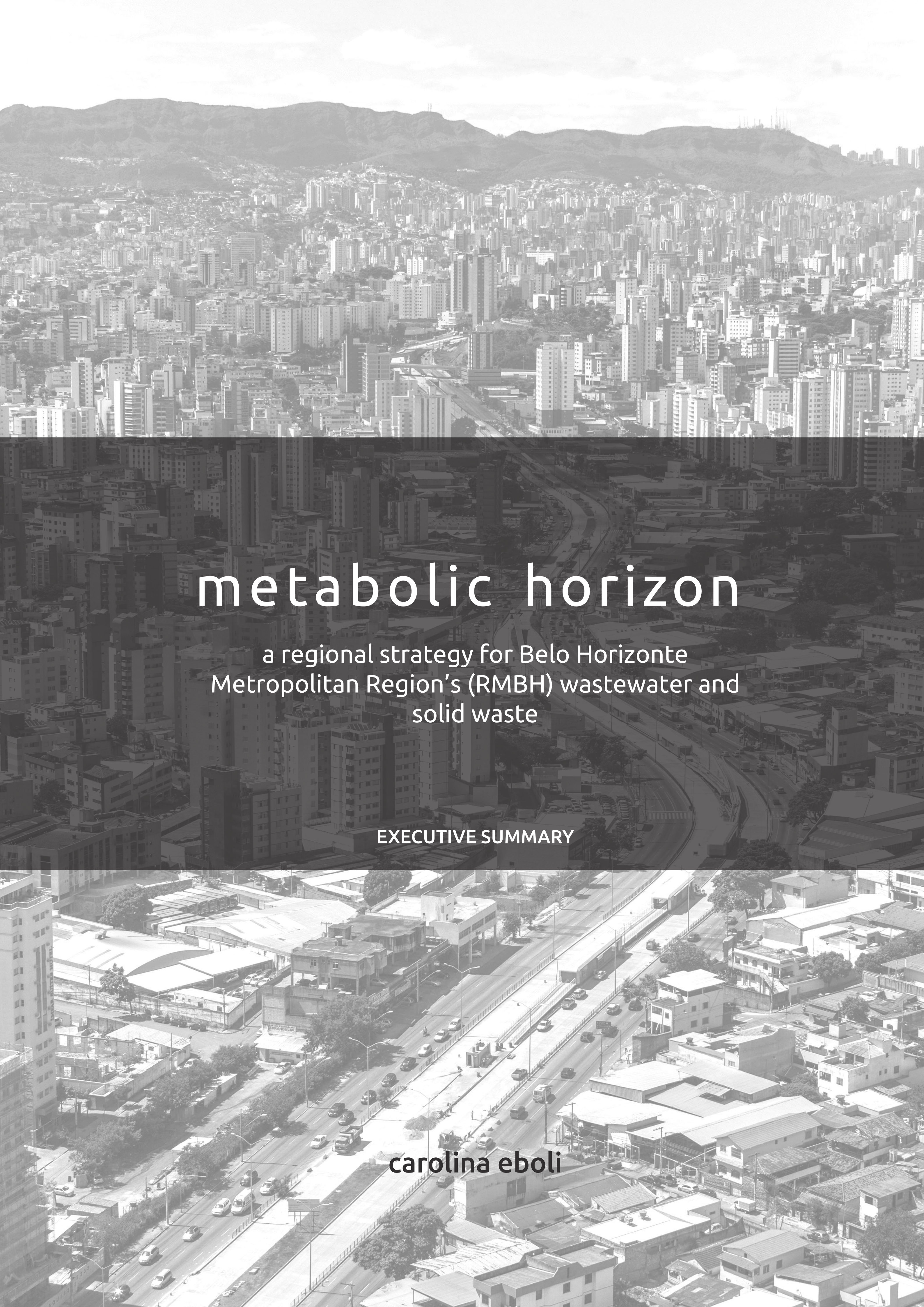

metabolic horizon

a regional strategy for Belo Horizonte Metropolitan Region's (RMBH) wastewater and solid waste

EXECUTIVE SUMMARY

carolina eboli

metabolic horizon

a regional strategy for Belo Horizonte Metropolitan Region's (RMBH) wastewater and solid waste

Carolina C. P. Eboli

Executive Summary

Delft University of Technology | Faculty of Architecture and the Built Environment | MSc Urbanism

July, 2018 | Delft, Netherlands

METABOLIC HORIZON

a regional strategy for Belo Horizonte Metropolitan Region's (RMBH) wastewater and solid waste

EXECUTIVE SUMMARY

July, 2018

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2nd mentor: Lidewij Tummers

Research Group: Smart Cities and Urban Metabolism
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Found at www.copa2014.gov.br. Edited by author.

This executive summary presents the most relevant aspects of the Graduation Thesis. For the complete report please refer for the P5 report at TUDelft's repository: https://repository.tudelft.nl.

ACKNOWLEDGMENTS

First, I would like to thank my mentors, Ulf Hackauf and Lidewij Tummers, for their commitment and enthusiasm, from the early stages of this work. I would like to thank Ulf for our long discussions, especially when things were still very confusing. They guided me to set a solid foundation for my project and stirred me through smooth transitions between phases. I always appreciated his genuine curiosity over my city and topic and I am happy to believe we had mutual exchanges over the past year. I would also like to thank Lidewij for her inputs, always giving me precise feedbacks and showing me different angles to consider. I very much appreciate that she participated throughout the entire process and that I could fully rely on her expertise. I believe you both have pushed me to go in depth in each step of the way, leaving no room for any gaps.

I also would like to thank my studio colleagues, with whom I have shared the complaints (a lot of them), but also laughter, uncountable breaks and, mostly importantly, words of support. Special thanks for my girls Esmee, Concha and Mona. Each one of you followed my steps differently, but you were always present. And, of course, thank you to all my friends in the Netherlands and Brazil, for sharing this moment with me.

In addition, I especially want to thank Thaís, which put up with all my difficulties during this time, from defining the thesis theme to asking for data to her contacts. Your help, together with Júnia's, were crucial to make the focus group and interviews a successful reality. To you both, my sincere thank you.

I would also like to acknowledge the EFL foundation, for funding my field trip. This certainly increased the work's quality and added different perspectives in my proposal.

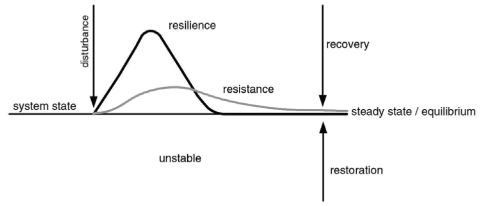
Last, but not least, I would like to thank my family, Inês, Ivo and Júlia. I definitely could not have come to TUDelft without your unconditional support. You have always made sure the missed birthdays, celebrations and also difficult moments, enfim, a saudade, were worth it. I never doubt it, but at the end of this graduation, it is a consolidated fact.

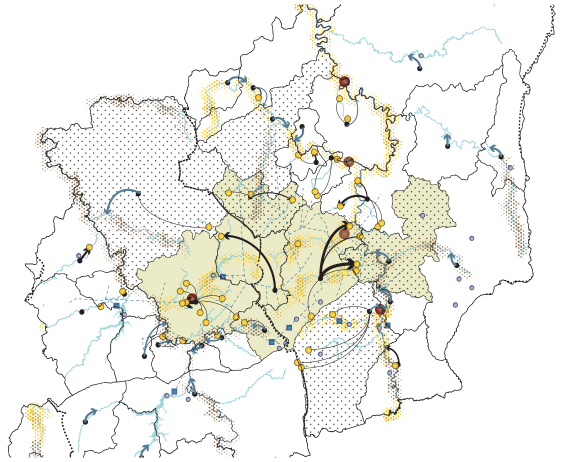
ABSTRACT

This thesis seeks to explore relations between Urban Metabolism's framework and regional planning in Belo Horizonte Metropolitan Area (RMBH) - Brazil, and possible solutions to promote sustainable development through a better management of resources. In order to do so, the problem field defined in this research focuses on the area's rapid urbanization heritage and its main environmental pressures: water (storm water flooding, drinking water shortage and river pollution); solid waste (large generation and inappropriate disposal and treatment); mining extraction; consequences of urban fabric expansion (informal settlements, infrastructure shortage, conflicts between urban and environment and alteration of natural ecosystems); and CO2 emissions. The research also restrains itself to wastewater and solid waste flows, pointing out their urgencies and opportunities through the combination of territorial, policy and metabolic analysis, providing a new perspective on the urban comprehension of the region. In combination, this thesis puts forward a catalog of solutions and a regional strategy. The proposal embraces the regional scale, the flows perspective and specific challenges due to rapid urbanization processes, translated into 4 different systems applied in regional clusters. It also explores the spatial implications of the proposed strategy, together with local governance and stakeholders with two test cases: Belo Horizonte and Ribeirão das Neves. Moreover, by understanding the metropolitan region as part of the same tissue rather than seeing it as a poor version of the capital, this thesis contributes towards, not only diminishing the existing inequality, but also strengthening the region as a whole. Lastly, this thesis reflects upon the translation between theory and design, within the concept of Urban Metabolism, contributing to the academic field.

1 | problematic horizon 8

2 | theoretical horizon 52





3 | analytical horizon 54

4 | design horizon 110

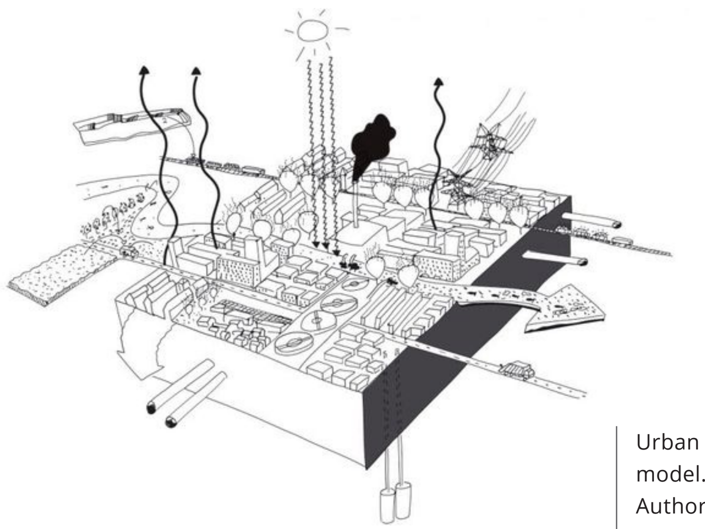
5 | reflection horizon 210

6 | references 220

1 |

problematic horizon

turning around the territorial approach



Urban Metabolism model.
Authors: Dirk Sijmons and Jutta Raith

1.1 motivation

My personal motivation for this research comes first from the academic field, specifically regarding Urban Metabolism concept. Although this concept is not new, I was exposed to it for the first time throughout my studies at TUDelft (Q3 Studio) and it provided me different understandings of urban contexts. This triggered the will to test this concept in my hometown, Belo Horizonte, in an attempt to propose a shift from the fixed and outdated planning framework to a more holistic perspective that would also have a better chance of being successful. This also relates to my personal perception of planning in Brazilian contexts as rigid frameworks that stumble upon bureaucracy and simplistic perspectives of what are, in reality, complex relations. Therefore, the lingering feeling is that they never achieve the desired goals. By choosing Smart Cities and Urban Metabolism research group, I could deepen my knowledge on Urban Metabolism topic, explore relations between this concept and urban design/planning and reflect upon the spillover effects of this approach. Moreover, using Urban Metabolism as a core element of the project goes in line with the research group's idea of analyzing the performance of an urban system, using material and energy flow analysis, and co-relate it with people and the built environment.

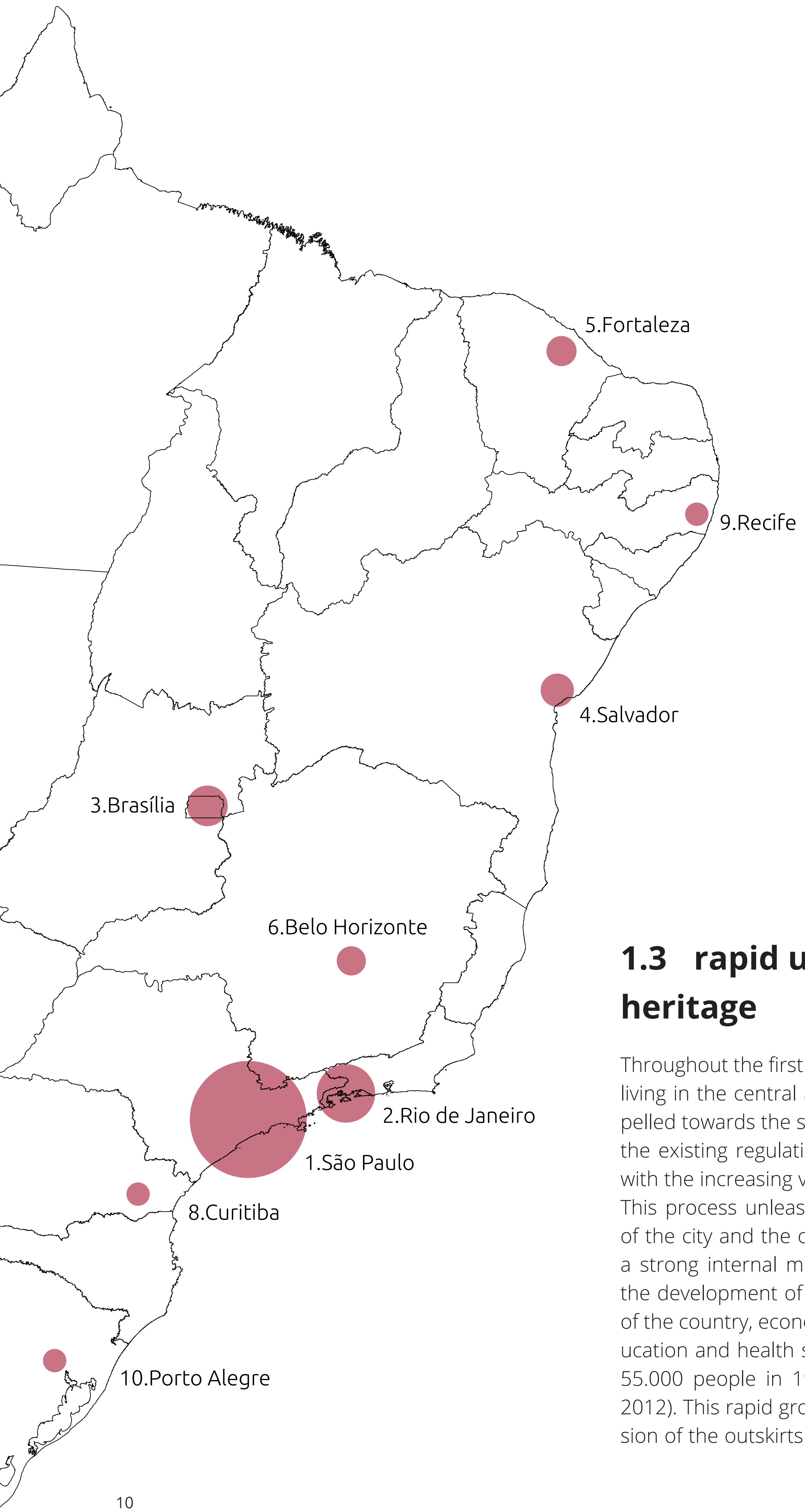
1.2 introduction

Some people advocate that we have been living in a new geological era, the Anthropocene. This era reflects humanity as the dominant geological actor associated with changes technology has caused in nature (Trischler, 2016). This new age is not yet official (maybe it will not even become) and there are nine different possible dates prosed so far for when it has begun (Trischler, 2016). However, regardless of the precise date or formal approval, the Anthropocene concept brings a reflection towards the future. If we accept that humans will continuously have impacts on the planet's systems, then it is relevant and necessary to discuss how we desire this impact to be.

Urbanizations can be seen as one of the greatest impacts humankind has had on Earth's surface, since it completely altered its natural conditions. Rapid urbanization is even more serious, since it is harder to manage unbalances this process causes such as "rapid sprawl, pollution, environmental degradation, [...] unsustainable production and consumption patterns" (UNDESA, 2014). Considering the future's prospect, urbanization is bound to become the rule rather than the exception, where the urban population is expected to reach 66% by 2050 (UNDESA, 2014). This scenario poses challenges to urban planners in order to remediate rapid urbanization effects on existing areas and reduce their impact in other locations, such as Asia and Africa, areas expected to become around 15% more urban than what they are now by 2050 (UNDESA, 2014). In that sense, how humans deal with urbanization in the coming decades and centuries will be crucial to determine the planet's life quality.

When talking about urbanization or rapid urbanization, Latin America presents itself as an important region to be studied. According to the United Nations, Latin American and the Caribbean is the second largest urbanized area (80%), following only the United States (82%) (UNDESA, 2014). Moreover, Latin America, as many parts of Asia and Africa, is a developing region, with multiple challenges due to urbanization and many structural issues, such as housing deficit, basic infrastructure and social inequality (UN-Habitat, 2012). In that sense, several urban strategies applied in this setting can also contribute to the large-scale discussion on how to improve life quality within cities in developing regions.

An alternative to address to urbanization quests is Urban Metabolism, an approach that allows comprehension of operational relations within the city and helps to improve its performances, since it is process-based. In this sense, urbanization is seen as an ecosystem in which vital flows take part, being "useful for understanding, identifying and measuring inefficiencies and quality loss within urban areas and for tracing opportunities to improve the metabolism" (Schuetze, van Bohemen, & van Bueren, 2012). One potential implication of this view is the creation of planning strategies that provide interconnections and possible disentanglements between flows. Moreover, addressing the city from the flows perspective allows a holistic approach (Ferrão & Fernandez, 2013), assuring the chosen solutions include the complex relations that come with urban challenges.



1.3 rapid urbanization heritage

Throughout the first decades, the poorer population living in the central area of the urban zone was expelled towards the suburban zone, being pushed by the existing regulations of the time in combination with the increasing value of urban land (Filho, 2012). This process unleashed an unorganized expansion of the city and the creation of slums. Together with a strong internal migration due to factors such as the development of connections with other regions of the country, economic growth and increase of education and health services; the city exploded from 55.000 people in 1920 to 214.000 in 1940 (Filho, 2012). This rapid growth culminated in a fast expansion of the outskirts that even planning instruments

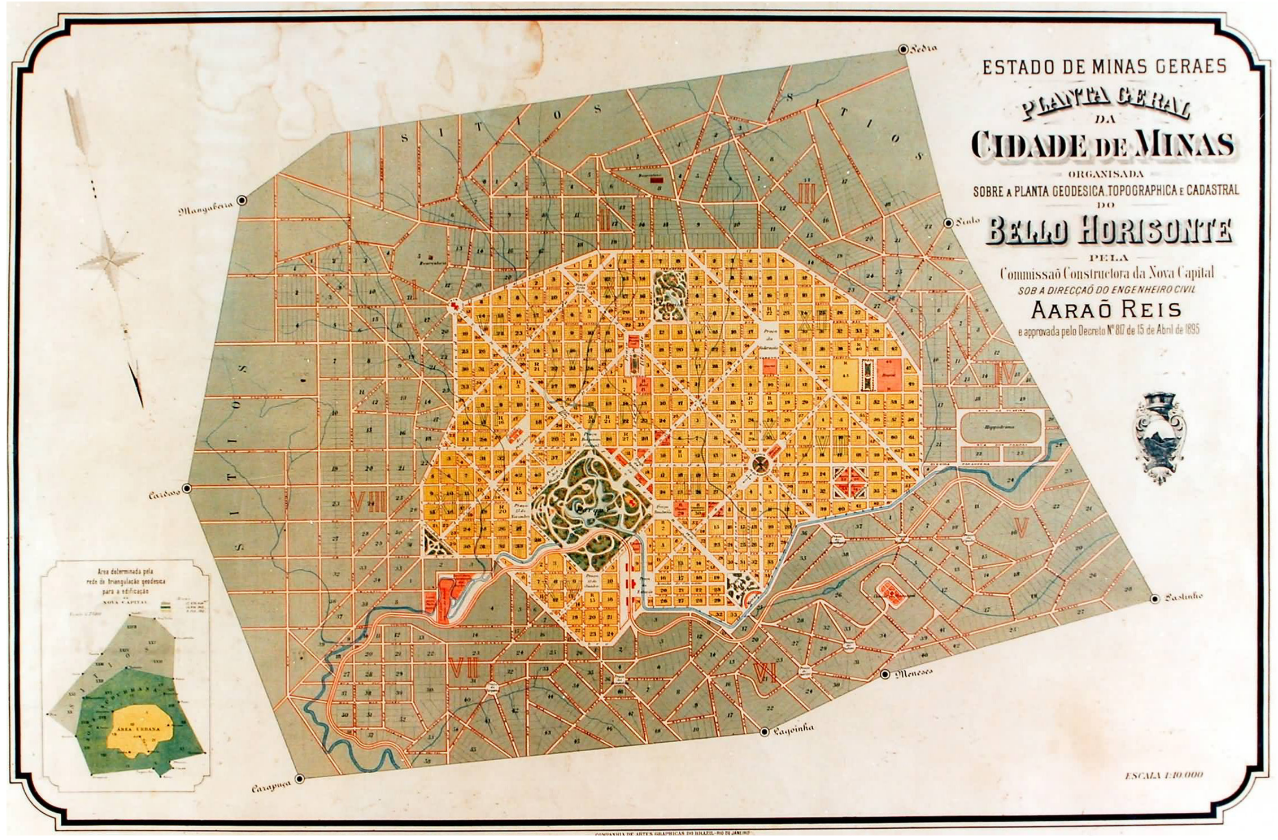
Overview of Belo Horizonte
Found at: zacmac-innes.wordpress.com

BELO HORIZONTE

Belo Horizonte is the capital of Minas Gerais state and the 6th largest city of Brazil, with around 2,5 million people (IBGE, 2017), and the 4th largest GDP of the country (IBGE, 2014). The city was planned to be the new capital of the state in the late 19th century, substituting the colonial city of Ouro Preto, which no longer seemed to suit the needs of urban life. Inaugurated in 1897, the city was designed based on positivist and republican concepts: geometric lines, control of space through urban legislation and programmatic zoning and sanitary concepts (Filho, 2012). It also had an urban and suburban zones that were expected to accommodate 30.000 people in its central area (urban zone) and 200.000 in the city as a whole (Filho, 2012).

implemented at the time were not able to control (Filho, 2012). Moreover, the following decades (1950 and 1960) were defined by local industrialization that required massive infrastructure, which fomented migration and commuting, resulting in the early formation of the metropolitan area (Filho, 2012). As consequence of the accelerated urbanization, structural problems emerged, such as the lack of water and energy supply and sewage systems, not to mention the reduction of urban space quality, slums proliferation and environmental implications from the reduction of green areas and impairment of water basins (Filho, 2012).

In 1973, the Metropolitan Region of Belo Horizonte (RMBH) was officially established and in 1974, an institution named Plambel was formed to plan the region, through a state autarchy, which led to completely top-down planning decisions (UFMG, n.d.). This institution was also created with the intention of allowing federal interventions, especially regarding infrastructure and sanitary measures, such as eradication of slums (Filho, 2012). Therefore, regional actions were focused on technical aspects and intended urban organization through functionalism (UFMG, 2011). Moreover, during this decade, the urban population became larger than the rural one (UFMG, 2010), which contributed to extend the metropolitan region, marked by social and urban inequality, together with the consolidation of urban-suburban relation between Belo Horizonte and its surroundings (Filho, 2012). In the following decade (1980), the region already presented 94% of urbanization (UFMG, 2010). Associated with the economic crisis during 1980's and 1990's, the urban and social situations worsened, which slowly started to be addressed only after the monetary stabilization in 1994. In 1996, Plambel was extinguished and no other institutions were created or actions taken regarding the metropolitan region. From 2000 onwards, the economy of the region became dependent on the car industry and started to re-explore its natural resources, mining iron ore rather than the colonial gold of the past (Filho, 2012). In 2004, though, the State Government of Minas Gerais implemented a new model of regional management and planning (UFMG, n.d.), which led to the current two main regional management and planning instruments: Director Plan of Integrated Development of the Metropolitan Region of Belo Horizonte (PDDI-RMBH) and the Fund for Metropolitan Development. The first comprises an extensive



Original Plan for Belo Horizonte (1895). Picture: Public domain

diagnosis of the region and defines guidelines/policies for main projects and intervention areas, whereas the last is a financial instrument. The PDDI's last official report was finalized in 2011 and has urban objectives aiming for 2023 (medium term) and 2050 (long term). As consequence of this plan, a new regional zoning law is currently under discussion (Macrozoning), expected to become official in 2018[1].

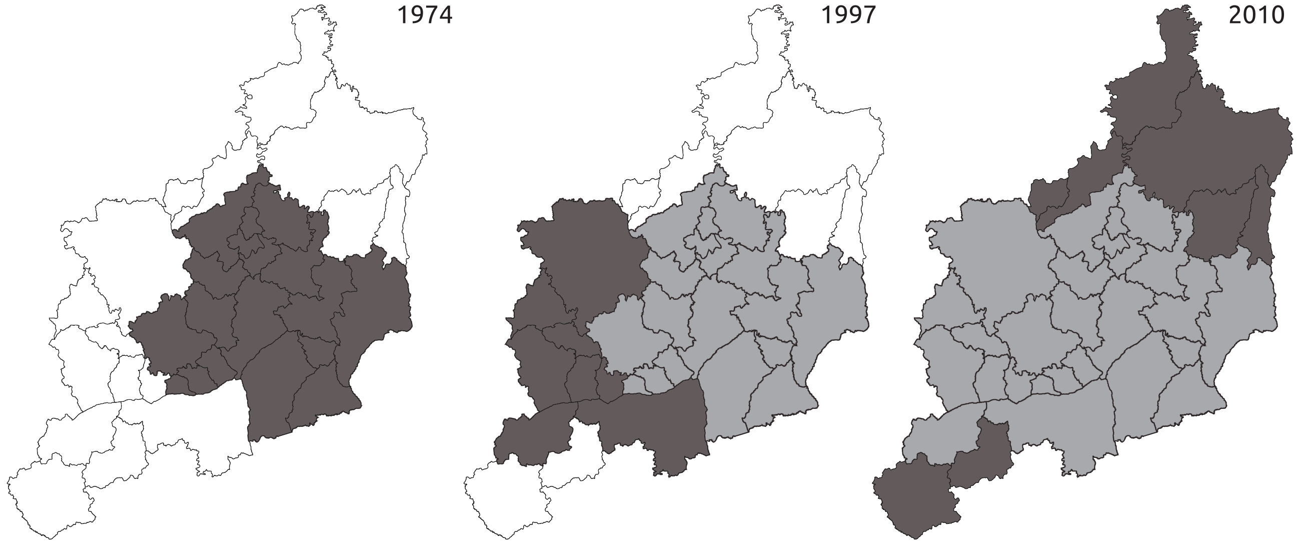
[1] See item "1.6 what has been done so far" for a detailed overview of these policies.

Densification of Belo Horizonte's downtown by 1930. Picture: Public domain

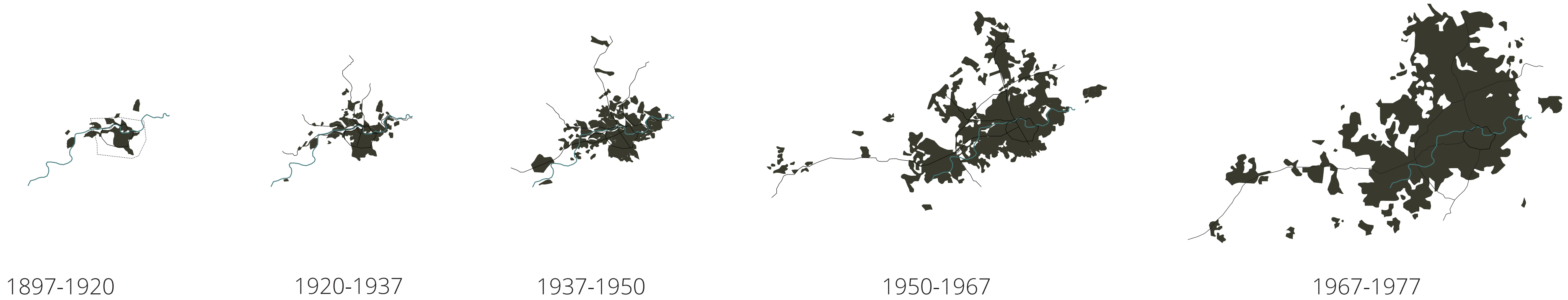
Belo Horizonte's plan structure and beginning of verticalization process (1950). Picture: José Góes Collection

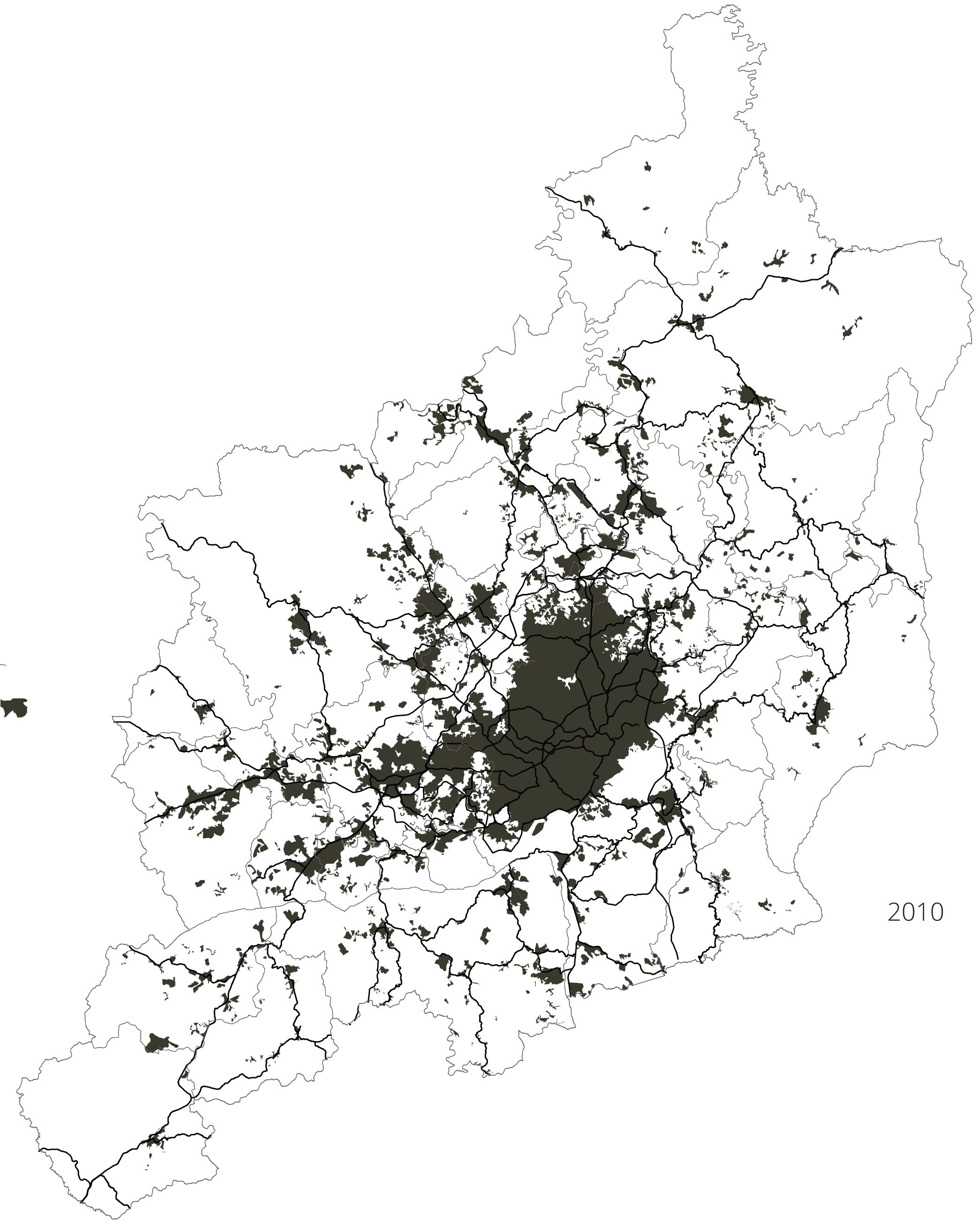
Contrast between planned and unplanned areas (background) in Belo Horizonte in 1955. Picture: José Góes Collection

Belo Horizonte Metropolitan Region is currently the 3rd largest metropolitan area in Brazil and the 7th largest in Latin America (Development Agency RMBH, 2017). As consequences of its historical evolution, environmental issues increased such as: "depletion of natural resources; accelerated processes of desertification; intensification of extreme weather events; lack of basic sanitation, housing, transportation and public security; chemical pollution in urban and rural areas; and the emergence and reemergence of diseases" (UFMG, 2010- Translated by author). Some structural projects were implemented after the year 2000 (UFMG, 2011) mainly addressing mobility issues. One important project was the execution of the "Green Line", finalized in 2008, connecting Belo Horizonte's city center and Confins International Airport. It is important to highlight that, although this project improved around 35km of roads, (Belo Horizonte Municipality (PBH), n.d.), it also included the covering of Belo Horizonte's main river Ribeirão Arrudas (that suffered historical flooding episodes), reflecting the reliance on traditional car-oriented drainage and urban solutions. The new headquarters for the Administrative City of Minas Gerais State, inaugurated in 2010, was also placed next to the Green Line in an attempt to stimulate future expansion on this direction. Another important project was the implementation of the BRT (Bus Rapid Transit) in Belo Horizonte (called MOVE) and the expansion of Confins International Airport, as consequence of 2014 World Cup investments. In addition, there are several large projects foreseen for the future that will affect not only the urban dynamics of the region, but also increase the existing environmental pressures. These pressures and challenges for the future sustainable development of the metropolitan region are topic of the next section.



Evolution of municipalities included in the RMBH.





Rapid evolution of urban fabric in Belo Horizonte and Metropolitan Area in roughly a century.

1897
Belo Horizonte founding

1973 1974
Belo Horizonte Metropolitan Region (RMBH) and Plambel creation

1996
Plambel extinction Planning gap

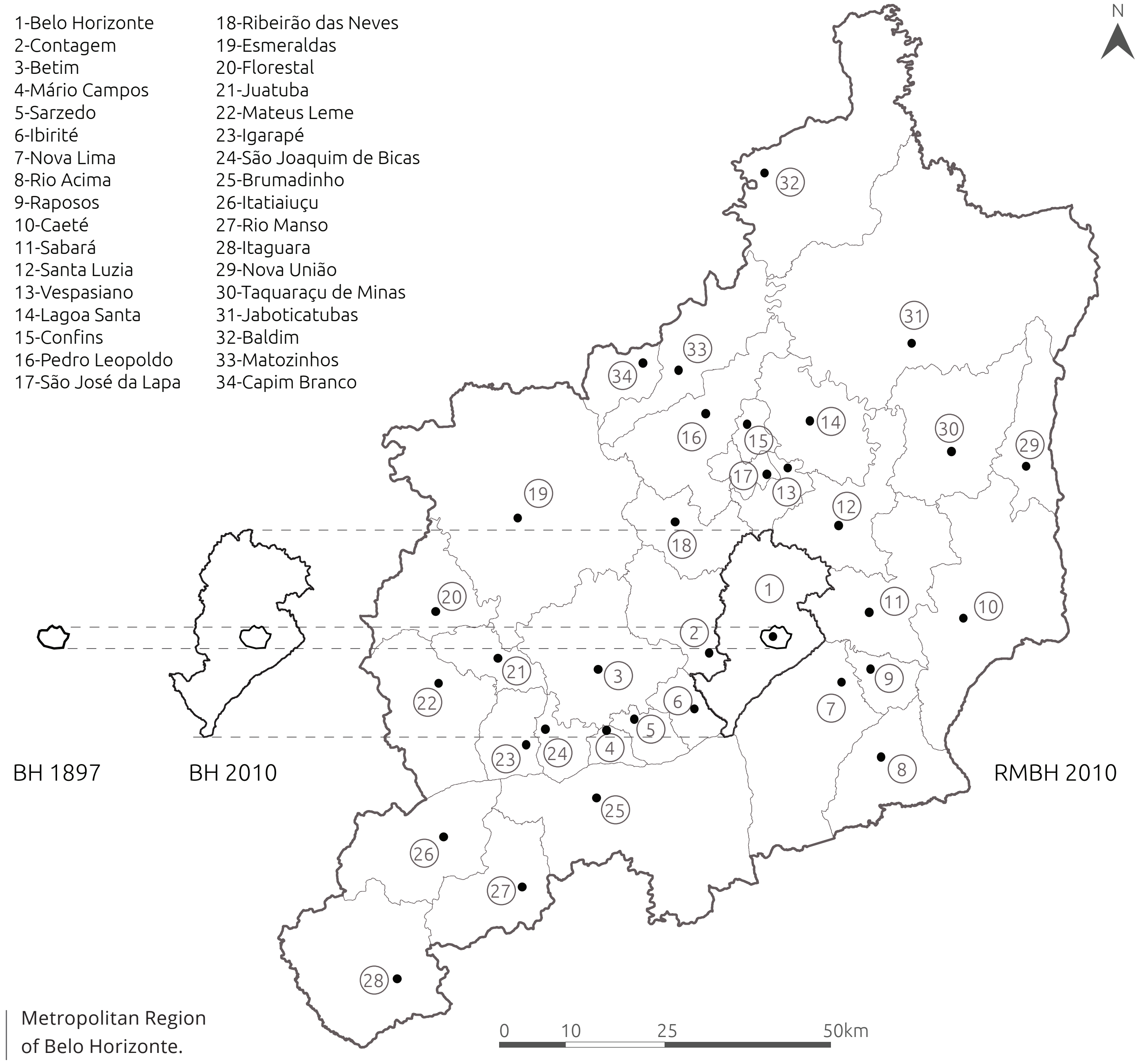
2004
Implementation of the new model of regional management and planning

2011
PDDI-RMBH final report

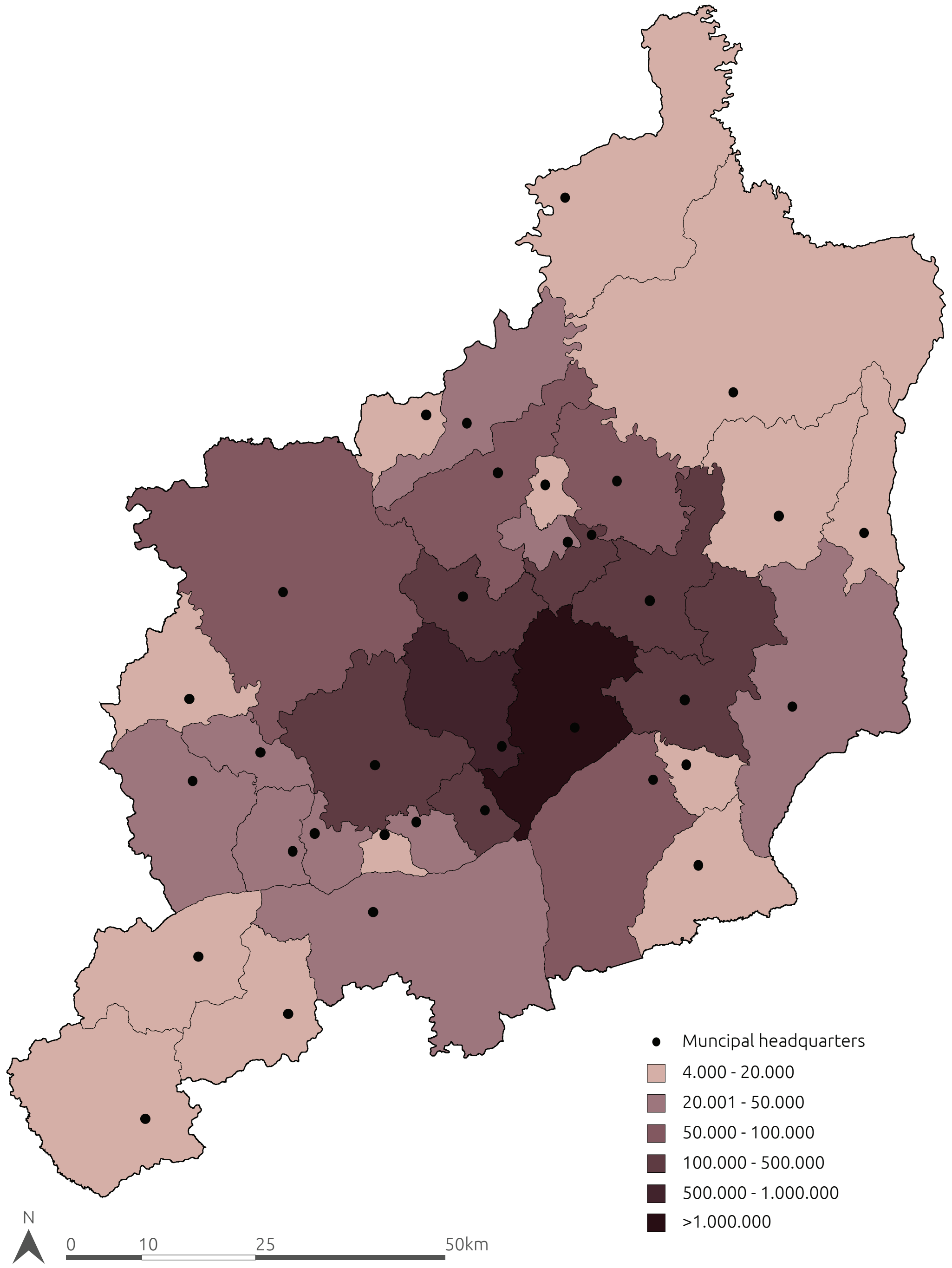
2018
expected Macrozoning approval

Planning evolution and structure in the RMBH.

Loose planning instruments between during the first decades of its foundation until the creation of Plambel in the 1970s. In the following decades, Plambel focused on infrastructure planning and organization of the urban fabric through functionalism. After the extinction of Plambel, regional planning actions were inexistent until 2004, when a new model of regional management was implemented. This process resulted in the PDDI diagnosis and policies, which in turn led to the Macrozoning, currently in process of approval.

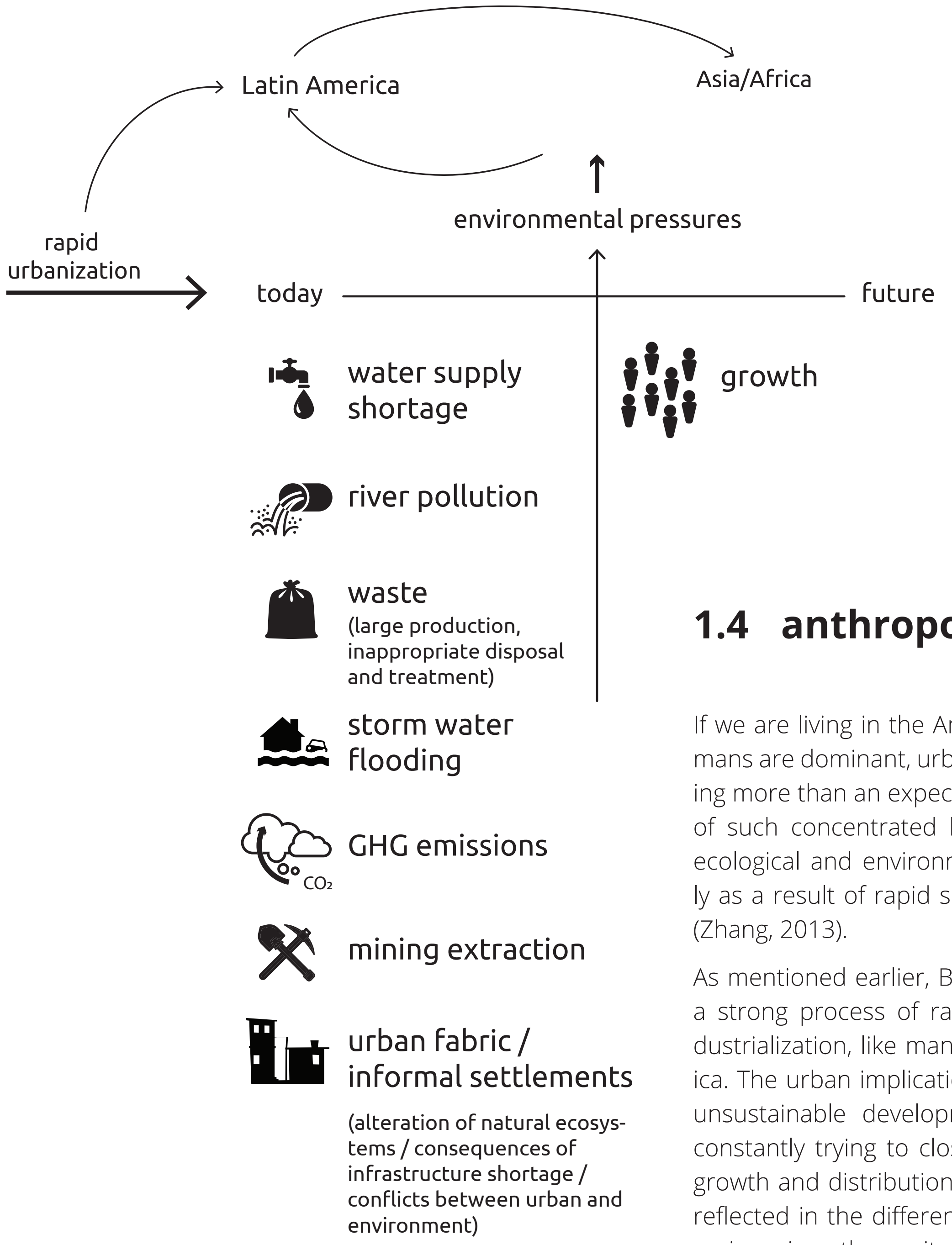


Metropolitan Region of Belo Horizonte.



Population in the RMBH. High concentration in the capital and immediate surroundings.

Notes:
Map based on the National System of Sanitary Information (SNIS) 2015.



Main environmental pressures in RMBH.

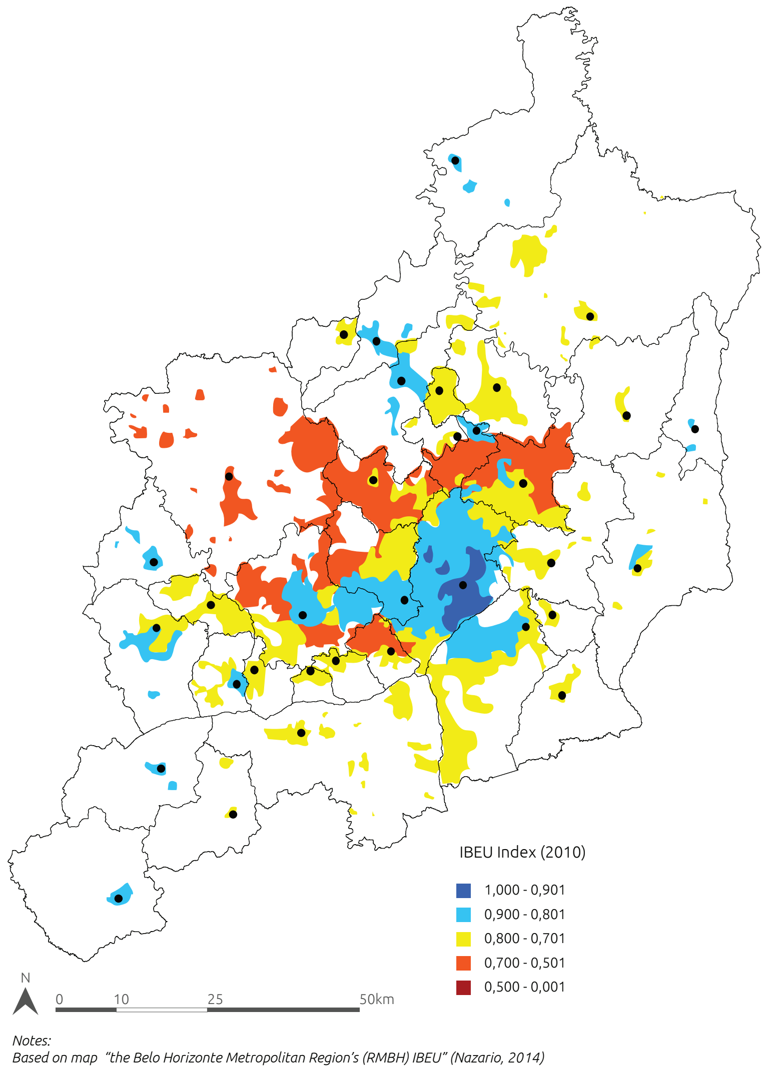
1.4 anthropocentric RMBH

If we are living in the Anthropocene age, where humans are dominant, urban agglomerations are nothing more than an expected consequence. The result of such concentrated human activity has "serious ecological and environmental problems, particularly as a result of rapid socioeconomic development" (Zhang, 2013).

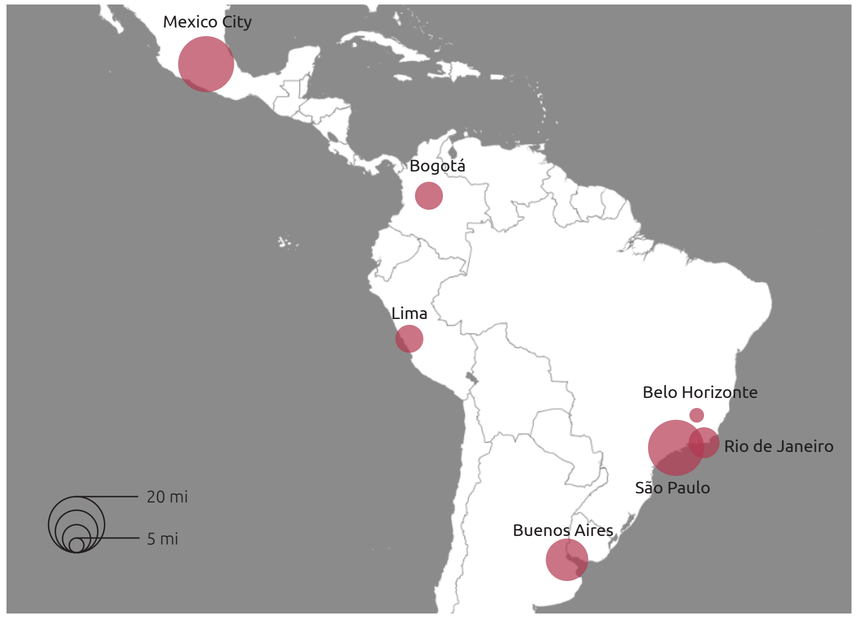
As mentioned earlier, Belo Horizonte suffered from a strong process of rapid urbanization due to industrialization, like many other cities in Latin America. The urban implications of this process relate to unsustainable development, leaving governments constantly trying to close the eternal gap between growth and distribution of services. This gap is also reflected in the differences within the metropolitan region, since the capital received more investments throughout the years than its surroundings. The Urban Well-Being Index (IBEU) illustrates these variations, using 5 dimensions (mobility, urban environment, housing conditions, public services, and urban infrastructure) to assess the urban quality of RMBH (Nazario, 2014). Moreover, a large impact of rapid urbanization's consequences reflects on the current environmental problems in the region. According to the diagnosis of the Director Plan of Integrated Development for RMBH (PDDI-RMBH), the main environmental pressures in the region relate to water (storm water flooding, drinking water shortage and river pollution); solid waste (large generation and inappropriate disposal and treatment); mining extraction; consequences of urban fabric expansion (informal settlements, infrastructure shortage, conflicts between urban and environment and alteration of natural ecosystems); and CO2 emissions.

Another aspect that raises challenges over the environmental performance of the region is future projections. Nowadays, Belo Horizonte's growth is no longer rapid: it is expected to grow 3,0% between 2000 and 2050 (UFMG, 2010). However, the housing occupation is expected to rise 38% in the same period (UFMG, 2010), meaning less people living in more units, posing questions on environmental impacts due to this layer of urbanization. In addition, the Metropolitan Region is projected to continue growing, matching the capital's population by 2020 and finally peaking in 2040, reaching 5,8 million people (UFMG, 2010). This means around 400.000 people more in the region, from 2020 to 2040, which will consume more resources and produce more waste.

It is important to highlight, though, that urbanization itself is not necessarily negative. Considering density, diversity, proximity and dynamism as key aspects of an urban context (Jo, Basudeb, & Ravi, 2010), cities are attractive areas, since they are capable of providing social and economic opportunities that add to the increase of productivity; concentration of well-educated individuals, which contribute to knowledge spill overs and access to diverse facilities and services (OECD, 2015). Therefore, cities are "the sources for efficiency and dynamic growth" (Jo et al., 2010). In this context, planning the future of the RMBH is necessary to unlock its potential, becoming more integrated, productive and sustainable.



Urban Well-Being Index (IBEU) of RMBH. 5 dimensions (mobility, urban environment, housing conditions, public services, and urban infrastructure) assess the urban quality of RMBH. The result indicates inequality between the capital and the surroundings.

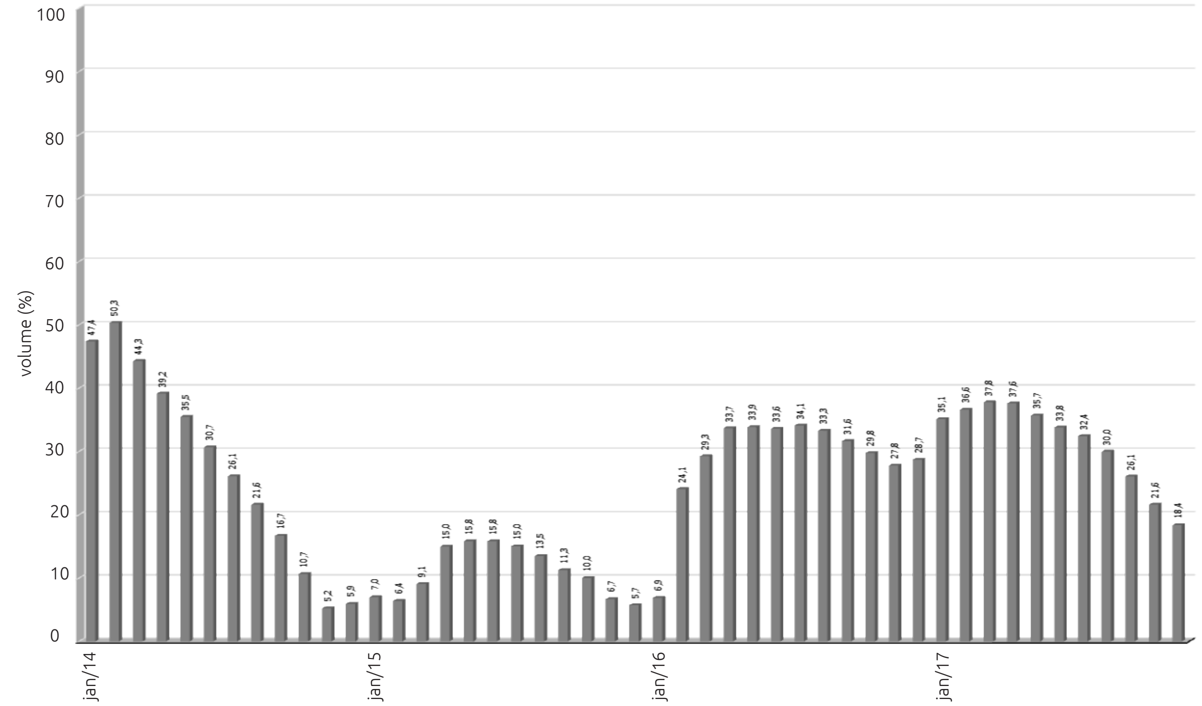


Largest metropolitan areas in Latin America. RMBH is the 3rd largest of Brazil and 7th of Latin America.

water

Critical situation of Serra Azul Reservoir in 2015.
Picture: TV Globo, 2015

According to Rômulo Pirilli, the volume of precipitation between January and September 2017 was equivalent to half of the historical average of the last 65 years (Werneck & Vale, 2017).



Critical situation of Serra Azul Reservoir between 2014-2017. Source: Copasa, 2017

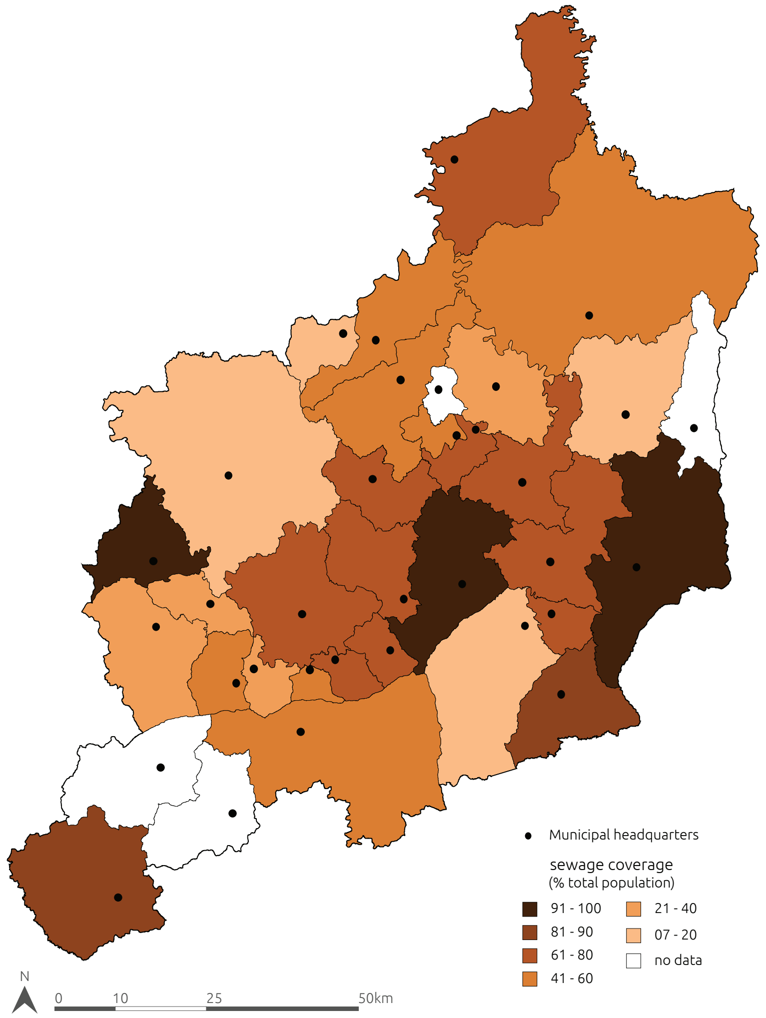
1.5 a closer look at RMBH's pressures

There are many challenges in the RMBH regarding water resources, related to drinking water supply, pollution and flooding. Already in 2010, the diagnosis of the PDDI-RMBH (UFMG, 2010) pointed to an uncertainty scenario over availability of water supply. Since then, two major droughts events happened in 2015 and 2017, when the reservoirs reached a critical situation. This situation is aggravated due to substantial losses in the region's distribution network (estimated in 39%) and issues such as illegal connections, waste, leakages and obsolete infrastructure (COPASA, 2003), which also add substantial costs in the water abstraction (UFMG, 2010). In addition, there is a great pollution of water bodies in the area due to industrial, agriculture and mining activities that release toxins, fertilizers containing heavy metals and sediments, compromising the natural ecosystem. In popular touristic areas, waste and damage of riparian zones also become relevant factors when discussing drinking water resources (UFMG, 2010). Moreover, there is still a considerable amount of sewage discharge in the rivers, making it the main organic water pollutant in the region (UFMG, 2010). This occurs due to lack of proper infrastructure, low coverage (estimated 56%) and low treatment (estimated 39%) (UFMG, 2010). For example, several cities in the region have high extension of sewage network per connection, which demonstrates the network's obsolescence (UFMG, 2010).

On the other hand, even though storm water helps balancing the reservoirs levels, the urban occupation of the region also suffers from flooding episodes in

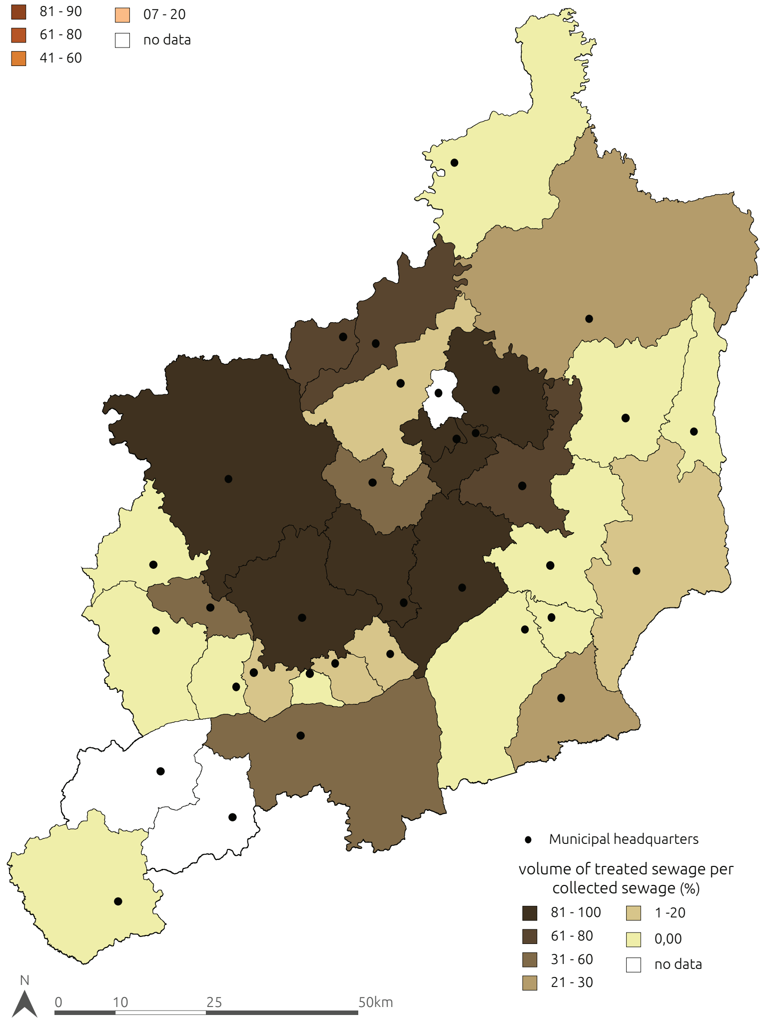
Pollution in Onça Watershed, in Belo Horizonte.
Picture: Michelle Parron & Bianca Aun

Sewage coverage in the RMBH.
Average of 56% of sewage collection in the region.



Notes:
Map based on the National System of Sanitary Information (SNIS) 2015.

Sewage treatment in the RMBH.
Average of 39% of sewage treatment in the region.

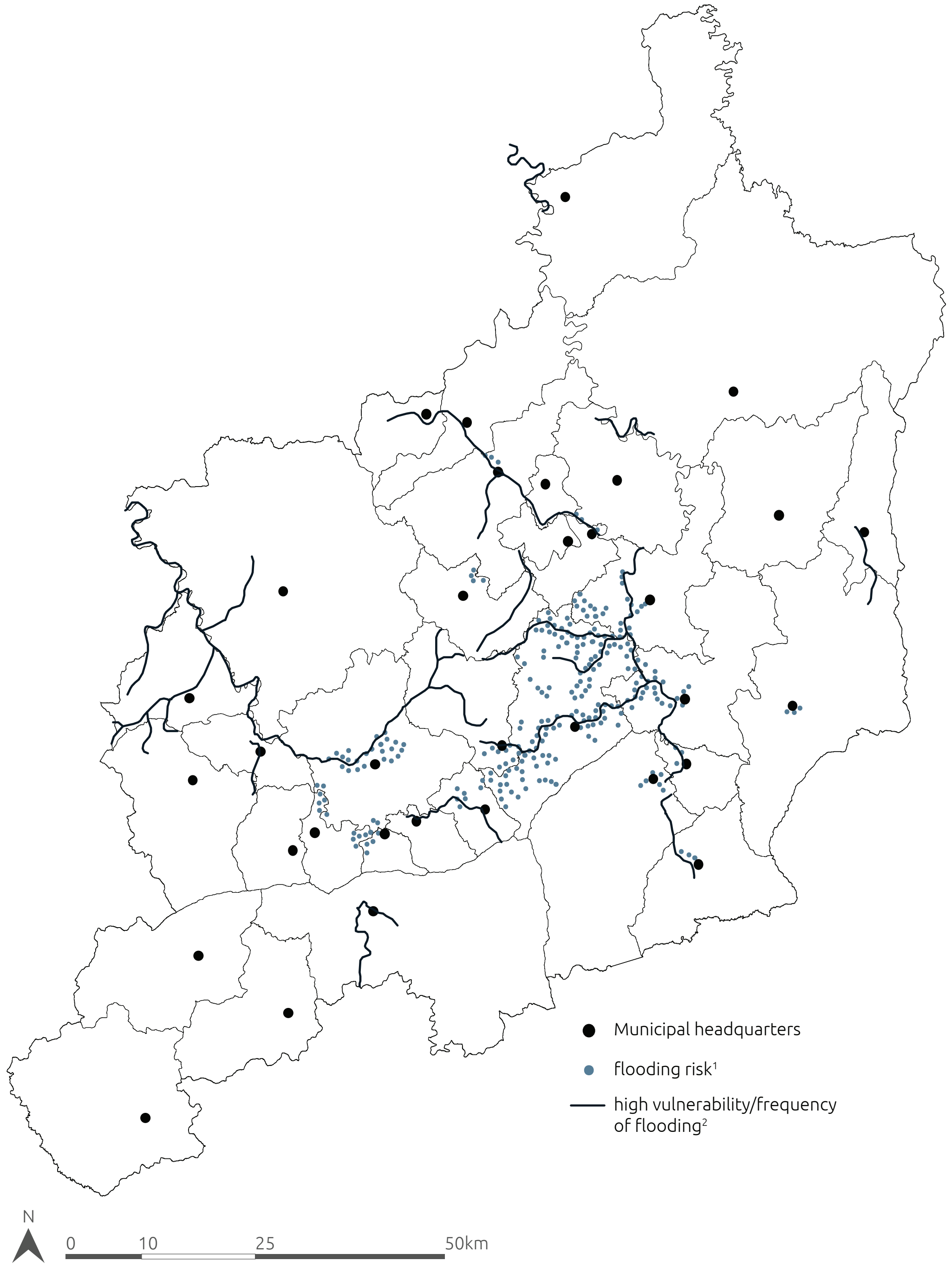


Notes:
Map based on the National System of Sanitary Information (SNIS) 2015.

the rainy season. According to the PDDI-RMBH, the large area of impervious paving associated with traditional drainage solutions (artificial canals) are the main causes for storm water flooding occurrences, since the first one reduces water infiltration and the last speeds the concentration of water in low valleys and is not flexible to adjust to urban expansion (UFMG, 2010). In that sense, the rapid urbanization process the region has gone through is one important factor for aggravating erosion and flooding incidents (UFMG, 2010).

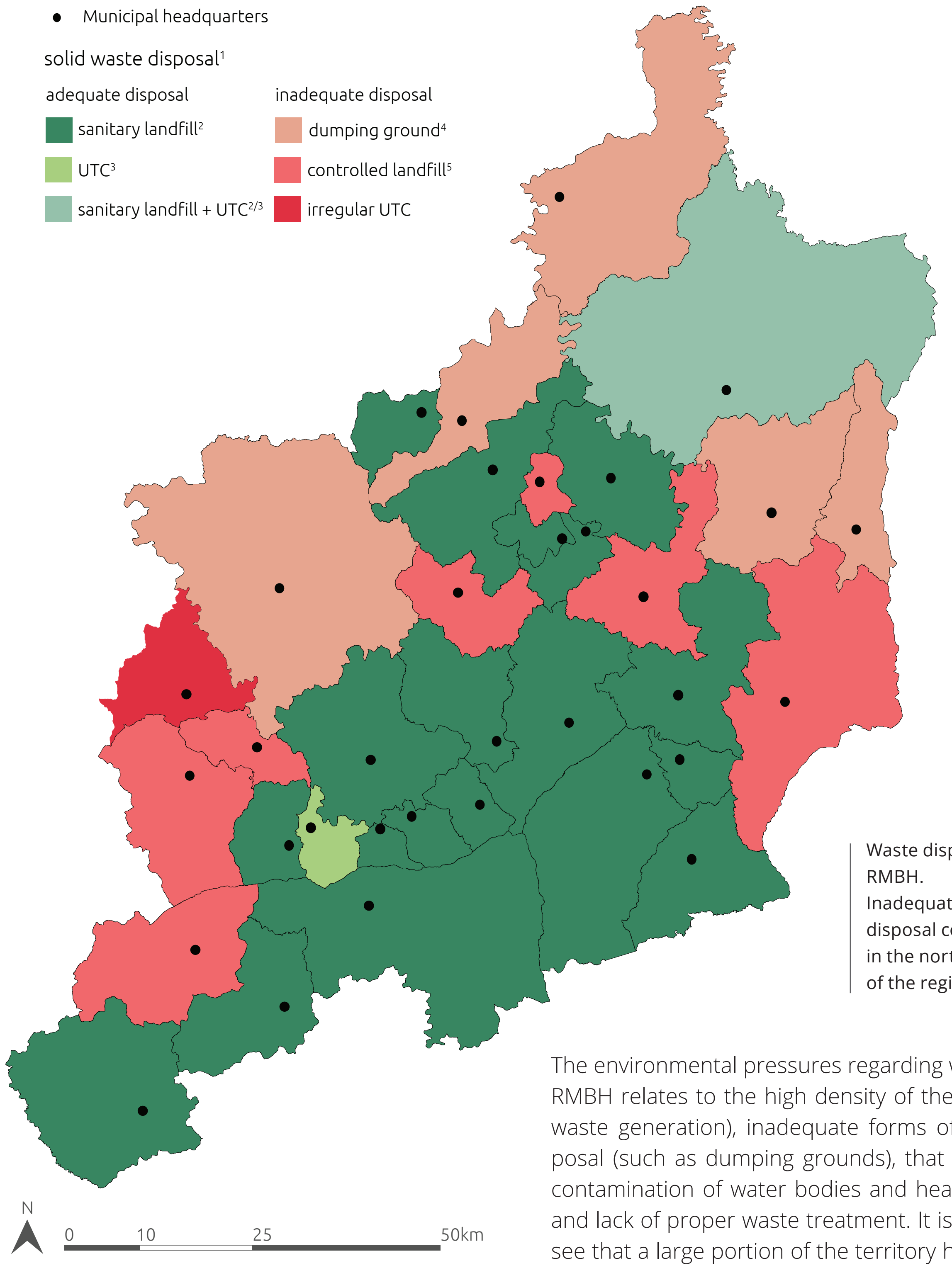
Lastly, it is possible to note that all these problems are linked to a particular reliance on heavy infrastructure, or centralized solutions, where the "hardware" (coverage of sewage networks, treatment plants and traditional drainage systems) is the main solution provided, reflecting the region's low resilience.

Flooding risk.
Flooding risks concentrate in highly urbanized areas.



Notes:
[1]Based on the map "Occupation density and hydrography RMBH and Metropolitan Belt" (UFMG, 2011 - translated by author)
[2]Based on information from the National Water Resources Information System (SNIRH), 2014

Before and during heavy rainwater 2011. Junction of Arrudas and Ferrugem Streams. Picture: Alessandro Borsagli



Waste disposal in the RMBH. Inadequate waste disposal concentrates in the north and west of the region.

waste

large production, inadequate disposal and treatment

The environmental pressures regarding waste in the RMBH relates to the high density of the area (large waste generation), inadequate forms of waste disposal (such as dumping grounds), that can lead to contamination of water bodies and health impacts, and lack of proper waste treatment. It is possible to see that a large portion of the territory has inappropriate systems. Even though the majority of population falls under the category of adequate disposal, around 13% of the population, or almost 780.000 people, are still relying on obsolete facilities.

Regarding waste generation, the amount of waste per capita in the region in 2008 was 0,92 kg/capita/day (UFMG, 2010). In 2001, the Brazilian waste generation average was 1,0 kg/capita/day, but had a projection to reach 1,6kg/capita/day, by 2025 (Hoornweg & Bhada-Tata, 2012). Even though the RMBH's figure could be considered as average in the national context, in absolute numbers, it means that the RMBH produced 4.715 tons of solid waste per day, or 1,7 million of tons, for that year alone. This amount of waste associated with deficient waste separation and small-scale recycling programs (UFMG, 2010) cause large environmental impacts, pressuring the biocapacity of land and the availability of resources, since they do not cascade back into the environment. This becomes even more relevant if the waste generation in the region progresses as the national tendency, associated with the expected population growth, contributing to shorten landfills' lifespan and increase their monitoring needs (UFMG, 2010). In that sense, the eternal gap between population growth and provision of services, partially due to the historical urban evolution of the area, is bound to be continued. Moreover, it is important to highlight that 40% of the residues in the region are domestic, from which 60% are organic (UFMG, 2010), whereas in developed countries, the amount of organic waste is around 30% (Bain & Company, 2012).

