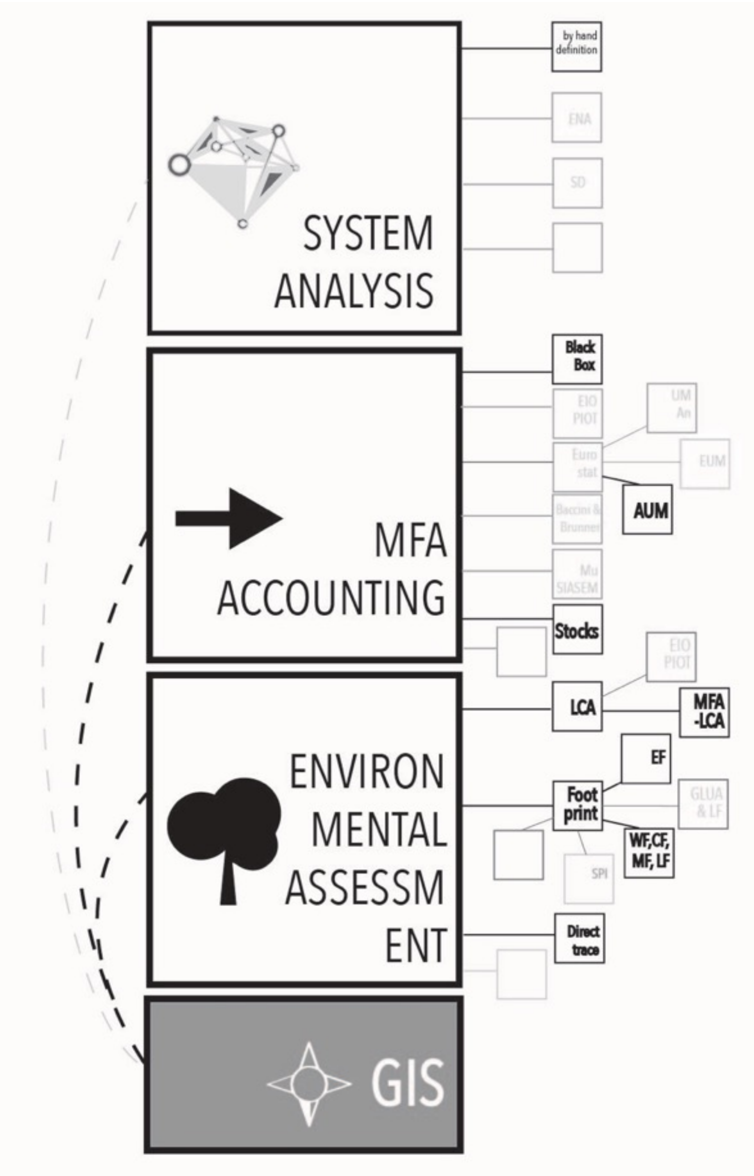


Figure 3.30 An appropriate tool set for the study of Urban Metabolism in San Luis Potosí, as a result of the decision matrix processed described in this section. Highlighted boxes are the tools that will be integrated into the method. Greyed-out boxes are the rest of the global UM toolkit resulting from the methods review in section 3.3.

The tools chosen are:

A) In the System Analysis category: an empirical definition of the system, drawing on available knowledge of local conditions (See the Odum diagram in Fig. 3.30). The initial sketch can be refined by dialogue with specialists, by revision of literature on specific topics.

B) In the accounting category: Black box analysis (BBA) is a first option. It has already been experimented with by Delgado (2012)[325] for four Latin American cities, and although calculation methods are not disclosed, there is the advantage of having a reference to compare results with. BBA is relatively simple and brief, but has the disadvantage of having little chances to be connected to other factors to refine the study. BBA would be a good choice where very little data exists, or time is exceedingly short, for example. Also, and given that LCA databases exist or could be developed for the selected flows, BBA could eventually be extended to illustrate environmental impacts through the MFA-LCA method proposed by Kalmykova and Rosado, or by direct tracing of impacts. Footprint analysis could be done as well, albeit very rough ones, of the EF type, as only gross input-output data data would be known, with no possibility of carrying out consumption-based footprinting. Abbreviated Urban Metabolism (AUM), also has been tried out in LAC: in Curitiba by Conke and Ferreira (2015)[287] and in São Paolo, Rio de Janeiro and Buenos Aires by Hoornweg *et al.* (2012)[137]. It has several advantages over BBA. First, there is a list of indicators prepared by Hoornweg et al, the gathering of which has already been tested in the region. Second, it allows for far more detailed while not being necessarily too demanding in data. Finally, it can be assessed for environmental impacts following any of the two selected methods.

Stocks accounting is considered secondary but possible to a certain extent, and very useful in the context of rapidly growing cities as is the case of intermediate Latin-American cities like the one in our study case. Cadastral data is well kept by construction permits at the municipal level, and construction procedures are fairly enough standardised so as to allow for the application of a method similar to the one proposed by Deilmann (2009)[296]. Stocks of certain ordinary materials in construction such as asphalt, brick, concrete, gravel and steel could be calculated, and with that starting point, many interesting environmental indicators as well, (e.g. the consumption-based land, water and/or carbon footprint of the construction industry). Other stocks, such as nutrients, heavy metals and other chemical compounds seem more difficult to calculate, albeit not totally impossible through a combination of field work, scholarly research, and a detailed analysis of potentially relevant economic activities and its flows (through LCA, for example).

C) In the environmental assessment category:
LCA and its variants MFA-LCA were chosen primarily because there is ample experience with LCA in Mexico. Not few researchers and practitioners are working with applications of LCA beyond the known product or industrial process-based ones. In SLP itself, architecture and urban design professors have been researching into the possibilities LCA when applied to urban design[374]. Moreover, LCA is also widely practices throughout the world, and although calculations and databases may vary, using a same framework and similar software makes comparability of results more likely. EIO-LCA is not chosen due to uncertainties similar to the reason for excluding the Eurostat indicators, namely, uncertainties as to what the current state of EIO and PIO table construction is in Mexico, and on the experience of local LCA practitioners with EIO/PIOT-LCA, as such studies did not appear to have been made in Mexico after the initial literature and data surveys. Nonetheless, a revision of the national accounts reports provided by INEGI, where nation and sector wide input-output matrices up to the year 2008 can be consulted, and an expert practitioner in the field on environmental economics was consulted. However, time constraints did not allow for this issue to be fully resolved.

Footprinting is a valuable tool in communication as has been discussed, and relatively simple to carry out, especially when using the Ecological Footprint (see section 3.3.3). However, knowing that the methodological procedures for EF metrics are highly debated among sustainability scientists, I would advise to use the consumption-based "four footprints" (4F) whenever possible, which provide for a more rigorous metric and reliable result. Although quite laborious, fair quality consumption data that is necessary to calculate the 4F can be obtained at the city level through bottom-up research, as will be shown in chapter 4. Downscaling methodologies can also be applied for many flows.

Finally, direct tracing of impacts through the localising of its flows, through methods like thoses presented in section 3.3.3 is always an option, given time is available. In the context of setting baselines, and surveying and compiling information, this method is of additional value, as, when duly reported, its findings could feed into a potential and highly desirable research/information data base for urban environmental impacts.

3.4.2 Weaving the tool set into a multi-tool urban metabolism analysis method (for Mexican cities)

Because there are currently no methods defined for UMA, the mere application of the tools has become the method. Although it may so suffice, as has done so in many studies, by having an ordered set of steps to apply the tools and a defined framework to orient those steps and to pour the information obtained back into, replicability, comparability, and potential to revise and improve a study is better guaranteed. I have then constructed a simple method to apply these tools (Fig. 3.31), which shall be partially tested in the case study in chapter 4, and whose results will be reported, both in the form of the direct results of urban metabolism analysis, and as a report of the efficacy, convenience, needs and obstacles for a further use of the tools and their method both in Mexico and in the wider Latin American context. The steps in the method have been modelled partially after Baccini and Brunner's (2012)[50] sequence for the performance of an MFA (Fig. 3.16), and generally building on the cited authors' reported experiences. Because the appropriate toolset (Fig. 3.30) has more than one tool in each category, allowing for different combination of tools to be used, the method can take different versions, depending on the data availability and other constraints. I judge convenient to outline they way the tools could be combined and in what moment each of them should be used, and for that purpose the method synthetised in Fig. 3.31 is described extensively (step by step) is the next few pages.

This method was re-written after the field work phase of this thesis, and therefore benefits from the confirmation that there does not exist a centralised database where all or most of the information needed to fulfil the indicator set (table 3.3, see also table 4.1) is concentrated. This will likely prove true for most cities in the region, with some exceptions such as Curitiba[287]. Therefore, it combines a bottom-up approach for locally sourcing data while at the same time surveying and compiling available data at the macro level, and looking into the research team's possibilities to downscale it.

In brief, this is a method to perform an Urban Metabolism Analysis in cities with limited data availability, unlikely or uncertain institutional cooperation and lack of compiled environmental baseline data. The method is based the Abbreviated Urban Metabolism proposed by Hoornweg *et al.* (2012)[137], and adds to it other tools, as a sort of "extensions" to render the method more powerful.

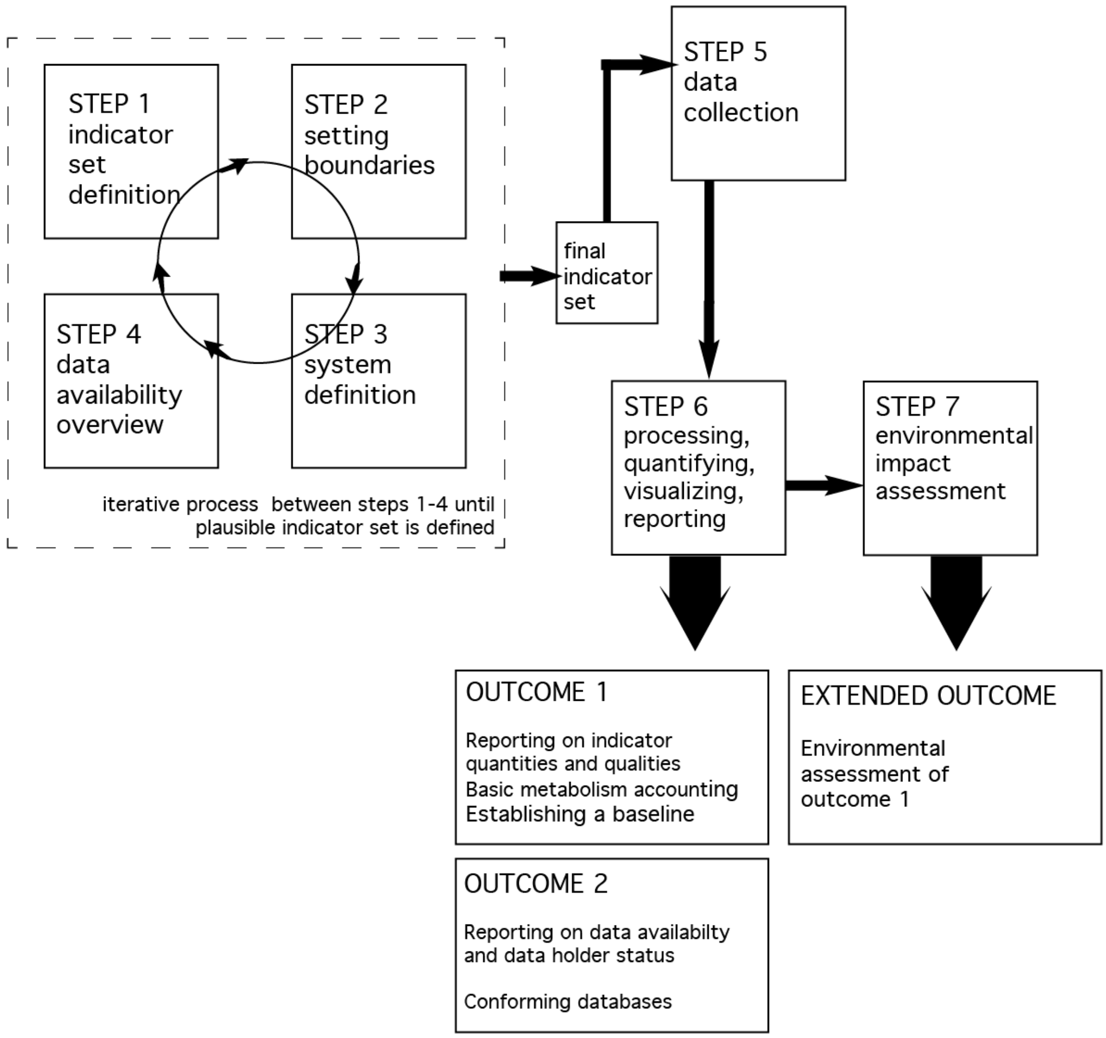


Figure 3.31 An appropriate method for the study of the urban metabolism in Mexican cities with great emphasis on the data scoping and surveying phase (steps 1-4). The method was modelled following the Abbreviated Urban Metabolism method (Hoornweg *et al.* 2012), and the MFA sequence proposed by Baccini and Brunner (2012, see Fig. 3.16). Notice there are 3 possible outcomes for the method, depending on the depth of the study, time available and other factors. Obviously, the ideal case would be to have all three outcomes, but having only outcome 1 would be already an advantage.

Steps description

STEP 1 Indicator set = research questions

TOOLS

- Abbreviated Urban Metabolism
- Black box accounting
- Stocks accounting

The proposed base indicator set is that of the Abbreviated Urban Metabolism method (Hoornweg *et al.*, 2012[114]), which consists of 20 indicators grouped in four categories (table 3.3). The authors note that the indicator set is relatively easily compiled, because many of the indicators required are already being calculated by cities who are engaged in GHG accounting. At the same time, they can provide a fair overview of a city's environmental performance.

Depending on the needs of each study, the indicator set may be modified. Priority flows from among the set may be defined when it is deemed necessary, for example when it is uncertain that there will be enough time or data to fulfil all indicators, or when one indicator depends on another to be calculated, etc.

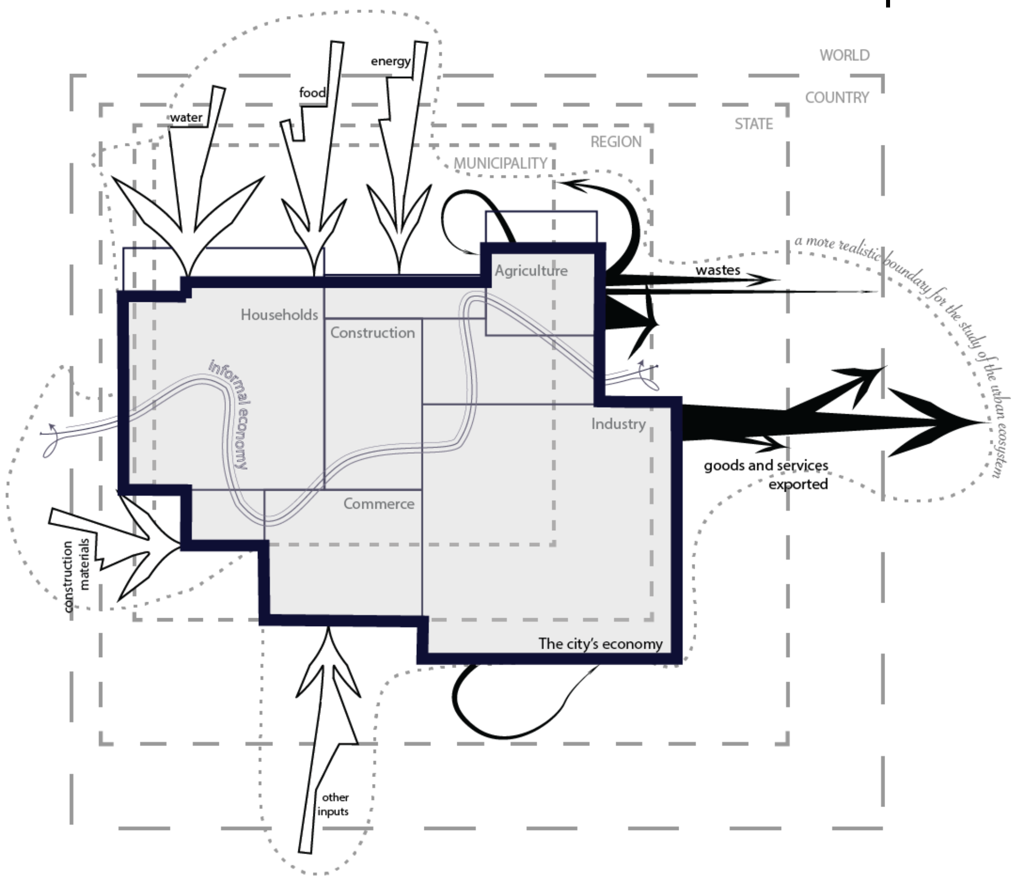
Table 3.3 Abbreviated Urban Metabolism Indicator set (as proposed by Hoornweg *et al.* 2012)

Inflows	Produced	Stocks	Outflows
Food	Food	Construction Materials	Exported landfill waste
Water (imports)	Construction Materials	Phosphorous	Incinerated waste
Water (precipitation)		Landfill waste	Exported recyclables
Groundwater abstraction		Construction/demolition waste	Wastewater
Construction Materials			Phosphorous
Fossil fuel (by type)			SO2
Electricity			NOx
Total Incoming Radiation			CO
Phosphorous			Volatle organics
			Particulates
			Methane
			O3
			Black carbon

STEP2 Setting boundaries

The limits of the area in which the indicators are going to be quantified will be defined according to the goals of the analysis, initial knowledge about data availability, administrative convenience, and so on. A mixture of boundaries (see fig. 3.32) is likely to be necessary, as flows of different types have different spatial dynamics. It could well be that the boundary of a certain flow deemed important for the study falls beyond city administrative boundaries or beyond the boundaries adequate to calculate other flows in the study. A somewhat obvious example is that of international trade, bringing and flows from very distant places into concentration in a single city, or that of the long-distance ecological impacts caused by a certain discharge into a river. Setting boundaries is also a exercise of decisions as to what is important to focus on, what scales we deem relevant, what interrelationships we wish to highlight, etc., and thus is an integral part of the definition of a system's identity that must be practiced by the analyst[20,73].

TOOLS



STEP 3 System Description (System Map) 1.0

TOOLS

Considering the boundaries and the flow indicators defined in steps 1 and 2, an initial approximation to the description of the system including components (or compartments[74]) and their interrelations (flows of matter, energy, money, information, etc.) is at this point to be made. Because representing the entire complexity of an urban system is obviously (almost?) impossible, this initial description should focus on at least describing the nodes and flows related to the indicators chosen in step 1.

If there are hierarchies and/or interdependencies in the system, or different territorial patches[42] that the team would like to address (different neighbourhood typologies or land uses, etc.) this is a good moment to visually define them in the system description. Ideally, the descriptions would be as detailed as possible. Although the actual accounting exercise may perhaps not cover its totality, having a thorough characterisation of the system will prove useful to make present efforts more assertive and to come back in the future and refine or add missing pieces, for example. Additional maps, further detailing the priority flow(s) should ideally also be made.

The system description, which can be considered a map of nodes and relations, and can also be made on the base of actual *geographical* maps if desired. But even as an abstract map of relations, it is a valuable reflection exercise to shed light upon the linkages happening in reality, the extents of boundaries, and how the indicators we aim at quantifying may be shaped by other factors. When discussed and drawn several times by the team, many new linkages may appear, and things that seemed unimportant may appear now as more central, or vice versa. It is a good idea to also discuss the map with experts in specific fields and other stakeholders, who will always have something to suggest to refine the model. Additionally, by visually highlighting the interlink ages of nodes in the system, new ideas may come up as to how to calculate a certain difficult indicator, or how to obtain data or proxies for it, etc.

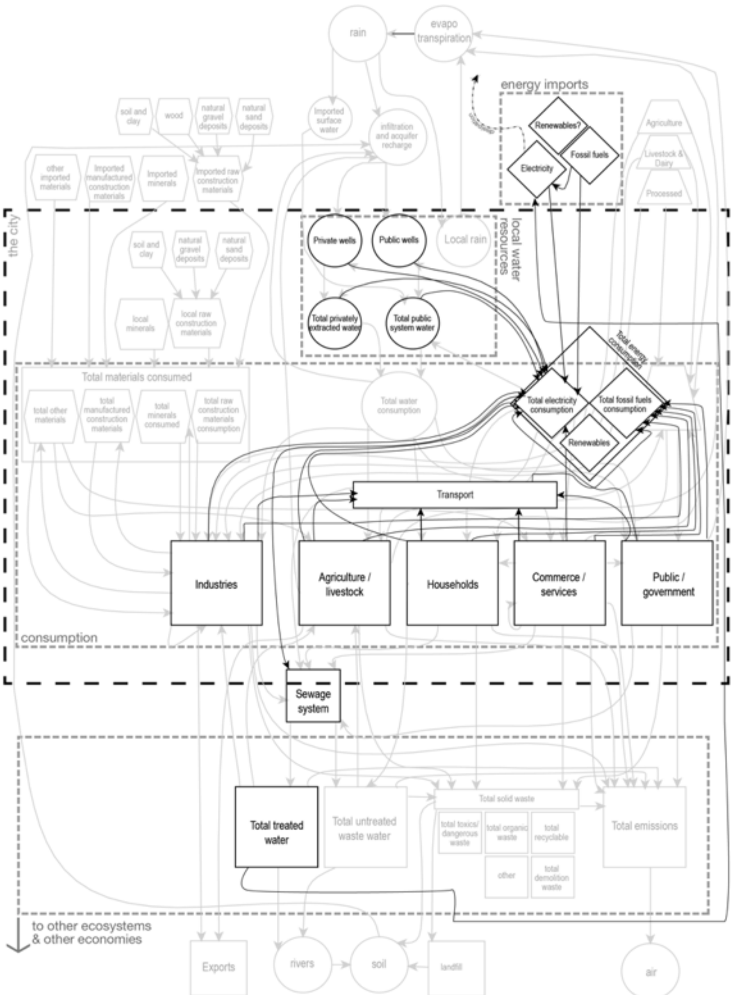


Figure 3.33 An initial empirical system description of the energy system of San Luis Potosí. No weighing of factors is done. The scheme serves to illustrate components and relations and it is the base for the quantitative analysis of the metabolic system, that proceeds by assigning quantities to each box and arrow.

STEP 4 Brief initial data overview

TOOLS

= does it appear as though there is enough accessible data for these indicators to be calculated?

A preliminary list of potential data sources for each indicator should be made and briefly surveyed to obtain an overall idea if which data seems likely to be obtained in time and quality needed. It is important to invested in identifying possible data sources, specially when data is highly dispersed and one of the aims is to report on data availability. A data holder database should start to be made at this point. Data holders can be many different actors, and this list will always depend on the local specificities. Although data at the local scale is the ideal, macro scale data (aggregated at higher administrative levels) would probably be useful too, and often will be the only one available, and should therefore be also noted, possibly as a "plan B". Pincetl *et al.* (2014)[92] stress that data gathering process for UMA is "somewhat opportunistic" due to pervasive data scarcity. –i.e. whatever data from whatever trustworthy source should be compiled. An example of how data sources can be ordered to move quickly and orderly through a list of data sources used can be seen in the case study.

This data overviewing step will likely provide insight to trigger a useful iterative process back to step 1, and readjusting of indicators, boundaries, the system description or all. Adjustment will be made accordingly. Again, priority flows can be set –i.e. the indispensable set of flows that is wished to quantified, so as to focus efforts initially on them. After this step, a revised indicator set might replace the original one, with better probabilities of actually being quantified.

STEP 5 Data collection

TOOLS

By the time this step is reached, there should exist a refined, preferably prioritised, indicator set, which would be associated to a list of possible data sources by indicator, and a thought process as to whether bottom-up or top down data is preferred, or both, and if so, which one would be privileged in case of having access to both, etc. With that in hand, a research team will decide the proper way to go about the gathering process, including visiting virtual or real facilities, contacting data holders, sorting, filing, classifying, assessing validity and accuracy, and other considerations that must be taken to ensure the quality of the data, and particularly its compatibility when different sources are being used. A sort of "production" line is set up to gather the data, and then a "quality control" line.

In the case study presented in chapter 4, a particular data gathering protocol was devised, as well as an "emergency plan" to operate in the likely case that not enough data had come in by a certain deadline. Details are discussed in the case study

.

STEP 6 Processing, quantifying, visualizing, reporting

After the data gathering process is finished, processing and quantification will occur on the desired and/or possible indicators/flows quantified. Ideally, the system description 1.0 is updated, now with quantities (see fig 3.34) and more detail. The original system description can now be enriched with the quantities calculated, and the model itself can be further refined, perhaps for a future second run. Composed indicators, relations with GDP and other indicators can be calculated and communicated.

The produced datasets and results would be shared to the extent possible. There are probably local efforts trying to compile urban environmental data. There are also global efforts happening in a variety of venues, including for example, metabolismofcities.org.

TOOLS

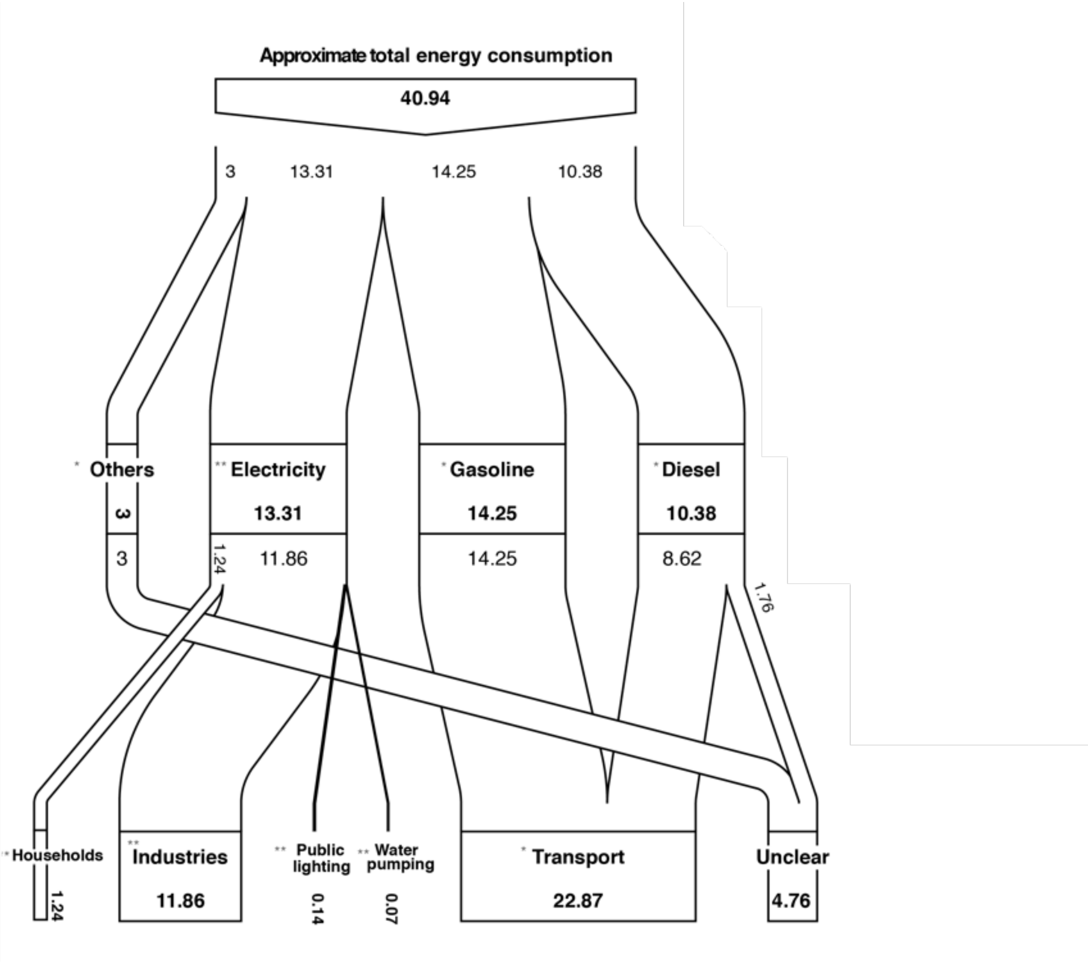


Figure 3.34 A quantified metabolic flow diagram for the energy system of SLP.

STEP 7 Environmental Assessment & reporting

Having quantitative knowledge of flows, stocks and other traits of the UM is the basic point for performing environmental impact assessments. The UM study could end in step 6 reporting flow magnitudes, and perhaps, but it would ideally it could also continue to investigate the environmental impacts of the metabolic system, or a part of it, depending again on the information that was gathered and the aims of the system.

Life cycle analysis (LCA), MFA-LCA, footprinting and direct tracing have been identified in the choice matrix as as appropriate tools for our particular context, and could be performed at this stage. The requirements to perform them vary, and it may be possible to perform only one, or several. Details on their procedure and references to methodological guidelines are given in section 3.3.3.

TOOLS

Chapter 4

Case study: Preliminary steps

4.1 Definition, method and specific objectives of this exercise

The need for comprehensive environmental assessments in intermediate Mexican cities is introduced in its broad, global implications in chapter 1, and described in detail in the justification of this thesis, in chapter 2.3.1. In fulfilment of the thesis objectives 1 and 2 (chapter 2.3.2), a framework for such an assessment was chosen–urban metabolism– among other reviewed, its theoretical bounds and methodological possibilities were discussed, and a method tailored for its application in the case study of San Luis Potosí, Mexico (chapter 3).

The present chapter chapters correspond to objectives 3 and 4 of the thesis:

> *3. To execute a "trial run" of the chosen method. Report findings on the environmental performance of SLP. Based on the results, and if applicable, outline policy recommendations and useful communications to relevant stakeholders, such as public officials, civic associations and the research community.*
>
> *4. Report on environmental data availability as experienced through the case study. Ideally, report on such issues as data sources and banks, relevant actors related to data generation, and gathering, data gaps, future research needs, and desirable future research lines.*

The following pages present the unfolding of the UMA method originally proposed (fig. 4.1). The way each of the seven steps was performed, as well as the results of each, is reported in detail. The final results of the analysis of the metabolism of San Luis Potosí are reported in steps 6 and 7, in chapter 5.

Within the limits of the two general objectives stated above, and considering the nature and possibilities of the urban metabolism framework as well as the time possibilities of a master thesis, it seemed reasonable to establish a hierarchy of milestones or specific objectives, which are as follows:

> 3.1. To describe the identity of the system[247,313] – i.e. its (major) compartments and nodes, the (major) flows that relate these parts and the system to the exterior, and, when possible, the key drivers of this structure.
> 3.2 To find or calculate the quantities and qualities of the main flows.
> 3.3 To estimate or at the least point to environmental impacts associated to the metabolic pattern of SLP.
> 3.4 To outline policy and future research recommendations in relation these findings.

The hierarchical placement of these objectives means of course that priority was assigned first to 3.1 and last to 3.4. As one of the aims of this exercise is to report on the data availability situation, work was undertaken knowing that it was possible that objectives 3.2 - 3.4 were not thoroughly achieved, due to perhaps impossibility to access data, or other unexpected complications. The best effort was made to fulfil all objectives, and the outcome of these efforts is thoroughly reported in the following pages, as well as in the conclusion chapter.

Finally, I would like to underscore that this work was performed as one of the very first approximations to a metabolic analysis of a Mexican city (the only other example being the assessment made by Delgado (2015)[375] assessment of Mexico City, see literature review in annex). In the context of very scarce similar studies in Latin America, and the impossibility to perform UMA analysis following European guidelines (see chapter 3.4), methodological or empirical references to perform this analysis were very limited. Therefore, thus a method had to be envisioned, with many possibilities imagined, tried and discarded. It was confirmed that much of the data ideally wanted was not available or that its collection demanded time and efforts beyond the limits of this thesis. Therefore, although the best effort has been made to provide results that are accurate and can reliably inform on the environmental performance of SLP, the of the UMA results must be considered partial and a first approximation. In this sense, I find important value in this exercise as a way-paving exploration for future, more thorough studies. This exercise can be considered a draft run of an envisionable holistic and more complex method for urban environmental assessment. Consequently, I find that the reports on data inconsistencies, quality and availability, and in general on the experience of running the UMA method are particularly important outcomes of this exercise. These are presented in the last two chapters.

4.2 Set up: Steps 1 <--> 4: Indicator set and initial data overview

As explained in the method model (fig. 4.1), the process of deciding the final indicator set was an iterative one, going back and forth between steps 1 and 4 (indicator definition, definition of boundaries, system description and overview of available data) in order to adjust all of them with the insights of the other. Steps 1 and 4 will be discussed together in this section, because iteration was most often between them, with steps 2 and 3 being shaped along the way.

Table 4.1 shows the comparison between the guideline indicator set as proposed by Hoornweg *et al.*

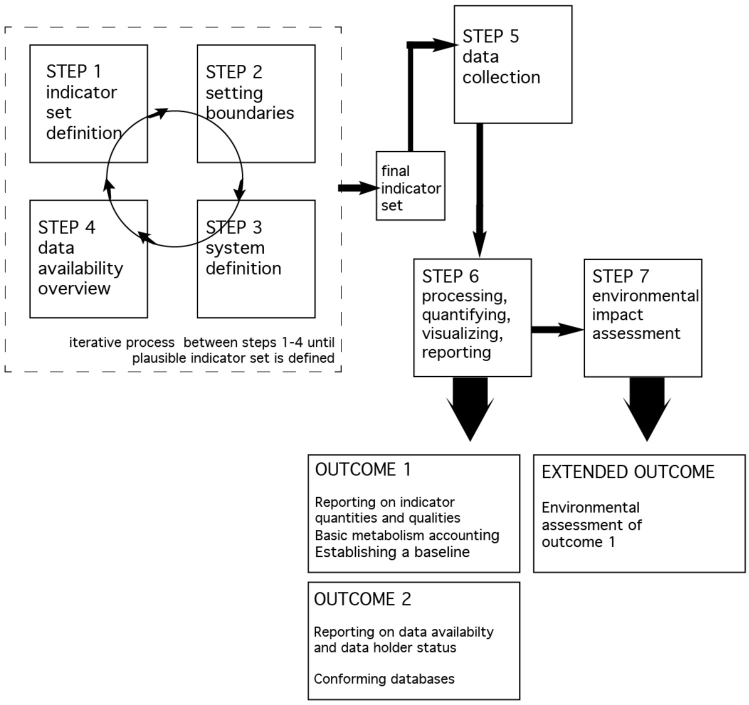


Figure 4.1 (same as 3.31) The method to be followed for the assessment of the urban metabolism of San Luis Potosi

(2012)[137], the "ideal set" initially developed, following what is recommended by Minx *et al.* (2014)[332], and the resulting indicator list obtained after the data overview. The first adjustment of the AUM set was the breakdown of its indicators into more manageable, smaller categories (e.g. "food" into "agricultural products", "dairy", and so on). Second, some indicators were added almost *a priori*, as the importance of including them was straight forward after studying the geographical and economic traits of the city: the preponderance of industrial activities, and their environmental negligence reported by some authors[376,377] made it clear that in order to understand, even if only in a general way, the metabolism of SLP, insight into the consumption patterns of the industrial sector is needed. With these two adjustments, the initial "ideal" indicator set was ready. Preliminary ideas for boundaries (step 2) and the general system model (step 3) were drafted on this set. An initial data overview (step 4) was performed, by surveying data available on public databases kept by municipal, state, and federal government levels, as well as reports published by these same institutions. Literature was searched for, with thesis written at the local university (Universidad Autónoma de San Luis Potosí, UASLP) were also surveyed, although with very few results (see further detail in step 4). Additionally, several researchers were interviewed to know their opinion and the experience they could share on how to access this type of data. A common opinion was that its was an interesting idea but that it would be very difficult (or impossible, some also said) to access information, particularly in relation to material flows (construction materials, food), and that nobody had ever compiled such a diverse indicator set before. It was often also mentioned that the only way to access data, and even then not very likely, would be to personally ask every government facility in charge of each topic. Indeed, lack of data is perhaps the most commonly singled out obstacles for UM studies (cf.[291,292,306,311,332]).