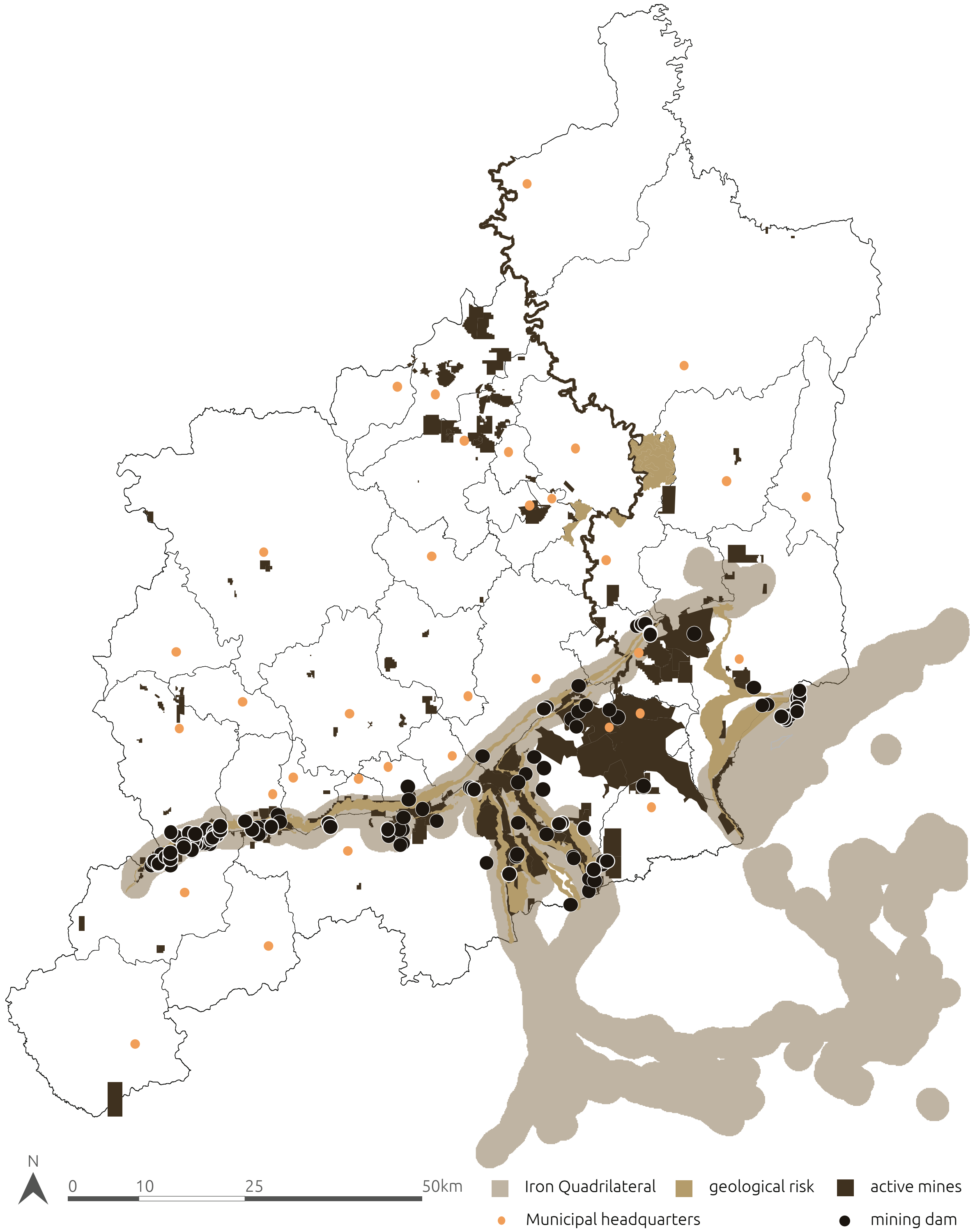
In addition, the reliance on heavy infrastructure poses the question if sanitary landfills are the best waste treatment system. For example, in 2007, Belo Horizonte's municipal landfill was closed, due to sanitary requirements after 30 years of usage. However, the solution for the capital's waste was transferring it to another sanitary landfill further away (UFMG, 2010). This reflects the concern for adequate waste disposal, but disregards impacts of transport, space allocation for a new facility and the rehabilitation of the closed one. This aspect raises questions regarding the dependency the region has over those facilities and perpetuity of fixed solutions, also reflecting RMBH's low resilience.

Dumping ground in the city Vespasiano. Picture: Municipal Director Plan Revision Team

Sanitary landfill in Mateus Leme. Picture: Municipal Director Plan Revision Team

mining

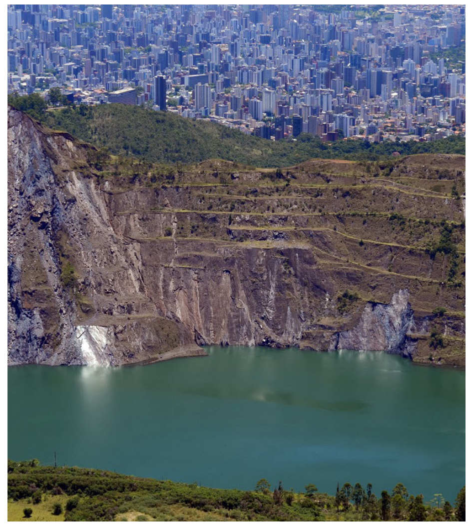
economy x environment



Notes:
Map based on information from the "Free access WebGis system to the environmental database" (Instituto Prístino, n.d.)

Tragedy in Mariana, after the rupture of 2 tailings dams in 2015, spreading millions of m³ of mud into the rivers.
Picture: Rogério Alves

Contrast between Belo Horizonte on the background and and Águas Claras mine, closed in 2002. Rehabilitation projects are still undergoing.
Picture: Fernando Rabelo



One of the greatest environmental disasters in Brazil occurred after the rupture of two tailings dams of Samarco Company in 2015, unleashing millions of m³ of mud, causing deaths, destroying multiple cities and contaminating rivers along 650km, also reaching the ocean (Camargo, 2017). The disaster happened about 125km from Belo Horizonte in Mariana district.

Minas Gerais State is notably known for its mineral resources, reason why its name means "General Mines". Part of this fame is due to a geological area of about 7.000km² known as the Iron Quadrangle (Quadrilátero Ferrífero), discovered in the 17th century and responsible for the development of the state (Francisco, n.d.). This geological area is present in almost half of Belo Horizonte Metropolitan Region and the widespread mining activity also reflects its economic importance. However, there are many environmental issues related to it, such as deforestation, alteration of superficial and underground water dynamics, creation of tailings dams, water pollution through heavy metals and development of associated erosion processes, which contribute to deposit large amount of sediments in water bodies (UFMG, 2010). For example, from the annual amount of sediments the rivers receive, 30% comes from mining activities (UFMG, 2010). It is important to highlight, though, that the small and illegal mining companies are highly responsible for this figure (UFMG, 2010).

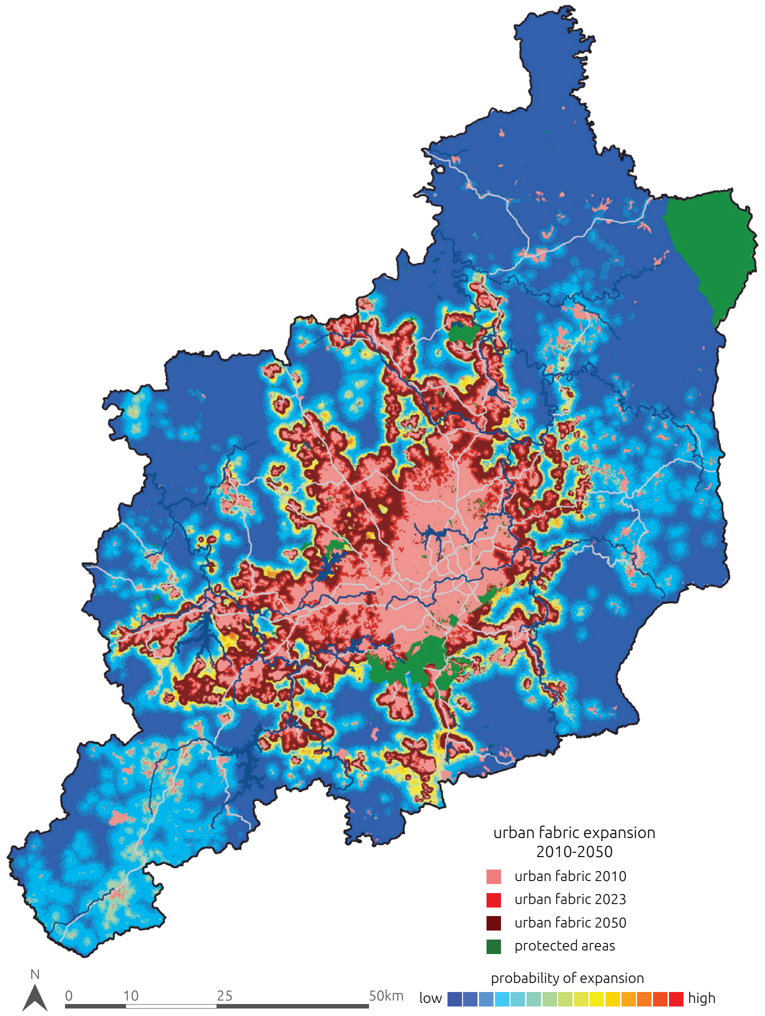
[left page] Mining activity in RMBH. Iron Quadrangle in RMBH and high concentration of mining activities on the east.

urban fabric

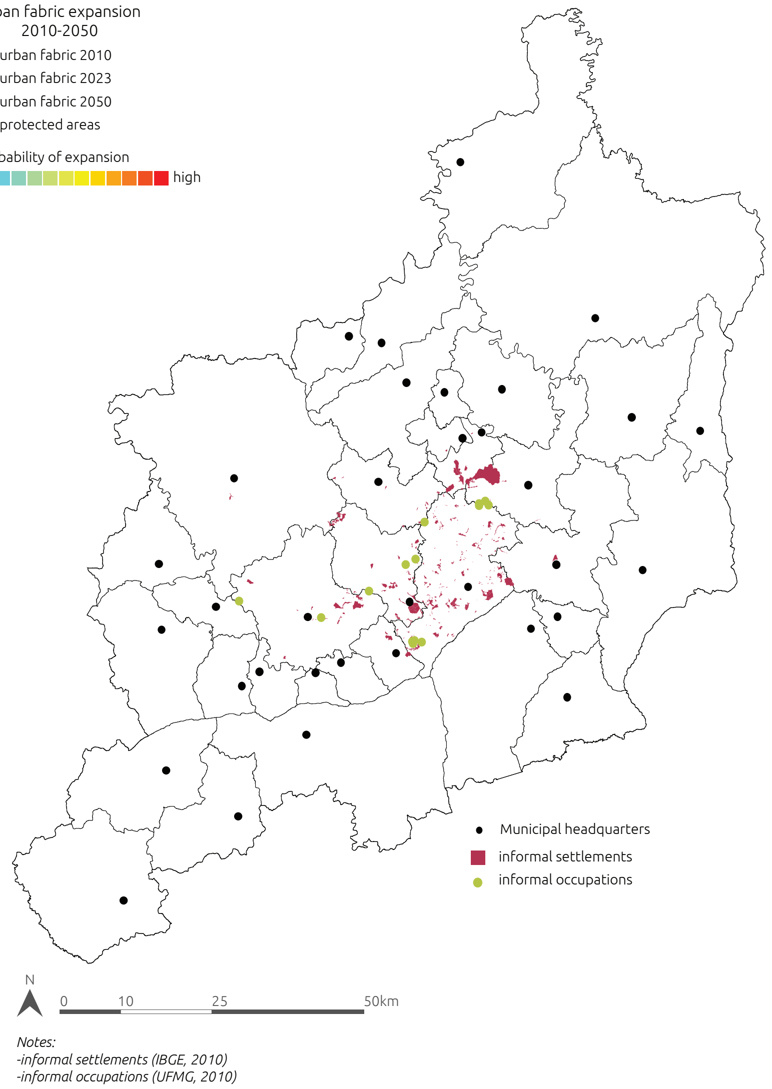
informality, conflict and expansion

Informal settlement in Belo Horizonte. Picture: M. Parron & B. Aun

Two main factors related to the urban fabric contribute for pressuring the environment: urbanization/expansion and informal settlements. Urbanization causes changes in the landscape and the environment since it “removes the natural vegetation, alters the hydrological cycle (mainly runoff and infiltration) and produces sediments given the soil exposure” (UFMG, 2010 – translated by author). The process of rapid urbanization the region suffered, though, contributed to worsen those consequences. Moreover, even though the region will grow at a slower pace until 2050, expansion will still occur, which implies in the natural occurrence of conflicts over space and resources, given the very nature of heterogeneity in cities (Jo, Basudeb, & Ravi, 2010). In the RMBH, the main conflicts are between areas with environmental interest and areas with urban expansion interest. The informal settlements also reflect some of these conflicts, since they are usually associated with risky areas (flooding or geological instable areas for example) and suffer from the lack of proper infrastructure, aggravating flooding episodes, increasing losses in the water system as well as intensifying water pollution due to sewage and solid waste (UFMG, 2010). The informal settlements are concentrated in the most urbanized areas, especially in the capital and its surroundings.

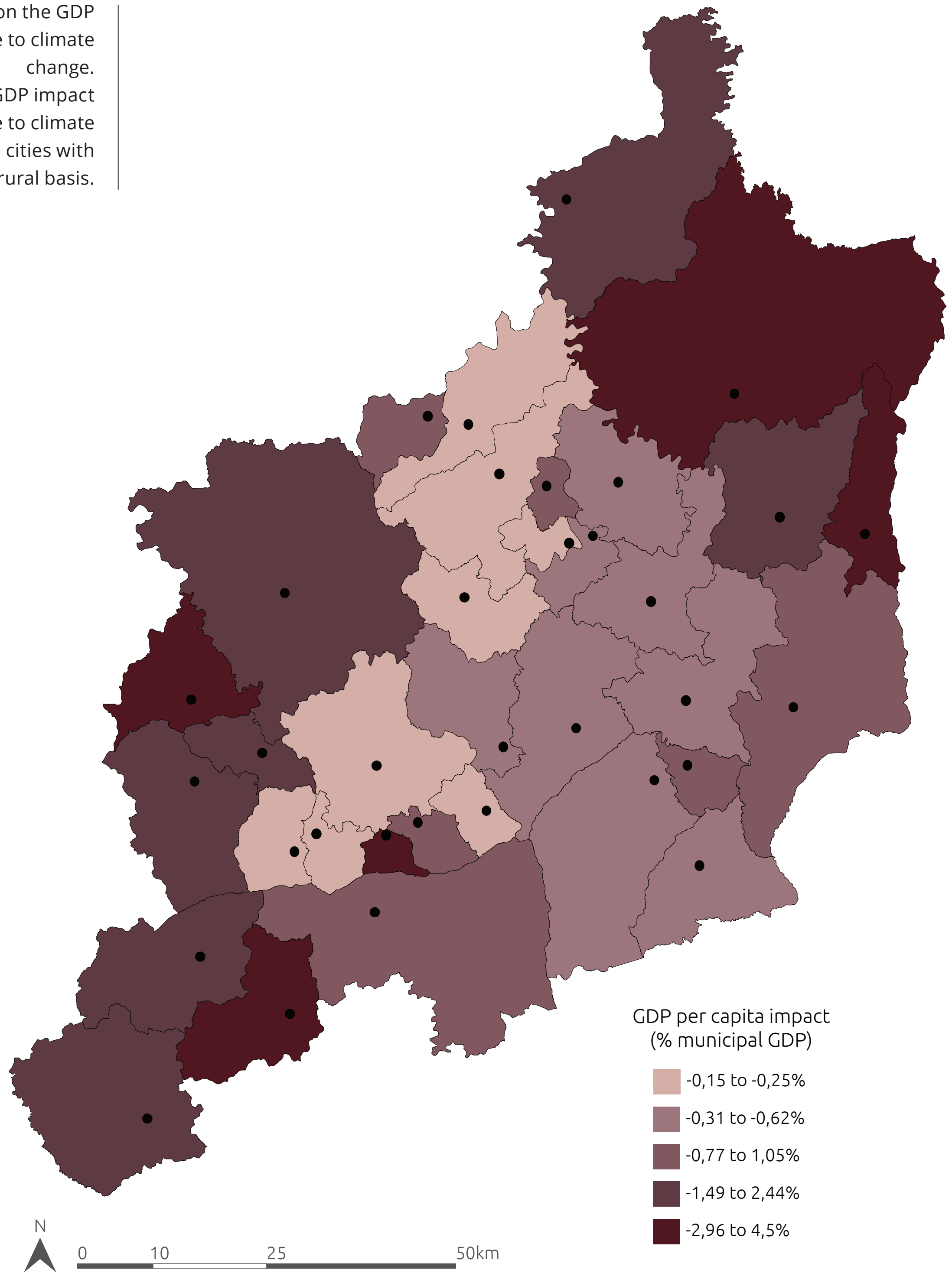


Projected growth for RMBH: Until 2050: +400.000 people. Source: UFMG, 2011



Informal settlements in RMBH are concentrated in highly dense urban areas.

Impact on the GDP due to climate change. Higher GDP impact due to climate change in cities with stronger rural basis.

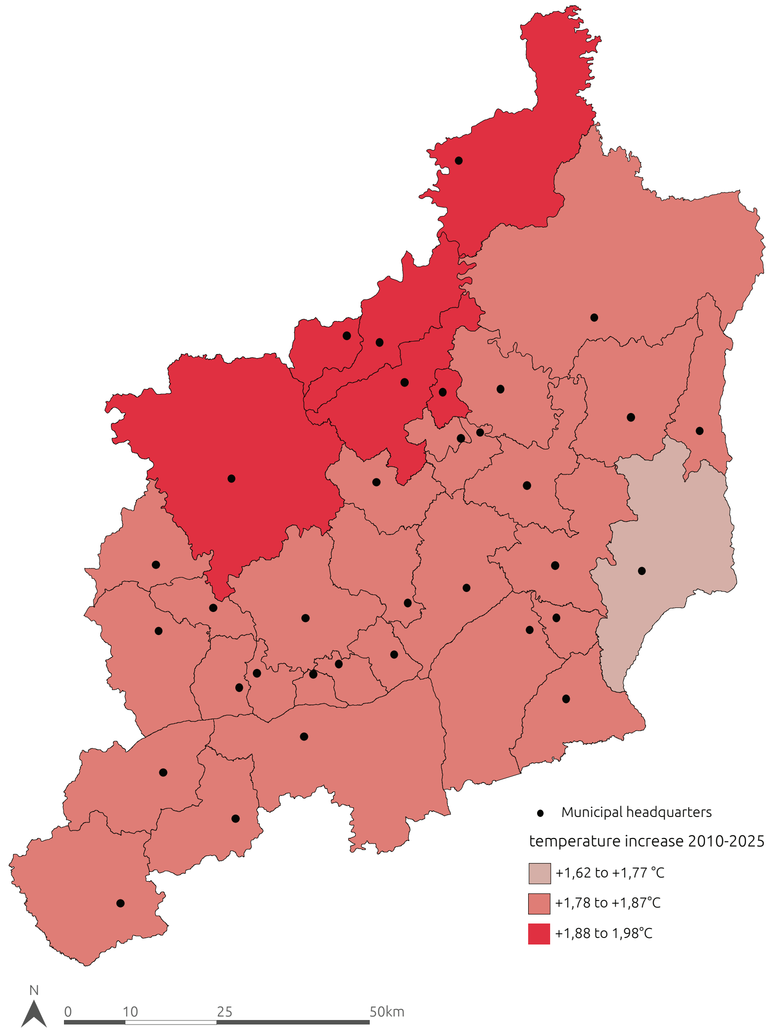


Notes:
Based on the map "Impact of climate change on" RMBH (variation % of municipal GDP) (UFMG, 2010).

CO_2 emissions

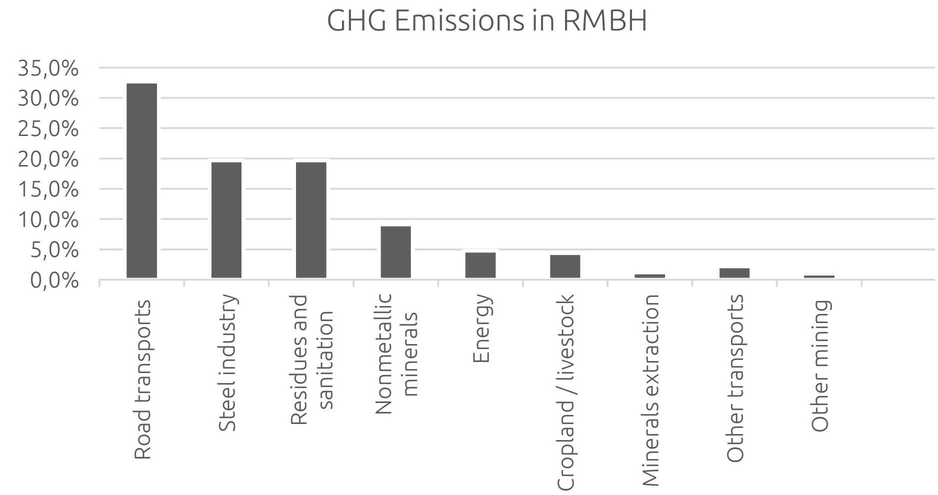
negative impact for the environment and the economy

Like the rest of the world, the RMBH is subject to climate change impacts. A study conducted to assess the economic impact of climate change in the region suggests that, by 2025, the region would suffer a loss of 0,7 to 0,9% in the GDP and reduce job offer by 0,3 to 0,6% (between 7.000 to 14.000 less jobs opportunities), as consequence of changes in the food production and energy sectors (UFMG, 2010). Maps 22 and 23 illustrate the predicted temperature increases and their economic effect on the region. Green House Gases (GHG) emissions are closely related to temperature increase and have substantial environmental impacts and, therefore, are relevant to be considered. In 2007, the metropolitan region produced 23,4 t Gg CO2eq, which represents 19% of the emissions in the entire state of Minas Gerais (UFMG, 2010). The main sectors responsible for Green House Gases (GHG) emissions are transports (32,7%), steel industry (19,7%) and residues/sanitation (19,7%) (UFMG, 2010). A study also projected the increase in GHG emissions 6,6% larger than the projection of GDP growth between 2010-2025, especially due to expected development of iron and steel, non-metallic and road transport sectors (UFMG, 2010).



Notes:
Based on the map "Temperature increase estimates for RMBH (2010-2025)" (UFMG, 2010).

Temperature increase due to climate change. Higher increase on temperature on the northwest of the region.



GHG emissions in RMBH.
Source: UFMG, 2010 - edited by author

conclusions

Territorial conclusions.

1- Urban fabric summary: conflict between flooding areas and urbanization, especially regarding future expansion areas.

2- Sanitation summary: North of the region suffers from sanitation, mining and pollution issues, whereas the mid-south suffers drinking water pressures.

3- Urban conditions summary: Northeast and west: climate change vulnerability; concentration of expansion areas on peri-urban locations.

Considering what was presented previously, it is possible to summarize the main environmental pressures of RMBH in three different clusters: urban fabric; sanitation and urban conditions. The first one combines elements closely related to the urban fabric: informal settlements, expansion and flooding. It is possible to note a relation between flooding and the most urbanized areas around the capital, where impervious paving, infrastructure systems and informal settlements play an important role. It is also possible to note the overlap between potential expansions areas and flooding risk areas, alerting for a possible increase of flooding risks in the future. Regarding sanitation, the areas that lack sewage and waste infrastructure are concentrated on the north portion of the region and are closely related with river pollution, since the lack of sanitation implies discharge of sewage and waste into the rivers. This area is also coincident with the lower areas of the region. Therefore, the north region suffers both from local sanitation issues as well as receives pollution from higher areas and mining activities in the south. Concerning drinking water pressures, they concentrate on the middle-south area, since water supply bodies are located on this region, and they overlap with mining activities. Lastly, the overall urban conditions of RMBH include potential development areas, vulnerable areas due to climate change, expected expansion and areas with concentration of conflicts. Here it is possible to determine two clear vulnerable areas due to climate change: the northeast and the west. They are vulnerable due to rural activities and their delicate relation with temperature increases. However, these areas also mostly coincide with those with sanitation issues. In addition, the potential development areas are mainly concentrated on the peri-urban areas around the capital (except the south, due to mining presence). Therefore, these areas require close attention in developing metropolitan planning strategies, taking consideration their potentials, threats and their impact on the environmental performance of the region, also considering that they can be explored as drivers for changes.

QUICK VIEW

1. Most of the urbanized areas around the capital concentrate flooding risks and informal settlements;

2. Peri-urban areas around the capital are potential areas for development;

3. The north suffers from pollution and sanitation issues whereas the south concentrate mining activities;

4. The west and the northeast are most vulnerable to climate change areas (influence of the increase of temperature on the local GDP) and coincide with areas with sanitation issues;

1.6 what has been done so far

In this section two main policies will be presented: the Director Plan of Integrated Development of the Metropolitan Region of Belo Horizonte (PDDI-RMBH) and the Macrozoning Project of Belo Horizonte Metropolitan Region (MZ-RMBH). The last is a consequence of the Territorial Restructuring proposal put forward by the PDDI-RMBH.

PDDI RMBH

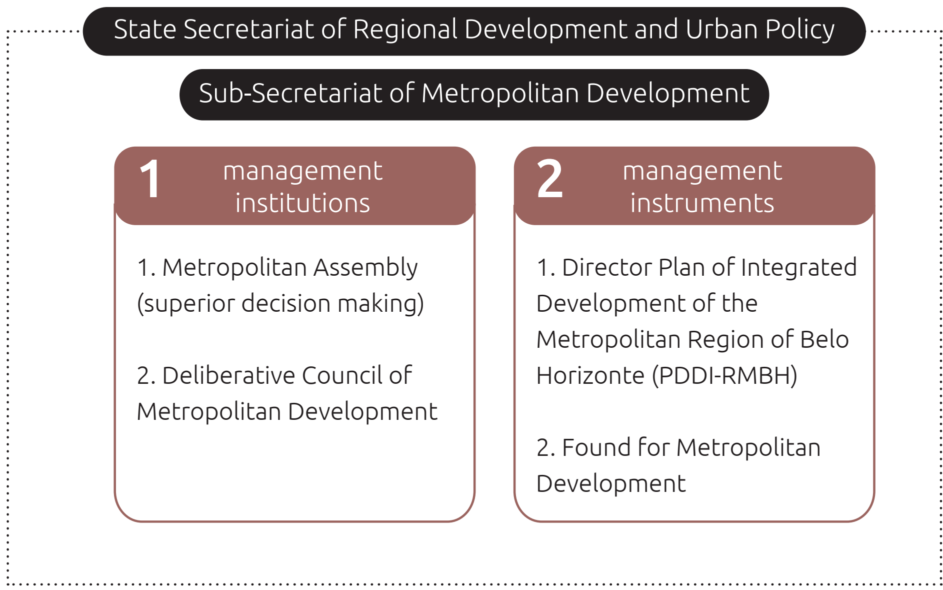
As mentioned previously, the Director Plan of Integrated Development of the Metropolitan Region of Belo Horizonte (PDDI-RMBH) was created as consequence of a planning transition initiated in 2004 by Minas Gerais State. This plan was developed "as the starting point of an integrative planning process of the various agents and visions, and should become the main guiding instrument for ordering, mobilizing and articulating actions in the territory over time" (UFMG, 2011- translated by author).

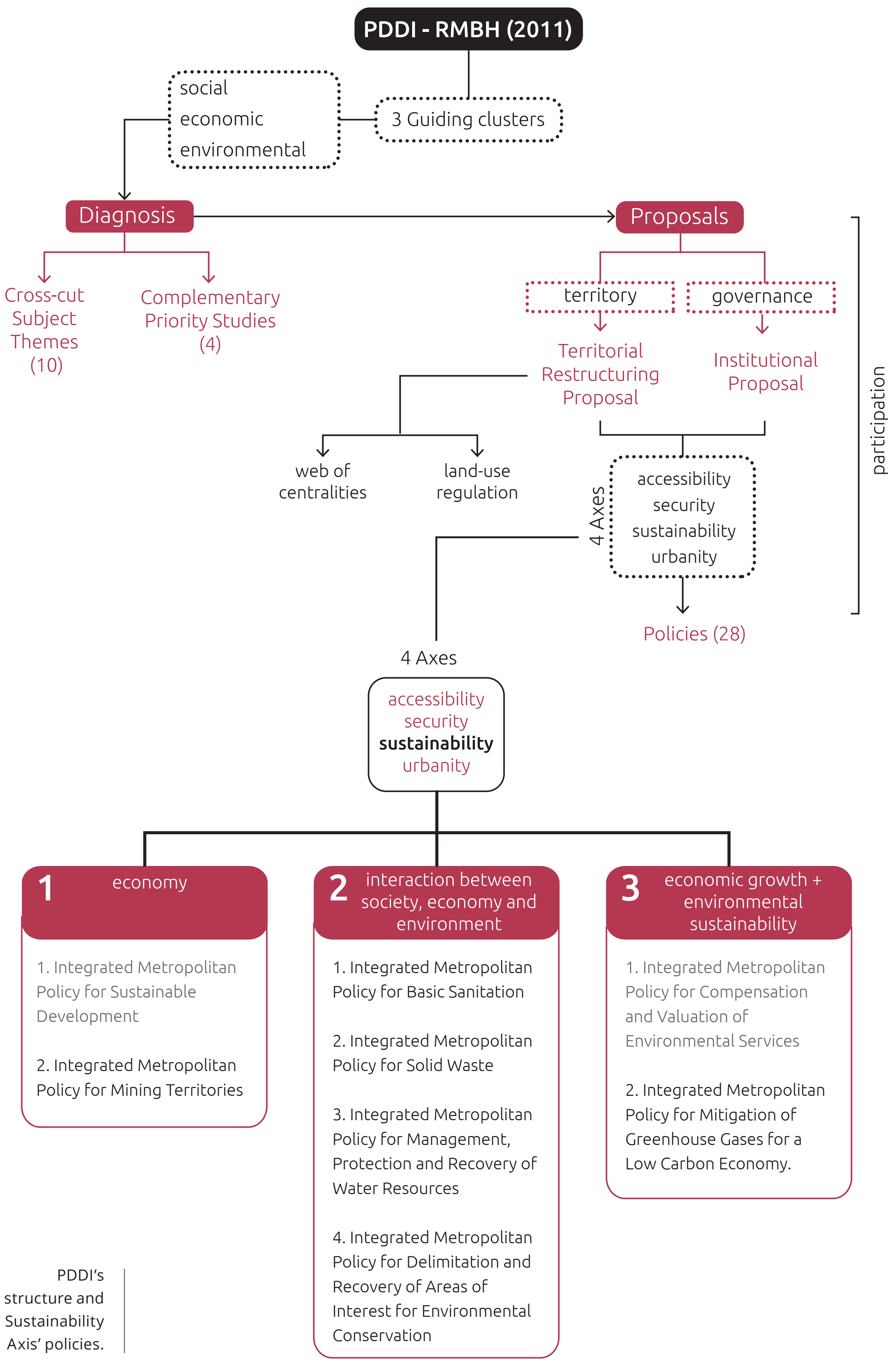
The PDDI-RMBH is one of the management instruments created for the regional area, together with the Fund for Metropolitan Development. This Fund is responsible to finance priority projects and invest in regional projects in accordance with the PDDI's guidelines (UFMG, 2011). Its resources come from both Minas Gerais State and the 34 metropolitan municipalities, in a 50-50% division, respecting the proportion between the municipalities' revenues (UFMG, 2011). The management instruments that operate these instruments area a Metropolitan Assembly, which has superior decision power, and the Deliberative Council of Metropolitan Development, which has representatives from the State, the cities Belo Horizonte, Betim and Contagem (75% of the region's GDP concentrates in those cities (UFMG, 2011)), three other municipalities and the civil society (UFMG, 2011). The structure of the PDDI-RMBH consists of two main products: diagnosis (UFMG, 2010) and proposals (UFMG, 2011). The diagnosis was developed under three guiding clusters: social, economic and environmental that led to 10 cross-cut subjects and 4 complementary priority studies. The proposals were structured having the Territorial Restructure Proposal as core element. The association with the Institutional Proposal gave foundations for the development of 28 policies divided in 4 different axis: accessibility, security, sustainability and urbanity (UFMG, 2011). In relation to the environmental pressures presented previously, the sustainability axis is the one that presents relevance to those topics.

In the sustainability axis, the PDDI puts forward 8 policies that are divided into 3 blocks. The first block includes those related to economic aspects of RMBH, contemplating the Integrated Metropolitan Policy for Sustainable Development and the Integrated Metropolitan Policy for Mining Territories (UFMG, 2011). The second block has policies addressing the relation between society, economy and environment, particularly considering the historical planning gap and the economy activities in the region (UFMG, 2011). They consist of the Integrated Metropolitan Policy for Basic Sanitation; the Integrated Metropolitan Policy for Solid Waste; the Integrated Metropolitan Policy for Management, Protection and Recovery of Water Resources; and the Integrated Metropolitan Policy for Delimitation and Recovery of Areas of Interest for Environmental Conservation. The last block's policies aim to align economic objectives of different economic activities with environmental sustainability (UFMG, 2011), proposing the Integrated Metropolitan Policy for Compensation and Valuation of Environmental Services; and the Integrated Metropolitan Policy for Mitigation of Greenhouse Gases for a Low Carbon Economy.

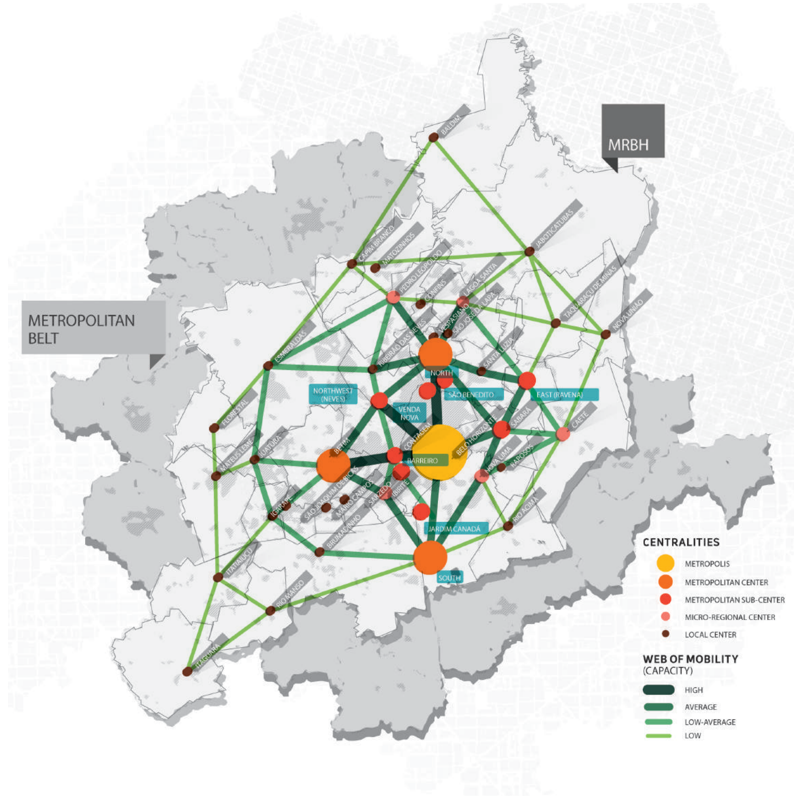
From these policies, the ones that address to the presented environmental challenges are in block 2, together with the Integrated Metropolitan Policy for Mining Territories and the Integrated Metropolitan Policy for Mitigation of Greenhouse Gases for a Low Carbon Economy. All these policies indicate programs and actions, stakeholders involved, general and specific goals, possible financing instruments and institutions, co-related policies and existing programs and, sometimes, preliminary studies related to the topic. However, given the very nature of the PDDI, some proposed actions are broad and do not point responsibilities, leading to challenges in their implementation.

Regional planning structure.





PDDI's structure and Sustainability Axis' policies.



PDDI GUIDELINES

"To establish a web of centralities;
To lead the occupation of the urban expansion;
To intensify the use of urbanized and idle areas;
To enhance the distribution of activities within the territory, reducing unnecessary displacement;
To assure the water supply in RMBH as a whole to future generations;
To promote ecological corridors, to keep biodiversity and to preserve water springs;
To ensure a collective built legal framework." (UFMG, 2013)

Proposed Territorial Restructure in the PDDI. source: UFMG, 2013

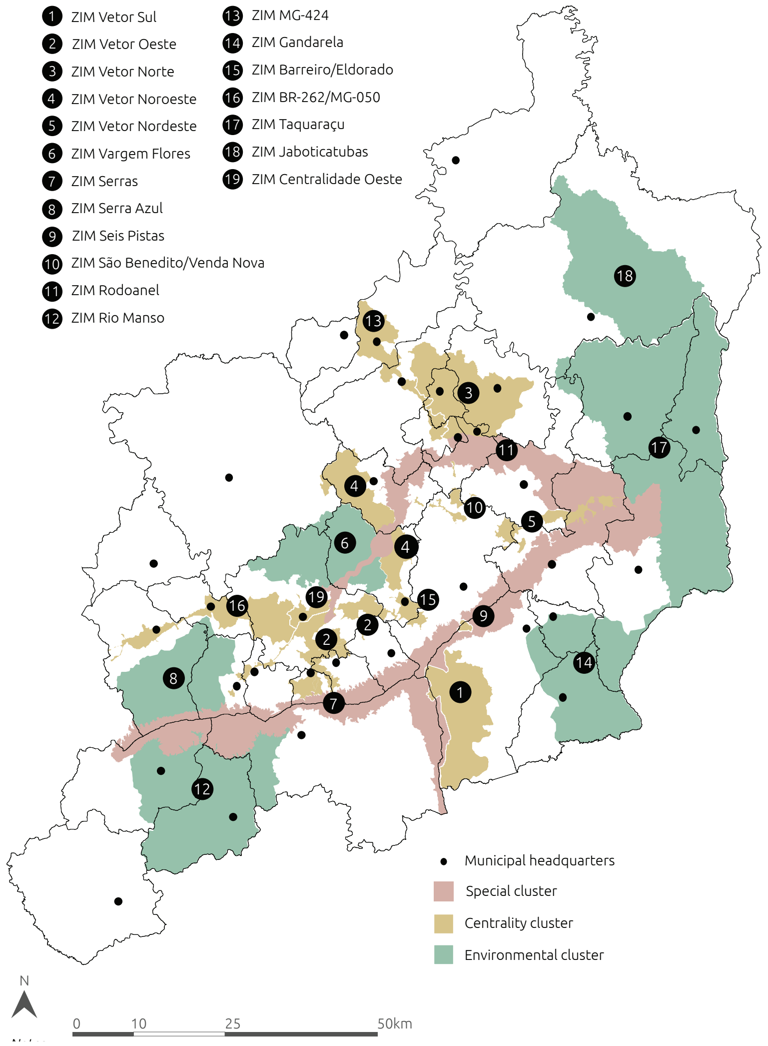
MACROZONING

As consequence of the Territorial Restructuring proposal put forward by the PDDI-RMBH, the Macrozoning Project of Belo Horizonte Metropolitan Region (MZ-RMBH) was developed to expand, regulate and territorialize guidelines established by the PDDI (UFMG, 2014b). However, since the Macrozoning does not intend to regulate the entire metropolitan region, it developed two clusters: the Zones of Metropolitan Interest (ZIM) and the Areas of Metropolitan Interest (AIM) (UFMG, 2014b). The first one (ZIM) includes areas where the metropolitan interest prevails over the local, in relation to themes highlighted in the PDDI's territorial proposal, such as web of centralities, mobility, sustainable development, among others (UFMG, 2014b). The areas have different sub-clusters with specific urban parameters and zoning regulations. The second group (AIM) are priority areas for PDDI's policies implementation that are not subjected to zoning.

GOALS:

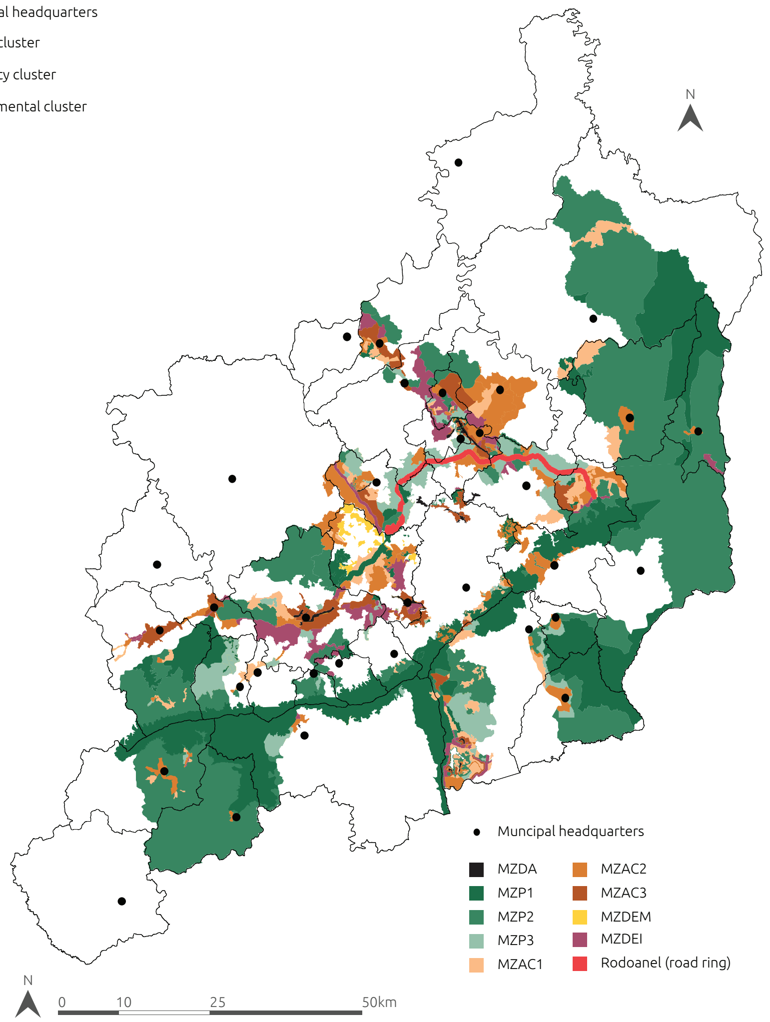
"• To control the urban growth and densification;
• To protect areas of cultural and environmental interest;
• To stimulate collective and economic inclusive activities for the population;
• To reduce conflicts between uses and activities." (UFMG, 2013)

Its aim is to guide future municipal planning (UFMG, 2014b). Currently, it has been developed a preliminary definition of the AIMs and a proposal defining specific urban parameters for 19 elected ZIMs. The new zoning proposal for the ZIMs divides the ZIMs in 3 different clusters: environmental (protection); centrality/development axis (for densification/diversity); special (for implementation of the green blue infrastructure) (UFMG, 2015). There are 5 zoning categories that can be applied within the ZIMs: 1) Protection Macrozone (MZP), unfolding into MZP1 (more restrictive), MZP2 and MZP3 (less restrictive). 2) Complementary Activity Macrozone (MZAC), unfolding into MZAC1 (low density), MZAC2 (medium density) and MZAC 3 (medium to high density). 3) Densification and Diversity Macrozone (MZDA); 4) Industrial and Economic Development Macrozone (MZDEI) and 5) Special Guidelines Zone



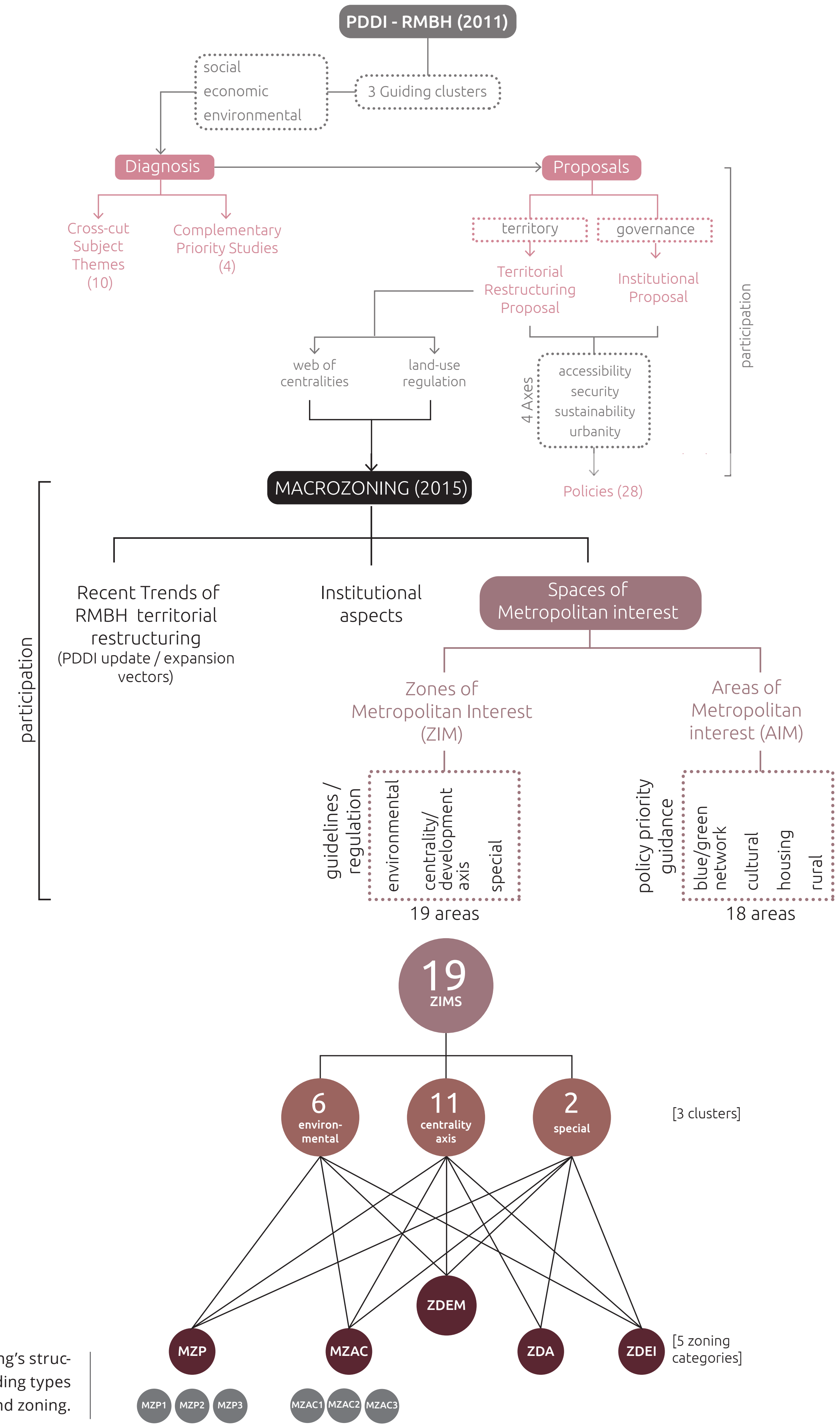
3 main zoning clusters in the RMBH. Special cluster includes the region's mountain range and accessibility Centrality cluster prioritizes areas for expansion; Environmental cluster protects resources of the region;

(ZDEM), which prevails over the others (UFMG, 2015). Furthermore, the ZDEM unfolds into: Environmental Interest (Green/Blue Structure); Mining Territories; Requalification; Social Interest; Large developments; and Consolidated urban areas (Minas Gerais State, 2017). The Macrozoning puts forward preliminary parameters for the ZDEM areas until consolidation of their delimitation and special parameters (Minas Gerais State, 2017). It is important to highlight that the Macrozoning is currently under discussion and, therefore, alterations on the zoning proposals might still occur and differ from what is shown in this thesis. The proposal is expected to become a State Law by January 2018 (ADRMBH, n.d.).



Zoning areas in the RMBH. Multiple zoning parameters are defined in the Macrozoning. Highlight to the several protection zones (in green) and their extensive distribution on the territory.

Notes:
Map based on the Complementary Law Project of the Director Plan of Integrated Development of the Metropolitan Region of Belo Horizonte (Minas Gerais State, 2017), still under discussion. Changes might occur.

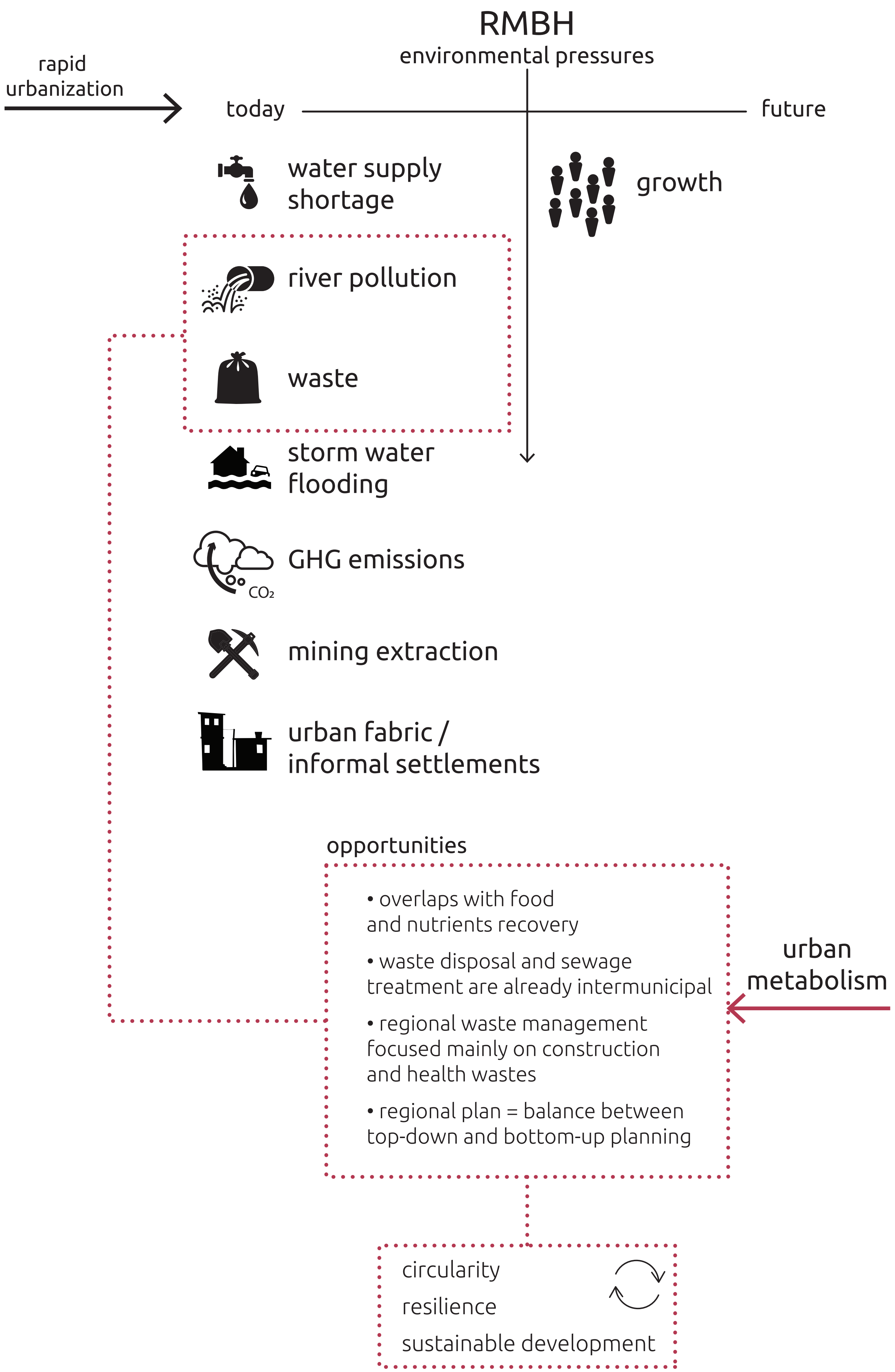


Macrozoning's structure, including types of ZIMs and zoning.

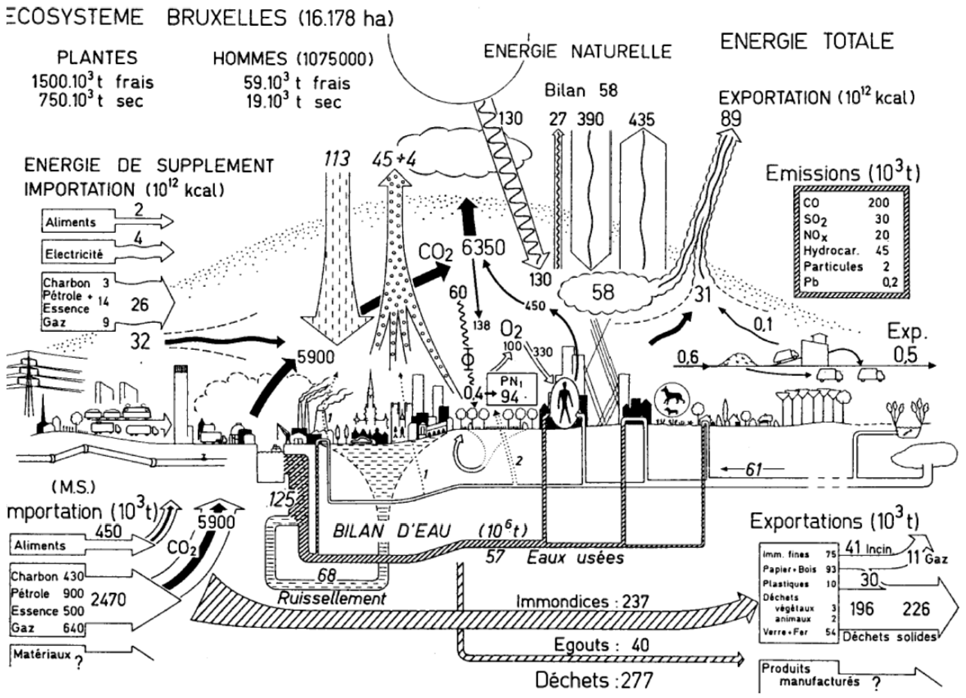
1.7 key flows

As mentioned previously, there are many environmental challenges in the RMBH, which are significant bearing in mind impacts they have on human health, natural ecosystems and the regional economy. However, issues related to water and waste, such as drinking water shortage, water pollution and adequate waste management, present more urgency, since they are structural for providing basic life quality. This urgency is also reflected on the existing governmental focus to create programs and policies to address to these matters, especially considering their social impact. Those programs attempt to benefit those in particular who do not benefit from proper infrastructure, such as dwellers in informal settlements. In addition, these flows have spillover effects, taking in account the impact residues and sanitation have in other fields, such as in GHG emissions for instance. Moreover, these issues also associate with the fact that, together with other Latin American cities, RMBH has low adaptability and high vulnerability (UFMG, 2010). The unsustainable use of the environment and its resources reflects that "human activities are not resilient to changes in its patterns of resources consumption", in adapting to the privation of primary resources (Timmeren, 2014). The current challenges, the projected future and the global scenario of climate change, where drastic weather events might occur more frequently, urges for the increase of the region's resilience concerning environmental issues. Therefore, increasing the region's resilience in water and waste flows will contribute to address other challenges and is the focus of this thesis.

In relation to the water cycle, this thesis focuses mainly on wastewater, given its social impact on life quality and the "unbreakable relationship between drinking-water and waste water" (Timmeren, 2012, especially concerning river pollution. Moreover, the improvements made in this cycle can have spillover effects in addressing other water related challenges, such as flooding. Another aspect is that both wastewater and solid waste flows display clear potentials, such as the large amount of domestic organic waste and domestic sewage discharge, which points for possible interconnections with other flows (for example food and nutrients recovery). It is important to highlight, though, that this potential interconnection is not new. It has been intuitively promoted in several parts of the world for a long time, even if at times not entirely safely (Faraud, 2017). Lastly, the focus on those two flows attempts to fill a regional planning gap, considering the existence of inter-municipal facilities (sewage treatment plants / waste treatment facilities) and the lack of a regional structure behind it.



1.8 Urban Metabolism (UM)



Urban Metabolism of Brussels. source: Duvigneaud and Denaeyer-De Smet (1977)

As Arjan van Timmeren highlights, interventions within the built environment require their metabolic comprehension, since "metabolism is a precondition of life" (Timmeren & Delft University of Technology, 2013). By understanding the city as an ecosystem, it is possible to understand hidden processes that are responsible for the "disorder of urban metabolism", which directly influences a city's potential for sustainable development (Zhang, 2013). Moreover, Ferrão and Fernandez point the potential Urban Metabolism has specifically in developing regions, providing "a holistic understanding of the physical needs and resource intensities [... and indicate] the most effective design and technology choices" to governments (Ferrão & Fernandez, 2013). In the RMBH, Urban Metabolism also offers a systemic perspective in comparison with the territorial emphasis of the PDDI-RMBH 2011. It allows understanding relations between flows and their associated territory and infrastructure. Moreover, a metabolic perspective on RMBH can point to opportunities to close gaps between flows, increase efficiency, reduce resource consumption, recover/re-use waste and, thus, assists upsurge urban performances and a more circular metabolism. Therefore, UM presents itself as a framework that permits different perceptions of RMBH's context, enabling to enlarge its resilience, environmental performance and livability. The main metabolic tool used in this thesis is the Material Flow Analysis (MFA), since the study of flows allows enhancing the description of environmental pressures to support resource and sustainable management (Zhang, 2013). This tool is especially interesting considering that most of the information the existing diagnosis provides only reflects the general state of the municipalities (See item "1.13 methodology" for an overview of methods included in this thesis.

1.9 hypothesis

Considering what was presented, this thesis presents the following hypothesis: studying the Metropolitan Region of Belo Horizonte through Urban Metabolism perspective, can offer insights into how to deal with current and future environmental challenges by managing better its resources related to wastewater and waste.

RESEARCH QUESTION

How to develop a feasible regional strategy for RMBH's wastewater and solid waste flows?

1.10 problem statement

The Metropolitan Region of Belo Horizonte has gone through an intense process of rapid urbanization for the past century, which has led to sprawl, pressure on resources, infrastructure shortage and environmental hazards. Although the Plan of Integrated Development for RMBH (PDDI-RMBH 2011) addresses to some of these issues, the region can benefit from a new perspective on its urban comprehension in order to embrace existing proposals and develop solutions that increase its environmental performance and resilience. Urban Metabolism, thus, can contribute to this understanding, by looking at the urban relations and flows rather than only focusing on territorial aspects. In the field of resources, wastewater and solid waste flows present urgent issues, especially due to their environmental implications and reliance on heavy infrastructure. However, these flows also possess potentials that point to interconnections in a regional scale, which would permit circularity and contribute to the sustainable development of the region.

SUB QUESTIONS

1. What and where are the main challenges in wastewater and solid waste?

2. Where and how wastewater and solid waste flows take place?

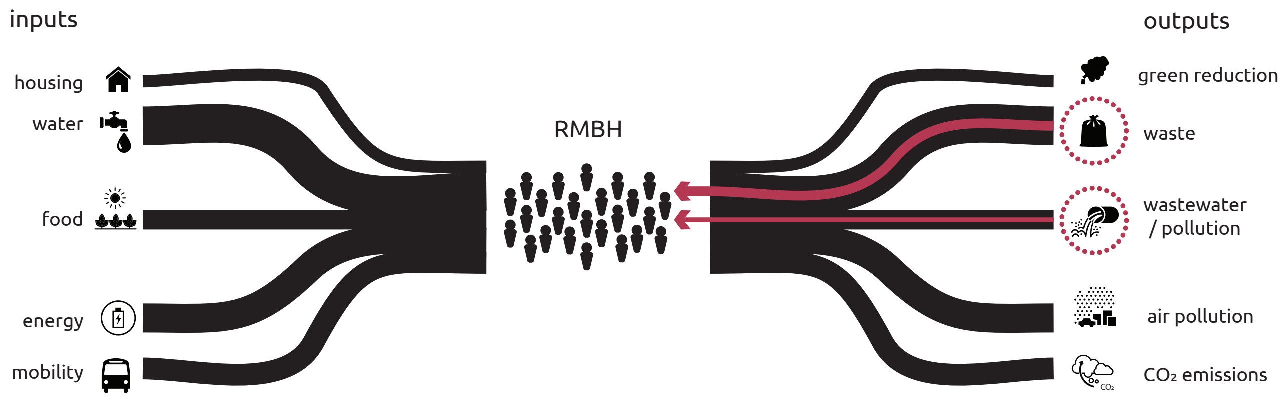
3. What are the zones of interventions that have potential to maximize effects of wastewater and solid waste interventions?

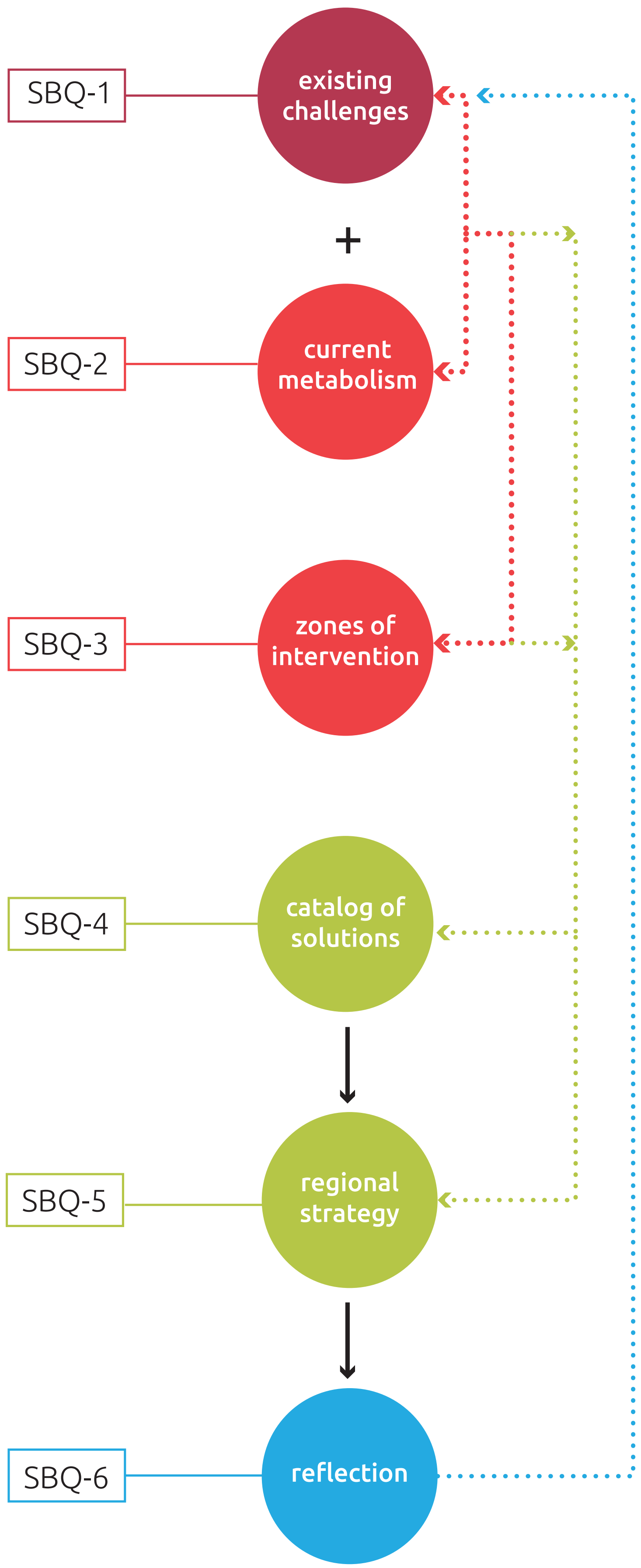
4. What are possible solutions to increase environmental performance of wastewater and solid waste flows, within the elected zones of intervention?

5. How can these solutions be implemented in the elected zones of intervention?

6. How did UM approach contributed for the development of RMBH's regional strategy?

Thesis approach.





1.11 aims

This thesis has aims to increase the environmental performance of RMBH, by creating a regional strategy for wastewater and solid waste that guarantees resilience and sustainability for the area in the long term. In order to do so, this thesis centers on Schuetze et al. steps to increase the sustainability of an Urban Metabolism: apply ecosystem thinking, investigate the optimal resource consumption in different processes and promote "synergies between the different sectors and flows" (Schuetze et al., 2012).

1.12 UM mutations

scientific relevance

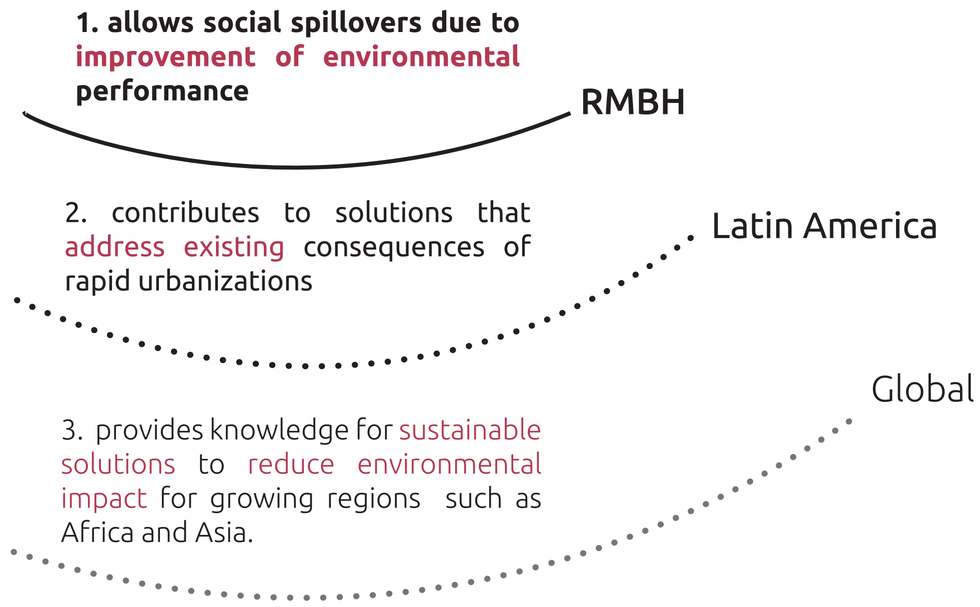
One of the aims of Urbanism track in the Master of Architecture Urbanism and Building Science is to teach students to "integrate social, cultural, economic and political perspectives with the natural and man-made conditions of the site in order to shape and plan for more sustainable development" (TUDelft Department of Urbanism, n.d.). Urban Metabolism proposes to explore this integration by understanding the city from the flows perspective and creating synergies between those flows. The growing interest over Urban Metabolism as a tool highlights the relevance of the topic, since it assists urban planners and designers to develop more sustainable solutions. However, as a framework, it is bound to be continuously in expansion or mutation. How this framework is used or translated considering different contexts and demands, can contribute to stretch its scientific discussion. This thesis triggers a debate on the universality of Urban Metabolism concept by reviewing current sustainable strategies in developing countries and by applying the concept itself in Belo Horizonte Metropolitan Area. Moreover, the thesis touches upon the discussion of how UM's framework, soundly based on scientific research, contributes for design/planning assignments. It puts forward the hypothesis that this framework can provide different insights about urban contexts, which can be translated into design practices. In other words, this thesis provokes discussions on the relation between research and design.

1.13 sustainable societies

societal relevance

This thesis has societal relevance at three different scales: regional, Latin American and global. The largest relevance relies on the regional one. By improving the metabolic performance of RMBH in key waste flows, social spillover effects will take place. One of them relates to health issues, since an efficient management of waste and improvement of the general basic sanitation condition reduce possibilities of contamination and spread of diseases, for example. Another aspect is the increase of the region's environmental protection. With less river pollution and consumption of resources, to name a few, the region's performance increases, ultimately also addressing to climate change issues. Lastly, a good management of resources allows economic opportunities, improving efficiency and reinforcing the existing regional structure, which adds to the urban life quality. Those social benefits, furthermore, can be transferred to other Latin American cities that underwent similar processes of rapid urbanization and struggle with similar issues. Moreover, since RMBH is inserted in Latin America, one of the most urbanized regions of the world, it can also contribute to other regions that are currently being urbanized, such as Africa and Asia, especially considering their environmental impacts in the global scale. In sub-Saharan cities, for example, waste is projected to increase until 2100 (Hoornweg, Bhada-Tata, & Kennedy, 2013) and how these cities develop are "determinant to the date and intensity of global peak waste" (Hoornweg et al., 2013). Therefore, these regions can absorb knowledge from this work and use it not only to increase their environmental performance in waste flows, but also to increase life quality of their cities.

Societal relevance through scales.



[left] Sub-questions and iterations.

1.14 unconscious waste relations

ethical perspective

Waste, in all its forms, is a product of human and urban development (Zapata Campos & Hall, 2013) and, as cultural performance, is what defines how society is seen and who we are (Hawkins, 2006). As such, it also embodies ethical obligations that have close relation with individual habits, including social and cultural memory, and are responsible to create social identity (Hawkins, 2006). According to Hawkins, ethics are indispensable to develop "cultivated sensibilities that establish the range of possibilities in perception, enactment, and responsiveness" regarding waste (Hawkins, 2006). This becomes even more relevant considering that the current environmental pressures over climate change have generated shifts in governmental rules and societal waste practices. As Gay Hawkins continues to explain, these changes alter the relation between individual and waste and can be triggered by "moral injunctions" (enforcement of moral code based on the feeling of guilt); compulsory acceptance, (change in the system without leaving options for the citizen); and genuine individual consciousness (also associated with less altruistic reasons, such as social status) (Hawkins, 2006). From the governmental perspective, effective waste policies are only possible with the engagement of the population and their social context, especially considering their obstructive power (Zapata Campos & Hall, 2013). Moreover, the political pressure over waste management (including solid waste and wastewater) allowed the emergence of public, private and hybrid organizations that also have economic interests and are regulated by its own market rules (Zapata Campos & Hall, 2013). Therefore, when discussing waste flows, urban planners and governments have to bear in mind that urban interventions and policies have impacts in social habits and affect ethical relations. These relations can be reflected either in situations such as waste separation in every day life or in the creation of waste infrastructures such as sewage treatment plants. However, they can also blind the individual from waste itself, endorsing repudiation and exemption (Hawkins, 2006), and, therefore, should be taken in account when putting forward new solutions.

Current patterns of high waste production can be associated with the lack of ethical relations between the individual and waste.

Waste	
32,954,512	Tons of electronic waste thrown out Worldwide, this year
453.1245	US$ income for e-waste worker So far, this year
22235938.91	Square kilometers of plastic soup In world's oceans
1,746,589,161	Tons of waste dumped in oceans Globally, this year
1,347,839,560	Tons of waste from households Globally, this year
329,545,124	Tons of hazardous waste thrown out Globally, this year
4,119,314,071,429	Number of plastic bags produced Worldwide, this year

Screen shot of the world's waste production (28/10/2017 at 19:02). source: http://theworldcounts.com

1.15 methodology

The methodology of this thesis is based on Lucienne T. M. Blessing and Amaresh Chakrabarti's book DRM – a design research methodology (Blessing & Chakrabarti, 2009). This methodology consists of four main stages:

1. Research Clarification (R.C.)
2. Descriptive Study I (D.S. I)
3. Prescriptive Study (P.S.)
4. Descriptive Study II (D.S. II)

1. Research Clarification (R.C.)

This stage relates to understanding the problem this thesis wants to tackle. It requires evidence collection and literature studies that clarify the issue and support the research goal (Blessing & Chakrabarti, 2009). This phase consists of: description of the existing situation (problem field); formulation of criteria that can be used to evaluate the proposal in later stages (key flows); and description of the desired situation (a regional strategy) (Blessing & Chakrabarti, 2009). Chapter one of this thesis clarifies these matters and already starts to answer Sub-question 1: "What are the main challenges in wastewater and solid waste?", by making use of literature, existing diagnosis of the PDDI-RMBH (UFMG, 2010), policy and data analysis, GIS and mapping.

2. Descriptive Study I (D.S. I)

The Descriptive Study I consists of literature review that supports the detailing of the existing situation put forward in the Research Clarification phase, having the desired aims in mind (Blessing & Chakrabarti, 2009). In this thesis, it occurs through the revision of concepts and a theory paper. The first gives a brief definition on sustainable development and resilience concepts. The second explores Urban Metabolism approaches in Latin America, with a set of examples of sustainable strategies in Latin American cities and their relation with the concept of Urban Metabolism.

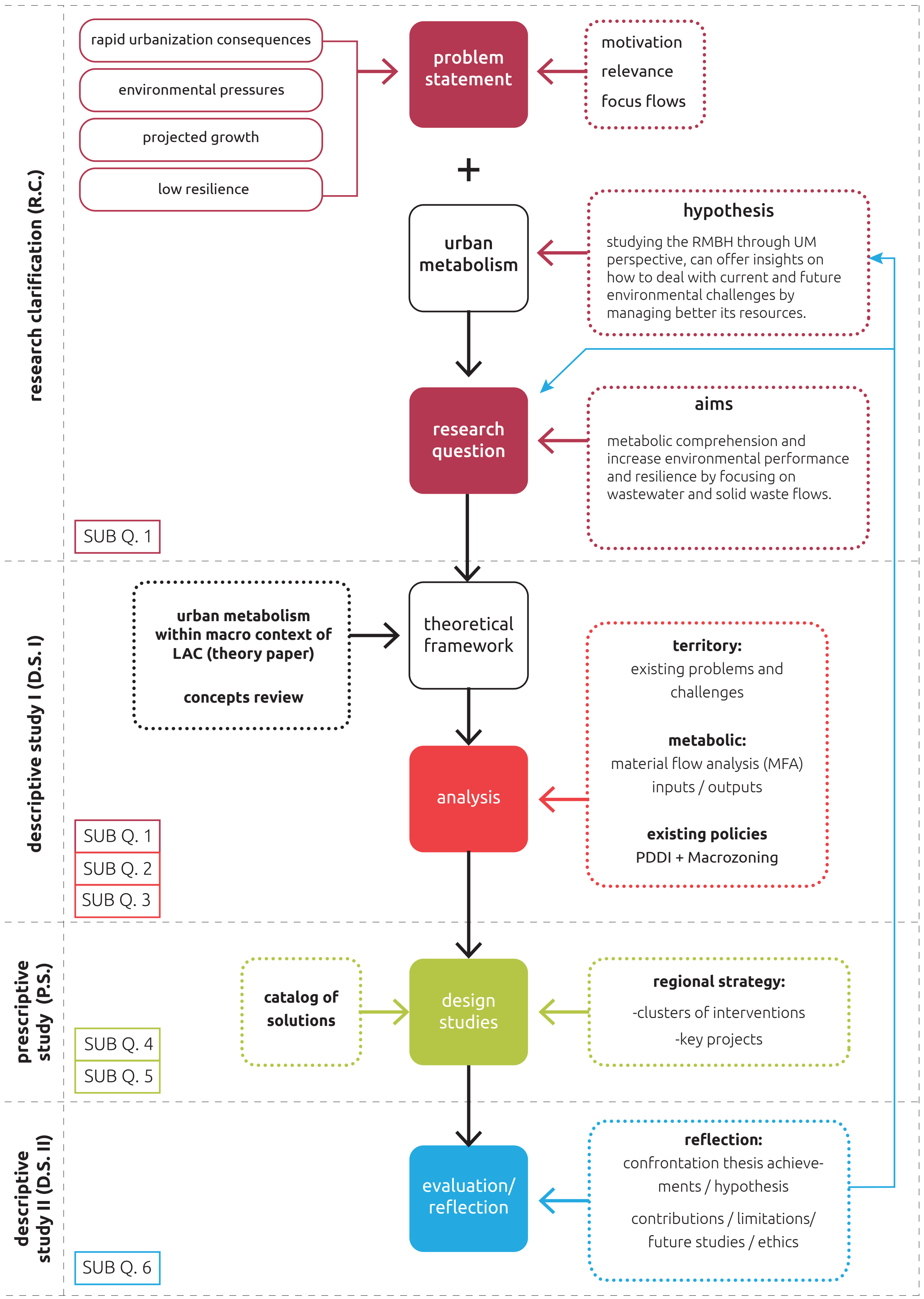
In addition, considering that the purpose of this stage is a detailed understanding of the existing situation, this thesis puts forward the site analysis as an additional layer of the Descriptive Study I. This analysis consists of three steps that occur in parallel. The first one is the continuation of Sub-question 1: "What and where are the main challenges in wastewater and solid waste?". This question is answered by studying current policies and engaging in an iterative process with the metabolic analysis developed for Sub-question 2. The second step addresses Sub-question 2: "Where and how wastewater and solid waste flows take place?". This metabolic analysis reveals relationships within wastewater and solid waste flows, also supporting the development of Sub-question 1. It uses Material Flow Analysis (MFA), data analysis (including inputs/outputs), GIS and mapping. The last step regards defining zones of intervention. This definition derives from the confrontation between the territorial analysis, the metabolic analysis and the existing policies. The first one addresses the current challenges, the second points to areas with most potential to maximize metabolic interventions and the last highlights the already established priority areas, increasing the feasibility of the proposals, developed in the next phase. This conclusion uses policy review, data analysis, GIS and mapping as methods and answers Sub-question 3: "What are the zones of interventions that have potential to maximize effects of wastewater and solid waste interventions?"

3. Prescriptive Study (P.S.)

According to Lucienne T. M. Blessing

and Amaresh Chakrabarti, in this stage occurs the refinement of the desired situation, by putting forward a "vision on how addressing one or more factors in the existing situation would lead to the realization of the desired, improved situation" (Blessing & Chakrabarti, 2009). For that purpose, this thesis elaborates design studies, namely a regional strategy for the RMBH and key projects that elaborate on its spatial implications in the area, divided in 2 steps. The first step answers Sub-question 4: "What are possible solutions to increase environmental performance of wastewater and solid waste flows, within the elected zones of intervention?", by creating a solutions catalog. The election of alternatives derives from sustainable solutions developed in existing projects, other existing catalogs or toolkits originated in academic research and new proposals, when necessary. The methods used in this step are literature and existing projects review and impressions (diagrams, images). The second step is the proposal of a regional strategy for RMBH, by creating clusters of intervention, using the catalog and the metabolic analysis as base. A set of criteria that relates to relevance and design impact assists on the selection of the best-fit solutions for the strategy. For a detailed discussion of these criteria, see Chapter 3. The development of the strategy also relies on a field trip, with site-visits, interviews and a focus group. The site-visits provide insight for the translation of the spatial implications of the strategy into key projects, whereas the other two methods allow to incorporate stakeholders and increase the proposal's feasibility. The focus group, in particular, is also a cost and time effective method that creates opportunities to gather actors from different backgrounds and get insight from their experience and expertise. The main methods in this phase are mapping, sections, impressions (images, collages, diagrams), site-visits, interviews and a focus group (for a detailed description of the methodology of the interviews and the focus group, see Annex B). The combination of clusters of interventions and key projects answers Sub-question 5: "How can these solutions be implemented in the elected zones of intervention?".

Methodology scheme.



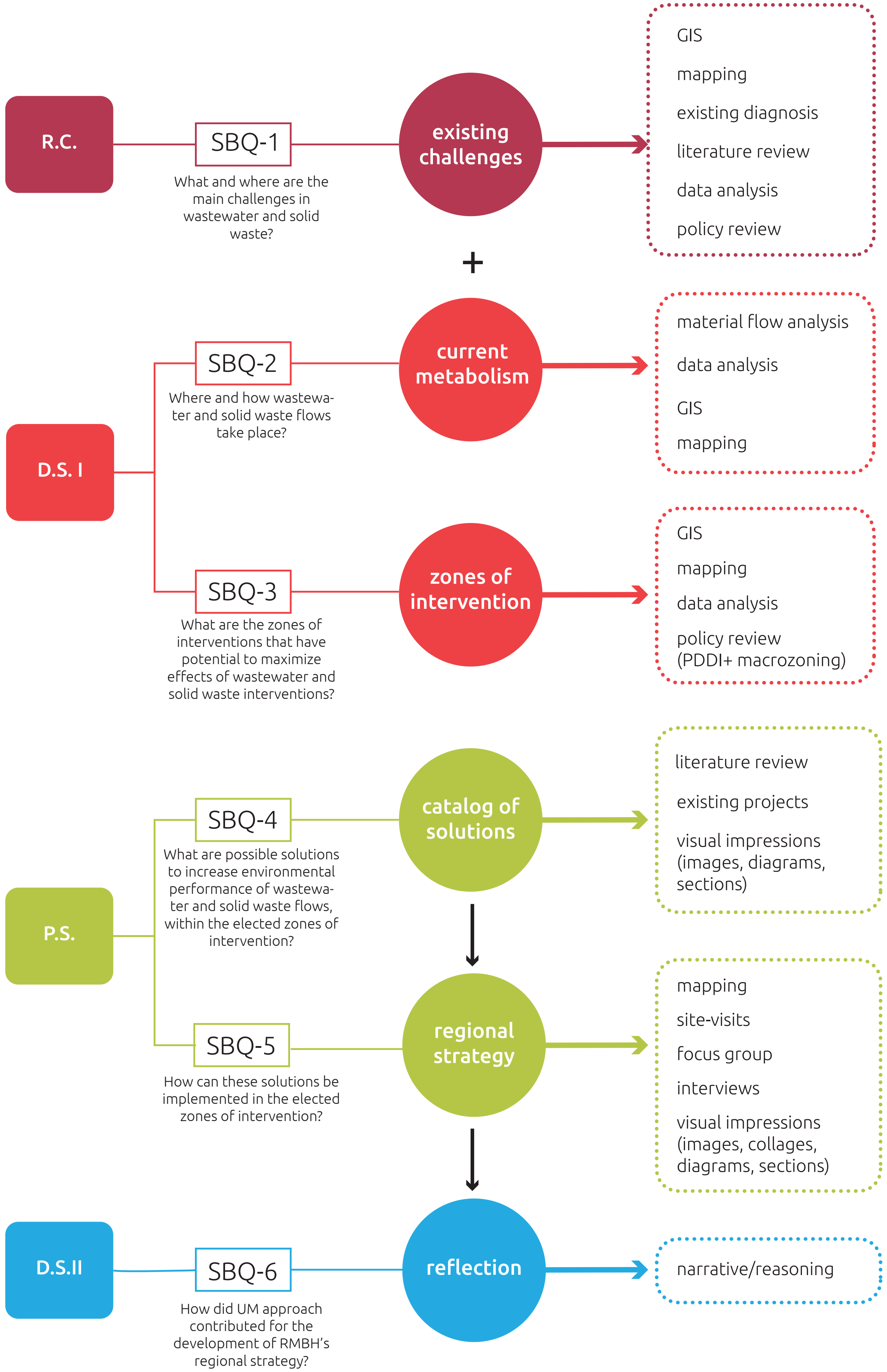
4. Descriptive Study II (D.S. II)

The purpose of the Descriptive Study II is to examine the effects of the proposal and evaluate its achievements, applicability and usefulness (Blessing & Chakrabarti, 2009). Moreover, in this stage there is an indication of conclusions and need for further studies (Blessing & Chakrabarti, 2009). In this thesis, this is realized through a reflection. This reflection has two different goals, first to provide a critical review of the proposal, confronting its findings and achievements with the hypothesis put forward, thus answering Sub-question 6: "How did UM approach contributed for the development of RMBH's regional strategy?". Second, to highlight the contributions the thesis has given, in the social and scientific spheres, as well as its limitations, culminating into suggestions for further studies and investigations. Moreover, the reflection also encompasses ethical dimensions. This stage uses narrative and reasoning as main methods.

It is important to highlight that, as Blessing and Chakrabarti clarify, this methodology should not be understood as a linear process, but a summary of its main flow (Blessing & Chakrabarti, 2009). Iterations increase understanding and efficiency and are natural to occur within and among stages (Blessing & Chakrabarti, 2009). Therefore, even though some iterations were stressed in the previous descriptions, they are not exclusive, since different studies within each stage will occur in parallel. Also, a same study can be deepened at different stages, according to the development of the work.

Criteria for comparing solutions from the Catalog.

Methods scheme.



2 |

theoretical horizon

shifting to metabolic understanding

2.1 introduction

The theoretical framework of this thesis is developed to provide substantiation to the Urban Metabolism topic and co-related themes. Therefore, it consists of two steps:

1. Urban Metabolism: with the purpose of clarifying the foundations of UM and discuss its application in the macro context of this study, this thesis presents a theory paper that provides a brief overview of UM concept itself, a set of existing sustainable solutions in Latin American cities and the translation of the concept in those solutions (see Complete Report Volume).

2. sustainable development and resilience: considering the aims of this thesis, a definition of these concepts in relation to urban metabolism is provided as well.

2.2 concepts review

sustainable development from an UM perspective

According to Arjan van Timmeren, a sustainable environment is one that closes its flows of materials with minimal effort and losses (energy and materials) and, therefore, focuses on "cyclic thinking and design" (Timmeren, 2012). In addition, sustainable development relies on constant knowledge and technology evolution and is often based on corporate responsibility theories (Timmeren, 2012). This concept is also used as a marketing tool for politicians to secure investments and economic competitiveness (Timmeren, 2012).

This "cyclic thinking and design" can follow the principles of the "New Trias", where the local context and its associated dynamics play a major role:

"(1) extending energy, water and material consumption;

(2) reusing waste flows; and

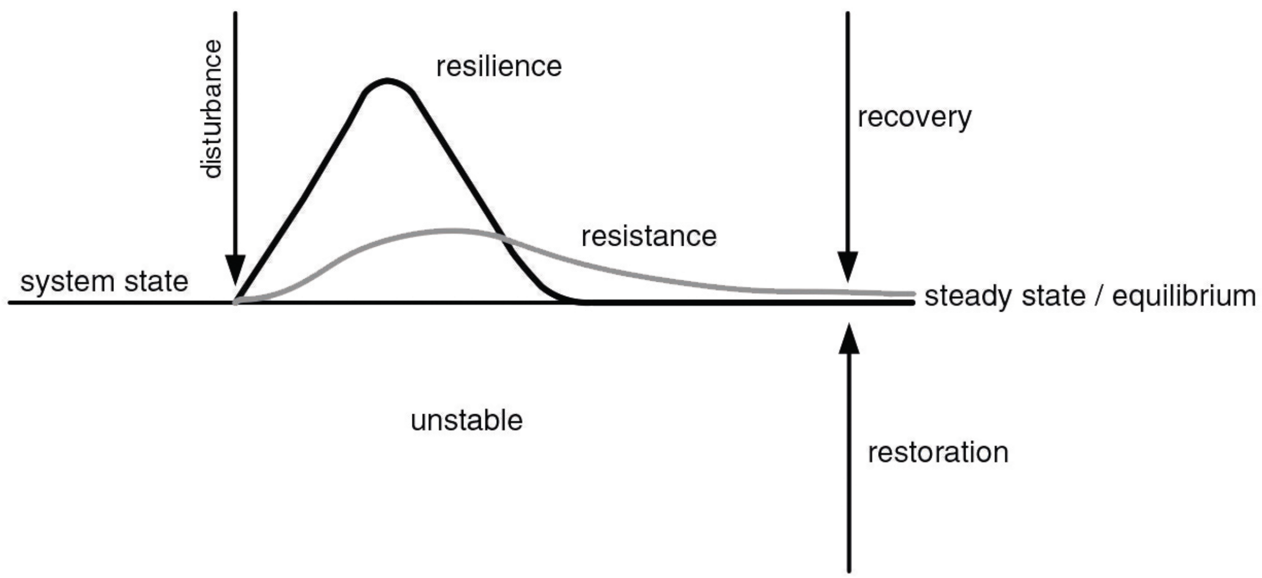
(3) filling in the remaining demand with renewables and apply a 'waste = food' approach" (Timmeren, 2012).

Therefore, following this concept implies on developing urban strategies that prioritize local and decentralized solutions.

resilience

Resilience can be understood as "the ability of a system to be subjected to changes in input and status variables and then to return after some time to its original status" (Schuetze et al., 2012). Urban resilience, then, relates to the amount of stress an urban system can support and its adaptive response capacity regarding changes (Ferrão & Fernandez, 2013). In addition, it is important to note that this concept can be applied to different scales (from individual to territory) and includes abiotic and biotic structures (Schuetze et al., 2012).

Resilience.
Source: (Schuetze et al., 2012)



3 |

analytical horizon

follow the flow

3.1 introduction

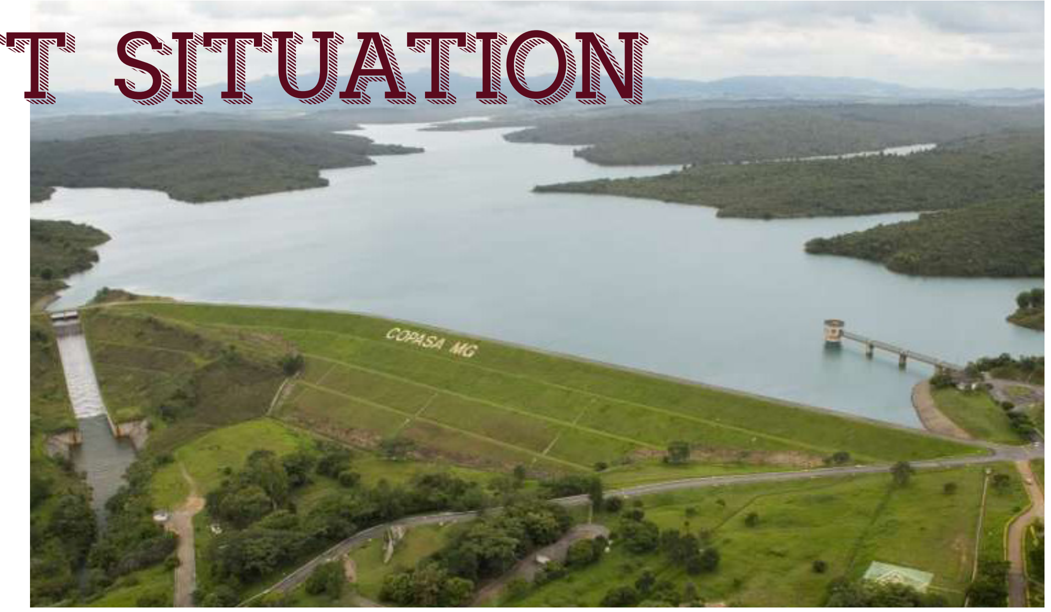
This chapter provides a detailed analysis of RMBH's metabolism regarding wastewater and solid waste. The metabolic analysis for each flow illustrates the current situation and challenges and is followed by a decentralization investigation. This investigation results in a catalog of solutions for both flows (see Catalog of Solution Volume). Lastly, each flow analysis ends with the election of the most suitable solutions in relation to the existing demands. These relations are the basis for developing a combined regional strategy, presented in the following chapter.

3.2 wastewater: the end point?

In this section, there are two main studies: wastewater metabolism and wastewater decentralization investigation. The first provides an overview of the elements of the metabolic flow, together with their qualitative and/or quantitative dimensions. This overview starts with the analysis of the drinking water resources of the region, given their relation with consumption and disposal phases. In sequence, the domestic focus is put forward, explaining the 3 different types of wastewater disposal present in the region (inexistent, individual solution and centralized) and their associated infrastructure. Subsequently, other parameters are also analyzed, such as Biological Oxygen Demand (BOD) and its association with river pollution. Lastly, there is an overview of future actions, which mostly focus on centralized solutions. The combination of these information results in a metabolic flow map, followed by conclusions, which reflect the urgencies in the metabolism and its relation to the territory.

The second study of this section is the decentralization investigation, providing a counterpoint from the existing centralized planning intentions. This study also puts forward an inventory of solutions for wastewater treatment (detailed in the Catalog of Solutions Volume). It also develops a matrix to compare and elect the most suitable solutions for the existing metabolic demands concluded previously.

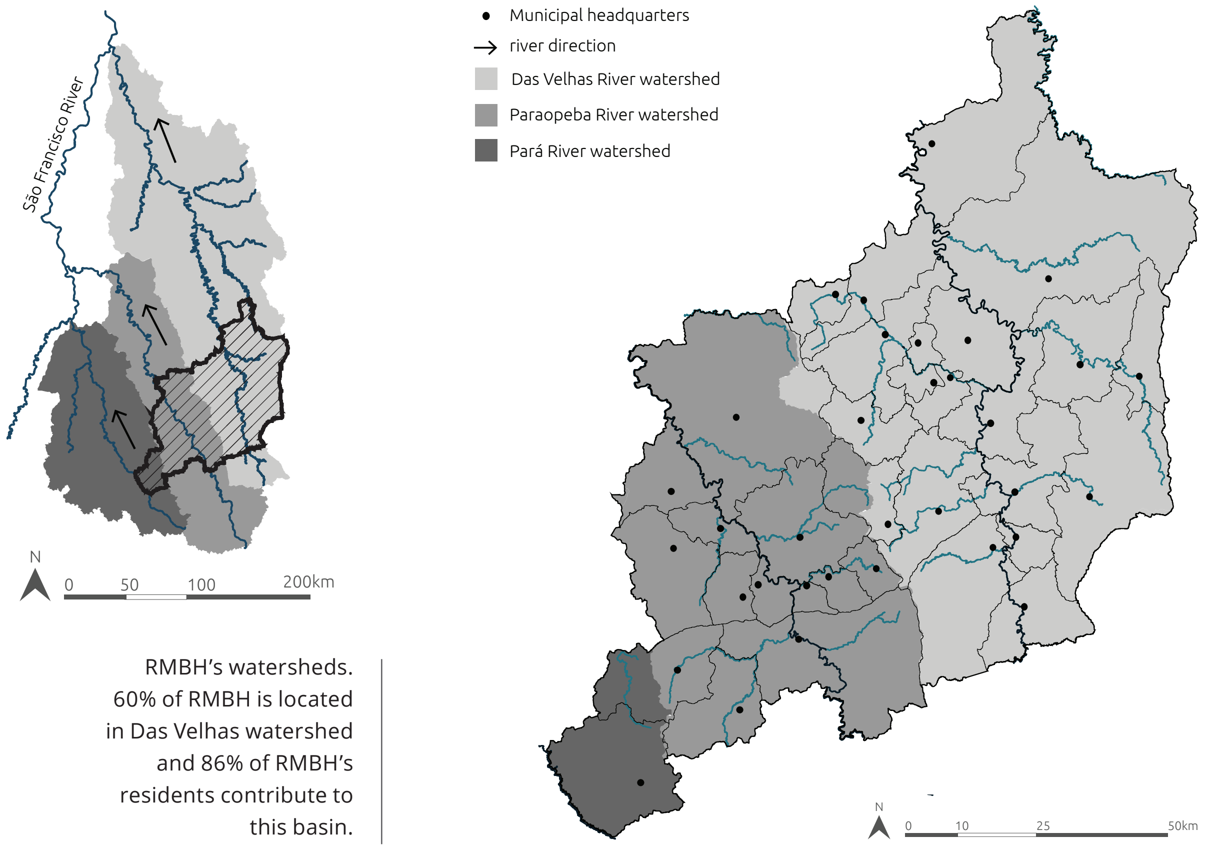
CURRENT SITUATION



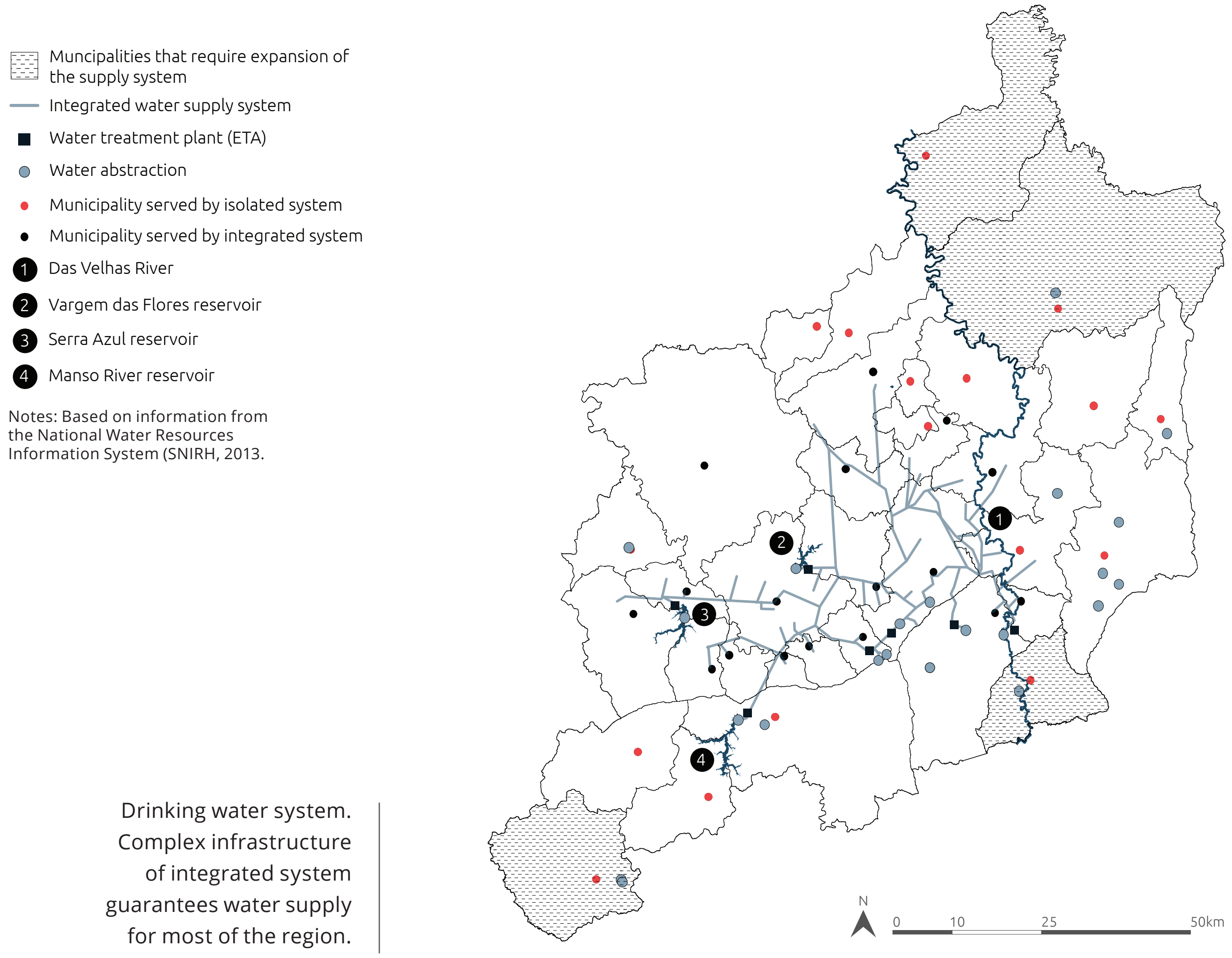
Manso River reservoir in 2018 recovering from the severe drought of 2015. Source: COPASA/ Divulgação

In order to understand the metabolism of RMBH's wastewater, first there is a need to have an overview of its drinking-water resources, since there is "unbreakable relationship between drinking water and waste water", which together form the 'small hydrological cycle' (Timmeren, 2012). Belo Horizonte Metropolitan Region is part of 3 different watersheds: Das Velhas River, Paraopeba River and Pará River, all part of the São Francisco Basin. Almost 60% of the territory belongs to Das Velhas watershed and 86% of RMBH's residents contribute to this basin (UFMG, 2010). Therefore, even though RMBH occupies only 21% of this watershed's area (UFMG, 2010), it causes a large impact on the basin as a whole, especially concerning river pollution. Das Velhas river is also one of the most important drinking water resources, together with 3 other reservoirs (Vargem das Flores, Serra Azul and Manso River). Together, these resources possess a complex infrastructure of water mains, abstraction areas and treatment plants that provide for region. Das Velhas river system is the main supplier for Belo Horizonte, where the majority of the region's population concentrate. Its Water Treatment Plant (ETA) has flow rate of 9,0m³/s (National Water Agency (ANA), 2010). The reservoirs are responsible for supplying the rest of the region and have ETAs with flow rates between 1,5 e 4,2 m³/s (National Water Agency (ANA), 2010). Even though most of the population is served by the integrated water system, 7 municipalities have isolated water abstraction systems. From those, 4 require expansion of their drinking water systems (National Water Agency (ANA), 2010).

Water Treatment Plant (ETA) of Das Velhas River managed by COPASA. Source: Barbosa Melo Construtora

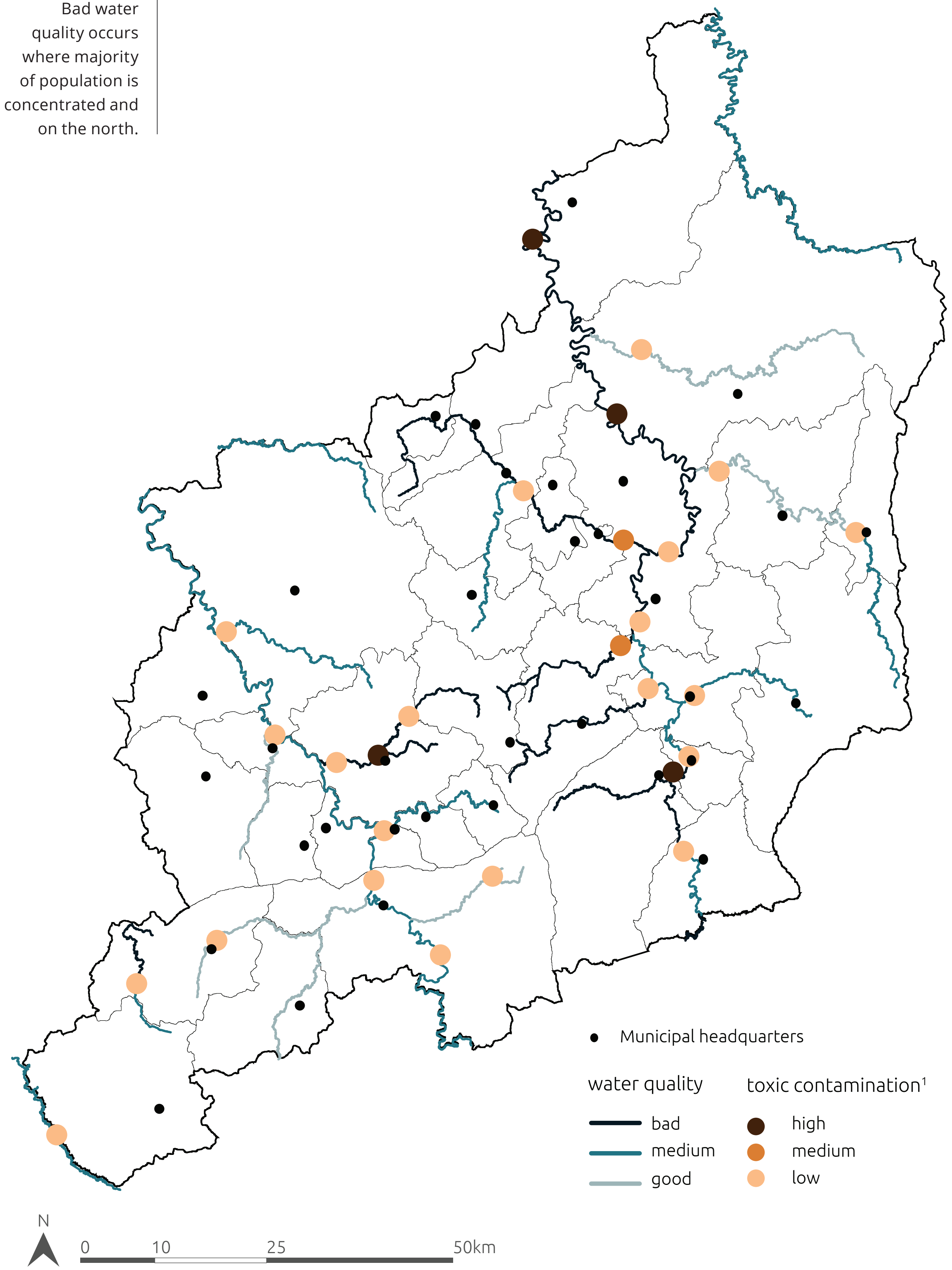


RMBH's watersheds. 60% of RMBH is located in Das Velhas watershed and 86% of RMBH's residents contribute to this basin.



Drinking water system. Complex infrastructure of integrated system guarantees water supply for most of the region.

River pollution. Bad water quality occurs where majority of population is concentrated and on the north.



Notes:
Based on the map "Surface water quality first quarter 2010" (UFMG, 2011)
[1] Concentration of the following parameters: Ammonia, Total Arsenic, Total Barium, Total Cadmium, Total Lead, Free Cyanide, Total Copper, Dissolved Copper, Hexavalent Chromium, Total Chromium, Total Phenols, Total Mercury, Nitrites, Nitrates and Total Zinc (National Water Agency - ANA).

wastewater

domestic wastewater + not-domestic wastewater

Domestic wastewater focus: main organic pollutant causing social and environmental issues.

main organic water pollutant

a. focused on centralized solutions
b. lack of proper infrastructure
c. low coverage
d. low treatment

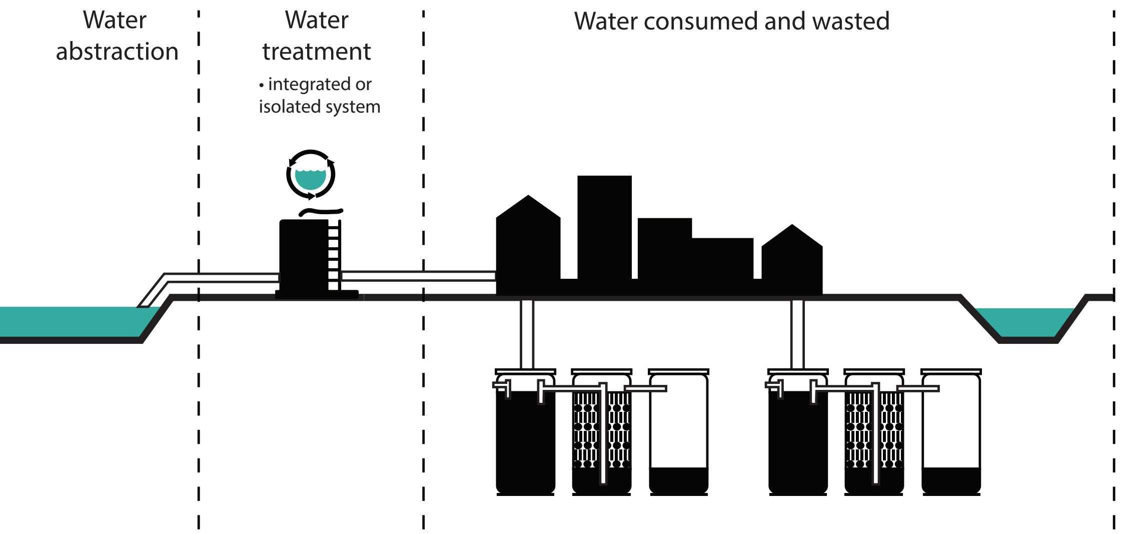
social and environmental issues

a. soil and water contamination
b. associated diseases
c. river pollution
d. excess of residues causes silting and increases demand for oxygen (BOD), harming aquatic life and water quality

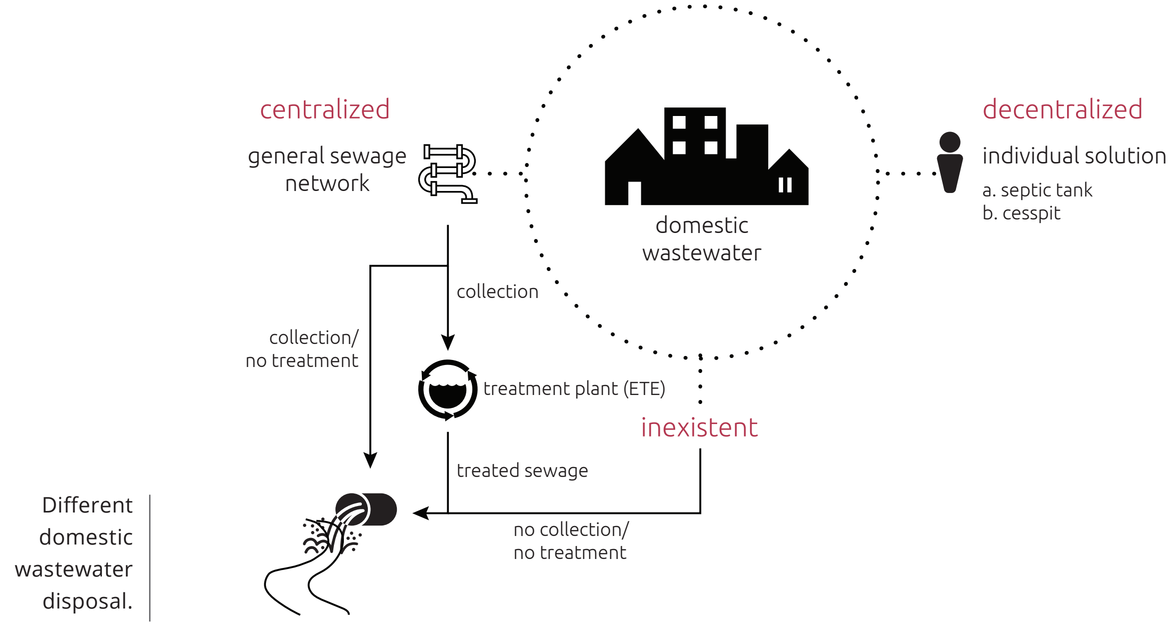
Once drinking water is distributed and consumed, domestic and non-domestic wastewater are produced. This thesis focuses on domestic sewage, since it is the main organic water pollutant in RMBH, due to low sewage coverage and treatment and lack of proper infrastructure (UFMG, 2010). Another aspect that adds to this situation is the focus on centralized facilities. If the infrastructure is not present, there are limited options to treat wastewater before discharging it into the rivers. River pollution and uncontrolled sewage discharge have health and environmental impacts, such as water and soil contamination, dissemination of diseases and river pollution (together with its associated consequences). Das Velhas river and its tributaries are the most polluted and toxically contaminated in the region.

Waste along Das Velhas River in Santa Luzia (2017). Picture: Leandro Durães.

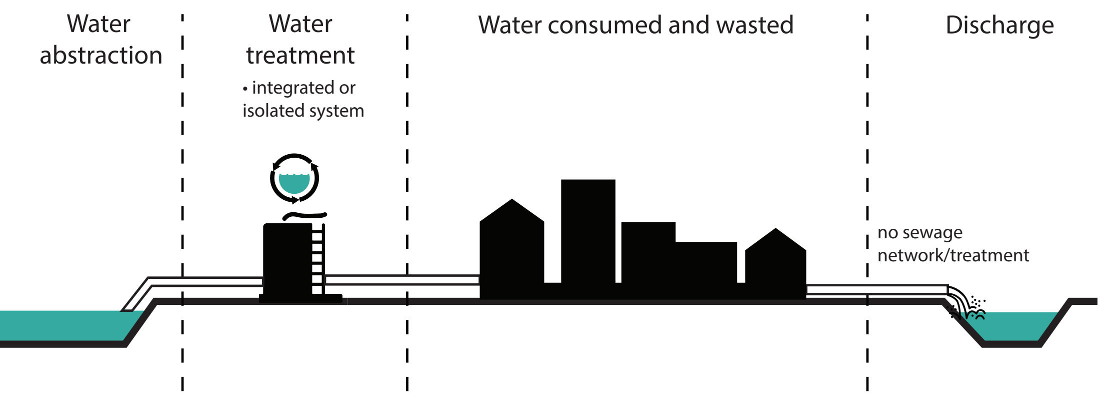
Pollution along Das Velhas River in Santa Luzia (2017). Picture: Leo Boi



Systemic section: individual solution. Septic tanks and cesspits are common solutions in rural areas.



Different domestic wastewater disposal.

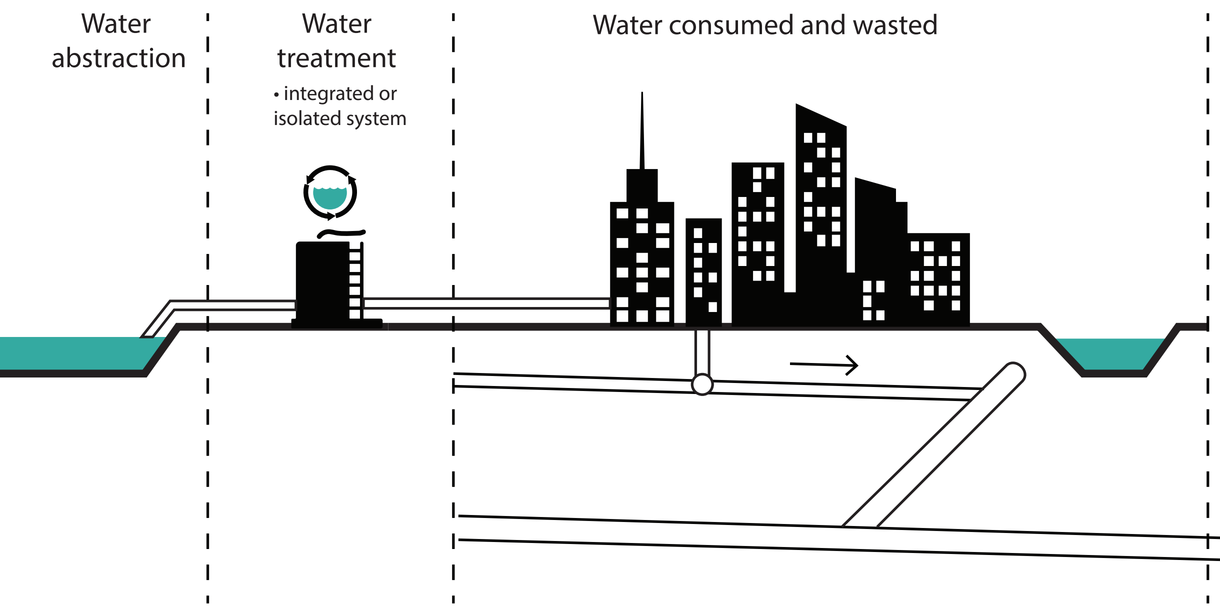


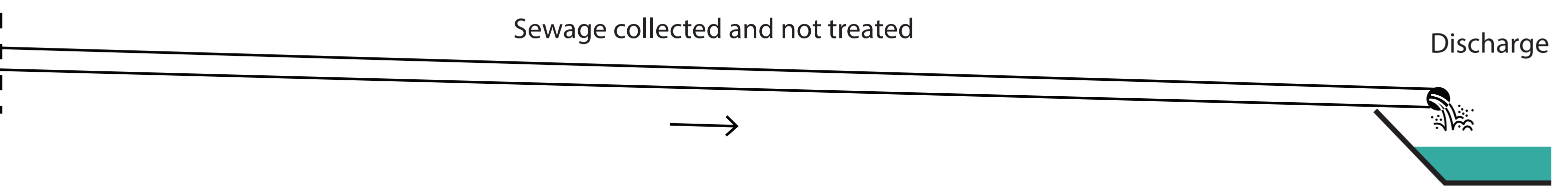
Systemic section: inexistent solution. Most common in poor neighborhoods and informal settlements.

In the region, there are currently 3 situations of wastewater disposal: centralized solutions, decentralized solutions and inexistent. The centralized solution is the preferred one for urban areas. The sewage from households is first collected and directed to main pipes (trunk pipes), which in turn lead the sewage towards the interceptors, which are pipes placed along the rivers. The interceptors are the ones which further carries the sewage to Sewage Treatment Plants (ETEs), before discharging treated wastewater into the rivers. When there is collection, but no treatment, the missing infrastructure can be either trunks pipes or interceptors. In many cases, the sewage network is not connected to treatment plants most likely due to high-cost infrastructures and the sewage is collected, but not treated. The current decentralized system, on the other hand, includes individual solutions such as septic tanks and cesspits. They are more common in rural areas and may contaminate groundwater, if not realized properly. The last situation, which is in fact the absence of any solution, refers to when there is no form of sewage collection or treatment. This condition is most common in poor neighborhoods or informal settlements.

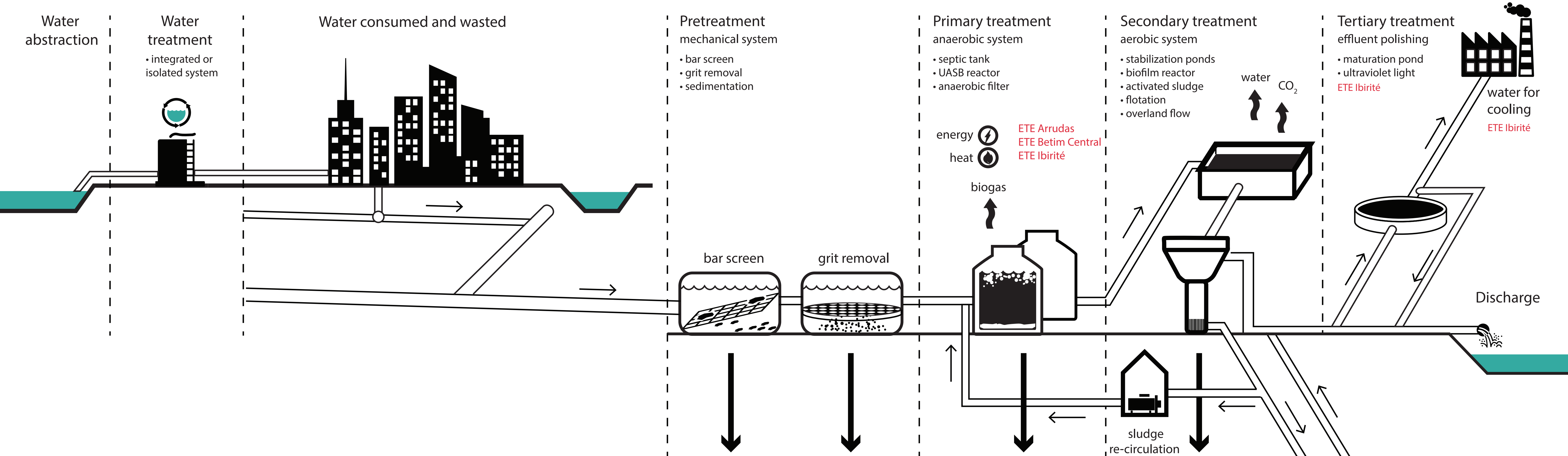
QUICK REMINDER

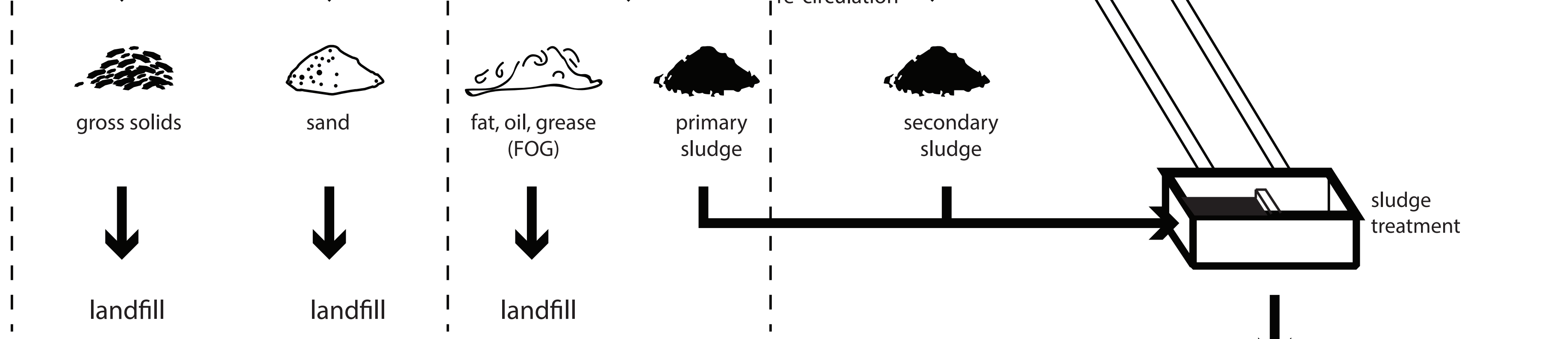
It is important to highlight that the region's sewage network is completely separated from the rainwater system (UFMG, 2010). One of the benefits of this separation is the reduction on contaminated water in case of overflow due to storm water. However, in ares with no sewage treatment, it is common to have the household sewage connected to the rainwater network.

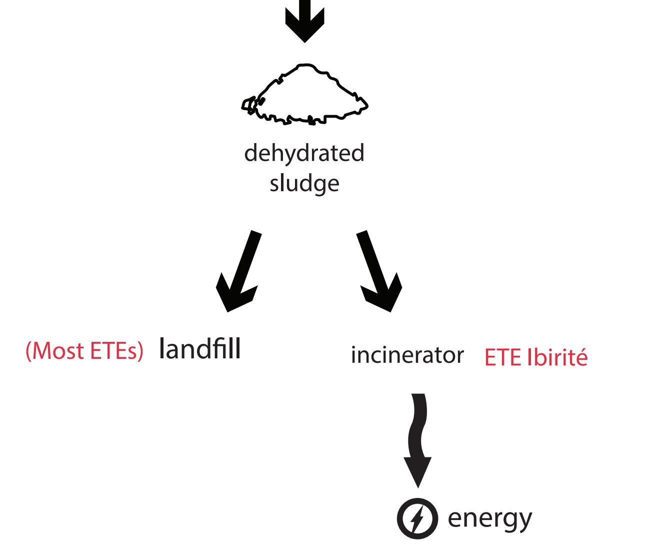




Systemic section: centralized solution - collection / no treatment. Occurs when sewage infrastructure is being implemented, but it is not complete. Possible reasons are high costs and slow implementation process.



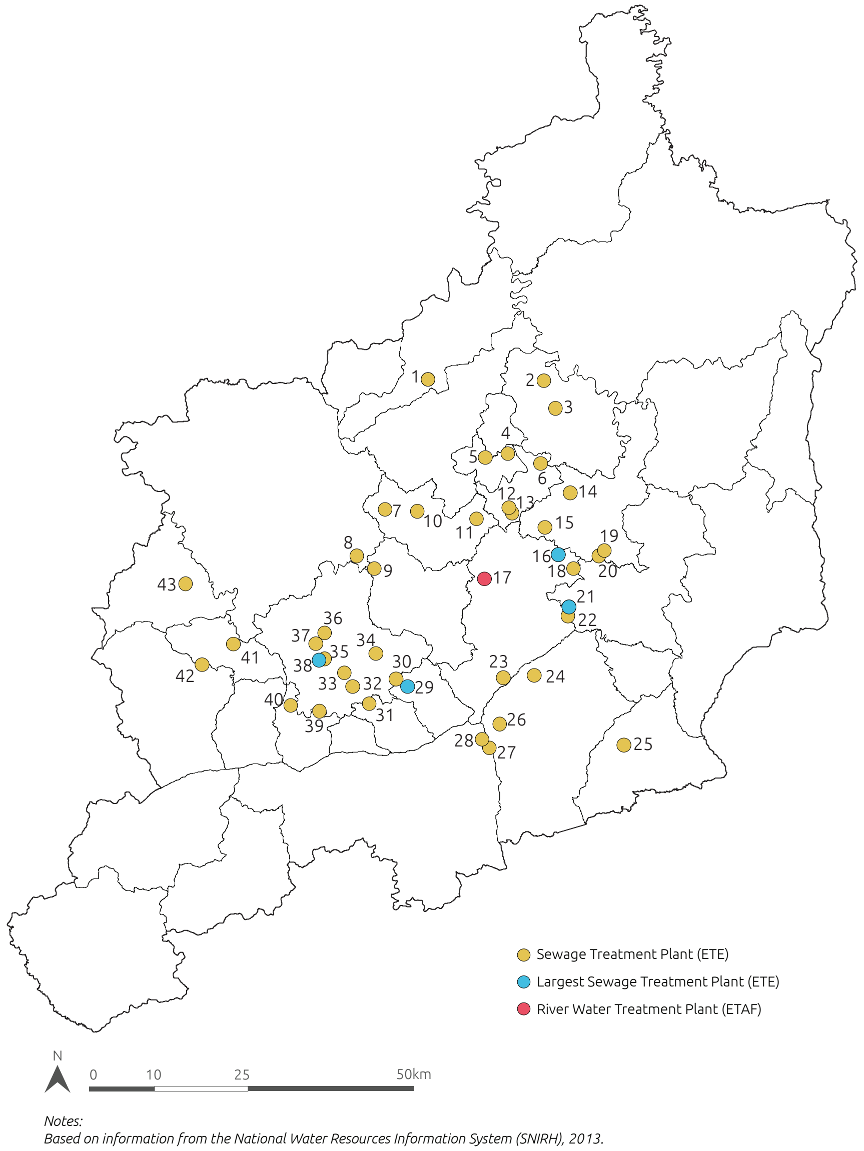




In case of wastewater treatment through Sewage Treatment Plants (ETE), it includes multiple phases. Most of the systems in the region have preliminary, primary and secondary treatments. The preliminary phase removes large solids using mechanical systems such as bar screen and grit removal (COPASA, n.d.-c). The by-products of this phase are gross solids and sand. The primary treatment reduces the sewage's BOD, using anaerobic digestion, which is "the biological conversion of organic materials to methane and carbon dioxide in the absence of oxygen" (Porteous, 1996). The by-products of this phase are fat, oil, grease and primary sludge. The secondary treatment uses aerobic systems that reduce BOD to environmentally safe conditions and guarantee a risk-free discharge of treated water into the rivers (COPASA, n.d.-c). The by-product of this process is the secondary sludge. For an environmentally safe disposal of the sludge, it also undergoes a specific treatment process, where it is dehydrated before final destination (COPASA, n.d.-c). The sludge can be re-circulated as many times as necessary to achieve the required levels of treatment (COPASA, n.d.-c).When there is a need for a higher water quality, a tertiary treatment follows the secondary one. This is called effluent polishing and consists of removing specific pollutants too allow further use of the water (COPASA, n.d.-c).

Systemic section: centralized solution - collection / treatment. Complete sewage infrastructure, most common in urban cores.

1-ETE Matozinhos
2-ETE Vila Maria
3-ETE Lagoa Santa
4-ETE São José da Lapa
5-ETE Inácio de Carvalho
6-ETE Vespasiano
7-ETE Veneza
8-ETE Esmeraldas
9-ETE Nova Contagem
10-ETE Ribeirão das Neves-Sede
11-ETE Justinópolis
12-ETE Nova Pampulha
13-ETE Morro Alto
14-ETE Santa Luzia
15-ETE Cristina - Sede
16-ETE Onça
17-ETAF Ressaca Sarandi
18-ETE Jardim Vitória
19-ETE Bom Destino Norte
20-ETE Bom Destino Sul
21-ETE Arrudas
22-ETE Minas Solidária
23-ETE Olhos D'água
24-ETE Vale do Sereno
25-ETE Rio Acima
26-ETE Jardim Canadá
27-ETE Mirante Brumadinho
28-ETE Ecológica
29-ETE Ibirité
30-ETE Petrovale
31-ETE Sarzedo
32-ETE Bandeirinha
33-ETE Cidade Verde
34-ETE Santo Antônio-Betim
35-ETE Cachoeira-Betim
36-ETE Teixeirinha
37-ETE Salomé
38-ETE Betim Central
39-ETE Bicas
40-ETE Igarapé
41-ETE Nova Esperança
42-ETE Mateus Leme
43-ETE Sede Florestal



Notes:
Based on information from the National Water Resources Information System (SNIRH), 2013.

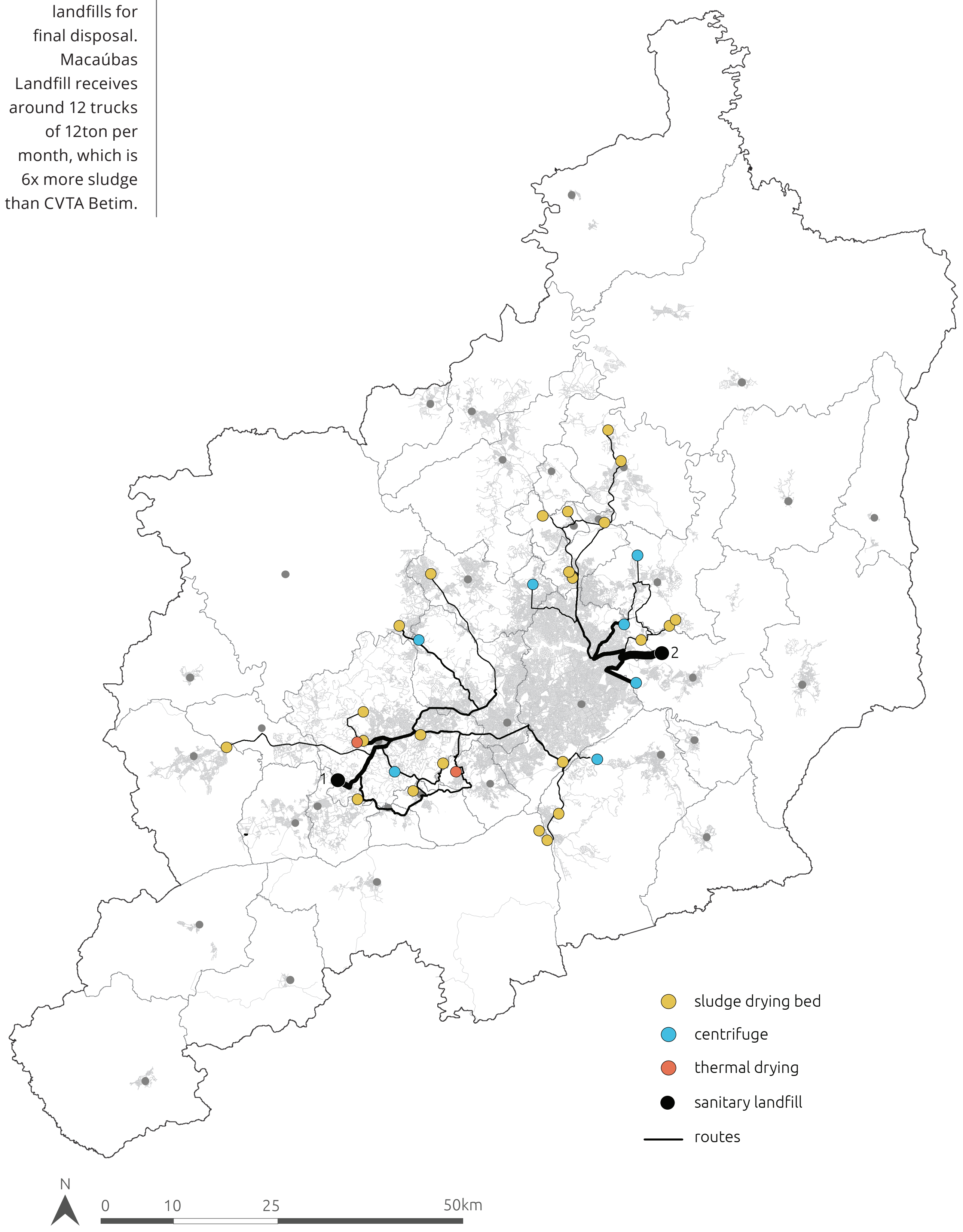
Existing Sewage Treatment Plants.

FUTURE PLANS

According to data retrieved from the National Water Resources Information System (ANA), the planning ambition is to collect and treat (via ETEs) 90% or higher of all municipalities in the region by 2035. The estimation of necessary investments made in 2013 to achieve this scenario was around 3,5 billions of reais, which roughly corresponds to 900 million euros.

Most of the by-products of the treatment plants are sent to landfills. However, some ETEs in the region use by-products created along the treatment processes themselves. ETE Arrudas, ETE Betim Central and ETE Ibirté use the methane released during the primary treatment to produce biogas. The energy produced from the biogas is then re-used within the treatment plants (COPASA, n.d.-a). ETE Ibirité also incinerates the sludge and re-use the energy in its facilities. It is also the only treatment plant in the region with tertiary treatment, which allows the re-use of the water inside the treatment plant or to sell it to the industry sector (Petrobrás) (COPASA, n.d.-a). It is important to highlight that most of the facilities are not operating on their full capacity, most likely due to lack of enough connections. This situation reflects not only the reliance on heavy infrastructure and the long investment return, but also the possibility to absorb future connections due to enlargement of the system or expansion of the region.

Treated sludge is taken to sanitary landfills for final disposal. Macaúbas Landfill receives around 12 trucks of 12ton per month, which is 6x more sludge than CVTA Betim.

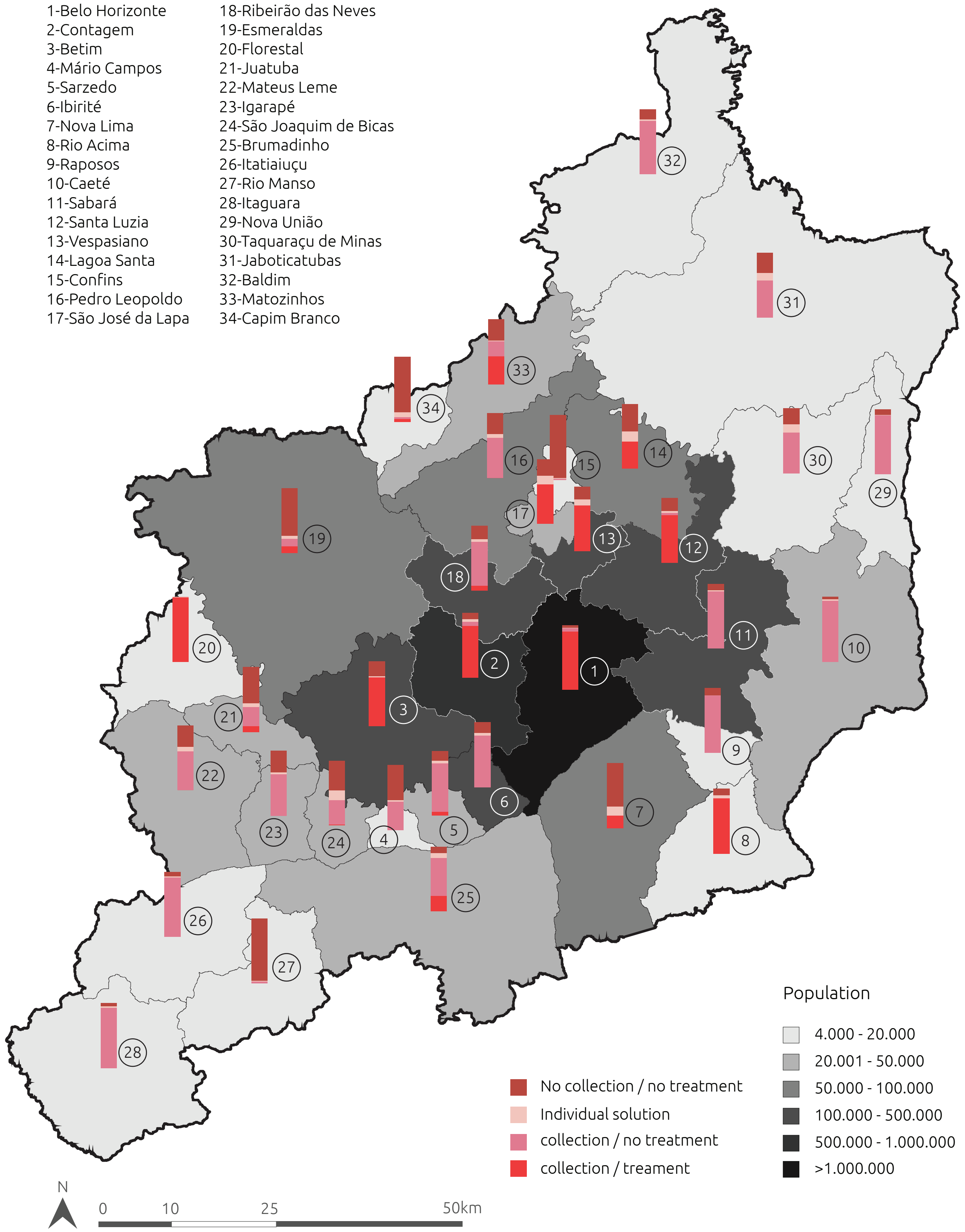


Notes:
Based on information received from COPASA via interviewee - 2017 data

1-CVTA Betim - average 662,35 ton/month .... 55 trucks (12ton)

2- Macaúbas Landfill CTRS - average 3.778,09 ton/month .... 315 trucks (12ton)

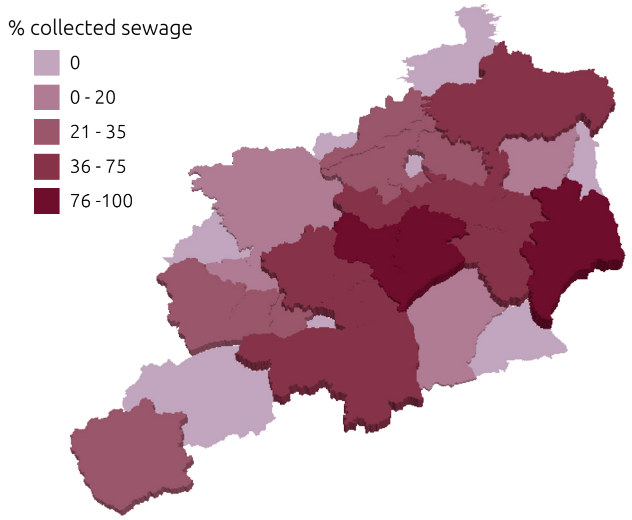
Types of sewage situation x population.
Distribution of the different types of wastewater disposal in the region.

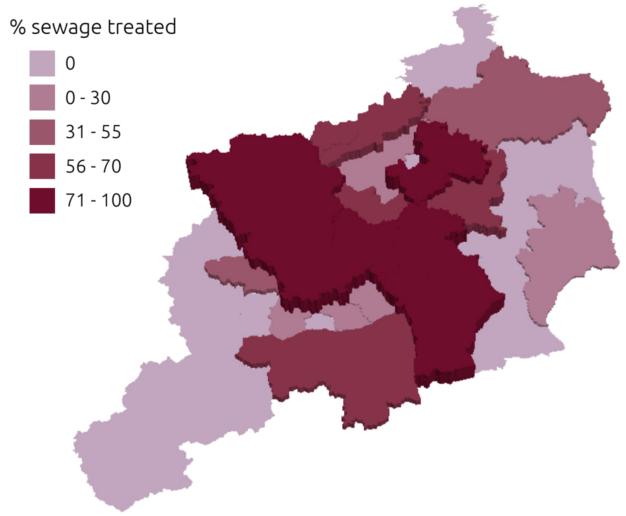


Notes:
Based on information from the National Water Resources Information System (SNIRH), 2013.

Percentage of collected sewage.
Concentrated infrastructure in the capital and its immediate surroundings.

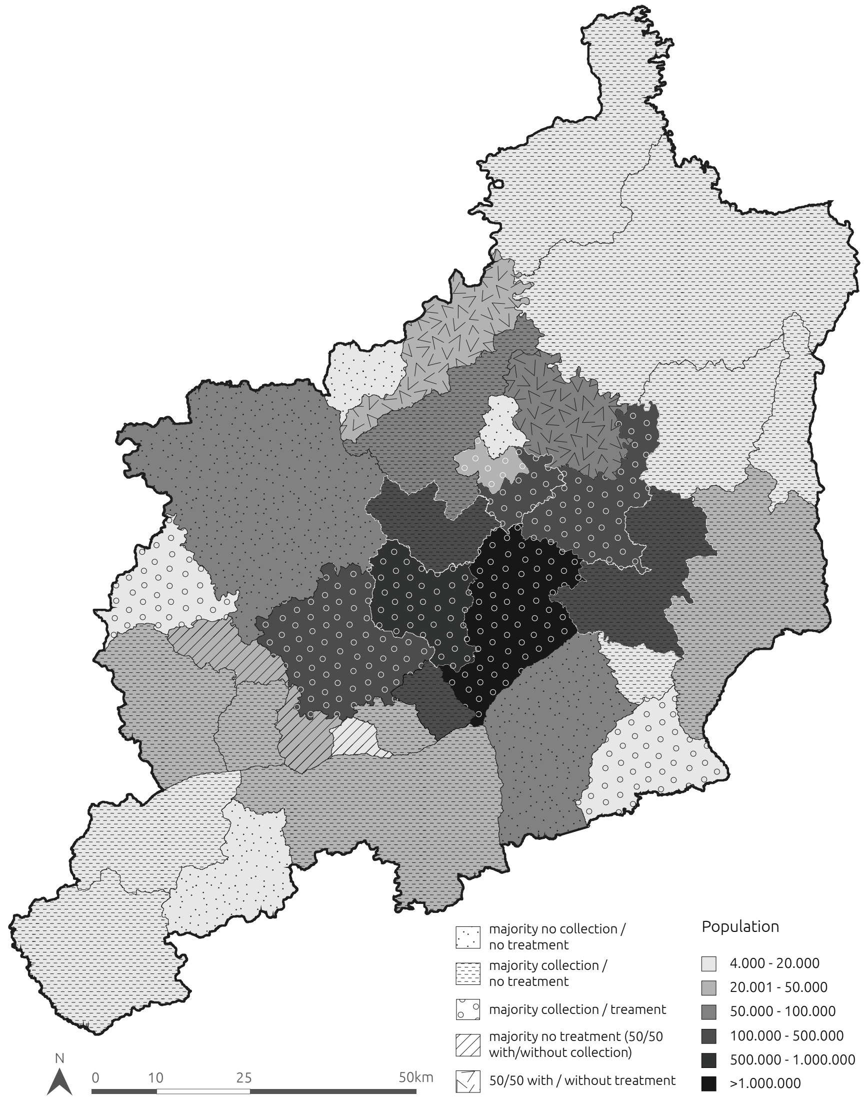
Percentage of treated sewage.
Cities with expressive population still lack sewage treatment.



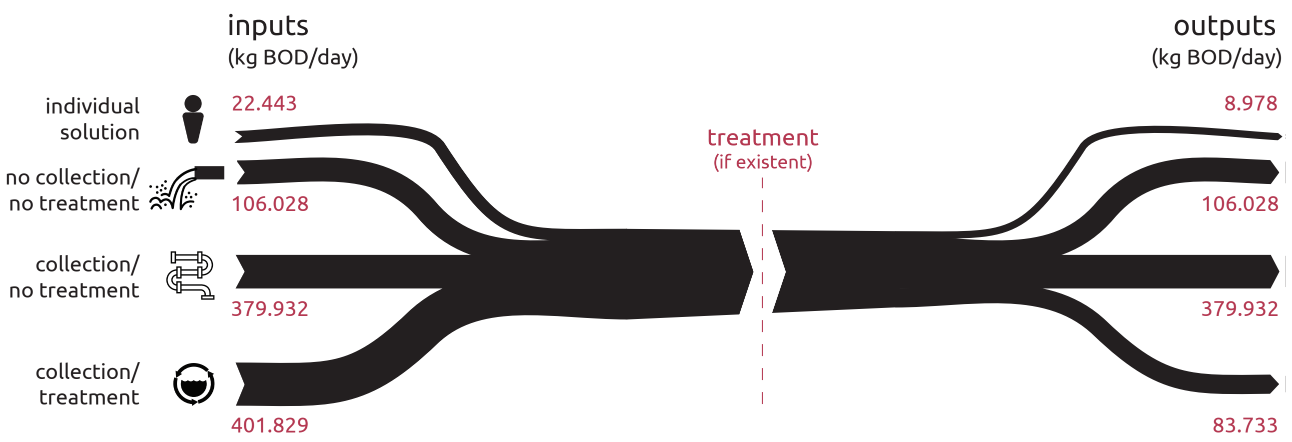


According to the data from the National Water Resources Information System (SNIRH) (National Water Agency (ANA), 2013b), it is possible to visualize the spatial distribution of these solutions in the region in relation with population. As expected, in most of the densely populated cities, the majority of people have collection and treatment of their sewage, with the exception of Ribeirão das Neves and Sabará. However, several cities that still have expressive population lack treatment and, in some cases such as Nova Lima and Esmeraldas, most of the population lack sewage collection and treatment. In addition, when looking at inputs and outputs of sewage collected and treated, it is possible to note the concentrated infrastructure in the capital and its immediate surroundings and the higher deficiency in sewage treatment rather than collection.

Majority sewage disposal situation x population.
The most densely populated cities have majority of people with sewage collection and treatment.



Notes:
Based on information from the National Water Resources Information System (SNIRH), 2013.



BOD overview: inputs x outputs.
Based on data from (National Water Agency (ANA), 2013).

RMBH has higher deficiency in sewage treatment rather than in sewage collection.