After this initial data overview, it was evident that data for many of the indicators was unlikely to exist, or to be able to access or calculate within a reasonable time frame. The industry sector, for instance, poses a singular challenge, as in affairs having to do with the industrial zone (IZ), all three levels of government intervene: land concessions or tenant agreements are managed by the state government, who also manages some of the concessions for water use. Other water assignments are granted by the federal government. This means that data is scattered in so many different government facilities that it would be impossible to obtain information from all of them within the time frame of this thesis. Likewise, the municipality is generally in charge of waste collection throughout the city, but for some special categories waste (toxics, dangerous, construction residues, etc.), private entities with federal or state permits collect and dispose of the wastes. Reasons like these were behind, for example, the breaking down the water consumption indicator (D.1) into a more feasible "total water", and a more uncertain to obtain "per sector". In this way, at least the general indicator would be known, and if possible, the more detailed one would also be included.

Another example of how the initial data survey helped adjust the indicator set is in the ideal indicator "raw materials to industry" (inflows category). It is of course an indicator which would have been ideal to have, but after initial surveying, it was rather unclear who the data holder for such an indicator would be. Hypothesis were: (i) the enterprise owners or managers themselves, for which intensive field work outside the possibilities of the present project would have had to be carried out. (ii) Tax declarations, in which the payments made for raw materials and other inputs should be stated. Obtaining individual enterprises' tax declarations is of course unlikely (and unpractical to process by one by one), but INEGI compiles a database based on administrative information reported by enterprises to construct the national accounting input-out tables. Thus, there exist national-level reports on, for example, the total value of inputs down to the subsector level (e.g. synthetic coating manufactures within chemical industry manufactures). Performing the calculations following a method such as the Economic Input-Output tables was considered, but it was esteemed that the time needed would have ruled out practically all other indicators. The "raw materials to industry" indicator was thus discarded, but its presence in the system definition remains (see fig 4.3). The "stocks" category was also discarded from the start, as it was evident that estimating them would be a study of its own.

Despite all these limitations, the process of choosing and refining indicators resulted in a good first step toward a full characterisation of the urban metabolism of SLP. It is important to "know what we don't know", and be able to identify these items as boxes (black, but whose relative position to the rest of the elements in the system, and also perhaps some other properties, are known) in the system model. This was indeed done to the best of the knowledge gained, and the results can be seen in fig 4.3. Furthermore, much progress was made in knowing where the information is (or should be), and this registry will be useful for future studies (see steps 4 and 5).

Finally, geographical "indicators" were added, which are not considered in the guideline AUM set, providing for a quite de-contextualized analysis that does not help to understand the city as an inter-connected entity. If the city is to be understood as an ecosystem, a key part of its study should include the relations it holds with other (eco) systems. The geographical items included are not quantitative, but are rather indications of where a flow comes from and goes to. They begin to annotate relations that are important to understand the generals of UM in SLP, in terms of how it relates to its *hinterland* and to the places it is *hinterland* of. These items include, for example, the origin of water imports, the destination of exported waste water, the destination of industrial exports (discarded in the final set), the origin of food consumed (partially included), and others (see table 4.1). Despite apparently simple for now (in reality they proved to be quite difficult to obtain, as will be discussed later), they could be a first step to move toward quantitative geographical indicators, as understood by, for example, the Land Footprint approach discussed in chapter three.

Table 4.1 Indicator set: comparison between guideline, ideal and final sets

	AUM	This study		
		ideal set	Final set	
CONTEXT	0	3	2	**A**
	-	City surface	City surface	A.1
	-	Population size	Population size	A.2
	-	Relative contribution of each sector to the economy	-	
INFLOW	9 + sub-indicators	25	18	**B**
	Water imports	Water imports	Total water imports	B.1
	-		Water imports origin	B.1.1
	Groundwater abstraction	Total Groundwater abstraction	Total Groundwater abstraction	B.2
	-	Groundwater abstraction (total public wells)	Groundwater abstraction (total public wells)	B.2.1
	-	Groundwater abstraction (total private wells)	Groundwater abstraction (total private wells)	B.2.2
	-	Abstraction private wells (industry)	Abstraction private wells (industry)	B.2.2.1
	-	Abstraction private wells (agriculture)	Abstraction private wells (agriculture)	B.2.2.2
	-	Surface water	Surface water	B.3
	Rain water	Rain water	Total rain water	B.4
	-	-	Rain water discharged into sewage	B.4.1
	Incoming radiation		-	-
	-		Total Energy consumption	B.5
	Electricity	Total electricity	Total electricity demand	B.5.1
	-	Electricity by sector - households	Electricity by sector - households	B.5.1.1
	-	Electricity by sector – industry and commerce	Electricity by sector – industry and commerce	B.5.1.2
	-	Electricity by sector – public lighting	Electricity by sector – public lighting	B.5.1.3
	-	Electricity by sector – water system	Electricity by sector – water system	B.5.1.4
	Fossil fuels by type	Total Fossil fuels	Total fossil fuels consumption	B.5.2
	-	Fossil fuels by type - Gasoline	Fossil fuels by type - Gasoline	B.5.2.1
	-	Fossil fuels by type - Diesel	Fossil fuels by type - Diesel	B.5.2.2
	-	Fossil fuels by type - Coal	Fossil fuels by type- others	B.5.2.3
	-	Fossil fuels by type - Gasoline		
	-	Fossil fuels by type- others	-	-
	-		Renewables generation	B.6
	-			
	Construction materials	Construction materials: steel, cement, wood, gravel, sand.	-	-
	-	Origin of construction materials	-	-
	Phosphorous	-	-	-
	Food	Raw agricultural products	Main raw agriculture products	B.7
	-	Packaged food	Meat	B.8
	-	Meat	-	-
	-	Diary	-	-

Table 4.1 (continued) Indicator set: comparison between guideline, ideal and final sets

	AUM	This study		
		ideal set	Final set	
PRODUCTION	2	5	3	**C**
	Food	Food	Fruit and legume production	C.1
	-	Meat	Fodder production	C.2
	-	Packaged food	Meat	C.3
	-	Dairy	-	
	Construction materials	Construction materials: steel, cement, gravel, sand	-	
CONSUMPTION PATTERNS	0	14	6	D
		Total Water consumption	Total Water consumption	D.1
	-	Water consumption per sector - households	Water consumption per sector - household	D.1.1
	-	Water consumption per sector - industry	Water consumption per sector - industry	D.1.2
	-	Water consumption per sector - agriculture	Water consumption per sector - agriculture	D.1.3
	-	Water consumption per sector - commerce	Water consumption per sector - commerce	D.1.4
	-	Water consumption per sector – public facilities	Water consumption per sector – public facilities	D.1.5
	-		Water losses due to leakage	D.1.6
	-	Electricity per sector - industry	Electricity per sector – see inflow indicators	-
	-	Electricity per sector – domestic	-	-
	-	Electricity per sector – commercial and services	-	-
	-	Electricity per sector - agriculture	-	-
	-	Fuel per sector - industry	Total fuels use – see inflows	-
	-	Fuel per sector - agriculture	-	-
	-	Fuel per sector - transport	-	-
	-	Fuel per sector- other	-	-
STOCKS	4	0	0	
	Construction materials	-	-	
	Demolition waste	-	-	
	Landfill waste	-	-	
	Phosphorous	-	-	

Table 4.1 (continued) Indicator set: comparison between guideline, ideal and final sets

	AUM	This study		
		ideal set	Final set	
OUTFLOWS	13	26	21	E
	Exported landfill waste	Total waste to landfill	Total municipal solid waste	E.1
	-	Organic waste to landfill	Destination(s) of municipal wastes	E.1.1
	Incinerated waste	Inorganic waste to landfill	Total organic waste	E.1.2
	-	Destination of inorganic waste	-	-
	Exported recyclables	Recyclable waste	-	-
	-	Destination of recycling	-	-
	-	Demolition residues	-	-
	-	Destination of demolition wastes	-	-
	-	Total toxic/ special waste	Total toxic/ special waste	E.1.1.3
	-	Destination of toxic wastes	Destination of toxic wastes	E.2.2
		Total waste water	Total waste water	E.3
	Wastewater	Waste water - domestic	Waste water - domestic	E.3.1
	-	Waste water - industrial	Waste water - industrial	E.3.2
	-	Waste water treated	Waste water treated	E.4
	-	Destination of waste water	Destination of waste water	E.5
	-	Users of waste and treated water - industry	Users of waste and treated water - industry	E.5.1
	-	Users of waste and treated water - agriculture	Users of waste and treated water - agriculture	E.5.2
	Phosphorous	-	-	
	-	Co2e	CO2e	E.6
	SO2	SO2	SO2	E.6.1
	NOx	NOx	NOx	E.6.2
	CO	CO	CO	E.6.3
	Volatile organic compounds	Volatile organic compounds	VOCs	E.6.4
	Particulates	Particulates	PM10	E.6.5
	-	-	PM2.5	E.6.6
	Methane	Methane	Methane	E.6.7
	O3	O3	O3	E.6.8
	Black carbon	Black carbon	Black carbon	E.6.9
	-	-	NH3	E.6.10
	TOTAL INDICATORS			
	28	**80**	**59**	

Step 2: Defining boundaries

Spatial limits

Spatial phenomena have no clear or sharp boundaries, they are continuums. Real regions have *fuzzy* borders[378]. But to be able to study anything, humans have to delimit it somehow. This need for definition comes at a cost: the choices a researcher makes as to where to place the boundaries will immediately affect the way the object or phenomenon is perceived. This situation, well known in geography as *the boundary problem*, implies that, for instance, objects may appear clustered when the study area is large, or dispersed when it is smaller. Likewise, flows will appear to be local or foreign depending on the extents of the boundaries chosen[379].

Ecosystem ecologists also deal with the boundary problem, as ecosystem dynamics are defined by factors operating at multiple time and spatial scales. The boundaries set for an ecosystem will affect its conceptual definition (and vice versa), and influence the researcher's perception of the phenomena being studied (O'Neill *et al.*, 1986, cited in[380]. Different approaches are used in geography and ecology to overcome the boundary problem, such as fractal geometry appoximations[95], the application of buffer zones or other mediums to correct statistical data in spatial analysis, and the process-function approaches in ecology[380]. In urban ecology, Pickett *et al.* (2001)[114] find that:

> *"...it is clear that many fluxes and interactions extend well beyond the urban boundaries defined by political, research, or biophysical reasons. [...]There is little to be gained from seeking distinctions between "urban" and abutting "wild" lands, as a comprehensive, spatially extensive, systems approach is most valuable for science (Pickett et al. 1997) and management (Rowntree 1995) ..."*

Indeed, urban phenomena occur, simultaneously, at many spatial and temporal scales[274], and functional relations are so varied in their extents that boundaries are a challenge to establish. There is yet the question of how the 'city' is defined –i.e. what the key attributes of 'urban' are that allows us to say "the city ends here"[95]. From the above quote, it follows that if we ambitioned total rigour, in order to encompass the whole of urban metabolism, from cradles and graves of material flows to impacts on hinterlands and so on, the study boundary of any given city would have to extend well beyond the administrative city limits and, in some cases, maybe to the entire planet (fig. 4.2). And it would be not only desirable but also possible, given time, data and technical capacity, to discover the planetary linkages of any given city through its material flows, as have for example began to attempt Minx *et al.* (2011)[332]. But because research itself is normally working within boundaries –those of time–, some practical decisions must be made to reduce the extents of any study. Often, the decisions to set a

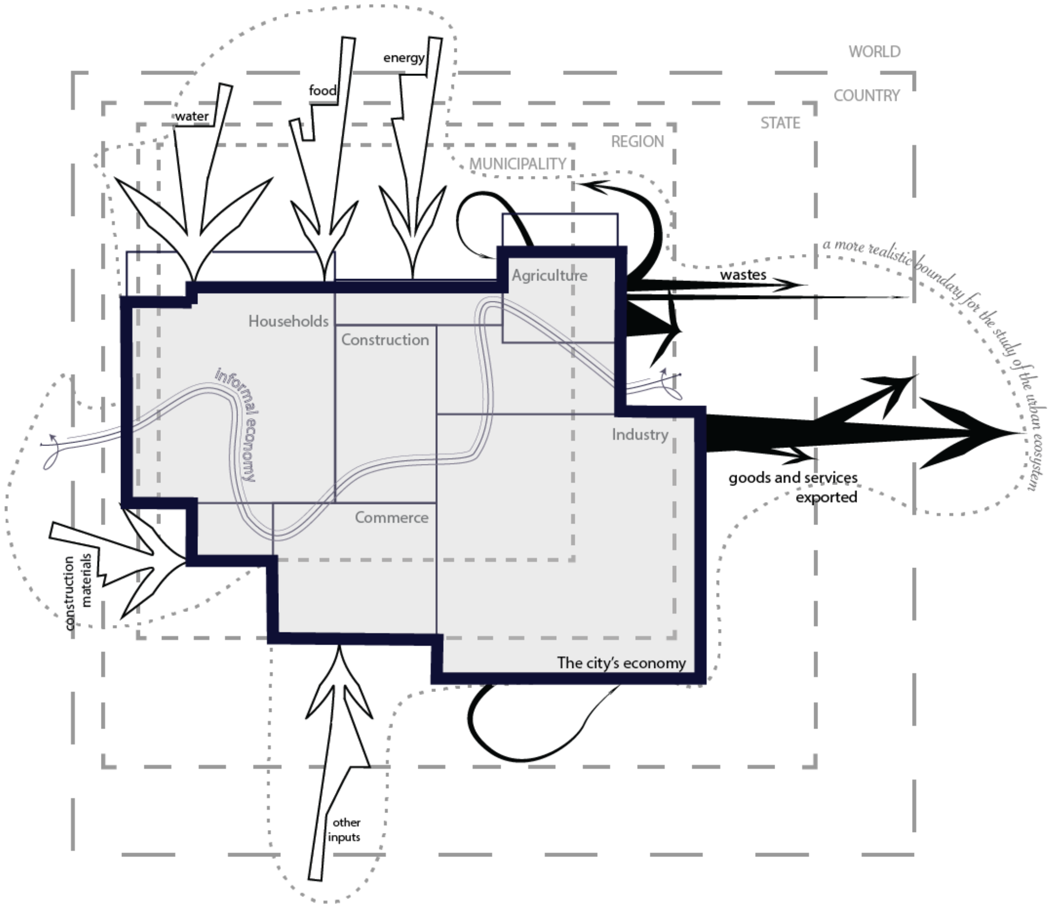


Fig 4.2 A schematic representation of a hypothetical city, loosely based on the urban system of San Luis Potosí. seen as an economy entity whose borders "spill over" administrative boundaries into the neighbouring region. This urban economy, like that of SLP, does not occupy its whole administrative demarcation, but instead does occupy other adjacent territories. Also, some of its components occupy two territories simultaneously (houses that are within the administrative boundary but whose occupants are economically linked to another city, for example). Beyond the physical continuum of constructions and infrastructure, the city's territory is farther expanded across boundaries (from the municipality to the world) by the flows it demands and emits. Therefore, a global boundary for the study of an urban ecosystem could well be drawn (small dotted line), and it would not be inaccurate, although perhaps quite unmanageable for the researcher. A more elaborate diagram would include a third dimension, to represent the vertical processes linking the subsoil and the atmosphere as nodes of the system. This figure is meant to illustrate the difficulty of drawing boundaries that accurately represent what is "really" happening on the ground. While perhaps a study encompassing all possible dimensions is unachievable, we will do well in keeping this complexity in mind when isolating any part of an urban ecosystem to study it, and remember that *our* whole is not the whole story.

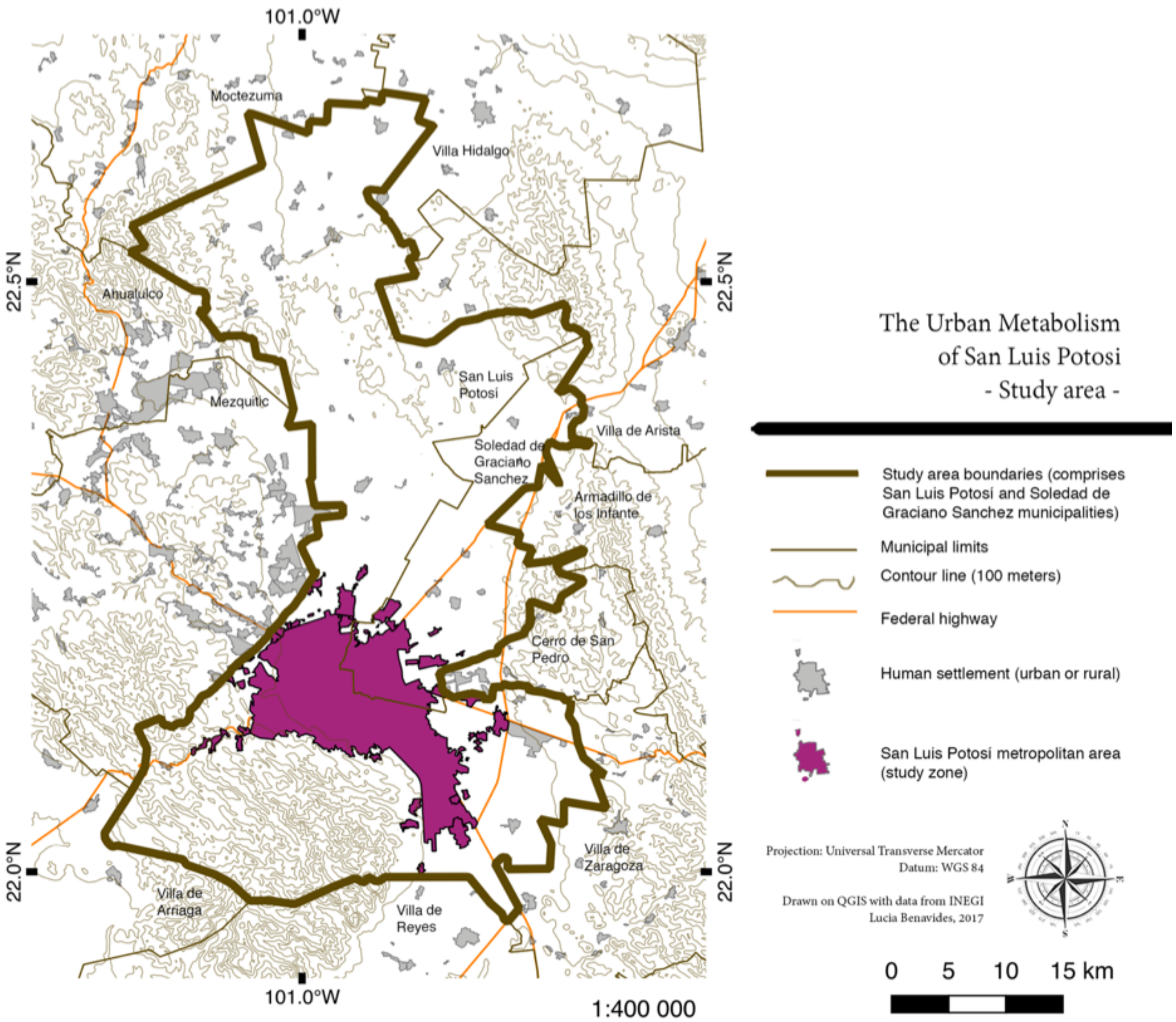
boundary will simply follow the researchers' best criteria in reason of the topic to be studied, the goals of the study, and frequently, the availability of data. Data relevant to UM studies is most often gathered for administrative demarcations, and therefore most UMA analysis use these same boundaries. This criteria –administrative boundaries– was used for SLP. The boundaries of the two municipalities that officially constitute the metropolitan zone of San Luis Potosí (SLP and SGS) were taken as the limits of the study (see map 4.1). There were two working options within those boundaries: one was to use the entire municipal limits, which as can be seen in map 4.1 seen are far larger than the city itself. The second, use the much smaller basic geo-statistical units (AGEB) used by the National Institute of Statistics and Geography (INEGI), which correspond to roughly homogeneous economical areas within cities and rural areas, and are much smaller (the metropolitan zone of SLP has for example 445

AGEBs). However, if not all data is disaggregated to the municipal level, it is much less so to the AGEB level. For example, AGEBs include population by age but not waste recollection amounts, nor do they register the number of economic entities present in the AGEB. In the case of economic entities, they are published in the Statistical Directory of Economic Units (DENUE), and by performing additional steps it would be possible to locate many activities within their AGEBs (not all however: for example, agricultural activity is mostly registered in other catalogues). In other topics, such as water use, it was also uncertain whether statistics were available or whether a method to downscale from state or municipal data would have had to be found. It was then clear that significant amounts of additional work would have been required to ensure that the potential of using higher resolution boundaries was really taken advantage of, and therefore AGEB boundaries were also discarded, but this scale of analysis seems to be a promising future line of research, capable of shedding light on the intra-urban resource consumption spatial patterns and allocating major consumer nodes, for instance[XX].

The limitations of this choice of boundaries (municipal with no internal disaggregation) are as follows:

(i) The built-up continuum of the city takes up only ~11% of the total area of SLP municipality and 13% of that of SGS. Contrary to what is common for metropolitan areas, in SLP the city as a physical continuous entity is smaller than the surface administratively designated as "metropolitan area". In a sense, the administrative demarcation can be seen as having an urban component and a much larger rural component (see map 4.1). More than 90% of the economic activity of both municipalities occurs in the urban area, and a similar proportion of all inhabitant of both municipalities lives in it. Because the territory recognized as "metropolitan" is much larger than the actual built-up city, it is likely that indicators built relative to surface or to population (density, any per capita indicator) are inaccurate. Furthermore, this level of aggregation will hide disparities in income, lifestyles and resource intensities between urban and rural inhabitants of SLP. There will very likely be, for example, large differences in the consumption of the semi-rural periphery to the east and newly settled high-end neighbourhoods to the west, and with the industrial zone. This detail of spatial disaggregation is not possible to capture with the boundaries chosen. However, an effort was made to at least distinguish between sector of the economy (industries, households, third sector, etc.).

[XX] There are other scales of analysis that would be very interesting and useful to perform. Household metabolism, as has been studied by Liu *et al.* (2005)[295] in China is one example. Particularly desirable would be to analyse the metabolism of the industrial sector, so preponderant in SLP. Fig 4.7 illustrates the central role of the industrial sector in SLP, and some of the major flows that were identified to be be linked with it during my analysis. The thorough analysis of the industrial sector's metabolism would require a project of its own, and it is likely that detailed data is even more difficult to obtain for the sector, but I consider it to be of major importance, as industrial activity in SLP is not only major, but growing and encouraged to do so by current policy. Although it was not possible to go into finer detail because the main objective of this thesis is to experiment with and report on appropriate methods for city-wide metabolism studies, some findings in this respect were indeed made, and are reported in the following sections, as well as in the conclusions chapter.



Map 4.1 Study area

(ii) Although not officially part of the metropolitan area, adjacent municipalities (Mezquitic, Cerro de San Pedro and Villa de Reyes, see map 4.1) are functionally integrated into the city economy through commuting workers and students, commerce and some industrial activity. This means, for instance, that some consumptive activities measured in the city can be "inflated" by this floating population, while other indicators may be underestimated. The number and origin of commuters being unknown at the time of writing, a possible adjusting of the data was discarded.

(iii) Practically no metropolitan data seems to be available (i.e. data comprising both municipalities). For most indicators, calculations will have to be made by adding what is reported for SLP municipality and for SGS municipality. But even municipal level data did not seem to be available for all the indicators when the initial overview was done. This exercise will allow us to know to what extent it really is available and therefore this is not necessarily only a limitation, but also an opportunity.

Temporal limits

After data was initially surveyed, it was decided that 2015 would be target year in which to assign quantities to the indicators. The main limitation of this choice is that 2015 was an atypically rainy year (30% above average). Therefore, it seemed possible that the water flow, which according to the literature is already the largest flow into any urban system by far, would lead to non-representative results, affecting the results of for example sewage discharge, incoming water into the system, etc. It was then considered to choose 2014 or 2012 (rainfall in 2013 was also above average), which was well within usual rain ranges. However, after interviews held with municipal government facilities, it was clear that data before 2015 would be quite difficult to obtain, as the present administration started in January 2015 and information generated by the past administration was said to be unavailable. It could have been perhaps possible to obtain it by making formal application to visit the files, for example, but the field visit was of limited duration, and attempting to be granted permissions to review archived files and having to invest time in navigating such files, did not seem like a practical idea. This meant that, in reality, if municipal data was to be obtained, 2015 was the only choice of year available. During the data gathering period it was also found that some data collected by federal institutions were only available up to 2014 or before. Therefore, the final decision was to obtain 2015 data, or the closest possible year in the case 2015 was not available.

Step 3 – system definition

Understanding the structure of the city is fundamental to begin to study its metabolism[50,247]. Economic entities demand resources whose flows form the metabolic patterns that are of interest for the metabolic analyst. Indeed, it is not the city per se that demands flows of materials, but the economic actors within it – industries, commercial activity, households, consumers all. The system description for SLP was done in an empirical manner, as it suggested by the toolkit (chapter 3.4.2) using the diagraming software yED to describe the system and perform some basic analysis of the interconnections (Fig. 4.4). Graphic design software was used for the final layouts. Empirically describing the system meant carrying out a thought and comprehension process as to how the economy of the city is built in relation to resource use, and drawing the diagrams according to this reasoning. As was stated elsewhere in this text, it was clear from the start that describing the totality of nodes and connections that the urban system exhibits in real life was hardly possible (efforts in this direction certainly are under way in many cities, and with computer modelling one can come one step closer) and therefore, I focused on the four central flows of the ideal indicator system (see table 4.1): water, energy and food and materials, although the latter was not developed in detail.

The process of describing the system started with a very general diagram (fig. 4.3a), that was gradually refined, working iteratively as findings from steps 2 and 4 revealed more information (fig 4.3b and 4.3c). Main components of each subsystem were outlined, and their relations established in a conceptual manner, by arrows without any difference as to their weight, quantity or importance. The choices of indicators were also affected by the system definition, as it became clear that some flows were either too complex or too marginal to be considered for this study. Also, the exercise of disentangling the urban system in this way was very helpful in understanding what information was needed to calculate indicators (e.g. what sub-quantities make up the larger "total water consumption" quantity), where possible internal embedded flows could be that also needed calculation (water used for energy generation and vice versa), and also what information we cannot know for the moment but would be eventually necessary for a full evaluation of the urban metabolism, (e.g. the identity of foreign nodes connected to the opposite end of entering flows; embedded flows). After a satisfactory version of the system map was achieved (fig. 4.3c), the flow pathways for water, food and energy were singled out and further detailed (see step 6). The flow of materials was not considered for further detailing, as the materials category was ruled out during the indicator refinement process. Finally, other diagrams could also be made to explore and emphasize interconnections between the three different categories of flows (fig. 5.5). After these diagrams were complete, the data gathering process (step 5) and processing (step 6) were performed, attempting to discover or calculate the quantities belonging to each box and arrow. Further adjustments of the system map continued to be suggested, particularly during data gathering, as interrelations between nodes (or new nodes) became apparent. The version presented here (fig 4.3c) is that which resulted at the moment of closing step 4, but new and different inter-linkages were made clear through the thesis process, and an updated, more detailed version could be made as a result of this thesis.

It is important to state that these diagrams, although crucial for the later steps and for the result of this case study altogether, do not pretend to be exhaustive or final, but rather constitute a first step towards a better understanding of the structure of the urban system, and an exercise to find the best ways to go about such a task. To understand the drivers of SLP's environmental performance for example, a future refinement of the system description that better defines connecting flows, going further into the detail of each of the subsystems would be useful. A layer could perhaps be added, that would help explain the social, political and economic patterns driving shaping SLP's particular structure, many of which will likely be found to be quite outside the urban system itself.

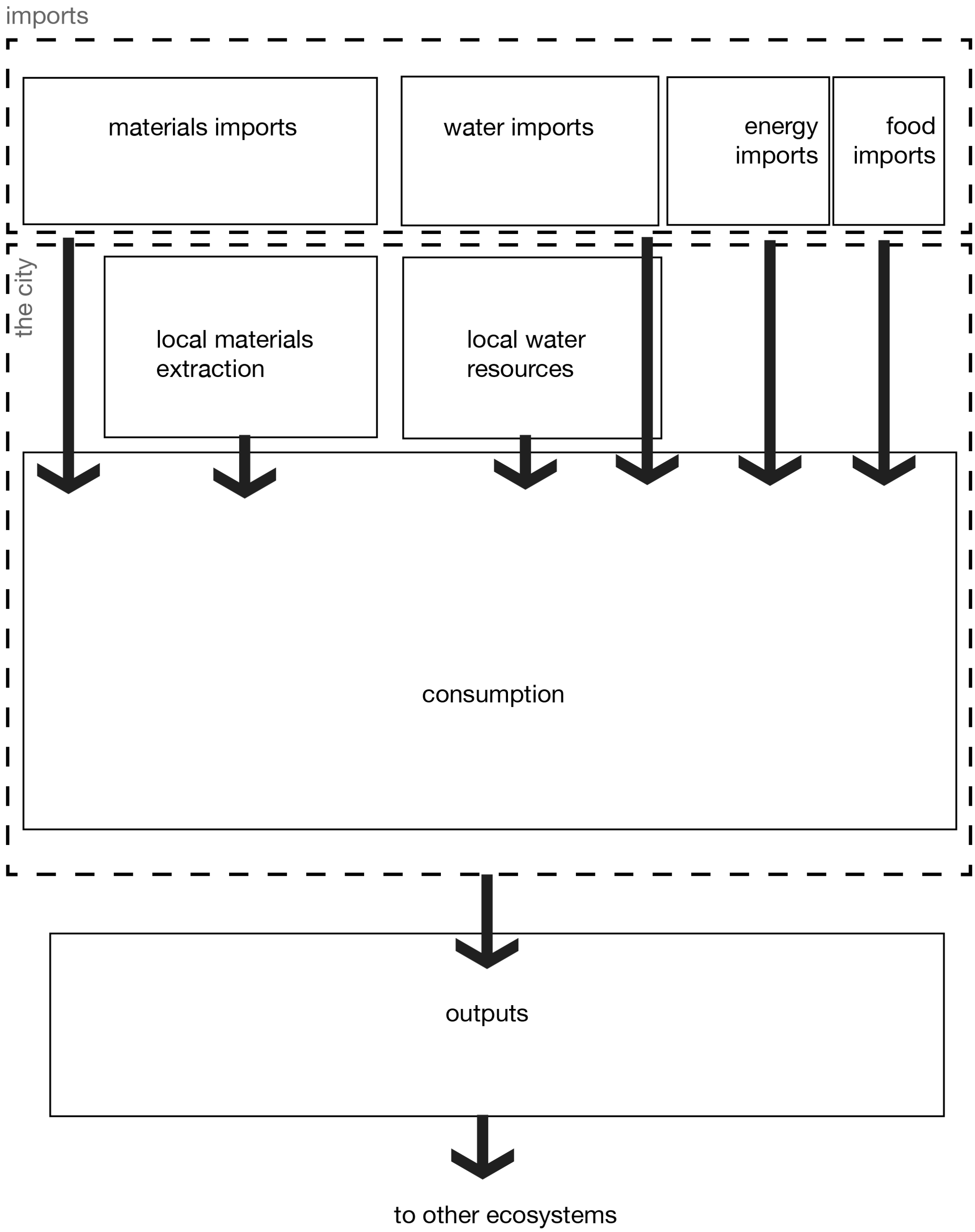


Fig 4.3a First approximation to the system description. An initial and basic sketch capturing only main compartments and basic flows.

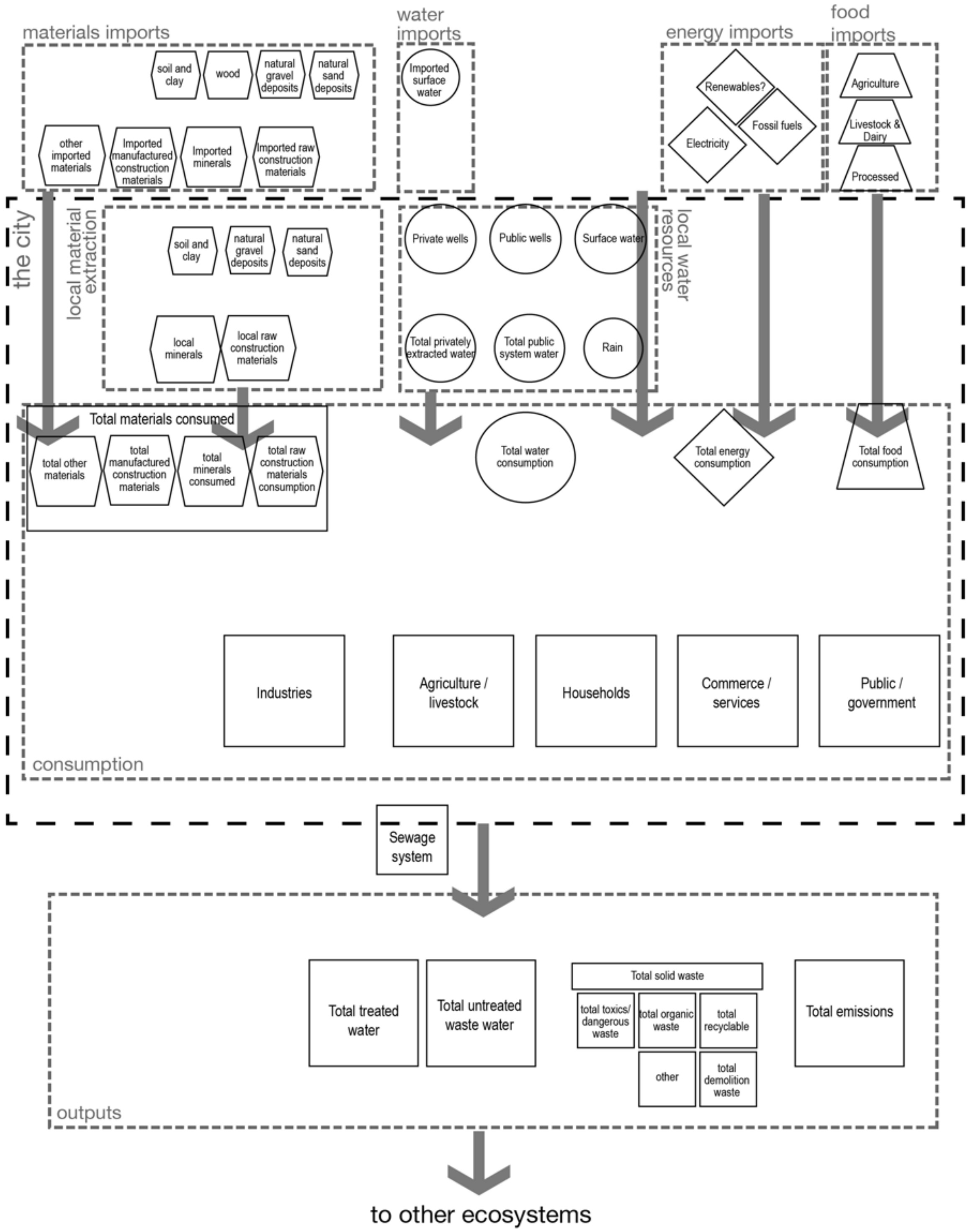


Fig 4.3b System description B. Looking inside the black box, identifying nodes and detailing compartments within the system.

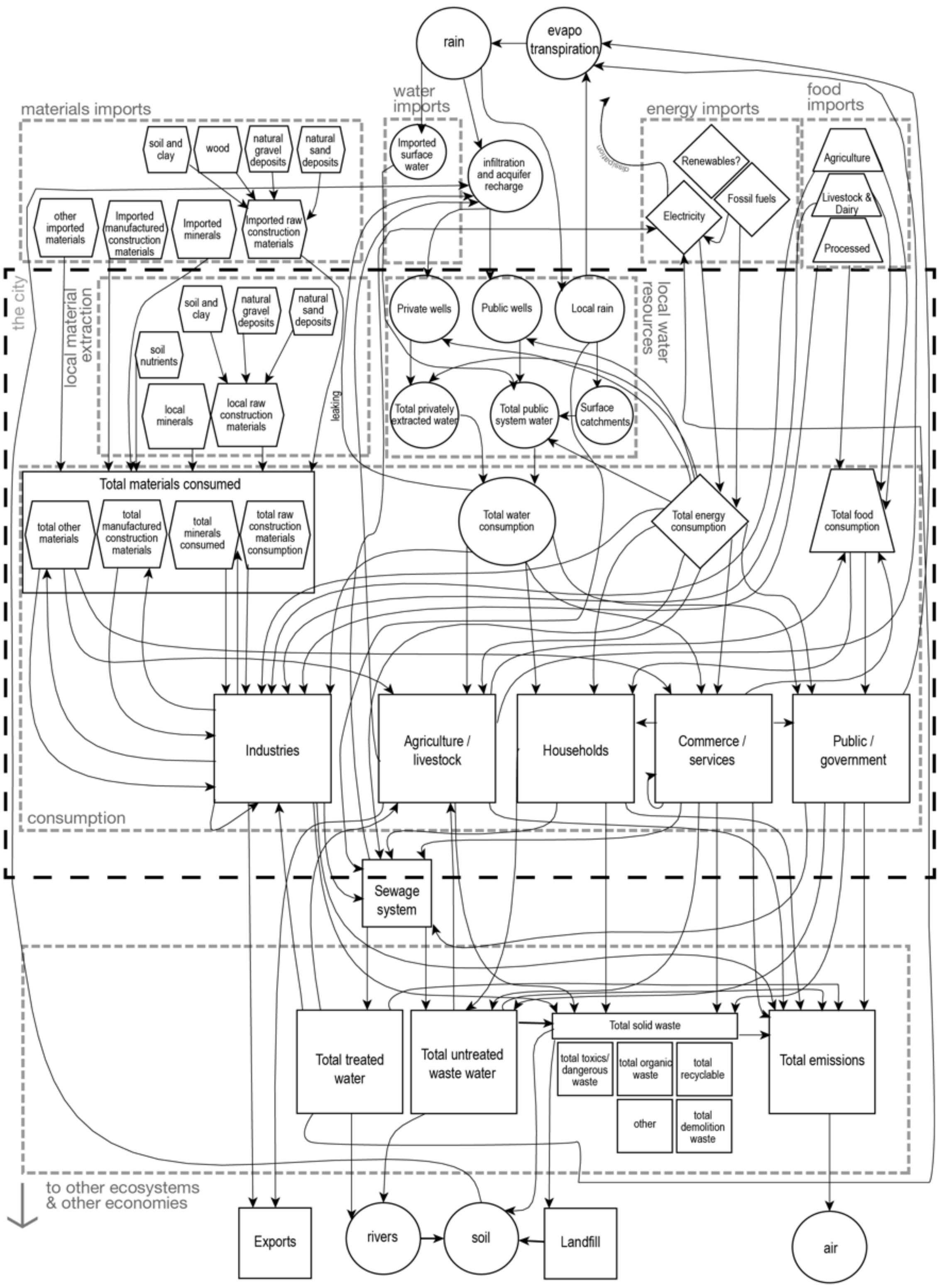


Fig 4.3c System description C, identifying connections (flows) between the nodes. This version of the system description guided the metabolic analysis presented in chapter 5. It is a first approximation to a detailed description of the metabolism of SLP. As such, it has potential for future use in a possible environmental assessment of the whole city, or in partial assessment of certain metabolic compartments.

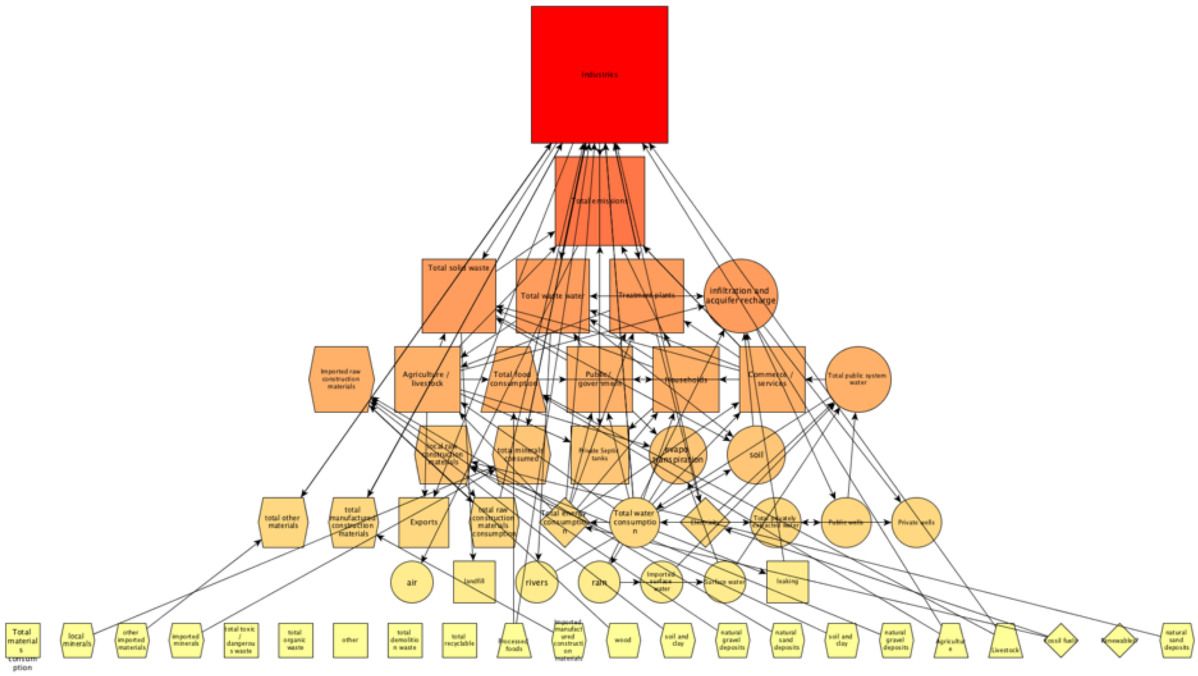


Fig 4.4 A simple analysis in the system analysis software y-ED. An algorithm arranges the nodes of the system according to the number of incoming and outgoing edges that each node has. It is a simple measure of the degree of interconnectedness that a given component of the system may have. In this analysis of the system description presented in fig 4.5c, the node 'industry' shows the highest degree of interconnectedness, pointing to the industrial sector's central role in the dynamics of SLP city.

Step 4 – initial data availability overview(s)

The initial data overview is also described in step 1, because assessing whether data was available (or seemed to be) at the desired scales and on the desired topics was crucial for defining the final indicator set, and in reality, step 4 was happening at the same time as steps 1-3, with the iteration ending again on step 4. Different sources were reviewed during this process. They are described, along with a short note mentioning main findings or remarks in each, in the below paragraphs.

1) Local experts. It seemed like a basic first step to discuss the idea with researchers and environmental experts working in the SLP area. As stated before, it was almost a consensus that gathering specific information to quantify these flows would be very difficult, and that there was no comprehensive data base comprising all of the information needed to quantify even one single flow indicator. A clear message was that data may exist, but would be scattered and obtaining it may depend on the willingness of public officials to help out. Most researchers interviewed recommended asking for appointments with government facilities.

2) Research and reports. Internet and library searches (at the local University, UASLP) were made for documents, reports and scholarly research treating the general environmental situation or the sustainability of SLP. While several books and a few articles treating specific environmental topics, mainly water and solid waste issues were found, no comprehensive multi-topic reports seem to exist. The two reports on Mexican cities published by the UN-Habitat (discussed in chapter 2) make no mention of SLP in a specific way. The reports published by BANAMEX (see also chapter 2) do contain a few paragraphs with general information, e.g. that the aquifer that serves SLP is overexploited, that its waste management facilities are in general norm-compliant, and that its energy consumption is around the national average. Reports issued by several federal entities including the National Ecology and Climate Change Institute (INECC), ministry of Territorial Development (SEDATU), and the National Institute of Geography and Statistics (INEGI, were also examined, with no results.

The State Ecology and Environmental Management Secretariat (SEGAM) was expressly asked about the possible existence of such a study, and they replied that nothing of the sort had been done, and that they do not keep a database where environmental indicators are compiled. At the state level, the only document found that gathers environmental information in a comprehensive and thorough way is an environmental and land zoning proposal (*Ordenamiento ecológico*), finished in 2008 by a research team led by Dr. Medellín Milán at the UASLP[381]. It reports on the economic vocation and carrying capacity of territories throughout the entire San Luis Potosí state, which it divides into management units corresponding to the surface of the 33 sub-drainage basins in the state. This 1,500-page document seems to have been intended to become the state government's land use planning instrument, but was not officially published and has no legal value at the present time. It is also unclear whether it was reviewed by other researchers or experts, and if other stakeholders (NGOs, civic groups, industry representatives) were involved in its elaboration. Due to to this uncertain status, it was only used as a general reference and will not be quoted in this thesis.

3) Public databases of the three levels of government all levels were scanned. Much of the information used in step 6 from them.

4) University databases, including thesis projects and the extinct urban observatory at the school of architecture.

5) NGOs and civic associations. Organised civil society does not seem to be a strong component of the environmentally-related activity in SLP. Although a few environmentally-oriented citizen groups are working in the area, they do not appear to be participating in the production of environmental knowledge, at least not in a formal or written format, and also seem to be quite disconnected from the scientific community. Some exceptions are: a civic group formed in the 1980s to protect the reserve on the Sierra de San Miguelito mountains, a well known cyclist association, and a pair of recently formed but very active and promising, groups of students, professors and professionals who are organising around general topics of urban renewal and sustainability. Interviews with them were held when possible, but practically none held any specific, quantitative that was relevant for this project.

6) Private stakeholders, such as chambers of commerce or private enterprises were also identified, and in a few cases, contacted to inquire about the data they could possible have.

Given the generalised lack of urban environmental reporting in Latin America and Mexico discussed in chapter two, the situation of scattered, un-compiled and incomplete information was to be expected. Nonetheless, it was important to examine all available information to fulfil the objective of this thesis.

Once the indicators were defined, the data collection procedure occurred mainly using official sources and public databases. NGO information, thesis projects and NGO reports were seldom used. However, their existence and possibilities for further use were noted. Besides the identification of the data sources that were finally used, important outputs of this step and the first steps towards identification of data gaps. The data holder directory can be of use for future expansions of this analysis, or for the eventual compiling of a comprehensive database on SLP environment, for example. Data gaps found are reported throughout the coming pages, and further discussed in chapter 5.

4.3 Step 5: Data gathering process

Field work was carried out for 9 weeks in the spring of 2017, and consisted on travelling to SLP and attempting to obtain data for the indicators through a variety pf strategies. With the results from step 4, possible data holders had been identified and registered. As it was unclear where data would really be, many possible sources for every indicator were identified and contacted. The potential data sources were classified into in six different categories: 1) municipal, 2) state, 3) national, 4) supranational/NGO, 5) scholarly research and 6) private stakeholders. Fig 4.50 shows this classification of data holders for the indicator group B, corresponding to water inflows, in the empty data gathering table, as it looked before the gathering process started.

In the data gathering tables, answers from each data holder were registered, and when multiple information was available from different sources, it was compared for consistency. It was indeed often the case that different sources reported different results. A slot was destined in the gathering table to make a note on the quality of the data, where through a simple grading system the data reliability and possible accuracy was classified as 1= excellent, 2= medium and 3=uncertain. When the data was unreliable, or it needed further processing, or it was not available at all, notes were made in the gathering table. Keeping track of these annotations was also crucial to be able to come make sense of the data once the field work ended. The filled data gathering tables that resulted from the process can be consulted in Annex 3. They disclose where the information for each indicator was obtained and give further detail on each of the quantities that was finally used in the metabolism analysis.

Managing such a large collection of possible data sources and stakeholders and keeping track of the results of all inquiries was a challenging part of the process. To be able to proceed with order, two measures were taken: one, a small protocol was established, in which the steps to move down through the data holder levels were specified (fig 4.6). The sources were contacted in order, starting first with municipal actors and when necessary, moving down to private, although it was seldom necessary, and/or possible, to contact private stakeholders. It was decided to place municipal sources as the first step both because it would be expected that city officials would know best about city behaviour, and because it was of particular interest to survey the availability of data at the local level, to, among other things, explore the potential for future bottom-up or combined top-bottom/bottom-up research, and to provide information for proposals on better city management strategies.

The first steps of the protocol are the fundamental steps (i.e. they were run in all cases), and deal with public sources (data holder categories 1-3), including public databases kept by government facilities and interviews with public officials. Once these steps were exhausted, a transparency request was filed when it seemed likely that information was available but for some reason access to it was not being agile. Transparency requests are public information instruments through which citizens can request data or ask specific questions via internet to any public office at any government level of and, after a waiting period of up to 20 days, may obtain the information, or be asked to provide more detail or be denied. It can also occur that a positive answer is received, but stating that the information requested does not exist or is classified as non-public. Five transparency request were filed, out of which only one resulted in useful information.

INFLOWS /WATER ***all information per year (2015) or closest available**							
Indicator Description	indicator number	data holder level	(Possible) Source	Quantity	Year	Quality	Notes
Water imports. Total annual 2015	**B.1**	1	Interapas				
			Dirección de Ecología				
		2	CEA				
		2	SEGAM				
		3	Conagua				
		3	INEGI				
		4	ICLEI				
		5	COLSAN				
		5	Tesis UASLP				
		6	Empresa operadora de la Presa el Realito				
Water imports origin	**B.1.1**	1	Interapas				
		2	CEA				
		3	Conagua				
		3	Open data				
Groundwater abstraction per type (domestic or industrial)	**B.2**	1	Interapas				
		1	Dirección de desarrollo rural				
		1	Dirección de desarrollo económico				
		2	CEA				
		2	Secretaría de Economía (for industrial use)				
		2	Secretaría de Desarrollo Rural (for agricultural use)				
		3	Conagua				
		3	SAGARPA (for agricultural use)				
		3	Open data				
		5	COLSAN				
		5	UASLP				
Local surface water	**B.3**	1	Interapas				
		2	CEA				
		3	Conagua				
		3	Open data				
Rain water	**B.4**	1	Interapas				
		2	CEA				
		3	INEGI				

Fig 4.5 The data gathering table for indicators B.1-B.4 (water inflows), empty as before the data collection process began. See Annex to see the resulting (filled-out) tables.

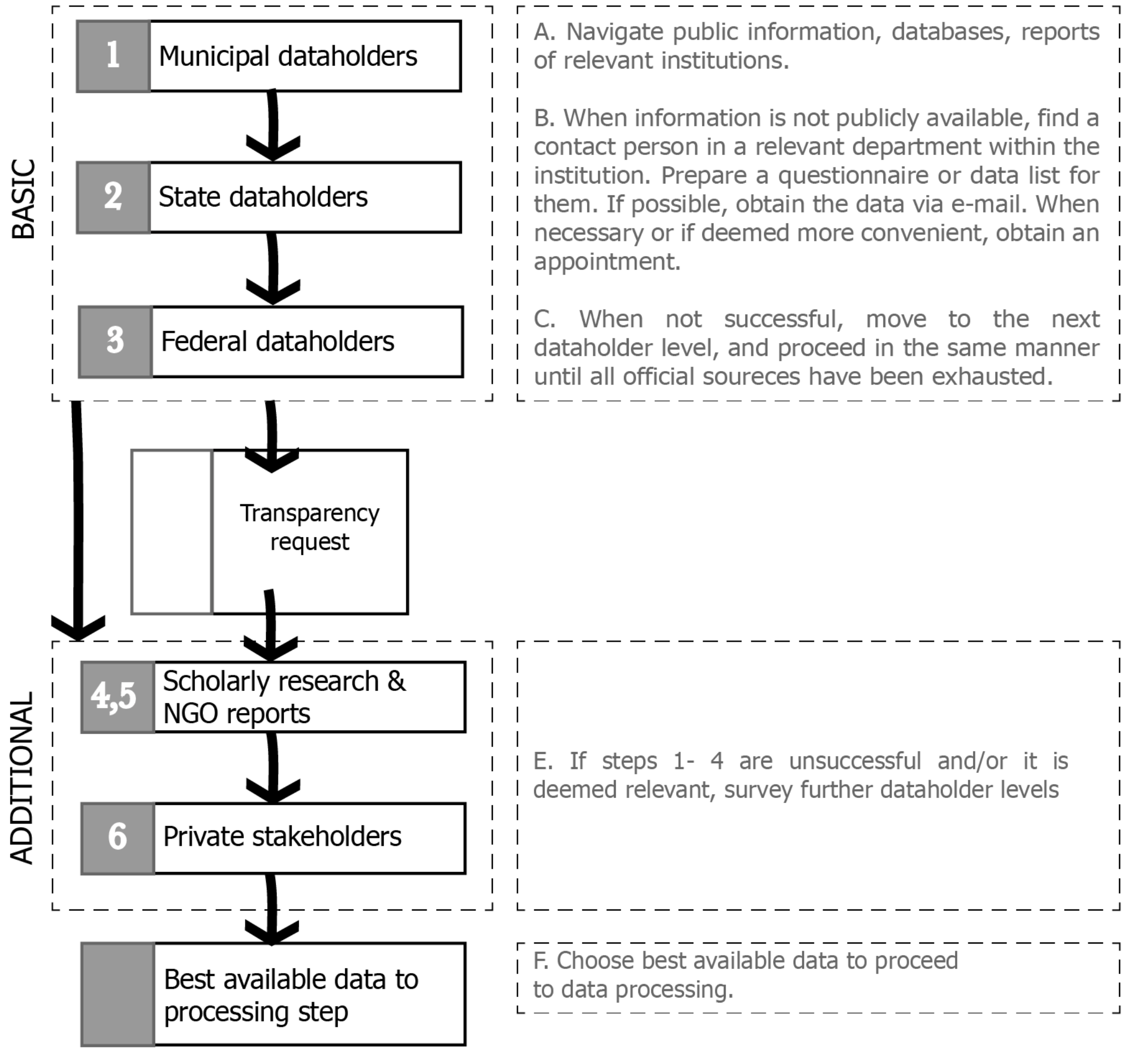


Figure 4.6 Data gathering protocol

Data holder categories 4,5,6 were left as additional possible steps to recur to in the case that previous steps were unsuccessful. In practice, various levels of data holders were being surveyed at the same time, because waiting periods were most of the times very long (several weeks and in some cases up to two and half months) and waiting for one data holder to answer before proceeding to survey the next one down the protocol would have obviously made little sense, and probably resulted in very little information collected. Nonetheless, the protocol was very helpful in guiding operations and keeping a structured frame around a possibly chaotic situation, specially at moments when several different sources were being explored at the same time, and information and replies came from many "fronts" at the same time. In the case that data for one same indicator was collected from more than one dataholder, or only approximate data was obtained, all relevant data pieces were registered, and the best available data was highlighted in the gathering table and chosen to work with in the data processing step (step 6 of the UMA method). The criteria, knowing that it could be difficult to obtain every single data item needed, and that inconsistencies or quality uncertainties would be likely, was to work with the best available data and estimate whatever data was unavailable, given it was possible to perform calculations.

The second measure taken to navigate the abundance of data holder possibilities and advance the gathering process with the best order possible, was to keep a detailed journal where the status of each step of the protocol was registered, as well as the situation of appointments, interviews and the expected reception dates of information from stakeholders who had committed to sending data. This journal, which had not been foreseen at the beginning, was in practice a crucial part of the field work, because the search for some indicators sometimes became unexpectedly complicated, with dozens of e-mail and phone conversations with public officials and/or researchers having to be held and official written requests from the university having to be written, signed and sent daily, all to obtain information for one single indicator. It was for instance quite common that a public office was contacted, and the inquiry was re-directed through two or three further offices, each of which sometimes assured to be able to provide information, in a few days, etc. Keeping track of the waiting periods, assuring to get back to stakeholders in time, etc., was a complicated and time-intensive process. The journal was then quite useful in organising the logistics of these procedures. Colour codes were used to indicate whether a certain "lead" was open, closed, or in standby. The journal grew to almost 30 pages. A sample of it is shown in fig 4.7. Indeed, other UM studies who have also attempted bottom-up procedures have also noted the importance of journals and "back stage" organisation for the success of data gathering processes[382].

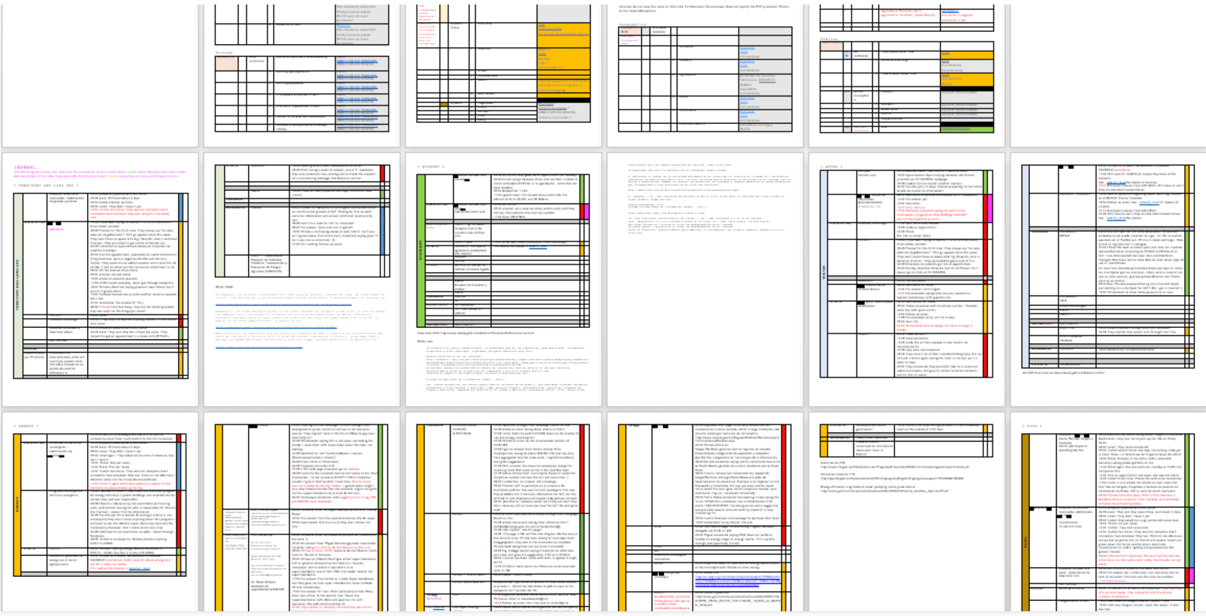


Fig 4.7 A view into the data gathering journal, a critical part of the gathering process.

Significant amounts of time and effort were spent on obtaining and following up interviews with municipal and state government officials, many of which in the end turned up much less information than expected, and in some cases, none. While many functionaries were interested and willing to cooperate, others showed no interest, never answered any calls or emails, and/or failed to produce data they assured would be sent.

In general terms, the data gathering processes showed that public offices at the municipal level gather very little data, and what data they do have is often not systematised or organised. It took for instance several days for one public official to "find" basic information that was requested. Furthermore, interviewed officials at both state and municipal levels explained that in some departments it is quite normal for data and projects from one administration to be filed once their term ends (every three years), and it was then difficult for them to provide data before 2015, which is the year the current administration started on. Also, municipal and state level officials seem to be quite unaccustomed to receiving inquiries and were in general slow or reluctant to attend requests through phone, mail and directly in their office. In the exceptional cases were they were willing to provide information and/or manifested enthusiasm on the project, it often happened that they finally delivered no useful information. Federal level officials were, also with exceptions, much faster and diligent to reply to questions, sometimes within the same day, and the data they provided was more solid and coherent.

Despite difficulties, an acceptable amount of useful data was collected, compiled, processed and analysed, allowing to perform the metabolic study proposed. The report on data availability is presented at the end of the next chapter.

Chapter 5

Case study : The metabolism of water, energy and food in San Luis Potosí

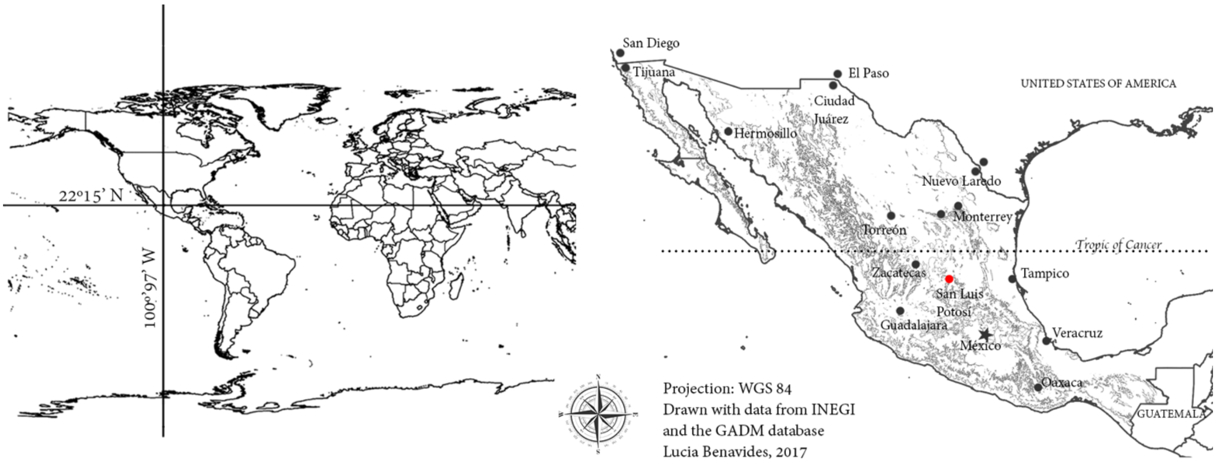
This chapter, as well as the previous one , correspond to objective 3 and 4 of the thesis:

> *3. To execute a "trial run" of the chosen method. Report findings on the environmental performance of SLP. Based on the results, and if applicable, outline policy recommendations and useful communications to relevant stakeholders, such as public officials, civic associations and the research community.*
>
> *4. Report on environmental data availability as experienced through the case study. Ideally, report on such issues as data sources and banks, relevant actors related to data generation, and gathering, data gaps, future research needs, and desirable future research lines.*

The results of the first five steps of the seven-step method designed for and followed in this draft UM analysis of San Luis Potosí have been thoroughly described in the preceding chapter, disclosing all initial preparations in steps 1-4 (setting boundaries, defining the system, scoping data availability, defining indicators) as well as step 5, which is the data gathering process itself. This chapter will now present the results of step 6: quantifying metabolic flows.

5.1 Study area

5.1.1 Geographical situation



Map 5.1 **Left:** Location of San Luis Potosí in relation to the world.
Right: San Luis Potosí is located almost exactly in the centre of the country. The map shows other major cities in Mexico. The national capital is marked with a star.

San Luis Potosí (1864 m above msl) is the capital city of the homonymous state in central Mexico. About 200 kilometres south of the Tropic of Cancer, and amidst the semi-arid climate of the southern central plateau (Mesa del Centro), its total surface lies within the limits of the small San Luis Potosí Valley, a Quaternary alluvial fill, of between 60 and 250 m in depth, that rests on a much deeper volcanic formation, which in turn constitutes the upper limit of the aquifer where the major share of the city's water supply is taken from (Cardona 2007, cited in[383;384]). The valley, where clay-textured, shallow leptosols and partially formed, calcareous cambisols dominate, is limited to the east by the first slopes of the limestone formations of the Sierra de Álvarez (highest point 2700m); partially to the south and west by the igneous, granitic, Sierra de San Miguelito (highest point 3000 m) and partially to the north by the also igneous Sierra el Mastranto[385–387] (fig. 4.2).

SLP valley receives a yearly average between 340-380 mm of rain, concentrated mostly (83%) in the summer and early fall months of may-october[388]. The mean annual evapotransporation rate is estimated at 348 mm. With an average temperature of 17°C, and extremes at 32° an 1°, its ecoregion is classified as a temperate-warm, dry to semi-dry desert[389], and the valley itself is part of the southernmost limits of the highly biodiverse Chihuahuan Desert[390]. The naturally occurring vegetation at the valley floor and the lower part of the sierras is the dominant floristic typology in around 40% of the national territory –the *matorral xerófilo*, a thorny scrubland with patches of grasses and succulents[391]. Amongst the *matorral* in the lowest parts of the valley, marshes and grassland were traversed by seasonal creeks and streams. These areas were occupied by the Spanish conquistadors to establish the city in the 16th century[392]. Filling water bodies and paving over creeks and streams to develop a city was deemed necessary then[393] and continues to be so in our time[234]. Flooding problems during the rainy season are very common in contemporary SLP as were in the 17th and 18th century.

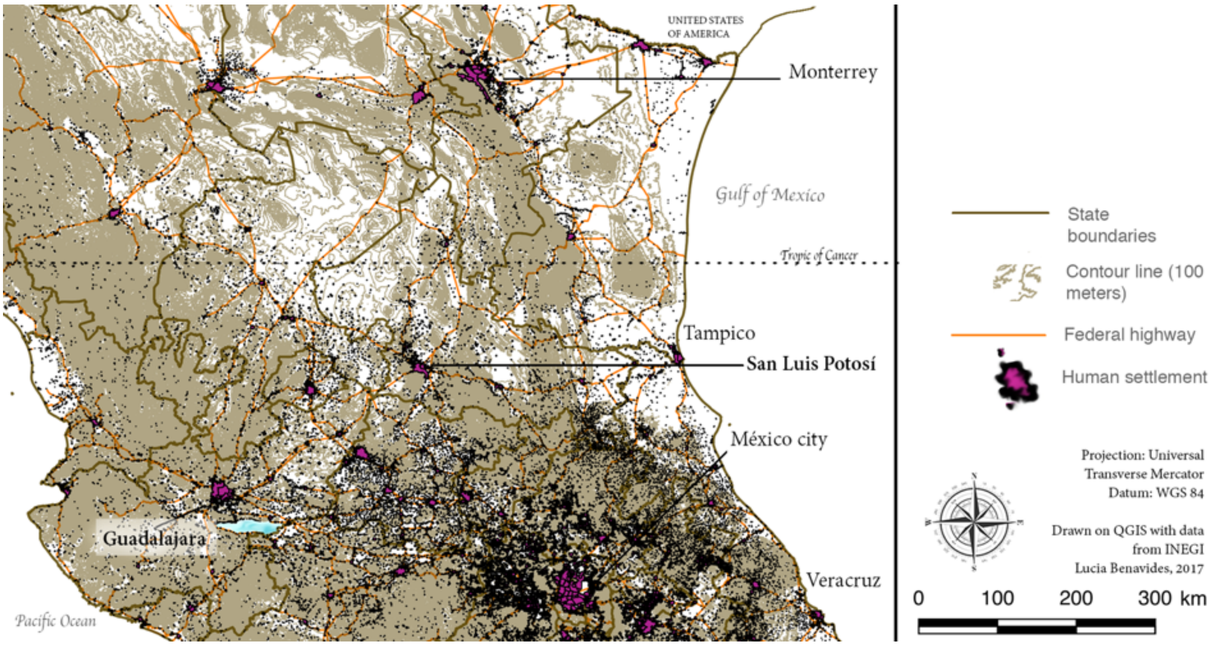
The *matorral* has been cleared during centuries, for agriculture and human settlement. The Sierras around the city have been subject to grazing, wood extraction and mining, and medium to high perturbation conditions prevail today in them[394–397], although some important patches of the original scrubland, oak and pine-oak forest do remain. A large portion of the Sierra de Álvarez to the west is classified as a national priority conservation area[396], while Sierra de San Miguelito is almost totally without legal protection except for two small protected patches under state jursidiction[398] (around 1,500 ha together, less than the surface covered by local industrial parks).

With a population of 1'133,571(2015)[385] and an average density of 105 h/ha[188] SLP is since 1976 classified as metropolitan area[400,YY], whose official limits[ZZ] spread over 1788 km^2, 82,9% of which corresponds to the municipality of San Luis Potosí (SLP) and 17,1% to that of Soledad de Graciano Sanchez (SGS)[188,399]. It should be noted that, as can be seen on map 5.3, the city does not occupy the whole municipal surface, but rather a small fraction of both municipalities. However, ~95% of the total population of both municipalities is concentrated in the urban area[401]. The official metropolitan limits encompass the entire territory of the two municipalities, including rural and virtually un-inhabited areas.

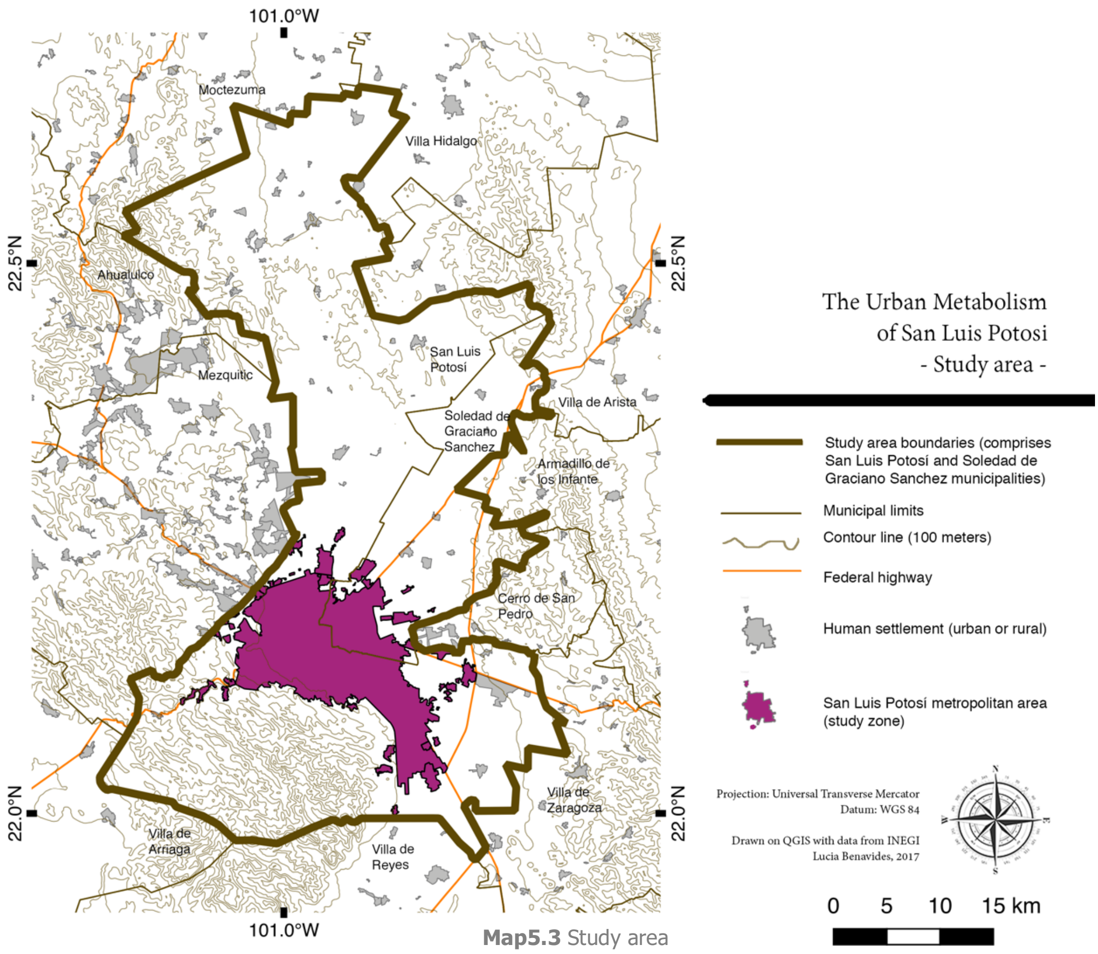
The city has been expanding steadily for the last 40 years, and displayed an overwhelming "boom" in the mid 1990s[402] (see map 4.4), largely due to the growth of employment offer in the manufacturing and industrial sector brought by economic liberalisation under the North America Free Trade Agreement (NAFTA), and to a large difference in life quality conditions between rural and urban settings[400]. This period of urban growth occurred similarly in many other Mexican cities, and has been defined by Garza (2010) as the "urban consolidation under neoliberalism" phase, characterized by the sprawl of low quality construction in informal settlements with little or no urban infrastructure (running water, electricity, sewage, etc.), paired with an important growth of the informal economy[400].