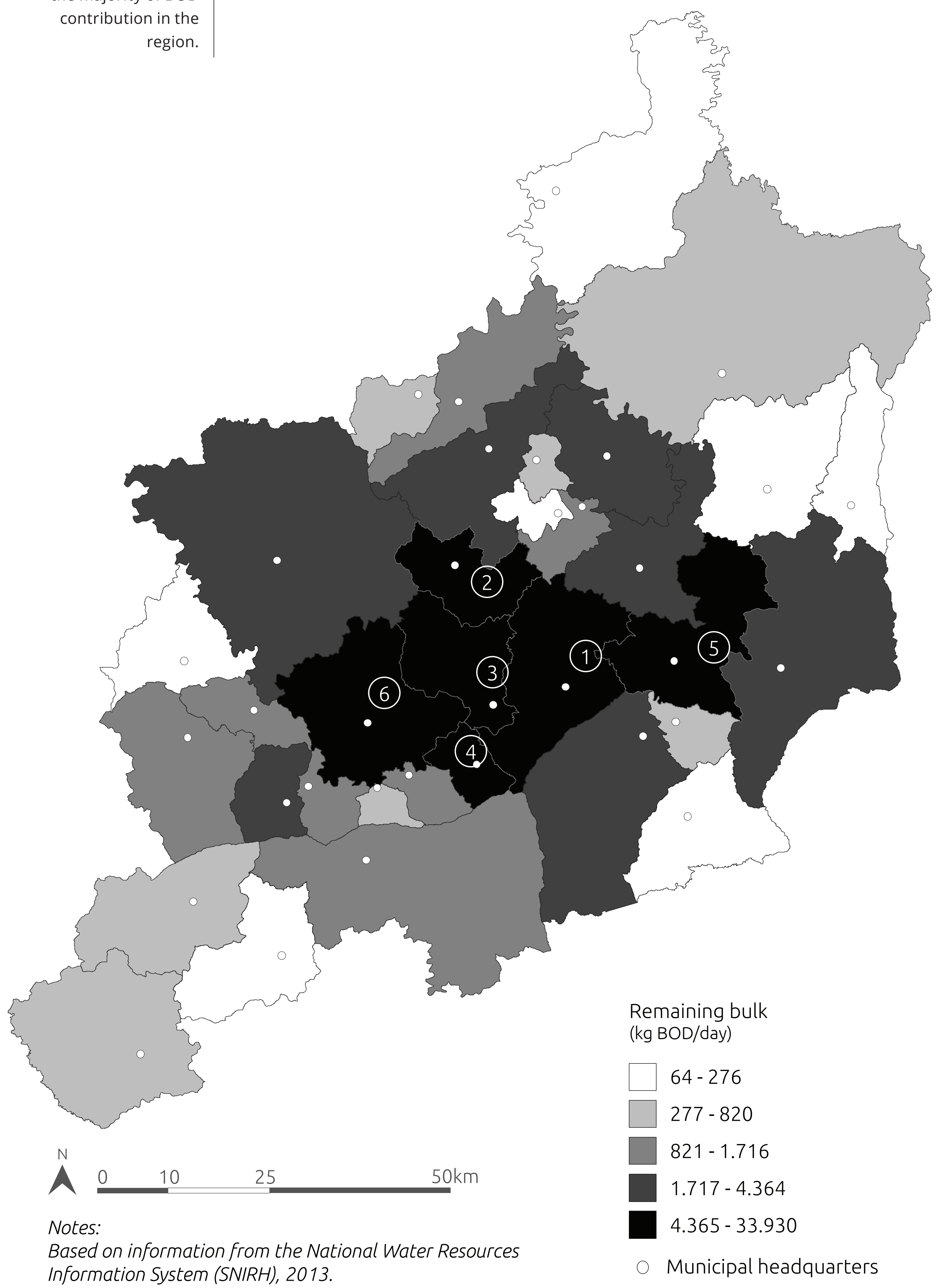
Another aspect that is relevant to discuss, especially in order to understand water pollution caused by wastewater discharge, is the Biological Oxygen Demand (BOD). This parameter indicates the amount of oxygen necessary to absorb organic matter by bacteria (Sasse, 1998). As a pollution indicator, the higher the BOD that is discharged into the rivers, the higher the pollution, since the oxygen will be consumed for decomposition of organic matter rather than for aquatic life (Sasse, 1998). Crossing the population without sewage treatment and the amount of BOD discharged, it is possible to point the cities that most negatively contribute to river pollution. These cities together represent around 1 million people without sewage treatment. It is important to highlight that, even though Belo Horizonte has a minority of inhabitants without sewage treatment (less than 10% (National Water Agency (ANA), 2013b)), it represents the size of a medium city (200.000 inhabitants). This situation has a large impact on the existing water conditions of the region as a whole.

	City	Population without sewage treatment (2013)	Remaining Bulk (kg BOD/day - 2013)
1	Belo Horizonte	236.264	33.930
2	Ribeirão das Neves	280.594	15.740
3	Contagem	101.156	10.299
4	Ibirité	162.840	8.938
5	Sabará	123.303	6.885
6	Betim	93.049	6.310

Cities with largest BOD contribution x population.
Based on data from (National Water Agency (ANA), 2013).

The first two largest contributors reflect two different situations: the first the minority has collection and treatment (but it is still expressive); the second the majority does not have sewage treatment.

Remaining BOD.
The capital and its immediate surroundings are responsible for the majority of BOD contribution in the region.



Notes:
Based on information from the National Water Resources Information System (SNIRH), 2013.

Drinking water

- reservoir
- watershed
- water mains
- water treatment plant (ETA)
- water abstraction

Water quality

- moderate pollution
- high pollution
- moderate toxic contamination
- high toxic contamination

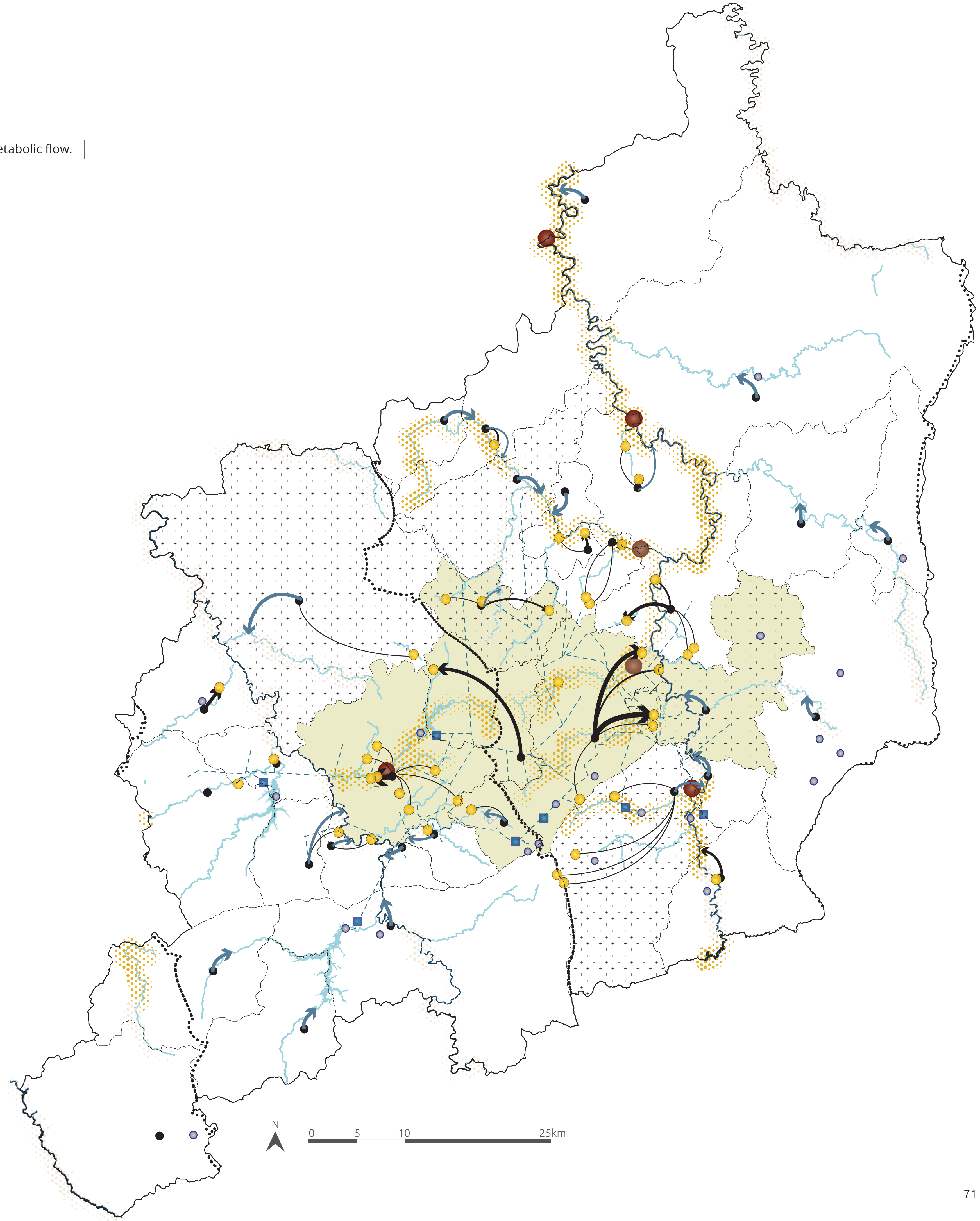
Wastewater

- sewage treatment plant (ETE)
- sewage treatment plant discharge
- untreated sewage discharge

- no treatment majority (population> 50.000)
- largest BOD contribution

- municipal headquarters

Wastewater metabolic flow.

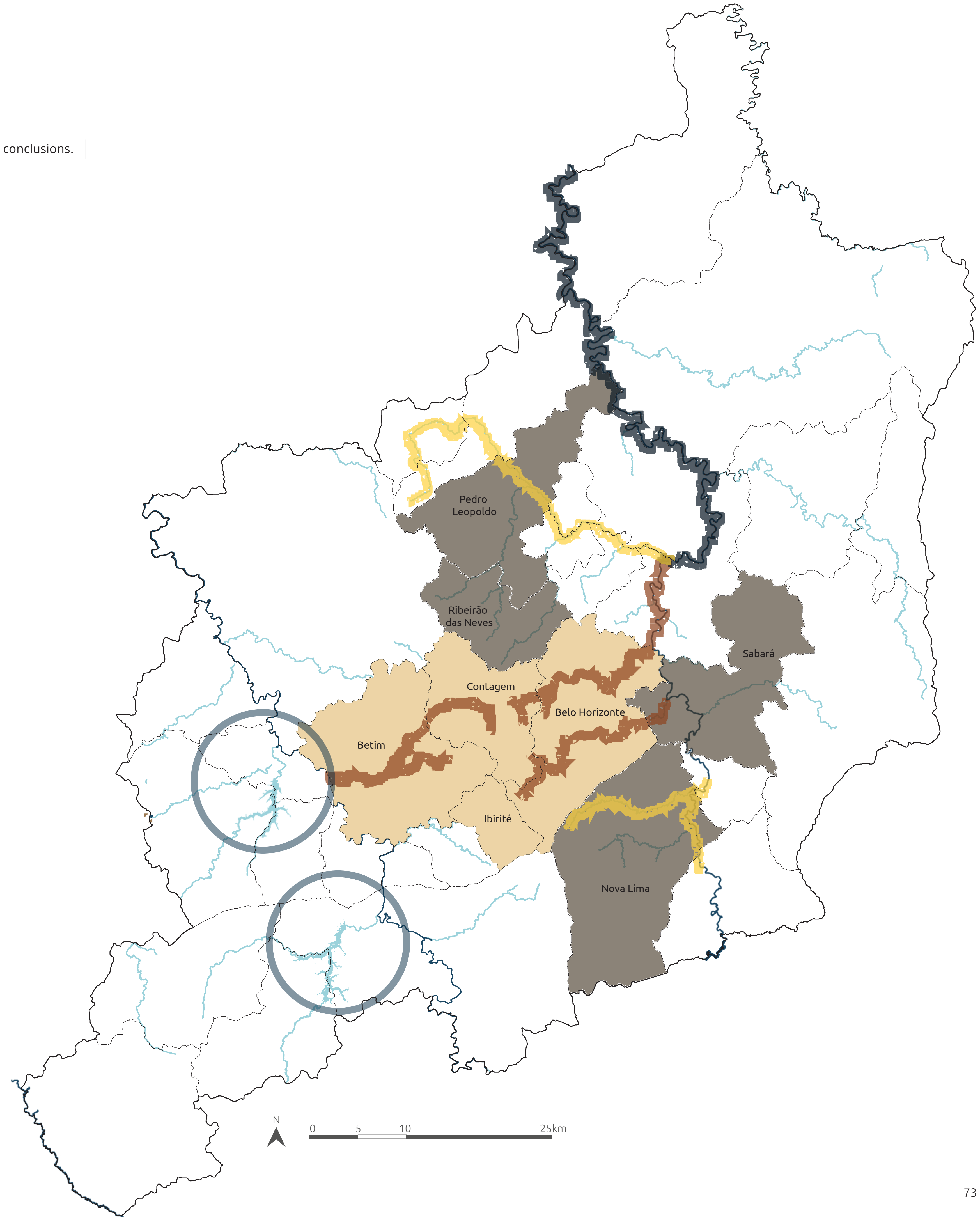


WASTEWATER METABOLISM

When combining river pollution, largest populations without sewage treatment and high BOD contribution with drinking water and wastewater facilities, presented previously, it is possible to outline RMBH's metabolic flow on domestic wastewater. It is possible to note that the mid-north presents more infrastructure and at the same time suffers more from water pollution (Das Velhas River). The south concentrates drinking water resources. The extreme north and south have less influence on the overall wastewater metabolism of the city.

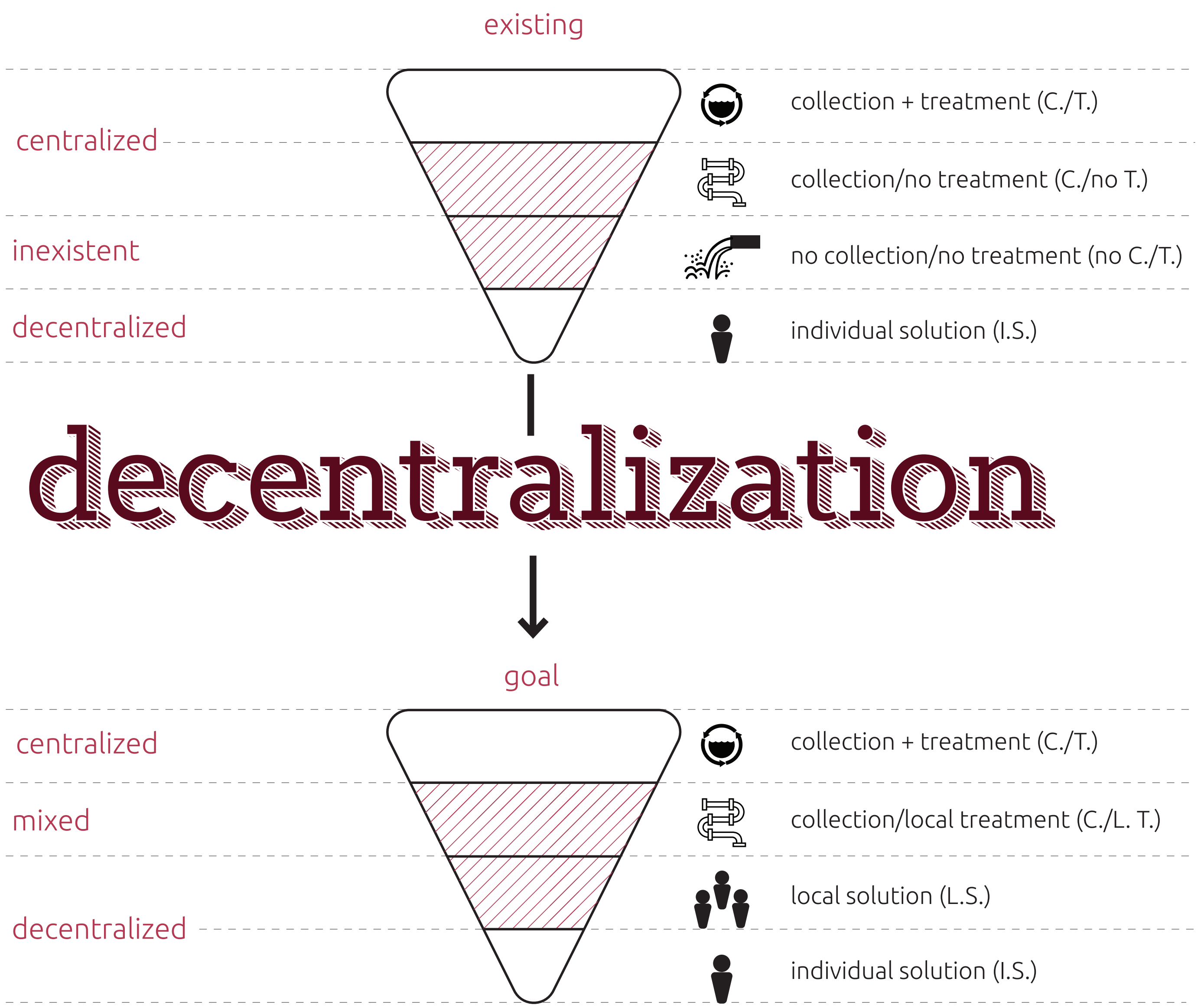
- pollution due to upstream contamination
- pollution due to expressive minority without treatment (high density)
- pollution due to majority without treatment
- critical area A.1 - Belo Horizonte, Contagem, Betim, Ibirité (population x minority without sewage treatment x pollution)
- critical area A.2 - Pedro Leopoldo, Ribeirão das Neves, Sabará, Nova Lima (population x majority without sewage treatment x pollution)
- critical areas for expansion (drinking water x no sewage treatment)

Wastewater conclusions.



WASTEWATER METABOLIC CONCLUSIONS

From the previous map, it is possible to highlight the cities which contribute the most to the river pollution, based on their lack of wastewater treatment, large population and discharge direction (to which watershed they contribute). This results in two distinct critical areas that have a straight relation with the current environmental pressures in the region. Area A.1 is where the urban core is located. This area has as main characteristic high density and large infrastructure systems, but with an expressive minority in absolute numbers without sewage treatment. The areas that most likely represent this situation are informal settlements and the outskirts (possibly in areas close to the borders with Area A.2). Area A.2, on the other hand, has the opposite scenario. The majority of population does not count on sewage treatment and the population is expressive in terms of wastewater production. Another aspect is that the lowest part of Das Velhas River is probably polluted due to upstream wastewater discharge rather than the contribution from the cities in the north, given their lower density. Lastly, there are two areas that are considered critical for expansion. They are an overlap between drinking water resources, population density and majority with no sewage treatment. These areas require special attention to assure the availability of water resources in the future.



Shift from centralized to decentralized solutions. Decentralized solutions produce less sludge, do not use chemicals, require less energy and cost 20-25% of the corresponding operational, management and maintenance expenses.

As stated before, RMBH relies on heavy infrastructure when it comes to wastewater disposal. Planning ambitions indicate the perpetuation of this situation, aiming for a 90 to 100% of the population with sewage collection and treatment by 2035 (National Water Agency (ANA), 2013a). However, in order to achieve this, there is a need of large investments over long periods of time, as well as political will and stakeholder engagement. Moreover, as the population expands, even if at slower rate, it becomes harder to close the gap between infrastructure and population. This occurs since a centralized system requires wastewater transportation through long distances (Pötz, 2016). In addition, treatment plants require large amounts of energy for aeration and sludge treatment (Pötz, 2016). Leakage is another setback concerning centralized systems (Pötz, 2016), given the maintenance difficulties of such large network of pipes, creating possible health and environmental issues due to groundwater contamination.

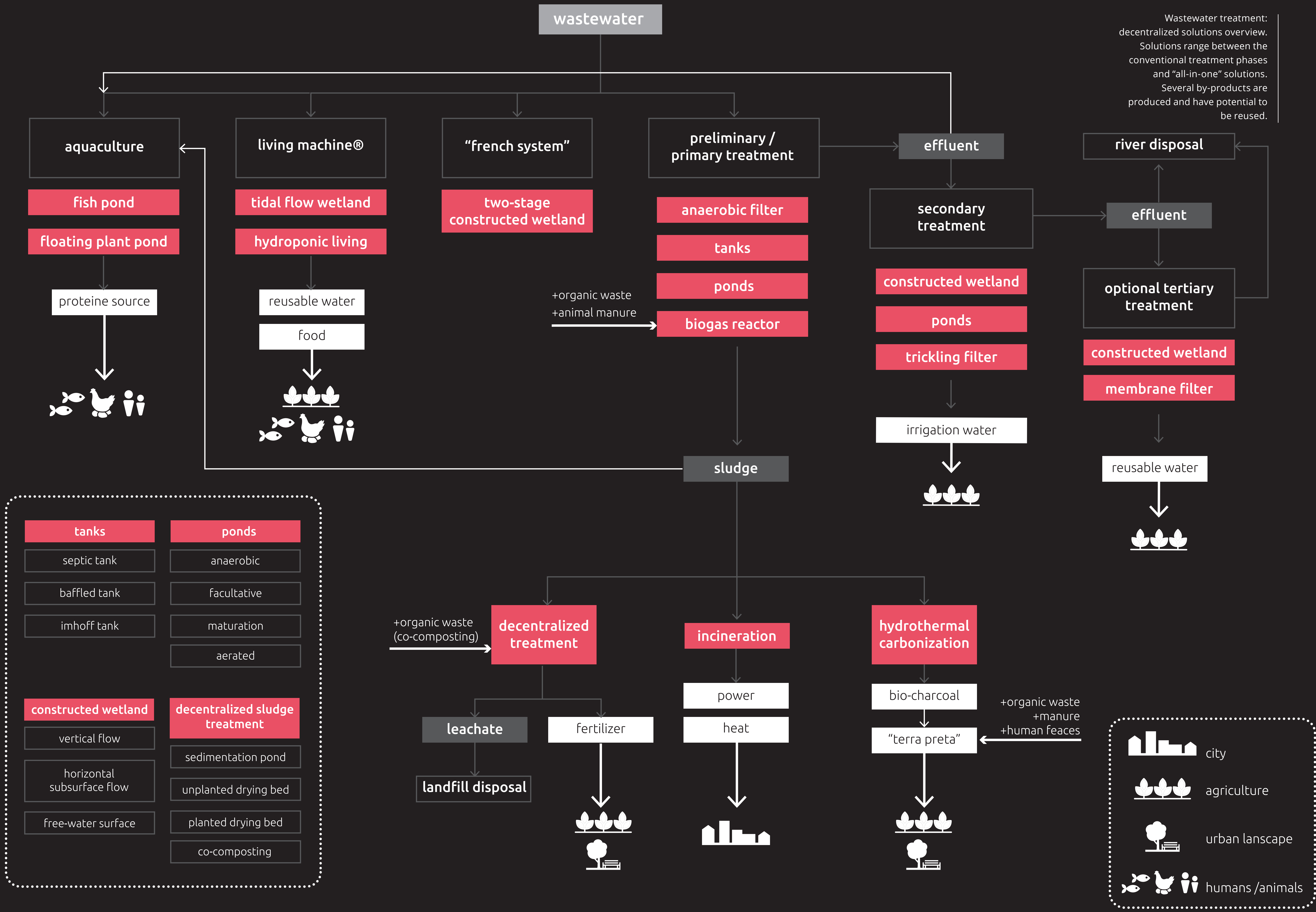
Alternatives to a centralized system are decentralized biological treatment systems. These solutions produce less sludge, do not use chemicals, require less energy and cost 20-25% of the corresponding operational, management and maintenance expenses of a conventional sewage treatment plant (Pötz, 2016). Moreover, Pötz advocates that compact decentralized solutions are possible ways to deal with urban expansion (Pötz, 2016), since they are more flexible. Associated with local landscape and context, these solutions can not only be integrated in the urban fabric, but also provide possibilities of closing the water cycle loop, as well as facilitating interconnections and synergies with other flows. Therefore, in the context of RMBH, **what if instead of aiming for connecting 100% of the population to a centralized system, decentralized wastewater treatment solutions could be applied in areas with currently individual solutions and with collection, but not sewage treatment?**

When discussing decentralized solutions, it is common to need multiple steps in order to treat wastewater and achieve the required levels of water quality. These steps follow the same logic behind a conventional sewage treatment plant: pre-treatment (removal of gross solids), primary treatment ("removal of easily degradable organic solids" - anaerobic digestion systems) and secondary treatment ("removal of more difficult degradable organic solids" - aerobic digestion systems) (Sasse, 1998). A tertiary treatment can also take place for effluent polishing.

There are many techniques and possible combinations between solutions and treatment phases (hybrid solutions), where the pre-treatment can be included in the primary treatment, for example, or that scape the conventional treatment logic. One exception is what is known as the "French System", where no pre-treatment is required and a two-stage vertical constructed wetland functions as one unique treatment (Hoffmann, Platzer, von Münch, & Winker, 2011). Each stage is also subdivided into steps, all using the same solution for each treatment phase (Hoffmann et al., 2011). Another exception is the "Living Machine". This system subdivides into two: the tidal flow wetland living machine system and the hydroponic living machine system. It is similar to a constructed wetland, but incorporates additional systems, such as aquaculture and hydroponic. Aquaculture, on the other hand, can also be used as unique treatment, using fish or floating plants ponds.

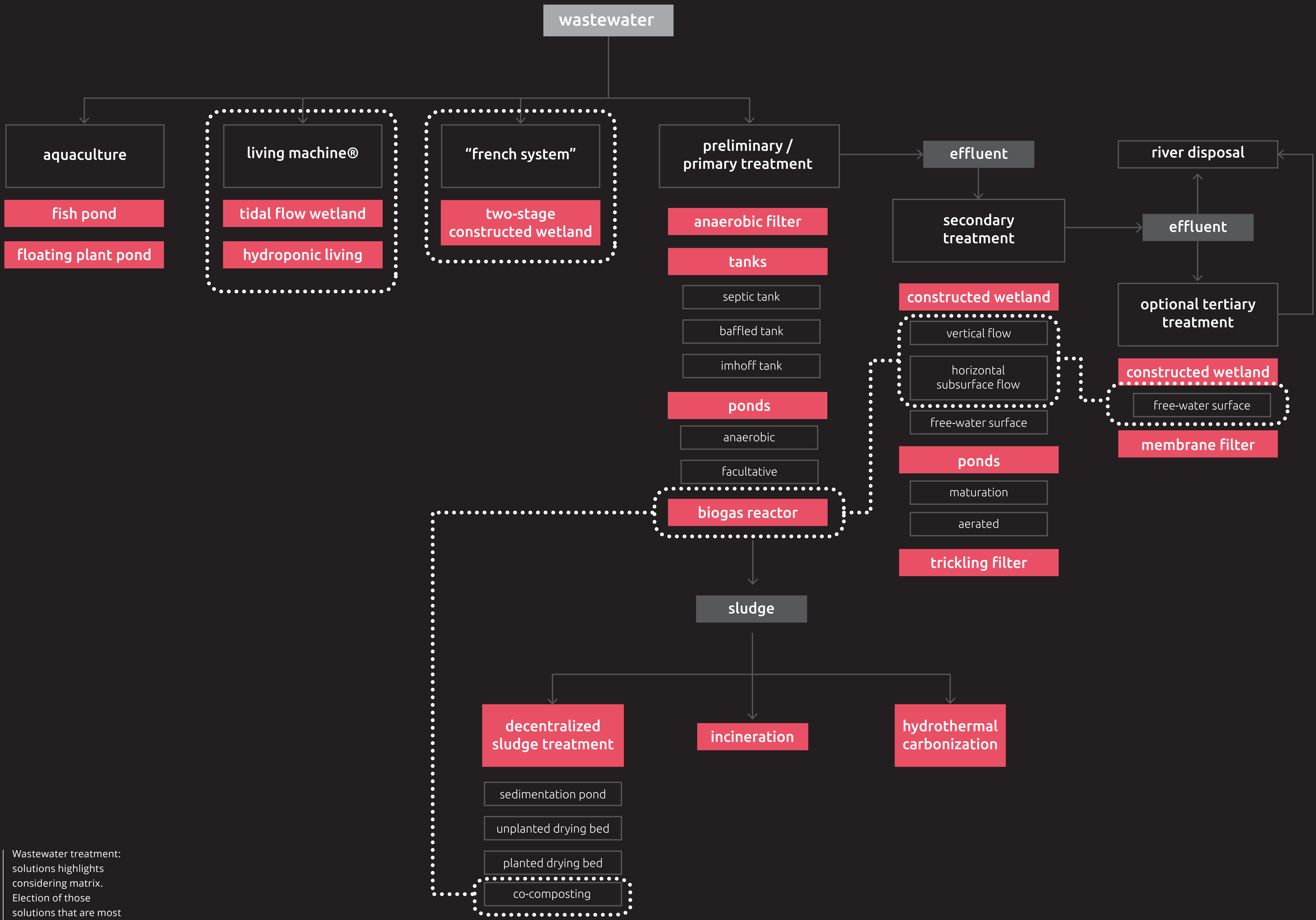
What defines the most suitable combination of solutions are local conditions and treatment purpose (Sasse, 1998).

This section presents a selection of decentralized solutions, which were selected using a set of criteria, projects and literature review (Hoffmann et al., 2011; Pötz, 2016; Sasse, 1998; Tilley et al., 2014). These criteria were defined in order to assist and guide the election of those solutions that can benefit an urban a regional strategy. Naturally, technical requirements for each solution cannot be disregarded for implementation. The first criterion is the neighborhood or city scale, which varies between 200 to 20.000 people. The second one is the area requirement for each solution. This is defined by m² per population equivalent (PE), which refers to 160L of wastewater per person (according to interviewee Breno Cota, Wetlands Construídos). The third criterion refers to the relation between the solution and the possibility of integration with the public space. This is particular interesting given the decentralized nature of the selected solutions. In other words, it relates to the potential to strengthen the missing link between society and the wastewater flow. In order to evaluate this criterion, the matrix considers 3 qualitative groups: avoid, when citizens should not have contact with the solution; neutral, when there is no harm for the citizen, but the solution does not add value to the public space; and add value, when the solution itself has elements that can be integrated into the public space. The forth criterion reflects the economic value of the by-products of the solution. Again, 3 qualitative groups were considered: low value, when the solutions do not produce by-products that can be commercialized; medium, when the by-products could be commercialized; and high, when the by-product have a high market value. Lastly, the most relevant criterion reflects the relation between the solution and other flows, divided in: none, when the solution does not relates to other flows; only one, when the solution creates interconnections with another flow; and multiple, when it is possible for the solution to interconnect with more than one flow. Those solutions which perform best in the matrix are, therefore, the most interesting to be implemented in an urban strategy. The detailed description of each solution can be found in the Catalog of Solutions Volume.



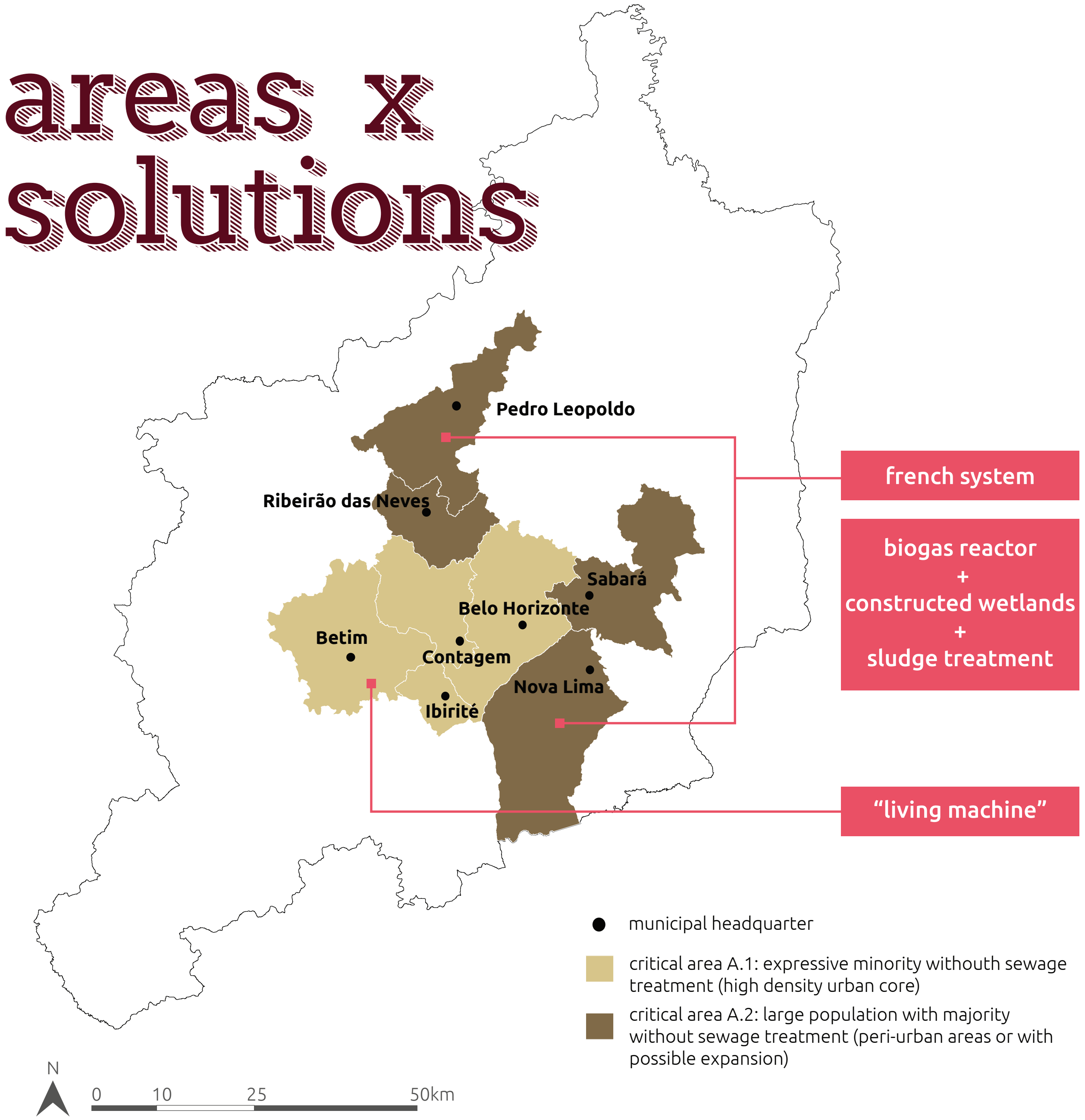
Wastewater treatment: decentralized solutions overview. Solutions range between the conventional treatment phases and "all-in-one" solutions. Several by-products are produced and have potential to be reused.

Wastewater treatment: solutions matrix. Each solution is evaluated considering 5 criteria that relate to urban quality.



Wastewater treatment: solutions highlights considering matrix. Election of those solutions that are most suitable for urban strategies.

areas x solutions



Critical areas x chosen wastewater treatment solutions.

Considering the conclusions derived from the metabolic analysis, RMBH possesses two types of situations that require different wastewater solutions: high density urban core (Critical Area A.1) and peri-urban areas or areas with possible expansion (Critical Area A.2). Using the matrix of solutions, the "living machine" presents itself as the most suitable choice for the high density urban core. Although it requires large space per person equivalent, this solution can be implemented in a wide range of scales. This flexibility is crucial in dense areas. In addition, this solution can treat wastewater to higher quality levels in a single system. Therefore, not only it is possible to re-use water locally, but also to associate the system with public space or other functions. Constructed wetlands combined with biogas reactor and sludge treatment or the French System, though, are better choices for peri-urban areas or areas with possible expansion, due to its simpler construction and large space requirements. These solutions have a direct relation with other flows, since the plants used in the wetlands can be commercialized as animal feeding; the sludge produced does not require any additional treatment and can be used as a fertilizer; the water can be re-used; and there is landscape integration potential. The biogas reactor additionally produces biogas (highly valued by-product that can be used in the city) and it can also incorporate organic waste and animal manure in order to increase the reactor's efficiency. It should be noted that in the case of the bioreactor, a sludge treatment must also take place. It is also important to highlight that choosing the best-fit option does not imply that other solutions cannot be associated or used.

3.3 solid waste: the waste that no one sees

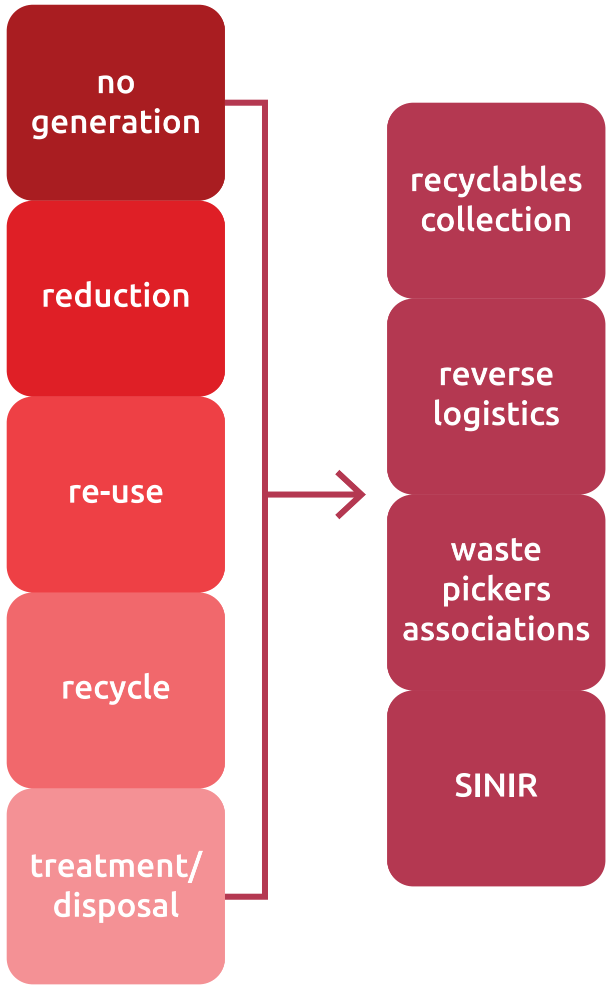
In this section, following the same structure of the previous one, the solid waste metabolic analysis and decentralization investigation take place. For the metabolism, there is a brief contextualization on the National Solid Waste Policy of Brazil (PNRS/2010), responsible for setting current requirements for waste management. This is followed by an overview of the general waste flow and the introduction of the domestic focus. Subsequently, there are two main analyses: household waste and recyclables waste. For each one of them, it is presented qualitative and quantitative characteristics. Lastly, there is an overview of the existing and planned actions regarding waste management. The combination of these information results in a metabolic flow map, followed by conclusions, which reflect the urgencies in the metabolism and its relation with the territory.

The decentralization investigation for solid waste is alike the wastewater one. It creates an inventory of solid waste solutions (detailed in the Catalog of Solutions Volume) and includes a similar matrix to compare and elect the most suitable solutions for the existing metabolic demands concluded previously.

QUICK REMINDER

It is important to highlight that the data used for this analysis comes from the National Sanitation Information System (SINIS -2015) and that not all the municipalities are part of that system. The PDDI already stated in 2010 the difficulties of gathering proper information regarding waste and the lack of a consolidated database (UFMG, 2010). The following analysis was produced based on the best understanding of the available data by the author of this thesis.

PNRS goals and tools: supporting circular principles



INTRODUCTION

national perspective on waste

According to the National Solid Waste Policy of Brazil (PNRS/2010), solid waste is every “material, substance, object or disposed item from human activities in society, whose final destination is carried in solid or semi-solid states, including gases present in containers and liquids whose peculiarities make them inadequate for disposing in the public sewage system or water bodies, or in order to do so, require technically or economically inviable solutions in the face of the best available technology” (Federal Government of Brazil, 2010- translated by author).

This national policy has as goal to assure the “integrated management and environmentally correct management of solid waste” (Federal Government of Brazil, 2010- translated by author). In order to do so, it establishes a hierarchy for waste management, which goes in line with circular principles: no generation; reduction; re-use; recycle; treatment and environmentally correct disposal.

The PNRS points the main actions and instruments to achieve its goal:

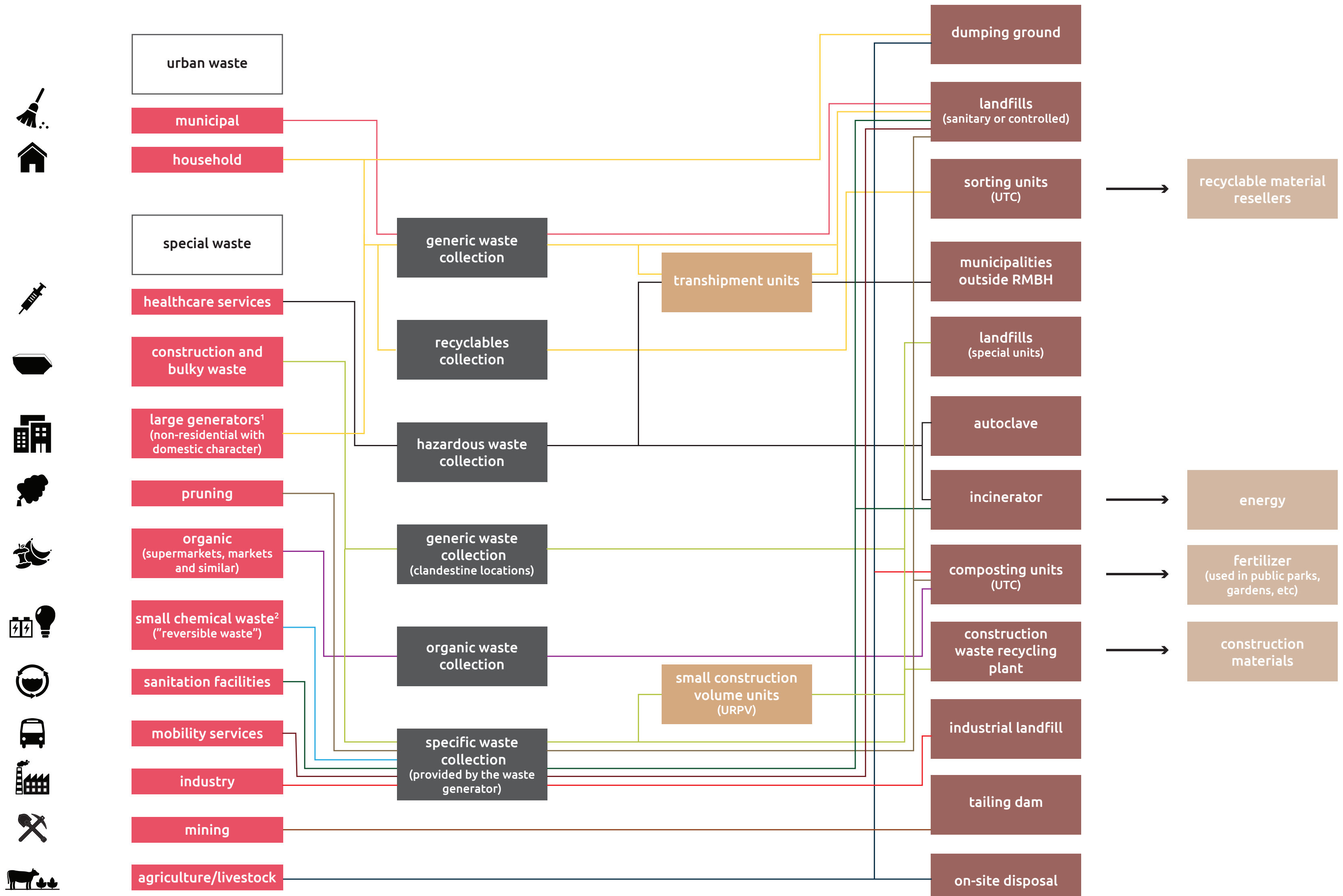
1-enlargement of recyclables collection

2-implementation of reversed logistics systems (collection and devolution of products after consumption for re-use)

3- promote the development of associations of recyclable waste pickers

4-development of the National Information System on Solid Waste Management (SINIR)

It also establishes that, in order to have access to federal resources, each Municipality should develop a Municipal Plan for Solid Waste Integrated Management (PMGIRS). Until 2013, in the RMBH, only 7 municipalities had developed this document (Belo Horizonte, Betim, Brumadinho, Florestal, Lagoa Santa, Mateus Leme and Ribeirão das Neves) (Environment Ministry, 2014). In the regional scale, so far there are plans for Healthcare and Construction Waste. However, the Regional Plan for Urban Solid Waste is still under progress.



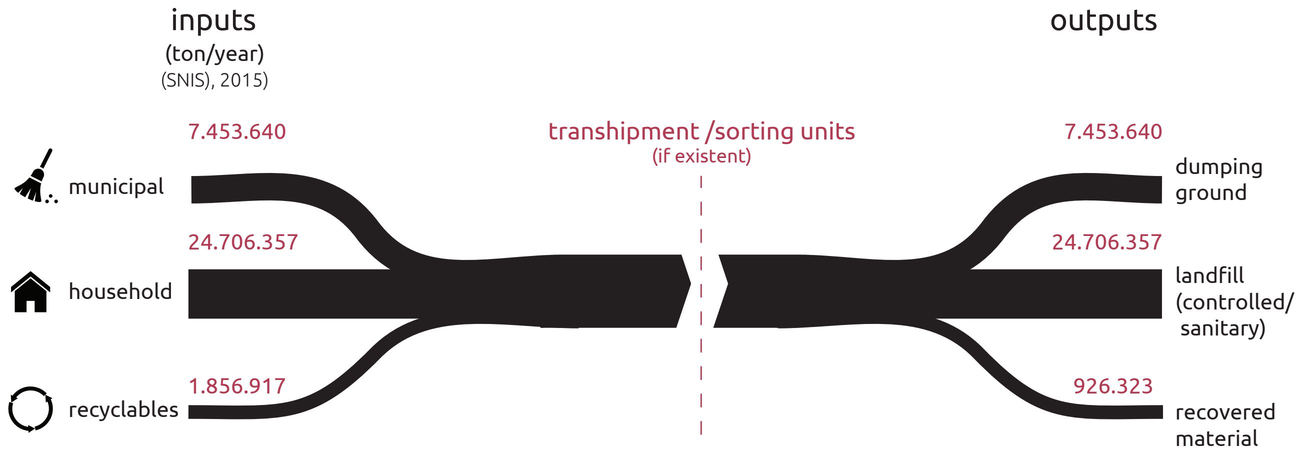
[1]>120L or 60kg/day
[2] agrochemicals; batteries; tires; oils; lamps; electronics

Waste flow in RMBH. According to BH’s PMGIRS, waste can be subdivided into urban and special waste and their sub-categories.

There are many types and categories of waste. In this thesis, waste is categorized based on Belo Horizonte’s PMGIRS, which divides solid waste into urban waste (municipal + household) and special waste (with several sub-categories).

Inputs x outputs solid waste.
Landfilling is the most common form of waste disposal. Highlights to the large lost potential for recycling.

It is possible to note that the majority of municipalities has high coverage of general waste collection, but low coverage of recyclables collection.

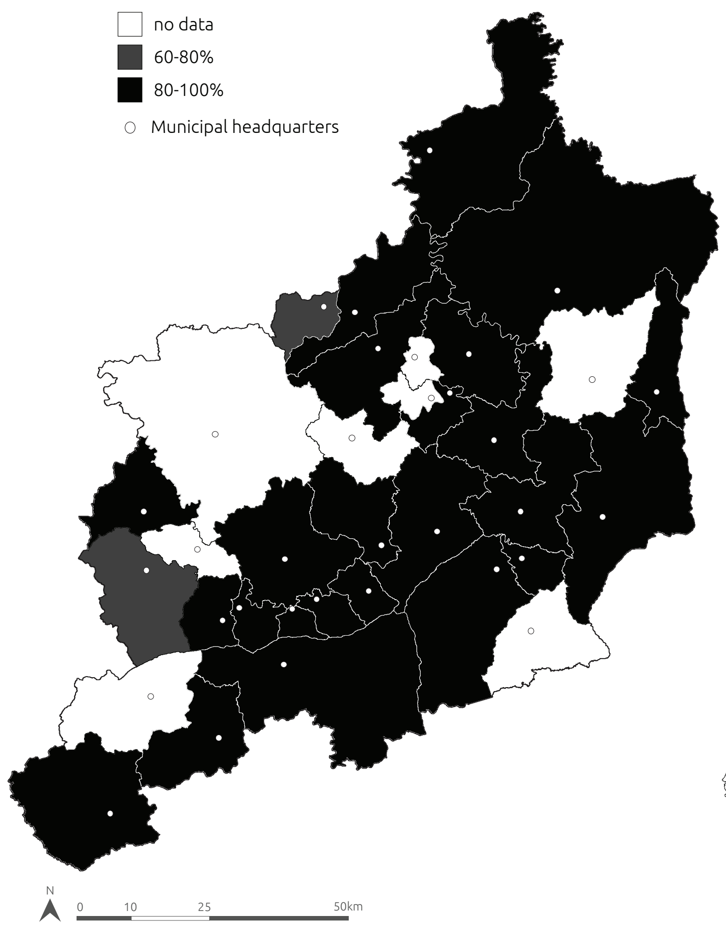


CURRENT SITUATION

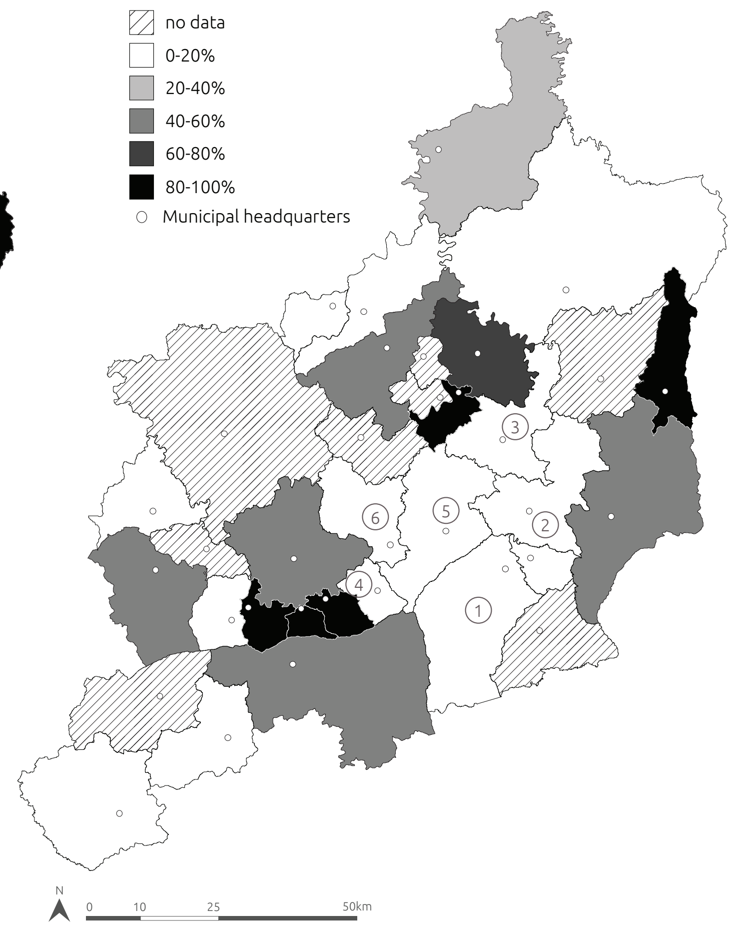
Waste has multiple generation sources and outputs, which increases its complexity and challenges. In line with the wastewater focus of this thesis, urban solid waste is the predominant emphasis of this study. This is particularly interesting considering that 60% of the domestic waste is organic matter, with high pollution risks (soil and water) (UFMG, 2011). However, this same aspect can be seen as a potential, since it is possible to re-use this organic matter in other forms. Moreover, the PDDI highlights that the current waste management structure in the RMBH is diverse among municipalities, but in general focused on a sanitary approach (UFMG, 2010). This results in the alienation of waste in society, increasing the feeling of repulse regarding waste itself and reinforcing the role of the Municipality as the responsible actor for treating and disposing waste (UFMG, 2010). Therefore, urban waste becomes a potential to shift the current urban relationships between waste and society.

When discussing urban waste, three main aspects are analyzed: municipal waste (all waste resulted from city cleaning); household waste (waste produced by each person) and recyclable waste (which subdivides in paper, plastic, glass and metal). It is possible to note that the majority of municipalities has high coverage of general waste collection, but low coverage of recyclables collection. In relation to the last, it is also important to highlight the amount of lost potential, considering that some of the cities with largest population have a minority of recyclables collection.

Household waste collection coverage.
The majority of municipalities has high coverage of general waste collection...



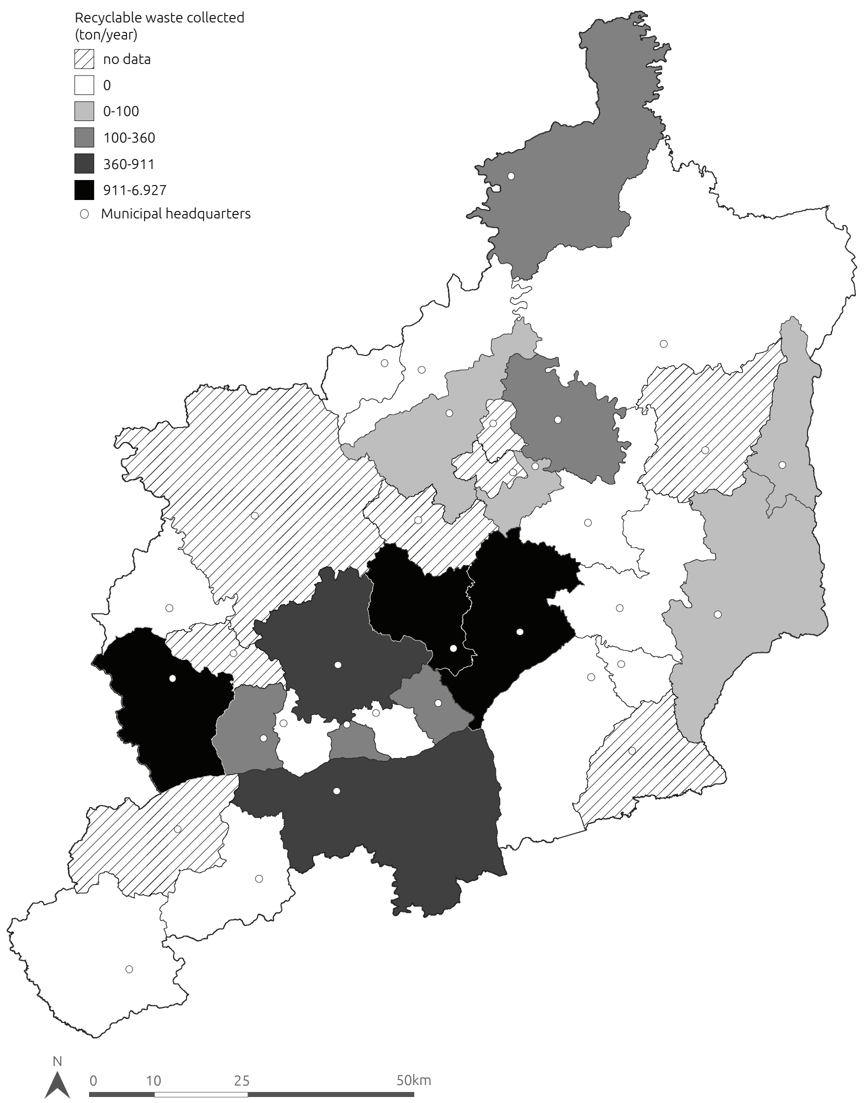
Recyclables collection coverage.
...but low coverage of recyclables collection.



Some municipalities with large population do not even have recyclables collection. In the capital, where half of the population of the region lives, only 15% has access to this service.

	City	Population with recyclables collection <20% (2015)	Population (>50.000) (2015)
1	Nova Lima	0%	89.900
2	Sabará	0%	134.382
3	Santa Luzia	0%	216.254
4	Ibirité	2,88%	173.873
5	Belo Horizonte	15%	2.302.557
6	Contagem	20%	648.766

Recyclables collection x population.

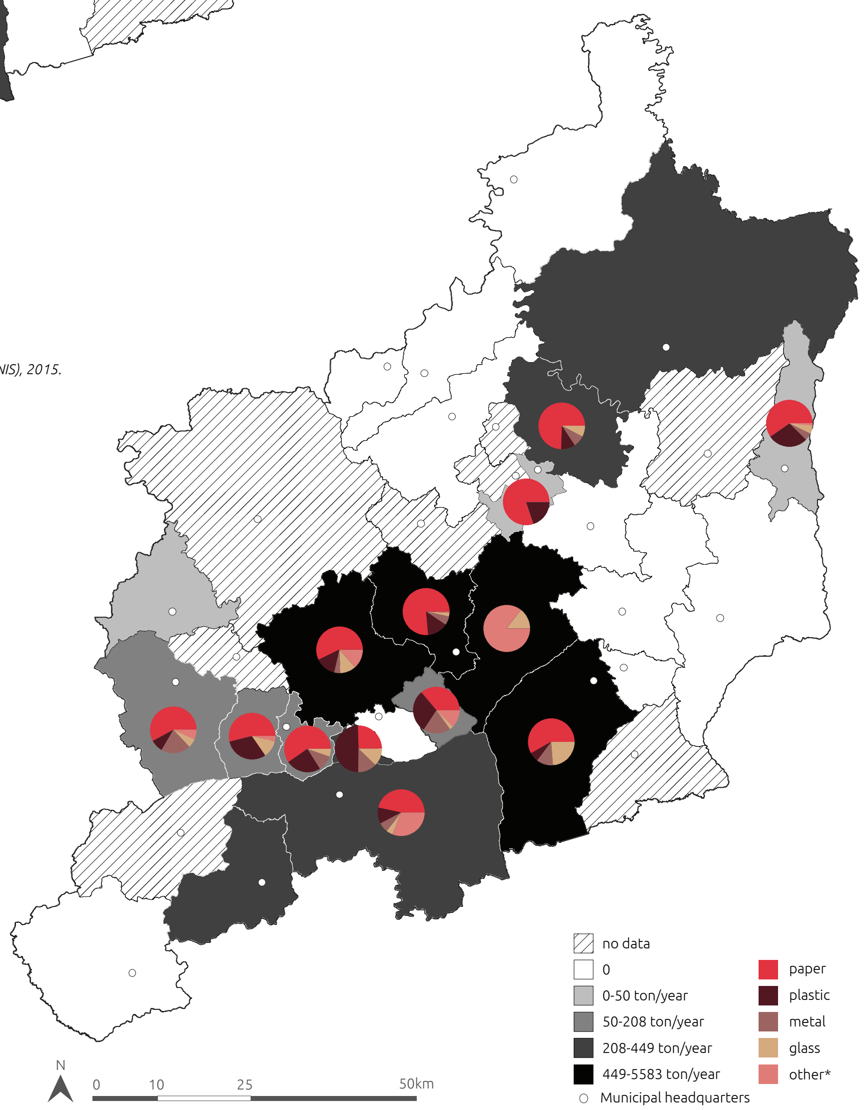


Notes:
Based on information from the National Sanitation Information System (SNIS), 2015.

Recyclable waste collection volume. The capital stands out of the rest of the region, with largest volume of recyclables collected.

Material recovery from recyclable waste. Despite the low volume of collection, there is material recovery in most municipalities. However, it is still very small in absolute numbers, when compared with waste generation.

When looking at the volume of recyclables and the material recovery in each municipality, the capital stands out of the rest of the region, with largest volume collected and recovered.



Notes:
Based on information from the National Sanitation Information System (SNIS), 2015.
**any other recyclable material except tires and electronics*

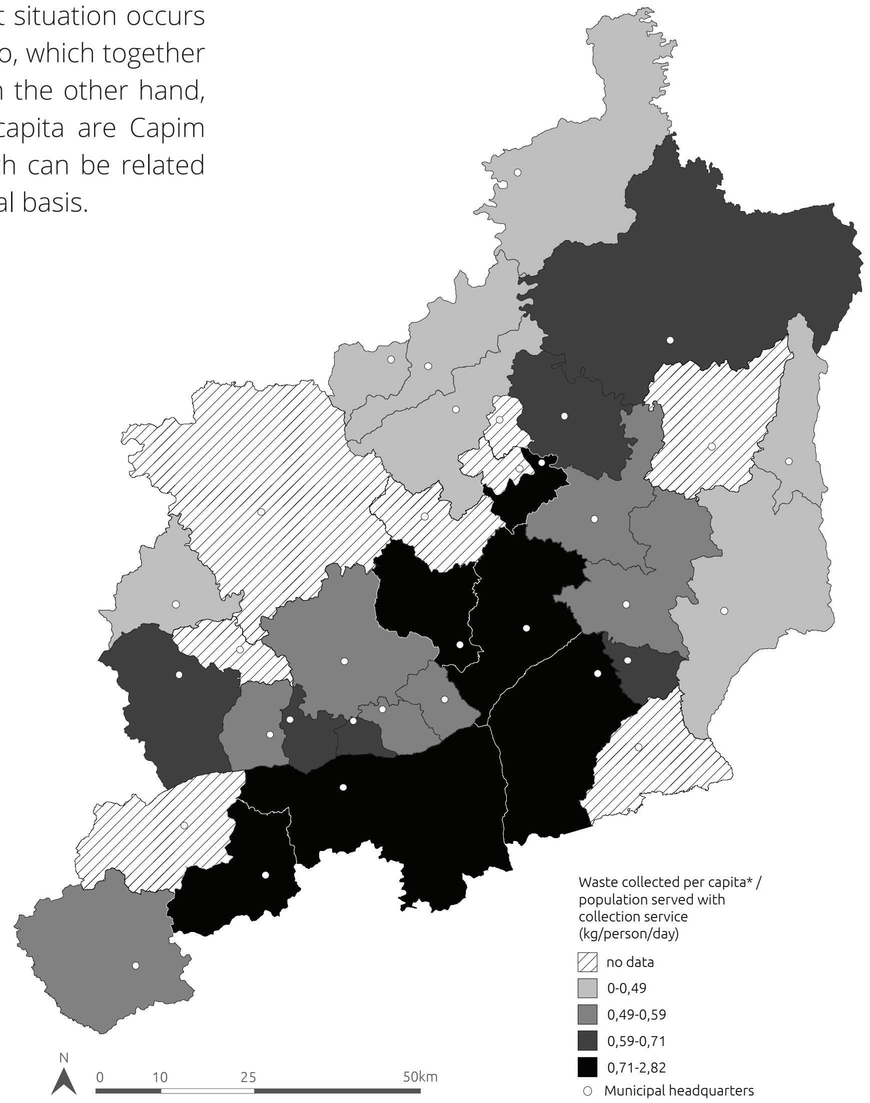
City	Lowest and highest waste collection per capita	Population
Capim branco	0,13	9537
Florestal	0,16	7209
Baldim	0,23	8071
Brumadinho	1,39	37.857
Vespasiano	2,82	118.557

Waste collection per capita (highest and lowest values).

In principle, the largest population, the largest waste production. However, one interesting variable to take in consideration is the amount of waste per capita that is produced. In a developing country it is normal to have an average waste production between 0,6 and 1,3 kg/day/per capita (Bain & Company, 2012). A high waste per capita can indicate excessive consuming habits, whereas low waste per capita can indicate lack of proper waste disposal and/or lower social status. In the RMBH, the first situation occurs only in Brumadinho and Vespasiano, which together have an expressive population. On the other hand, the cities with lowest waste per capita are Capim Branco, Florestal and Baldim, which can be related with their small population and rural basis.

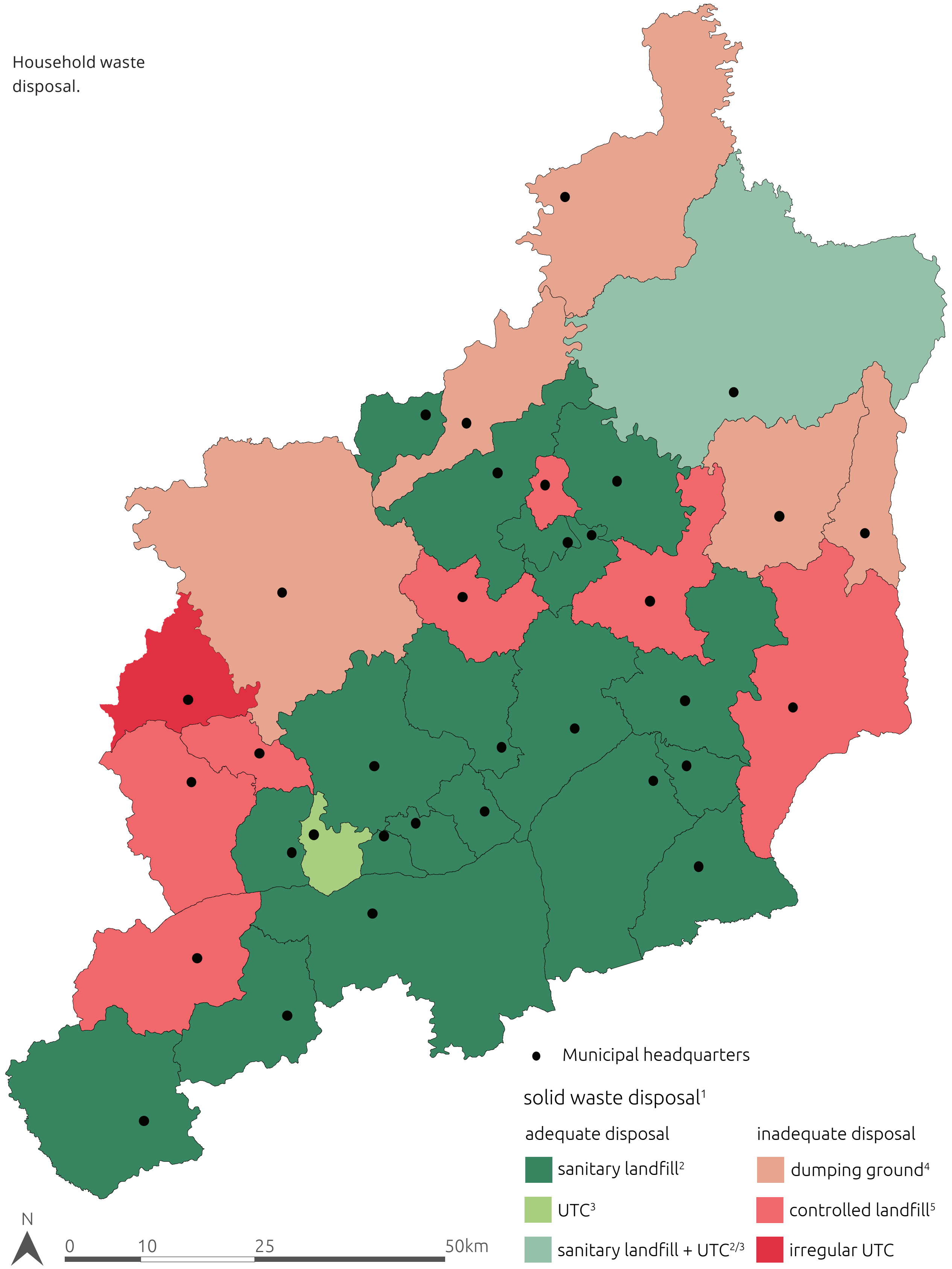
Urban waste collected per capita.

High waste per capita occurs only in Brumadinho and Vespasiano, which can indicate excessive consumption habits. On the other hand, Capim Branco, Florestal and Baldim have lowest waste per capita, which can be related with their small population and rural basis.



Notes:
Based on information from the National Sanitation Information System (SNIS), 2015.
** Domestic+Public waste*

Household waste disposal.



Notes :
[1]Map based on the document "Overview of waste disposal of urban solids in Minas Gerais State in 2015" (FEAM, 2016).
[2] Sanitary Landfill = includes environmental and technical treatment, such as waterproofing, drainage system, collection of gases and monitoring. It is considered an adequate system. (FEAM, 2016)
[3] UTC = Screening and Composting Plant (UTC). It separates the waste into potentially recyclable materials, organic matter and tailings. It is considered an adequate system. (FEAM, 2015)
[4] Dumping ground = does not have any environmental or technical treatment. It is not an adequate system (FEAM, 2016).
[5] Controlled Landfill = includes only minimal environmental and technical treatment such as rainwater drainage system, location restrictions and frequent covering of the residues. It is not considered an adequate system (FEAM, 2016).

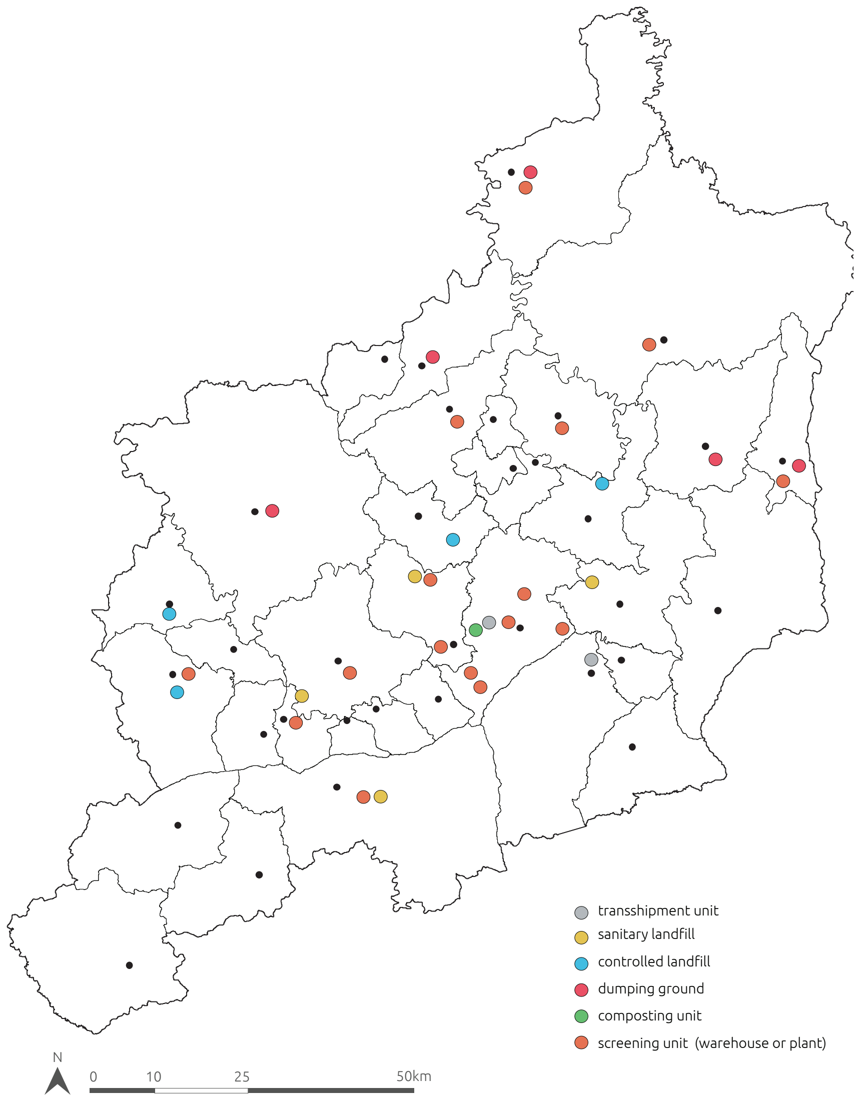
In relation to the municipal waste disposal, in the RMBH there are multiple types of solutions, including landfills, dumping grounds and recycling units. It is important to note that these categories are based on the Environmental Foundation of the State (FEAM)'s definitions. These definitions include the types of waste disposal facilities that are considered adequate (sanitary landfill, composting and sorting units) or inadequate (dumping ground and controlled landfill), based on health and environmental parameters (Environmental Foundation of the State (FEAM), 2016). It is possible to note that several municipalities still rely on inadequate disposal facilities.

Several municipalities in RMBH still rely on inadequate disposal facilities.

Waste disposal facilities.

FUTURE PLANS

Regarding planning actions, in 2011, the PDDI presented clusters of municipalities that shared interests and funds for waste management actions. It also highlighted the intention to build a new sanitary landfill in Esmeraldas, which would also receive Belo Horizonte's waste, reducing the pressure of Macaúbas Landfill. Apart from that, another sanitary landfill is planned to be implemented in Santa Luzia, to substitute the existing controlled landfill, and Matozinhos actually built one, but it is currently abandoned. Another remark is that Minas Gerais State implemented a private-public partnership (PPP), with the intention to eradicate the existing dumping grounds and controlled landfills and assist smaller municipalities on their waste management. The private sector is responsible to build the necessary infrastructure (waste treatment facilities and transshipments units in a maximum radius of 12km from the municipality), whereas the municipalities remain in charge of the waste collection and transportation to the appropriate unit. The public sector not only assures the private sector, but also gives incentives for recycling practices and energy production in the waste treatment plants (Minas Gerais State, 2012). However, even though a consortium was hired, the partnership is currently suspended (Radar PPP, 2017).