[YY] In Mexican legislation, a metropolitan area is defined as (a) a city of fifty thousand or more inhabitants, whose functions and activities have overpassed the borders of the municipality that originally contained it, incorporating other predominantly urban areas by direct physical connection or through high economic and functional integration, or (b) a municipality with one million or more inhabitants. The MASLP fulfils both of these criteria[188]. For convenience, throughout the text we shall use 'SLP' to refer to the metropolitan area comprising SLP and SGS.

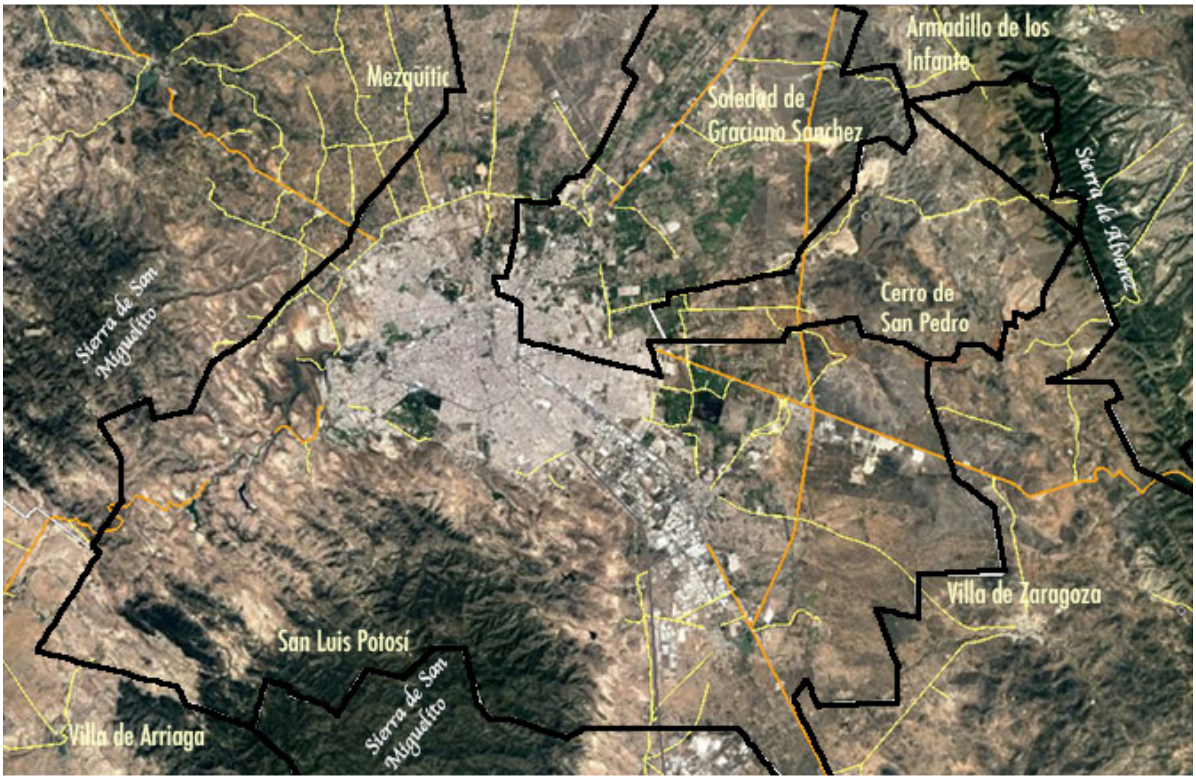
[ZZ] All federal sources referring to metropolitan areas state that the SLP-SGS metropolitan area comprises only these two municipalities. However, in interviews held during the filed work phase, state-level authorities at the urban development secretariat (SEDUVOP) insisted that there were five municipalities in the official conurbation, but failed to produce a plan or another document showing such borders. I received contradictory and unclear information in verbal communications with state and municipal functionaries. The State Urban Development Plan shows no map of the metropolitan zone, but does refer to it as "SLP-SGS". Therefore, I will assume the borders referred to in federal-level sources contained in references [188,399].



Map 5.2 The central location of San Luis Potosí within Mexico. Note the almost equidistant position with respect to major cities: Guadalajara, Mexico City and Monterrey, the three major economic centres in Mexico) and the good connection with highways (and rail, although not shown on the map, see map 4.4) leading towards the USA-Mexico border cities, and towards ports east and west.



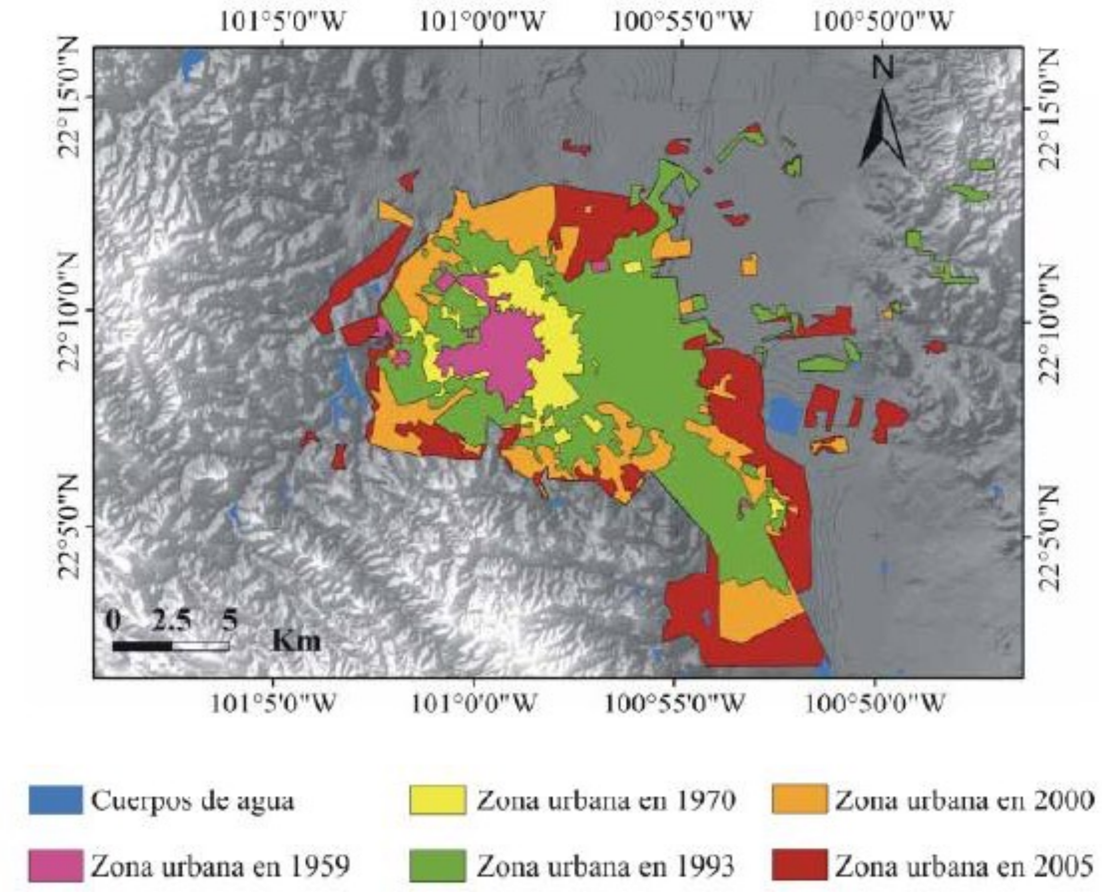
Map5.3 Study area



Map 5.4 The city of San Luis Potosí, showing adjacent municipality borders (black), federal highways (orange), state highways and roads (yellow), the railway line (grey) and the position of the city (purple) with respect to the Sierras. The small insert on the left shows the position of the city within the municipalities of SLP and SGS. Despite occupying a small portion of both municipalities, the city concentrates ~95% of their population. The insert in the bottom left shows city continuum (purple), in relation to the municipal borders and the metropolitan area. See also map 5.3.
Image drawn on Landsat image (2017) on Google Earth, with vector data from INEGI.

The growth in SLP was mostly concentric, with a clear bias towards the east and south, determined by the existence of the nearby Pan-American highway (Mexico 57), a key transport axis traversing the country north to south, passing through Mexico City, and crossing into the USA and Central America (see map 5.2). Industrial complexes occupied this southern "arm" along the highway, while the agricultural and grassland areas to the east and to a lesser degree to the north, were occupied in low densities and leaving large intra-urba gaps by low and middle-income housing, mostly unplanned[403,404] and developed not without conflict[404,405]. Agriculture continues to be practiced in the non- or semi-urbanized fringes of the city, now using waste water as an important share of the irrigation input[405].

Higher density development of medium-high and high income housing has occurred on the south-west end, colonizing the slopes of the Sierra de San Miguelito with gated communities, shopping malls, private schools and golf courses[406]. These exclusive developments, which tend to have better quality urban infrastructure and services than the city average[402], have experienced a new impulse since 2005, and already surpass 20% of the urban surface[406]. It is a segregated (and segregating) area, with fewer access routes as it climbs towards the hills, and practically accessible only with an automobile. Its expansion, over areas not necessarily the most appropriate for urban development, is found by Moreno



Map 5.5 Expansion of SLP from 1950 to 2005. Taken from Noyola-Medrano *et al.*, 2009.

Mata *et al.* (2015)[406] to be an expression of the growing rich-poor gap, and also of an increasing influence of private real estate enterprise on city planning officials, combined with the overall incapacity of the latter to produce and execute plans for an inclusive and sustainable urban development that integrates the city as a functioning –and democratic- whole. It is foreseen that physical expansion of the city will continue in this south-westerly direction, further occupying the piedmont of the Sierra[402], and likely endangering the already perturbed matorral and forest ecosystems, and possibly impacting recharge areas of the city's aquifer[407].

Besides the segregation of social classes and the low density, rapid expansion periods of the 1980s-2000[400,408], another common trait in the growth of Mexican cities, and many Latin American, is metropolization. Indeed, besides the already integrated SLP and SGS, the adjacent municipalities Cerro de San Pedro (CSP) to the east, Mezquitic to the west, Villa de Reyes and Villa de Zaragoza to the south are today functionally integrated into, or rather, subordinated to[409] the city, although their urban settlements are not physically adjacent. These municipalities provide (commuting, low skilled) labour, agricultural products and recreational space to the inhabitants of the metropolitan area[404]. Partly due to this, an updating of the metropolitan administrative limits is being discussed at the time of writing[410]. If approved, the metropolitan area would now comprise several additional municipalities[AAA], requiring an important institutional transformation to integrate them into a new management scheme. Metropolitan management is already a current challenge in SLP. An attempt was made in 2006 to establish a municipal planning institute (IMPLAN), but had no authority over SGS[411], and thus had no metropolitan scope. After limited success in general, the IMPLAN is currently off duty and on hold until the situation pertaining the new borders is defined[410, see note C.]

4.2.2 Economic dynamics

San Luis Potosí was founded in 1583 as a Spanish religious-military post (Puesto de San Luis, named in honour of the St. Louis king of France) during what was known as the Chichimeca war -the struggle to pacify the fierce hunter-warrior tribes of the central plateau[392,393]. The Chichimeca were eventually either pacified, killed or chased out of the region, and the discovery of silver ores in the nearby hill now known as Cerro de San Pedro in 1592 transformed the small settlement into the third most important city in the New Spain by 1630[392]. Mining of silver, zinc and gold in nearby areas continued to be the primary economic activity of not only SLP but of a large portion of the Mexican central plateau well into the 20th century. Goat herding and agriculture, not only rain fed but also irrigated, with irrigation systems similar to those in the arab world, using sub-surface flows below river beds and ground water drawn through wells, were also vital parts of the domestic economy[412,413]

Except for a few factories and industries related to mining, there existed little industrial activity in the city until the 1960s. At this time, triggered by national industrialisation policies, the first industrial zone of the city was created (1963) through a decree expropriating 1,086 ha of agricultural *ejidos*[BBB] south of the city. Two additional zones were added, through the same expropriation procedure, in 1981 (1,283 ha) and 2009 (19,103.2 ha), to cover today over 21,000 ha[377]. The industrial zone (IZ) is divided in two public parks (San Luis Potosí and Del Potosí), which were developed with public funds and are administered by the state, plus seven private parks[414] developed by private enterprises which receive land concessions to build infrastructure and manage the park[CCC]. 543 enterprises of different sizes currently operate within the IZ (public and private), 348 of which are manufacturing facilities[414], mostly

[AAA] The real number of municipalities in the new metropolitan limits project is not clear. The only documents regarding the plan to expand the borders metropolitan area to include more municipalities were newspaper particles reporting speeches or interviews given by state officials. The search I performed to find the project or the new conurbation, where perhaps the criteria to make such a decision would be stated, was unsuccessful. In a personal interview, municipal-level functionaries spoke of 10, bur were reluctant to give precise information.

[BBB] The *ejido* is a form of social land tenure created with the Agrarian Reform, in the 1930s in Mexico, whose spirit was providing land to those who had been historically dispossessed (indigenous or peasant communities mostly). Many *ejidos* were created through the fractioning of former private property (*hacienda*), some of which had grown to amazing extents: there were exceptional cases where one singe family could own 500,000 ha. An *ejido* consists of a State-assigned grant of land to a community, in a sort of perennial concession. Within it, there are individual plots over which the owning person or family has total control, plus a certain amount of communal territories, which the *ejido* assembly can decide to use in different ways, for example to farm them all together, to rent them temporarily to individuals, to assign them to newcomers who wish to settle there, etc. The *ejido* also comprises land destined to build houses, schools, churches and other infrastructure. An *ejido* is managed through the assembly of all owners –the ejidatarios- who elect a representative (*comisiariado*) periodically. Until the 1990s, *ejidos* could not be fractioned or sold, but since then the fractioning and selling of *ejido* property and an abandonment of agriculture is constant throughout Mexico.

[CCC] There are additional industrial facilities outside the bounds of the industrial zone, to the north and east, but their share of the production is marginal.

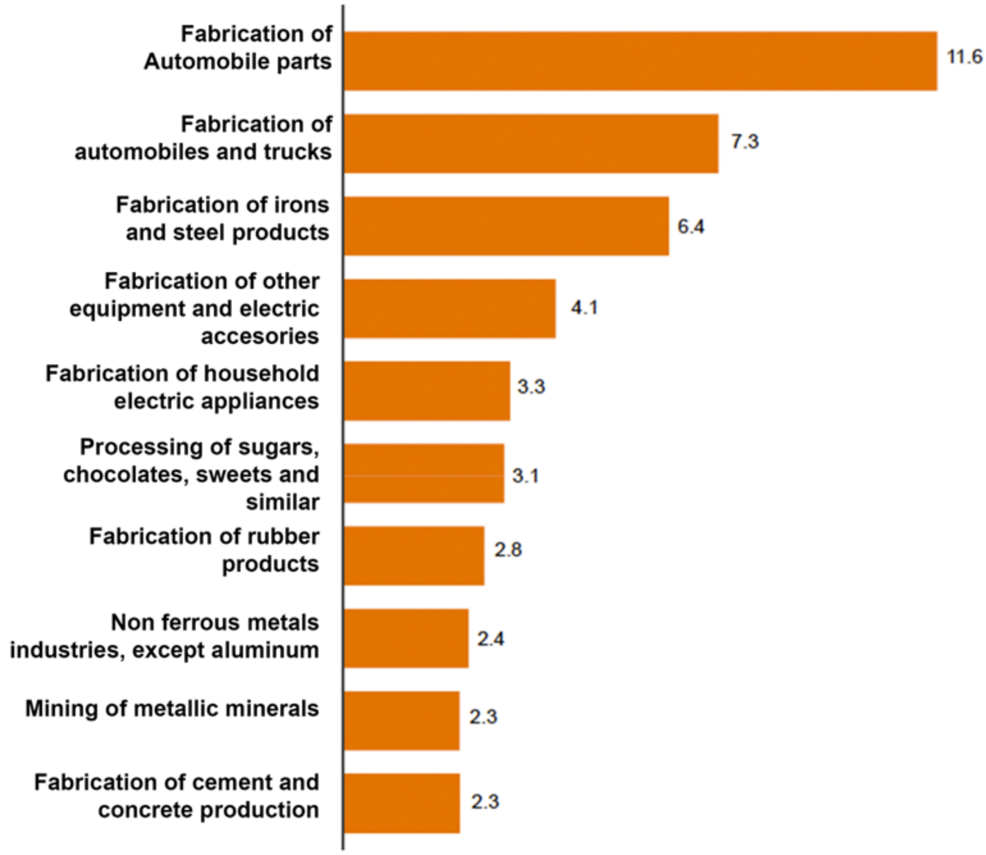


Fig 5.1 Participation of of different activities in the State-wide economy. Note that the only non manufacturing activity is the mining of metallic minerals. Modified from INEGI, 2016.

of automobile parts, which is the largest and fastest growing sector, and also of metal products, and electrical equipment and appliances[415]. Manufacturing industries, much of whose products are destined for export into the United States and in lesser quantities to Europe and Asia, produces the largest single share of the city's total local gross production (70%)[415] and also of the GP of the whole state (33%)[385,415] (Figs 5.1 and 5.2). In recent years, through the growth of local industry and foreign direct investment (5.6% of national FDI is in SLP), GDP in SLP grew at faster rates than the national average, and today contributes ~2% to the national GDP[416].

Reproducing the centralised development patterns of many other Mexican economies (see chapter 2), the economic activity of the entire San Luis Potosí state is very much concentrated in the metropolitan area of SLP: 52% of all enterprises and business are settled here, generating over 77% of the state's gross total production (GTP) with 69% of the total employed population[415]. If the neighbouring municipality of Villa de Reyes is considered, 83% of GTP is concentrated in the SLP city area, which amounts only to ~3% of the state's surface.

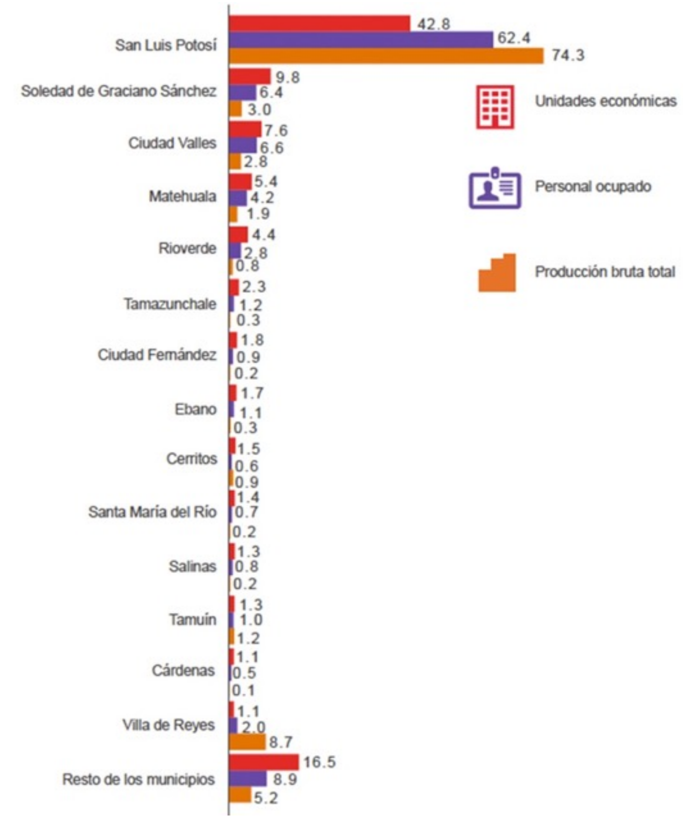
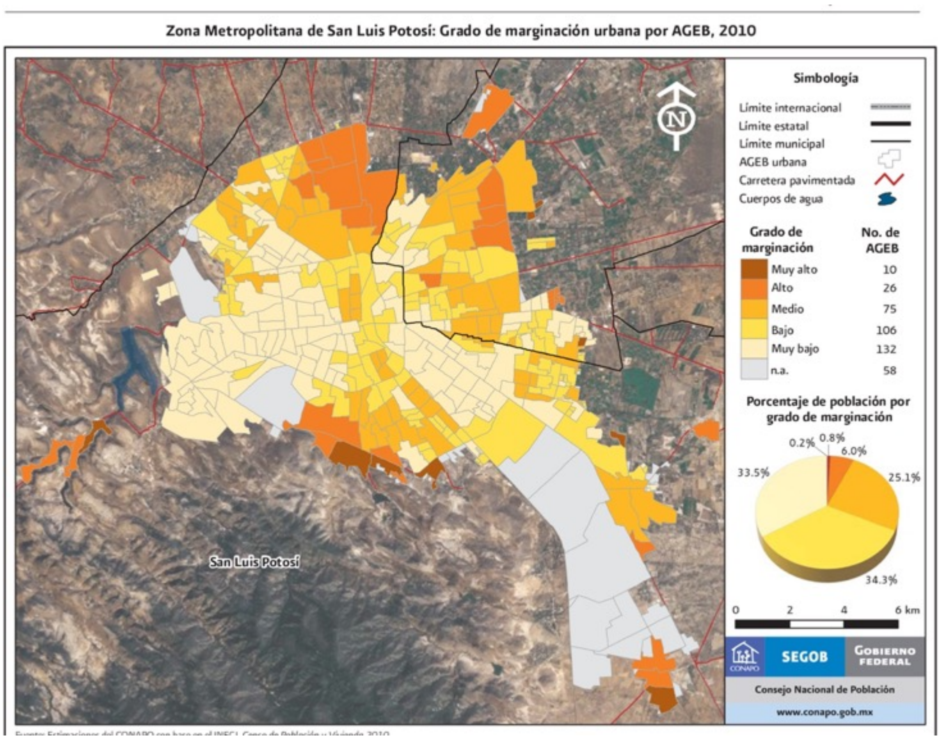


Fig 5.2 Participation of different municipalities in the economy of San Luis Potosí state as measured by occupied personnel (*Personal ocupado*), number of economic units –i.e. enterprises, businesses (*Unidades económicas*) and gross total production (*producción bruta total*)
Taken from INEGI, 2016.

Illustrating the 20th century shift in economic orientation, mining in the two municipalities is now quite low, with only 2.8% of GTP[415]. As for agriculture, the surface occupied by rain fed agriculture declined in around 95% between 1976 and 2009[376]. The total surface of irrigated agriculture also decreased, but much less dramatically, and is still a current activity in some parts of the east and north peripheries[376]. However, its participation in the municipal economy (both SLP and SGS) is marginal, with only with .01% of GTP[415], and involving <2% of the economically active population[188].

In effect, in field interviews carried out in former agricultural areas now in the urban periphery, Torres Escalante *et al.* (2016)[376] found that the inhabitants of these areas see agricultural work as unprofitable, demanding too much work for little revenue (or sometimes none), and taking too long to be able to attain the living standards they would desire. In general, people in these localities, who tend to have little qualification, prefer to look for work in the city, in the industrial zone and also as construction workers, general helpers or domestic aid. The authors however, suggest that this population is not necessarily achieving better incomes or easier life situations through employment in the urban and industrial economy. Low wages both in the industrial zone and in other employment, higher urban living costs, the loss of their former property (land that they sold to housing developers, for example) and an insufficient provision of urban services and amenities in the non-central, non-high end areas of the city, provide for high degrees of marginalisation precisely in those areas of SLP that were until recently, agricultural land (see map 5.6). This, despite the fact that SLP has the best socioeconomic ranking in the state, whose population is nationally ranked as highly marginalised[417].

Nonetheless, industrial growth, now heavily concentrated on the manufacturing-exporting sector, has been for decades seen by policy makers as the main road to development and is since the 1970s a state priority, well over others issues, including environmental aspects[377]. The general premise is that industries will create employment and economic growth and therefore development[377], and thus government efforts (state and municipal, but indeed also federal) focus on "being attractive"[418]. To encourage the settlement of industries, the state and local governments provide attractive terms and incentives, such as donating (expropriated) land for the building of plants and industrial parks, promising "competitive wages", and assuring "tailor-made" support schemes including "soft landing" packages complete with executive assistance, public relations representing, and special hotel discounts. In practice, and according to findings in recent research, the incentives would also appear to include looking away when industries fail to comply with environmental regulations such as number, distribution and capacity of wells, quality of industrial discharge to the sewage system and payment of water rights.



Map 5.6 Marginalisation degrees of different geo-statistical areas of SLP. Darker colours (brown, orange) indicate higher marginalisation degrees. The industrial zone, in grey, is classified as non-applicable because it is not a residential area. Taken from CONAPO, 2012

5.2 Step 6 – Processing, quantifying, visualizing and reporting on the metabolism of San Luis Potosí

Data gathered in step 5 was processed to find the quantities corresponding to each indicator. While some information was found with relatively few complications and in a straight forward format, for most indicators it was necessary to perform calculations and/or convert datasets from and to different formats in order to be able to manipulate it. The details of the calculation processes and the sources for each indicator are disclosed in annex 5. In the following paragraphs, the original system map (fig 4.3c) is looked at with a sub-system perspective, and subdivided into the three main flows set as a goal for this exercise (water, energy and food). The magnitude of their flows and nodes are quantified and shown in figures. "Metabolic flow" Sankey-style diagrams are made for each, and important aspects of each metabolic flow discussed.

1. Water

Fig. 5.3 shows the water sub-system of SLP, as conceptualized in this thesis. This sub-system diagram derives from the general diagram that resulted from step 3 (fig. 4.3c), and can be considered a first approximation to the understanding of the water metabolism of the city through the explicit disclosure of the links between its physical components. The diagram guided the data gathering process for this subsystem as for the remaining two (energy and food), where the goal was to provide a quantity for each box and arrow, which in turn roughly correspond each to one of the indicators on the indicator list (fig 4.9). The quantifying of boxes and arrows in this sub-system diagram leads to the creation of the metabolic Sankey-style diagrams, presented for the water subsystem in fig. 5.4. This initial phase of characterizing the subsystem proved fundamental to proceed to the data gathering and processing steps. With information from all phases, further diagrams can be made to include embedded flows (fig. 5.5)

Input

The analysis of the subsystem map and its quantities shows that SLP's water supply system can be seen as having two main input sources: publically-operated wells and dams, which make up for the largest share of the supply (between 74% and 54%), and individual concessions granted by the federal government to private users for agricultural, industrial and "various" activities, which make up for between 26% and 46% of the total water input to the city. The difference is due to the fact that there are two aquifers supplying the municipalities of SLP and SGS. While the city itself rests right above the San Luis Potosí aquifer, which supplies most of the water for all uses, at least 164 agricultural wells in the north end of SLP municipality are tapping into the Villa de Arista aquifer (see map 5.7). The

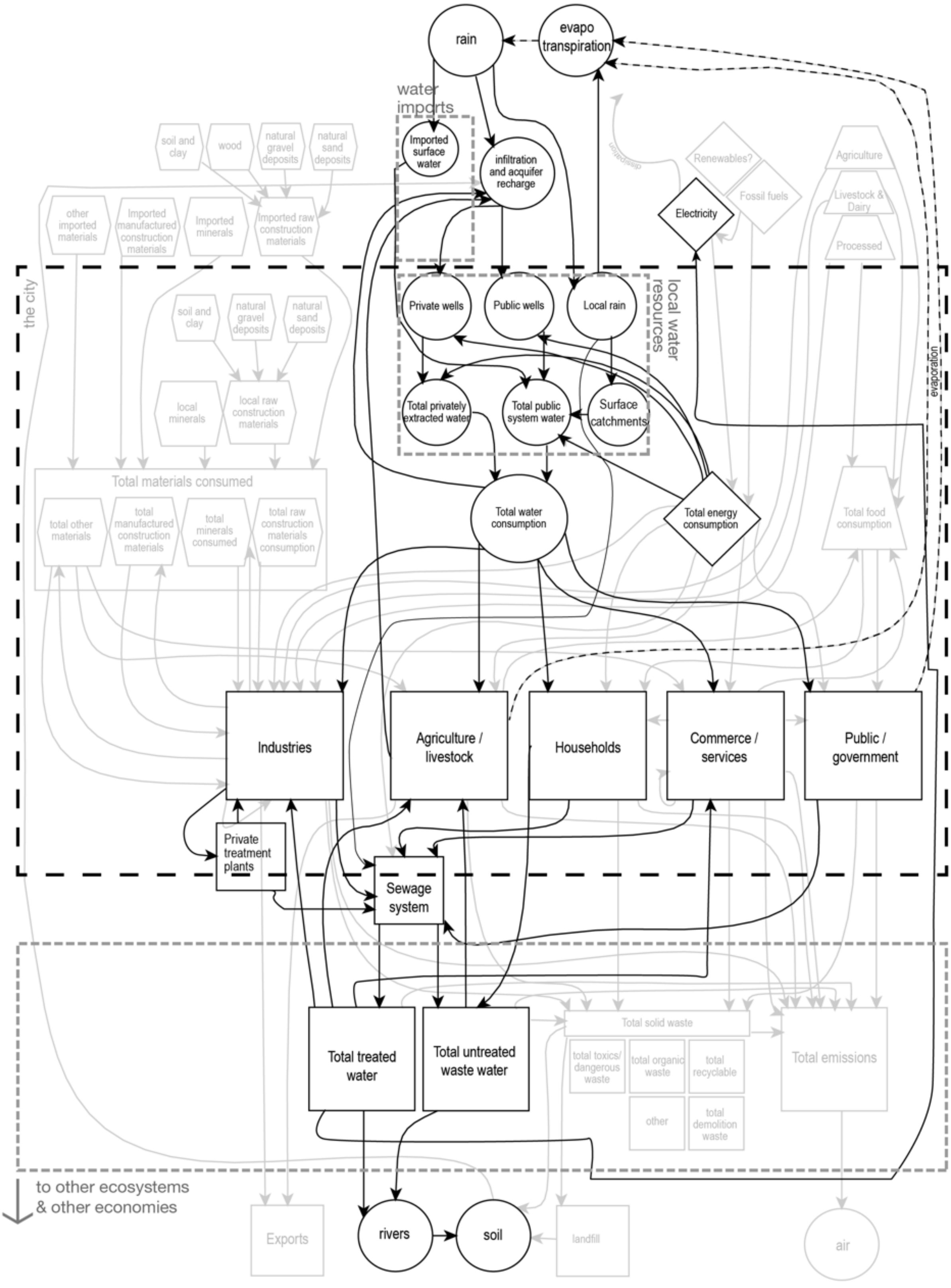


Fig 5.3 The water sub-system in SLP

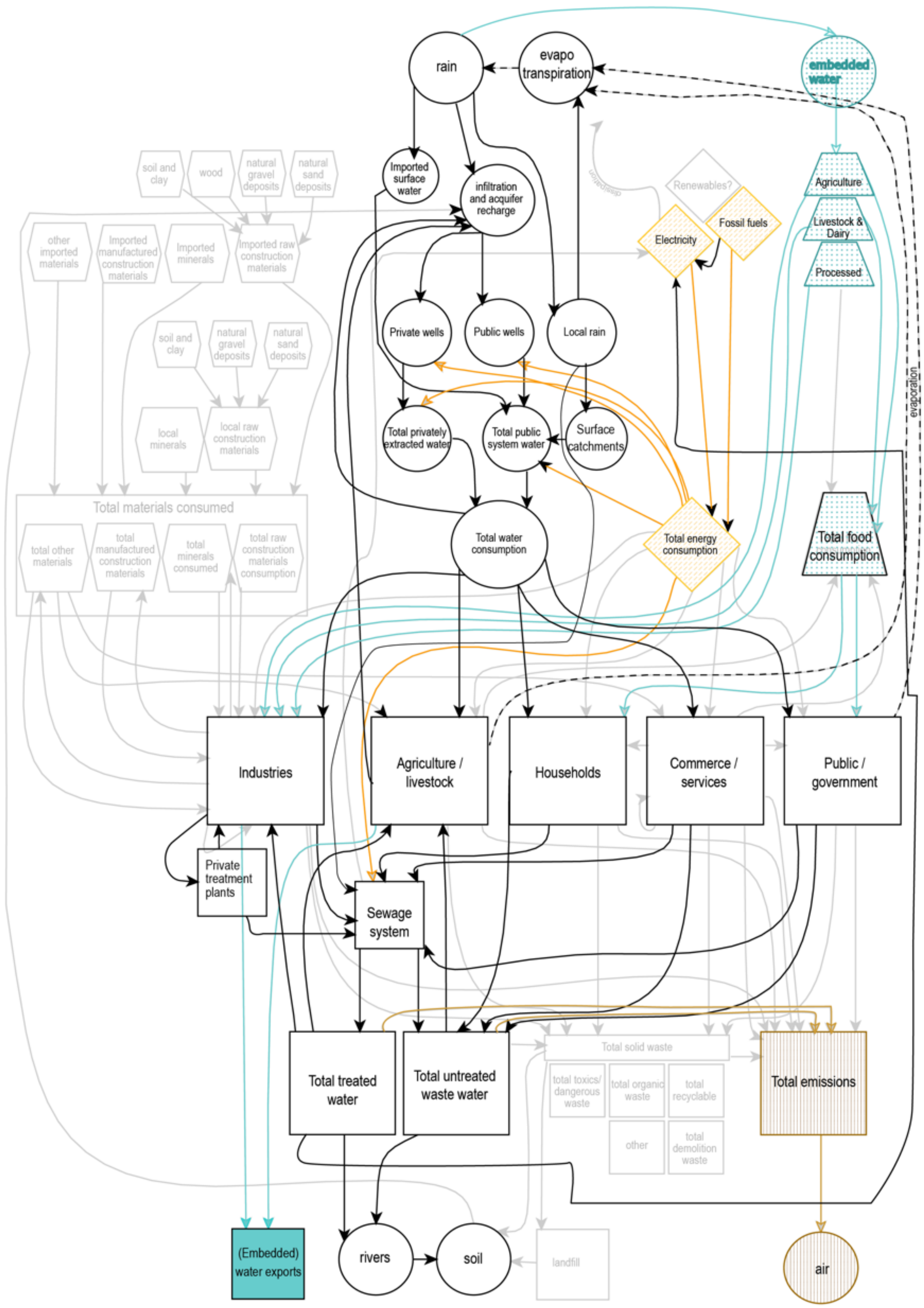


Fig 5.5 The water metabolism structure, now showing also embedded water in food imports, embedded water in food exports (turquoise arrows and boxes), and the energy flows needed to operate the water system structure, which can be considered embedded energy in water. Emissions resulting from water system operation are now also shown. This version of the diagram with embedded flows and including emissions was not quantified, but it served to explore and illustrate further possibilities of the UMA method adopted for this case study.

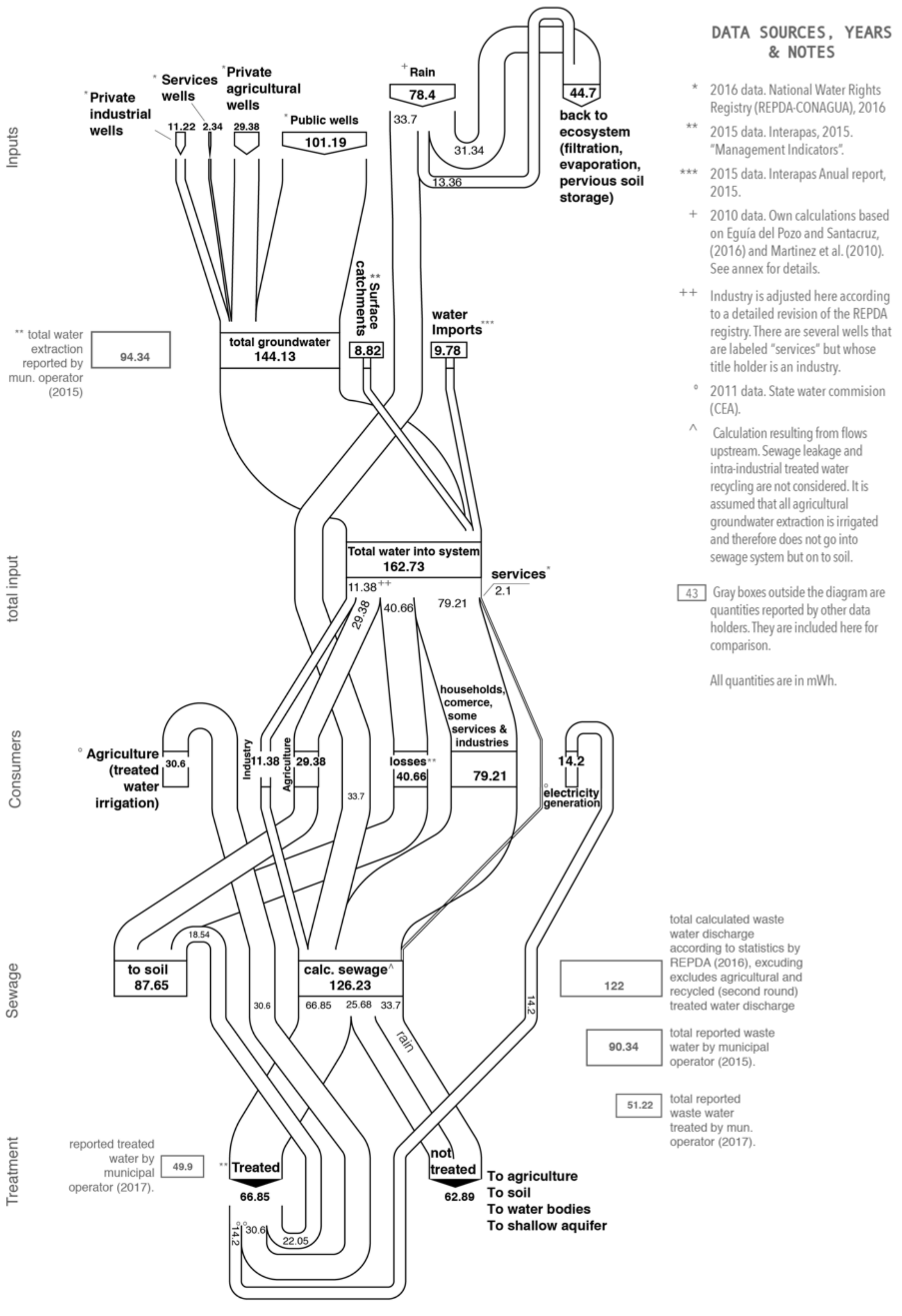
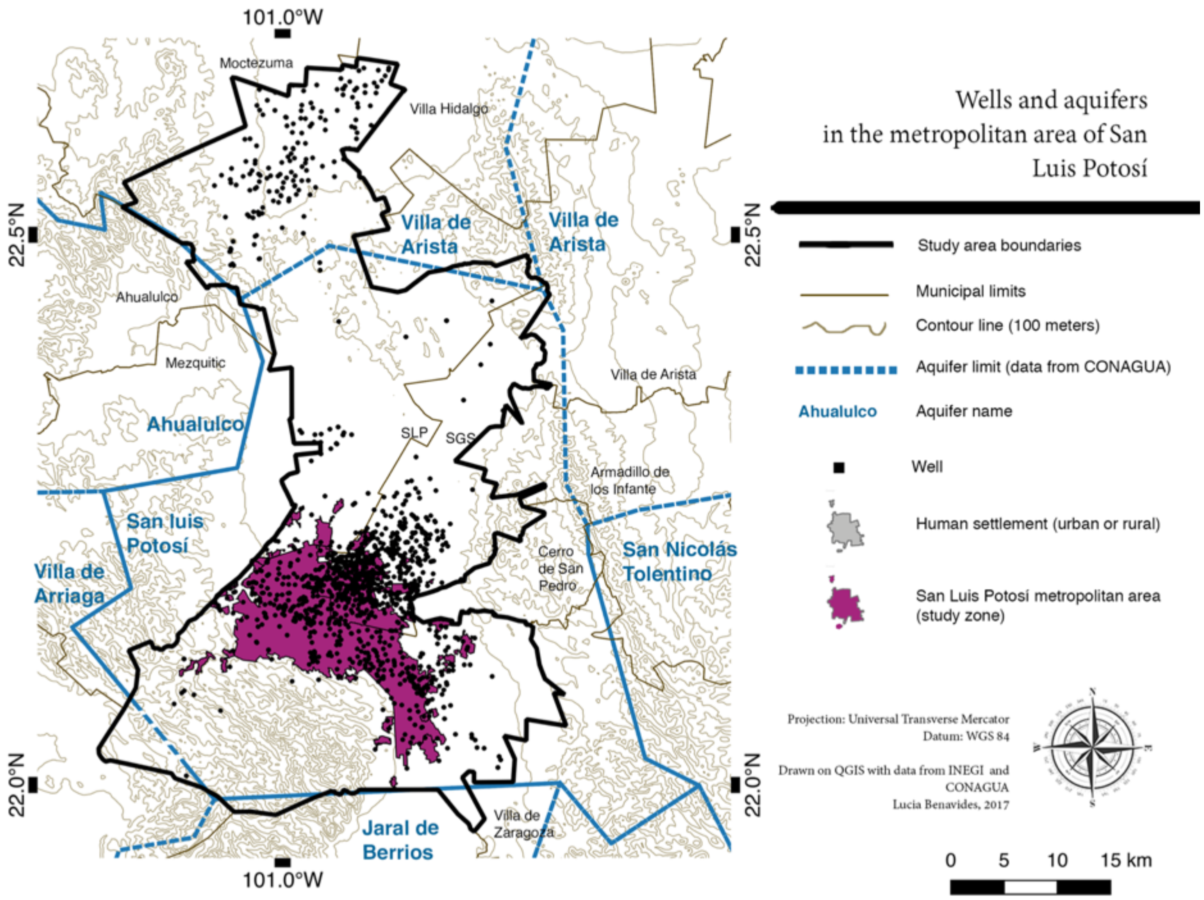


Fig 5.4 The structure of the water metabolism of San Luis Potosí, as quantified with the best data available.

flow in these wells is large enough to make the category "privately extracted water" drop from 46% to 26% if not considered in the total input to the system. These wells are not within the urban continuum, but because the study area comprises the entire surface of SLP municipality, they were identified and initially accounted for. However, because they do not tap into the same aquifer as all other private wells and most of the public wells, and because the area they serve is not part of the urban settlement, it was decided to exclude them from the final calculations.

One of the first things that were made clear when constructing the metabolic water diagrams is that privately extracted water is not accounted for by Interapas or by CEA (the state water commission) in their water consumption reports for SLP. Because it is the federal authority that grants the concessions (Conagua), it is also they who keep track of the water extracted in every region. While this may make administrative sense, it was surprising that not one pubic official made mention of it, when consulting with them about water use in SLP, and that virtually all official reports and documents speak about "water consumption" as though it only included what is extracted by Interapas. As is shown in fig 5.4, the share of privately extracted water is large enough to have to be considered in any water management plan for this city. Furthermore private extraction is again not accounted for by Interapas when it exits private grounds and enters the public sewage system, because waste water outflow is estimated on the basis of water "produced" by the municipal system (wells+dams) minus a transmission loss factor. But it can be assumed that privately extracted water in industries (11.8 million m3) are also channelled to the municipal system, which if true, would mean that the real amount of waste water output is higher than reported. Indeed, federal sources (INEGI and Conagua) report numbers above 61 million m3, as does an Interapas report (2015)[419] obtained through a direct request, which presents the quantity finally used. In general, very few mentions mention to these private wells were found during the data and literature revisions carried out for this thesis, which suggests that at least a fraction of the literature treating water demand and use in SLP may be failing to consider private wells, which account for ~30% of water consumption. The calculations and diagrams shown below have tried to capture these quantities.



Map 5.7 Wells and aquifers in the metropolitan area of SLP. The 164 agricultural wells tapping into the Villa de Arista aquifer were not considered in the calculations. There are 1,250 wells tapping into the San Luis Potosí aquifer divided approximately as follows: 871 for agricultural use, 213 for public use, 87 for industrial use, 69 for services. It is perhaps impossible to know only from the data and reports (i.e. without physically surveying the wells) exactly how may wells are in operation, because data sources are contradictory. For example, Interapas (2015) reports around 127 public use wells, while Conagua reports 213.

Rain water represents an important volume of water input, as well as an underused resource. Accounting for only the rain that runs off impervious surfaces of the city's built continuum, an estimated 33.7 million m3, currently channeled to the sewage system, would be available for use. This is more than four times the volume of the imported water that since january 2015 is brought in from the recently built *El Realito* dam, in the neighbouring state of Guanajuato, through a 132 km aqueduct, and costing the city around 87 million pesos yearly[212]. When estimating the total rain water available for the whole San Luis Valley, Santacruz de León and Eguía del Pozo (2016)[388] find that the whole domestic demand could be covered with less than 20% of the rainfall. In their 2012 report[420], Interapas outlines plans for the construction of absorption wells and other infrastructure to profit from precipitation and reduce pressure on the local aquifer, but no further mention of these plans is made in subsequent reports, and no plans for building such infrastructure are presently known. Efforts seem to be oriented to growing the offer of (imported) water resources through project like El Realito.

Consumption

In the consumption sector, it was not possible to know exactly the amounts of water consumed by different users: industrial, households, commercial and public. The precise request for such information was made on several occasions to both municipal and state-level water officials, with no success. The efforts made to obtain the closest possible estimation will be illustrated by the following example: besides federal concessions allocated to 87 industrial users according to the Water Rights Public Registry[DDD] (REPDA), amounting to 11.8 million m3, according to Interapas (2015)[212] there are at least 1,059 industrial users connected to the municipal water grid. Although it is reported that most of them (986 out of 1,059) receive a metered service, and that the volumes they demand are large[212], these volumes are not disclosed in pubic reports, nor information about them was received after specific requests. Inferred estimations were possible and are presented in fig. 5.4 and in the filled indicators tables the annex. I believe this type of detail is the next step in urban metabolic accounting for SLP, and particularly important would be to look specifically into the consumption patterns of industrial users, as environmental and social impacts have already been associated to intense groundwater extraction by industries and their discharge of untreated or not properly treated flows into the municipal sewer system[376,377]. However, the degree of detail available in the current data makes it impossible to support the common idea that industrial sector is consuming "enormous" amounts of water in SLP. It is clear that, unless the industrial uses hidden within the flow labelled "household & others" were at least 30 million m^3 (which is unlikely) the household sector + leakage are responsible for the largest share of consumption, and perhaps this is where quantitative reductions should be aimed for, while issues of quality, transparency and administrative improvement (regulations, tariffs) may be the priority for industry-related water issues[EEE].

An interesting advance was however made in the visualizing of the amounts of treated water that go to agricultural uses. This figure is somewhat opaque in the literature and reports consulted, and it was seldom clear what the real amount is. Reports often use different units in one same text (lps, m3, Mm3, $), for example, and/or include precise data on some agricultural areas but not on others, etc. This was the case for treated waste water usage. Using different data sources, it was possible to construct the metabolic flow map showing a clearer picture of how waste water consumption is structured.

Finally, the amount of water that is being lost due to leaks is very large: just about the same being extracted from the aquifer to serve industrial and agricultural users. This obviously means that if leaks

[DDD] Estrada (2013)[421] and Santacruz de León and Peña (2016)[422] also examined the Water Rights Public Registry (REPDA) and report only 37 and 26 industrial wells. In my own examinations of this same data source, I found 87.

[EEE] This does not attempt imply that industrial water use has no influential participation in urban matters in SLP. Domestic use is growing, at least partially, in relation to industrial growth that attracts workers and their families into the city. Beyond this link, industrial water use should of course be carefully reviewed, as it is opaque, fails to comply with regulations and its intensity is linked to a dramatic fall of aquifer levels in the industrial zone along with other social and environmental implications[376,377].

were repaired, "suddenly", an important amount of water would be available for use. This water leaked is unfortunately not necessarily simply going back into the underground reservoir of the aquifer, because vertical communication between the shallow and deep aquifers is limited, and because the predominant recharge of the deep SLP aquifer does not occur locally[407,423]. Water lost through leakage of pipes in the water supply system is likely joining the shallow aquifer, which approximately occupies the first ~40 m directly under the city[383,407] and is not used for human consumption due to high contamination levels[421,423]

The problem represented by leakage is well known in SLP. It has been constantly reported both by pubic officials and researchers through the years, but that remains unresolved. This is a good example of the limitations of the metabolic perspective presented here, and that was discussed in chapter 3. Metabolic analysis cannot illustrate these water quality problems or underscore the policy or administrative failure to address the issue. The value of the model resides in that it can, in this case, put the quantitative component of leakage into perspective by nesting it in a comprehensive diagram where other factors of the system are shown. Here, comparisons can be made, and relations found, and eventually the conceptual construction of the problem –and its solutions– could be improved.

Output

Inconsistencies in the data found were a challenge, but they were so particularly in the waste water sub-system. In one same report, different quantities could be reported for one same variable, or the sub-totals did not add up to a reported total. For example, in a report obtained from the State Water Commission (CEA) with information from Interapas[424], it is stated that the total waste water produced in 2016 (the target year was 2015, but they did not have the complete data available for that year) was 51,219,611 m^3, while the sub-totals of "treated" and "non-treated" waste water, reported in the same document, add up to 76,549,748 m^3. In other words, 25 million m^3 that were not accounted for in one category appear when adding its sub-categories. Furthermore, this 2016 CEA/Interapas data varies largely from the 90,336,957 m^3 reported for 2015 in the Interapas document "*Management indicators*"[419], obtained through a direct request to the institution. In fig 4.13 t can be seen that the calculated sewage output also varies significantly from that reported by other sources.

As to the generation of waste water per sector, it cannot be very detailed, both because the consumption section is not detailed enough, and because no direct measurement instruments seem to be in place. While it is more or less clear that agricultural water usage is not contributing to waste water flow, and that industrial and services discharges an should make up for at least 11 million and 2 million m^3 respectively, there is a large agglomeration of all other discharges into one same category.

Fig 4.13 shows the ensemble of the best available data, but it is clear that more detail is needed to better understand how waste water is being produced and how to better manage it. For example, upon close examination of the REPDA, it was found that waste water coming from hospitals and clinics is included in both "services" and "household & others" categories, with it not being clear what the criteria are for classification or how to distil the exact amount of hospital flows from the regular municipal sewage. Nonetheless, the construction of the flow diagram did help illustrate that the real amount of sewage must be larger than reported by local operating facilities, probably because of the same reasons described for the under-reporting groundwater extraction, and underscores the need to further treatment efforts (or reduce waste water output).

2. Energy

Fig 5.5 shows the energy subsystem as derived from the general system description. Energy input is divided into three main components: electricity, fossil fuels and renewable energy, whose presence is merely indicative, as they make up for less than .001% of energy input at the present time[425]. Indeed, it was clear that renewables would probably represent a very small fraction of energy use in SLP, as they account for only ~9% of total energy generation in Mexico[426], but because the information on its participation in the energy mix was available, and it is possible that renewable generation grows in the near future, as it is foreseen in national policy and currently being further explored in SLP and its region, it was decided to include them.

Data at the required scale was not abundant for the energy subsector. In what pertains electricity, its generation in Mexico is centralized, and can only be produced by the Federal Electricity Commission (Comisión Federal de Electricidad, CFE), or by private companies or individuals with whom it establish agreements. Electricity data was sought after with CFE and also in different departments of the national ministry of Energy (SENER), who handles all matters related to energy, including fossil fuels, nuclear generation, etc. Within these government facilities, data at the municipal level was extremely difficult to find and sources were inconsistent, even more so than those for water. For example, two different reports from CFE were obtained: one after a written request to the local SLP office, and one through the open data portal (datos.gob.mx). Both reports were not quite was expected and required significant amount of time to communicate personally again with CFE to clarify the contents. The open data files reported values two orders of magnitude below what was reported in the other CFE report, and also much lower than what was reported in SENER documents, and the proportions of each economic sector participations were absolutely different. Therefore this open data source was discarded. Other sources were surveyed, with the state programme for climate change (Programa de Acción ante el Cambio Climático, PEACC), which was executed at the local university and presented more consistent although older data (from 200-2006), as well as federal INEGI data being among the best available sources.

As to other energy carriers, the PEACC was also one of the best available data sources, together with the State Emissions Inventory. However, their data was mostly aggregated to the state level. Luckily, because SLP is the capital city, and also concentrates the most of economic activity in the state, some specific mentions to its particular case are made where data could be extracted from. Formal requests to obtain further detailed data at the required scale were made to several federal government facilities, with little success. Data on the municipality of Soledad de Graciano Sanchez (SGS), which holds about 25% of the population of the city was of insufficient quality and quantity. Therefore, the calculations presented here correspond only to SLP municipality. The following paragraphs present the best effort to compile and compare these different data sources.

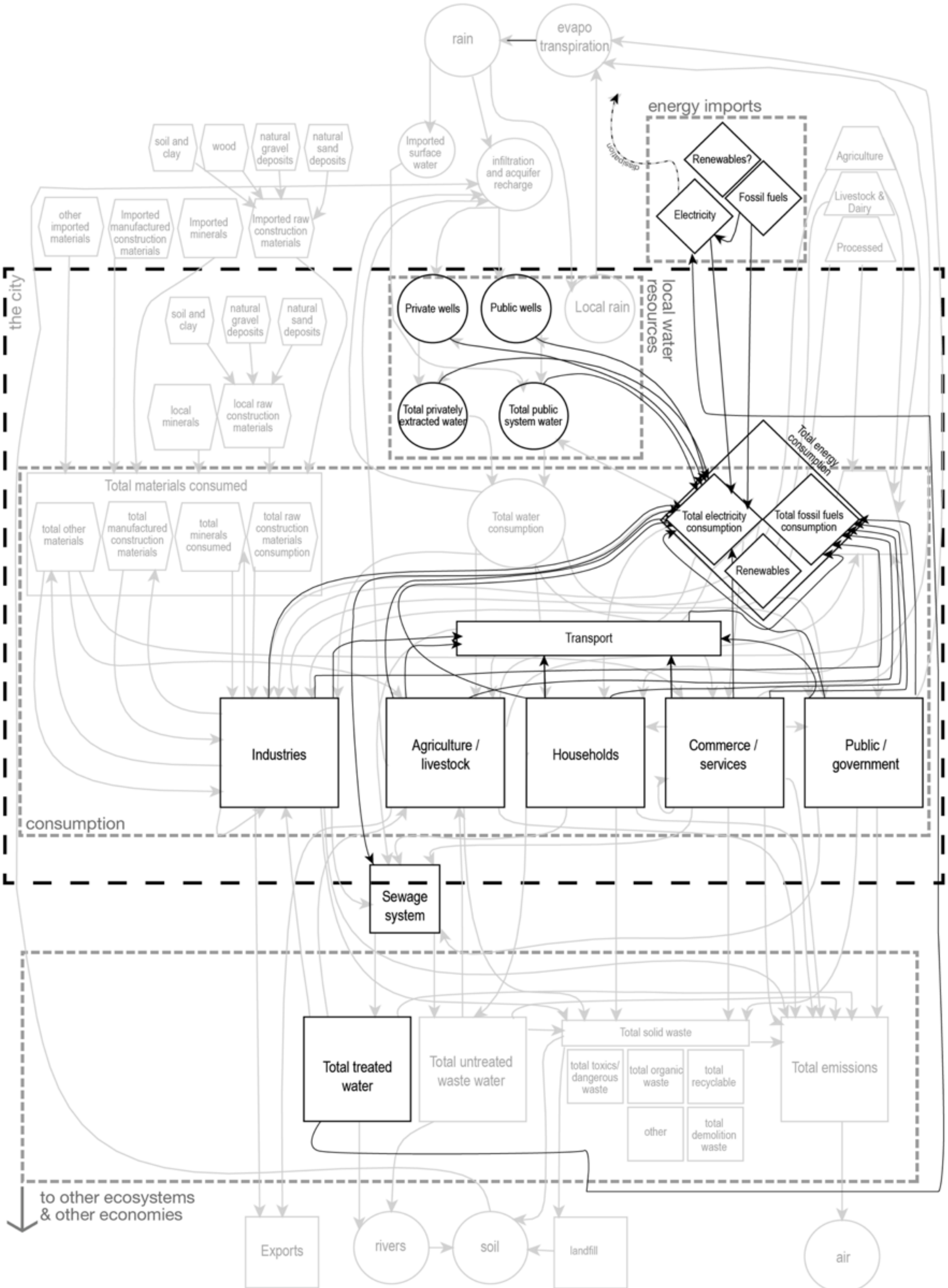


Fig. 5.5 A first approximation to the structure of the energy metabolism of San Luis Potosí.

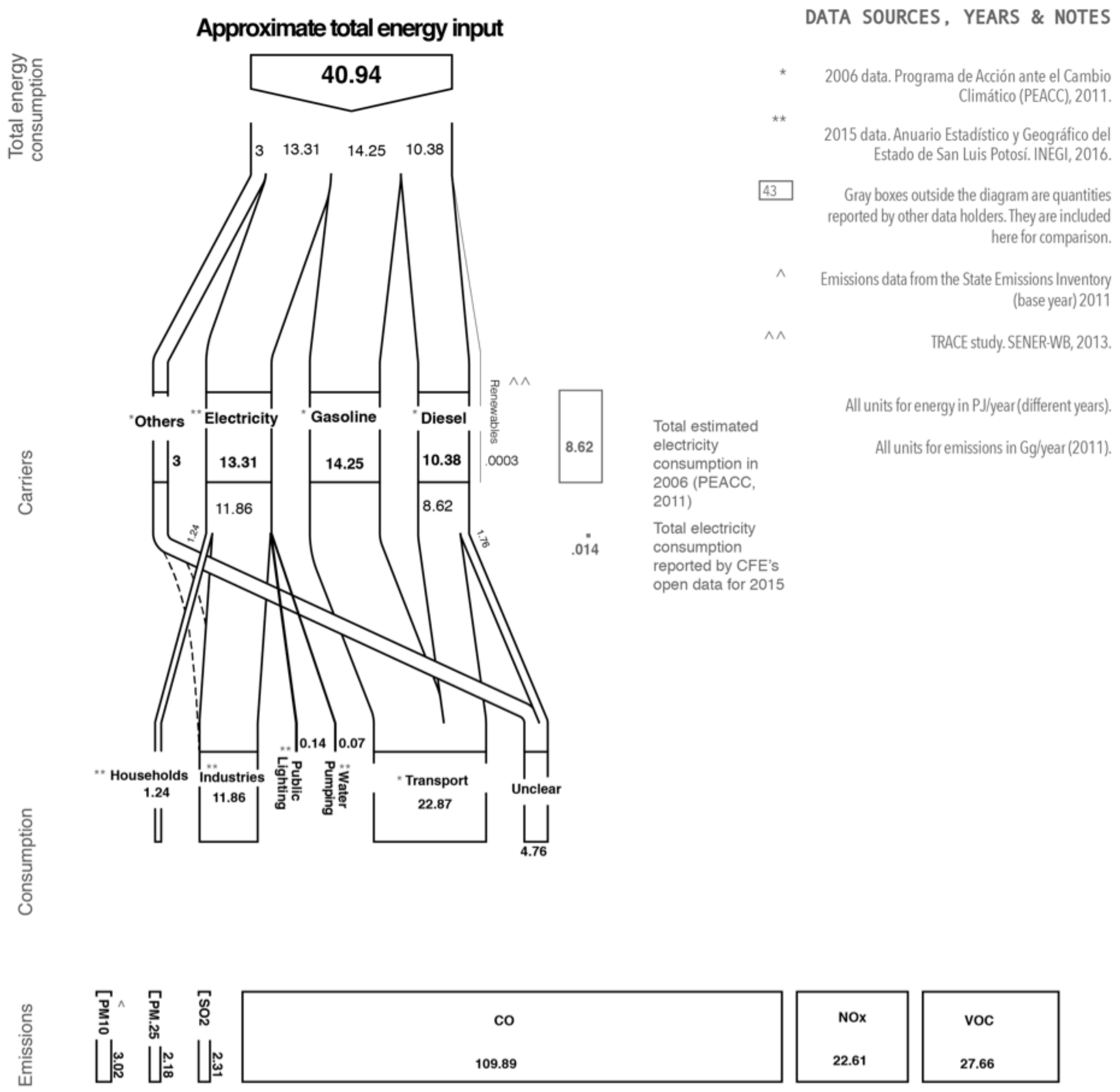


Fig 5.6 A first approximation to the quantification of the energy metabolism of San Luis Potosí, as made possible with the best available data. Note that only emissions in San Luis Potosí municipality are accounted for. The diagram shows the total emissions for SLP municipality, which means that emissions from non-energy sectors are also included. Only agriculture-related related emissions have been deducted. This is because, with the information available and within the time frame of this work, each sector's contribution to emissions and to each compound group could not be clearly singled out. For instance, the wastewater and solid waste sectors are poorly studied in terms of their contribution to emissions, as is land use change, which is not reported at all in the emissions inventory. Although the amounts of each compound are disclosed in the state inventory, the exact proportion that each economic actor (households, industries, etc) contributes at the municipal or city scale is not (the emissions inventory is state-wide). Because energy-intensive activities such as transport and industrial production are indeed linked to major emission compounds such as CO and NOx, energy and emissions are presented here together but unlinked, underscoring the need for further research to more accuraetly attribute missions to energy carriers and economic activities at the municipal and city scale.

Input and consumption

It is straight forward to see in the illustrations and was also foreseeable that industry and transport are the largest energy consumers and also the largest emitters[427]. Fossil fuels are by far the largest share of energy carriers input into the city, and are all imported, as no production occurs inside the city bounds. The PEACC provides some level of detail as to the origin of these carriers, and with further research in federal databases which keep a detailed track of origins, destinies and movements of energy carriers inside the national territory (although such disaggregation does not seem to be publically available), there exists the possibility to trace the links directly to the sources of the fuels consumed in the city, which would allow for a comprehensive environmental impact assessment (step 7) including for example detailed footprinting and quantifying hidden flows in consumption inside SLP.

Transport is by far the largest single energy consumer (~55%). A highly inefficient public transport system reciprocally reinforcing and reinforced by a heavy orientation towards private car-based transport both in urban development policy and in the population's personal preferences, along with the important role of the industrial zone, shape the largest energy-consuming node (transport) and ultimately, the whole city's energy mix. Indeed, SLP and its adjacent municipalities concentrate about >70% of the total vehicles in the whole state, and ~77% of the diesel engine vehicles[428].

Electricity makes up for about 1/3 of energy consumption, and is largely concentrated in the industrial sector (85%). Electricity for households comes next, with abut 3% of the consumption, with electricity consumed by street lighting and water pumping (both for agricultural use and for the public water system) demand together <1%. The exact shares of consumption of both electricity and fossil fuels within the industrial sector were however not possible to know, as they were not published in any of the datasets and reports reviewed for this thesis. During the research period for this thesis, it was though it would be possible to estimate energy consumption per economic sector and sub-sector through a method similar to economic input-output tables, perhaps scaling regional input-output tables that have been recently estimated[429] for Mexico, and using the economic census data that provides detailed information on the behaviour of each sub-sector in monetary terms, along with and literature coefficients of energy use in different industrial types, or INEGI microdata that can be available to researchers upon written, official request. Another possibility, and perhaps easier to perform calculations with, would be to request details on size, inputs and energy bills for each each of the ~500 industrial facilities operating in SLP (or a sufficient sample), through perhaps the state government economy department or a similar governmental facility. While it was impossible within the time frame of the present work to finally carry such calculations out, these possible ways to them were envisioned and rest as a future possibility.

Something similar occurs with emissions. The state-wide inventory, made in 2013 with 2011 base year data[427] gives some information for selected municipalities, including SLP and SGS, but not sufficient to understand the contribution of different economic sectors in emissions at the municipal scale. There is no information on the roles played in emissions by solid waste, waste water, land use change or the construction industry, for instance, in this report. It does mention relative contributions of agriculture different industries, transport and other sub-sectors, but only at the state scale, and the behaviour of each of these sub sectors is likely to be quite different when looked at at the city scale, where some activities found in the state don´t exist, while others have a much more predominant role. The metropolitan scale ProAire study does disclose the relative contribution of different sources (mobile, fixed, area and others), with a finer level of detail, but they are aggregated to include emissions from both municipalities, and because the energy data analysed here was only for SLP municipality, ProAire could not be used to allocate emissions to the different energy-consuming sectors.

3. Food

Figure 4.16 shows the structure of the food metabolism, including production and consumption, of San Luis Potosí. One very clear first impression from the analysis of the subsystem description in fig 4.16, is that the food system is linked to many more components at all stages than the other two sub systems analysed. This points to its dual role as both a producer/supplier and a consumptive economic sector. The role of the water sub-system, in contrast, is preeminently that of a supplier, although it of course consumes energy and some materials, but its need for inputs is minimal in comparison to its output, both in volume and in scope: the water system needs relatively little contribution from other sectors to operate, while in comparison all others sectors are irreplaceably dependant on water for their operation. Similarly, the energy subsystem, has a more succint set of interrelations than that of food, very clearly exemplified by its participation is outputs: while indeed consuming some materials that turn to solid and liquid waste, the energy metabolism produces, volume-wise, mostly only gaseous and particulate emissions as outputs (see figs. In water and energy sections).

Food production is dependent on all other subsystems, insofar as no food can be produced without water, but water can be extracted without using food, for example. Of course, humans who participate in the extraction of water do need food to live, but water itself would continue to be available for extraction even if the food system were to collapse, while the opposite is not true. On in the input side, the food metabolism relies on water, energy and materials inputs, and on the output side, is heavily related to outputs in all categories: emissions, solids (nationally, 52% of solid waste is organic[430]) and also with toxic or dangerous waste, when mismanagement of synthetic pesticides and herbicides as well as high concentrations of nitrates and other characteristics of modern agricultural production are considered. Indeed, food being not only a vital need but an important economic sector, is also an intricate and highly interwoven subsystem of the metabolism of a city, with outgoing and incoming edges leading into mostly all other sectors and nodes

A large part of industrial activity in SLP is concerned with food manufacturing and processing subsector (26% of total manufacturing facilities[415]). Industrial food production must therefore be accounted for in the food subsystem characterization and is thus included here (fig 5.7). Its material, energy and water usage, as well as outgoing wastes may be quite important in SLP and are currently understudied, but because it was not possible within the limits of this thesis to cover both agricultural and industrial aspects of the food system, the choice was made to focus data gathering efforts on agricultural production-and consumption only.

Inputs

Water imports were excluded from the subsystem 'agricultural production and consumption' because according to Interapas (2015)[212], these imports, coming from the *El Realito* dam, serve only to supply domestic connections in the southern parts of the city, and are not used for agricultural production. Irrigation is then made on the base of extracted groundwater and waste water, both treated and untreated. Groundwater extraction for agriculture is equal to about half of the volume of water extracted by Interapas for (mostly) domestic use, and agricultural extraction is shared almost equally between two aquifers, while most domestic use water and all industrial use water is extracted exclusively from the San Luis Potosi aquifer (see map 4.7). Although agriculture is a water intensive activity and currently uses about about 4 times more groundwater than industry (or 2.5 times if only the SLP aquifer is considered), its water extraction is better distributed in the study area than is industrial and domestic extraction, and thus the pressure exerted on water resources in the SLP valley does not seem to come primarily from the agricultural sector but from the hiperconcentration of industry and dwellers on the SLP aquifer area.

The amounts of treated wastewater used in production are those reported in a presentation available online, made by the State Water Commision (CEA) in 2011[431]. It was the best and most recent data available. As for waste water used, no information was found, exept that provided by the very thorough research carried out by Cirelli (2004)[405], which was however completed at a time when waste water treatment levels were much lower than today, and therefore discarded as a data source, because they would fail to reflect the current situation. This flow then remains unknown, but it is likely that a good share of the untreated waste water flow (~60 million cubic meters) flow is being used by farmers in parcels around the city.

As for energy inputs, the panorama is still rather incomplete, as they only clear data was on electricity used for water pumping, which is at around 60 TJ or 7,065 mWh. Fuel consumption is scarcely reported and can be seen reflected as emissions in the output stage in fig. 417. Other energy uses in the agricultural sector (tractor and machinery fuel, greenhouses, portable motors) remain to be unveiled. Fertilizer was estimated using the national average use of fertilizer per hectare provided by the World Bank for Mexico, as no local information was found in enquiries made to municipal and state government facilities. Rainfall on cropland was calculated using cropland surface provided by the federal agricultural data base SIAP[432] for SLP and SGS along with average local real rain fall as calculated by Santacruz and Eguía del Pozo and (2016)[388] for 2010 for the SLP valley. Data availability and the extent to which it was possible to bring together different sources in a coherent manner do not allow to make any concluding remarks about, for example, the energy or materials intensity of the agricultural sector, but efforts in this direction can be continued on the base of the metabolic diagrams presented here.

Production

Production reported in the diagram is as reported for SLP and SGS municipalities by the federal Agriculture and Livestock Information System (SIAP), which is the main information source on agriculture, and also the source where the State Agriculture Secretariat (SEDARCH), obtained the information they provided (discarded, as it was 2005 and 2010 data). The SIAP only reports 27 crops for SLP+SGS, likely the most important ones in yield. It can be assumed that either a fraction of the production is not reported because it is too small in yield (e.g. small land holders producing self consumption crops), or production is indeed quite small in the region. It is likely that both are true, as agriculture production in the region has drastically declined in the last decades[376]. No fruit production is reported in either municipality. Meat and fodder production is rather large in comparison to legumes and vegetables, with Soledad de Graciano Sanchez occupying the state's second place in goat production, and the state itself, the second nationally[415].

The relative share of resources allocated to livestock versus agriculture were impossible to know with the data gathered. The data does however display that SLP local production is focused on fodder and meat, and that meat production is more than four times larger than local demand. This information points to possibly important quantities of exported embedded water and perhaps biomass (if fodder is exported into other regions, which is not certain), and likely underestimation of sectorial emissions. Also, because no fruits are produced and local production of legumes is ~22% lower than estimated fruit and legume consumption, it is clear that SLP has food "supply lines", or metabolic linkages to other regions that need further study to assess their possible environmental implications. Finally, declining agricultural activity combined with marginalisation of formerly rural populations[376,433] seem to suggest that, although not a policy priority, reinvigorating agricultural activity, under a new sustainability paradigm in terms of water and resource consumption, may be an interesting option for economic development.