Notes:
Based on information from the National Sanitation Information System (SINIS), 2015 and FEAM 2016.
No information available for Itaguara, Juatuba and Itatiaiuçu

routes

domestic

Routes to each waste disposal facility and existing vehicles for waste collection.

1 generic domestic waste collection

2 transport

3 transship-ment unit (when exis-tent)

4 final disposal (controlled or sanitary landfill / dumping ground)

1 - Picture: TV Globo.
2-Picture: Divulgação.
3- Picture: Municipality of Belo Horizonte.
4- Picture: Municipal Director Plan Revision Team.

CVTA Betim and Macaúbas Landfill are the main facilities in the region, which also implies in long distances between waste production and disposal.

Regardless of the type of waste disposal, most of the municipalities require long distances to dispose their waste. That occurs due to two reasons. The first is the necessity of large areas away from the urban core. The second is that most of the municipalities that use adequate waste disposal facilities are not self-sufficient. Therefore, they rely on large facilities that can be more than 50km away. Regarding recyclables routes, this scenario is somewhat better. However, given the lack of recyclables collection, when upscaled, similar issues might occur as well.

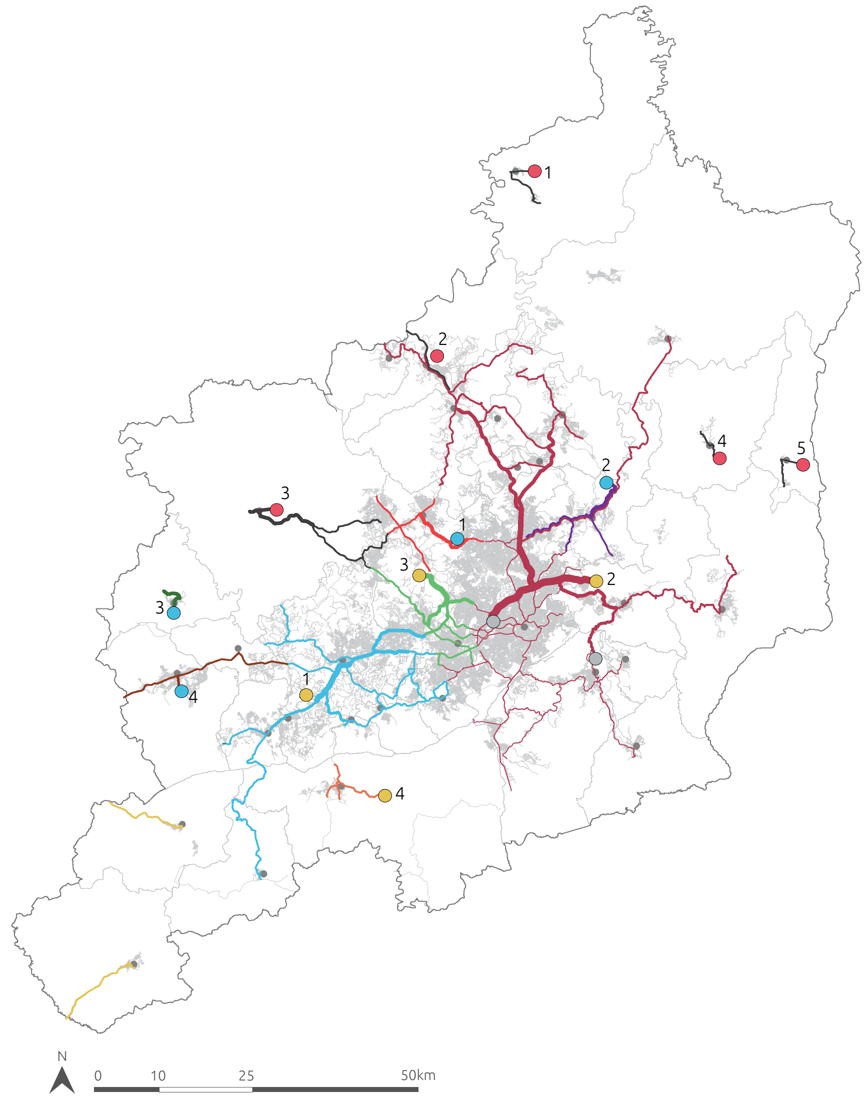
sanitary landfill
1-CVTA Betim
2-Macaúbas Landfill (CTRS)
3-Perobas Landfill
4-Brumadinho Landfill

controlled landfill
1-Ribeirão das Neves Landfill
2-Santa Luzia Landfill
3-Florestal Landfill
4-Mateus Leme Landfill

dumping ground
to dumping ground
1-Baldim
2-Matozinhos
3-Esmeraldas
4-Taquaraçu de Minas
5-Nova União

transshipment unit

to other municipality



sanitary landfill
1-CVTA Betim - 143.418ton/year .... 74 vehicles
2-Macaúbas Landfill (CTRS) - 1.041.412ton/year .... 278 vehicles
3-Perobas Landfill - 288.367ton/year .... 72 vehicles
4-Brumadinho Landfill - 19.156ton/year .... 6 vehicles

controlled landfill
1-Ribeirão das Neves Landfill - 82.439ton/year .... 30 vehicles
2-Santa Luzia Landfill - 43.020ton/year .... 23 vehicles
3-Florestal Landfill - 350ton/year .... 1 vehicle
4-Mateus Leme Landfill - 6.200ton/year .... 11 vehicles

dumping ground
1-Baldim -582ton/year .... 2 vehicles
2-Matozinhos -3.800ton/year .... 3 vehicles
3-Esmeraldas - 17.172ton/year .... 30 vehicles
4-Taquaraçu de Minas - 1.030ton/year .... 1 vehicle
5-Nova União - 822 ton/year .... 1 vehicle

routes

recyclables

1 - Picture: Carlos Henrique.
2-Picture: Pedro A. de Oliveira.
3- Picture: Adriano Alves.
4- Source: B2Blue.
5- Picture: SLU/CEMP.
6- Picture: Divulgação [Brasil Pet]
7-Picture: Deivid Correia
8- Picture: Divulgação [Casa do Vidro]

Recyclable waste routes.
Even the portion of recyclable waste that is not suitable for recovery has to be taken to sanitary landfills.

1

recyclables collection

2

transport

3

sorting units

4

sorted material ready for processing

5

disposal of non-recyclable waste: sanitary landfill

6

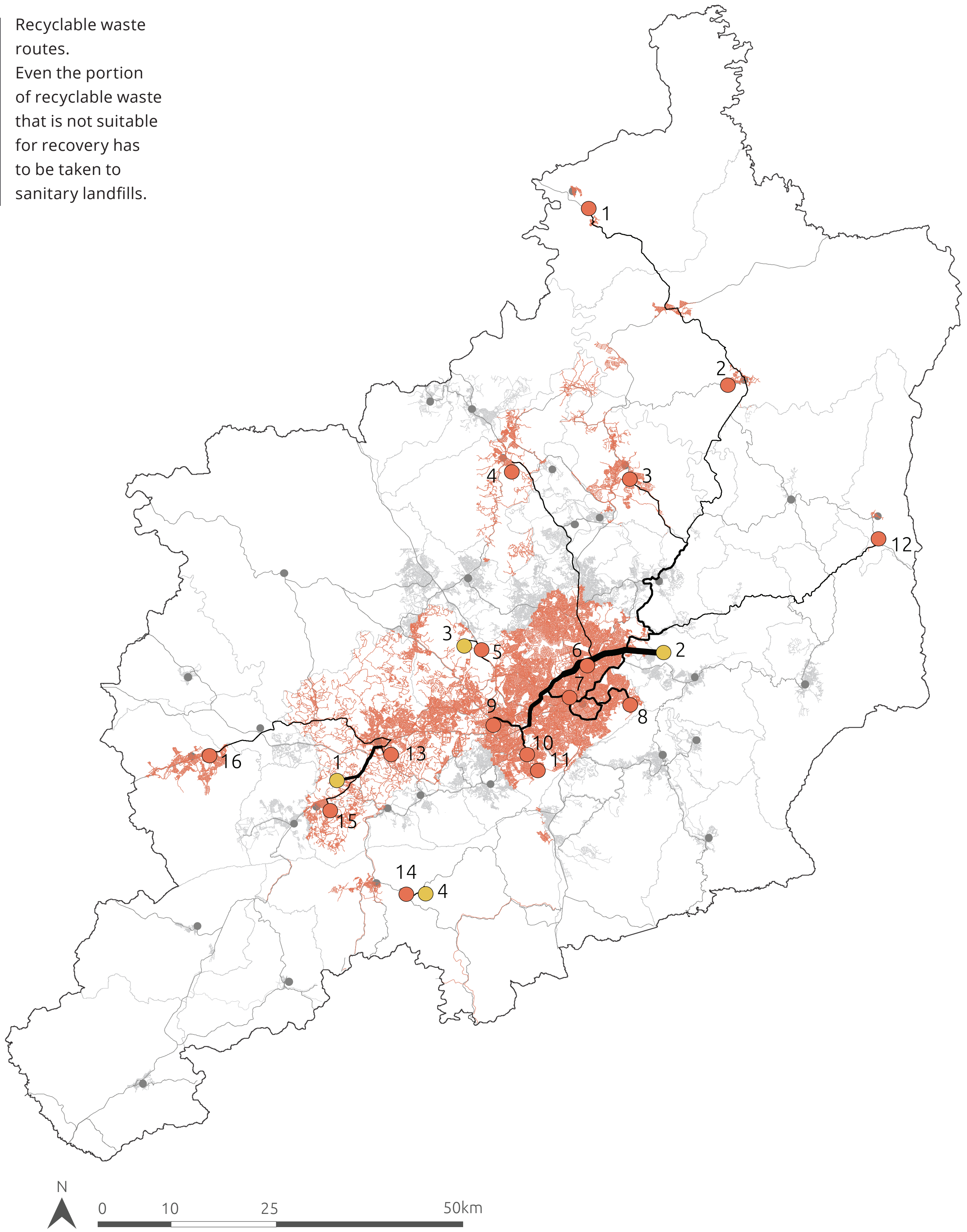
recycled material in form of new product

7

commer-cialization of recycled products

8

new uses for recycled products



Notes:
There is insufficient data to highlight the areas within a city that have selective collection. Therefore, this map represents the municipalities as a whole that provide this service.

sorting unit

1-Baldim Sorting Unit
2-Jaboticatubas Sorting Unit
3-Lagoa Santa Sorting Unit
4-ASCAPEL
5-ASMAC Perobas

recyclables' collection to sorting unit

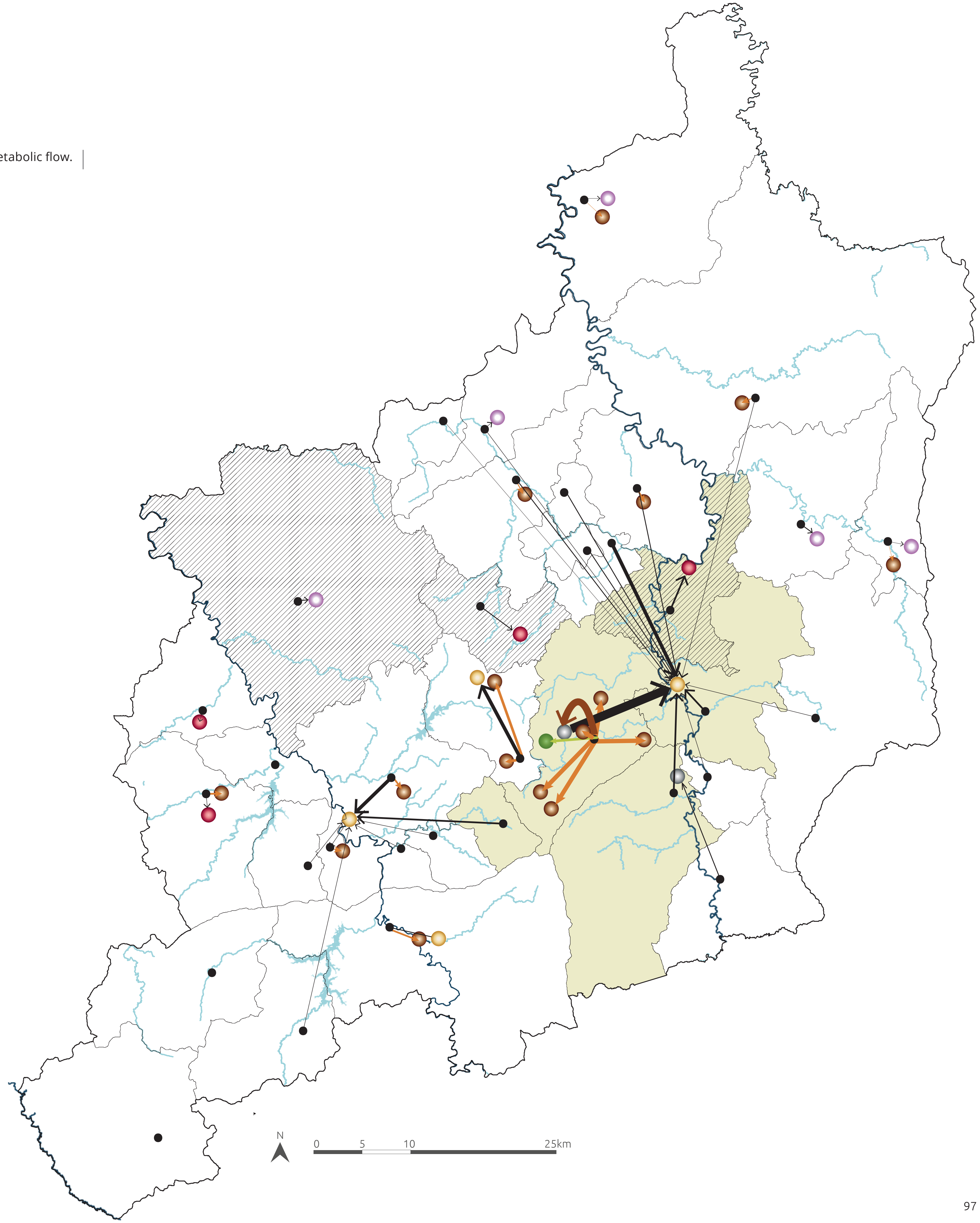
9-ASMAC Riacho
10-COOPEMAR
11-COOPERSOL
12-ASCAP
13-ASCAPEL HQ

sanitary landfill

1-CVTA Betim
2-Macaúbas Landfill (CTRS)
3-Perobas Landfill
4-Brumadinho Landfill

non-recyclable waste to sanitary landfill

Solid waste metabolic flow.



Solid Waste

- sanitary landfill
- controlled landfill
- dumping ground
- composting unit
- transhipment unit
- sorting unit
- urban waste disposal
- organic waste disposal
- recyclable waste disposal
- to transhipment unit

population >50.000:

- without adequate waste diposal
- with lowest recyclable collection (<20%)

- municipal headquarters

SOLID WASTE METABOLISM

When combining solid waste facilities with the largest population without adequate waste disposal and lowest recyclables collection, it is possible to understand the urban waste flow of RMBH. This map illustrates the many inter-municipal relations regarding urban solid waste disposal, as well as the local flows of recyclables and the concentration of facilities in the main cities of the region. It is possible to note that two main landfills are responsible for treating most of the metropolitan waste: Sabará and Betim, which mark them as regional nodal points, especially considering the transportation requirements for this activity. In addition, the capital concentrates the flows regarding recyclable waste.

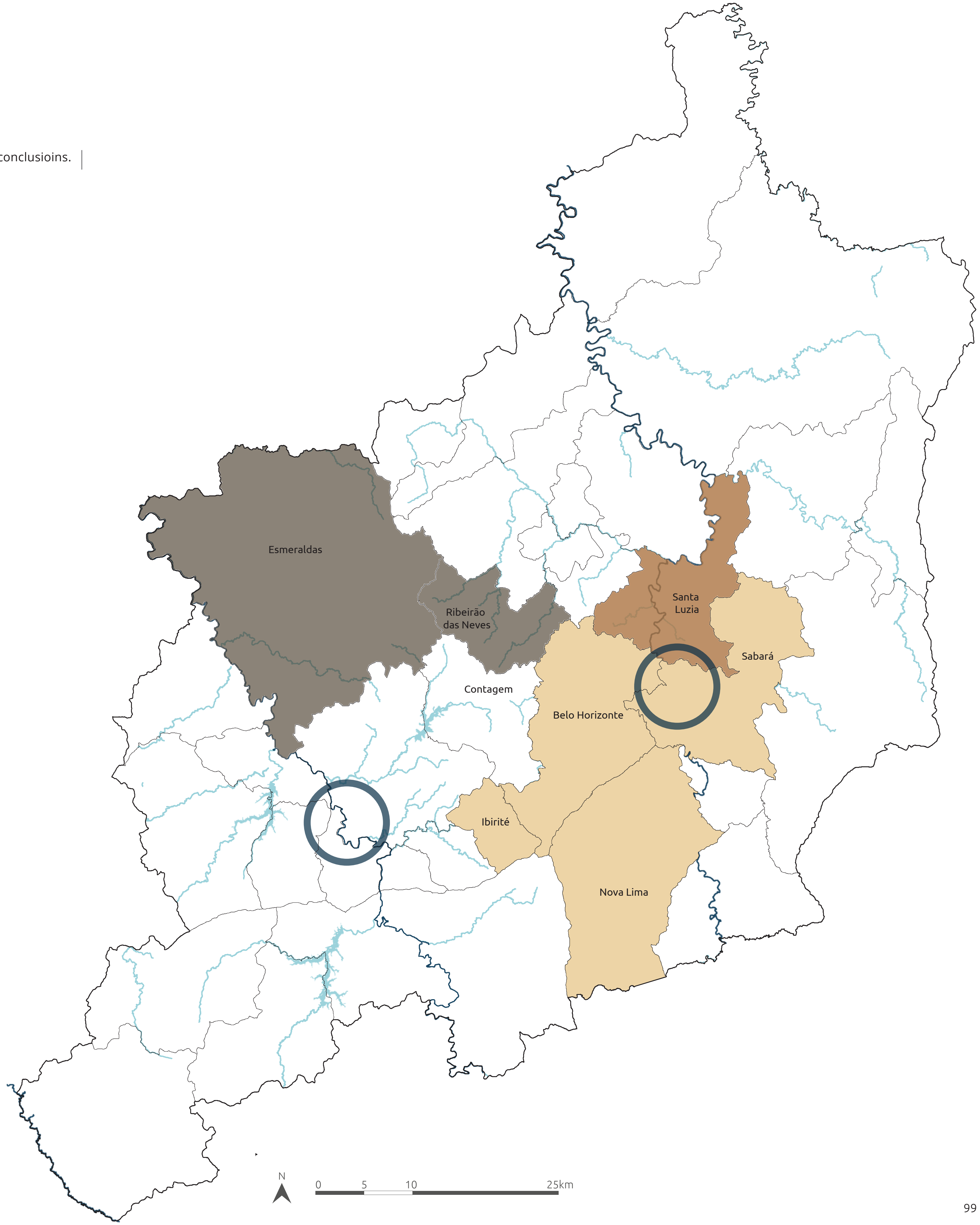
critical area B.1 - Esmeraldas, Ribeirão das Neves
(population x inadequate waste disposal facility)

critical areas B.2 - Belo Horizonte, Ibirité, Nova Lima, Sabará
(population x recycling deficiency)

critical areas B.3 - Santa Luzia
(waste disposal and recycling deficiency)

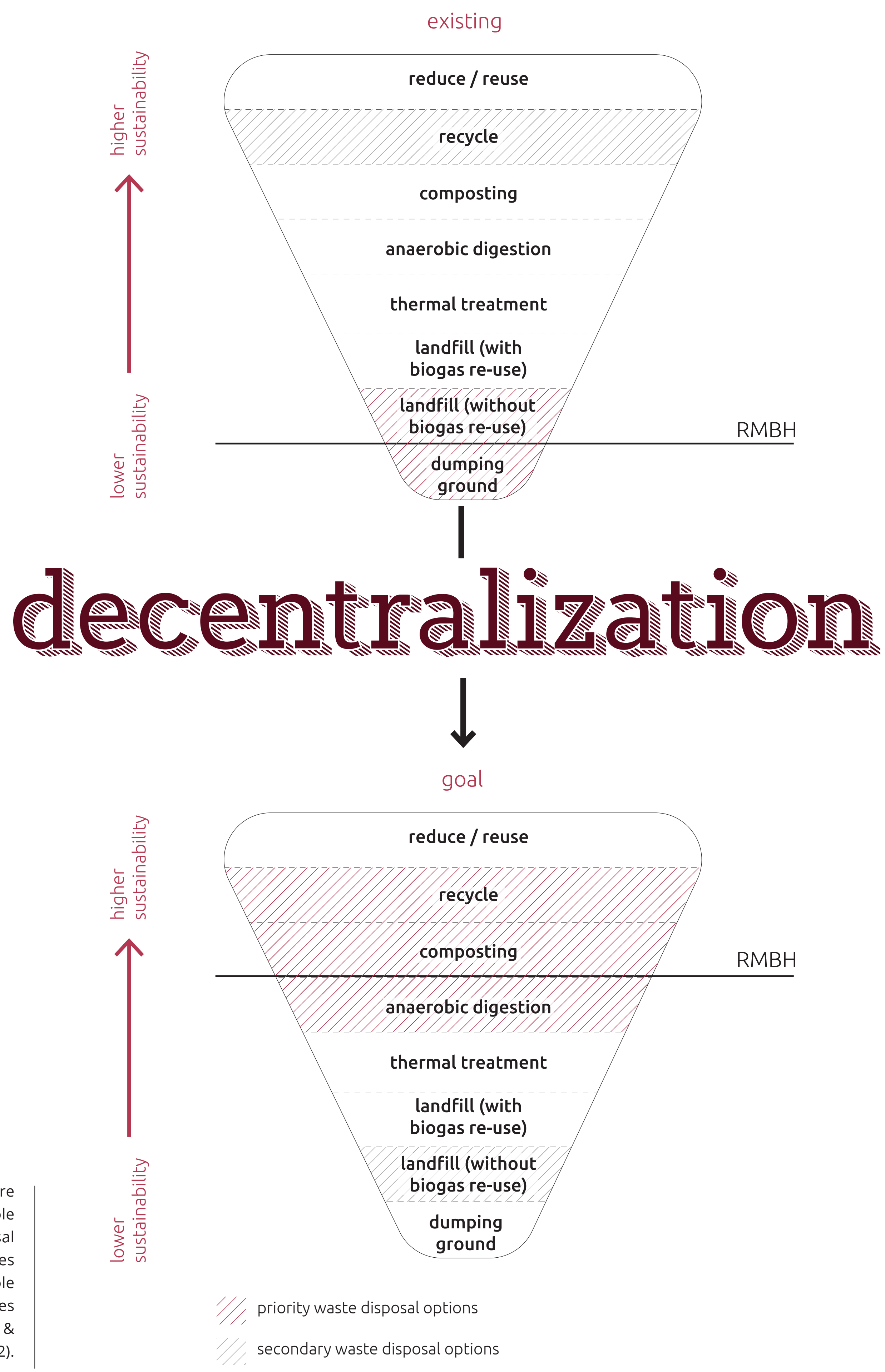
concentration of waste disposal facilities

Solid waste conclusioins.



SOLID WASTE METABOLIC CONCLUSIONS

From the metabolic analysis, it is possible to outline three critical areas: B.1, B.2 and B.3. Critical Area B.1 reflects the main areas without proper waste disposal. They are located in an east-west line north of the capital and represent cities with high solid waste deficiency, given their large populations. Critical Area B.2, on the other hand, represents those areas specifically with high recycling deficit. In other words, cities responsible for large waste generation (especially given their population size), but with low recyclables collection. They concentrate mainly in the mid-south portion of the region. Lastly, critical Area B.3 reflects the overlap of both Critical areas B.1 and B.2, pointing to Santa Luzia as the most critical city in the RMBH, in relation to waste.



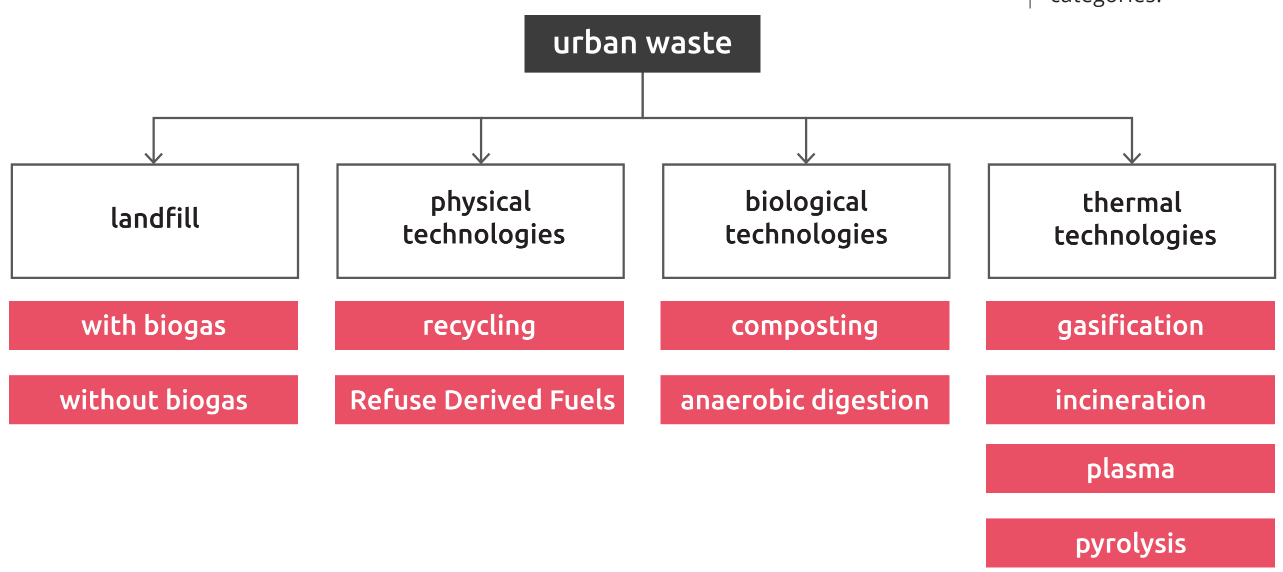
Shift to more sustainable waste disposal practices sustainable categories based on (Bain & Company, 2012).

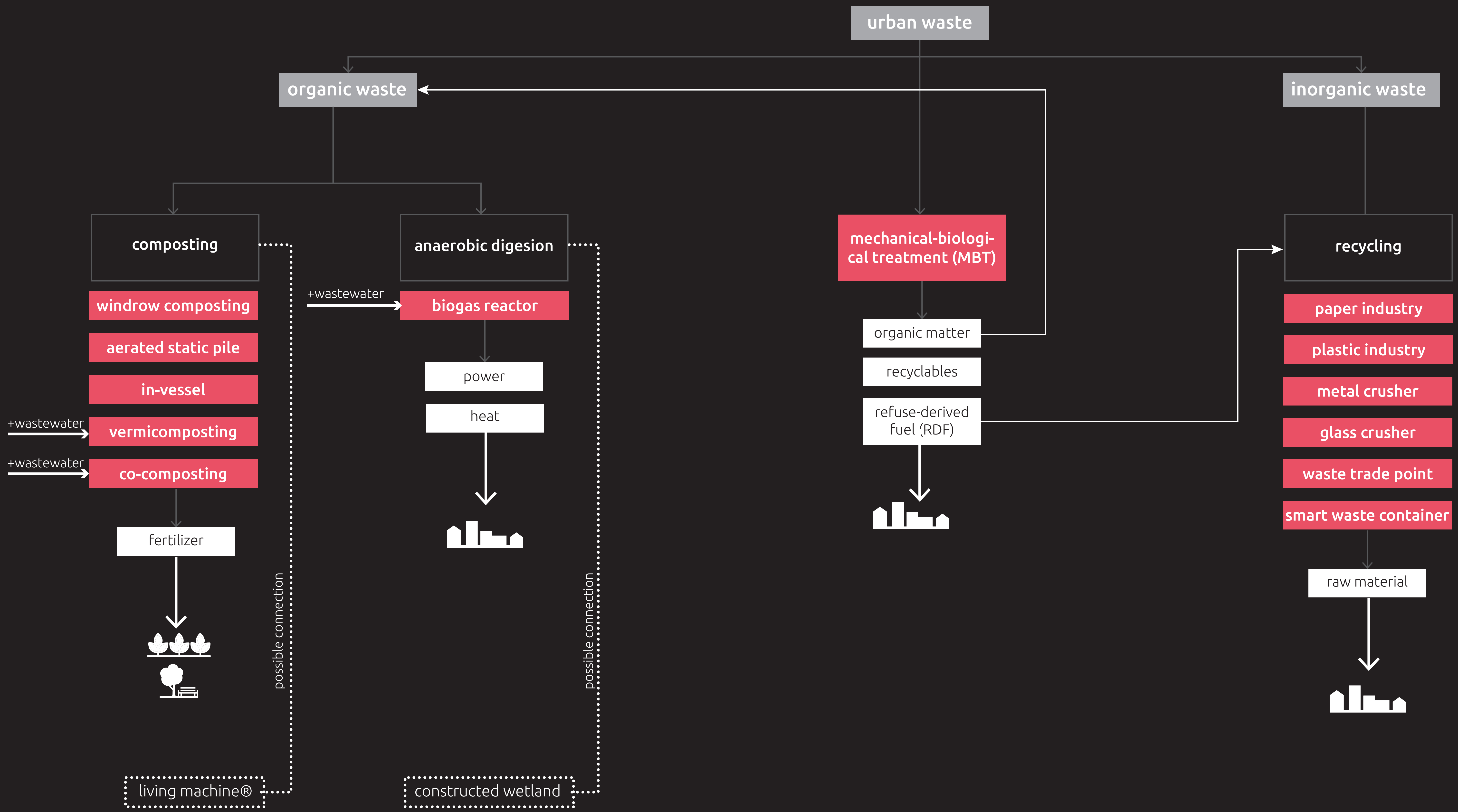
There are many technologies for waste disposal. In 2012, an Economic-Financial Study for Final Disposal of Urban Solid Waste in the RMBH was conducted in order to analyze existing waste disposal technologies and their financial requirements for implementation (Bain & Company, 2012). This study explains and compares the main existent waste disposal technologies, also taking in account international practices. This study is the primary source of this thesis and assisted the development of possible waste solutions in the RMBH. The main existing technologies regarding waste treatment/disposal can be divided into landfill, physical technologies, biological technologies and thermal technologies (Bain & Company, 2012). However, these technologies can also be categorized from a sustainability perspective, according to international standards.

Even though Bain & Company's study provides an overview of several technologies, from an economic-financial perspective, it concluded that the sanitary landfill with biogas recovery is the best viable option for the RMBH (Bain & Company, 2012). This result goes in line with the National Solid Waste Policy, the PDDI and the PMGIRS-BH, noting that those policies also put forward parallel actions, such as the increase of recyclables collection (including empowerment of local agents, such as waste pickers) and reuse of its raw materials. The PDDI, in particular, reinforces the sanitary landfill as best waste disposal choice in relation to incineration plants, with the argument that the latter are costly facilities and do not adjust to fluctuations of waste volumes (since there is an intention of upscaling recycling actions, there would be less amount of waste to be incinerated) (UFMG, 2011). However, it is also important to note that landfills have an average lifespan of 30 years, as well as large environmental impacts. Moreover, even with the upscale of recycling actions, the sanitary landfill does not allow the reuse of the significant portion of organic household waste. Therefore, it is important to investigate possible solutions that could enhance the environmental performance of the region and assure the circular national goals for waste disposal. In that sense, decentralization presents itself as a desired path, since it allows smaller scale and more sustainable approaches that can reduce costs and have potential to interconnect the metropolitan region. The goal of this thesis, thus, relies on shifting from the predominant landfill treatment towards more sustainable practices involving recycling, composting and anaerobic digestion.

The proposed goal is to rely less on landfills (especially the inadequate ones) and prioritize alternative options such as recycling and composting.

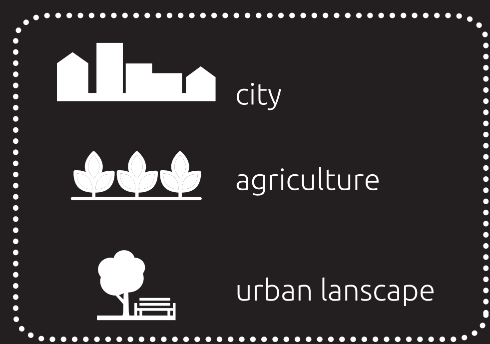
Waste disposal categories.



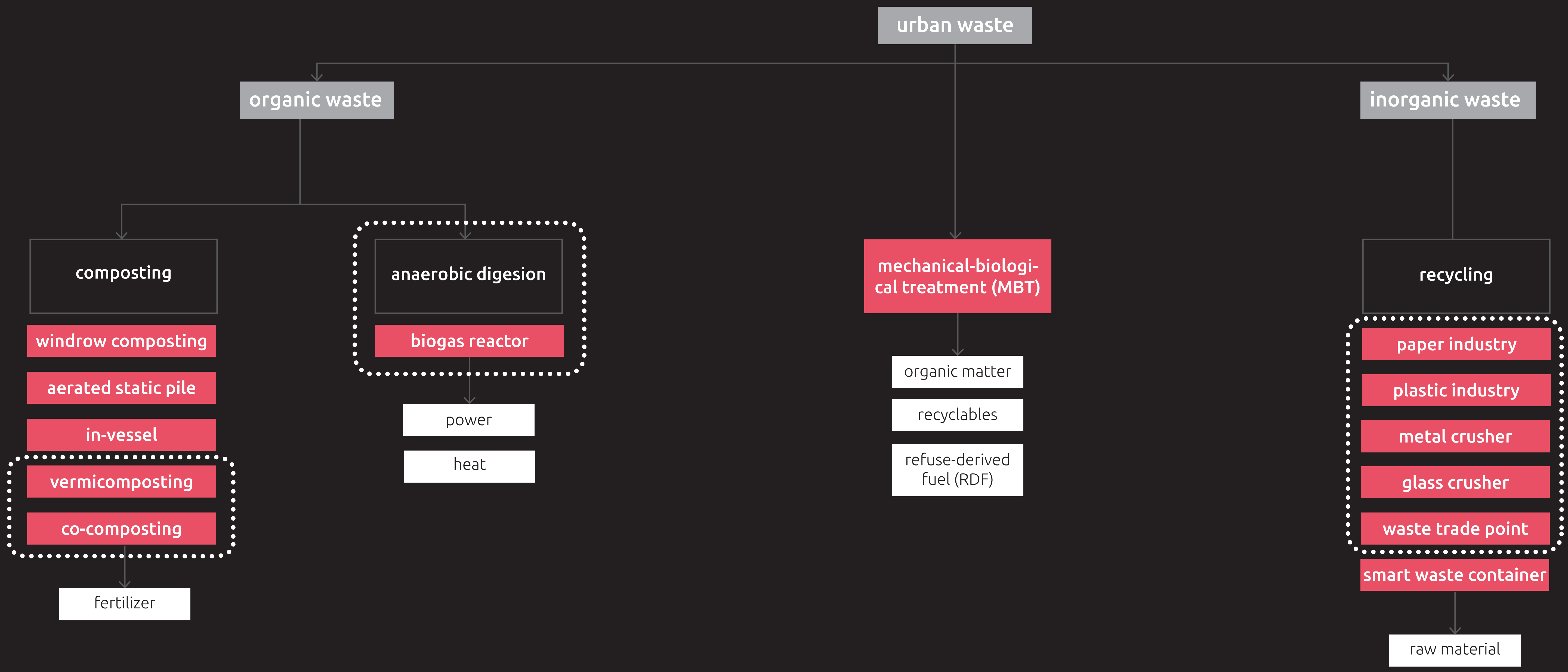


Solid waste treatment: decentralized solutions overview. Solutions are mostly divided in organic waste and recyclables, given their different treatment nature. Some by-products are produced and have potential to be reused. Some solutions also can be associated with wastewater solutions presented previously.

Following the same logic and criteria used in the Wastewater Flow, this scheme presents a selection of decentralized solutions and the possible re-use of their by-products, followed by a matrix that relates each solution with the used criteria. Lastly, there is an overview of those solutions that are most interesting to be implemented in an urban strategy. The detailed description of each solution can be found in the Catalog of Solutions Volume.



Waste disposal:
solutions matrix.
each solution is
evaluated considering
5 criteria that relate to
urban quality.

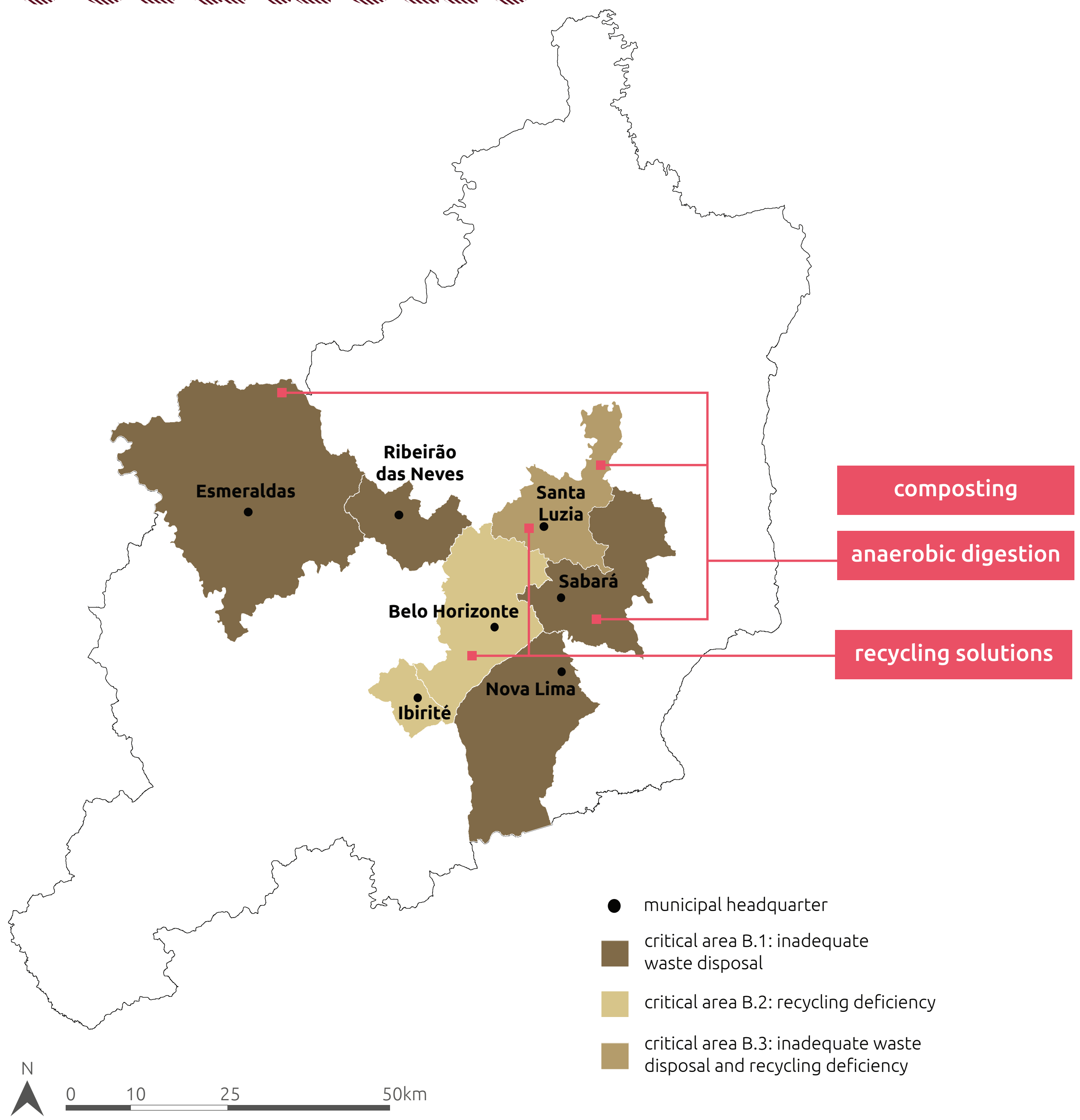


Waste disposal: solutions highlights considering matrix. Election of those solutions that are most suitable for urban strategies.

Following the same logic and criteria used in the Wastewater Flow, this scheme presents a selection of decentralized solutions and the possible re-use of their by-products, followed by a matrix that relates each solution with the used criteria. Lastly, there is an overview of those solutions that are most interesting to be implemented in an urban strategy. The detailed description of each solution can be found in the Catalog of Solutions Volume.

Critical areas x chosen waste treatment solutions.

areas x solutions



It is important to highlight that there is a need for inorganic waste processing in order to re-use its material. Therefore, all the solutions for inorganic waste processing were selected. On the other hand, in relation to organic waste, the choice for the co-composting technique in relation of other techniques relies on the possible connection with wastewater treatment. The vermicomposting solution was chosen for being a more flexible technique, which is also becoming popular on the household level. In that sense, when implemented in larger scales, this solution also has the potential to contribute on the improvement of the relation between society and waste. The MBT solution was not chosen, given the fact that its minimum capacity for economic feasibility would require a large plant, not to mention its high costs for implementation (see Catalog of Solutions Volume for a detailed description of this solution). Lastly, the anaerobic digestion was elected given its close relation with wastewater and high value by-product (biogas).

Considering the conclusions derived from the metabolic analysis, RMBH possesses two types of situations that require different solid waste solutions: Critical Area A, where the existing waste disposal facilities are inadequate from a sanitary perspective; and Critical Area B, where there is an expressive deficiency regarding recycling actions, in relation to its population. Critical Area C was also introduced in Santa Luzia, since it has both problems. Using the matrix of solutions, the most suitable solutions are separation of organic and inorganic wastes, allowing small scale recycling solutions to be implemented and use composting or anaerobic digestion for treating the organic matter. The treatment of organic matter is particularly important, considering the by-products that are possible to extract from these treatments. In the next section, it will be presented the translation of the demands and elected solutions for both flows into a urban strategy.

4 | design horizon

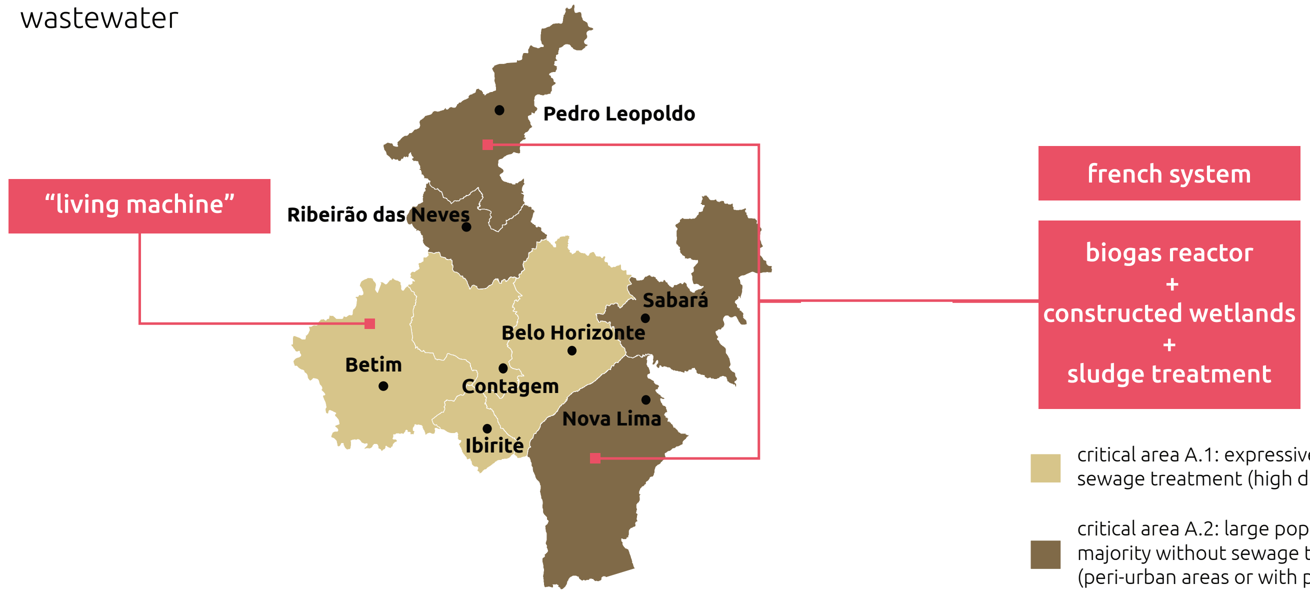
from waste to asset

4.1 introduction

This chapter is dedicated to design studies in relation to the information revealed by the metabolic analysis. These studies include the definition of a combined strategy to address the demands of both flows and the creation of 4 systems: Urban Machine; Recycling Hub; French System and Landscape Machine. Each system is presented separately, with its associated principles and design considerations. This overview is followed by a comparison between systems in terms of functions, by-products and areas. Lastly, it is presented two test cases, to investigate the spatial implications of these systems. The first one is Belo Horizonte, the capital of the state, focusing on the implementation of the Urban Machine. The second one is Ribeirão das Neves, one of the most urgent areas of the region, illustrating how the Landscape Machine and Recycling Hub could be implemented.

Combined critical areas.

wastewater



critical area A.1: expressive minority withouth sewage treatment (high density urban core)

critical area A.2: large population with majority without sewage treatment (peri-urban areas or with possible expansion)

solid waste

critical area B.1: inadequate waste disposal

critical area B.2: recycling deficiency

critical area B.3: inadequate waste disposal and recycling deficiency

wastewater + solid waste

cluster 1: expressive minority withouth sewage treatment + recycling deficiency

cluster 2: expressive minority without sewage treatment

cluster 3: large population with majority without sewage treatment

cluster 4: large population with majority without sewage treatment + recycling deficiency

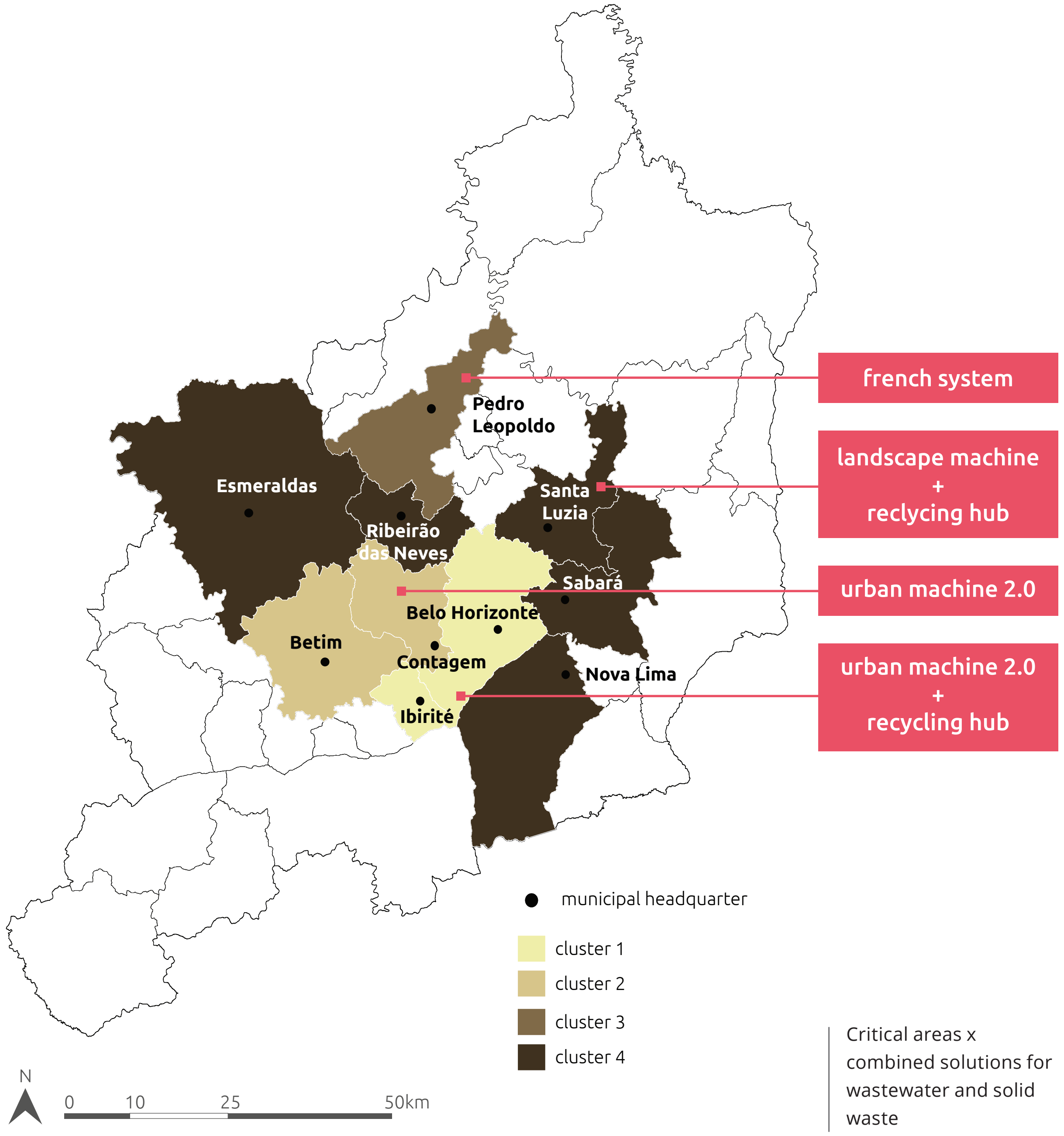
4.2 wastewater + solid waste

The previous chapter provided a detailed analysis of both Wastewater and Solid Waste flows in the RMBH, also pointing decentralization as a desired scenario and illustrating the most suitable solutions for each area. It is possible to combine the existing critical areas from both flows, creating 4 clusters that reflect the different scenarios. Clusters 1 and 2 refer to the highly dense areas, where the majority of population has access to the infrastructure, but an expressive minority still lacks sewage treatment. The difference between them is that Cluster 1 has an additional recycling deficiency. In other words, it has a large population associated with a low recycling rate. In contrast, Clusters 3 and 4 have the majority of people without proper sewage treatment infrastructure. However, Cluster 4, the same as Cluster 1, also has recycling deficiency.

WASTEWATER AND SOLID WASTE STRATEGY

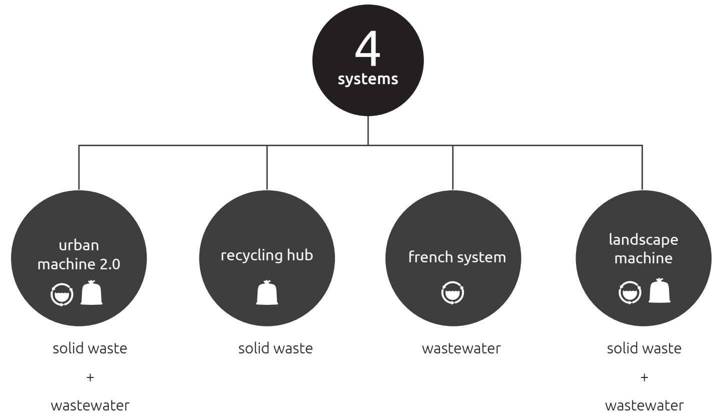
previously, this thesis puts forward integrated solutions, resulting into systems. These systems incorporate a technical solution, associated with its potential interconnections between flows, and explore the added value they can bring to the urban fabric. For Clusters 1 and 2, it is proposed the Urban Machine 2.0. This solution is an upgrade of the “living machine”, using the same concept for the wastewater treatment, but integrating social functions. For Clusters 3 it is proposed the French System and for Cluster 4, the Landscape Machine , which is a combination of biogas reactor + constructed wetland + co-composting. Lastly, in order to address to the recycling deficiency of Clusters 1 and 4, it is proposed the Recycling Hub.

The proposed integrated solutions (systems) incorporate technical aspects and potential interconnections between flows.



Critical areas x combined solutions for wastewater and solid waste

Overview of the 4 elected systems and their related flows and the principles, matrix categories, function and by-products used for detailing the proposed systems



principles

- A area
- Lu land-use
- T topography
- Sr system requirement
- So system output

matrix categories

- area requirement
- integration with public space
- economic value of the by-products
- allows connections between flows

SYSTEMS

In this section, each integrated system will be detailed one by one. The systems Urban Machine 2.0 and Landscape Machine combine strategies to address both wastewater and solid waste treatment, whereas the Recycling Hub focuses only on solid waste and the French System only on wastewater. For each system, there is a brief introduction of its components, together with references of existing elements or similar systems. The introduction is followed by a systemic section that explains the relations between components, flows, associated functions and by-products. Then, there is a set of principles for implementation of the system, divided by categories (area, topography, land-use, system requirement and system output) and their relation with the criteria defined in the matrices, presented previously. Lastly, an impression of the spatial implication of each system is presented, taking in consideration the individual particularities of them.

functions

- agriculture
- livestock
- leisure/recreational
- urban farming
- waste pickers association
- educational
- community center
- industrial sector (machinery)
- recycling industry

by-products

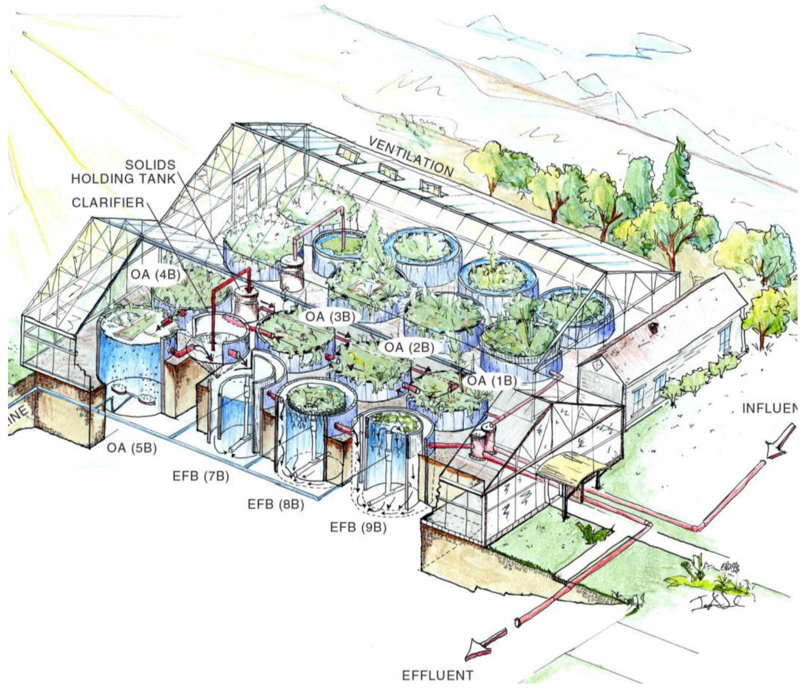
- local food production
- animal feeding
- power/heat (biogas)
- gross solids / sand
- fertilizer
- water for re-use
- raw material for re-use
- pre-sorted recyclables
- semi-processed recyclables

urban
machine 2.0

urban machine

The eco-cells are responsible for treating wastewater and give potential for educational programs. In addition, the waste trade point and community garden assure a better waste management for local residents, as well as incorporate social functions.

Impression of the Urban Machine 2.0.

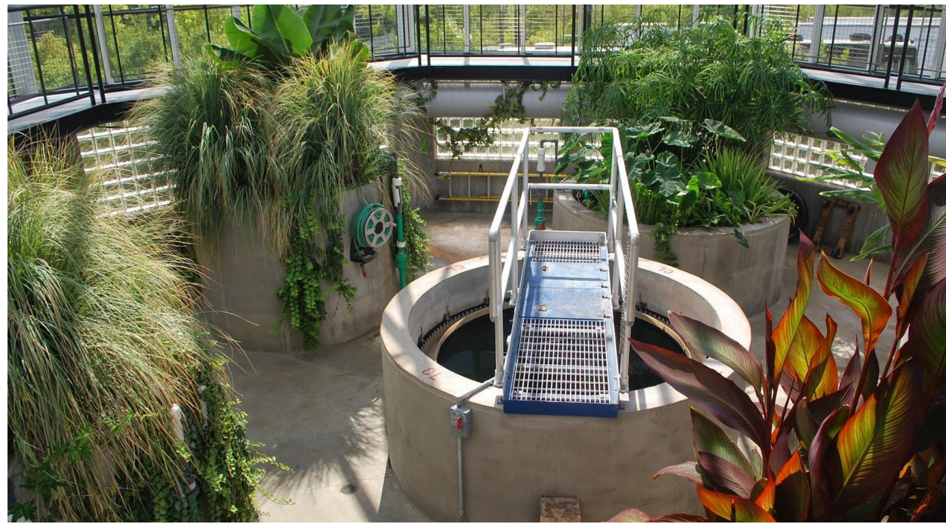


South Burlington Municipal Eco-Machine®. Source: John Todd Ecological Design. Illustration: Ian Ambler

QUICK REMINDER

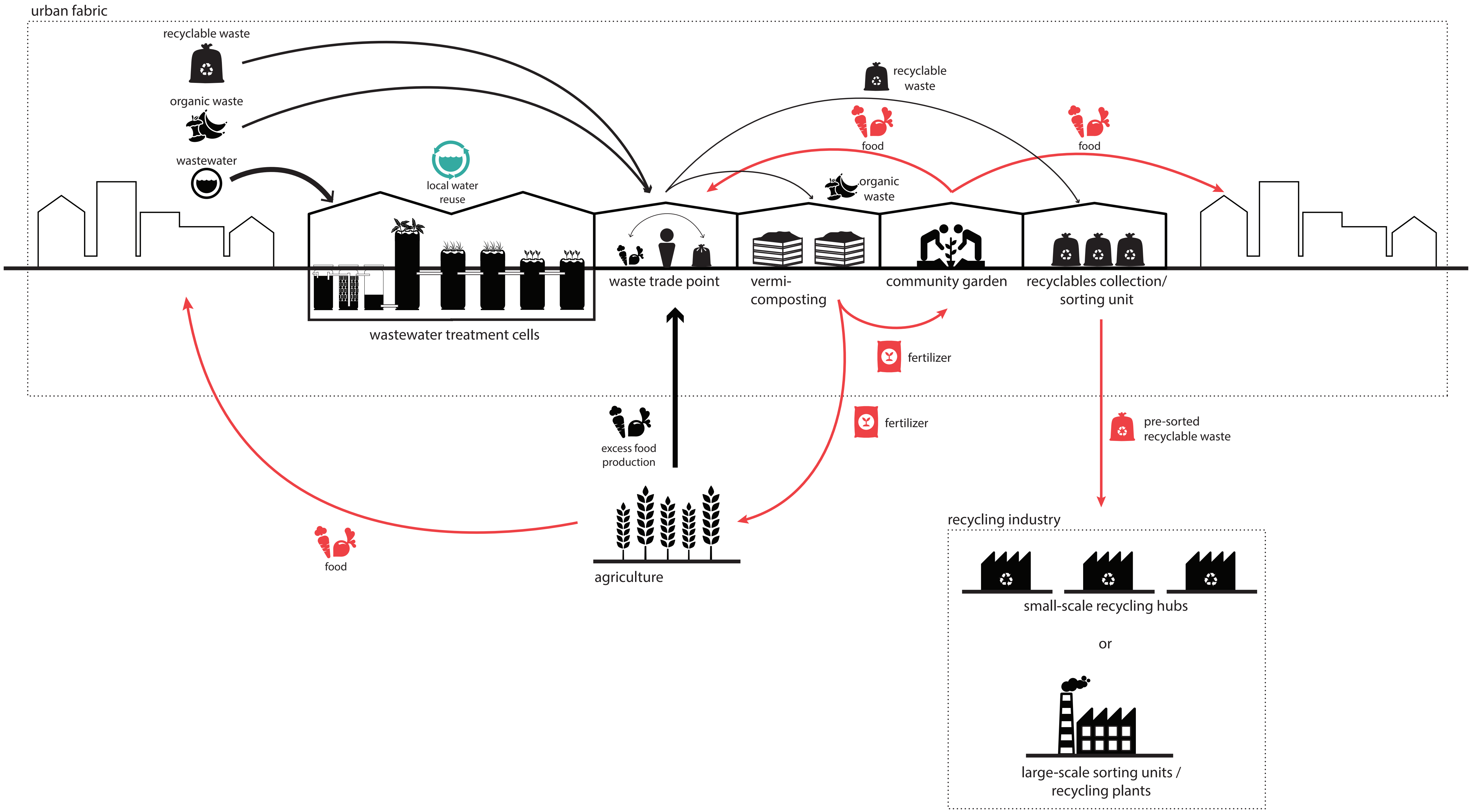
It is important to highlight that the Urban Machine 2.0 should provide for those areas where the population lack sewage treatment, which also include informal settlements. In order to reduce implementation costs, the system should preferably be placed lower than the houses so the sewage can be directed to the facility by gravity. Other alternatives for implementation include using existing unused buildings and/ or derelict areas. Lastly, this solution contributes for the universal access of this service, by reducing the pressure of the local sewage treatment company (COPASA) to provide an extensive and complex network.

The proposed Urban Machine 2.0 follows similar principles of systems such as the Living Machine® or the Eco-Machine®, which uses ecology cells for wastewater treatment. These cells should host species with economic or ornamental value, which contributes for the aesthetic appeal of the system and raises the opportunity for awareness and educational programs. These programs are important, because they also contribute to reduce the gap between society and their perception of waste. Associated with the wastewater treatment, other functions also take place, interconnecting flows. One of them is the waste trade point, where the population takes their sorted waste in exchange of fruits or vegetables. This action is particular interesting in informal areas where waste collection is difficult due to the narrow streets. The organic waste can be composted in situ (vermicomposting) and the recyclables can be transshipped to sorting units. This action also contributes for giving incentive for the population to separate their waste. Another important function in the Urban Machine is the community garden, which can partially provide the exchangeable food, but also reinforces community spirit and highlights the public space integration this system can have. The garden will vary with the land availability and should be implemented together with local dwellers and neighborhood associations. The following diagrams and impression give a detailed description of how this system works and should be implemented.



I-89 Vietnam Veterans Memorial Rest Area Eco-Machine®. Source: John Todd Ecological Design

The associated social functions complement the system creating a network of exchangeable by-products and interconnecting flows.



Systemic section of the Urban Machine 2.0.

A area

T topography

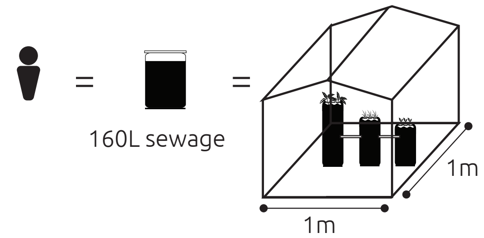
Lu land-use

Sr system requirement

So system output

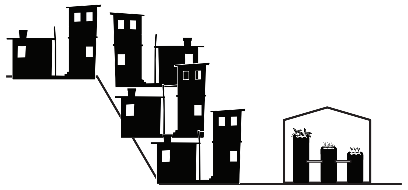
Several principles relate to the matrix criteria presented previously. They assure the system can be implemented in different locations, maintaining the desired urban qualities. For the Urban Machine, derelict areas should be prioritized as well as those lower than the urban core.

A 1m² / population equivalent



area requirement

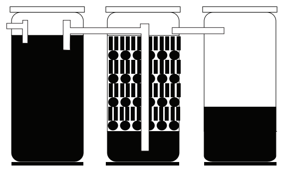
T lower than urban core when possible, but necessarily in informal settlements



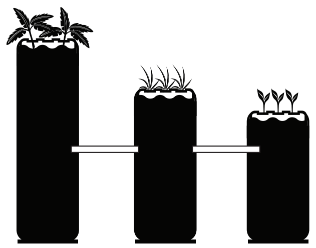
Lu greenhouse construction: preferably in derelict areas or unused buildings

integration with public space: add value

Sr septic tank for primary treatment

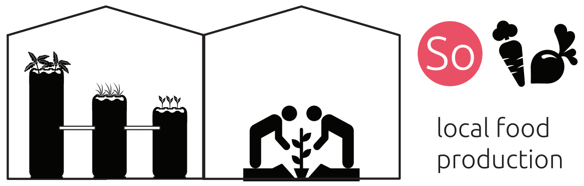


Sr use of fish and plants with economomic value



economic value of the by-products: high

Sr include community garden

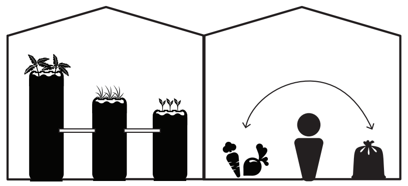


economic value of the by-products: high

integration with public space: add value

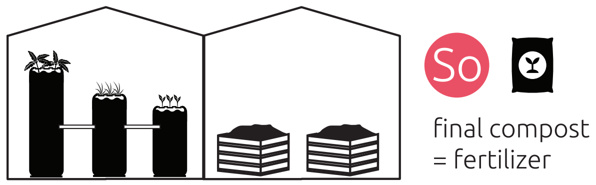
allows connections between flows: multiple

Sr include waste trade point



allows connections between flows: multiple

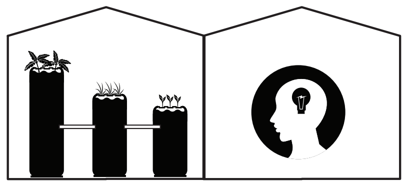
Sr organic waste = vermicomposting



economic value of the by-products: high

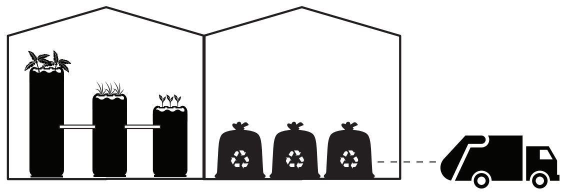
allows connections between flows: multiple

Sr promote awareness programs



integration with public space: add value

So transshipment unit / pre-sortment of recyclables



allows connections between flows: multiple

Principles for implementation of the Urban Machine 2.0.

recycling hub

recycling hub

The Recycling Hub is a small-scale recycling industry that combines early stages of recyclables processing. Given the possible noise and smell, the Hub should have safe distances from housing areas, but still be easily accessible.

Impression of the Recycling Hub.

Baling press machine.
Source: Sinobaler

Glass crusher
Source: KRS Recycling Systems GmbH

The Recycling Hub is a small-scale recycling industry that combines early stages of processing of plastic, paper, glass and metal (see Pictures 50-53 and Catalog of Solutions Volume). The goal of this system is a two-fold: increase recyclables collection / processing and raise awareness. This is possible given the smaller scale of system, which allows integration with neighborhoods. The local population will have incentive to separate and correctly dispose their waste. Moreover, the larger the amount of processed recyclable waste, the larger is the possibility of material recovery. In order to be more successful, the Recycling Hub should be placed within a 5 to 10km radius, so more neighborhoods are directly benefited from them. The Hubs should also have close relation with the municipal waste management, to complement the recyclables collection, so the system does not rely solely on the citizen commitment. It should be noted that the machinery used for processing materials can be noisy or smelly and, therefore, should have a minimum distance (50m) of housing. Same as the Urban Machine, unused buildings or derelict areas should have priority for implementation. The following diagrams give a detailed description of how this system works and should be implemented.

Metal crusher.
Picture: Russ Willcutt

Plastic shredder.
Source: KRS Recycling Systems GmbH

A area

T topography

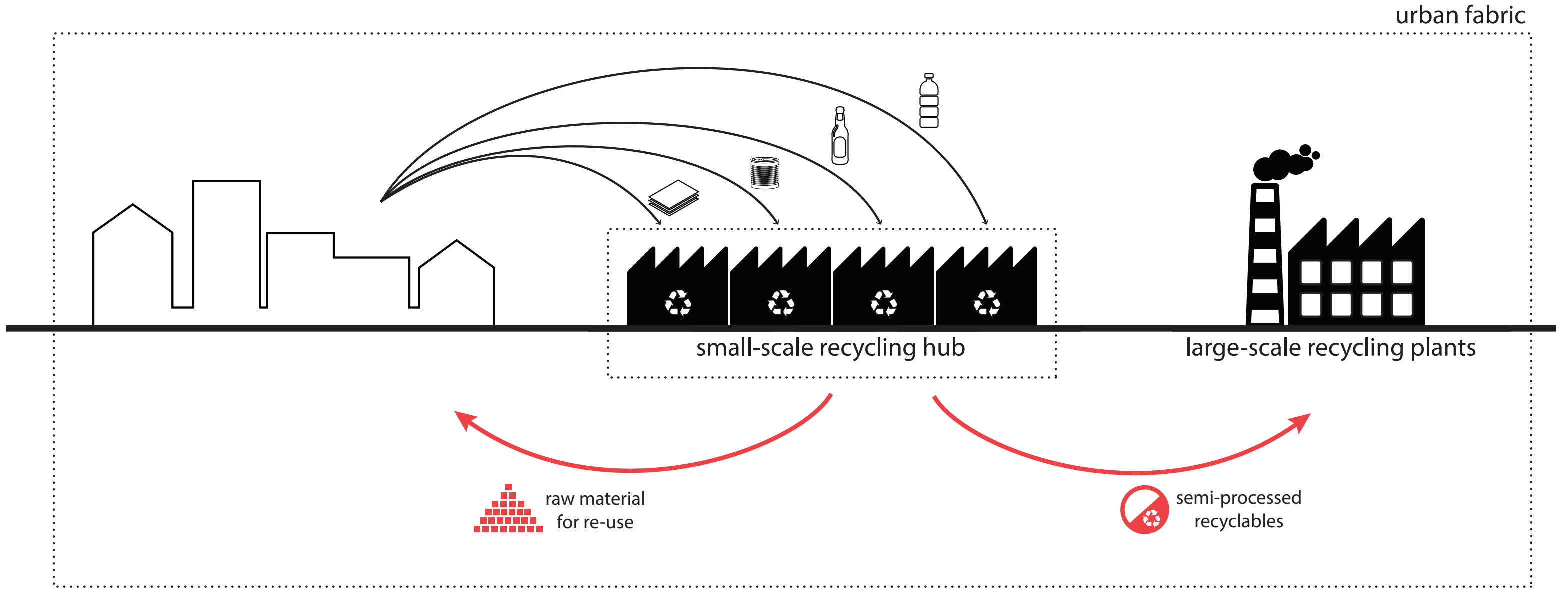
Lu land-use

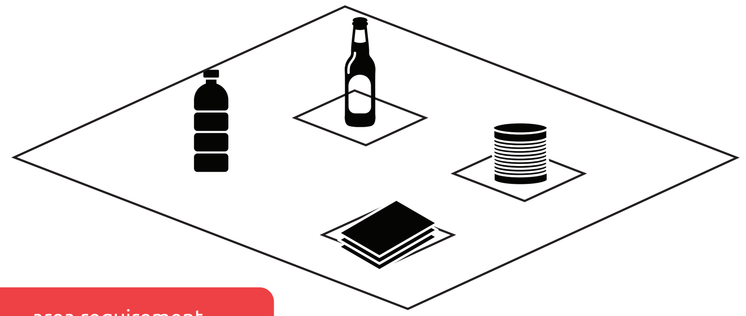
Sr system requirement

So system output

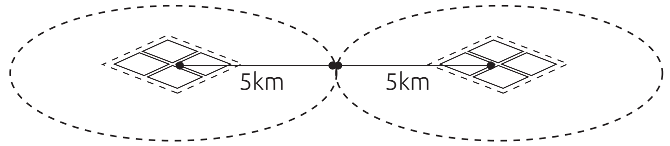
The Hub provides an intermediate step in the recycling process. Sorted waste can be taken for primary processing, which can cascade back into the city in form of raw material or continue the recycling process in large scale plants.

Systemic section of the Recycling Hub.





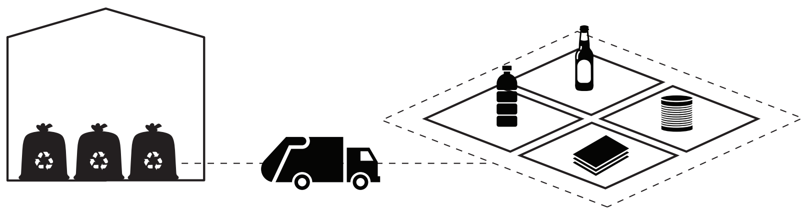
area requirement

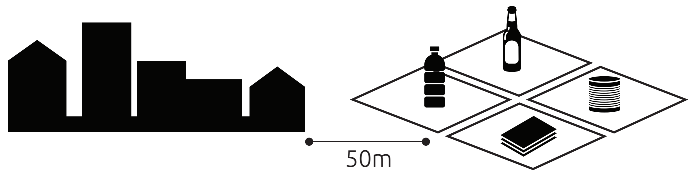


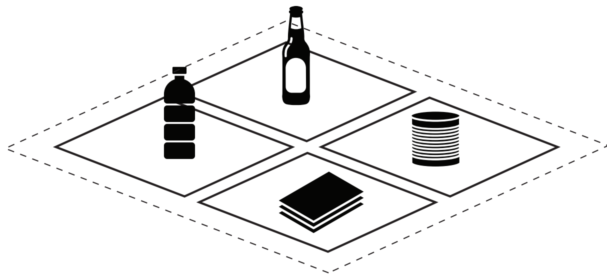
Lu preferably close to sorting and/or collection units

Lu at least 50m away from housing

Sr small scale recycling industries (plastic, paper, glass and metal) should be clustered

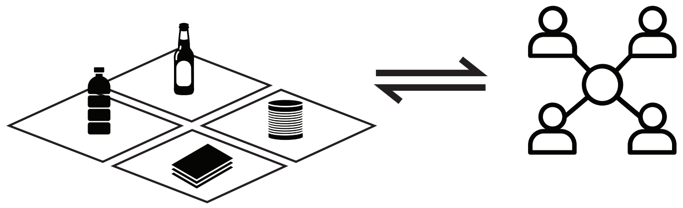






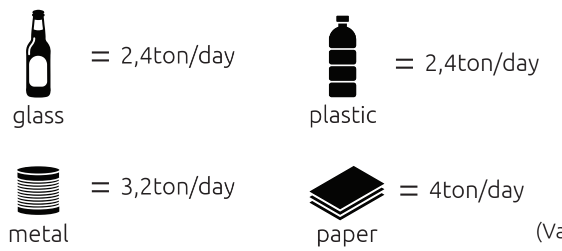
integration with public space: avoid

Sr create partnerships with waste pickers' associations



allows connections between flows: none

So processing yields



(Van Leer, 2016)

economic value of the by-products: medium

Derelict areas/buildings should be prioritized and the Hub should be implemented in a radius of 5km to give access to more neighborhoods.

Principles for implementation of the Recycling Hub.

french system

french system

The French system is a decentralized wastewater system that necessarily includes a two-step constructed wetland. The use of ornamental species guarantees a aesthetic pleasant environment.

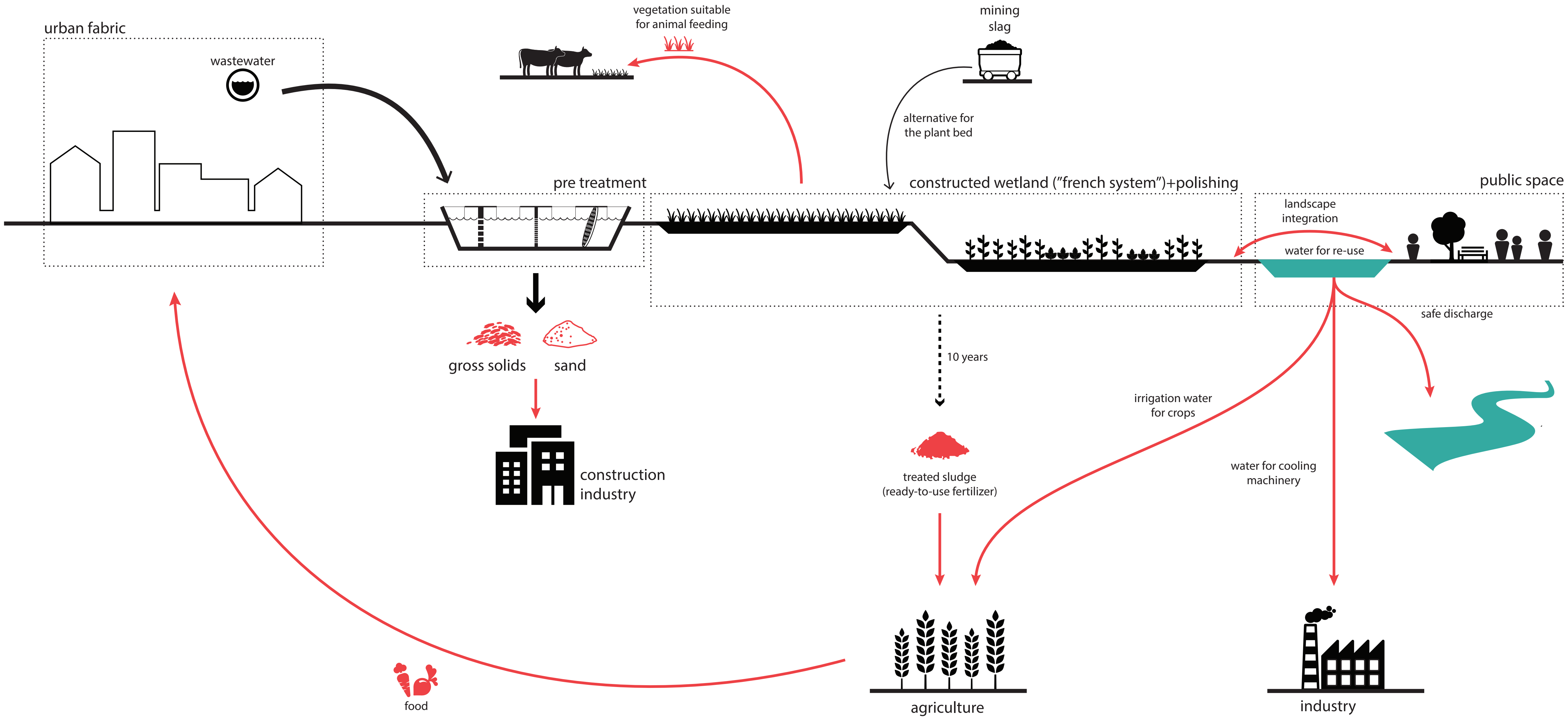
Impression of the French System.

Fist stage of the French System for wastewater treatment. Picture: SuSanA Secretariat.

The French system is a decentralized wastewater system that necessarily includes a two-step constructed wetland (CW) (see Catalog of Solutions Volume). Even though, it is possible to realize this system without the pre-treatment phase, this proposal includes it, since it reduces maintenance requirements. The highlight of this system, though, is the possibility of integration with the local landscape and public space. The pleasant aesthetics and the lack of odors or mosquitoes favor the implementation of larger parks or green areas, since the large area requirement of system difficult its execution within the urban core. In order to successfully achieve this integration, the system should not be placed in flooding or protected areas and preferably should be lower than the urban core, in a 10-20% slope, to favor gravity use. In addition, in order to increase the feasibility of the system, it should be implemented close to expansion areas that can be planned to connect straight to this system, shortening distances for wastewater treatment. It is also important to highlight that some of the by-products produced in this system have economic value. In the pre-treatment phase, gross solids and sand can be separated and used in the construction industry. Part of the constructed wetland can harvest species suitable for animal feeding (balancing with ornamental species). The sludge produced is also a ready-to-use fertilizer that does not require any further treatment. Lastly, it is possible to design the system with additional polishing phase (chlorination, ozonation, H202 or UV disinfection) so that the water can be re-used for agriculture irrigation or sold for industries (for machinery cooling). The following diagrams give a detailed description of how this system works and should be implemented.

Second stage of the French System for wastewater treatment. Picture: SuSanA Secretariat.

The highlight of this system is the possible integration with public space. and by-products with economic value.



Systemic section of the French System.

A area

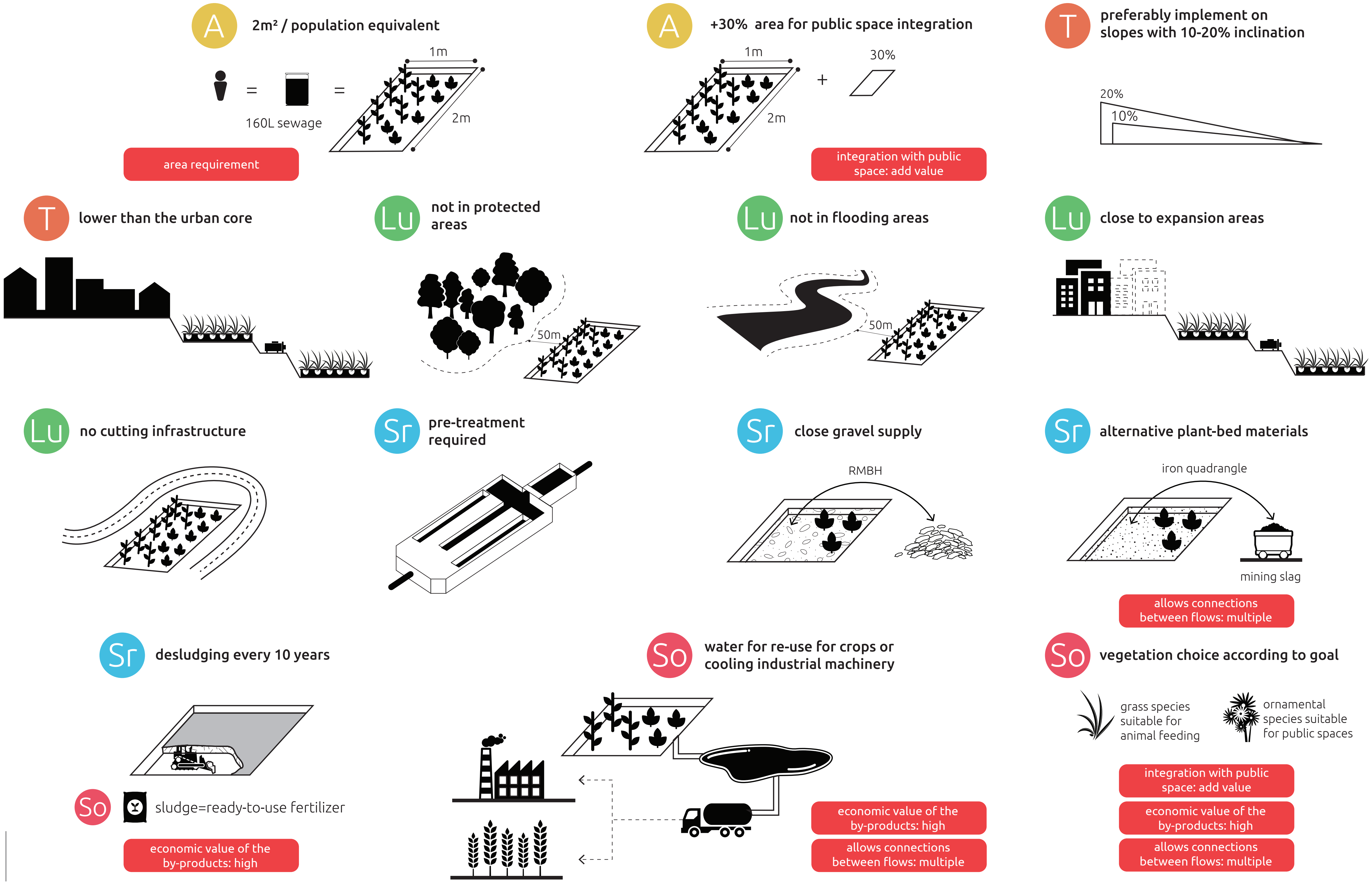
T topography

Lu land-use

Sr system requirement

So system output

Implementation of the system close to expansion areas and lower than the urban core guarantees the system's feasibility, together with the reuse of its by-products.



Principles for implementation of the French System.

landscape machine

landscape machine

The Landscape Machine is a combination of elements (biogas reactor + constructed wetland (CW) + co-composting) that makes it suitable for wastewater and organic waste treatment. The constructed wetland is the main assent for integration with the landscape.

Impression of the Landscape Machine.

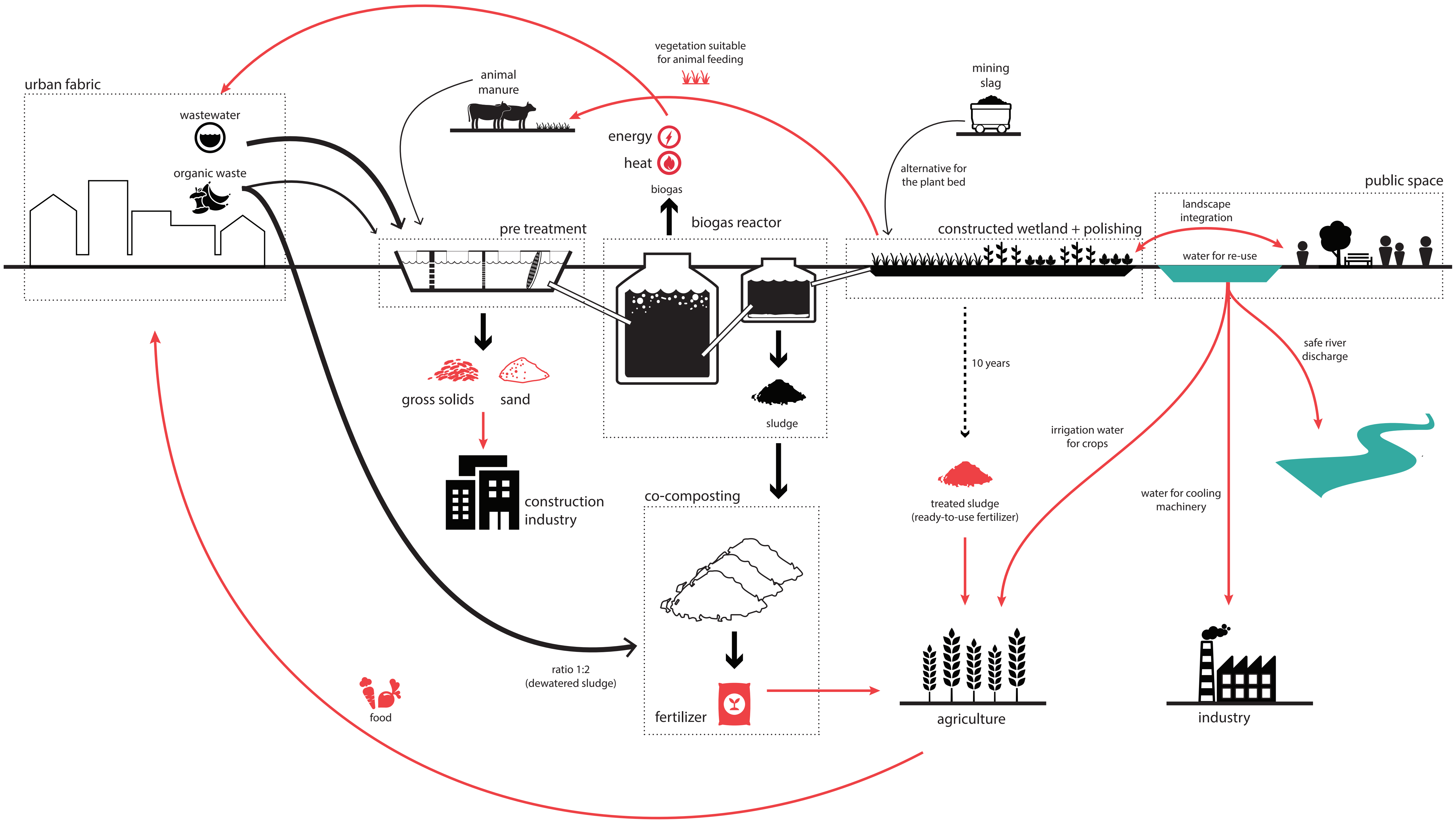
Biogas reactor. Source: Veolia

This system is a combination of elements (biogas reactor + constructed wetland (CW) + co-composting) that makes it suitable for wastewater and organic waste treatment. The Biogas Reactor is a key element for that goal, interconnecting flows, since it combines input of wastewater, organic waste and animal manure for higher efficiency. The biogas produced can be burned into electricity or heating. The reactors also produce sludge that requires further treatment. Again, associating with organic and green waste it is possible to treat these elements by co-composting, which in turn provides fertilizer for crops. The secondary treatment for the wastewater is realized through constructed wetlands (CW). Similar to the French System presented previously, the CW can harvest specific species for animal feeding and for ornamental purpose. Therefore, it also allows integration with public spaces with the same considerations as the French System, as well as has similar by-products. It is important to highlight that the biogas reactors can be designed both under or above ground, depending on the local conditions; and that it is desirable that the Co-Composting system is close to the reactors and CW, but should not be accessible for citizens or close to housing areas. The same as the French system, for reuse of the water is it necessary additional polishing phase (chlorination, ozonation, H202 or UV disinfection). The following diagrams a give a detailed description of how this system works and should be implemented.

Composting site in Germany.
Picture: Crystalclear
CC BY-SA 3.0

Vertical helophyte filters (CW) in Shenyang, China.
Picture: Ingenieurbüro Blumberg.

With the association of the constructed wetland with a biogas reactor and a co-composting unit, it is possible to treat wastewater and solid waste. The combination results in rich by-products that allow interconnections between flows.



Systemic section of the Landscape Machine.

A area

T topography

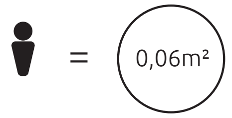
Lu land-use

Sr system requirement

So system output

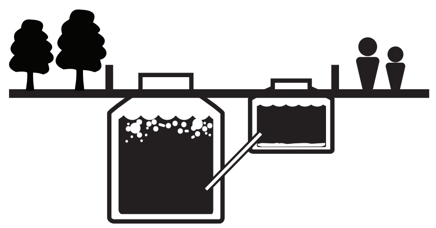
The biogas reactors produce biogas that can be burnt for electricity. With further treatment (co-composting), the sludge it produces also becomes a rich nutrient fertilizer.

A 0,06m² / person



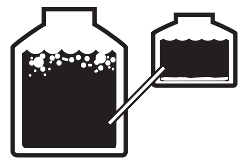
area requirement

Lu can be built underground/ no construction on top



integration with public space: neutral

Sr reactors 100 to 200.000L (specific project required)



calculation takes in consideration hydraulic retention time and volume of fermentation slurry (daily amount of slurry x hydraulic retention time)

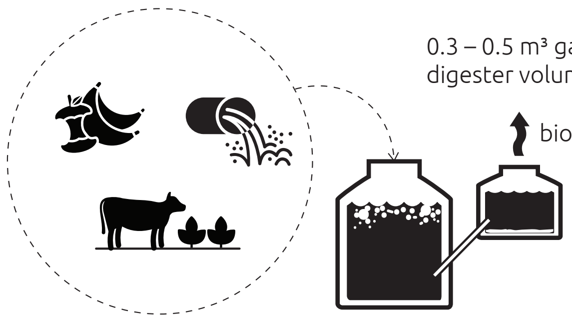
retention time: 40 to 100 days

(Eawag & Spuhler, n.d.)

area requirement

Sr requires regular feeding and combined inputs (blackwater +organic waste and/ or animal manure)

0.3 – 0.5 m³ gas/m³ digester volume/day



ratios varies greatly depending on local compositions of waste and wastewater

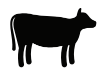
(Eawag & Spuhler, n.d.)

allows connections between flows: multiple

So biogas yields

= 0,02m³/person/day

human yield



= 0,4m³/kg dung

cow yield

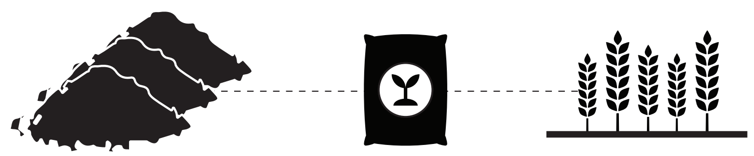
= 500m³/ton (methane)

food waste (dry)

(Eawag & Spuhler, n.d.; Spuhler, n.d.)

economic value of the by-products: high

So digestate (nutrient-rich sludge) = fertilizing soil (additional treatment (composting) increases safety for use)



economic value of the by-products: high

allows connections between flows: multiple

Principles for implementation of the Biogas Reactor.

A area

T topography

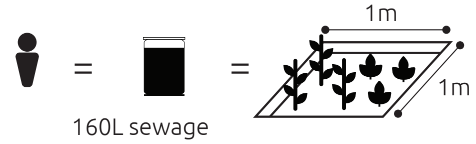
Lu land-use

Sr system requirement

So system output

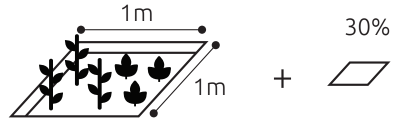
Principles for the constructed wetlands are similar to those of the French System. The main difference is that in this system it is only necessary a one-stage CW.

A 1m² / population equivalent



area requirement

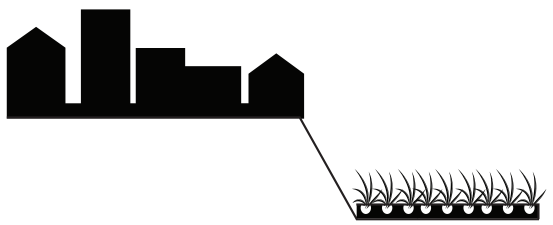
A +30% area for public space integration



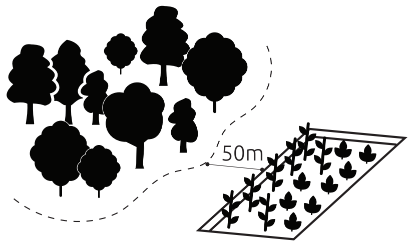
integration with public space: add value

T preferably implement on slopes with 10-20% inclination

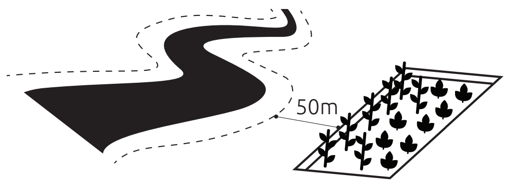
T lower than the urban core



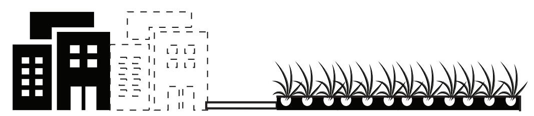
Lu not in protected areas



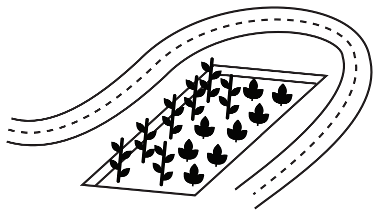
Lu not in flooding areas



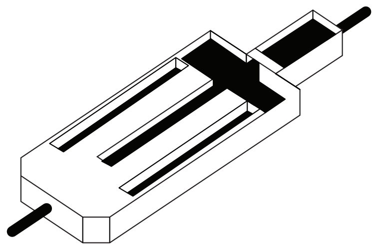
Lu close to expansion areas



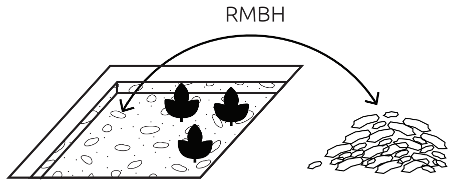
Lu no cutting infrastructure



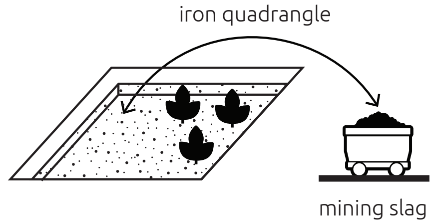
Sr pre-treatment required



Sr close gravel supply

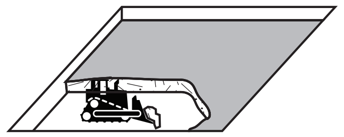


Sr alternative plant-bed materials



allows connections between flows: multiple

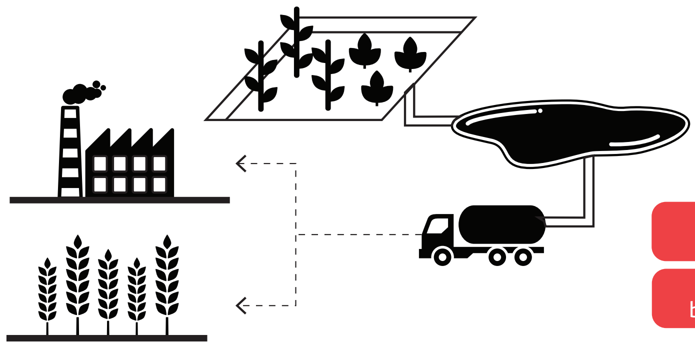
Sr desludging every 10 years



So  sludge=ready-to-use fertilizer

economic value of the by-products: high

So water for re-use for crops or cooling industrial machinery



economic value of the by-products: high

allows connections between flows: multiple

So vegetation choice according to goal

grass species suitable for animal feeding

ornamental species suitable for public spaces

integration with public space: add value

economic value of the by-products: high

allows connections between flows: multiple

Principles for implementation of the CW.

A area

T topography

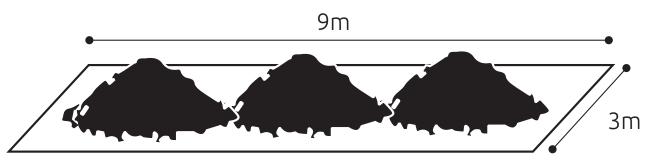
Lu land-use

Sr system requirement

So system output

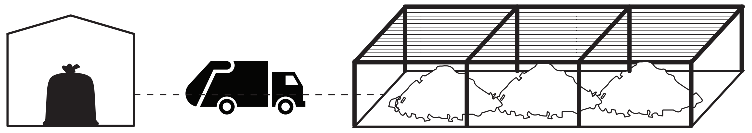
The co-composting unit should be close to the other components of the system, but not accessible to the citizens or close to housing areas.

A ~270m^2 per ton/day (plants receive 10-200ton/day)

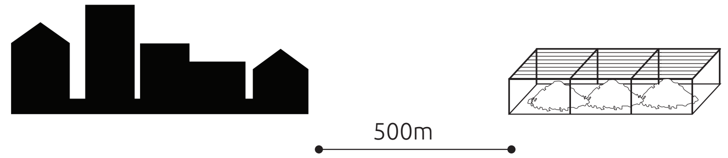


area requirement

Lu preferably close to waste transshipment units

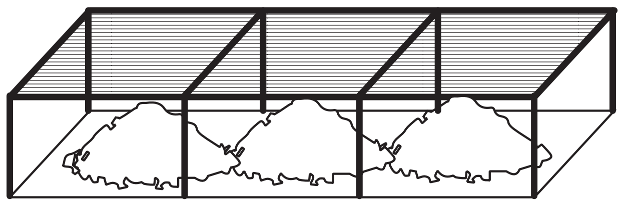


Lu preferably not close residential areas



integration with public space: avoid

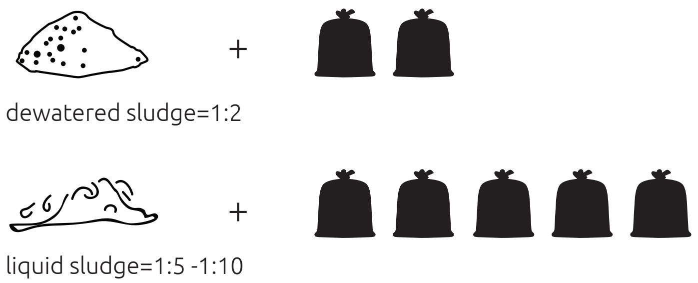
Sr should be covered in areas with heavy rainfall



Sr requires separation of organic waste

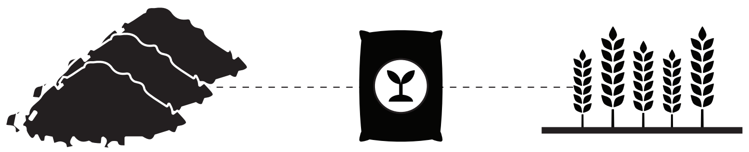
allows connections between flows: multiple

Sr sludge ratios



allows connections between flows: multiple

So final compost = fertilizer



economic value of the by-products: medium

allows connections between flows: multiple

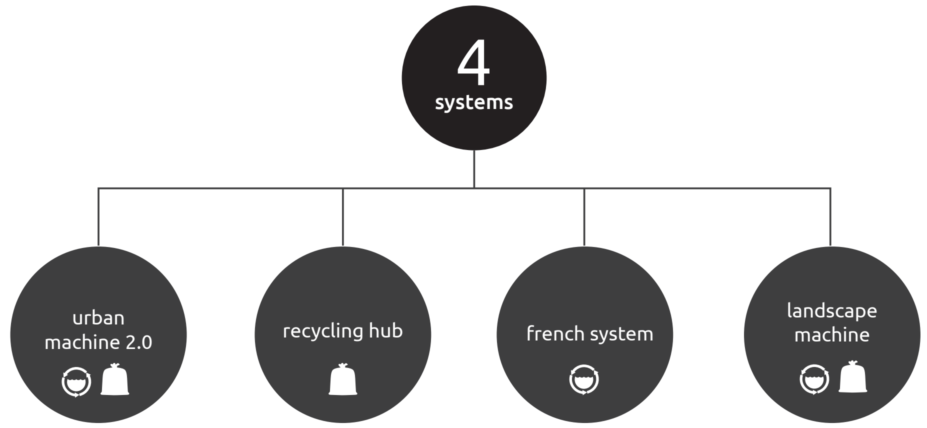
Principles for implementation of the Co-composting.

COMPARING SYSTEMS

Even though the systems address different demands for both wastewater treatment and solid waste, it is possible to compare them regarding the associated functions and by-products they produce. It is possible to observe that, as expected, the French System and the Landscape Machine system are closely related, since they both use constructed wetlands as main component. However, the Landscape Machine produces more by-products, being the biogas one with significant economic value. This is possible due to the association between wastewater and solid waste, which turns the system more complex, but also adds value. On the other hand, the Urban Machine 2.0 is the one that allows more integration with other urban and social functions, posing as a valuable and strategic urban instrument. In addition, the Recycling Hub presents itself as the most isolated solution, despite its important value for activating the waste recycling chain.

URBAN INTEGRATION

By comparing these systems is possible to conclude that the ones which associate both flows (Urban Machine and Landscape Machine) promote more opportunities for integrating urban and social functions and produce more by-products that support their economic feasibility.



associated functions

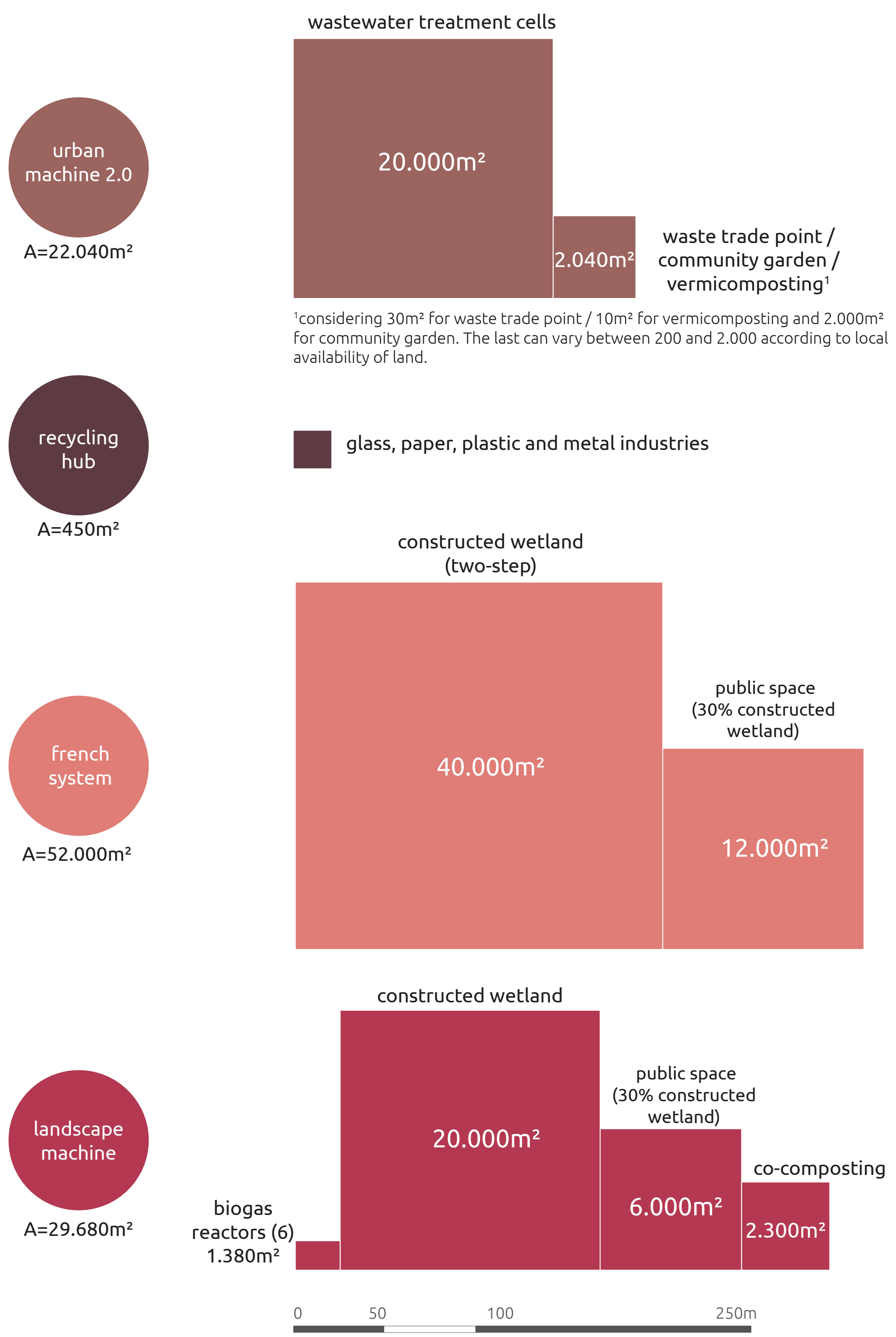
urban machine 2.0	recycling hub	french system	landscape machine
industrial sector (machinery)	industrial sector (machinery)	**industrial sector (machinery)**	**industrial sector (machinery)**
agriculture	agriculture	**agriculture**	**agriculture**
livestock	livestock	**livestock**	**livestock**
urban farming	urban farming	urban farming	urban farming
recycling industry	**recycling industry**	recycling industry	recycling industry
waste pickers association	**waste pickers association**	waste pickers association	waste pickers association
community center	community center	community center	community center
leisure/recreational	leisure/recreational	**leisure/recreational**	**leisure/recreational**
educational	educational	educational	educational

by-products

urban machine 2.0	recycling hub	french system	landscape machine
local food production	local food production	local food production	local food production
animal feeding	animal feeding	**animal feeding**	**animal feeding**
fertilizer	fertilizer	**fertilizer**	**fertilizer**
water for re-use	water for re-use	**water for re-use**	**water for re-use**
power/heat (biogas)	power/heat (biogas)	power/heat (biogas)	**power/heat (biogas)**
gross solids / sand	gross solids / sand	gross solids / sand	**gross solids / sand**
raw material for re-use	**raw material for re-use**	raw material for re-use	raw material for re-use
pre-sorted recyclables	pre-sorted recyclables	pre-sorted recyclables	pre-sorted recyclables
semi-processed recyclables	**semi-processed recyclables**	semi-processed recyclables	semi-processed recyclables

Comparison between systems: functions and by-products. In color, highlight of the associated functions and produced by-products in each system.

AREA REQUIREMENTS OF SYSTEMS FOR 20.000 PEOPLE EACH.



Area comparison between systems.

In relation to dimensions comparison, it is possible to have an overview of areas required for each system, considering a population of 20.000 people. For the calculation of these areas, a few considerations were taken:

Biogas Reactor

According to Carlos Chernicharo, (see Annex B), the proportion between wastewater, organic waste and manure will vary according to the reactor's characteristics and involves specific calculations and testing. Given the impossibility of pre-defining the adequate ratios and taking a 200.000L biogas reactor as parameter (diameter =7,8m / height=5,5m) (Puxin, n.d.), it is possible to divide the area of the reactor (~230m²) by the area per person found in literature (0,06m²/person) (Van Leer, 2016). Therefore, each reactor is capable to serve around 3.800 people. In a system for 20.000 people, it is necessary 5-6 reactors of 200.000L.

Co-composting

The calculation of the required area considered the average of waste per capita in the RMBH (0,70kg/day - based on information from SNIS 2015) and that 60% of the waste is organic (Bain & Company, 2012). Therefore, it was considered a 0,42kg/capita/day of organic waste. In a system for 20.000 people (8,4ton/day), the required area is 2.300m².

Recycling Hub

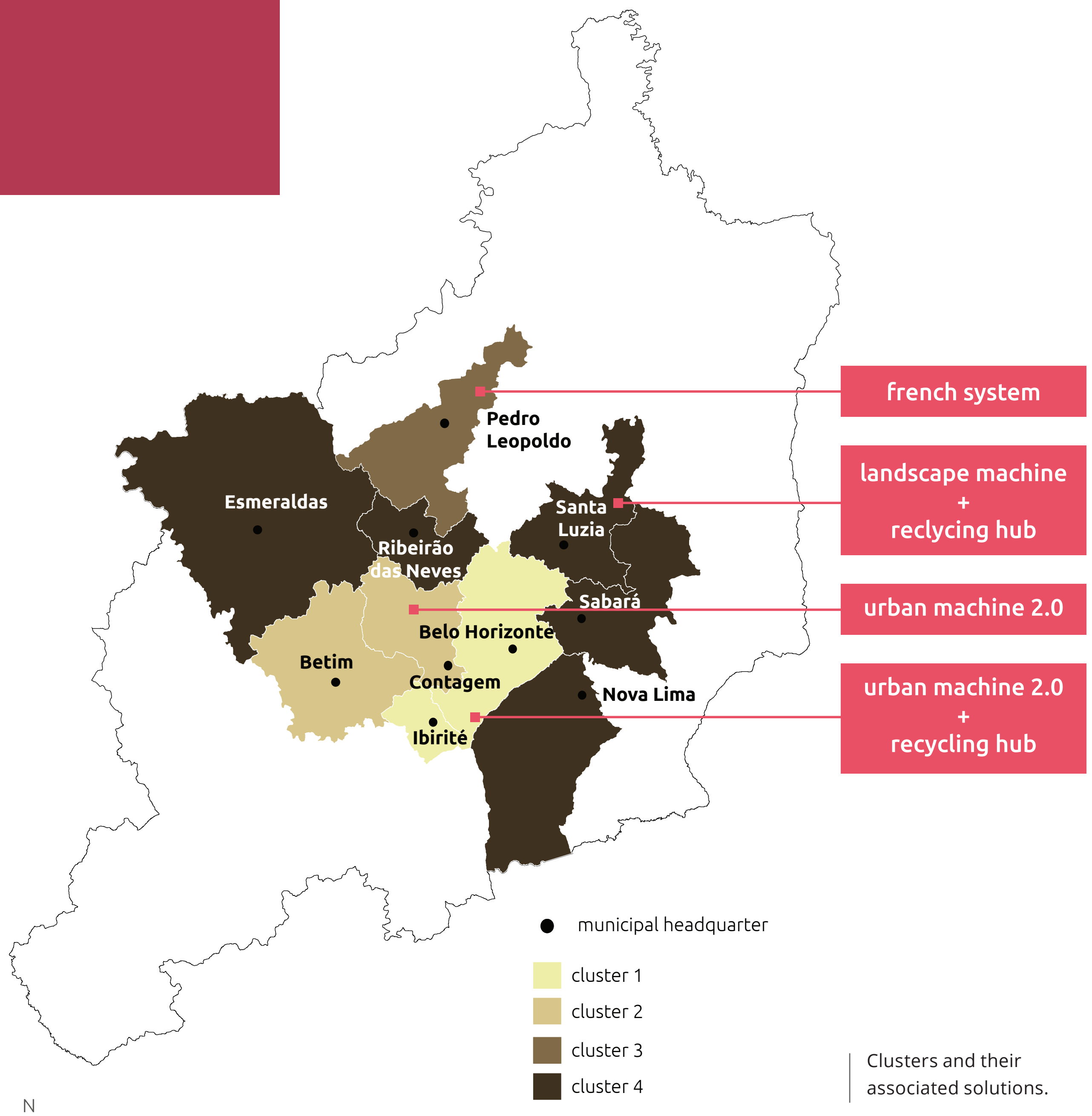
The calculation of the required area considered the average of waste per capita in the RMBH (0,70kg/day - based on information from SNIS 2015) and that 25% of the waste is recyclables (Bain & Company, 2012). Therefore, it was considered a 0,175kg/capita/day of recyclable waste.

In a system for 20.000 people (3,5ton/day) and considering the average processing rate of the recycling industries of 3,0ton/day (see Catalog of Solutions for processing rates), the minimum area defined in the catalog would be sufficient. Therefore, the total required area would be 450m².

When analyzing the defined clusters in relation to the population without sewage treatment, it is possible to calculate the number of systems each cluster requires and compare their areas. Clusters 1 and 4 are, thus, the ones that need more space.

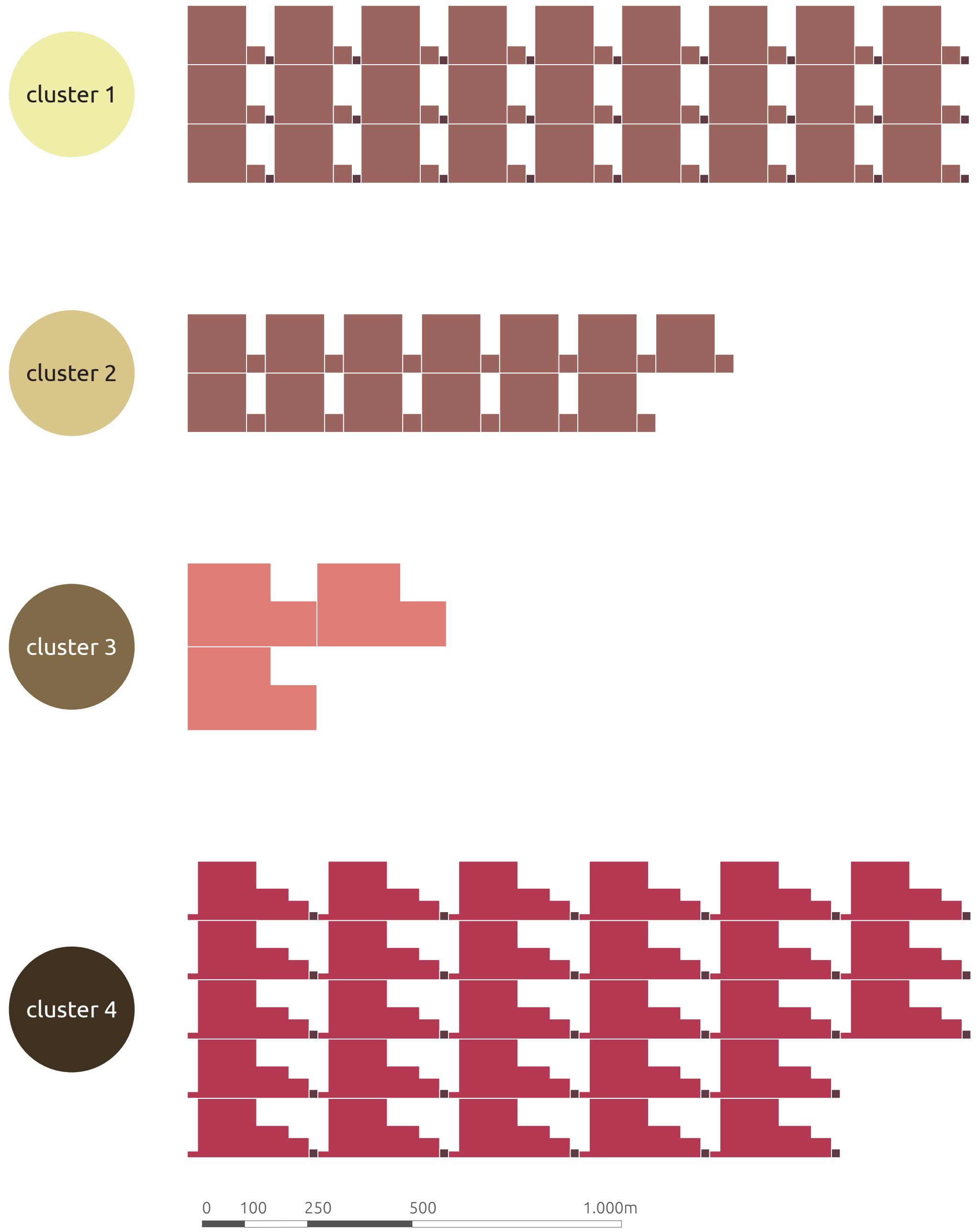
Cluster	Urban population (2013)	Population (without sewage treatment)	Elected solutions	Area required (km²)	Number of systems
1-Belo Horizonte + Ibirité	2.648.684	399.104	urban machine 2.0 + recycling hub	0,60	27
2-Contagem + Betim	1.039.311	194.205	urban machine 2.0	0,29	13
3-Pedro Leopoldo	52.704	49.805	french system	0,16	3
4-Nova Lima + Sabará + Ribeirão das Neves + Esmeraldas + Santa Luzia	801.876	563.473	lanscape machine +recycling hub	0,83	28

Estimation of the number required systems for each cluster, based on the population without sewage treatment and the area required for each system.

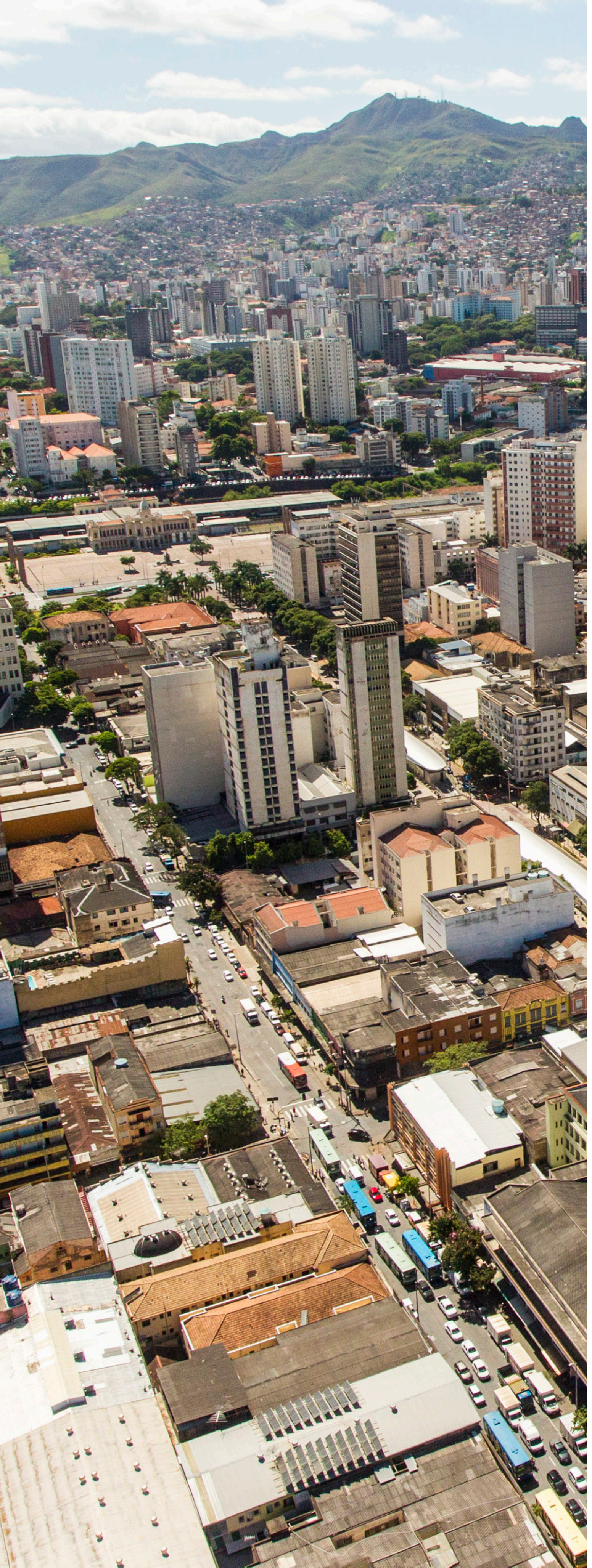


Clusters and their associated solutions.

Area required per cluster.



Clusters 1 and 4 are the ones that required more systems / area to fully serve the population currently without sewage treatment.



Belo Horizonte's
current landscape
(2014): highly dense
and vertical.
Picture: public domain

BH
[BELO HORIZONTE]

4.3 testing Belo Horizonte

The following section presents Belo Horizonte test case. The test case provides an overview of the existing situation on the city level; followed by a 3-step analysis to find suitable locations for implementing the elected system; and a detailed intervention of one of them. This intervention takes in consideration metabolic relations, the territory and the local context (economic-social relations). It also includes a study of the by-products produced, as well as a stakeholders and phasing strategy.

Belo Horizonte is part of Cluster 1 and it was chosen as test case for implementation of the proposed solutions (Urban Machine 2.0 + Recycling Hub). Apart from being the capital of the state and hosting around half of the population of the entire region, BH is also the second city with largest population without sewage treatment and the first one with largest BOD contribution (most likely due to the highly urbanized surface, which decreases the BOD reduction capacity). Therefore, the city becomes relevant for the overall metabolic improvement of the region.

Considering that Belo Horizonte has 236.264 people without sewage treatment and Urban Machine's maximum capacity of 20.000 people, the area would require a minimum of 12 systems to cover the entire population without infrastructure. However, the population without sewage treatment is spread out on the territory and, thus, smaller systems can also be considered depending on local conditions. To define potential locations, it is possible to highlight areas that have sewage collection, but no treatment and areas that are not connected to the sewage network and, therefore, also do not have sewage treatment. It should be noted that there is a difference between areas with collection, but no treatment. One of them is collected, intercepted and not connected to treatment plants. The other one is collected and not even intercepted, having only trunk pipes, which collects the sewage from the houses, but does not reach an interceptor for further disposal. The existing slums and informal occupations are also overlapped in the map. The difference between the two is that the first are consolidated areas, already acknowledged by Municipality, whereas the second are more recent occupations and not yet formalized. Most of the areas without collection and treatment coincide with informal settlements, even though they are not exclusive. It is important to highlight that the databases are not from the same year, and therefore, differences between the variables may occur.

With the existing situation, it is possible to visualize that the areas with collection but no treatment are located closer to the south and north borders and provide an estimative of the number of people affected by it. Considering that areas with no interceptors are one step behind than the ones with interceptors, the areas with 32.500 and 25.000 people were selected for site visits.

Most people without sewage treatment are located closer to the city's north and south borders . Some of these areas coincide with slum or informal occupations. Areas with one trunk pipes and no interceptors are considered on step behind than those with interceptors and, therefore, were chosen for site visits.

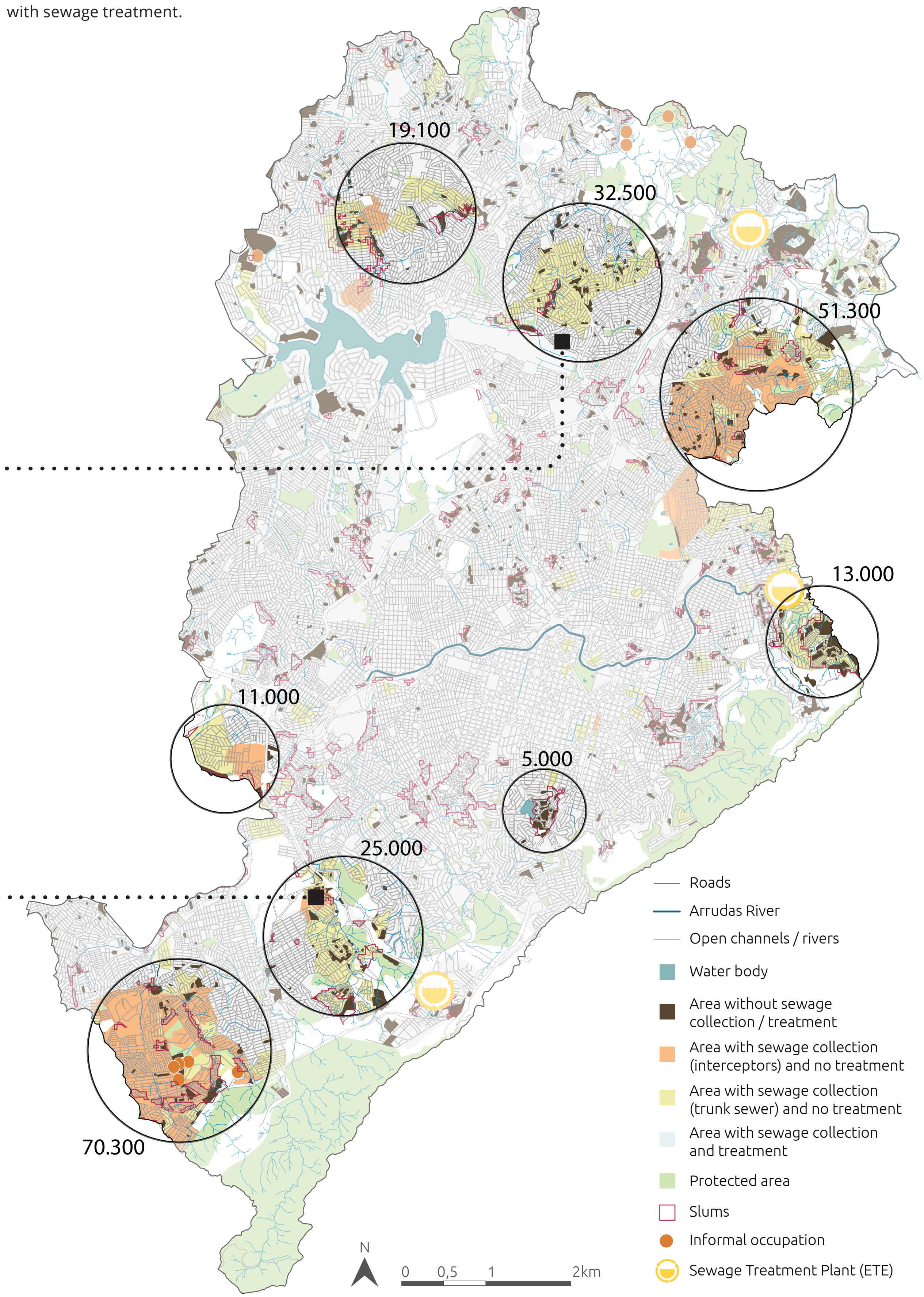
Existing situation Binquinhas neighborhood (2018). Picture: Carolina Eboli

Existing situation Bonsucesso neighborhood (2018). Picture: Carolina Eboli

QUICK REMINDER

The sewage from households is first directed to main pipes (trunk pipes), which in turn lead the sewage towards the interceptors, which are pipes placed along the rivers. The interceptors are the ones which further carries the sewage to the treatment plants.

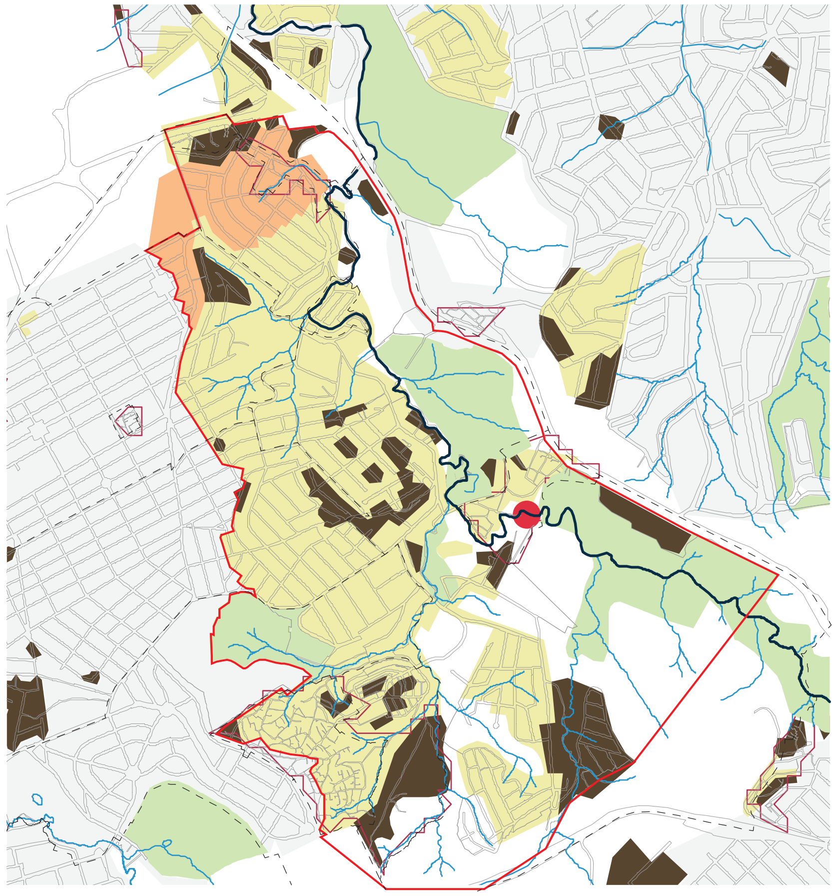
Belo Horizonte: population division with sewage treatment.



Notes:
Estimated values based on the neighborhoods' population available on the website Bairros de Belo Horizonte (de Souza, 2010).

bonsucesso

3-step analysis

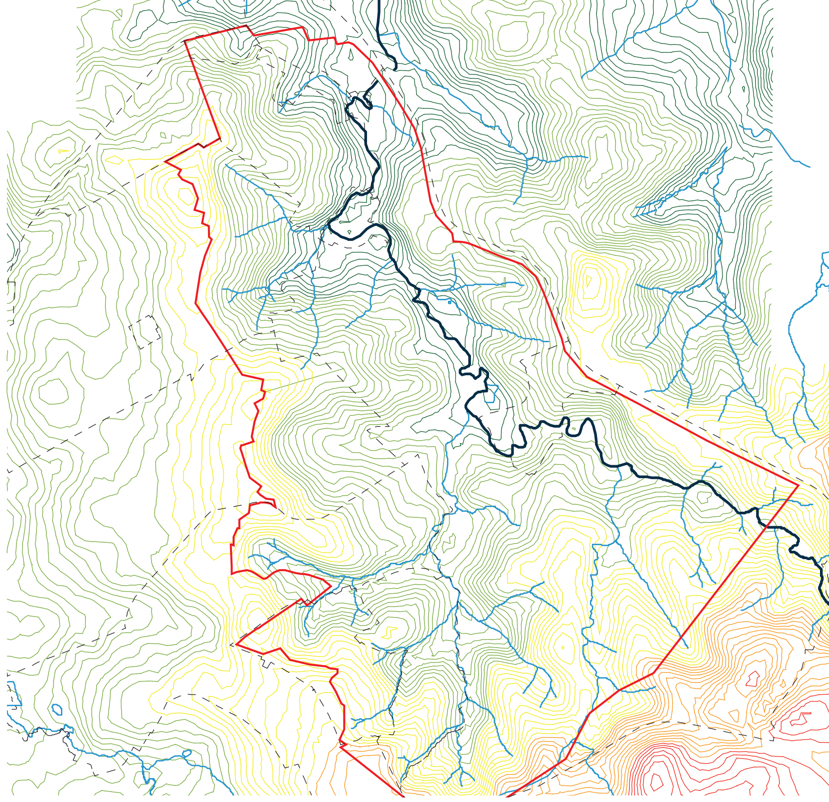


Notes:
Based on the map "Diagnosis of the sanitary Sewage System" from the Municipal Sanitation Plan for Belo Horizonte 2016-2019 (Municipality of Belo Horizonte, 2016).

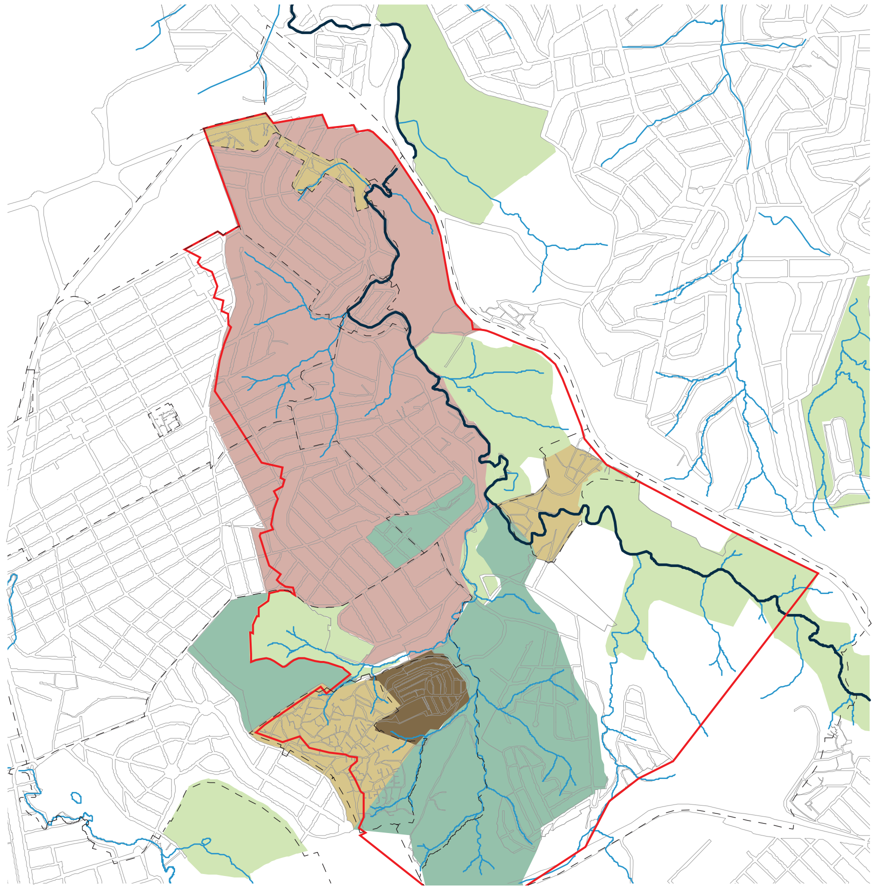
Study area: existing situation.
The study area included both areas with/without sewage collection. Slums are also present .

Considering the insight gained during the site visits, the south area (25.000) was elected as test case, given its worse urban quality. It should be noted that this area is part of Barreiro region, an area that was considered "far" from Belo Horizonte and hosted several farms in the early XIX century (APCBH, 2008). Its great rural potential relied on the existence of several water bodies in the region, which made this area responsible for producing food supplies for Belo Horizonte in the first half of the century (APCBH, 2008). During the 1950s, though, sprawl started to reach the region, also due to the industrial growth of the north (Contagem) (APCBH, 2008). The unplanned urbanization led to several issues, such as bad quality housing and infrastructure problems (APCBH, 2008). The area also suffered from flooding episodes from Bonsucesso stream (APCBH, 2008). For that reason, the Municipality implemented an extensive drainage project, with the inclusion of a flood retention basin and the removal of 440 families that lived in risky areas into new housing complexes (finished in 2011) (Municipality of Belo Horizonte, n.d.). Recently (2018), the Municipality started a bidding for implementation of sewage network along Bonsucesso stream (Municipality of Belo Horizonte, 2018), which reinforces the relevance of this proposal.

Study area: topography. Multiple water bodies and valleys in the region favor smaller systems.



n order to apply the principles defined for the Urban Machine 2.0 + Recycling Hub, a 3-step analysis guided the election of the most suitable areas for implementation: current situation (sewage disposal situation, water streams, protected areas, slums); topography and zoning plan. With this analysis is possible to guarantee principles related to topography and landuse, such as: lower than the urban core, identification of derelict areas and areas with safe distance from housing (for the Recycling Hub).

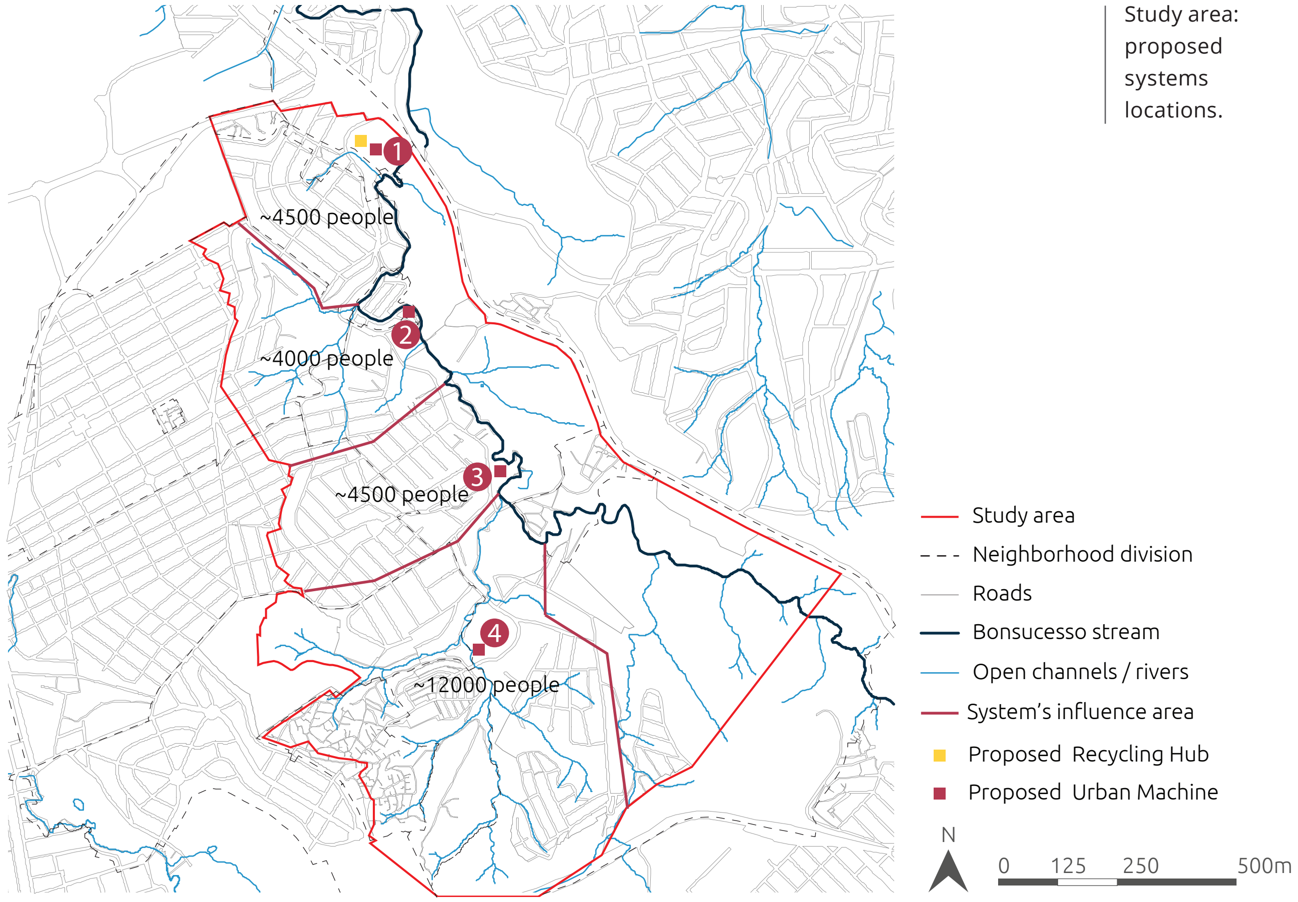


Study area: existing zoning.
Protected areas along the river have been reduced due to urbanization.

The five proposed locations have different potentials in relation to their surroundings. Area number 1 is an open space, well accessed from the highway BR-040 and it is probably suffering from illegal occupations. The potential of this area relies on providing a facility that would serve the local population and provide social services, while solving an existing conflict (private owner x illegal occupants). For example the public sector can acquire the land, compensating the private owner, and relocate the current occupants to other housing programs. Area number 2 relates to a similar situation. The proposed area would require removal of existing poor quality housing, which is next to a social housing complex built for the drainage project in 2011. If combined, the Urban Machine could support the housing complex, given its strong social dimension. Same as in Area 1, these removals could be incorporated in existing or new housing programs. Area 3 refers to an area where occupation invaded protected areas close to the river. Even though after the drainage works these houses might not be in risk anymore, there is a probability this occupation expands further into the protected area. If these houses are replaced with an urban and social equipment, it would guarantee the discontinuation of this process. Lastly, Area 4 proposes an association with an existing elderly institution. The unused space of the surroundings and the social character of the proposal can contribute for integrating these two functions, strengthening local identity and increasing the proposal's success.

PROPOSED AREAS

The division and location of the systems takes in consideration the best option considering topography (to use gravity) and areas that can be occupied.



Study area: proposed systems locations.

1

Area 1: derelict area close to highway (BR-040). Source: Google Earth

Area number 1 is an open space, well accessed from the highway BR-040 and it is probably suffering from illegal occupations. The potential of this area relies on providing a facility that would serve the local population and provide social services, while solving an existing conflict (private owner x illegal occupants).

Area 1: possible illegal occupation. Source: Google Street View, 2015

2

Area 2: Poor quality occupation next to new housing complex. Source: Google Earth

3

Area 3: Poor quality occupation in protected area. Source: Google Earth

The proposed area would require removal of existing poor quality housing, which is next to a social housing complex built for the drainage project in 2011. If combined, the Urban Machine could support the housing complex, given its strong social dimension.

Area 3 refers to an area where occupation invaded protected areas close to the river. Even though after the drainage works these houses might not be in risk anymore, there is a probability this occupation expands further into the protected area. If these houses are replaced with an urban and social equipment, it would guarantee the discontinuation of this process.

Area 2: new housing complex. Source: Google Street View, 2014

Area 3: Poor quality occupation. Source: Google Street View, 2015

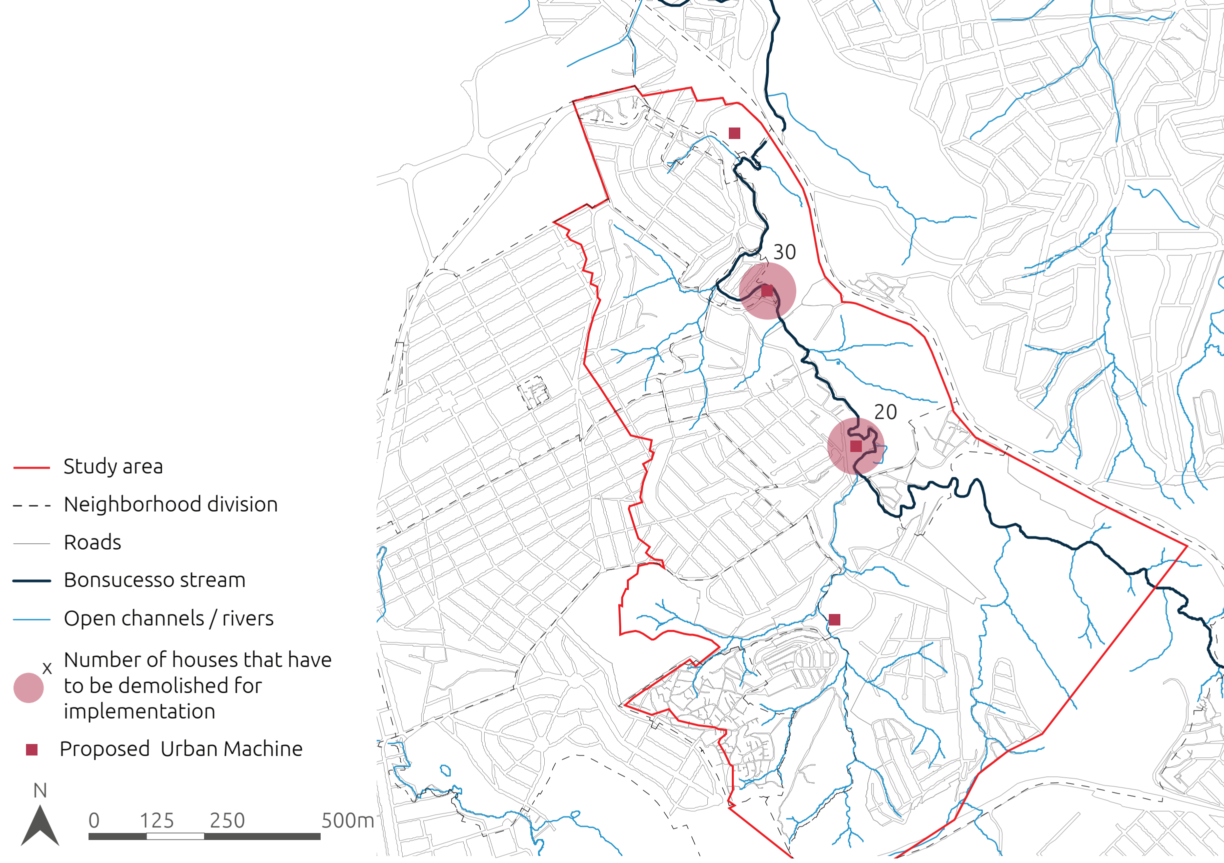
4

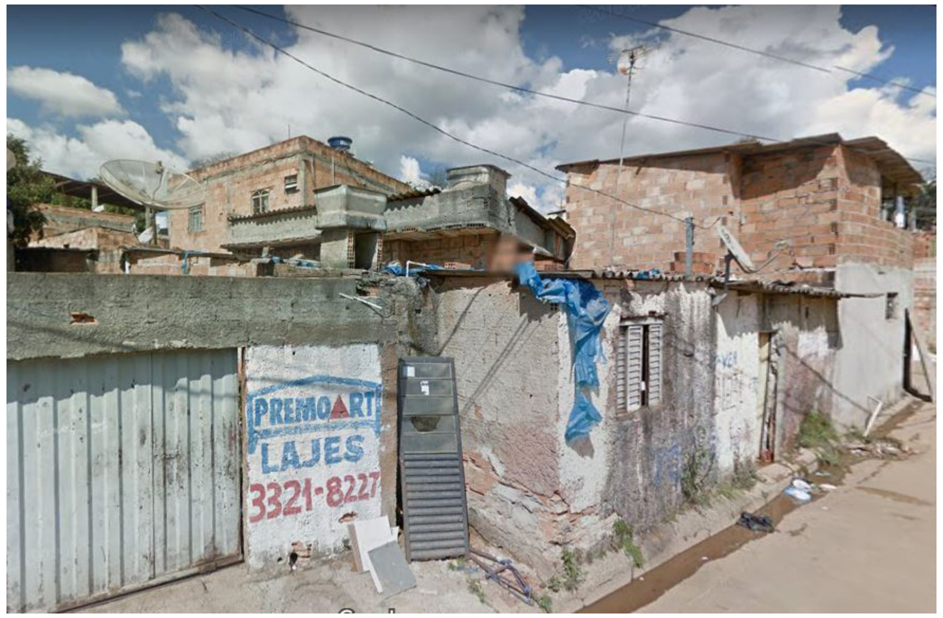
Area 4: derelict area next to elderly house. Source: Google Earth

Area 4 proposes an association with an existing elderly institution. The unused space of the surroundings and the social character of the proposal can contribute for integrating these two functions, strengthening local identity and increasing the proposal's success.