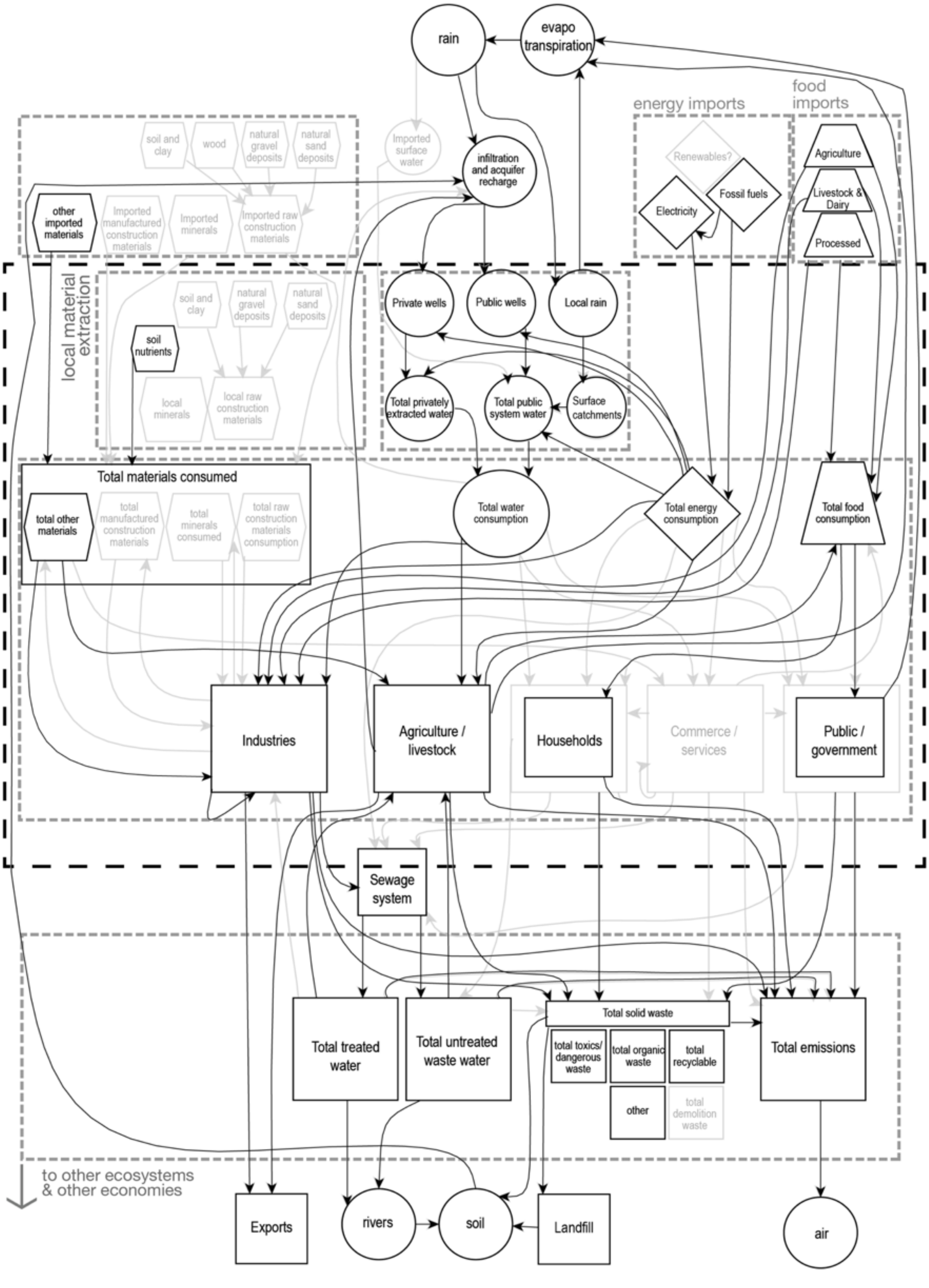


Fig 5.7 A first approximation to the structure of the food metabolism of San Luis Potosí.

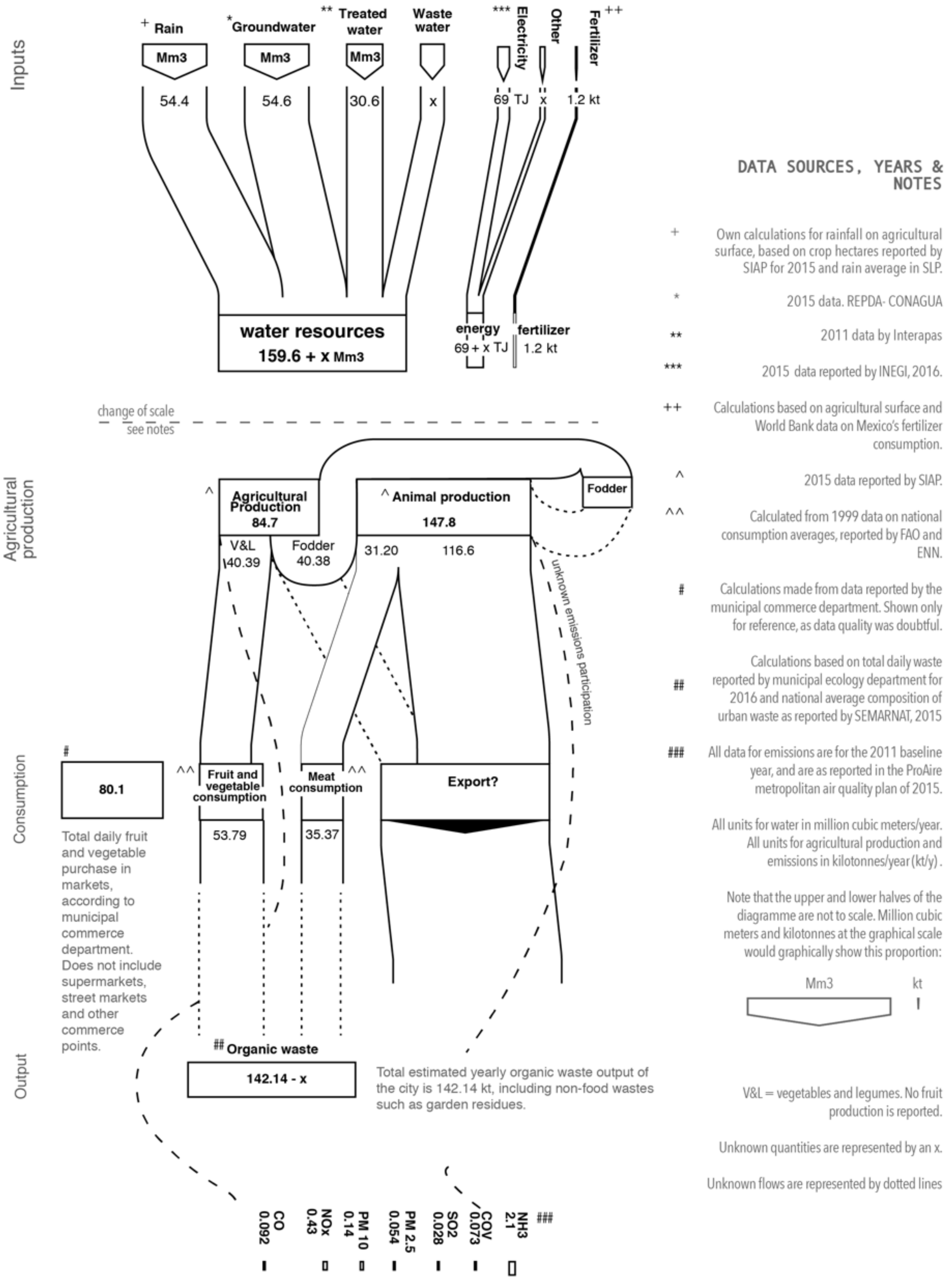


Fig 5.8 Quantification of the food metabolism of San Luis Potosí, in the particular subsystem 'agricultural production and consumption'. This diagram focuses on agricultural production and consumption, including main crops and meat, and excludes industrial food manufactures. The quantities are a first approximation, as there are several unknown quantities in all stages. Particularly under reported seem to be emissions associated to agricultural production.

Consumption

Consumption quantities were not possible to find exactly, and were estimated on the base of the results of the National Nutrition Survey of 1999 (ENSANUT), which is still used by FAO[434] in its statistics for Mexico. At the beginning of this research, it was thought it would possible to estimate food consumption by knowing the amount of food purchased, and that municipal or state government facilities would be able to provide information on the matter. Long attempts were made through different potential data holders. Besides public online databases, potential data holders explored were the state economy secretariat (SEDECO), and the municipal commerce department, where all markets and retailers are registered and obtain operating permissions. "Markets" include established markets and "nomad" markets known as *tianguis*, which change their location every day. After about two months of paperwork, appointments and requests to state and municipal government facilities, it was only possible to know how many fruit stands there are in the city (338 in tianguis and 373 in markets, 711 in total), and where they are. The specific request was made to obtain an estimate of the produce and meat sold. The data received did mention 320 daily tons of fruits and vegetables handled in markets, but the figure was discarded as it what inconsistent with other more reliable figures, such as per capita average consumption[FFF].

In the light of unreliable results, the possibility of performing estimations by directly interviewing market vendors was studied, and field visits were made to the local *Central de Abasto*[GGG], to one market, two supermarkets, three *tianguis*, and one large neighbourhood fruit and vegetable shop. Several conditions, including the political affairs of *tianguis* leaders and an automatic distrust of strangers asking questions, made most of the vendors unwilling to participate in the survey, and all who provided information were somewhat reluctant and/or their information resulted sometimes plainly incredible. One supermarket manager was interviewed and did provide helpful information (see footnote I), as did also the large neighbourhood shop, whose owner even took out his accounting book to provide precise data. Because at the beginning of this research it seemed certain that requests to government sources

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[FFF] If one applies the national fruit and vegetable consumption average (~47,5 kg/y) to the total SLP population, the demand for fruits and vegetables should be somewhere around 54,000 t/year. The quantity provided by the municipal commerce department (320 t daily) results in ~81,000/year t of fruits and vegetables, if only working days are considered (253 days), and this without accounting for demand in *tianguis*, supermarkets and smaller stores. Even assuming that supermarkets serve a much smaller share of the demand than *tianguis* and markets, because there are at least 95 supermarkets in the city[433], the figure must be at least of some importance. Indeed, a supermarket manager who was interviewed (and willing to participate), provided data that allowed for an estimation of a supermarket's yearly sales of fruits and vegetables: ~71 t. If both quantities were true (commerce department and supermarket manager) SLP food demand would be well over ~87,000 t, in order to include the amounts that tianguis and smaller shops sell. Even when a large waste factor of food bought but not consumed (for example, the frequently cited 30% food waste), estmated demand would be well below these numbers.

[GGG] The *Central de Abasto* is the main food supply centre of a city (and normally, its region) in Mexico, handling millions of tons every day. The Central de Abasto in Mexico City, for example, handles around 30,000 t every day. (The one in SLP is evidently much smaller, but still regionally important). A very large share of food consumption in any city in Mexico passes through the local Central de Abasto, whose retailers are normally well organised in merchant associations and are many times part of national and international food retail networks. They keep detailed registries of their financial transactions. I visited their facilities twice, obtained and held an interview with the *president* of the Central, and was assured that they had and would share much detailed information, including yearly volumes handled and national/international origins of many products. This data would have drastically changed the course of this research and the perspective of the food sub-system presented in fig. 4.17, but it unfortunately never arrived. If a f*oodprint* or food metabolism study is to be made, the Central de Abasto is a key (although perhaps not very accessible), stakeholder to consider, probably holding more detailed and more precise data than government facilities themselves.

would provide the necessary information, the bottom-up/survey data generation option was only explored at the end of the field phase as a possible emergency option, when the data obtained so far proved to be of little use. While the information obtained through surveys work seemed of much better quality than the official data, it could finally not be used because the original field plan did not include field surveys and the statistical design and adjustments they require, and there was in reality no space or time to accommodate them. The experience was nonetheless quite useful to illustrate how a consumption-based survey of the *foodprint* of SLP would be possible. Proper planning would need to include a networking phase and researchers would probably require credentials that encourage functionaries and other stakeholders to participate.

Outputs

Emissions were allocated to agricultural production activities following the Metropolitan Air Quality action plan (ProAire) which used 2011 as a baseline year and was published in 2015[435]. The first data source for emissions which was used for the energy sub-system (the State Emissions Inventory)[427] states the proportion of the participation of agricultural activities per emission compound at the state scale (5% of CO, 7% of NOx, for example). However, the relative shares of agriculture in emissions of each compound very likely vary widely from the state-wide panorama to the urban case, given that SLP concentrates much of industrial and transport activities of the state. A cross check exercise was made, reviewing what is reported by ProAire (metropolitan scale), which discloses the shares in the emission of each compound group of several precise activities. It was found that, according to ProAire, agriculture-related activities account for only <.1% of CO, and 1.68% of NOx emissions in metropolitan SLP, a very large variation from the what is reported in the state inventory. Therefore, agricultural sector emissions were calculated following ProAire[HHH]. This has the inconvenient that fuels used in tractors and other mobile sources of the agricultural sector seem not to be reported, and "biogenic" emissions are not disaggregated to differentiate, for example, urban parks from cropland. No methane is accounted for, and emissions linked to the more than 84,000 tons of meat produced are then certainly under-reported[III]. Furthermore, no land use change emissions, deforestation or soil perturbation emissions are reported either. Emissions linked to agricultural production then appear to be quite small. I believe a closer look at the agricultural sector, for example through an agriculture emissions inventory, would likely result in much higher quantities.

Because almost each data component in the metabolic quantification diagram (fig. 4.17) came from a different source, and there are still some unknown flows in the subsystem, it is likely that the figures presented here are underrepresenting the real consumption of resources by the agricultural sector, as well its real outputs in terms of emissions and waste, and that inconsistencies will emerge upon closer

[HHH] It should be noted that emissions of the energy sector were calculated following the State inventory and only including SLP data (not SGS), making the emissions of two subsystems slightly different and not directly comparable.
[III] FAO statistics are between 300 and 50 ton CO_2e per kg. of animal protein produced, depending on the type of livestock.

examination and cross-checking. The metabolic perspective however has the virtue of explicetly showing these data gaps and inconsistencies, and the advances made here seem promising for future refinement. Important points to study next, and whose study can be done on the bse of the work presented here, would be, in my opinion: (i) consumption-based *foodprint*, which would allow for detailed descriptions of nutrient and biomass flows (import-export) and their spatial behaviours, as well as their environmental implications both locally and outside the city; (ii) resource intensity and emissions of agricultural production, and (iii) the industrial food sector, which is currently largely understudied and was not treated in this thesis.

5.3 Step 7 – Environmental impact assessment

Urban development and industrial activity are known to local researchers to be understudied[406,436], and although advances have been made, notably in water topics (e.g.[377,405,422], as well as in emissions[427,435]) no comprehensive, cross-sectorial or multidisciplinary studies that shed light on overall and/or systemic environmental behavioural patterns and their local and foreign environmental impacts have been published[JJJ]. Export goods production is driving an increase in material and energy consumption (which can be visualized by making a metabolic map series comprising several years), and an occupation of land and water resources, whose net benefits are not clear to everyone[377], as in reality the effects of this growth on the social en ecological system are simply not sufficiently studied. Gaps in knowledge far outnumber certainties, with particularly urgency found in establishing basic knowledge (e.g. some estimates exist, but the real amount and composition of waste produced by the city is not known) to be able to assess city-wide sustainability. The work carried out in this thesis suggests that general research lines are needed around the fact that SLP is not only exporting auto-parts and electrical appliances but also embedded biomass, water, nutrients, and using in the process increasing amounts of energy. Also, it is importing a likely increasing amount of foreign nutrients that are not being dispersed back into ecosystems, but rather are being concentrated and mixed with other compounds in landfills, soil and water bodies.

Baccini and Brunner (2012)[50] have proposed a set of basic criteria for assessing the sustainability of an urban metabolism:

1. *Demand of essential goods (as water, biomass, construction materials and energy carriers) can be satisfied autochtonously by more than 80% in the long term. The degree of self sufficiency, arbitrarily chosen with respect to a set of essential goods, determines the ecologically defined border of an urban system.*

2. *Remaining needs can be covered form the external market in such a way that the global resource stock is not reduced significantly.*

3. *The outputs are no burden for future generations.*

4. *No environmental system may be used as a sink for anthropogenic flows in such a way that the receiving system or part of it becomes a hazardous site for the biosphere.*

[JJJ] There are (fortunately) several studies treating issues such as the social dimensions of waste management, or the land use changes in a certain region of the periphery resulting from industrial growth. But no city wide, multiple topic study or compendium of studies seems to have been made to discuss the general sustainability of SLP. A doctoral thesis[437], on sustainability indicators for SLP, attempting a multi criteria sustainability assessment of SLP is the only example I found of such a study.

The main advance accomplished here is the trial of a method that would allow to assess the criteria above. The metabolic diagrams constructed compile and disclose knowledge, and allow for calculations and analysis that permit to answer the questions posed by these criteria. The metabolic maps make it possible to either identify data gaps that need to be covered in order to assess impacts, or perhaps to go ahead and perform some first approximations to the impact assessment of certain compartments of SLP metabolism. For example, using the food sub-system description as a base, it would already be feasible to perform a first approximation to the estimation of food production sector emissions (not well covered by the emissions inventory). LCA, MFA-LCA could be used in this operation, for example. Biomass depletion or imbalance caused by the food sub-system through meat exports, could also be assessed with the food metabolic map, enriched perhaps with field surveys. Such a study could underpin further research into the implications of meat exports on soil and ecosystem health and/or on future food production capacity.

The degree of self sufficiency in terms of food, energy and water can also be studied through the metabolic maps presented here, when combined with resource availability and carrying capacity information. Also, with some refinement, the energy diagram makes it possible to estimate the energy intensity of the SLP economy, or of its inhabitants' lifestyle, or of a certain economic sector, all bits of information which are currently unknown.

The time limitations of this thesis made it impossible to further explore this step 7 of the proposed method. Also, it is true that the metabolism description exercise seems to have produced more additional questions than answers (how much energy is cattle raising consuming and what emissions is that causing? How much water are industries extracting under a "domestic extraction" label? How much food is being turned into nitrogen output in water bodies? How self sufficient in terms of food is SLP?) However, it seems clear that these type of questions first need to emerge (know what we don´t know), and then be answered, before a thorough environmental assessment of SLP can be made.

5.4 Data availability report

Data availability is assessed using the original indicator table, and showing which indicators were obtained, which ones were so partially, and which ones were not, as well as which were estimated of inferred. The details on data sources, calculation methods and other information for each indicator can be consulted in the Annex 2.

Table 5.1 Data availability for the indicator set

			found / reliable	found / unreliable or outdated	found/ partial	estimated or inferred	not found
CONTEXT	A						
	A.1	City surface	■				
	A.2	Population size	■				
INFLOW	B						
	B.1	Total water imports	■				
	B.1.1	Water imports origin	■				
	B.2	Total Groundwater abstraction	■				
	B.2.1	Groundwater abstraction (total public wells)	■				
	B.2.2	Groundwater abstraction (total private wells)	■				
	B.2.2.1	Abstraction private wells (industry)	■				
	B.2.2.2	Abstraction private wells (agriculture)	■				
	B.3	Surface water	■				
	B.4	Total rain water				■	
	B.4.1	Rain water discharged into sewage				■	
	B.5	Total Energy consumption				■	
	B.5.1	Total electricity demand		■			
	B.5.1.1	Electricity by sector - households		■			
	B.5.1.2	Electricity by sector – industry and commerce		■			
	B.5.1.3	Electricity by sector – public lighting		■			
	B.5.1.4	Electricity by sector – water system		■			
	B.5.2	Total fossil fuels consumption					■
	B.5.2.1	Fossil fuels by type - Gasoline		■			
	B.5.2.2	Fossil fuels by type - Diesel		■			
	B.5.2.3	Fossil fuels by type- others					■
	B.6	Renewables generation	■				
	B.7	Main raw agriculture products					■
	B.8	Meat					■

Table 5.1 (continued) Data availability for the indicator set

	C		found / reliable	found / unreliable or outdated	found/ partial	estimated or inferred	not found
PRODUCTION	C.1	Fruit and legume production	■				
	C.2	Fodder production	■				
	C.3	Meat	■				
	D						
CONSUMPTION	D.1	Total Water consumption				■	
	D.1.1	Water consumption per sector - household				■	
	D.1.2	Water consumption per sector - industry				■	
	D.1.3	Water consumption per sector - agriculture				■	
	D.1.4	Water consumption per sector - commerce					■
	D.1.5	Water consumption per sector – public facilities				■	
	D.1.6	Water losses due to leakage	■				
	-	Electricity per sector – see inflow indicators					
		Total fuels use – see inflows					
	E.1	Total municipal solid waste		■			
	E.1.1	Destination(s) of municipal wastes			■		
	E.1.2	Total organic waste				■	
	E.1.1.3	Total toxic/ special waste					■
	E.2.2	Destination of toxic wastes					■
	E.3	Total waste water		■		■	
	E.3.1	Waste water - domestic					■
	E.3.2	Waste water - industrial				■	■
	E.4	Waste water treated	■				
	E.5	Destination of waste water	■				
	E.5.1	Users of waste and treated water - industry					■
	E.5.2	Users of waste and treated water - agriculture					■
	E.6	CO2e	■				■
	E.6.1	SO2	■				
	E.6.2	NOx	■				
	E.6.3	CO	■				
	E.6.4	VOCs	■				
	E.6.5	PM10	■				
	E.6.6	PM2.5	■				
	E.6.7	Methane					■
	E.6.8	O3					■
	E.6.9	Black carbon					■
	E.6.10	NH3	■				

Another way of visualizing data availability that proved useful in the course of this work, was to directly mark on the system maps the boxes and arrows whose quantities are unknown or uncertain. Fig 5.8 presents the status of data availability for the water sub-system. Opaque boxes represent, precisely opaque compartments, and undefined arrows represent unclear or unknown flows. This way of representing data knowledge can be refined to make finer distinction of the degrees of uncertainty, but already is useful to know, for example, that the incoming fraction of the water metabolism is much better known than the outgoing fraction, and that agricultural water use is the only one of the consuming sectors that is well studied is terms of water use.

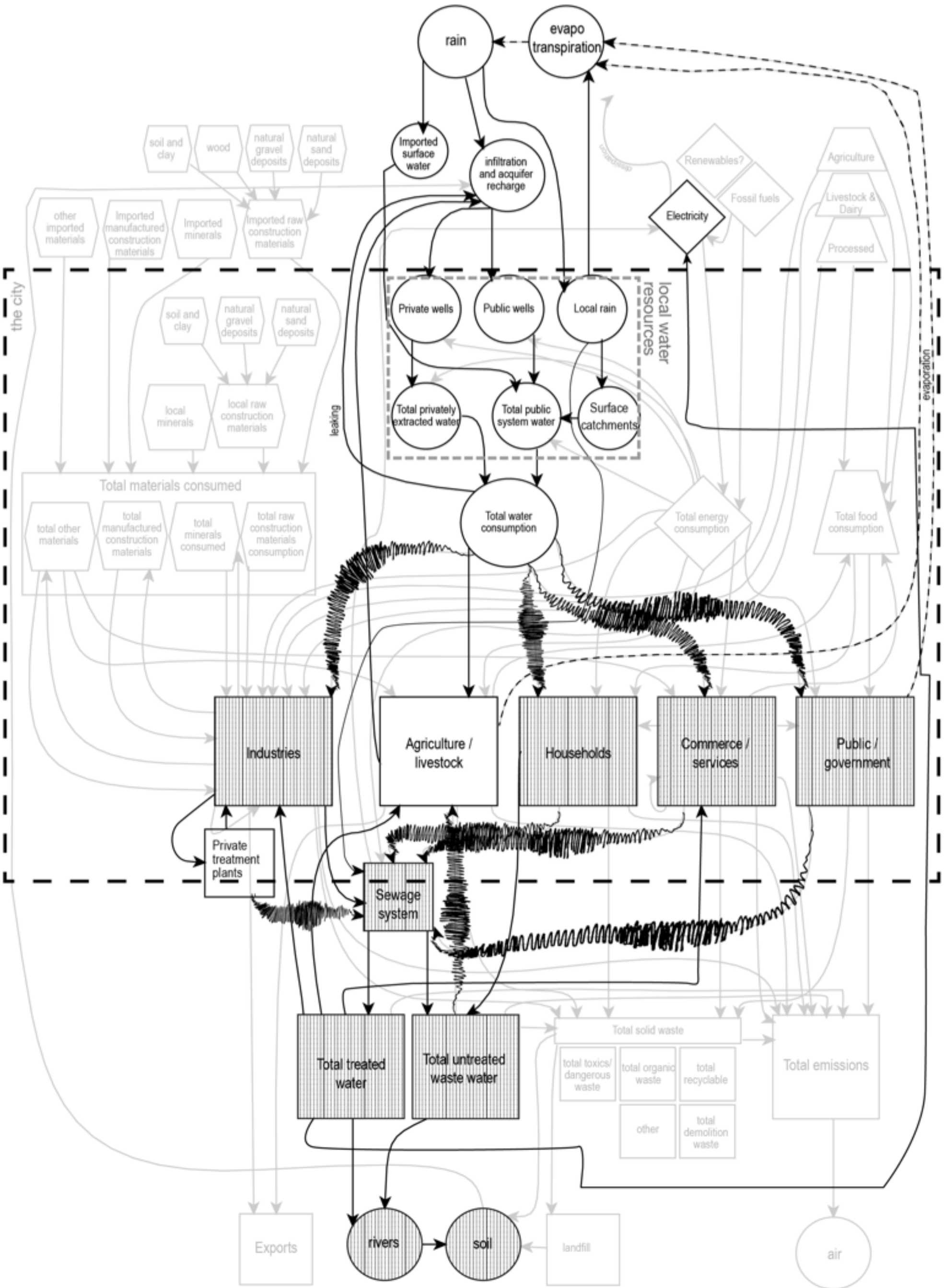

Fig 5.9 Data availability for the water subsystem.

Chapter 6

Conclusions

« It is not sufficient to construct only « new ecological cities » as additions to the existing stock. A reconstruction of the urban system is required. However, the process of reconstruction is a cultural one and has to include all relevant properties of human society ; the political, socioeconomic, and ecological ones. It is a new challenge never encountered before in society»

Baccini and Brunner (2012)[50]

In this thesis I have:

(i) Discussed the global relevance of cities in relation to sustainability.

(ii) Underscored that Latin American and Caribbean region (LAC) is highly urbanized, facing severe environmental challenges partially linked to its conditions as a gross supplier of natural resources (to the world, quite low levels of environmental reporting and *greenwashing* practices found in urban development and policy.

(iii) Reflected on the fundamental need to tackle urban environmental reporting and assessment by finding innovative and comprehensive frameworks and tool sets to apply to LAC cities. To contribute to this task, the case of an intermediate city in Mexico was proposed as a case study.

(iv) Established a first objective for the thesis as:

> *1. To review major frameworks applied to urban sustainability, as well as their tools and methods, and identify a framework and/or a toolkit that fulfils all or most of the 6 context criteria.*

The objective is considered to be fulfilled by the work presented in chapter 3, which looked extensively through different theoretical frameworks that allow for an deep and thorough understanding of the city as a system, and for integrated and holistic assessments of its environmental performance. Through the review, connections between the fields of urban ecology, social ecological systems (SES) and societal metabolism (SM) were found to lead to urban metabolism (UM) as an overarching and integrative framework, still under development and seemingly promising for application in Latin America. The questions of whether UM fulfilled the context "criteria" is analysed below.

(v) Established a second objective for the thesis as:

> *2. Perform any necessary adjustments to the framework chosen and define a methodology to apply it to the study of the environmental performance of San Luis Potosí.*

In order to do so, the production of UM- related research in LAC and world wide was examined, looking deeply into the methodological possibilities of UM, and compiling a review of tools used world-wide. The results of this review can be seen in the annex (literature review) and in chapter 3.

A systematised potential UM toolkit, composed of four blocks (system description, accounting, environmental assessment and GIS tools) and tailored a 7-step method to apply the tools to the case study.

(vi) Established a third and fourth objective for the thesis as:

> *3. Execute a "trial run" of the method. Report findings on the environmental performance of SLP. Report on data gaps and current data availability. Based on the results, and if applicable, outline policy recommendations and/relevant future research lines.*
>
> *4. Report on environmental data availability as experienced through the case study. Ideally, report on such issues as data sources and banks, relevant actors related to data generation, and gathering, data gaps, future research needs, and desirable future research lines.*

These objectives are also considered to be fulfilled through the draft or trial run of the method presented in chapters 4 and 5. The general situation of the water, food and energy metabolic sub-systems is discussed in chapter 5, the data compiled is presented in the annex, future research lines are identified throughout chapter 5 and further discussed below. Data availability ahs been discussed at the end of chapter 5. Unfortunately, it was not possible to draft concise policy recommendations, but conspicuous hints in that direction are certainly to be found for the interested reader upon consideration of the contents of this work.

The final objective of the thesis was:

> *5. Evaluate the usefulness, limitations and perspectives of future use of the method itself, reporting on its performance in relation to the context criteria. If applicable, to report on the possibility of applying other related tools and/or frameworks that emerge from the initial searches and reviews.*

This evaluation is done in the following pages. Table 6.1 presents the results of the method as compared to the context criteria. Further comment on limitations and possibilities is also made below.

6.1 Evaluation of the UMA method

Table 6.1. Evaluation of the urban metabolism assessment as a method applicable to Latin American cities

	Context criteria	Fulfils?	Discussion
i.	Should help set up a starting point. It should able to provide a comprehensive panorama of the urban system and its environmental performance– i.e. a baseline, if not at great detail, at least in an overall manner that would at the same time allow for later refinement. Ideally, it would allow for the inclusion of cultural, social and political specificities.	**YES**	UM is useful to set up a baseline because it allows to compile data from different sources and for many different topics in one same graphic representation. The extent to which it can overarch and unite topics depends on the goals set by the research team, and is potentially boundless. UM analysis can encompass the planetary implications of a certain aspect of a city, or focus on the detailed flow of single substances within city or sub-city limits. In the case study presented here, it proved useful to draw a wide panorama on fundamental flows water energy and food, which together serve to understand in general but useful terms, resource consumption in the city, and the different contributions of economic sectors to it. of the city. Some of the main strengths of UM as applied in this thesis are related to systemic understanding. System description maps were very useful to guide the data gathering process and to identify hidden flows and internal feedbacks.
ii	Should not be data intensive, and be able to work with the possibility of having large amounts of data for one topic and little for another. Ideally, it would at the same time be able to gather and compile whatever data is available, and report on availability and status quo of data.	**YES**	UM can be as data intensive as the research team decides. It can accommodate small indicator choices, and also very detailed data sets. When working with the system description maps as was done in chapter 5, UM analysis will show data gaps in a very straight forward manner.
iii	Relatively quick, simple and inexpensive, not requiring important inter-institutional collaboration, for instance, or extensive research staff or large funding sums.	**PARTIALLY**	UM is not necessarily quick in situations where data availability is limited, or where data is highly scattered as was the case in San Luis Potosí. The time needed to gather data was much longer than expected, and collaboration from government officials and other stakeholders was crucial. When they did not participate, the capacity of the metabolic analysis to provide detail and even to draw an accurate general picture was much limited. Comparison between data sources to contrast data or convert it in order to be able to use different sources in one same diagram, also required significant amounts of time. This is true for all bottom-up research, and should be considered when time is a serious constraint. Data choices would then tend to national statistics, with the downside of losing perhaps much accuracy at the urban scale. Several "workarounds" to data collection exist, depending on the composition of the research team. If for example a research team has technical capacities in the field of economics and statistics much can be achieved through the downscaling of national accounting data, although this would also be time-consuming in the case where, as in Mexico, very few regional input-output tables exist, and no physical input-output tables have been constructed.

			An advantage is however, that UM can be performed by a relatively small research team with basic equipment, and that more than one route exists to obtain desired indicators. UM is therefore not necessarily resource-demanding.
iv	Be applicable through local experience –i.e. not requiring intensive training or learning curves, or large technological imports, and be able to profit from local experience that is already well established.	**YES**	UM displays capacity to add knowledge from different fields and therefore can be participative and inclusive. Its methodology is straight forward to grasp. Its basic set up can be performed with basic tools, but the method and toolset proposed here allow for scaling up in in complexity and technical sophistication. The method is then plastic and adaptable to the possibilities of each city, including existing knowledge and technical capacities of the research team.
v	Have pragmatic, applicable results, easily "translatable" into policy-maker language, so as to inform decision makers and public officials in a straight-forward manner.	**YES**	Perhaps one of the major strengths of UM is the clarity of its visual communications. Communications made though Sankey diagrams are straight forward to understand, also for the non-specialists. Time series composed of different year diagrams can demonstrate progress towards a goal, and serve as a measure of policy success. The quantitative pictures obtained can be immediately communicated in various formats to different audiences, without requiring these to be thoroughly informed or trained in environmental matters.

In conclusion, the UMA method proposed and tried seems extremely useful for the assessment of environmental performance of Mexican, and potentially of other Latin American cities. It offers several advantages, notably on systemic comprehension and on revealing resource flows and intensities, both of which are basic needs for sustainability assessment. UMA also allows to bring together knowledge from several fields, has a plastic nature that permits adaptation to particular local circumstances such as technical capacity, time constraints, previous knowledge, research desires, etc. It is potentially expansible: it can be combined with several other methods and techniques to look into whatever aspect or subsystem is needed to be further detailed. Its visual clarity and easy comprehension make its outputs valuable for communication with stakeholders and the general public, while maintaining accuracy through scale representation.

The main limitations found were related to the time requirements typical of bottom-up analysis as well as to data gathering, quality and comparability of sources. There were an overwhelming amount of problematic situations in the data gathering process, which will not be further detailed here, but that made it clear that if a future refinement of the calculations for SLP were to be made, or if the method is to be applied elsewhere, it would be advisable to foresee a considerable amount of time for the processing "deciphering" the data, comparing between sources and probably interviewing different stakeholders.

The commonly cited limitation of metabolic approaches as being incapable of capturing social and political circumstances does not seem to hold true after having performed this draft run. When the system is properly described and quantification are made on economic and social compartments, much information is revealed about resource allocations, major consumers and underserviced sectors of the population, etc. The ability to shed light on environmental justice issues depends on the way that the researches shape the study and revealing quantitative aspects of resource consumption is a pre-condition for distributive discussions. Also, the metabolic maps can be shaped to show the origins and destinations of resource flows, and this information then be used to perform analysis on the dependency/autonomy of regions, on hinterland topics and on hidden flow/footprint topics.

The capturing of dynamics through time seems to be also possible by constructing metabolic maps for different years, and therefore another of the criticisms made to metabolic approaches seems to also not hold true. By comparing the metabolic maps of different periods, changes in behaviour will be explicit and material for analysis will be provided.

6.2 Recommendations and future perspectives for UM research in SLP and Mexico

1. The work carried out in this thesis suggests that general research lines are needed around the fact that SLP is not only exporting auto-parts and electrical appliances but also embedded biomass, water, nutrients, and using in the process increasing amounts of energy. Research into the depletion of local water, soil and possibly resources as a result of or in linkage with export-oriented industrial activity seem urgent. The consequences of land use change are incipiently studied[376], but have focused on aquifer recharge, and have yet touched upon for example biodiversity or local climate conditions issues.

2. Imported food appears to be of growing importance as local agricultural land is converted to urban uses and local food production diminishes. This suggests at least two research lines: one on the ecosystemic consequences of imports, including nutrients and biomass that are concentrated in landfills or soils, and of foreign vegetable species as well. Another, on the convenience of recovering agricultural land uses with a sustainable perspective, not necessarily as a replacement for industry but certainly as an option for a decreasing marginalisation, diversifying economic activities, managing land more sustainably and improve possibilities of autonomous development, employment and health.

3. The LCA community has been active in SLP for some time now and has recently also begun to be occupied with urban issues. At the national scale, solid experience exists in LCA. The efforts and expertise of this community could be of much use in holistic sustainability assessments, and collaborations with them to expand the UMA method proposed seem to be a promising exploration terrain.

4. Similarly, the EIO community in Mexico, among other institutions at the University of Coahuila and at the Colegio de México is quite active and has retaken efforts to analyse regional economies through the construction of EIO tables[429]. Their expertise can play an important role in creating more robust metabolic models, and specially in overcoming the limitation of data availability and comparability.