Area 4: derelict area. Elderly house at the center. Street View, 2013

Study area: required demolitions. Two of the proposed areas would require demolitions. In this study their reallocation will be considered per system.





Example of housing condition of largest demolition area (30). Source: Google Street View, 2014

QUICK REMINDER

It should be noted that the number of required systems takes in consideration the estimated amount of people without sewage treatment in that area (25.000), which is based on the population of the neighborhoods. Therefore, one system would be roughly enough for this area. However, given the local topography and spatial distribution of the houses, for the Urban Machine, smaller systems are more suitable. For the Recycling Hub, though, there is no need for smaller systems. Area 1 was chosen to host it, given its accessibility and open/larger space. Moreover, there are several industries on the adjacent highway (BR-040), which can become partners for receiving the recycled material produced in the Hub. As for the required removals, there are different possibilities: to create one single program that incorporates all the affected families from areas 1-3; or solve each of them separately, within the area of study. For the purpose of this study, it will be considered separately.

unraveling the metabolism

1. Proposed demolition: 18 houses
2. Proposed demolition: 12 houses
3. Derelict area: suitable for housing
4. Derelict area: suitable for public space
5. Social housing complex

Existing situation: areas and potential uses.

After considering the potentials of each proposed intervention area, the Urban Machine in Area 2 was chosen to be detailed (for a detailed example of Recycling Hub, see “testing Ribeirão das Neves”). This choice relates to two different aspects. First, this area requires the removal of most houses, and therefore, detailing it becomes relevant. Second, informally occupied areas have not only poor housing conditions, but also low quality public space. The implementation of the Urban Machine creates an opportunity to improve local conditions of both housing and public space. Moreover, with the successful implementation of this facility, there is incentive for the implementation of the other units, which can incorporate any complementary social functions needed, according to local conditions.

The area is well accessible by one of the main roads of the neighborhood (Dr. Cristiano Rezende St.), which in turn is connected to the highway (BR-040). Existing social housing is also present in the area (finished in 2011), as mentioned previously. There is also a derelict area between the housing complex and Bonsucesso stream, with potential to become a public space and connect to an existing soccer field across Dr. Cristiano Rezende St. In order to implement the Urban Machine, though, removal of around 30 houses will be necessary, which can be replaced in the immediate surrounding, by including an extra building to the social housing complex.

QUICK REMINDER

The existing typology of the social housing buildings is part of an extensive federal housing program (“Minha Casa, Minha Vida - PMCMV”). This program was launched in 2009 “as a ‘anti-cyclical’ tool of the government in the face of the international economic crisis [of 2008]” (Romagnoli, 2012). This program aimed to give economic incentive in the construction and infrastructure sectors by addressing to the large national housing deficit, guarantying economic and social improvement. In the first phase, the program provided housing for population with low income (0-10 minimum wages), using subsidies and financing tools. Nowadays, the program is still on going, with some differences. This thesis does not aim to discuss the PMCMV or the quality of the pre-defined typologies. However, it should be highlighted that this program touches upon several social aspects (common critics of this program are the implementation of houses on the outskirts of the cities, increasing distances and segregation of the users; and the negligence of incorporating existing vacant buildings). In the context of this study area, the affected population would be relocated to the immediate surroundings, keeping unaltered some of the local dynamics. Other aspects, though, might create negative impacts, such as the change in typology that can imply in a life style change (single house to apartment; social interactions). In addition, it is also possible to discuss the or the architectural quality of these constructions and their contribution to the aesthetics of the city.

Good accessibility of the area. Derelict areas are suitable for other uses. 30 houses need to be demolished for implementation of Urban Machine

Existing situation: area of intervention.

- highway (BR-040)
- main accesses
- Bonsucesso stream
- intervention area

Overview of the existing situation: poor housing quality, derelict areas and social housing complex.

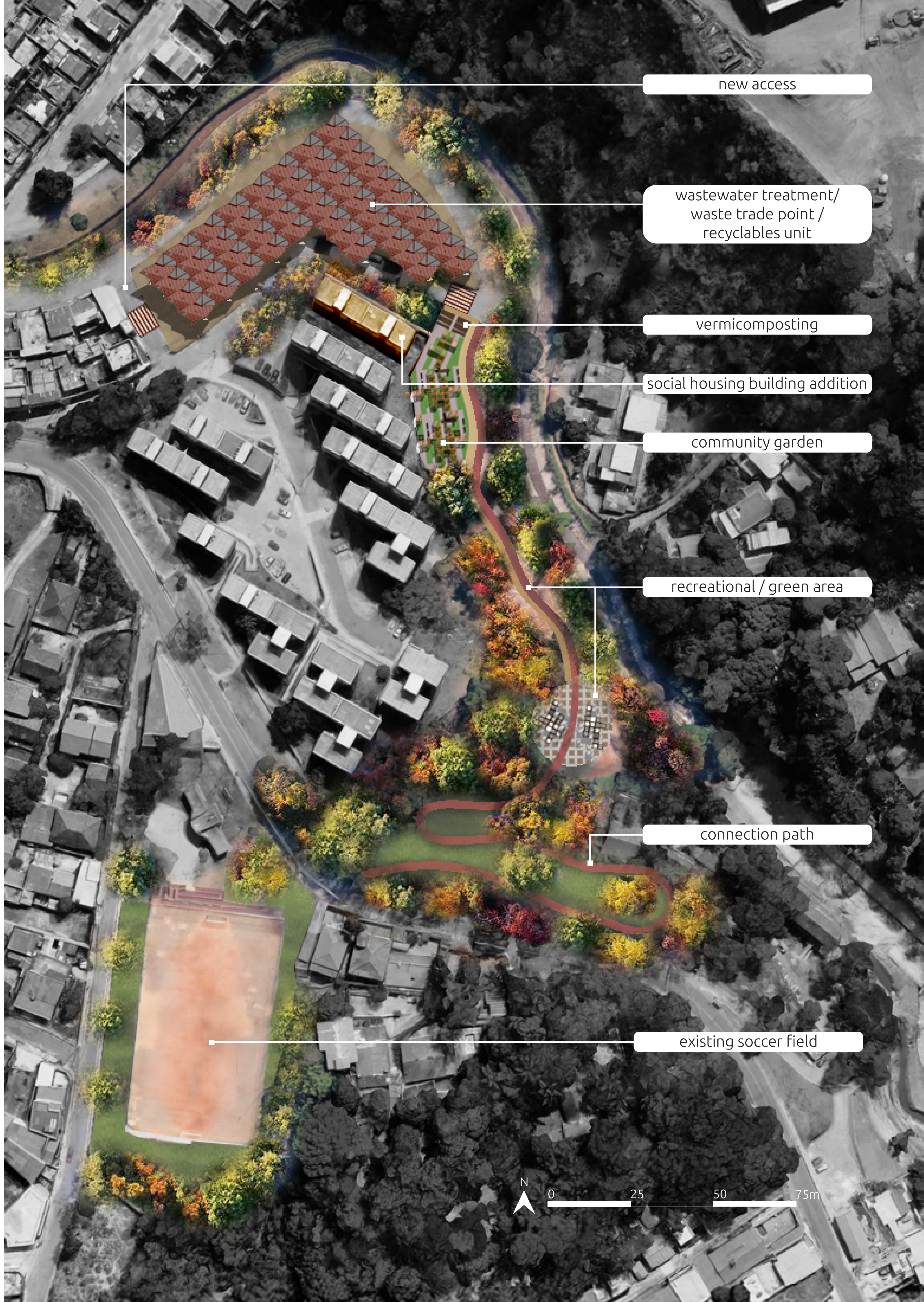
Existing situation: overview. Source: Google Earth

[top] Existing situation #1 . Social housing complex x low quality housing. [middle] Existing situation #2 . Derelict areas. [bottom] Existing situation #3 . Low quality housing proposed to be demolished. Source: Google Street View, 2014

Proposed plan. Wastewater treatment and waste trade point facility on top and its relation with the additional social housing building and the proposed public space along Bonsucesso stream.

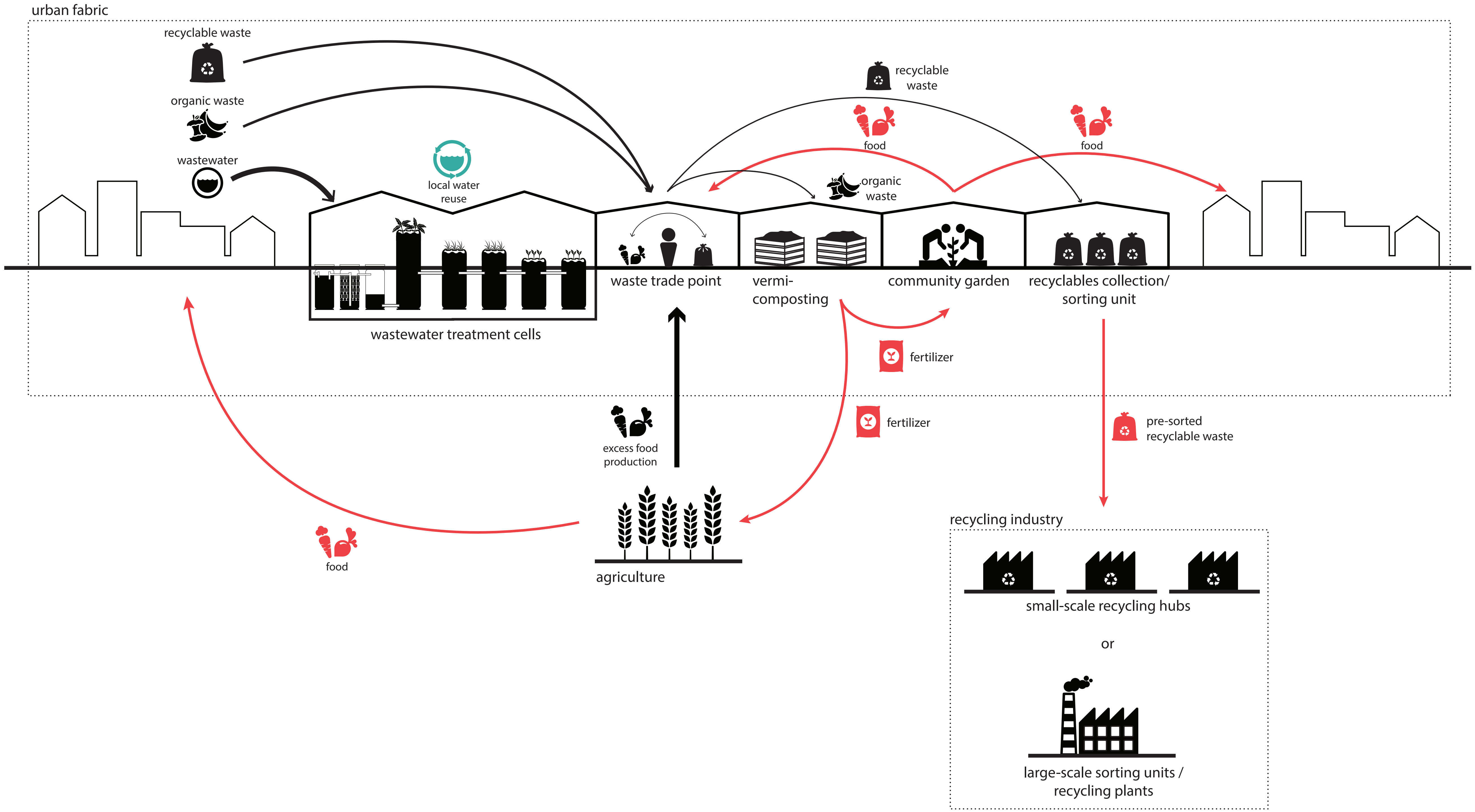
SYSTEM IMPLEMENTATION

The first consideration to take in order to implement this proposal is its large social impact due to the required demolitions. Therefore, it is crucial to work closely with the local users and inhabitants during all the phases of this process for a successful development. For that purpose, awareness programs, meetings with community leaders and educational programs before and after construction are necessary to explain the benefits of this proposal and reduce any negative pre-conceptions, especially related to the wastewater treatment facility. Second, the Urban Machine is a system that addresses two sanitation issues: wastewater treatment and solid waste management and, thus, has different components. It includes a large facility for wastewater treatment, with capacity for around 4.000 people, a waste trade point and a recyclables collection unit. Together they occupy around 4.200m². The proposed waste trade point (see Solutions Catalog Volume) is based on the successful experience of Curitiba's program "Green Exchange", where the population with low income (0-3,5 minimum wages) take their sorted waste in exchange of food. The building itself hosting these functions can also incorporate other sustainable aspects (such as local materials, clean energy, etc), which also give opportunities to incorporate users either by providing workshops or awareness programs throughout the process. For the implementation of this facility, it is also proposed an alteration on the roads, shifting the access to the border of the wastewater treatment building. Furthermore, this complex relates with the adjacent proposed linear green/recreational areas. The new public area not only protects the water front, but incorporates other elements part of the Urban Machine system, such as the vermicomposting and the community garden. Moreover, this public space connects with an existing soccer field, integrating with the surroundings. Lastly, it is proposed the addition of a social housing building to absorb the 30 removed families. This building follows similar conditions as the existing ones, and therefore would have 32 apartments. This configuration aims to create a minimum impact on the surroundings. However, as mentioned earlier, the pre-defined constructions raise the discussion on their urban quality. This thesis will not go in depth on that subject, but triggers the debate over this topic, by proposing two different situations: one which is the most pragmatic choice, taking in consideration the existing governance relations; and the other is a slight variation of the construction, including sustainable features, such as green facades and solar panels, which could be funded by third parties.



URBAN MACHINE

The Urban Machine system follows the principles defined previously. Its main component is the wastewater treatment facility that uses ecology cells for treating the sewage. These cells use species with economic or ornamental value, contributing for the feasibility and aesthetic appeal of the system. Associated with the wastewater treatment, there is a waste trade point, where the population take their sorted waste in exchange of fruits or vegetables, giving incentive for waste separation. The organic waste can be composted in situ (vermicomposting) and the recyclables can be transshipped to sorting units or to the Recycling Hub. Another important function in the Urban Machine is the community garden, which can use the compost from the vermicomposting and partially provide the exchangeable food. Moreover, the community garden reinforces community spirit and public space integration.



The associated social functions complement the system creating a network of exchangeable by-products and interconnecting flows.

Urban Machine's components and relations.

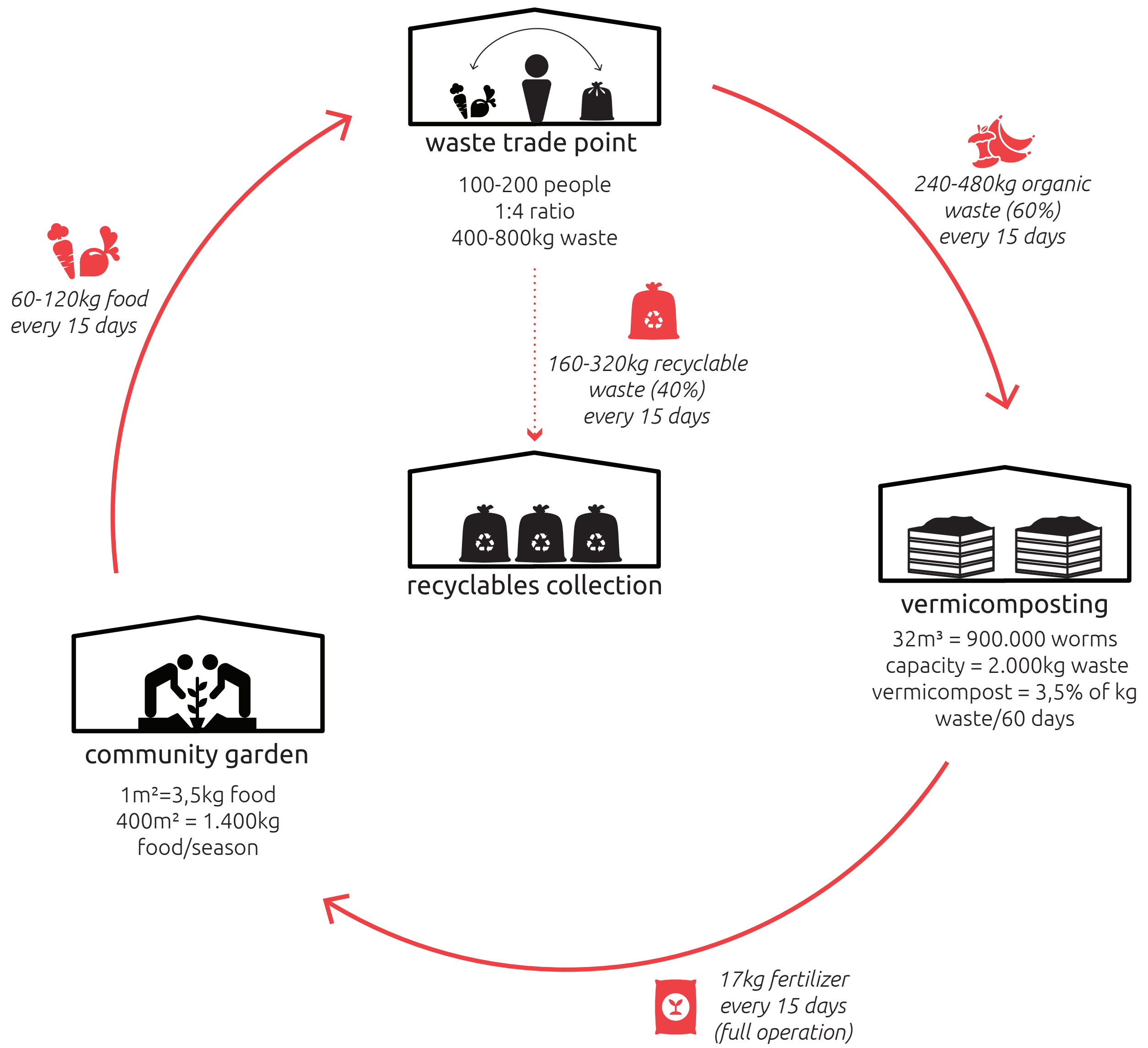
View from the community garden. Integration with social housing and wastewater facility on the background.

Social housing complex with sustainable features as a form to trigger a debate over the urban quality of the existing social housing program.

View from the wastewater treatment facility.
The new social housing building can be integrated with the proposed public space

by-products

circular relations between components assures self-sustainability of the system in almost all components.



By-products of the proposed Urban Machine.

WASTEWATER TREATMENT

As illustrated previously, the Urban Machine system also relies on relations between the by-products produced by each of its components. The largest component is the wastewater treatment. The eco-cells will be able to treat sewage of around 4.000 people. Considering that each person produces 160L/day (0,16m³) of wastewater and 10% of lost in the system due to evaporation, this facility would produce 576.000L/day (576m³) of water suitable for reuse. The reuse would take place locally, first feeding the eco-cells of the wastewater system and second in the maintenance of the community garden, vermicomposting and green areas of the surroundings. The remaining volume that is not used can be safely discharged into Bonsucesso stream.

WASTE TRADE POINT

Another component part of the Urban Machine is the waste trade point. As mentioned, this service is based on an existing program in Curitiba. Using a similar approach, families with lower income would be able to participate in the program (0-3,5 minimum wages). The ratio for exchange is 1kg of sorted waste (organic waste from recyclables) in exchange for 4kg of food (fruits and vegetables). The trade would take place every 15 days. This trade point would have the capacity to serve 100-200 people, leading to a recovery of 400-800kg of waste per service day. Considering that 60% of the waste is organic (Bain & Company, 2012), that would result in 240-480kg of organic waste and 160-320kg of recyclables waste per service day. The recyclables can be stored and sent to a sorting facility or to a Recycling Hub (when implemented). The organic waste will be the main input for the vermicomposting unit.

VERMICOMPOSTING UNIT

This is an essential component of the Urban Machine to treat organic waste. Taking in account that 1kg of worms can consume 1kg of waste (Misra, Roy & Hiraoka, 2003) and that 1.000 breeders weigh 2,2kg (Appelhof, Olszewski & Stewart, 2017), in order to consume the 480kg received from the trade point, around 220.000 worms are necessary. Also bearing in mind that a compost heap of 1,8m³ (0,6m dept) can host 50.000 worms (Misra, Roy & Hiraoka, 2003) and that the proposed compost heap is 32m³, the system can host around 900.000 worms and consume around 2.000kg of waste. The proposed compost heap also takes in consideration the 60 days necessary for kitchen waste to be vermicomposted (Singh & Singh, 2017) and the regular input of 480kg of organic waste every 15 days. Therefore, the unit has capacity to receive waste from 4 service days of the trade point, which equals the required 60 days for composting. The result is a cycle where the unit will be always in full operation. After the first 60 days, 3,5% of the first input (480kg) will be turned into vermicompost (Singh & Singh, 2017), resulting in around 17kg of fertilizer that can be used in the community garden. When the system is fully operating, a batch of 17 kg of vermicompost will be ready for use every 15 days.

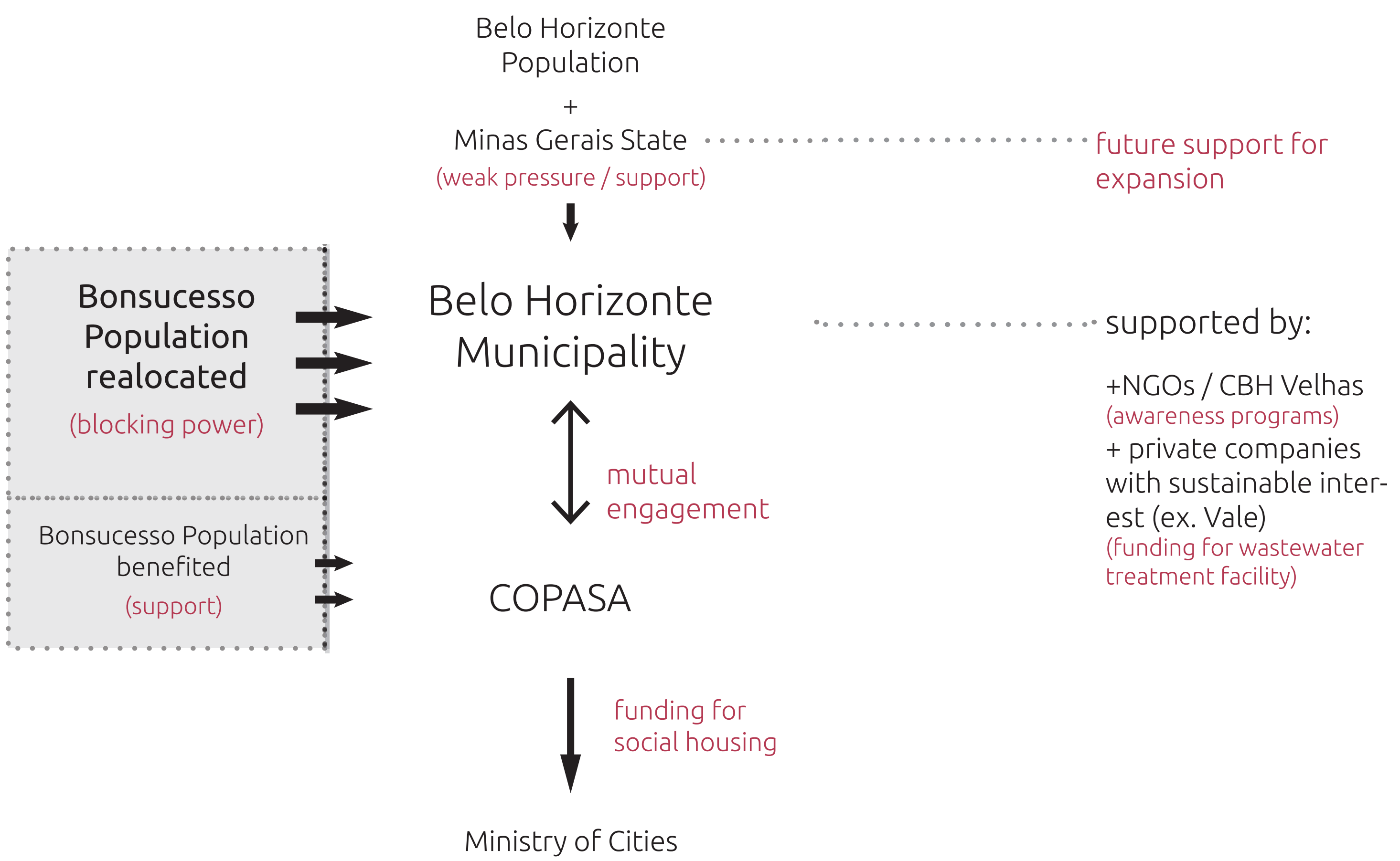
COMMUNITY GARDEN

This component has not only a social, but a metabolic importance. In this proposal, the harvesting area occupies 400m². Taking an average production of a community garden of 3,5kg/m² (Algert, Baameur & Renvall, 2014), it would be possible to harvest 1.400kg of food per season (here considered a 3-month period). This production can be exchanged in the trade point. For 200 people and 4kg of waste per person, the waste trade point requires to provide 200kg of food per service day in return. During a season, this results in 360-720kg of food. Hence, the proposed community garden will be able to fully supply this demand. The surplus can be sold to the local population or markets, for symbolic prices. It should be mentioned that it is required a proper planning regarding the production of these vegetables and fruits, to assure the continuous supply the system requires. Lastly, the community garden can also use the vermicompost produced. It is possible to estimate that a vegetable crop requires 1,2 kg/m² of vermicompost (AgriFarming,n.d), which means the proposed garden would require 480kg of fertilizer. Therefore, the garden would consume all the produced vermicompost and require external supply.

stakeholders

and phasing

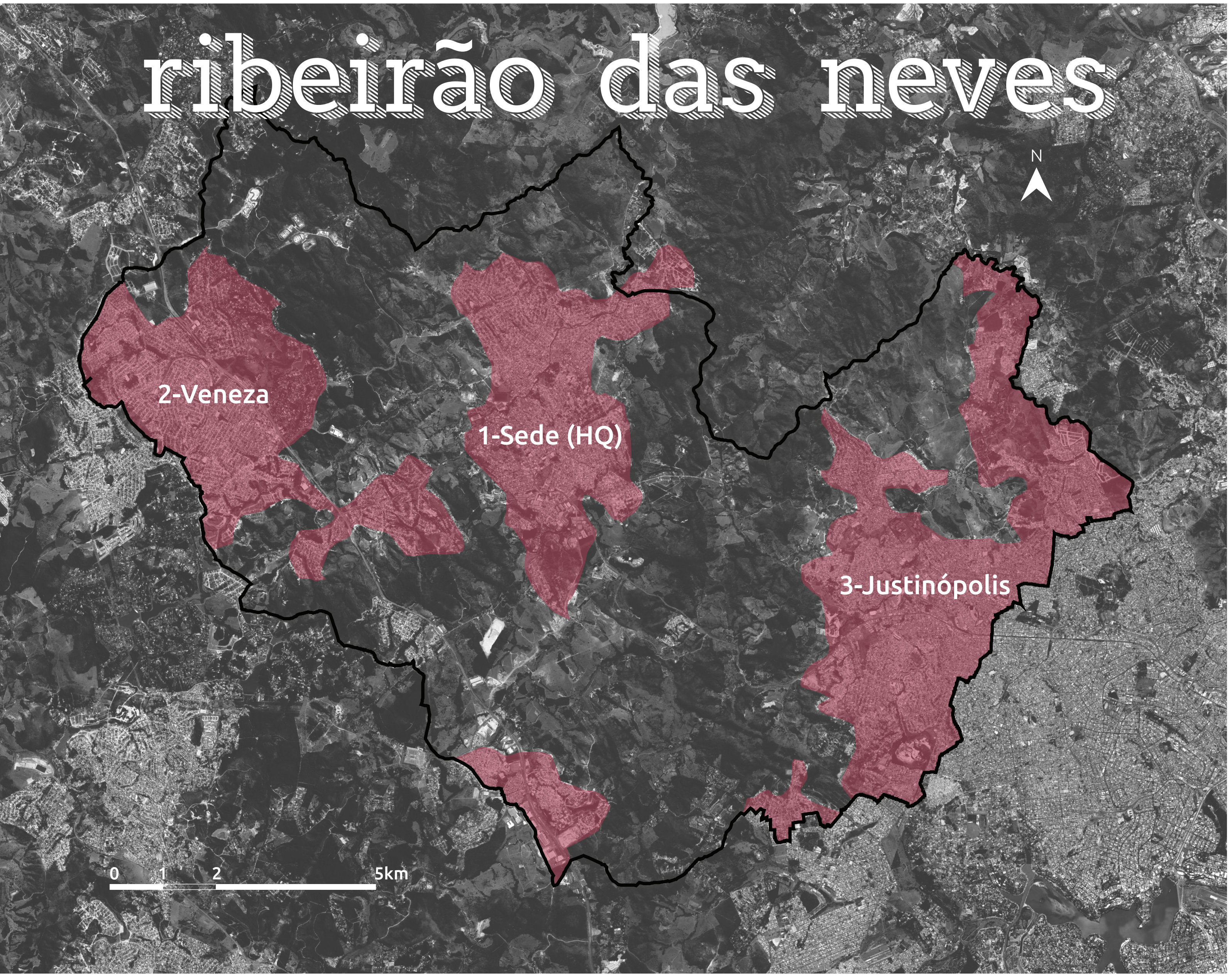
For the phasing of this development, naturally, the construction of the social housing building has to occur first. Then it would be interesting to implement the public areas, especially the community garden and vermicomposting. These activities can help create local identity and reinforce the sustainable aspect of the development. Moreover, the economic investment would be smaller, giving more time to gather the required financing for the remaining part of the system. Lastly, the construction of the wastewater treatment facility with its associated functions would complete the Urban Machine 2.0.



Stakeholders relations for Urban Machine implementation. Mutual engagement between BH and the local wastewater company COPASA. Social housing can be funded as part of the PMCMV federal program. Highlight for the people that will be removed, given their blocking power. External parties can support parts of the strategy and Minas Gerais state can support expansion of other systems.

Regarding the feasibility of the proposal, it is important to discuss the stakeholders that would be involved in this development. Considering that this proposal has greater impact on the local scale, the general population of Belo Horizonte and Minas Gerais State are likely to be less engaged. The local population of Bonsucesso neighborhood, though, will be actively involved, in two different groups. One of them is the people who will be removed and reallocated. They will, most likely, be against this development and will have a strong blocking power. On the other hand, the population who will benefit from this proposal will probably be in favor, but have limited power. Therefore, it is crucial to work together with the affected population already in the early phases, to include them in a participative process, listen and meet their demands, rather than force top-down decisions.

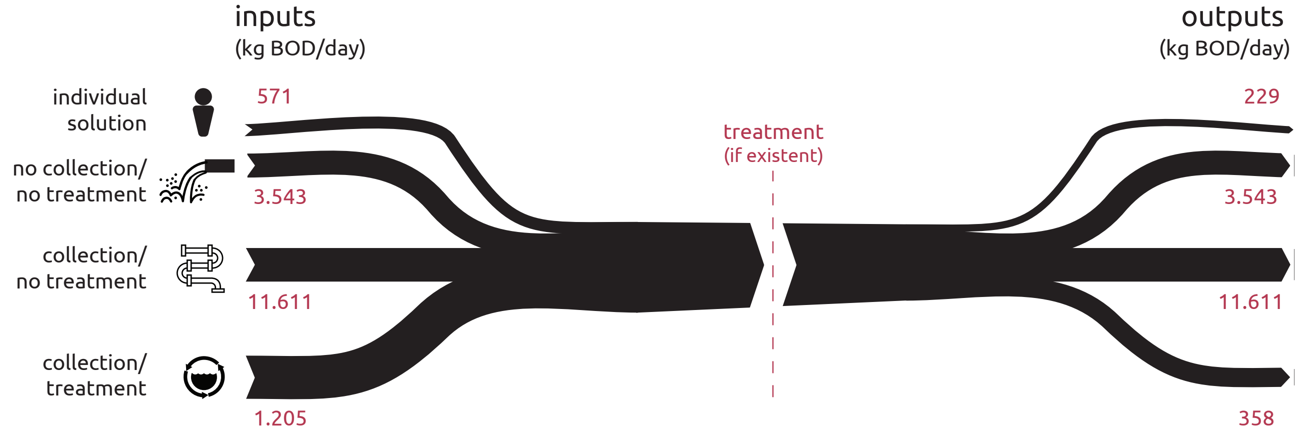
From the public sector, Belo Horizonte Municipality will be the major stakeholder in this development, for two reasons. First, the city has intention to universalize sewage treatment services. Second, because it involves public space, which is responsibility of the municipal power. However, since this proposal also includes social housing, it is possible that the Municipality searches for financing with the Ministry of Cities, through the PMCMV program mentioned earlier, for the removal of families and construction of the new building. Another support can come from the local wastewater treatment, COPASA. The company is responsible for providing all the sewage infrastructure and, in many cases, has difficulties reaching informal occupations. The added social value of this development could create a mutual partnership between the Municipality and COPASA, which can be economic interesting for both parties. The project of the Urban Machine can also be launched as a competition to get professionals from the construction industry involved and add marketing for the development. Combining with sustainable architectonic principles, private companies with special interest in sustainability could become potential partners, to share part of the construction costs in exchange of tax reductions of any other financial benefits. One company that could be interested is the multinational mining company Vale, with headquarters in Belo Horizonte and several developments in Minas Gerais State. The company has recently implemented alternative wastewater treatment systems in their buildings (constructed wetlands), in order to promote sustainable development. Furthermore, this might be a way to improve the social housing quality, adding sustainable features to the new building for example, at the expense of private companies rather than the federal government. Lastly, for the awareness programs (before, during and after), NGOs could be involved, as well as the CBH Velhas committee, given its direct relation with river pollution. Local schools can also promote educational activities to give support for integrating the facility into the identity of the neighborhood. With a successful implementation and proper branding, this strategic project can trigger the interest of other private companies and from Minas Gerais State. The State's interest would be twofold: have 100% of the population of the capital served with wastewater treatment and create feasible alternatives for wastewater treatment for areas of difficult access (since the state is also owner of COPASA). This would give the opportunity to implement other units of the Urban Machine throughout the city.



Ribeirão das Neves and its three urban districts.

4.4 testing Ribeirão das Neves

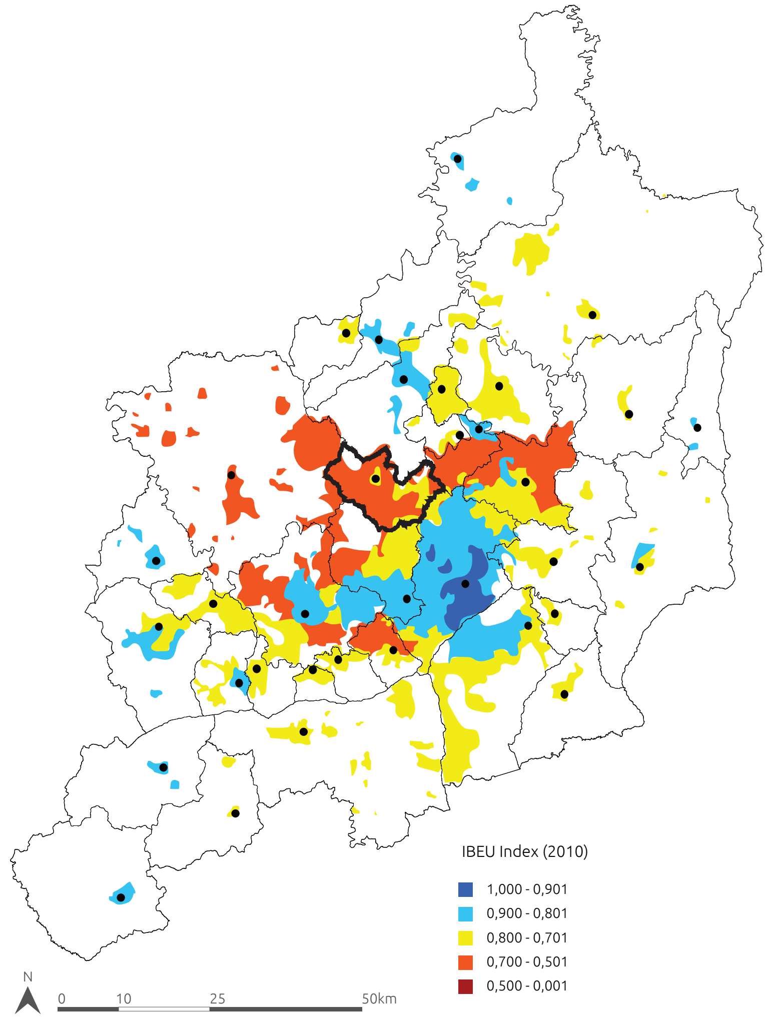
Following the same structure of Belo Horizonte test case, in the next section Ribeirão das Neves test case is presented. It provides an overview of the existing situation on the city level, including a brief history of the city. It uses the same 3-step analysis approach to find suitable locations for implementing the elected systems, including a detailed intervention of one of them. This intervention also takes in consideration metabolic relations, the territory and the local context (economic-social relations). It also includes a study of the by-products produced, as well as a stakeholders and phasing strategy.



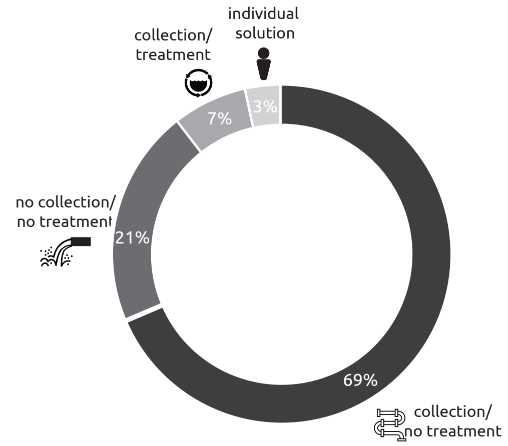
Wastewater inputs x outputs in Ribeirão das Neves. Reinforcement of the lack of sewage treatment. Base on: (ANA, 2013).

Ribeirão das Neves is part of Cluster 4 and it was chosen as test case for implementation of the proposed solutions (Landscape Machine + Recycling Hub). The choice of this city is due to the fact that it is the one with largest population without sewage treatment. Even though its BOD contribution is smaller than the capital's (most likely due to the less urbanized land, which increases BOD reduction capacity), it is the second largest contributor, having a significant impact on the existing river pollution. In addition, Ribeirão das Neves is one of the cities with worse urban living qualities, according to the Urban Well-Being Index (IBEU). It is also part of probable expansion areas and incorporated in the Macrozoning as an area with high metropolitan interest, both socially (poor living conditions) and economically (expansion of the industrial sector) (Minas Gerais State, 2017).

Ribeirão das Neves in the Urban Well Being Index (IBEU) of RMBH. The result shows great inequality between Ribeirão das Neves and the other cities of the region, especially the capital.



Notes:
Based on map "the Belo Horizonte Metropolitan Region's (RMBH) IBEU" (Nazario, 2014)

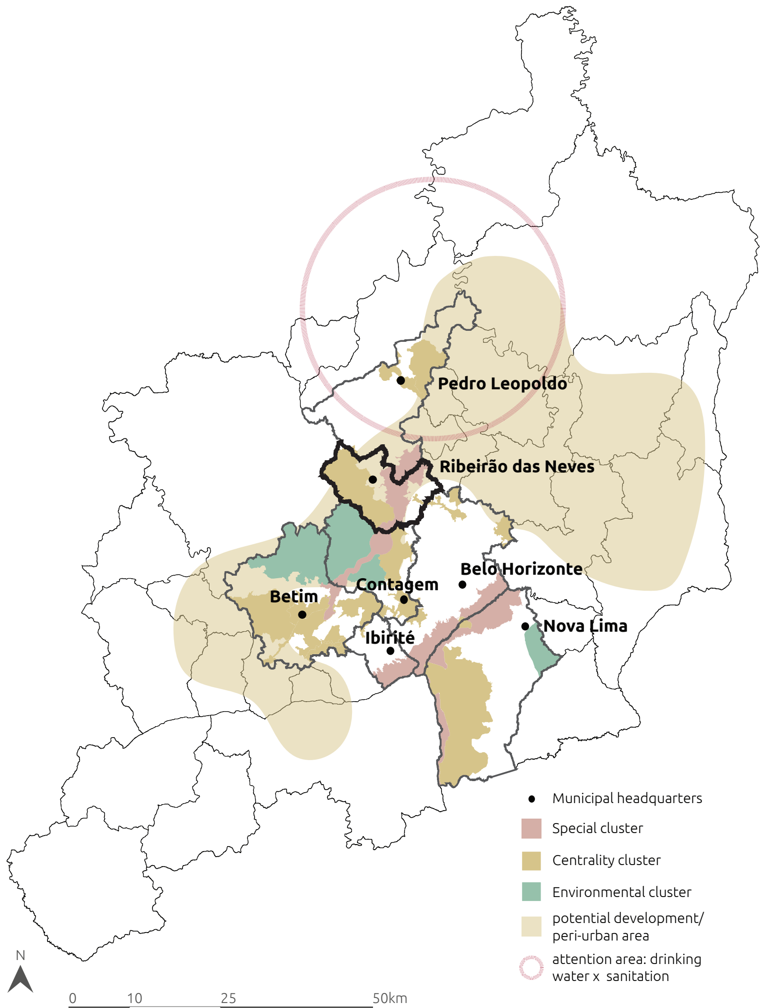


Wastewater disposal in Ribeirão das Neves. Base on: (ANA, 2013).

BRIEF HISTORY

Ribeirão das Neves' headquarters dates from the XVIII century, even before the implementation of Belo Horizonte. However, the city started to grow after the construction of José Maria Alkmin Penitentiary in 1937, especially due to the migration of inmates' families (Municipality of Ribeirão das Neves, 2006). The building of other prison units created a social and economic barrier in the area, increasing inequality issues and jeopardizing the local economy, at the time based on agriculture and mineral extraction (sand). (Municipality of Ribeirão das Neves, 2006). In the 1950s, Ribeirão das Neves received municipal status (Municipality of Ribeirão das Neves, 2006) and started to suffer from rapid urbanization process as many other cities in Belo Horizonte Metropolitan Area. Given its context and proximity to the capital, Ribeirão das Neves absorbed the population growth of Belo Horizonte due to its availability of cheap land (Municipality of Ribeirão das Neves, 2006). This land, though, lacked basic infrastructure, which contributed for increasing the social degradation of the city. The growing rate of Ribeirão das Neves was so intense that in the 1970s the city had an annual growth of 21,36% - the highest rate registered in RMBH (Municipality of Ribeirão das Neves, 2006). The occupation occurred in the outskirts of both Belo Horizonte and Contagem, as well as in the increase of its urban core (Sede-HQ) (Municipality of Ribeirão das Neves, 2006). The current urban configuration reflects this growing process, where the city presents 3 fragmented districts: the head-quarters is the central one and the other two are extensions of neighbor municipalities. Until now, Ribeirão das Neves suffers from the consequences of its rapid urbanization. Currently, it receives direct influence of the federal highway that connects Belo Horizonte to the capital Brasília (BR-040) and the industrial development along the road (Minas Gerais State, 2017).

The city is incorporated in the Macrozoning as an area with high metropolitan interest, both socially (poor living conditions) and economically (expansion of the industrial sector).

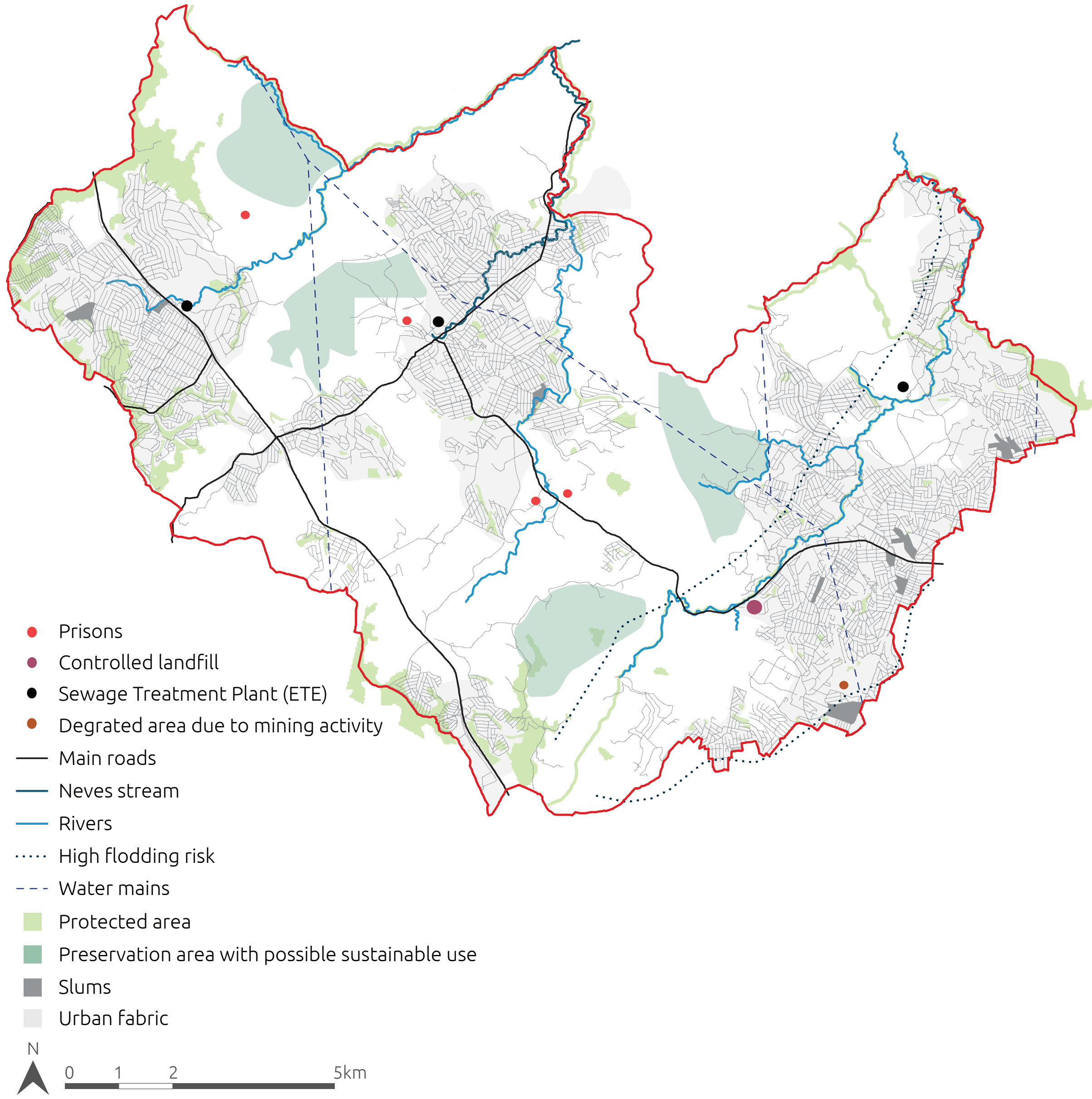


Notes:
Map based on information of the Macrozoning of the Metropolitan Metropolitan Region of Belo Horizonte (UFMG, 2015)

Ribeirão das Neves in the Macrozoning context and territorial dynamics.

the present

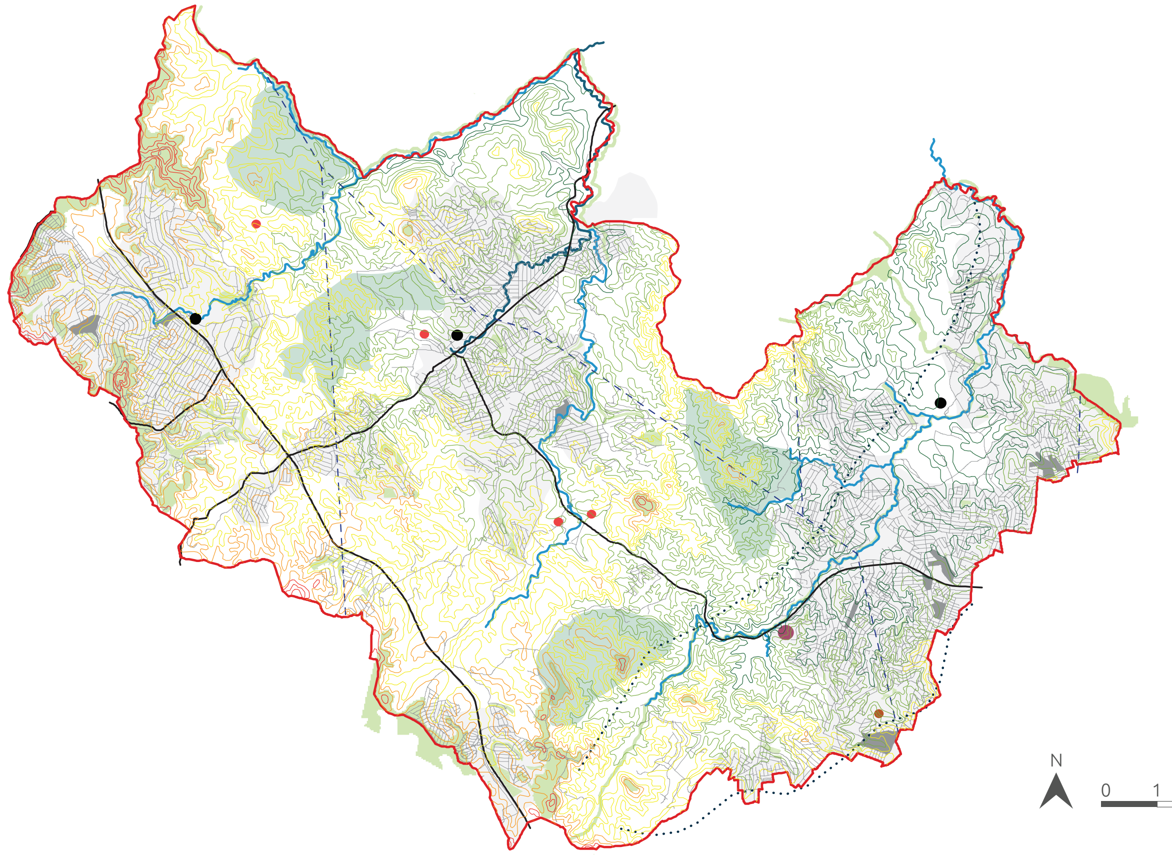
3-step analysis



Notes:
Based on information from RMBH's Metropolitan Plan (rmbh.org.br) and National Water Resources Information System (SNIRH), 2013

Current configuration of Ribeirão das Neves. Highlight to areas that should not be occupied, such as those with flooding risk or protected areas.

In order to apply the principles defined for the Landscape Machine + Recycling Hub, a 3-step analysis guided the election of the most suitable areas for imple-mentation: current situation (existing treatment plants, water infrastructure, protected areas, slums); topography and zoning plan (expansion areas). With this analysis is possible to guarantee principles related to topography and landuse. For the Landscape Machine, those principles are: locations close to

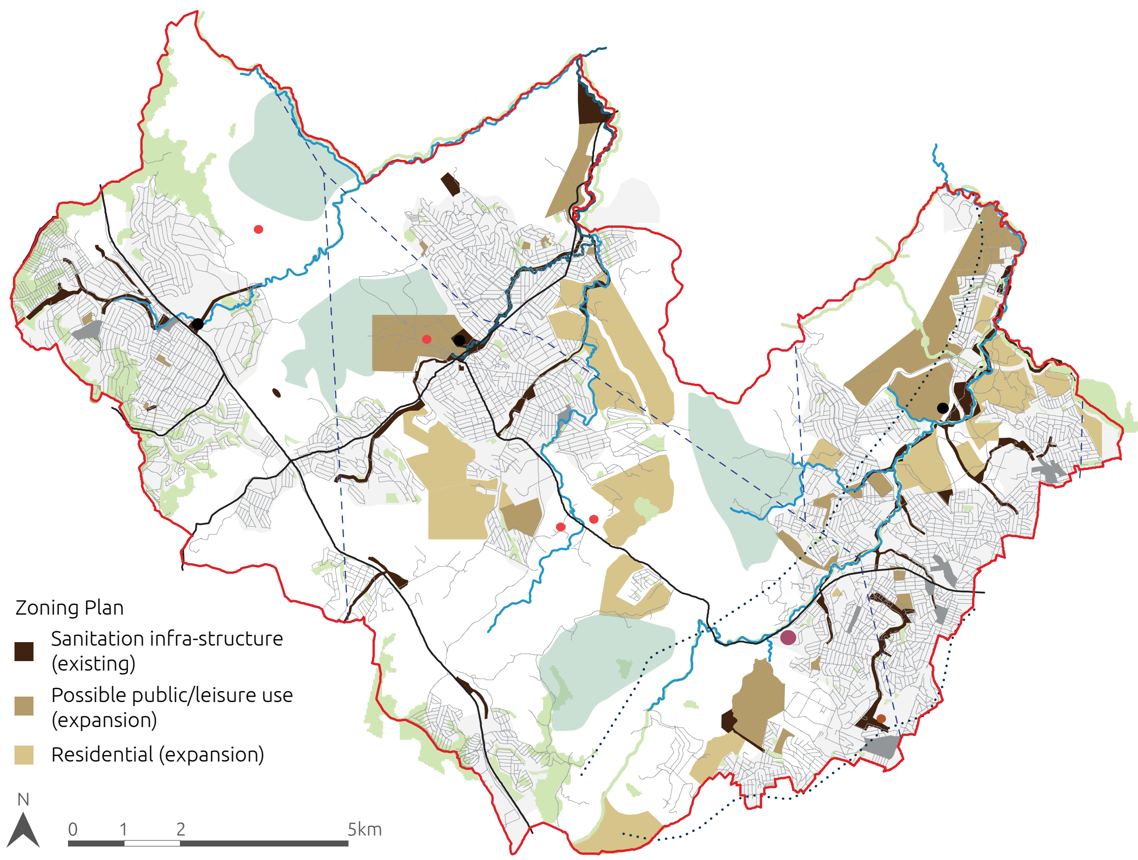


Ribeirão das Neves' topography. One of the principles of Landscape Machine is to implement the system in lower areas.

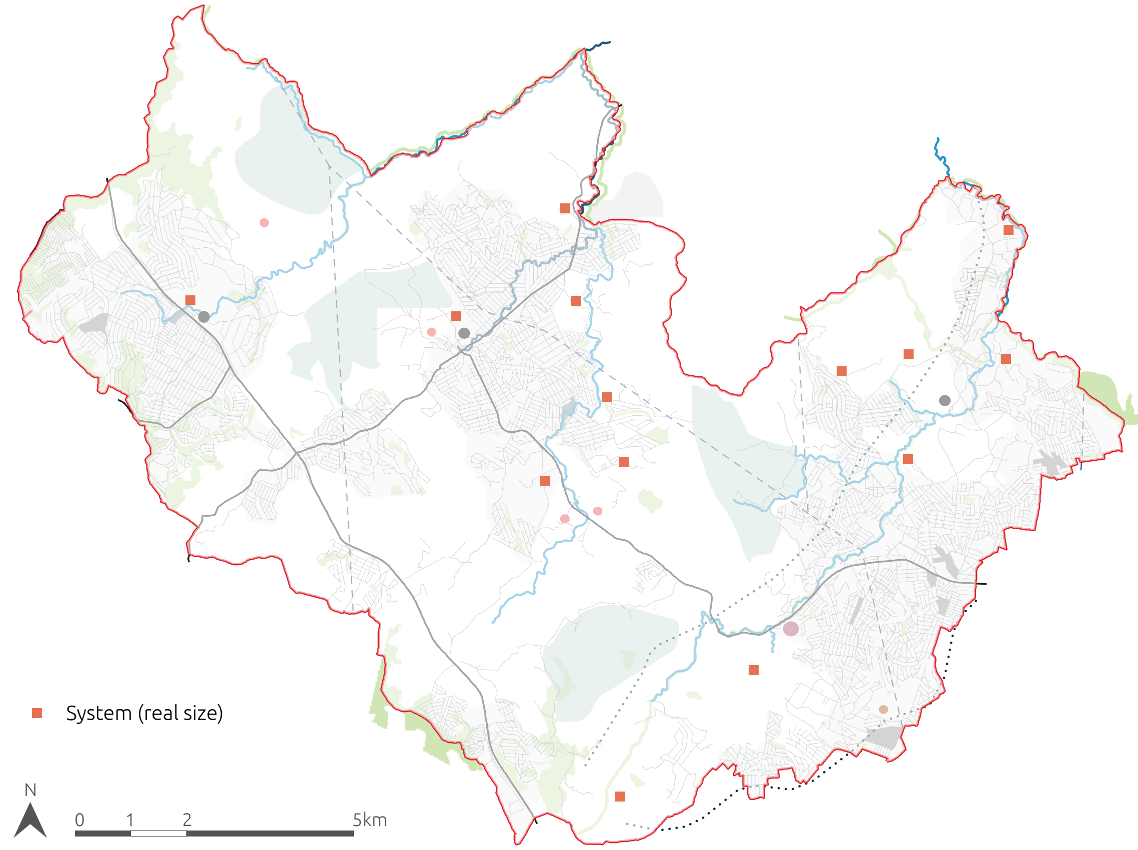
expansion areas; lower than the urban core; not in preservation or flooding areas and with no cutting infrastructure (constructed wetland); and with safe distance from housing (co-composting). For the Recycling Hub, the principles refer to the identification of derelict areas and with safe distance from housing.

It should be noted that the number of required systems takes in consideration the amount of people without sewage treatment (280.594) and that each system's capacity is 20.000 people. Therefore, Ribeirão das Neves needs 14 systems to cover the entire population without infrastructure. These combinations would allow the creation of a network of public spaces for the city, also giving incentive for implementing multiple units.

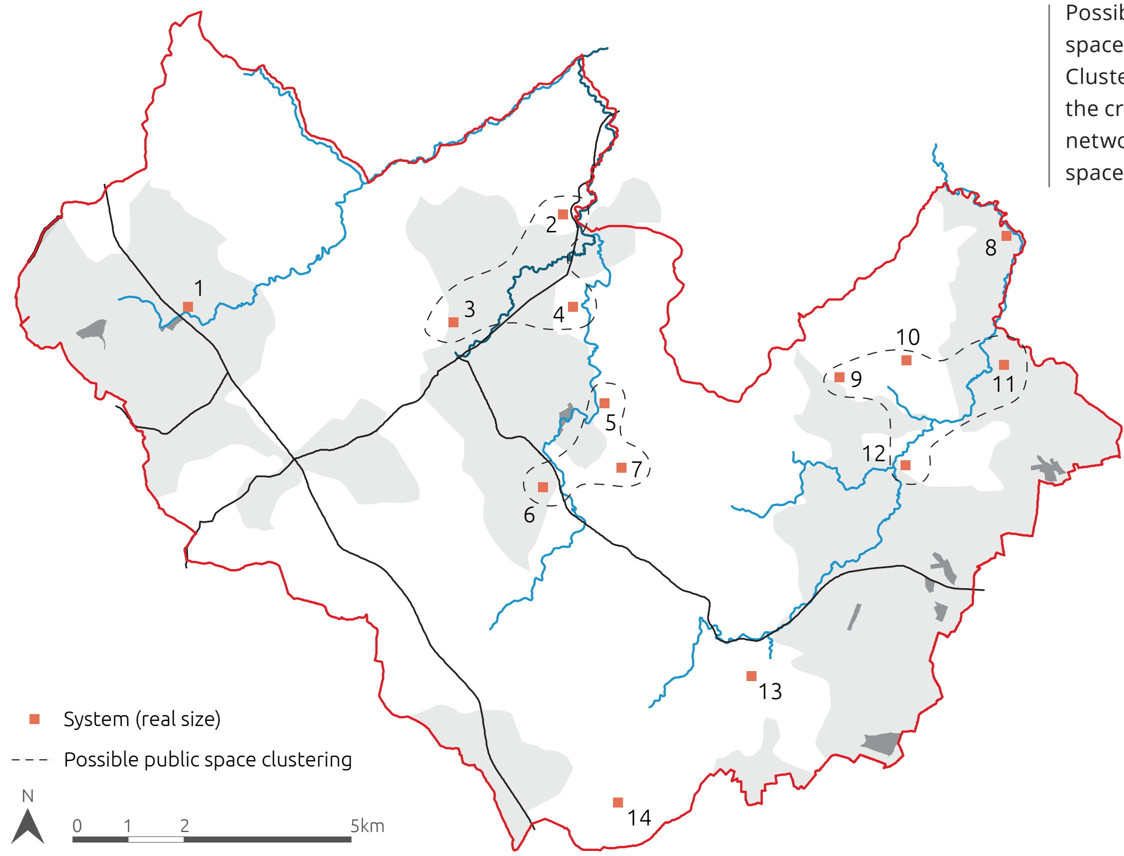
Ribeirão das Neves' zoning. One of the principles of Landscape Machine is to implement the system close to expansion areas



Elected areas for intervention. Distribution of the 14 systems required to cover the entire population without sewage treatment.



Considering the presented clustering, this thesis puts forward a detailed proposal for one of the elected areas for intervention. The chosen area is number 3, given its potential to integrate with the urban fabric, considering the existing functions and the proximity with the city center. This location is particular interesting since it incorporates one of the existing prisons, Penitentiary José Maria Alkmin, creating an opportunity to improve the quality of the public space around such equipment. In addition, it contributes for softening the city's current image of "prison city".



Possible public space clustering. Clustering allows the creation of a network of public spaces for the city.

unraveling the metabolism

Penitentiary José Maria Alkmin was the first penitentiary of the State (1938).

José Maria Alkimin Penitentiary.
Picture: Enzo Menezes

As mentioned earlier, Penitentiary José Maria Alkmin was the first penitentiary of the State and has been functioning for 80 years (since 1938). The buildings were conceived following European penal establishments at the time and since 2007 are considered heritage on the municipal level (Tupinambás, 2012). The long term construction of the prison, associated with its rural location, resulted in the construction of housing around it (for workers and employees) and, with the later inflow of the families of inmates, the city started to grow (Drummond, 2017). For that reason, this equipment is so close to the city center. However, even though the existing houses provide a more familiar atmosphere to the area (Tupinambás, 2012), the city center turns its back to the prison, in an attempt to isolate it from the urban core.

Another particularity of this facility is its agricultural basis and the idea of "self-sustainability" (Drummond, 2017). The facility, when created, included farming, cattle breeding, bakery, shoe factory, pottery and toy/uniforms factory (Drummond, 2017). The idea of using prisoner's labor as rehabilitation was taken as model for other institutions in the country and Latin America (Drummond, 2017). The success was such that the prison held a store in Belo Horizonte to sell its products and it was also responsible for baking bread and cooking meals that were distributed to other locations, such as police stations (Drummond, 2017). In the 80s and 90s, though, violence, rebellions and overcrowding compromised this vision (Drummond, 2017).

Existing situation: area of intervention.

1. Penitentiary José Maria Alkmin
2. Federal Institute of Minas Gerais - IFMG Ribeirão das Neves
3. Forum of the District of Ribeirão das Neves Judge Assis Santiago
4. Stabilization pond (wastewater treatment - COPASA)
5. City Council of Ribeirão das Neves

city center
main accesses
Neves stream

Nowadays, the prison was able to recover from the rebellions (the latest was in 2001) and restore its agricultural roots and rehabilitation though work (80% of the inmates currently work (Tupinambás, 2012)). Inside the complex, there are community gardens, bakery and a brick factory (Tupinambás, 2012). The inmates who have flexible sentences are allowed to work outside the prison without direct supervision (for example some of them worked in the renovation of New Mineirão Stadium, in Belo Horizonte, for the 2014 World Cup) (Tupinambás, 2012).

On the surroundings of prison, there are also a local Forum; a Federal Institute of Minas Gerais (IFMG), which offers superior education (technical and bachelor degrees); the City Council and a stabilization pond used for sewage treatment. A few soccer fields are also present in the area.

Existing situation #3.
Stabilization pond
March /018).
Picture: Carolina Eboli

Areas within the area of intervention.

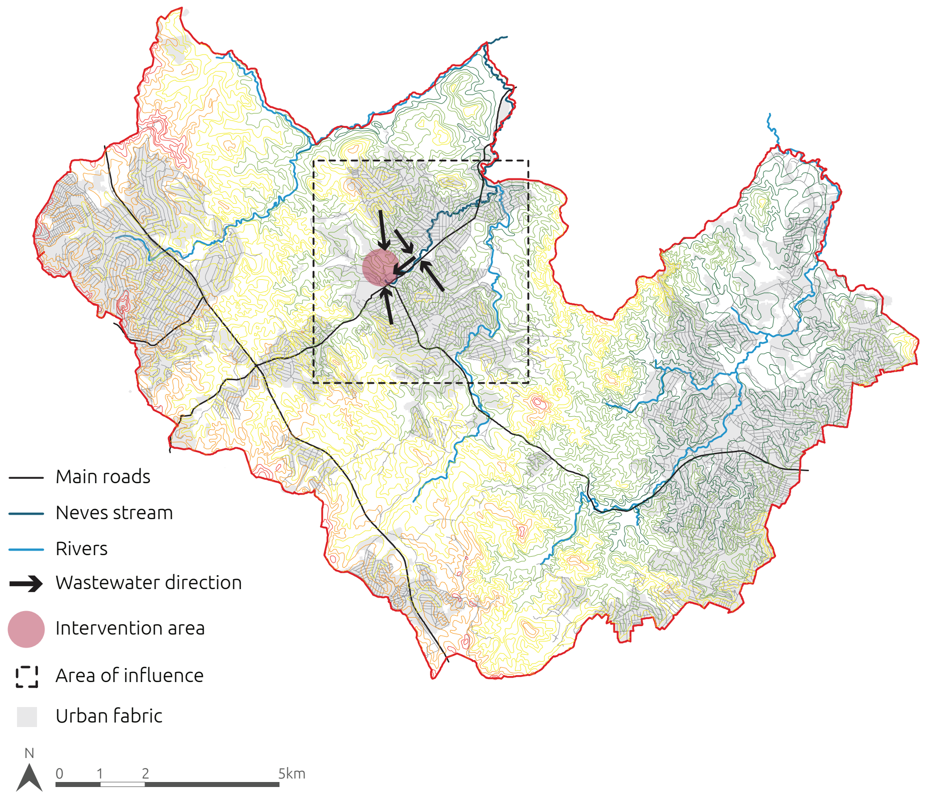
SYSTEM IMPLEMENTATION

For the successful implementation of the Landscape Machine, it is preferable to use gravity for conduction of the wastewater. When analyzing the existing topography, it is possible to understand that the area of intervention could serve two different portions of the urban fabric: east and west of Neves stream. For that reason, the distribution of two constructed wetlands is more efficient. Another aspect is that there is already a stabilization pond for wastewater treatment in place, which facilitates the construction of the new system. It should be noted that the existing pond occupies around 33.000m² and serves 3.614 people (SNIRH, 2013). On the contrary, following the area principles defined previously, to implement a Landscape Machine that serves 20.000 people, it is required 29.680m², from which only 20.000m² are used for the wastewater treatment. Moreover, since there is sufficient area for 2 constructed wetlands (40.000m²), it is possible to serve 40.000 people, 11 times more than the current situation.

Besides understanding the most efficient distribution of the constructed wetlands, accessibility is another aspect that requires attention. As mentioned before, the area of intervention is close to the city center, which increases its potential as a public space. For that reason, the accessibility of the equipment is crucial for its success. Currently, Cataguáses St. is the main access from the north portion of the city towards the city center, crossing between a soccer field and the stabilization pond. However, with the continuation of Cataguáses St. directly into the city center (connecting with Lauro S. Nogueira St.), it is possible to divert the heavy traffic from the site, preserving the easy access and increasing local quality. The existing road can be maintained as a secondary access, since the proposed systems function on synergetic relations between its by-products and local sectors, and therefore, requires space for logistics and easy access for trucks.

From the pedestrian point of view, the area could be easily accessed from the main shopping street Raimundo N. de Souza St. However, currently the

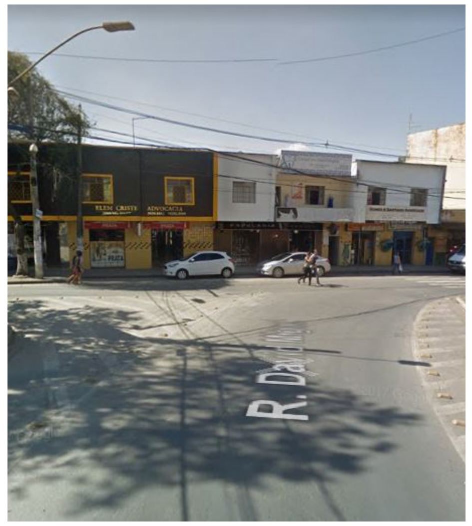
It is possible to serve east and west of Neves stream. For that reason, the two constructed wetlands is more efficient.



Natural direction of wastewater discharge in relation to intervention area.

(B) Houses to be demolished for new pedestrian access. Source: Google Street View, 2017.

(C) Houses to be demolished for new road access. Source: Google Street View, 2017.



The proposed continuation of Cataguáses St. directly into the city center diverts the heavy traffic from the site, preserving the easy access and increasing local quality. From the pedestrian point of view, the bridge would allow integration between the intervention, the river and the commercial street.

whole street is occupied and there are no bridges connecting the two sides of Neves Stream. Therefore, it is proposed a new pedestrian + bicycle connection, following the extension of Paraná St. The choice of the location of this bridge relates to the minimum impact on the current situation and the existence of free space on its immediate surroundings. Furthermore, the bridge would allow integration between the intervention, the river and the commercial street.

Accessibility intervention.

Function distribution.
Distribution of the components of both Landscape Machine and Recycling Hub. Complementary uses, such as a park, recreational areas and logistics center support the successful implementation of the proposal.

Taking in consideration what was presented previously, the proposal includes a Landscape Machine with two constructed wetlands and new accesses. One of the constructed wetlands uses part of the existing stabilization pond and the other one uses the hilly topography to serve the people east of Neves stream. An additional polishing phase is included to allow the reuse of the water (the method can be chlorination, ozonation, H202 or UV disinfection and they happen in tanks underground). The reuse water is directed to lakes in between the constructed wetlands. The lakes are integrated with a park, as well as recreational spaces. With the new accesses, there is space to provide a parking lot for visitors and a logistics center for storage, loading and unloading of by-products. Complementing the system, pre-treatment and biogas reactors are placed in strategic positions to receive wastewater. Moreover, the co-composting is located further from the city center, considering the required principles of distances due to possible smells.

Lastly, the Recycling Hub is placed on the corner of the area to receive more attention from users. The combination with shops and workshops also has the purpose of attracting visitors. Furthermore, it gives room for incorporating other functions, such as a themed recycling plaza or café, that can also serve as support for both users of the park and the soccer field across the street. One of the local shops can be designated for the prisoner's work, reviving its former success. This action also contributes symbolically, to reinforce the local identity and acceptance of the prison as part of the city.