5. Social-ecological systems have been long studied in rural areas of Sierra de San Miguelito[394] and Mezquitic[413] regions. The knowledge of this research community could be very useful in further understanding the local metabolism of resources, including patterns of example water use, food production, fertilizer and pesticide use, and the implications of social an cultural values in the shaping of those flows.

6. Urban ecosystem services are understudied SLP. A larger amount of research exists on the role of different land forms in aquifer recharge, but other aspects of ecosystem services provision are unstudied (food provision and production, climate regulation at the regional scale, for instance) and intra-city ecosystem services (for example, the role of vegetation, soils and water in temperature regulation, in carbon storage, in mental health) appear to be absolutely unstudied. Although this issue cannot be tackled through UMA alone, it was interesting to see that UMA actually unveiled the circumstance.

A final note

Current environmental challenges in Latin America can seem overwhelming. Through the work here, it was confirmed that the theoretical and methodological tools of the UMA perspective examined are potentially useful, relevant and applicable to urban sustainability in the LAC context. Although further refinement of the method would certainly be recommended, the general methodological outline seems robust enough to proceed with it into fine-tuning and then into further research on urban and regional sustainability. Much multi- and trans-disciplinary dialogue and construction, collaborative work across society and changes in cultural assumptions and mind-sets, are bound to be a part of the journey.

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Annex 1.

Literature review.

Metabolic approaches to urban sustainability in Latin America
A literature review

Lucia Benavides Mondragón
UASLP - ITT/FH Köln

april, 2016

Abstract: This review aims to answer to the question : « has urban metabolism (UM) been researched in Latin American cities? and if so, in what ways? ». In order to provide an answer, a process of finding, selecting and revising literature was made. An introduction on what urban metabolism is is provided, as well as a brief revision of the state of the art worldwide. Result analysis shows leading authorship in Mexico and Colombia for peer reviewed literature, with a more or less abundant production in non-peer reviewed and informal literature. A discussion on Latin American and Spain´s contributions to UM, such as Political Ecology being incorporated into strictly quantitative thinking. This finding also highlights the existence and liveliness of an academic and cultural Ibero-american region, as well as the leadership of certain Spanish and Mexican key authors. Conclusions hypothesize on the future of UM research in the region

I. Introduction: metabolic approaches

The sustainability of cities has been dealt with in several manners, through several methodological approaches. One of these approaches has considered the city to be an organism, or later, an ecosystem. Parting from this assumption, the energy (fuel, sunlight, coal, etc.) and material (water, food, fibers, etc.) inputs, internal processes and outputs of this ecosystem are quantified to offer a panorama of how the city consumes resources, and therefore of its impacts on the environment. This approach to the assessment of a city´s dynamics has been called « Urban Metabolism » (UM), in allusion to an organism´s metabolism (Wolman, 1965). From the release of the Wolman (1965) seminal paper on UM to today, progresses in the refinement of the theory and practice of this framework have been made. One of them has been to consider the city not as an organism but as an ecosystem. Alberti (2008) notes that the idea that humans and cities are integral parts of ecosystems (and not some outside factor to be studied separately only through the social sciences) is not new: it has been taken form all throughout the 20th century, at least since the works of park (1925), and through the work of many others (Odum, 1953; Berry, 1964; Rapoport, 1968, among others). Lately, the urban ecosystems theory has been refined through the interdisciplinary approach (Alberti, 2008) by MacDonell (1993, 1997), Grimm et al (2000), Picket et al. 2001), Alberti et al. and Alberti (2008).

An ongoing although increasingly fading debate in the urban ecology community has to do with whether the term « metabolism » is still appropriate to talk about an ecosystem´s dynamics (Grimm, 2012). Although there appears to be a general consensus among urban ecologists, urbanists and other urban experts as to the fact that the city should be treated as an ecosystem, not an organism, the term « metabolism » is being used to address the ensemble of inputs, processes and outputs of these urban systems. Authors dealing with exclusively natural ecosystems, such as estuaries and streams, or with global ecology, are using the term « ecosystem metabolism » (Findlay & Sinsabaugh, 2003; Bott *et al.*, 2006; Krebs, 2008; Howarth-Marino Lab at Cornell University; and others). In 2003 Enquist *et al*. (2003) published a proposal in Nature magazine to « scale metabolism from organisms to ecosystems. Consequently, this review would like to propose that the terms « metabolism of the urban ecosystem », or « urban metabolism » can be considered correct, or at least, widely accepted.

One of the approaches to study urban metabolism is to assess its flows and stocks of materials and energy. In this framework, three methodologies have been identified as components of the Urban Metabolism « toolkit » (Kennedy et al., 2010; Holmes and Pincetl, 2012). In this paper, the ensemble of the three will be referred to as « metabolic approaches ». These three methodologies are: Emergy Analysis (EA), Material Flow Analysis (MFA), and Life Cycle Assesment (LCA).

This grouping into the concept of « metabolic approaches » is proposed for two reasons, besides the fact that it is proposed by the above mentioned authors: One is that, although they have distinct procedures and provide different outputs, they share a common feature: all three trace quantitative features of input, internal processes, and outputs of given substances or materials through an urban system, to provide a general view of the variable´s pathways and behavior in the system. Consequently, all three can be and have been used for estimating environmental impacts or footprints of cities and are thus all, each with advantages and disadvantages, useful for assessing the sustainability of urban systems and designing management strategies. Furthermore, most of the literature in the field of Urban Metabolism refers indistinctly to one or more of these methods as appropriate for carrying out urban metabolism analysis.

The second reason is that initial searches of literature and projects have shown a very limited number of works in this field being carried out in the Latin America region. Limiting the review to one of the three categories would result in very few works available for reviewing. Furthermore, a lot of the work dealing with sustainable cities in Latin America has not dealt quantitatively with metabolism or flows, but only conceptually, resulting in a sometimes confusing mixing of these three -and other- methods in papers and books. Thus, it has seemed more reasonable to treat all findings in this same review, in order to provide a general overview of how urban system assessment has been carried out in Latin American cities. A brief overview of each of the three methodologies is provided in Table 1.

UM, MFA, LCA

The first to introduce the concept of urban metabolism was Abel Wolman, in a 1965 seminal paper appeared in Scientific American called « The metabolism of cities ». In this paper, Wolman quantified the inputs (food, water, energy) and outputs (sewage, refuse, air pollution) of a hypothetical U.S. city of one million inhabitants (Fig. 1), basing his calculation on available country wide data to determine per capita consumption and waste generation (Holmes and Pincetl, 2012).

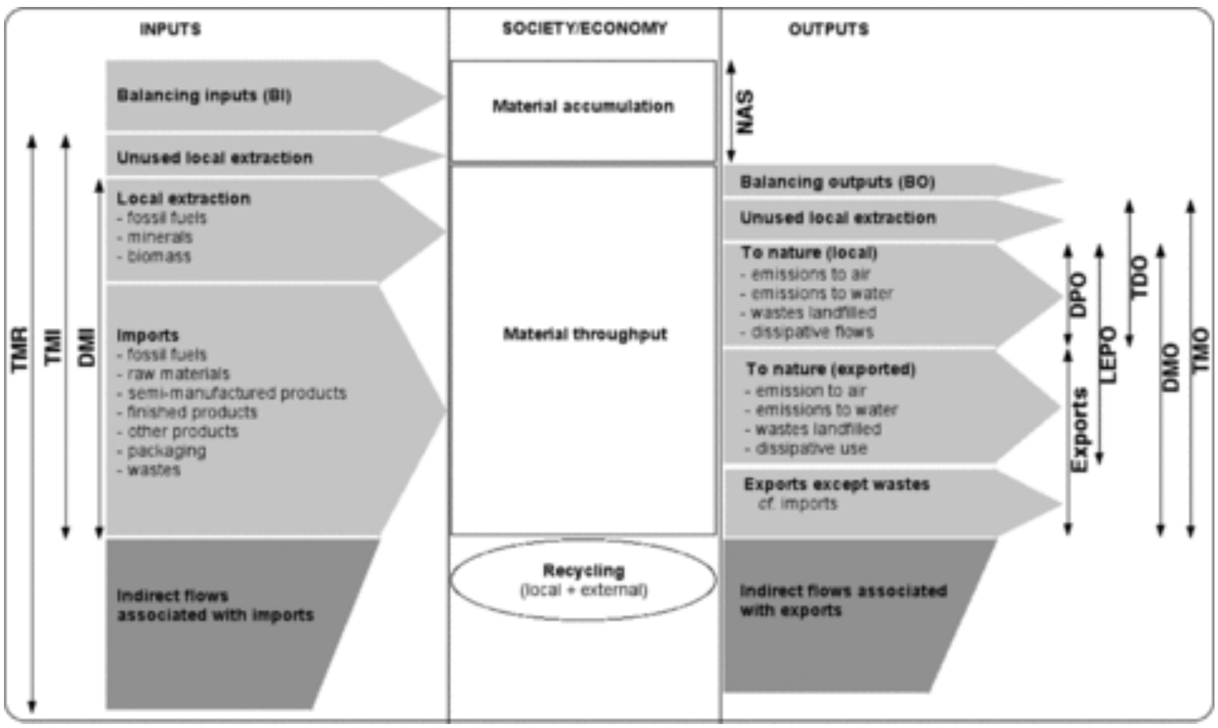

Figure 2. Urban Metabolism of Paris and its region. Main flows and indicators in material balance according to the method adapted from Eurostat (2001). Note the following: (1) The system (Society/Economy) is limited by its political or administrative borders; it comprises the society as a whole (population and artifacts) and excludes nature from which it extracts primary material. (2) Water balance is not included (except in the case of balancing outputs).
Taken from: **Journal of Industrial Ecology** Volume 13, Issue 6, pages 898-913 http://onlinelibrary.wiley.com/doi/10.1111/j.1530-9290.2009.00169.x/full#f1

This metabolic approach has continued to grow since, and around several dozen studies have been made ´following this methodology, referred by some authors as an *engineering* metabolic approach (Holmes and Pincetl, 2012), as opposed to the *ecological* approach, that has been developed since the 1970s, following the concept of *Emergy,* proposed by H.T. Odum. Th *Emergy* approach converts all inputs and flows into a same unit, solar energy Joules (seJ), while the engineering approach uses standard units: Tons, cubic meters, Joules, etc. (Holmes and Pincetl, 2012). Although advances continue to be made and several scholars practice Emergy analysis around the world, conversions from standards units (tons, for example), into seJ are still being done with tables provided by Odum himself (Holmes and Pincetl, 2012), and acceptance of this method is not general due to doubts on the validity of these conversions and the Emergy theory in general (Holmes and Pincetl, 2012).

These two approaches, UM and Emergy analysis, are in reality two different ways of dealing with territorial metabolism and can be considered as variants of the same idea of Urban Metabolism.

A different approach is Material Flow Analysis (MFA), and its variant, Material and Energy Flow Analysis (MEFA), which has been argued to be the most suitable to treat the urban system, as they are related to ecosystems ecology, and the city should be treated as an ecosystem (Golubiewsky, 2012). MEFA has been used to asses, por example, the flow on Nitrogen and Phosphorus through the city system (Bürstrom et al, 1997; Faerge et al., 2001), achieving important understanding of the possibilities to recover nutrients from urban wastewater for agriculture. Other MEFA analysis, specially when comparing between cities, have opened a window of opportunity into the understanding what strategies work best to reduce environmental impact of cities (Sahely 2003; Ngo and Pataki, 2008).

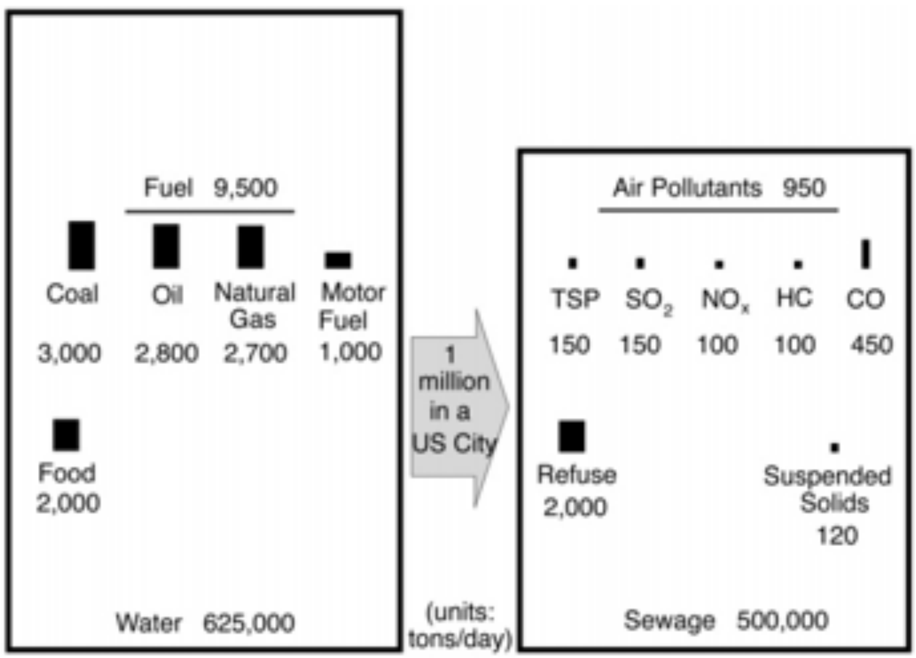

Figure 1. Material budget (tons per day) for a hypothetical U.S. city of 1 million residents. n 1965. Rectangle area is proportional to rate for each substance. Suspended solids are in sewage water. Taken from Decker et al. 2000.

MEFA analysis under the metabolic optic have proven to be useful in establishing dependency areas for a city, as in the study of Paris (Barles, 2007, 2009), where a territorial dependency for materials was determined in adjacent regions, and on suburban areas for waste treatment and management.

Lastly, MEFA is lately being used in urban design at the neighborhood scale, assessing different morphological configurations (distribution of building, for example) and physiological features (materials, for example) in the MEFA framework, looking at their differentiated behaviors in the terms of major UM components such as water, energy or food. (Quinn, 2008; Oswald and Baccini, 2003, 2008; Holmes and Pincetl, 2012).

Life Cycle Analysis (LCA) has only recently been used in the quantitative assessment ur urban systems. Originating in the disciplines of Industrial Engineering and Industrial ecology, the tool has been developed to provide cradle-to-grave assessments of a process or product, including its links and dependencies and its potential environmental impacts, through an exhaustive inventory of all inputs required and outputs produced by the item in question during its lifetime. (Holmes and Pincetl, 2012). It is normed by the International Standards Organization's (ISO) norm 14040. As cities do not have a limited or predictable life time, LCA and its variant LCSA (Life Cycle and Sustainability Assessment) have been primarily used to analyze discrete componentes of the city, such as road building, or construction material use (Holmes and Pincetl, 2012).

Urban System Assesment methodologies: a comparison			
	main characteristics	**Variants**	**Disadvantages**
Emergy Analysis	- Based on ecosystem ecology proposal by H.T. Odum (1985). - Converts all work into solar energy joules (seJ) using conversion tables provided by Ovum -		There is agreement among scientific community as to the validity of conversion equations. Not widely accepted. Cannot account for social, qualitative aspects.
Material Flow Analysis	- Related to ecosystem ecology - Has been used to trace, for example, the global Nitrogen cycle. - Widely used in nation wide economic studies. - Useful in defining dependencies and links between cities, their hinterlands and farther territories.	MEFA	Cannot account for social, qualitative aspects. Proposals have been made to integrate such factors.
Life Cycle Assesment	- Comes from the industrial engineering disciplines - Normed by the ISO - Fully tested, widely used in industry and lately in analysis of urban elements such as buildings, roads, etc. - Useful to understand de environmental impacts of a product, from cradle to grave.	LCSA	Cannot account for social, qualitative aspects.
Table 1.			

Relevance of metabolic approaches to sustainability

Metabolic approaches are important to sustainability because they provide insight into the behavior of ecosystems, natural or intervened by humans. These approaches are not only used in urban matters, but have been widely, and possibly firstly used in wild ecosystem analysis, to understand, for example, how incoming energy is processed and distributed in a forest environment, or what the routes for carbon are in a given ecosystem. The most basic example of a metabolic approach is the well-known carbon, water, nitrogen or phosphorous cycle illustrations, so ubiquitous in the study of ecology and earth systems. These illustrations can be made because an underlying quantitative analysis of the magnitude and pathways of flows(metabolic analysis) has been previously carried out.

The fundamental insight provided by the study of these cycles allows for better management and planning of human endeavors. In an urban age, where 54% of the world's population lives in cities, with the perspective of becoming 66% by 2050 (UN/ESA, 2014) and continually increasing through 2100, *« the battle for a more sustainable future will be lost or won in cities »* (World Urban Forum/ UN-Habitat, 2012). Cities are large consumers of resources, and large generators of environmental pollution. These impacts are so important today that it has been proposed to urgently study the role of cities in, for example, nitrogen fixation at the global scale (Decker et al., 2000), and studies are now being carried out to determine how pollution coming from cities in the Chinese coast are reducing crop yields elsewhere in Asia (Chameides et al, 1999).

It is thus clear that making cities´ material and energy fluxes more sustainable is a priority if we aim to have a sustainable future. Metabolic approaches that help understand how these fluxes work and behave, are a first step. Metabolic approaches are useful in developing strategies to close metabolic loops to resemble natural circular metabolism, as opposed to current linear reactor metabolism types dominant in cities (Brunner, 2007; Holmes and Pincetl, 2012), as well as in the estimation of cities' GHG and other polluting emissions relevant to climate change and environmental problems in general. Finally, UM studies are suggested to be useful in decision-making for public policy (Holmes and Pincetl, 2012), urban planning and design at the neighborhood scale (Kennedy and Hoornweg, 2012).

II. Metabolic approaches world wide

Since the 1965 seminal paper by Abel Wolman, several studies have been carried out worldwide under one of these different UM frameworks. A list reported by Kennedy et al. (2010) contains 45 papers, but there are several more (Ascione et al. 2008; Beck and Quigley, 2001; Brown, 1981) that are not included in that report. We can safely say there must be at least 60 of these studies in Europe, Asia and North America.

The study of urban metabolism continues to grow as the relevance of urban studies for the achieving of sustainable development has been increasingly realized. Recent papers now include the idea of refining the already powerful tool of UM analysis through better spatial and temporal resolution, the inclusion of urban stocks (Inostroza, 2014; Deilmann, 2009), the introduction of social and governance factors (Newmann, 1999; Costa, 2008) and political ecology factors (Leff, 1995; Martínez Alier, 2004; Delgado 2013, 2015)

III. Metabolic Approaches in Latin America

Latin America is one or the most urbanized regions of the world, with around 80% of its population living in urban centers (UN/Habitat, 2012). By 2050, this number is estimated to increase to 87 % (Delgado, 2015). Being such an important factor of the economy and all aspects of national life, one could easily expect to find many studies analyzing the dynamics of latin american urban regions. While many studies researching urbanization patterns, sprawl, design, architecture as well as social, historical and economic aspects do exist, practically none are in the field of urban metabolism, meaning there are virtually no quantitative studies. Conké and Ferreira (2015) reported to have found none. The aim of this review is to revise if UM has been addresed in latinamerica, and in what ways.

While not completely zero, there is undoubtedly a low number of Urban Metabolism research found when searching in database. This motivated the widening of the search terms in order to provide a comprehensive searching. In this paper, research in the fields of EA, MFA, LCA, and also other works having to do with quantitative approaches to the understanding of urban resource use dynamics, sustainability or ecological footprint are included.

Procedure:

1. An initial simple google search was made, with the keywords « metabolismo urbano » and « urban metabolism latin america ». Only the first ten pages were revised (100 results). Some of the results were not relevant, but lead, through more searching, to relevant results, i.e. finding possibly relevant

authors' names and then searching their work. Some results were dismissed because they only slightly touched the metabolic approaches subject, or because they were mere reviews of what urban metabolism is about.

2. Two google scholar searches were made, with the keywords « metabolismo urbano » and « análisis de flujos de materiales ». Only the first ten pages were revised for each set of key words (100 results each, 200 results total).

3. A third search was made through BIG, a comprehensive search engine powered by the Universidad Autónoma de San Luis potosí, that searches simultaneously in more than 10,000 databases, with the keywords « metabolismo urbano » (100 results revised) and « análisis de flujo de materiales » (only 35 results, all were revised).

4. First filter : having the keywords in the text, dealing with the Latin American region and being relevant to our topic (some examples of dismissed articles had topics such as the material flow of an industrial product through an industrial process, or with the modeling of material flow for industrial efficiency). All seemingly relevant proceedings from first-filtered search can be seen in Table 2.

5. Second filter: proceeding form peer reviewed journals and dealing with metabolic approaches quantitatively. These final results are presented in table 2.

Papers found: initial list

		Country, year	Author	UM quantitative	Peer reviewed/ published book	Other topics	Exclusively Theoretical	Thesis	Notes
1	Análisis de Flujos de Agua en áreas metropolitanas desde la perspectiva del metabolismo urbano	Colombia, 2014	María Isabel García Serna, Tito Morales-Pinzón, Jhoniers Guerrero Erazo	■	■				
2	Análisis de flujos de materiales en sistemas humanos - una revisión	Colombia, 2015	Jaime Diaz Gómez, Jorge Silva Leal		■		■		Historic review
3	Análisis de flujo de materiales de la economía Argentina (1970-2009). Tendencias y Conflictos extractivos	Argentina-Spain, 2013	Mariana Walter, Julien Brun, Pedro Manrique, Ana G. Martínez, Joan M. Alier	■					
4	Análisis del impacto ambiental asociado a los materiales de construcción empleados en las viviendas de bajo coste del programa 10 x10 Con Techo-Chiapas del CYTED	México, 2008	Teresa del Rosario Argüello Méndez, Albert Cuchí Burgos		■				it is a quantitative study, but not at a territorial scale. (Deals with architectural items)
5	Análisis del Metabolismo energético y de materiales de Brasil, Venezuela y Chile	Brasil, Venezuela, Chile - Spain, 2007	Eisenmenger, Nina Ramos Martin, Jesus Schandl, Heinz	■	■				
6	Apropiación de la Naturaleza por una Comunidad Maya Yucateca: Un Análisis Económico-Ecológic	México - Spain, 2007	Eduardo García Frapolli, Victor Toledo, Joan M. Alier.	■	■				
7	Cambio climático y metabolismo urbano de megaurbes latinoamericanas	México, 2012	Gian Carlo Delgado	■	■				
8	Cidades sustentáveis: uma nova condição urbana a partir de estudos aplicados a Cuiabá, capital do estado de Mato Grosso, Brasil.	Brazil, 2013	Geovany Jessé Alexandre da Silva, Marta Adriana Bustos Romero		■	■	■		
9	Ciudad y buen vivir	México - Argentina, 2015	Gian Carlo Delgado	■	■				
10	Ciudad, agua y cambio climático	México - Argentina, 2015	Gian Carlo Delgado	■	■				
11	Ciudades, gestión, territorio y ambiente	México, 2014	Lucía Álvarez, Gian Carlo Delgado		■		■		

Papers found: initial list									
		Country, year	**Author**	**UM quantitative**	**Peer reviewed/ published book**	**Other topics**	**Exclusively Theoretical**	**Thesis**	**Notes**
12	Complejidad e interdisciplina en las nuevas perspectivas socioecológicas: la ecología política del metabolismo urbano	México, 2015	Gian Carlo Delgado	■	■				
13	Complejidad e interdisciplina: ecología política del metabolismo urbano	México, 2015	Gian Carlo Delgado	■	■				
14	Criterios para el diseño de una ciudad sustentable	México, 2014	Benjamin Alva Fuentes				■		Newpsaper article
15	Diagnóstico de la gestión de residuos sólidos en el municipio de Mexicali, México.	México, 2014	Crescencio L. Calva, Rosa I. Rojas.		■	■			Only mentions UM
16	Discursos da Sustentabilidade Urbana	Brazil, 1999	Henri Acselrad		■		■		
17	Ecología Urbana, experiencias en América Latina	México, 2013	Ian MacGregor Fors, Rubén Ortega A.		■	■			
18	Ecosistemas urbanos e impacto multidimensional: los casos de Ciudad Valles, San Luis Potosí y Matehuala.	México, 2013	Adrián Moreno Mata			■			University magazine. Incorrect use of UM and other concepts.
19	El metabolismo de la ciudad	Argentina, 2004	Aljenadro Crojethovich				■		
20	Energy and Material Flow through the urban ecosystem.	covers three latin-american cities - USA 2000.	Ethan H. Decker, Scott Elliott, Felisa A. Smith, Donald R. Blake, F. Sherwood Rowland	■	■				
21	Entre fulgores de ángeles y máculas de tizne: energía, metabolismo y degradación ecológica en el Valle de Puebla-Tlaxcala, 1530-1820	México, 2015	Juan José Juárez Flores			■			Only mentions UM. Historic review of social metabolism and natural resource use in Puebla, México.
22	Estructura biofísica de la economía ecuatoriana : un estudio de los flujos directos de materiales	Ecuador - Spain, 2006	María Cristina Vallejo Galárraga	■	■				
23	Flores y flujos de materiales	Ecuador - Spain, 2006	Martha Moncada	■	■				
24	Flujos de materiales y energía en la economía colombiana	Colombia, 2009		■	■				

Papers found: initial list									
		Country, year	**Author**	**UM quantitative**	**Peer reviewed/ published book**	**Other topics**	**Exclusively Theoretical**	**Thesis**	**Notes**
25	Indicadores de tercera generación para cuantificar la sustentabilidad urbana. ¿Avances o estancamiento?	Colombia, Chile, 2013	Silvia León A.	■	■				
26	Indicador espacial del metabolismo urbano. Huella Ecológica de la ciudad de Tandil, Argentina	Argentina, 2007	Elsa M. Guerrero, Fernando Guiñirgo		■	■			Paper is on ecological footprint, only mentions UM
27	La ciudad como ecosistema: el metabolismo urbano	Colombia, 2003.	Diego F. Narváez Chica				■		University bulletin
28	La extracción y consumo de biomasa en México (1970-2003). Integrando la leña en la contabilidad de flujos de materiales	México - Spain, 2007	Ana Citlalic González	■	■				
29	La importancia conservacionista de las comunidades indígenas de la Reserva de Bosawás, Nicaragua: un modelo de flujos	Nicaragua - Spain, 2008	María Rosa Cordón, Victor M. Toledo	■	■				
30	La impronta del urbanismo privado. Ecología de las urbanizaciones cerradas en la región metropolitana de Buenos Aires.	Spain - Argentina, 2010	Leonardo Fernandez, Ana Carolina Herrero, Irene Martín	■		■	■		
31	Las bases materiales del sector exportador chileno: un análisis input-output	Chile - Spain, 2006	Pablo Muñoz Jaramillo, Jordi Roca	■	■				
32	Measuring urban ecosystem functions through « Technomass » — a novel indicator to assess urban metabolism.	Colombia - Germany, 2014	Luis Inostroza Pino	■	■				
33	Metabolismo de la ciudad de Bogotá : Una herramienta para el análisis de la sostenibildiad ambiental urbana.	Colombia, 2011	Cristian J. Díaz Álvarez.	■				■	Master´s thesis Universidad Nacional de Colombia
34	Metabolismo Social: Hacia la sustentabilidad de las transiciones socioecológicas urbanas	Colombia, 2013	Juan David Reina Rozo	■				■	Master´s thesis Universidad Nacional de Colombia
35	Metabolismo Urbano en el flujo de materiales de construcción en la ciudad de Pereira	Colombia, 2015	Cindy B. Quintero Avalo, Alexandra Tabares Ramírez	■				■	Bachelor degree

Papers found: initial list

		Country, year	Author	UM quantitative	Peer reviewed/ published book	Other topics	Exclusively Theoretical	Thesis	Notes
36	Metabolismo urbano y apropiación de excedentes ecológicos: de la estepa a la arquitectura burguesa	Chile, 2014	Luis Inostroza Pino		■	■			
37	Metabolismo urbano: herramienta para la sustentabilidad de las ciudades	México, 2014	Cristian J. Díaz Álvarez.		■		■		
38	Nuevas formas y procesos espaciales en el territorio contemporáneo.	Chile, 2008	Eduardo de Santiago		■		■		
39	Proposiçao para o Gerenciamiento de Ressiduos da Construçao e demoliçao da Cuiabá	Brazil, 2011	Roberto Naime, Eduardo Figuereido, Dioni M. Atilio			■	■		government proposal
40	Reducción del Consumo Eléctrico y C02 mediante Sistemas de Ahorro y de Aislamiento Térmico aplicados a Viviendas en Zonas Áridas de México	Chile - México, 2007			■	■			it is a quantitative study, but not at a territorial scale. (Deals with architectural items)
41	Residuos Sólidos municipales, minería urbana y cambio climático	México, 2016	Gian Carlo Delgado	■	■				
42	Sustentabilidad, territorios urbanos y enfoques emergentes	México, 2014	Mireya Imaz Gispert, Dalia Ayala Islas, Ana G. Beristain Aguirre		■		■		
43	Sustentabilidad urbana para Mexico	Mexico, 2012	Rafael Borrayo López				■		UNAM didactical presenation
44	Sustentabilidad y Ciudad	Chile, 1999	Henri Acselrad		■		■		
45	Urban Metabolism: measuring the city´s contribution to sustainable development	Brazil, 2014.	Leonardo Conke, Tainá Ferreira.	■	■				

Table 2. Preliminary list of results. Merely informative or newspaper articles as well as very low quality texts, which made up a significant amount of the search results have been excluded. **`Metabolic quantitative ´** refers to studies quantifying UM flows. **`Peer reviewed/published book´** means that the study is published in peer reviewed journals or in an edited book. Only studies falling under these two categories were considered as relevant for the review, although the findings in other categories help nurture the discussion and conclusions. **`Other topics´** means that the study does not deal with metabolic approaches even when it appeared in the search. **`Exclusively theoretical`**means that the article only talks about what UM is, or about why it is useful, etc, but does not present a study of its own. **`Thesis´** are generallty graduate students´ thesis, not appropriate to consider as influential metabolic studies although representative, as will be discussed below, of a growing interest in the topic in the Latin American region.

Result analysis and discussion

Out of 435 results analyzed, only 45 passed the first filter (table 2. for filter definition, see introduction to this section). Out of these, only 19 passed the second filter (see table 3). A closer look to these 19 final results revealed that six (31%) of them deal with nation-wide or even international scale economic metabolisms. This paper considers these findings also relevant because, even if they are not strictly urban in their scale, they are a testimony of the increasing importance that is being given to territorially focused metabolic studies. It is only a matter a of time before scaling down begins to occur, as it happened with studies in Europe, Asia and North America.

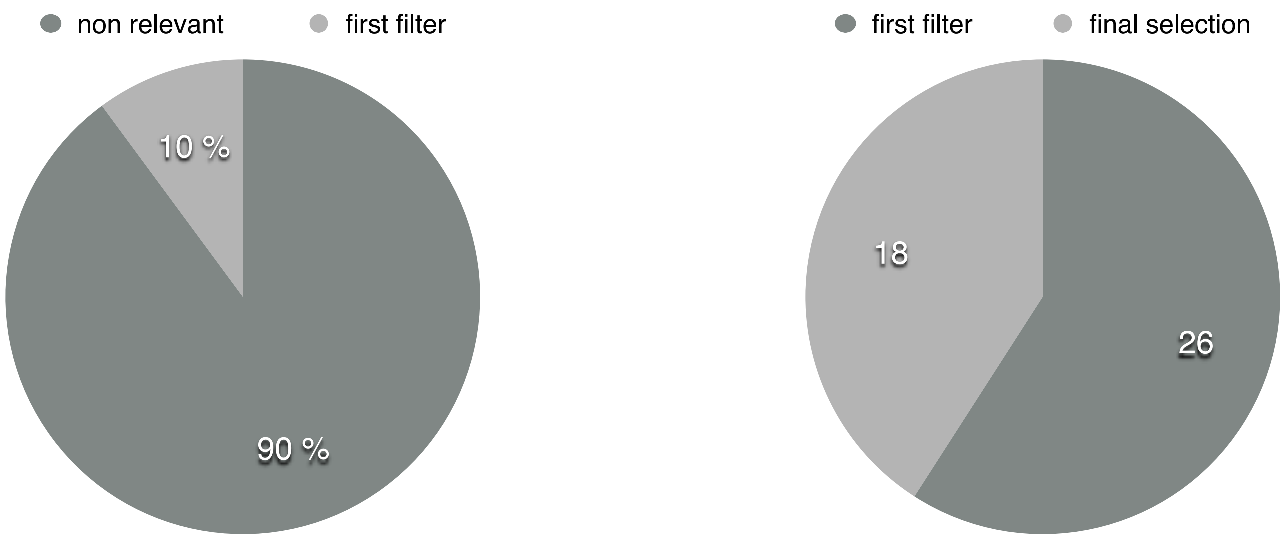

Figure 2. The graph to the left shows the proportion of studies appearing to be relevant in database searches to actual relevant literature, in percentage. The graph to te right shows the proportion, in number of studies, of these first-filtered articles to the ones actually dealing quantitatively with UM in latinamerican cities or countries.

While a finer search could be made to find even more studies and articles that this review could have missed, we think it is safe to say that, exclusively regarding the urban scale, it can be safely said that there exist at least 12 studies that analyze one or more aspects of urban metabolism in Latin America, mainly with the MFA/MEFA tools. This short list is already an advance compared to Conké and Ferreira´s (2015) reporting of there being zero UM studies in the region.

It is worth noting that the pioneering work (Decker et al., 2000) in the region was not carried out in any latin american country, bur rather in a US university. This study came 6 years before any research of latin american origin was published (2006).

Mexican cities lead the count, with 42% (8 studies), followed by Colombian cities (15.7%, 3 studies) and Brazilian cities (10.5%, 2 studies), while Nicaraguan, Chilean and Argentinian cities only have 1 study that represents them. All other Latin American countries are missing from the lists.

Practically all studies for Mexican cities, have been lead by the same researcher, Gian Carlo Delgado, and have dealt with Mexico City. This author does, however, treat some other Latin american cities in some of his texts. His appearance on the tables far outnumbers any other author´s appearance, probably meaning that Dr. Delgado, of the National University in Mexico (UNAM) is the most prolific of only around 5

Papers after filtering: final list						
		Year	**Country**	**Author**	**City-region scale**	**Nation-wide scale**
1	Energy and Material Flow through the urban ecosystem.	2000	USA. Includes Sao Paolo, Rio de Janeir, Mexico City and Buenos Aires.	Ethan H. Decker, Scott Elliott, Felisa A. Smith, Donald R. Blake, F. Sherwood Rowland	■	
2	Estructura biofísica de la economía ecuatoriana : un estudio de los flujos directos de materiales	2006	Ecuador - Spain,	María Cristina Vallejo Galárraga		■
3	Flores y flujos de materiales	2006	Ecuador - Spain	Martha Moncada		■
4	Las bases materiales del sector exportador chileno: un análisis input-output	2006	Chile - Spain	Pablo Muñoz Jaramillo, Jordi Roca		■
5	Análisis del Metabolismo energético y de materiales de Brasil, Venezuela y Chile	2007	Brasil, Venezuela, Chile - Spain	Eisenmenger, Nina Ramos Martin, Jesus Schandl, Heinz		■
6	Apropiación de la Naturaleza por una Comunidad Maya Yucateca: Un Análisis Económico-Ecológico	2007	México - Spain	Eduardo G. Frapolli, Victor Toledo, Joan M. Alier.	■	
7	La extracción y consumo de biomasa en México (1970-2003). Integrando la leña en la contabilidad de flujos de materiales	2007	México - Spain	Ana Citlalic González		■
8	La importancia conservacionista de las comunidades indígenas de la Reserva de Bosawás, Nicaragua: un modelo de flujos	2008	Nicaragua - Spain	María Rosa Cordón, Victor M. Toledo	■	
9	Flujos de materiales y energía en la economía colombiana	2009	Colombia			■
10	Cambio climático y metabolismo urbano de megaurbes latinoamericanas	2012	México	Gian Carlo Delgado	■	
11	Indicadores de tercera generación para cuantificar la sustentabilidad urbana. ¿Avances o estancamiento?	2013	Colombia, Chile	Silvia León A.	■	
12	Análisis de Flujos de Agua en áreas metropolitanas desde la perspectiva del metabolismo urbano	2014	Colombia	García et al.	■	
13	Measuring urban ecosystem functions through « Technomass » — a novel indicator to assess urban metabolism.	2014	Colombia - Germany	Luis Inostroza Pino	■	
14	Urban Metabolism: measuring the city´s contribution to sustainable development	2014	Brazil	Leonardo Conke, Tainá Ferreira.	■	
15	Ciudad y buen vivir	2015	México - Argentina	Gian Carlo Delgado	■	
16	Ciudad, agua y cambio climático	2015	México - Argentina	Gian Carlo Delgado	■	
17	Complejidad e interdisciplina en las nuevas perspectivas socioecológicas: la ecología política del metabolismo urbano	2015	México	Gian Carlo Delgado	■	
18	Complejidad e interdisciplina: ecología política del metabolismo urbano	2015	México	Gian Carlo Delgado	■	
19	Residuos Sólidos municipales, minería urbana y cambio climático	2016	México	Gian Carlo Delgado	■	

Table 3. The results have been ordered in increasing chronological order.

authors publishing quantitative urban metabolism studies for Latin america in peer-reviewed journals.

Two of the reviews, one in Mexico and one in Nicaragua, portray an analysis of a rather rural human settlements, but have been included because, while smaller in scale, the studies are also metabolic approaches to human settlements and provide interesting analysis of the metabolism between these settlements and natural systems.

Beyond the peer reviewed literature, of which we have seen there is only an incipient list which will probably continue to grow led by mexican and colombian authors, the initial result list (table 2), as well as unlisted findings that our research ran across, show that interest in UM and works related to it have been growing since the turn of the century. Bachelor and master degree thesis, especially in Colombia, and even government plans, in Brazil and Mexico city, are being written using the concepts of UM. There is a post graduate research line on UM in the Universidad Javeriana in Colombia, and a recent climate summit in Bogota had a UM section. Newspaper and science popularization magazines are also reproducing articles with these ideas, usually along with other concepts as sustainability, sustainable development, etc.

While this is surely exciting and could mean the beginning of a growing production of quantitative urban research in Latin American, we also found a downside: many of the articles, short texts and non-peer reviewed literature that we came across was of very low quality of misused terms and concepts like urban metabolism, ecological footprint, etc. Here is an aspect to be taken care of within the UM community: to produce high quality research and literature, and to make room in the academic world for student´s and governments´ growing interests in studying cities as ecosystems with quantitative and applied scientific methodologies.

Theory has come in advance of practice. The earliest mention to urban metabolism, or rather social metabolism of nature, was found in Leff (1995, not listed, see references). A 1999 theoretical study by Henri Acselrad also came out in Brazil. I would like to argue that the contribution of theory developed in Latin America, working along with Spain, is substantial to the refinement of UM works worldwide. There is a distinct trait in the treatment of UM studies in te region: the introduction of political ecology. Spanish (notably but not exclusively catalan) and Latin american authors (Martinez Alier, 2004; Toledo, 2011; Delgado, 2015) have been arguing for the considerations of such factors as uneven wealth distribution, unequal access to urban services and goods, and concepts derived from critical urban geography, like the right to the city (Lefebvre, 1968; Harvey, 2003) in UM studies. Authors argue that the typical per capita results of UM analysis hide the differences in resource consumption and environmental impact between sectors of the population, and that without Political Ecology it is not possible to understand why these flows occur the way they do, and thus possibilities for change are minimal, circumscribed to superficial technicalities. These contributions in theory are marking a great difference to the normally, of course with some exceptions, un-political technical studies carried out in Europe and Anglo America.

V. Conclusions

Interest in studying UM is growing in Latin America, led by works in Colombia and Mexico. Only a handful of authors are producing peer-reviewed literature for now, but this tendency is likely to change, as graduates from universities' graduate programs start doing research of their own. UM thought is beginning to permeate government discourse and non specialized literature.

A remarkable Ibero-american contribution is occurring in the field of Urban Political Ecology. The refinement of UM models through the inclusion of these considerations is likely to produce better calibrated and more accurate models to understand what sectors of society are more responsible for environmental impact, and why this is so. This knowledge is vital in order to find significant leverage points, in a world where no event is non-political, and where distribution of resource use and thus environmental impact is so strongly linked to the economy and therefore not politically neutral.

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Annex 2.

Selection of indicators used in resource flow accounting and environmental impact assessment as discussed in chapter 3.

Type	Indicator	Application scale	Developed by
INPUT	**DEU = Domestic Extraction Used** It is the total amount of materials obtained within the boundaries of the domestic territory and used in some way (consumption, further processing).	national, regional	Eurostat
	DMI = Direct Material Input DMI = DEU +imports It is the total amount of resources entering the economy (for production or consumption processes), be it from local sources or external ones.	national, regional	Eurostat
	HF = Hidden Flows. HF = hidden flows in imports + hidden flows domestic Materials and/or energy used for the extraction or fabrication of imported materials, but not directly imported themselves (embedded, or virtual materials). For example, the water used to grow a certain crop, or the emissions associated with energy required to manufacture a certain good. Data for this indicator is not readily available, but may come from the WTO's HS, or from a variety of scholarly research and national reporting sources.	national, regional, product	Wuppertal Institut
	TMR = Total Material Requirement TMR = DMI + HF TMR is a measure of the total material input into an economy, including those materials used in production processes within the economy (DMI) and hidden, indirect or embedded flows, such as soil loss in agriculture or materials used in manufactured products imported into the economy.	national, regional	Wuppertal Institut; Bringezu and Schütz, 2001[182]
CONSUMPTION	**DMC = Domestic Material Consumption** DMC = DMI - exports It is the total amount of materials consumed in an economy, discounting the materials locally sourced but exported. DMC will either stay in the system as additions to stock (NAS), or go out into the environment as part of the material output.	national, regional	Eurostat
	TMC = Total Material Consumption TMC = TMR – Exports - hidden flows exported The total amount of total material requirement directly consumed within the economy.	national, regional	Eurostat
	Global Land Use Accounting (GLUA) Is a form of Land Footprint. Quantifies the amount of land needed to produce a certain agricultural good on a consumption-base.	product, can be scaled	Wuppertal Institut
	"The four footprints" = Carbon, Water, Land and Materials footprints	several. See Giljum, 2013[181] authors, see	
STOCKS	**NAS = Net addition to stock** NAS = DMI-SPO-Exports Measures of the physical growth in stocks of any type. Total stocks should be equal to the difference between inputs and outputs.		Bringezu, 2009
	Technomass Echoing the notion of 'biomass', this indicator refers to the mass of anthropogenic materials accumulated in the city, including for example metals, concrete, plastics, and excluding any organic (biomass) material, as well as water, food and energy carriers. Up to now there has only been one application in a UM study[147].	urban, regional national, global	Kavaliuskas, 2004; Inostroza, 2014[147]
OUTPUT	**TDO = Total Domestic Output** TDO = DPO + disposal of unused extraction The total outgoing material received by the domestic territory, including emissions to the air and any resources extracted and disposed of although not necessarily used (e.g. soils moved for mining or construction processes).		Eurostat
	DPO =Domestic Processed Output DPO = Emissions + waste		Eurostat

	The total resources exiting the economy (to enter other systems, e.g. water, soils, rivers, other cities, etc.) after having been used. They can be wastes, dissipative flows or emissions to air.		
	TMO = Total Material Output TMO = TDO + exports Total amount of materials leaving the economy.		Eurostat
PRODUCTIVITY	**GDP/TMR = Total resource productivity** The Monetary gains associated with material consumption. When measured and compared over time, it is useful in establishing the degree of decoupling of resource use and economic growth. DMI, TMO and others can also be associated with GDP, or with other economic indicators. Per capita associations are also common, e.g. TMR/pop = per capita material requirements, etc.	national, regional	
IMPACT	**Ecological Footprint** Evaluates the hypothetical surface required to sustain a given process or entity.	all	Rees (1992)[155]; Rees & Wackernagel (1996)
	Sustainable Process Index (SPI) Evaluates the area needed to provide sources and sinks for the process, and compares it to the total available area per capita in the planet, giving insight into the « expensiveness » of a given process in relation to the total available resources.	process, regional	Krostschek and Narodoslavsky [173]
CONSISTENCY	**Sustainable resource supply** Share of consumption sources sustainably. Consistency indicators are still under development[19]. In general, the idea behind them is to understand the degree to which the metabolic processes of an economy are embedded within sustainable limits in provisioning ecosystems[19] –i.e. if what is being consumed and output as wastes can be sourced and sunk for an unlimited time without deteriorating the ecosystems that provide these sources and sinks. This idea relates well to the idea of planetary limits, (which are themselves consistency indicators although not called so) and to the *system feasibility* of the MuSIASEM framework	national, regional	Bringezu, 2009
	Feasibility An indicator in the MuSIASEM framework. The degree to which the system's function is in accordance to the possibility of its provisioning ecosystems to sustain it, system's activity under available resources is evaluated. It calculation is not straight forward.	theoretically, all	Giampietro *et al.*, 2000, 2009[73],2014[45]
	System Robustness (SR) An indicator coming from system analysis. SR is a measure of the balance between efficiency or performance and its resilience or capacity to evolve and self organize. It builds on ideas of stagnation (too little efficiency) and redundancy (interconnection between system components). It has been proposed in ecosystems ecology modelling[183], entered sustainability science as a measure for system sustainability[184], and has been only recently used in urban metabolism studes[185]	theoretically, all	Ulanowicz *et al.* (2009)[183] Fath, (2014)[184] Chen and Chen, (2016)[185]

Annex 3. Indicators.

Notes:

For some indicators, more than one answer was found. All answers are reported here, and the ones used for the final processing are highlighted.

Interapas, the water operating facility in SLP, includes in its service area also the municipality of Cerro de San Pedro (CSP). However, because the number of users is so small (~.2%), quantities given by Interapas will not be adjusted to exclude CSP.

A. CONTEXT

Indicator/description	ind #	dataholder level	Source	Quantity	unit	Year	Quality	Notes
City surface and limits	**A.1**	1	IMPLAN	not available				
		3	INEGI	1 793,00	km2	2015		Marco Geoestadístico Nacional 2015
		3	SEDESOL	**1 788,00**	km2	2010		Delimitacion de las Zonas metropolitanas de México.SEDESOL, 2010
Population size	**A.2**	1	INEGI	**1 133 571,00**	people	2015		Inegi, 2015.

B. INFLOWS/ WATER

Indicator	ind #	dataholder level	Source	Quantity	Unit	Year	Quality	Notes
Total Water imports	**B.1**	1	INTERAPAS	**9 775 502,00**	m3	2015	1	INTERAPAS, 2015. Informe Anual. p.103
Water imports origin	**B.1.1**	1	INTERAPAS	**132 km southeast, in San Luis de la Paz, in the state of Guanajuato**			1	Presa El Realito, 132 km southeast, in the state of Guanajuato. It was built. See http://www.sifra.com.mx/nuestros-clientes/sistema-acueducto-%E2%80%9Cel-realito%E2%80%9D-%281%29.aspx for details on construction.
Total Groundwater abstraction	**B.2**		Calculated from B.2.1 + B.2.2	**134 008 100,27**	m3	2015 or 2016	2	Total groundwater abstraction = abstraction in public and private wells of all types (B.2.1, B.2.2). The municipal facility (INTERAPAS) does not hold information on private wells. All concession volumes for private wells were obtained from the federal authority (CONAGUA)
Groundwater abstraction (total public wells)	**B.2.1**	1	INTERAPAS	**94 340 000,00**	m3	2015	1	INTERAPAS, 2015. Informe Anual. p.103
Groundwater abstraction (total private wells)	**B.2.2**	1	INTERAPAS	they don´t have that information				
		2	CEA	they don´t have that information				
Groundwater abstraction (total private wells)	**B.2.2**		Calculated using data from REPDA-CONAGUA.	**39 668 100,27**	m3		2	Total private groundwater abstraction = groundwater abstraction in industrial and agricultural private wells (B.2.2.1, B.2.2.2) only on the aquifer of SLP. These quantities were calculated by extracting tabular data from .kmz files available at http://siga.conagua.gob.mx/REPDA/
Groundwater abstraction private wells (industry)	**B.2.2.1**	3	CONAGUA REPDA	**11 219 979,30**	m3	2016?	2	All industrial wells are located on SLP aquifer. The extraction volume reported is the volume PERMITTED to the extract according to the concession title. It is not necessarily the real extraction volume, but it is likely to be close to it, because when users sub-utilize their granted concessions, the concession title can be retired. The quantities presented here were calculated by extracting tabular data from .kmz files available athttp://siga.conagua.gob.mx/REPDA/

Groundwater abstraction private wells (agriculture)	**B.2.2.2**	3	CONAGUA REPDA	54 559 969,97	m3	2016?	2	This is the total volume extracted from wells tapping into both the SLP aquifer and the neighbouring Villa de Arista aquifer (see map in text). It was not used, as it was deemed more accurate to present the volume extracted only from the San Luis Potosí aquifer (see below).
Groundwater abstraction private wells (agriculture)	**B.2.2.2**			**28 448 120,97**	m3	2016?		For wells using SLP aquifer only. This is the volume PERMITTED to the extract according to the concession title. It is not clear whether the user extracted less, or more, or none.These quantities were calculated by extracting tabular data from .kmz files available at http://siga.conagua.gob.mx/REPDA/
Surface Catchments	**B.3**	1	INTERAPAS	**88 246,00**	m3	2015	1	INTERAPAS, 2015. Informe Anual. p.103
Total Rain Water	**B.4**	1	INTERAPAS	not available				
Total Rain Water	**B.4**		Own calculations using data from Eguía del Pozo and Santacruz, (2016)	**78 402 000,00**	m3	2010		1) Research by Eguía del Pozo and Santa Cruz de León surveyed weather station data for the 2000-2010 time series and concluded that the average yearly rainfall for the period was 358 mm. 2)Using this quantity, I calculated the yearly precipitation on the surface of the urban area, which my own survey of GIS data resulted in 219 km2. This surface was considered, and not the total surface of the SLP valley for example, because rainfall on non-urban surfaces is rapidly absorbed into the soil or evaporated, and therefore cannot be considered an input into the water system. In contrast, rain falling on impervious surfaces of the city has the potential to be channeled and used.
Rain water for agriculture			Own estimate	**58 380 200,00**	m3	2015		First estimate, using crop surface reported by SIAP= 15190 ha, and rainfall average (358mm) for SLP. Only crop surface was considered (excluding hectares of field used for livestock)
Rain water discharged into sewage	**B.4.1**		Calculated with data from Enguía and Santacruz, (2016) and Martínez et al. (2010)	**33 682 200,00**	Mm3	2010		Martínez et al. (2010) report that about 40% of rainfall on the city of SLP is absorbed by pervious soil or evaporated. Of the remainign 60%, 61/mm year are estimated by them to be channeled though rainwater collectors back to streams. The reimaining rainwater is channeled as sewage. The quantity presented here is the result of my calculation using this information and the real rainfall calculated for the SLP by Eguía del Pozo and Santa Cruz for 2010.

B. INFLOWS/ ENERGY

Indicator/description	ind #	dataholder level	Source	Quantity	Unit	Year	Quality	Notes
			GENERAL NOTES:	Units are given here in mWh and/or PJ. Units used in the final quantification (sankey diagrams were always PJ). The conversion factor used is thae given by the Interantional Energy Agency: 1 mWh= ,0000036 PJ. Information here corresponds only to SLP municipality.				
Total energy consumption (all types)	**B.5**		Own calculations based on different sources, from the data below	**40.94**	PJ	multi year		This quantity results from adding total fossil fuels, total energy and total renewables, based of different sources as shown below.
Total electricity consumption	**B.5**	2	PEACC	1 834 620,83 6,60	mWh PJ	2006	1	Programa de Acción ante el Cambio Climático, UASLP, 2011. The study period for this document was 2000 - 2006. The quantity for this indicator was obtained dividing the estimated total electric energy consumption (12842345 mWh) by 7. This quantity includes only SLP municipality.
Total electricity consumption	**B.5**	3	SENER-WB, 2015	3 589 000,00 12,92	mWh PJ	2013	1	The minsitry of Energy (SENER) performed a study in partnership with the World Bank using the TRACE-ESMPA methodology. See reference list for direct link. This quantity includes only SLP municipality.
Total electricity consumption	**B.5.1**	3	INEGI, 2016	**3 695 856,00** **13,31**	**Mwh** **PJ**	2015	1	Anuario Estadístico y Geográfico del Estado de San Luis Potosí
Electricity by sector - households	**B.5.1.1**	3	SENER-WB, 2015	341 214,00 1,23	mWh pj	2013	1	
Electricity by sector - households	**B.5.1.1**	3	CFE, 2017	145 338 973,00 145 338,97 0,52	kwh mwh pj	2016	2	Information obtained through a direct information request to the regional CFE office in SLP. Units w and infromation format were not clear.
Electricity by sector - households	**B.5.1.1**	3	INEGI, 2016	**344 070,00** **1,239**	**Mwh** **Pj**	2015		Anuario Estadístico y Geográfico del Estado de San Luis Potosí

C. PRODUCTION

Indicator	ind #	dataholder level	Source	Quantity	Unit	Year	Quality	Notes
Total agricultural production	**C**	3	calculated from C.1. and C.1.2	**84 768,40**	ton	2015	1	Includes SLP and SGS municipalities. Database only shows the 20 products, apparently the most important in volume. It is unlcear what the amount of other products produced in the municiaplity is.
Total Fodder	**C.2**		SIAP, 2017	40 381,00	ton	2015	1	
Total Legume	**C.1**		SIAP, 2017	44 387,00	ton	2015	1	
Total animal production			calculated from C.2. and C.2.2	**#REF!**				
Total Meat	**C.3**	1	SIAP, 2017	**66 106,00**	ton	2015	1	Includes live and carcassed livestock, as well as all poultry

Electricity by sector - industrial	**B.5.1.2**	3	SENER - WB, 2015	3 182 900,00 11,46	Mwh Pj	2013	1	The minsitry of Energy (SENER) performed a study in partnership with the World Bank using the TRACE-ESMPA methodology. See reference list for direct link. This quantity includes only SLP municipality.
Electricity by sector - industrial	**B.5.1.2**	3	**INEGI, 2016**	**3 294 340,00** **11,86**	**Mwh** **Pj**	2015	1	Anuario Estadístico y Geográfico del Estado de San Luis Potosí
Electricity by sector - industrial	**B.5.1.2**	3	CFE, 2017	1 150 190 505,00 1 150 190,51 4,14	kwh mwh Pj	2016	2	Information obtained through a direct information request to the regional CFE office in SLP. Units w and infromation format were not clear.
Electricity by sector - public lighting	**B.5.1.3**	3	SENER-WB, 2015	42 218,00 0,15	mWh PJ	2013	1	The minsitry of Energy (SENER) performed a study in partnership with the World Bank using the TRACE-ESMPA methodology. See reference list for direct link. This quantity includes only SLP municipality.
Electricity by sector - public lighting	**B.5.1.3**	3	INEGI, 2016	**344 070,00** **1,239**	**Mwh** **Pj**	2015		Anuario Estadístico y Geográfico del Estado de San Luis Potosí
Electricity by sector - public lighting	**B.5.1.3**	3	CFE, 2017	15 851 555,00 15 851,56 0,06	kwh mwh pj	2016	2	Information obtained through a direct information request to the regional CFE office in SLP. Units w and infromation format were not clear.
Electricity by sector - water system	**B.5.1.4**	3	SENER-WB, 2015	4 138,00 0,01	mWh pj	2013	1	The minsitry of Energy (SENER) performed a study in partnership with the World Bank using the TRACE-ESMPA methodology. See reference list for direct link. This quantity includes only energy used for water pumping.

Electricity by sector - water system	**B.5.1.4**	3	INEGI, 2016	6 674,00 0,0240	Mwh Pj	2015	1	Anuario Estadístico y Geográfico del Estado de San Luis Potosí. This quantity includes energy used for water pumping, both for ground water extracion and waste water pumping. It does not include energy used in potabilization processess for example.
Electricity by sector - water system (only agricultural wells)	**B.5.1.4**	3	INEGI 2016	19 149,00	mwh	2015	1	Water pumping - only wells used in agriculture both in SLP and SGS.
		3	INEGI 2017	68,9364	TJ	2015		conversion to Tera Joules 1TJ=277.77 mWh
		3	INEGI 2018	0,07	PJ	2015		conversion to peta joules 1 PJ=277777.7 mWh
Total fossil fuels consumption	**B.5.2**		Own	**27,63**	PJ	various years		It is the result pof adding total gasoline, total diesel and others.
Fossil fuels by type - Gasoline	**B.5.2.1**	2	PEACC	14,25	PJ	2006	1	Programa de Acción ante el Cambio Climático, UASLP, 2011. The study period for this document was 2000 - 2006. The quantity for this indicator was obtained dividing the estimated total electric energy consumption (99.76) by 7. This quantity includes only SLP municipality.
Fossil fuels by type - Diesel	**B.5.2.2**	2	PEACC	10,386	PJ	2006	1	Climático, UASLP, 2011. The study period for this document was 2000 - 2006. The quantity for this indicator was obtained dividing the estimated total electric energy consumption (72,7 PJ) by 7. This
Fossil fuels by type- others	**B.5.2.4**		PEACC, 2011	3,00	PJ	2006	1	This quantity includes natural gas, liquified petroleum gas, coke and fuel oil. Programa de Acción ante el Cambio Climático, UASLP, 2011. The study period for this document was 2000 - 2006.Includes only SLP municipality.
Total renewables generation	**B.6**		SENER-WB, 2015			2013		

D. CONSUMPTION / WATER

Indicator	ind #	dataholder level	Source	Quantity	Unit	Year	Quality	Notes
Total Water consumption	**D.1**	1	Own calculations from INTERAPAS and REPDA - CONAGUA data	**162,73**	Mm3	2010/20	2	Data corresponds to several years, and therefore the quantity presented here is a hybrid calculation, a schematical aproximation but likely not too far off real consumption. See water inflows section of this annex
Water consumption per sector - household	**D.1.1**			unknown			0	This indicator was not possible to calculate exactly. It is however known that 79.21 million m3 a year are shared between households, commercial facilities, public offices,other users of small quantities and some of the industrial and services users (hospitals or schools for example) as well.
Water consumption per sector - industry	**D.1.2**		REPDA-CONAGUA	**11,38**	Mm3	2016	2	This is the quantity obtained from analysing the public registry of water rights (REPDA-CONAGUA) and accounting for all water concessions labeled "industrial", and also including concessions that are labeled as "services" but are assigned to industrial users (Kimberly Clark, Kansas City Southerna, among others). However, this number is likely not complete, as it is known from the INTERAPAS yearly report (2015) that 1,059 industrial users are connected to the municipal network, and therefore their usage is "hidden" inside the water assigned to municipal use, along with households and other small users. The exact consumption of those industrial users connected to the municipal network was requested to the municipal operator (INTERAPAS) and the state water commission (CEA), without success.
Water consumption per sector - agriculture	**D.1.3**	3	REPDA CONAGUA	54 559 969,97	m3	2016	1	This is the total volume extracted from wells tapping into both the SLP aquifer and the neighbouring Villa de Arista aquifer (see map in chapter 4). It was not used, as it was deemed more accurate to present the volume extracted only from the San Luis Potosí aquifer (see below).
Water consumption per sector - agriculture	**D.1.3**	3	REPDA CONAGUA	**28 448 120,97**	m3	2016	1	For wells using SLP aquifer only. This is the volume PERMITTED to the extract according to the concession title. It is not clear whether the user extracted less, or more, or none.These quantities were calculated by extracting tabular data from .kmz files available at http://siga.conagua.gob.mx/REPDA/
Water consumption per sector - commerce	**D.1.4**			unknown			0	This was not possible to calculate exactly. It is however known that 79.21 million m3 a year are shared between households, commercial facilities, public offices,other users of small quantities and some of the industrial and services users (hospitals or schools for example) as well.

Water consumption per sector – public facilities	**D.1.5**	REPDA-CONAGUA	**~2,1**	Mm3	2016	2	This is the quantity obtained from analysing the public registry of water rights (REPDA-CONAGUA) and accounting for all water concessions labeled "services",which includes universities, hospitals and other public facilities who have their own wells, and excluding the amounts included under this "services" label but assigned to industrial users (see "industry" indicator). However, this number is likely not complete, as it is known from the INTERAPAS yearly report (2015) that 1,142 public users are connected to the municipal network, and therefore their usage is "hidden" inside the water assigned to other uses such as households and other small users. The exact consumption of those public users connected to the municipal network was requested to the municipal operator (INTERAPAS) and the state water commission (CEA), without success.
Water losses due to leakage	**D.1.6**	INTERAPAS, 2015	**40 651 630,00**	m3	2015	1	Quantity reported in the "Management indicators" document, provided by the municipal operating facility (INTERAPAS) after a direct request.

E. OUTFLOWS

Indicator	ind #	dataholder level	Source	Quantity	Unit	Year	Quality	Notes
Total municipal solid waste to landfill	**E.1**	1	Municipal ecology department	**671,41**	T	2016	2	Daily average. Information given verbally at the municipal ecology department.
				245064,65				Yearly average consdiering daily average as reported by muncipal ecology department, assuming 365 days in a year
Destination of municipal wastes	**E.1.1**	1	Municipal ecology department	Peñasco and others				The location of the officiallandfill is known (at Peñasco) , but it is known that large and unaccounted amounts of waste go elsewhere. Construction material dumping sites were for example found on the north eastern outstkirts of the city on a field visit. This indicator on destination of waste was finally not used.
Total organic waste	**E.1.2**		Estimation	**127433,618**				Considering the national average given by SEMARNAT, 2015 of 52.4% of all wastes being organic
Total toxic/special waste	**E.2**	1		unknown				
Destination of toxic wastes	**E.2.2**			unknown				
Total waste water	**E.3**		Own calculations following data choices upstream in the sankey diagram (See chapter 4)	**126.23**	Mm3	2010-2016	3	Total waste water is equal to the total municipal + the total privatly discharged + rain channeled into sewage . The water operating facility (INTERAPAS) does not have a direct mechanism to account for the actual flow of waste water. It is estimated by applying a transmission loss factor to the amount of water input to the system. This means that the waste water amounts reported by INTERAPAS do not account for the water extracted in private wells and then discharged into the municipal sewage system, or for rain. Because water extracted from private agricultural wells is most likely not discharged into the sewage but on to fields, agricultural groundwater extractio has not been included.

Total waste water	**E.3**		REPDA-CONAGUA, 2016	**122 064 993,00**	m3	2016	1	This quantity stems from the analysis of the REPDA-CONAGUA database available at datosabiertos.gob.mx, which appears to report wastewater discharge not as a direct measurement but as an estimation based on the water extracted or captured by users. The quantity presented here excludes agricultural discharges, which are commonly not made into sewage systems but on to the soil, and "second-round" treated water (water that is discharged into the sewage system after it has been recovered from it and treated to use it, in an industrial process for instance). These second round discharges were excluded to avoid possible double accounting, but in any case made up for only <1% of the total REPDA reported quantities. This quantity was not used in the diagrams, but is included as an element for comparison. It is consistent with my own calculations.
Total waste water	**E.3**	1	INTERAPAS, 2017	**51 219 611,00**	m3	2016	3	Obtained through transparency request 523/EXP.-523/201. It is their reported estimated municipal wate water discharge, including treated and untreated water. It does not account for privately extracted water that is then discharged into municipal sewers. This quantity was not used as it is exceedingly low compared to other reported data by the same organism (see below), and also much lower than was is reported by both INEGI and REPDA-CONAGUA
Total waste water	**E.3**	1	INTERAPAS , 2015	**90 336 957,00**	m3	2015	3	This quantity is contained in the "Performance indicators" document for 2015, which was obtained through a through a direct request to INTERAPAS staff. This exact amount is not however, contained in the public reports available online. It is not clear how it was calculated, whether it includes rain and/or waste water originated in industry.

Waste water per type - domestic wastewater	**E.3.1**		Own calculations following data choices upstream in the sankey diagram (See chapter 4)	**79,31**	Mm3	various	2	It is th result of deducting the known quantitites of 1) agricultural fresh water extraction, assuming it is not discharged into sewage 2)industrial water intake, assuming it is dischgared into sewage as "industrial" waste water, and 3) reported lossess in the water network, assuming these do not go into the sewage system, from the total water intake. It is assumed that all non-industrial, non-service users discharge their waste water as domestic waste water.. It is inexact to the same extent that the accounting of water input to these users is inexact (see inflows section of this annex). Nonetheless, it seems to be the best available data and it is the one shownin the sankey diagram. Contrast with the amounts of waste water reported by the municipal operator facility.
Industrial wastewater	**E.3.2**	3	REPDA-CONAGUA, 2016	**11 219 979,30**	m3	2016	3	The quantity here is equal to groundwater abstraction made through privately operated wells. It is asusmed that the total amount of water extracted by private industrial wells is discharged as"industrial waste water" into the sewage system. The assumption is somewhat large, as the volumen of fresh water effectively used by industries is larger than was is privately extracted (see inflow section of this annex for details). Also, not all industrial wastewater is discharged. An unknown fraction of it is treated i*n situ* and recycled back into the industrial process. The quantity is considered the best available data and used instead of what is reported as industrial wastewater in the REPDA-CONAGUA database (see below), because the latter is exceedingly small.

Industrial wastewater	**E.3.2**	3	REPDA-CONAGUA, 2016	**1 220 308,00**	m3	2016		This quantity stems from the analysis of the REPDA-CONAGUA database available at datosabiertos.gob.mx, and reflects the quantity PERMITTED to discharge into water bodies or soil. It was not used because it is exceedingly small compared to the estimated water usage by the industrial sector. It is likely that industrial discharges are being directly made into the municipal sewage system and therefore do not need a special permit, and are consequently not accounted for in the discharge permits reported by CONAGUA.
Wastewater treated	**E.4**	1	INTERAPAS, 2015	**66 849 348,00**	m3	2015	1	This is the quantity reported for 2015, in the document "Management indicators" obtained from INTERAPAS through a direct information request. It was used instead of what is reported by the transparency request (below) because it is more consistent with data reported by the federal tatistics office (INEGI).
Wastewater treated	**E.4**	3	INEGI, 2016	**63,70**	Mm3	2015	1	This is the quantityt reported by INEGI (2016) for the SLP municipality only.
Wastewater treated	**E.4**	1	INTERAPAS, 2017	**49 917 932,00**	m3	2016	3	Obtained through transparency request 523/EXP.-523/201.However, within the same report, inconsistencies are found. It reports total waste water as ~51 Mm3 (see above), and states "between 20 and 25% of waste water is discharged without treatment". But the it reports 49.91 Mm3 of treated waste water, which amounts to >95% of the waste water total. This data was not used for these reasons and is presented only as reference.
Destination of waste water	**E.5**		unknown					

Users of waste water - industry	**E.5.1**		INTERAPAS, 2011	**14,20**	Mm3	2011	2	This quantity is calculated from the reported 450 lps by INTERAPAS, 2011, and reflects only the amount of treated wastewater used by the thermal power station in Villa de Reyes (35 km south of SLP), which recieves treated waste water from the Tenorios treatment plant. There are other industrial users of treated wastewater, including a zinc mine in the limits of the city. These users treat and re-use water extracted within their own facilities (e.g. water they extract from their own private wells), and/or water recieved through the public network. The numer of times such water is re-cycled may vary from plant to plant, and
Users of waste water - agriculture	**E.5.2**		INTERAPAS, 2011	**30,60**	Mm3	2011	2	This quantity is calculated from the 600 lps from the Tenorio pland and 370 from the Norte plant, reported as outgoing to agriculture in 2011 by INTERAPAS. It is unclear but likely whether there are other wastewater agricultural uses for agriculture.
CO2e		2	PEACC, 2011	not available				The State Programme fro Climate Change (PEACC) states that during 2000-2006, 1362111 Gg of CO2e where released in the state. But it does not include information on the participation of each municipality (only in the energy-generation subsector, where SLP municiaplity contributed 20,5% of state emissions, or 3988,71 Gg yearly between 2000 and 2006. No information on municipal CO2e estimations was found in the other two sources examined either
		2	Emissions inventory, 2011	not available				
		2	ProAire, 2015	not available				
SO2	**E.6.1**	2	State Emissions inventory, 2011	**2 313,71**	Mg	2011	1	Total for SLP municipality.
		2	State Emissions inventory, 2011	**365,63**	Mg	2011	1	Total for SGS municipality
		2	State Emissions inventory, 2012	**2 679,34**	Mg			Total for metropolitan area (SGS+SLP municipalities)
				2,68	kt			
SO2 Agricultural		2	ProAire, 2015	**28,18**	t	2011		
NOx	**E.6.2**	2	Emissions inventory, 2011	**22 614,56**	Mg	2011	1	Total for SLP municipality.
		2	Emissions inventory, 2011	**2 885,89**	Mg	2011	1	Total for SGS municipality.
		3	Emissions inventory, 2012	**25 500,45**	Mg	2012		Total for metropolitan area (SGS+SLP municipalities)

NOx agricultural			ProAire, 2015	**429,40**	t	2011		
CO	**E.6.3**	2	Emissions inventory, 2011	**109 881,48**	Mg	2011	1	Total for SLP municipality.
		2	Emissions inventory, 2011	**16 751,95**	Mg	2011	1	Total for SGS municipality.
		2	Emissions inventory, 2011	**5 494,07**	Mg	2011	1	Proportion of Agricultural CO for SLP. The report states that 5% of CO statewide is linked to agriculture. Here, the same proportion is assumed for the municipality.
CO agricultural		2	ProAire, 2015	**92,40**	t	2011		Proportion of Agricultural CO as reported by ProAire. Includes both SLP and SGS muncipalities
Volatle organics	**E.6.4**	2	Emissions inventory, 2011	**27 656,07**	Mg	2011	1	Total for SLP municipality.
		2	Emissions inventory, 2011	**4 427,90**	Mg	2011	1	Total for SGS municipality.
VOC agricultural			ProAire, 2015	**73,32**	t	2011		
PM10	**E.6.5**	2	Emissions inventory, 2011	**3 025,58**	Mg	2011	1	Total for SLP municipality.
		2	Emissions inventory, 2011	**303,65**	Mg	2011	1	Total for SGS municipality.
PM10 Agricultural		2	ProAire, 2015	**137,97**	t	2011		
PM2.5	**E.6.6**	2	Emissions inventory, 2011	**2 168,32**	Mg	2011	1	Total for SLP municipality.
		2	Emissions inventory, 2011	**303,65**	Mg	2011	1	Total for SGS municipality.
		2	Emissions inventory, 2011	**195,15**	Mg	2011	1	Proportion of Agricultural PM 2.5 for SLP. The report states that 9% of PM 2.5 emissions statewide is linked to agriculture. Here, the same proportion is assumed for the municipality.
		2	Emissions inventory, 2011	**27,33**	Mg	2011	1	Proportion of Agricultural PM 2.5 for SGS. The report states that 9% of PM 2.5 emissions statewide is linked to agriculture. Here, the same proportion is assumed for the municipality.
PM2.5 Agricultural		2	ProAire, 2015	**53.74**	t	2011		
Methane	**E.6.7**			not available in emissions inventory				
O3	**E.6.8**			not available in emissions inventory				

Black carbon	**E.6.9**			not available in emissions inventory				
NH3	**E.6.10**	2	Emissions inventory, 2011	**1 996,68**	Mg	2011	1	Total for SLP municipality.
		2	Emissions inventory, 2011	**1 433,05**	Mg	2011	1	Total for SGS municipality.
NH3 Agricultural		2	ProAire, 2015	**21 313,00**	t	2011		