The following reference images illustrate some of the urban and landscape qualities this intervention aims for and elements that can be successfully integrated into a public space.

Proposed plan and urban and landscape qualities this intervention aims for.

Typha latifolia

Chrysopogon zizanioides

Strelitzia nicolai

Capa x generalis

Species for constructed wetlands: animal feeding on top and ornamental on the bottom.
Source: Wetlands Construídos.

Recreational areas.
Picture: Federico Cairoli

Pedestrian bridge.
Picture: Carolina Eboli

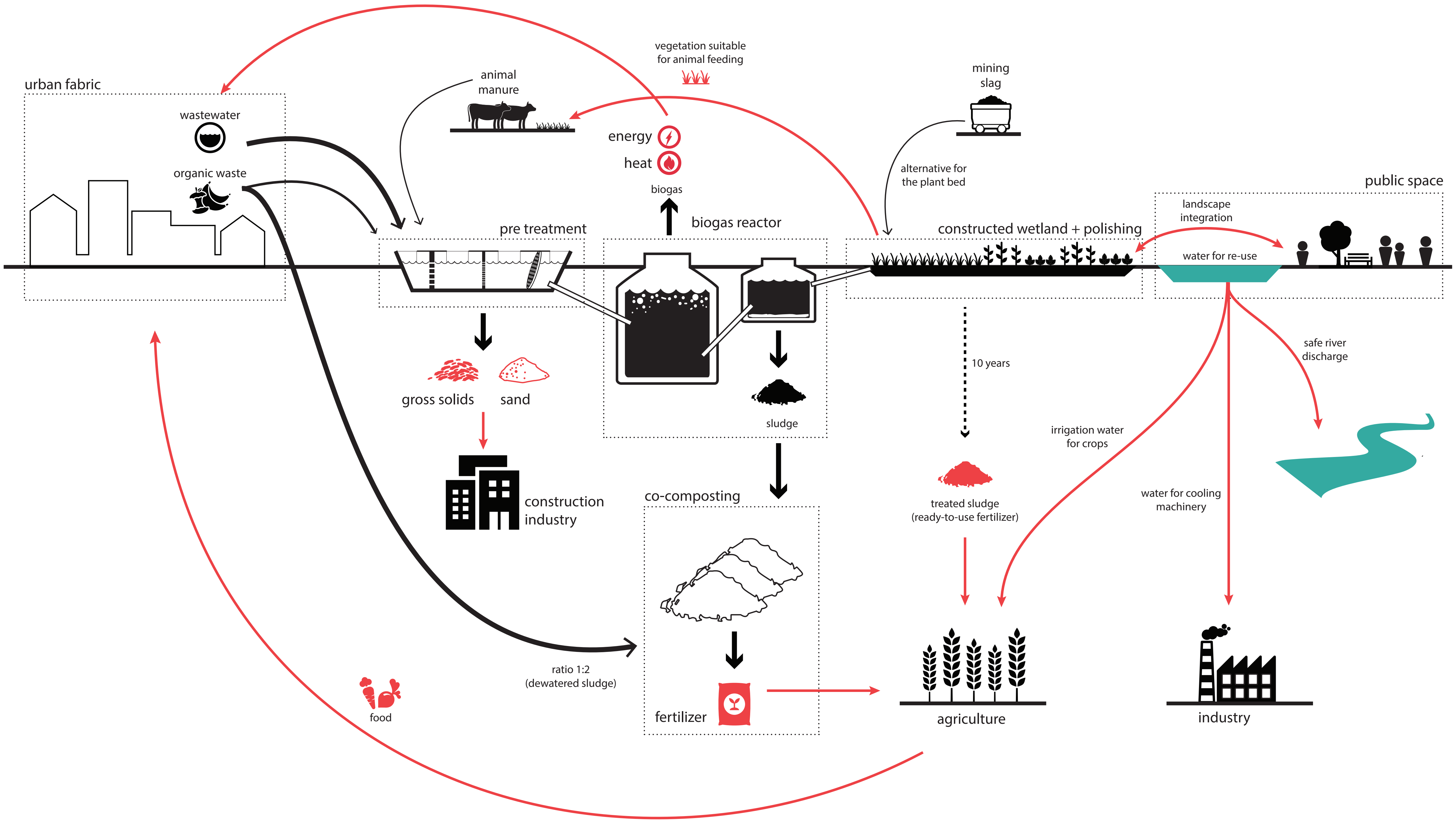
Recreational areas.
Source: Municipality of Madrid

Recycling Hub Plaza
Source: BySam

Recycling shops/ industrial vibe.
Source: NiT

LANDSCAPE MACHINE

The Landscape Machine follows the principles defined previously. It is a combination of elements (biogas reactor + constructed wetland (CW) + co-composting). The biogas reactors receive input of wastewater, organic waste and animal manure and produces biogas for electricity or heating. They include a pre-treatment phase, where sand can be separated and used in the construction industry. The CW provide secondary treatment for the wastewater and harvest specific species for animal feeding and ornamental purpose. The sludge produced in the CW is also a ready-to-use fertilizer that does not require any further treatment. The system also includes a polishing phase, to use the effluent as water for re-use, allowing integration with the landscape. The remaining treated water can be used for irrigation, sold for industries or safely discharged into the rivers. The last component is the co-composting that associates organic and green waste to treat the produced sludge, which in turn provides fertilizer for crops.



With the association of the constructed wetland with a biogas reactor and a co-composting unit, it is possible to treat wastewater and solid waste. The combination results in rich by-products that allow interconnections between flows.

Landscape Machine components and by-products.

View from the proposed Landscape Machine. Wastewater treatment integrated with landscape and public space. The lake uses treated water from the wetlands and provides qualities to the park and recreational areas in the surroundings.

by-products

The first set of relations can be created between the proposed systems and the neighbor prison José Maria Alkmin. The prison will be able to absorb and provide by-products only partially. However, there is a significant value in creating these relations to incorporate the prison positively in the urban life and contribute to the reduction of the negative vision of the city as "prison city".

Relation between the neighbor prison and the system's by-products.

As mentioned previously, the success of the Landscape Machine + Recycling Hub relies also on solid relations between producers and consumers of the by-products created within those systems and the products they require to function efficiently. The first set of relations can be created between the proposed systems and the neighbor prison José Maria Alkmin. The community garden inside the prison can receive treated water from the constructed wetlands and the fertilizer produced by the co-composting; the manure of the cattle and green waste produced in the prison can be used to increase the biogas reactors efficiency; and the brick factory can receive sand from the pre-treatment phase. It is important to highlight that the prison will be able to absorb and provide by-products only partially. However, there is a significant value in creating these relations to incorporate the prison positively in the urban life and contribute to the reduction of the negative vision of the city as "prison city".

In order to meet the scale requirements of these systems, though, other relations should be created. Each by-product requires a specific associated function, and at times, these relations can occur both ways (in and out of the systems).

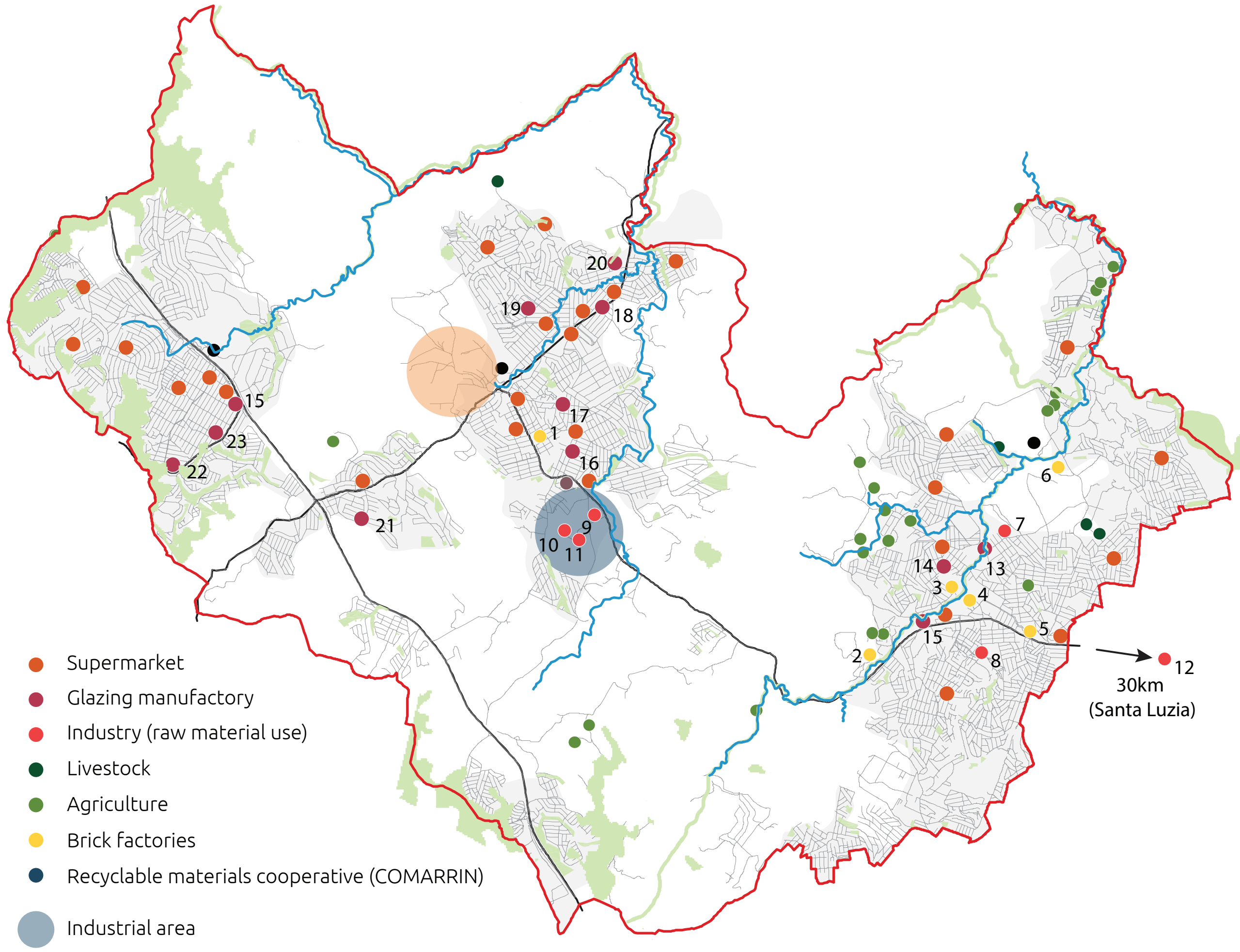
In relation to the Landscape Machine:

- sand from the pre-treatment can be used in brick factories;
- supermarkets can provide consistent organic waste for the biogas reactors and co-composting (volume and frequency);
- livestock producers can provide animal manure for the biogas reactors and use vegetation harvest in the constructed wetlands for animal feeding;

QUICK REMINDER

It should be noted that the biogas is also a important by-product of the Landscape Machine. However, its distribution has higher impacts on the subsurface and, therefore, were not represented in these set of maps.

Existing functions related to Landscape Machine's and Recycling Hub's by-products



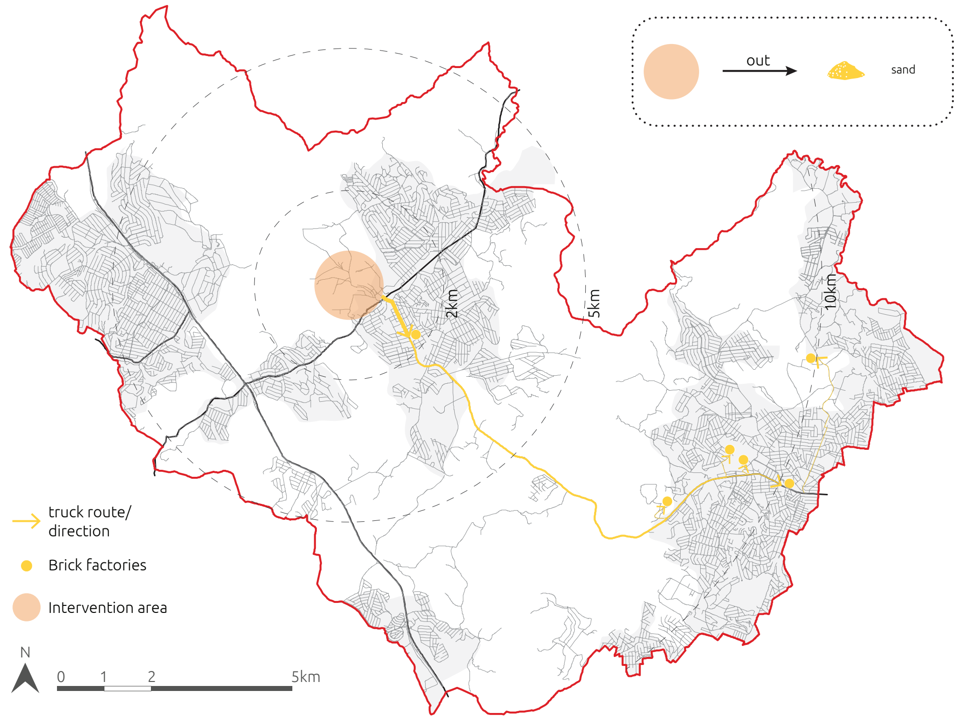
- Supermarket
- Glazing manufactory
- Industry (raw material use)
- Livestock
- Agriculture
- Brick factories
- Recyclable materials cooperative (COMARRIN)
- Industrial area
- Intervention area
- Main roads
- Das Velhas River
- Rivers
- Protected area
- Urban fabric

N
0 1 2 5km

1-Cerâmica Lolanda
2-Cerâmica Santo Antônio
3-Cerâmica Jacarandá
4-Cerâmica Marbeth
5-Cerâmica Braúnas
6-Cerâmica Tijolão
7-DVG Indústria e Comércio de Plásticos (plastic)
8-GK Industrial (metal)
9-Copersan (plastic/metal)
10-Isel (metal)
11-FUMEF (metal)
12-Celulose Irani (paper)
13-Mr. Vidro
14-Vidraçaria 2000
15-Acácia Vidros
16-Vidraçaria Santa Marta
17-Vidro Valle
18-Vidraçaria Dutra
19-Sandro Vidro
20-Vidraçaria do Orestes
21-Vidraçaria Louredo
22-Vidraçaria JP
23-Vidraçaria Master Vidros

Notes:
Agriculture and Livstock based on information from RMBH's Metropolitan Plan (rmbh.org.br) and National Water Resources Information System (SNIRH), 2013
The presented information is not extensive to the existing situation (other industries/shops may exist)

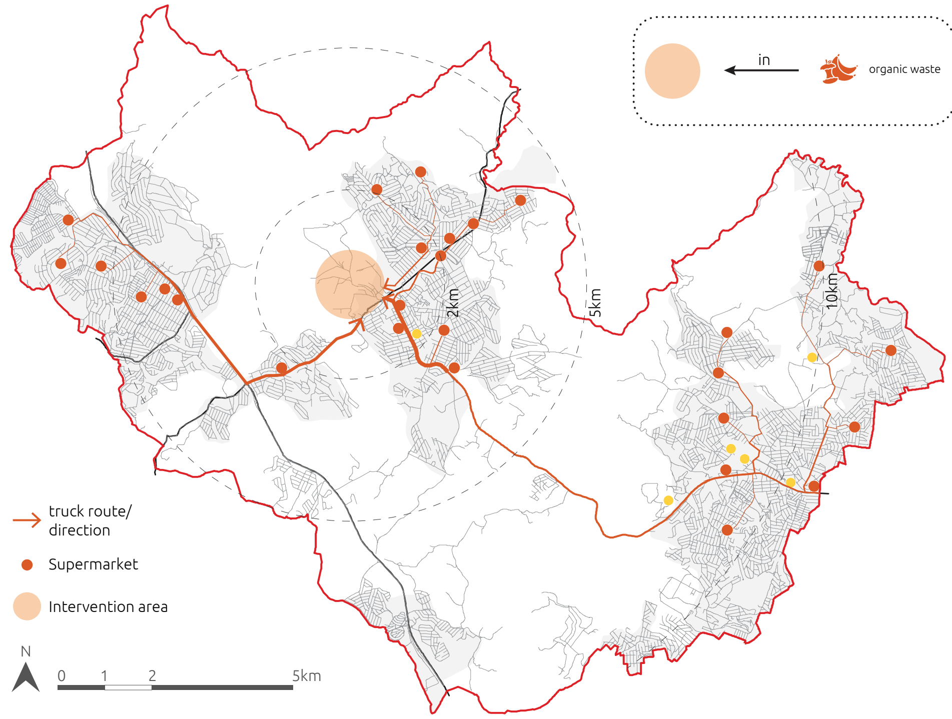
Associated function: brick factory. Brick factories can use sand removed on the wastewater pre-treatment phase.



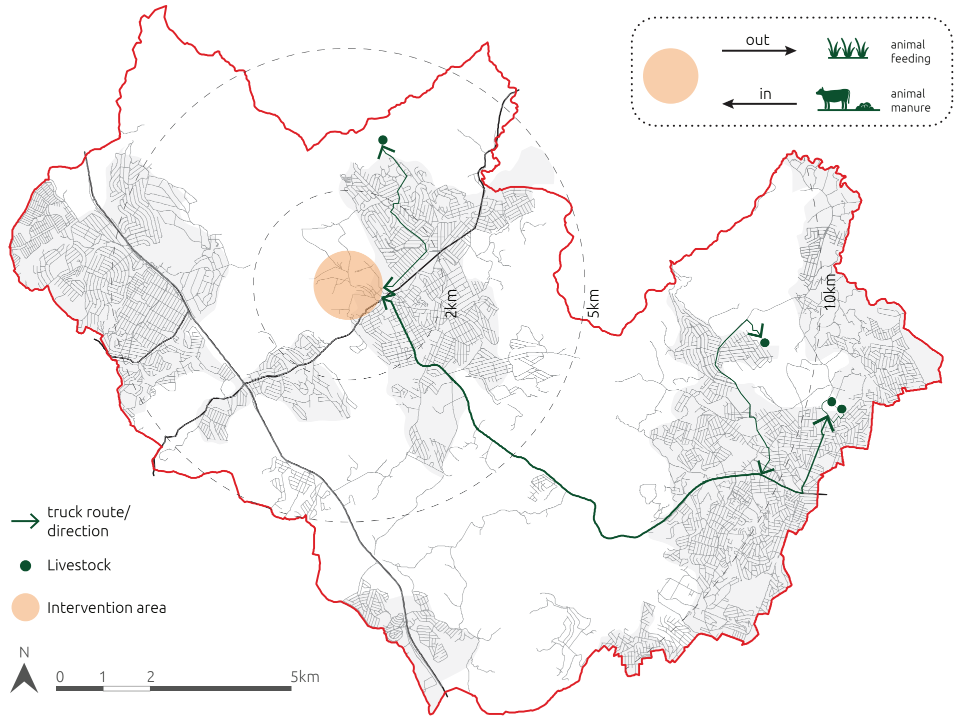
- agriculture fields can provide green waste for the biogas reactors and receive fertilizer from the co-composting (and eventually from the de-sludging of the constructed wetlands) and treated water for irrigation;
- treated water can be used for cooling machineries in heavy industries;

In relation to the Recycling Hub:

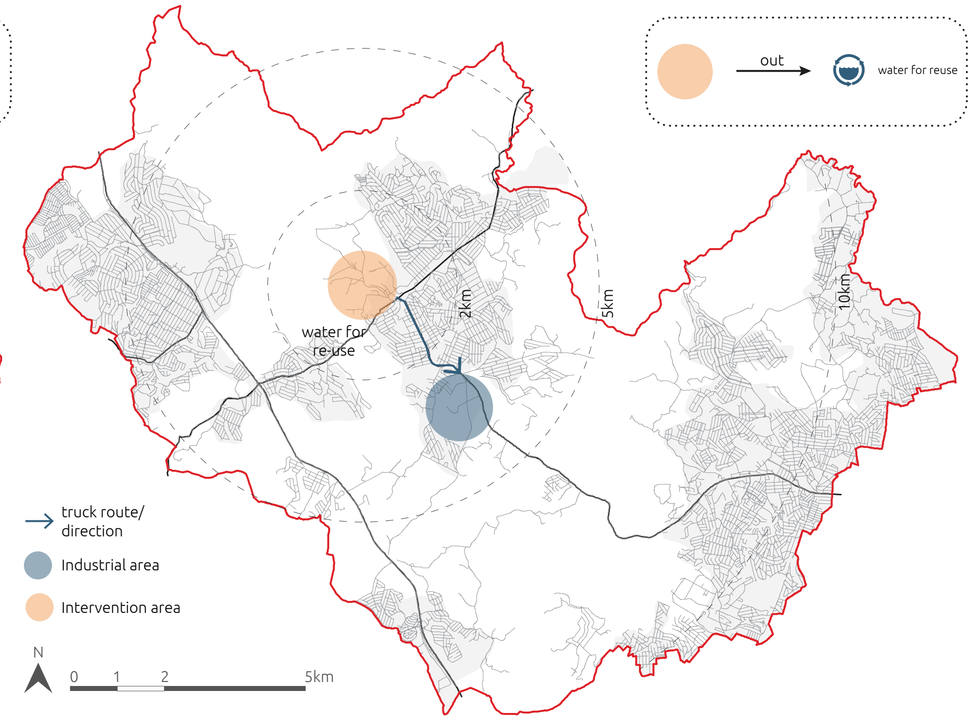
- glazing manufactories can receive crushed glass;
- industries that have as end products metal, plastic or paper components can receive crushed metal, shredded plastic and paper;



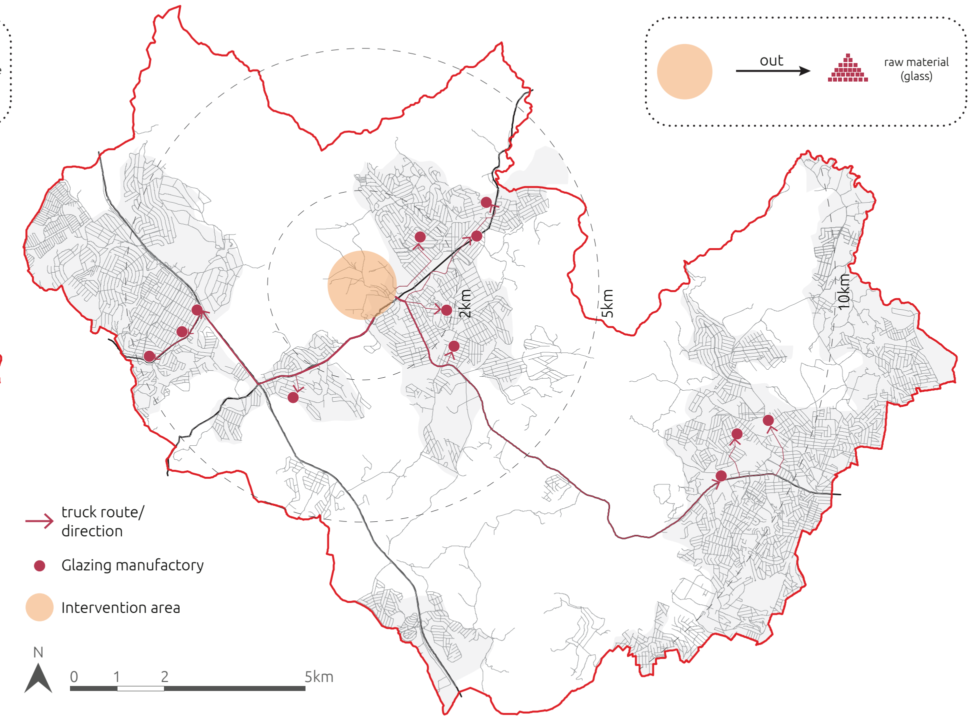
Associated function: supermarket. Supermarkets can provide constant supply and volume of organic waste to kick start the co-composting unit. It can also be used in the biogas reactors.



Associated function: livestock. Livestock activities can provide animal manure to increase the biogas reactor's efficiency. In addition, they can consume the species in the CW, harvest for animal feeding.

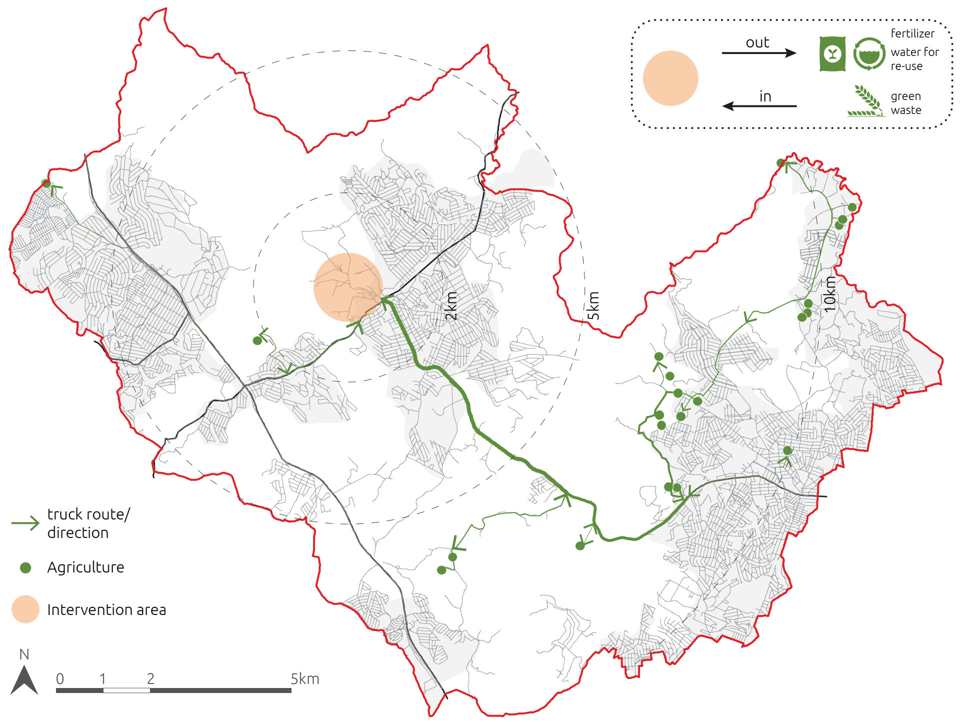


Associated function: industry (general). The industrial area in the city can consume the surplus of treated (reuse) water for cooling machinery.

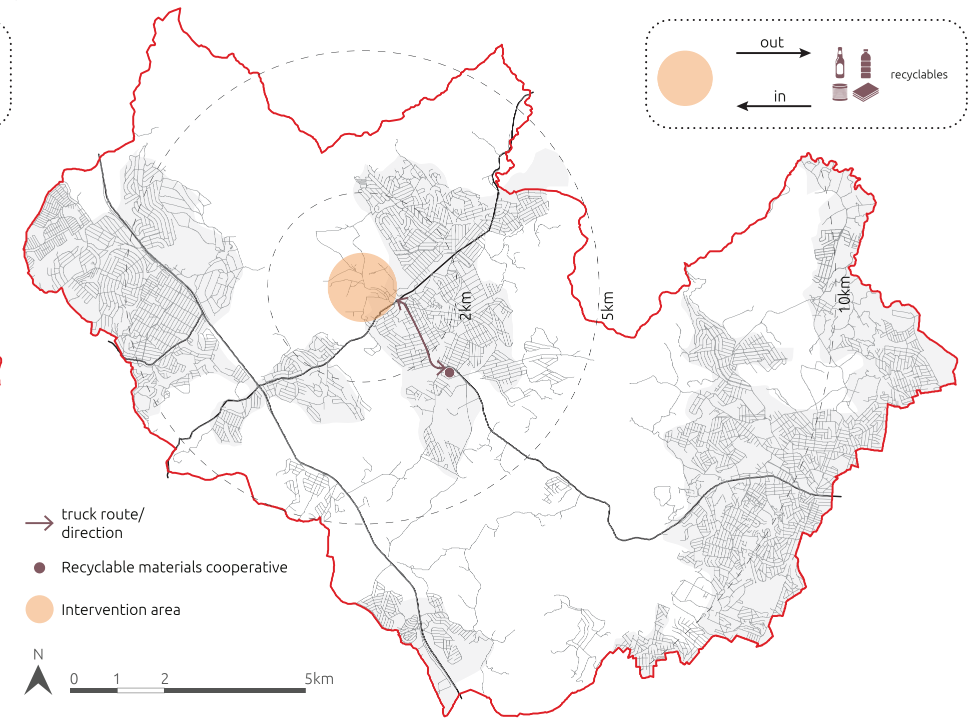


Associated function: glazing manufactory. Glass pre-treated in the Recycling Hub can be sold to local glazing manufactories.

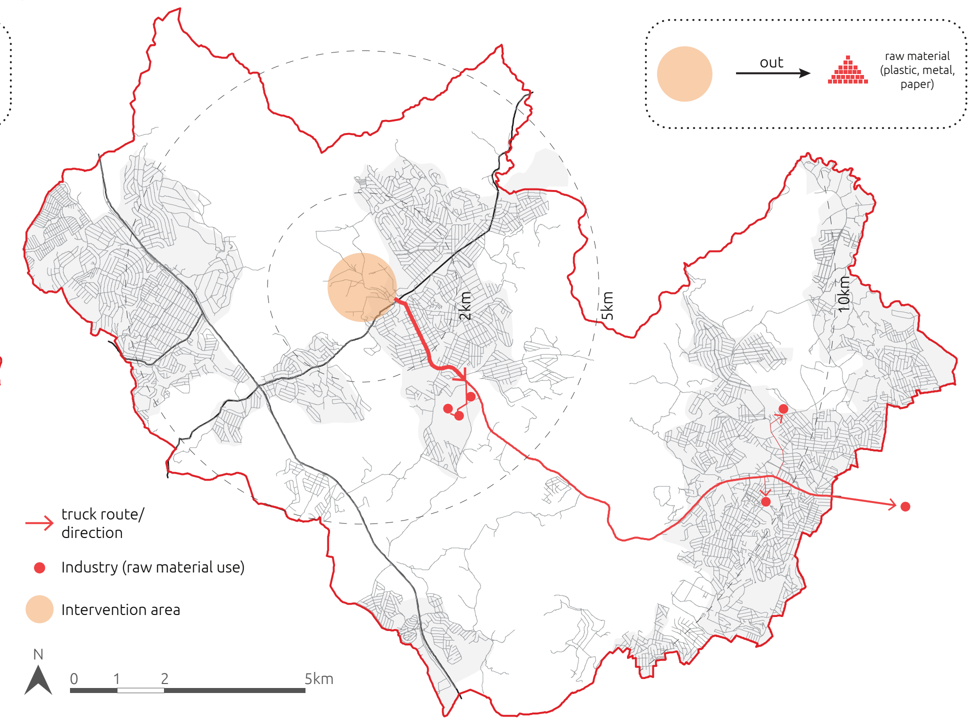
Associated function: agriculture. Agricultural activities can provide green waste to be used in the biogas reactors or co-composting unit. In addition, they can consume fertilizer produced in the Landscape Machine and use treated water for irrigation.



Associated function: recyclables cooperative. The existing recyclables cooperative can act as an extension of the Recycling Hub. It can storage and control the flow of recyclables, as well as do preliminary treatment actions (for example sorting).



Associated function: industry (specific use). Pre-treated paper, plastic and metal in the Recycling Hub can be sold to local industries that use those raw materials as part of their production process.



Transportation impacts of by-products.

The impact of transporting the by-products should also be taken in consideration. To assess this impact, it was studied inputs x outputs of each by-product:

Sand: it comes from the wastewater pre-treatment phase. The ratio between the volume of sand removed and volume of treated effluent is 2 to 4m³/100.000m³ of treated sewage (Cammarota, 2011). Considering that the proposed system treats sewage of 40.000 people (0,16m³/person/day), each day the system would remove 0,26m³ of sand. Considering that a truck for sand can carry around 10m³, it would be required one truck every 1,5 month to remove the produced sand.

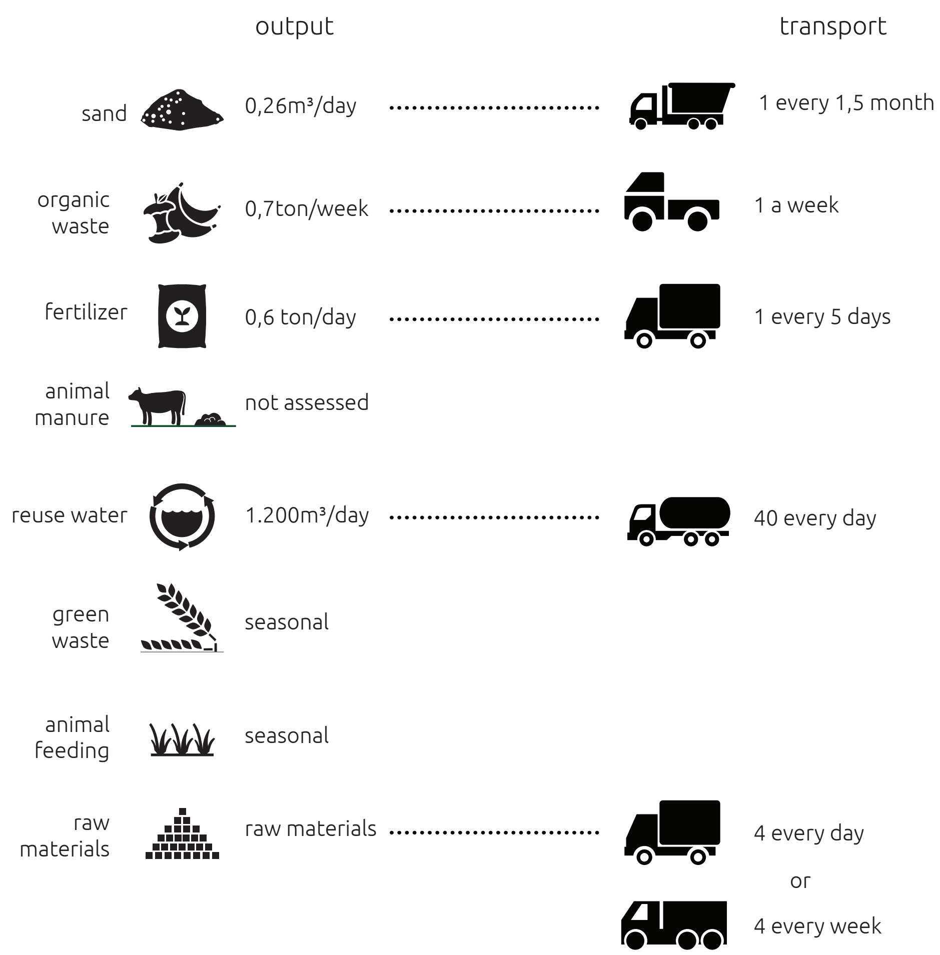
Organic waste: the main part of the organic waste will go to the co-composting unit. The first supply of organic waste can be the supermarkets. Using the example of one supermarket chain that have successfully implemented composting actions for their organic waste in Brazil, it is possible to estimate that a supermarket produces 0,1 ton/month of compostable organic waste. 28 stores were mapped in Ribeirão das Neves, which could provide 2,8ton/month. In a weekly waste pick up, that would lead to 0,7ton of organic waste. Estimating the density of the organic waste as 900kg/m³ (Hessami, Christensen, Gani, 1996), the volume of this cargo would be 0,8m³. Therefore, the waste can be stored in steel containers (1.200L) and be transported in smaller vehicles.

It is important to highlight that the proposed co-composting unit was designed taking in consideration the domestic waste production of 20.000 people, and therefore, it can receive up to 8,4ton/day. The association with supermarkets is not intended to achieve its full capacity, but to kick-start the system. When domestic waste is also introduced in the system, and the capacity of the unit is 100%, waste trucks for domestic pick-up will also have an impact.

Fertilizer: the fertilizer will come from two different ends. The first one is the co-composting unit. It can be considered that 7% of the organic waste can turn into fertilizer (Annepu, 2012). Therefore, with a capacity of 8,4ton/day, 0,6ton/day can be turned into fertilizer (it should be noted that this applies when the unit is operating in its full capacity, since the compost takes at least 10 weeks to be ready). The other source of fertilizer is the desludging of the constructed wetlands. However, this procedure only takes place once every 10 years and it was disregarded in this analysis. An urban truck has capacity for 3ton and could serve the purpose once every 5 days.

Animal manure: the animal manure is designated to increase the biogas reactors' efficiency. However, as mentioned previously, there is a difficulty to pre-defined the adequate ratios without specific calculations and tests. Carlos Chernicharo suggested during interview to use 1% of the rate flow. Nevertheless, this would require calculations of the entire system. Therefore, the assessment of the impact of this by-product should take place in further steps of implementation.

Water for reuse: each constructed wetland has capacity to treat 3.200.000L/day (3.200m³). Considering the volume of the proposed lakes



(4.500m³ - 1m deep) and a loss of 10% in the system due to evaporation (Breno Cota, Wetlands Construídos), the water surplus would be around 1200m³/day. Considering that a truck for this purpose can carry 30.000L (30m³), in order to transport the whole surplus, 40 trucks/day would be necessary. Naturally, the amount of water sold for re-use is dependent of market demands and operational arrangements. Therefore, probably part of this surplus will be directed for safe discharged into the local river. It should also be noted that an accurate estimative of reuse water requires flow rate values (inflow and outflow), which can only be known with an adequate calculation of the system.

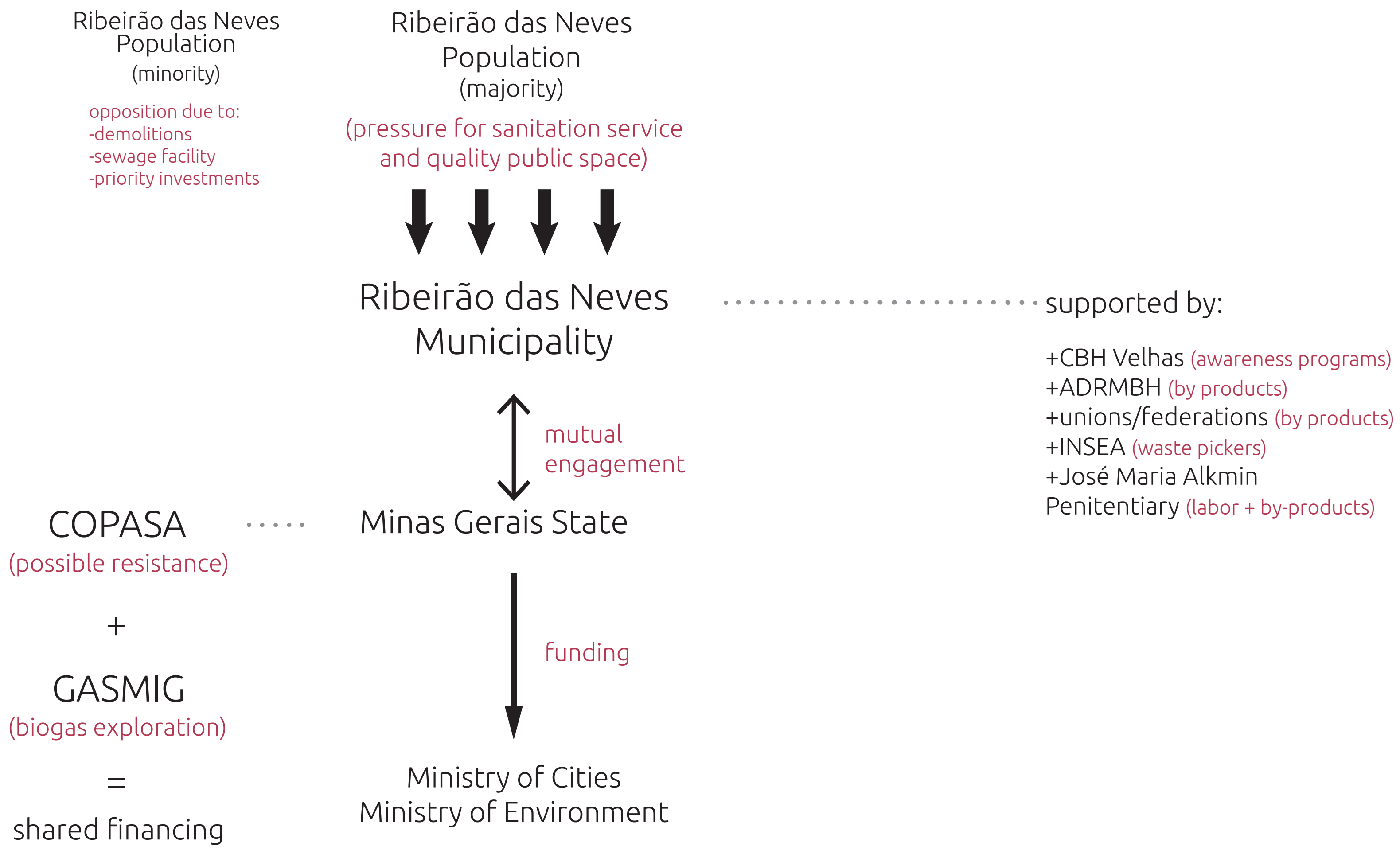
Green waste and animal feeding: these two outputs will have very little impact in the surroundings, since they are both seasonal. Therefore, they have will provoke only a temporary impact in a specific time of the year and were disregarded in this analysis.

Raw materials: considering the average processing rate of the recycling industries of 3,0ton/day, the Recycling Hub would require 4 urban trucks (3 ton) per day to transport the material of the four industries. For operational reasons, partial storage can be an alternative to have weekly shipments instead of daily ones. In that case, 4 medium trucks would be required, each with capacity of 14ton.

Transporting by-products also have impacts in the city. Most of them, though, will be able to be absorbed within the existing local conditions, without needing extra interventions.

stakeholders

and phasing



Relation between stakeholders for Landscape Machine implementation.

In order to implement the Landscape Machine and the Recycling Hub in the selected venue, stakeholders should be taken in consideration. Naturally, there are actors that have larger impact in this development. It is possible to consider the population of Ribeirão das Neves as the most interested part, since this development aims to improve the city's sanitation system and public space. However, it should be noted that a portion of the population might also be against it. This group can include owners of establishments and houses that would be demolished; people who do not wish to have sewage treatment close to their house; or even people who believes the Municipality should invest in other sectors first, such as education and health. In addition, the common misconception that by connecting the household to the sewage network adds cost to the dwellers can also be a factor for opposition (it should be noted this would happen with a minority of the population, since most of the city is already connected to the sewage network, lacking only the treatment phase). Yet, all of these groups can be persuaded with a transparent ad inclusive planning and design process. One necessary action will be to create awareness programs that explain the benefits of the Landscape Machine and the Recycling Hub for the city and the citizens. To support these actions, CBH Velhas can be an interesting ally, given its expertise and the close relation between the system and reduction of river pollution. These programs are also crucial to dismantle any prejudice or repulse the population might have towards the association of public spaces with wastewater treatment facilities, which can be a strong point of opposition. After implementation, educational projects can continue to take place (the Federal Institute Minas Gerais – IFMG can give support), also as a sort of branding for the image of the city, as well for strengthening its local identity.

In the public sector, the Municipality of Ribeirão das Neves can be seen as an actor with high interest, since the proposal increases wastewater treatment of the city, improves its image (which in turn has economic and social benefits) and promotes better usage of local resources. In addition, bearing in mind the municipal responsibility for solid waste treatment and the current reliance on an inadequate waste disposal facility, the use of organic waste and the implementation of the Recycling Hub come as extra incentives to support municipal solid waste management. On the other hand, the state company COPASA is the one responsible for providing sanitation infrastructure. Considering the centralized approach and future planning of the company, this development might not be appealing to it (even though the state could advocate for this intervention, being the majority partner of the company, the private shareholders might be against it). Possible downsides of a new investment is the replacement of an existing system (stabilization pond) and the eventual reduction of wastewater that could be directed to an existing treatment facility. One solution to avoid this is to promote a shared investment. GASMIG, the State's gas company, for example, can be interested in financing the biogas reactors, if given the right to explore biogas production. Moreover, Minas Gerais State has also high interest that the municipalities, especially within the Metropolitan Region, provide universal and adequate sanitation services for their population. For that reason, the state can articulate with the Ministries of Cities and Environment possible funds or financing programs for the system as a whole. In turn, there may be a need to create consortia for implementation of the other units and Ribeirão das Neves can become a pilot project (in that case, an expansion plan would become necessary).

While the state searches for financial feasibility of the development, the city hall can articulate partnerships with unions, federations and local entrepreneurs, supported by the Development Agency of RMBH, in order to guarantee the use of the by-products. It is important to highlight that some by-products may require incentive for development of a proper market (for example the fertilizer from the co-composting). Since these associations are crucial to make the system efficient, the Municipality can offer subsidies or tax reductions for those companies that compromise with the purchase of the by-products. The Municipality can also articulate with the local prison José Maria Alkmin to partially absorb by-products and provide labor for the construction and maintenance of parts of the system. Naturally, security restrictions may apply and should be taken in consideration. Therefore, they can be in charge of maintaining less appealing components, such as the biogas reactors and the co-composting unit. The spin-off of the remaining areas should be used to create jobs for the local population. Lastly, for kick starting the system and guarantying efficiency, it is possible to create partnerships with local supermarkets to assure regular supply of separated organic waste to be used in the co-composting. Certainly, the ultimate goal is to be able to use residential waste in the system as well. However, this set-up allows the Municipality more time to improve the city's sanitation structure (such as enlargement of the selective collection); together with the creation of awareness programs (waste separation and disposal, etc); and incorporation of local actors such as waste pickers (in this case, INSEA can give support to the Municipality). After these measures and the upscale of waste provision, organic waste will also be used for composting and in the biogas reactors.

PHASING

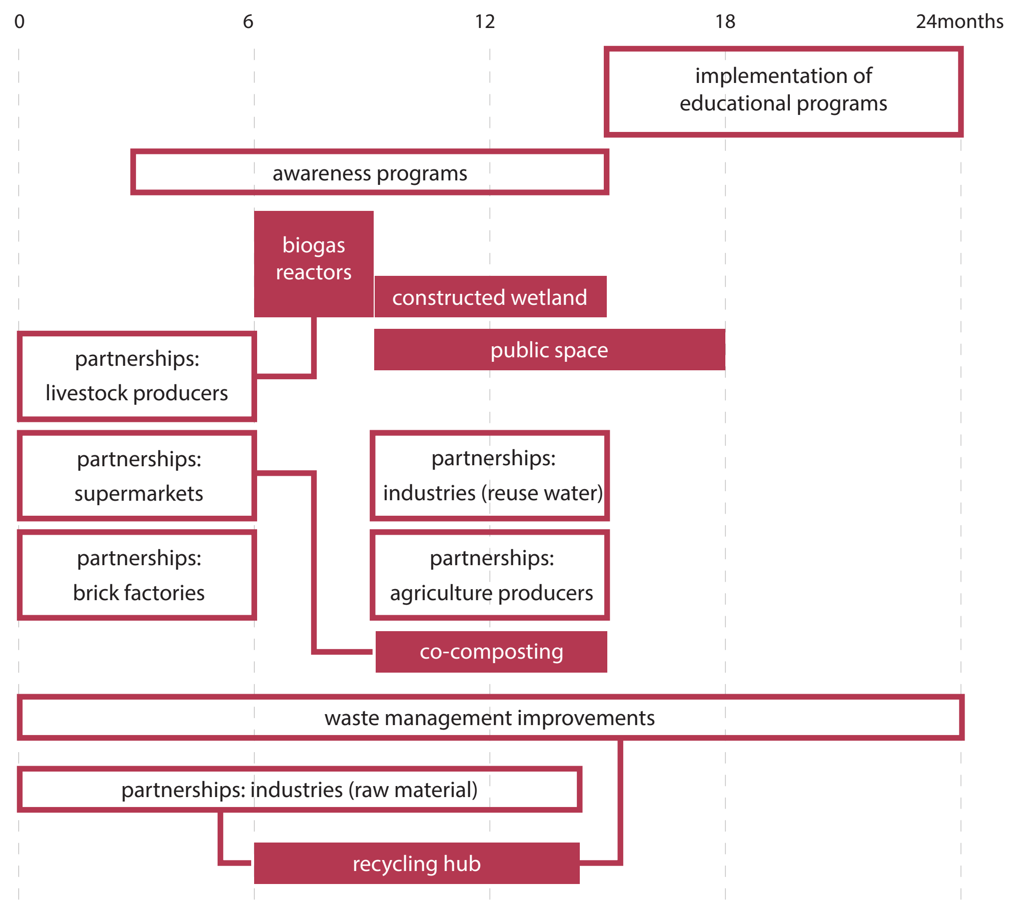
As mentioned earlier, some actions have to be taken before, during and after implementation of this proposal. For the Landscape Machine, it is crucial to create partnerships that guarantee the efficiency of the biogas reactors, since the gas company GASMIG is one major stakeholder involved. The awareness programs also are crucial for local acceptance. The remaining components of the system can be constructed after the biogas reactors, since it is possible to use them as primary treatment and the existing stabilization pond as secondary treatment, while the constructed wetland is not ready. The implementation of a constructed wetland takes between 3-6 months. As the construction of other parts of the system advance, the remaining partnerships should also be created.

For the Recycling Hub, it is important to have waste management improvements prior to implementation that guarantee material supply for the Hub. Another important action is to solidify partnerships with the local industries, to assure its economic feasibility. The waste management improvements should continue even after implementation of the Hub.

Alternatively, it is also possible to divide this proposal in two phases. This may me considered in case of financial feasibility, since the use of the existing stabilization pond makes the constructed wetland much simpler to be implemented than where the topography requires significant earth movement. However, it should be noted that a separation of the proposal in phases has the risk of never being done in the future, especially if federal funds are involved, since they come usually in batches. Therefore, the construction plan should be carefully studied together with the stakeholders involved.

Expansion area as alternative for a two stage construction.

Implementation phasing of the proposal

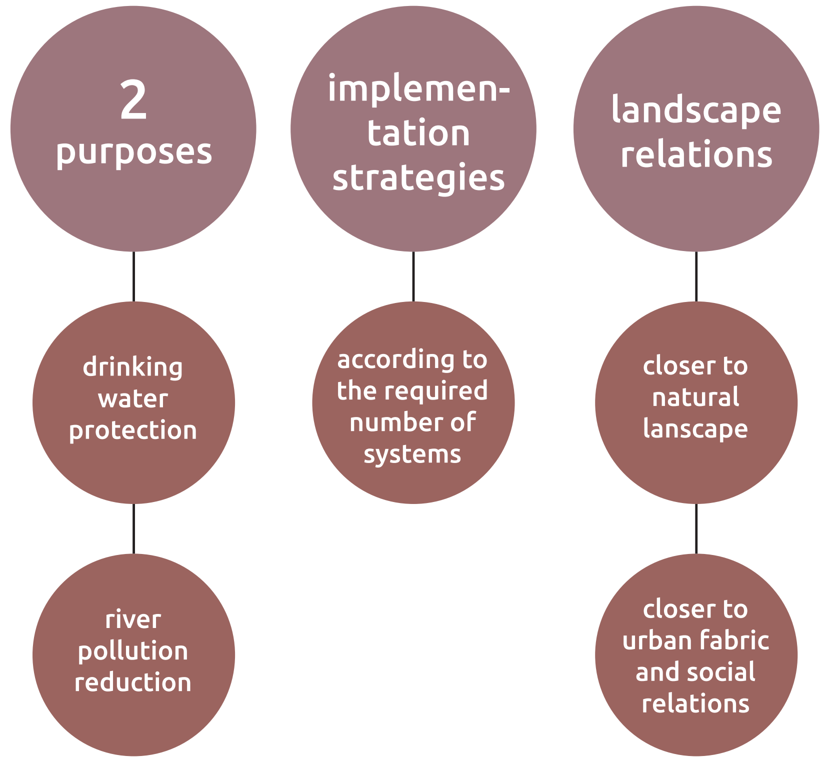


system construction
support activity

4.5 up-scaling and spin-off

Assuming that all the proposed systems are implemented, it is possible to outline the consequences of their up-scale and of the spin-off they will generate in the regional scale. Regarding the up-scale, first, implementing all systems serves two distinct purposes: protection of drinking water resources and pollution reduction. Due to the existing topography, the clusters are divided between two watersheds (see "Map 108. Possible distribution of the systems throughout the region"). Considering the direction of the streams and the existing conditions, it is possible to infer that the systems implemented in Ibirité, Betim and Esmeraldas will aid the protection of drinking water resources more than reducing river pollution in critical areas. On the other hand, those systems placed in Contagem, Belo Horizonte, Nova Lima, Sabará, Santa Luzia, Ribeirão das Neves and Pedro Leopoldo will directly contribute for river pollution reduction in Das Velhas watershed. Second, the systems will affect each city differently, also due to the number of required units (see Table 12) . For example, from Belo Horizonte test case, it is possible to state that there will be a concentration of Urban Machines in the North and South of the city, but not quite in the middle. On the contrary, Ibirité will be challenged to implement almost the same number of systems of Belo Horizonte, in a much smaller area. This condition implies the need of different implementation strategies in each municipality. In Belo Horizonte, the systems may be implemented one by one, without co-relation among them, whereas in Ibirité it might be more effective to implement all units as one unique system. Lastly, the different number of required systems creates distinct relations with the landscape. Some cities will have a stronger integration with the natural landscape, since they require fewer systems and have larger areas (Pedro Leopoldo, Esmeraldas, Nova Lima and Santa Luzia). However, other cities will require a closer integration with the urban fabric and social relations, given the necessity of a large number of systems in a restrict area (Belo Horizonte and Ibirité).

Regarding the possible spin-off effect, the systems can contribute to different possibilities separately and as a whole. The Urban Machine will benefit the organic food industry and urban agriculture practices. This has the potential to create a change in social behavior, bringing food production closer to people's homes and highlighting the benefits of these practices (both from human health and environmental perspectives). Moreover, the Urban Machine requires a vermicomposting unit, which uses a significant



Up-scaling to the region. Solutions serve two different purposes: protecting drinking water resources and contributing to reduce river pollution. In addition, the systems affect each municipality differently, according to local conditions.

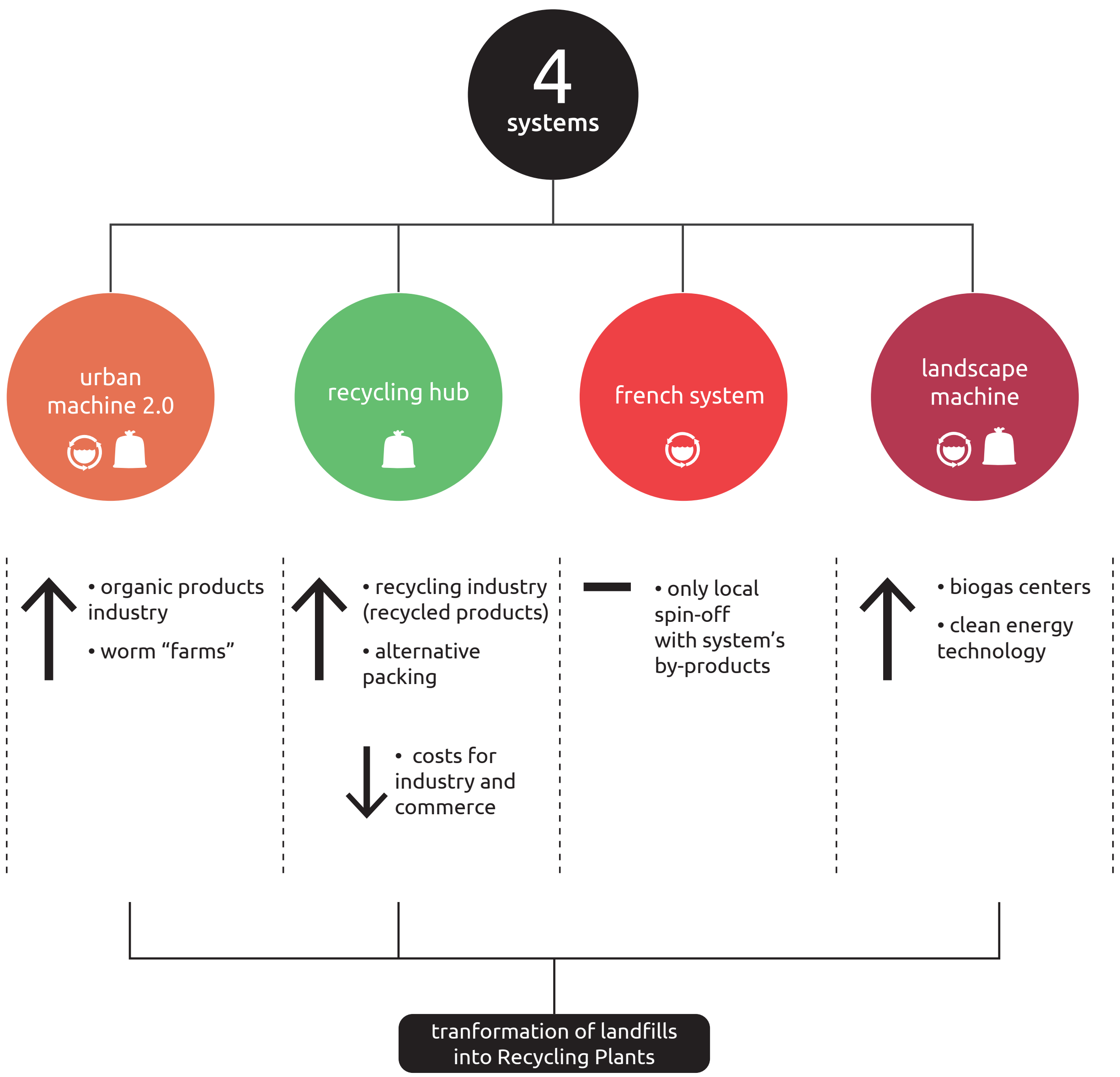
number of worms. In a scenario where this system is multiplied, worm "farms" are likely to be up-scaled as well, generating economic spin-off. Concerning the Recycling Hub, when spread out through the region, it is likely that the recycling industry as a whole would be benefited and enlarged. This would have two effects: increase the production of recycled products and the reduction of costs for production and commercialization. Moreover, apart from another possible change in social behavior (increase the consumption of recycled products and therefore, also society's awareness), up-scaling the recycling industry may create opportunities for other changes, such as alternative packing methods. Regarding the Landscape Machine, the concentration of multiple systems in Ribeirão das Neves and Sabará could potentially transform those cities into biogas production centers, having the largest regional impact of this proposal. These centers might also engage industries and technologies related to clean energy production, with a positive economic spin-off, creating jobs and attracting highly educated professionals. In turn, governments will be prone to improve the urban quality of those cities and partially shift the attention from the capital. As for the French System , it will have a limited up-scale and spin-off effect in the region, since it will only be implemented in Pedro Leopoldo.

City	System	Number of required systems (recycling hub excluded)
Belo Horizonte	Urban Machine	16
Ibirité		11
Betim		6
Contagem		7
Pedro Leopoldo	French System	3
Sabará	Landscape Machine	7
Ribeirão das Neves		14
Santa Luzia		1
Nova Lima		4
Esmeraldas		3

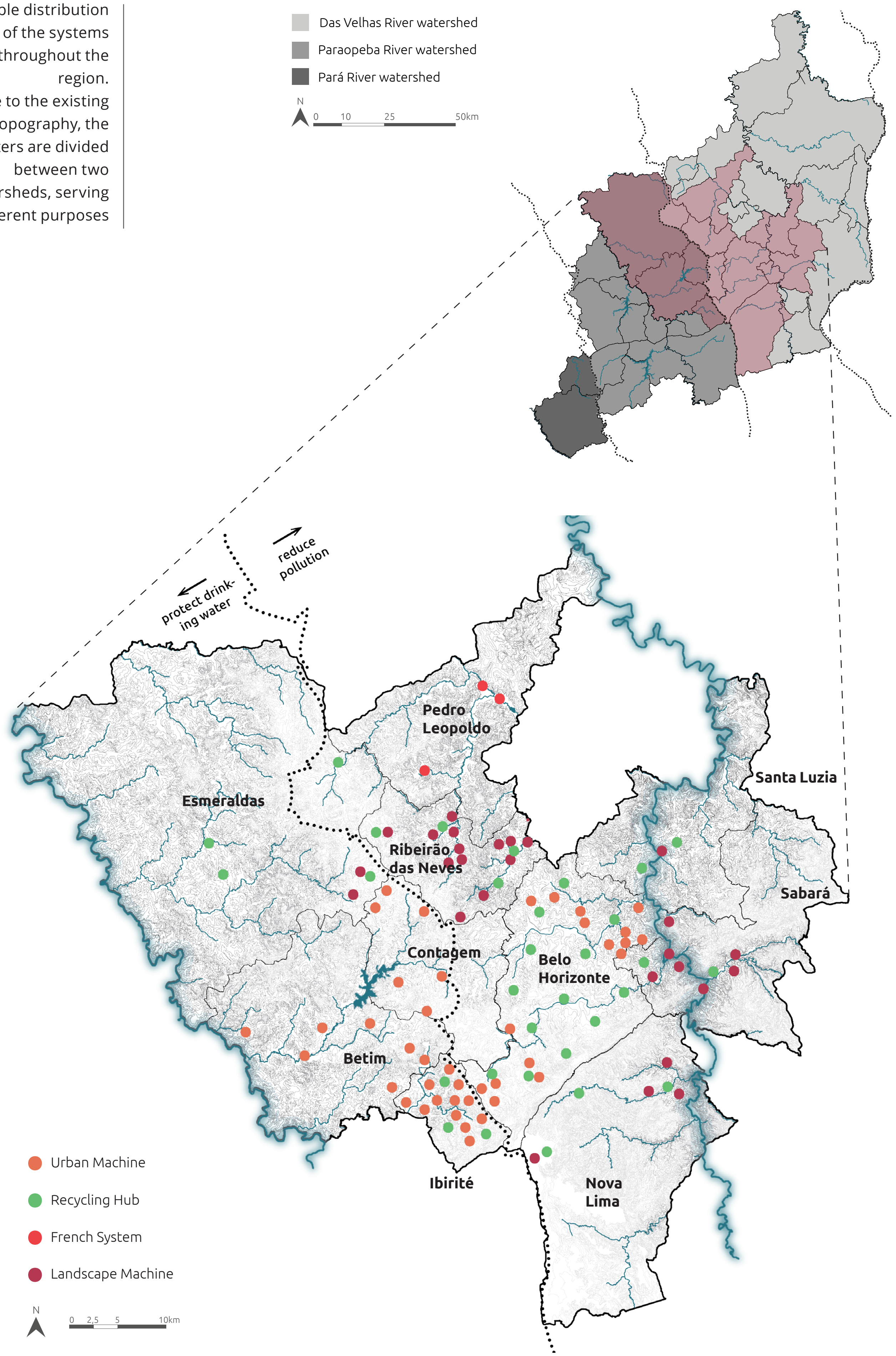
Number of required system units for each municipality. Highlight for Ibirité and Ribeirão das Neves, cities with large number of systems and small areas.

Lastly, the combination of the systems in the region will provide an alternative for the current waste management, reducing the reliance on existing sanitary landfills. Not only this proposal will contribute for increasing the landfills' life spans, but they will also create an opportunity to slowly transform them into large scale recycling plants. This transition could take advantage of already existing regional relations of those facilities with multiple cities. In addition, it addresses to future concerns of rehabilitation of the area when landfilling is no longer possible. The Recycling Hubs will be able to support those plants, being spread throughout the region. However, since they will be more concentrated in densely populated areas, some cities will be able to create stronger relations with these new plants (for example Belo Horizonte).

Possible spin-offs after implementation of the strategy. Each system will contribute to different activities and have multiple impacts.



Possible distribution of the systems throughout the region. Due to the existing topography, the clusters are divided between two watersheds, serving different purposes



5 |

reflection horizon

closing the loop

5.1 introduction

This chapter aims to discuss how this thesis was developed, pondering on its methods and results. This is done in two steps: conclusions and reflection. The first addresses what are the results of this thesis, answering its main research question and proposed sub-questions. The second, reflects on how those questions were answered, highlighting the learning process. For a detailed discussion over societal and scientific relevance, relation between the project and Urbanism track, as well as ethical considerations, see items "1.13 sustainable societies"; "1.12 UM mutations" and "1.13 sustainable societies".

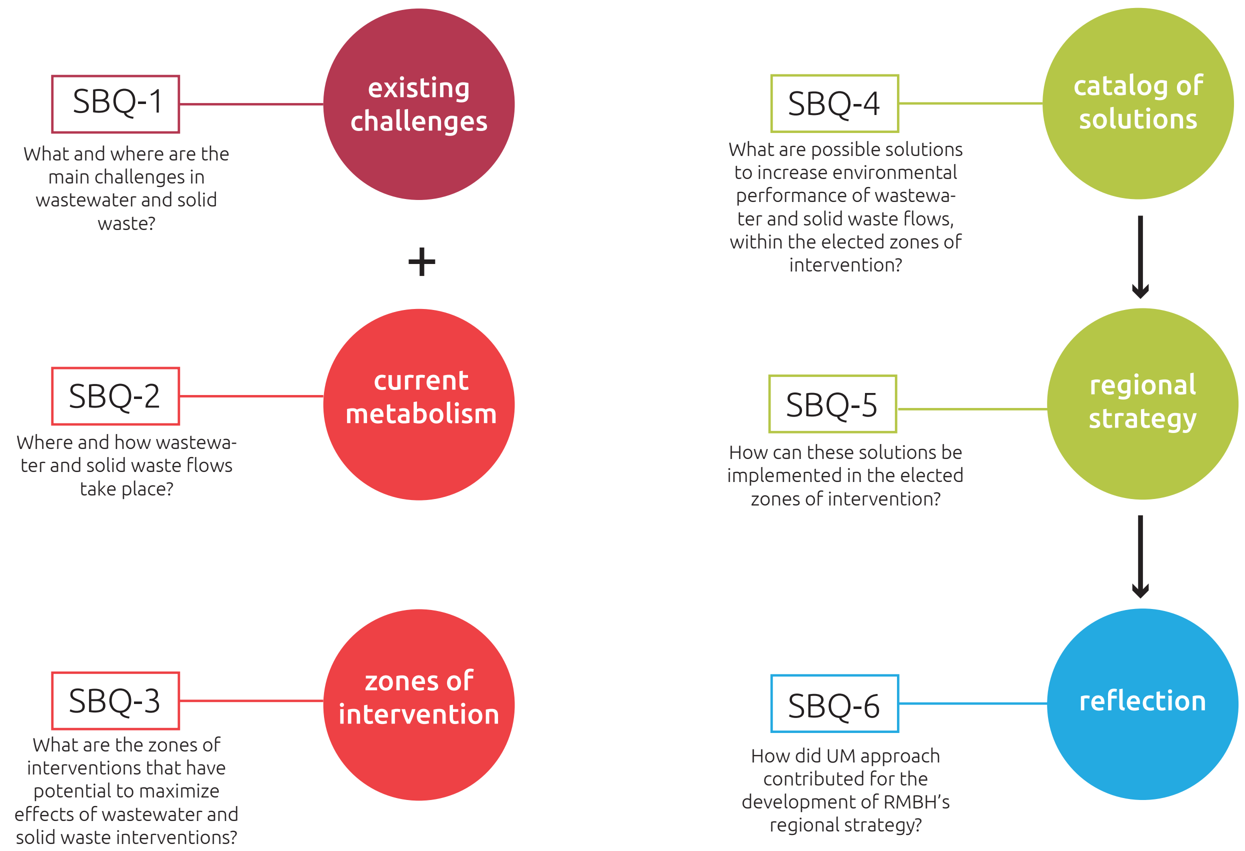
5.2 conclusions

This thesis's main research question is "How to develop a feasible regional strategy for RMBH's wastewater and solid waste flows?". In order to answer this question, 6 sub-questions were put forward:

1. What and where are the main challenges in wastewater and solid waste?
2. Where and how wastewater and solid waste flows take place?
3. What are the zones of interventions that have potential to maximize effects of wastewater and solid waste interventions?
4. What are possible solutions to increase environmental performance of wastewater and solid waste flows, within the elected zones of intervention?
5. How can these solutions be implemented in the elected zones of intervention?
6. How did UM approach contributed for the development of RMBH's regional strategy?

This section will focus on sub-questions 1-5, whereas item "5.3 reflecting on the Metabolic Horizon", answers sub-question 6. It should be noted that the answer for each question did not occurred in a linear, but iterative process.

The first sub-question is answered from the preliminary analysis given in Chapter 1, together with the metabolic analysis provided in Chapter 3. In a nutshell, the main challenge regarding wastewater is the lack of sewage treatment. In the solid waste flow, the main challenges are the existence of inadequate waste disposal facilities and lack of recyclables collection and material recovery. The metabolic analysis also answers where these challenges occur, by putting forward critical areas. In addition, it simultaneously addresses to Sub-question 2, explaining how wastewater and solid waste flows take place. Regarding wastewater flow, the analysis points out relations among drinking water, water quality and wastewater disposal and treatment. Some of the conclusions regarding this flow are:



Thesis structure based on sub-research questions.

Two different critical areas summarize the main urgencies of the region. Critical Area A.1, with high density and large infrastructure systems, but with an expressive minority in absolute numbers without sewage treatment. The areas that most likely represent this situation are informal settlements and the outskirts of the urban core. Critical Area A.2, on the other hand, is where the majority of population does not count on sewage treatment and the population is expressive in terms of wastewater production.

The lowest part of Das Velhas River is probably polluted due to upstream wastewater discharge rather than the contribution from cities in the north, given their lower density.

The overlap between drinking water resources, population density and majority with no sewage treatment are areas that require attention during future expansion.

As for the solid waste flow, the metabolic analysis explains the relations among existing solid waste facilities (adequate and inadequate) for both domestic and recyclable waste. It also includes qualitative aspects, such as cities with largest population without adequate waste disposal and lowest recyclables collection. Some of the conclusions regarding this flow are:

Three critical areas summarize the main urgencies of the region. Critical Area B.1 reflects the main areas without proper waste disposal. They are located in an east-west line north of the capital and represent cities with high solid waste deficiency, given their large populations. Critical Area B.2, on the other hand, represents those areas specifically with high recycling deficit. In other words, cities responsible for large waste generation (especially given their population size), but with low recyclables collection. They concentrate mainly in the mid-south portion of the region. Lastly, critical Area B.3 reflects the overlap of both Critical areas A and B, pointing to Santa Luzia as the most critical city in the RMBH, in relation to waste.

Sabará and Betim landfills are the two main responsible for treating most of the metropolitan waste.

It should be added, that regarding both flows, one important conclusion was acknowledging the region's reliance to centralized facilities. Therefore, this thesis puts forward a catalog of solutions within the decentralization topic for both flows. Moreover, it presents a matrix that evaluates these solutions, making it possible to conclude which solutions are most suitable for each critical area, in each flow separately. In wastewater flow those solutions are:

"living machine" presents itself as the most suitable choice for the high density urban core (Critical Area A.1), given its flexibility, high quality treatment level and potential associations with public space or other functions.

constructed wetlands combined with biogas reactor and sludge treatment or the French System, though, are better choices for peri-urban areas or areas with possible expansion (Critical Area A.2), due to its simpler construction and large space requirements. They also have the potential to interconnect flows and integrate with the landscape.

As for the solid waste flow, the main conclusion is the necessity to separate organic and inorganic wastes, allowing small scale recycling solutions to be implemented (Critical Area B/C) and use composting or anaerobic digestion for treating the organic matter (Critical Areas A/C).

With these conclusions, and overlapping the critical areas of both flows, it was possible to define 4 different clusters (zones of intervention - Sub-question 3). Clusters 1 and 2 refer to the highly dense areas, where the majority of population has access to the infrastructure, but an expressive minority still lacks sewage treatment. The difference between them is that Cluster 1 has an additional recycling deficiency. In other words, it has a large population associated with a low recycling rate. In contrast, Clusters 3 and 4 have the majority of people without proper sewage treatment infrastructure. However, Cluster 4, the same as Cluster 1, also has recycling deficiency.

The conclusions derived from the catalog of solutions, combined with the proposed clusters led to the creation of 4 different systems: Urban Machine 2.0, Recycling Hub, French System and Landscape Machine. The systems Urban Machine 2.0 and Landscape Machine combine strategies to address both wastewater and solid waste treatment, whereas the Recycling Hub focuses only on solid waste and the French System only on wastewater. Therefore, the elected zones of intervention and their associated solutions (Sub-question 4) was defined as follows:

Cluster 1: Urban Machine 2.0 + Recycling Hub

Cluster 2: Urban Machine 2.0

Cluster 3: French System

Cluster 4: Landscape Machine + Recycling Hub

In order to apply these systems in the proposed clusters (Sub-question 5), this thesis relied on two test cases: Belo Horizonte (part of Cluster 1) and Ribeirão das Neves (part of Cluster 4). The first test case aimed to implement the Urban Machine 2.0. Some of the conclusions from this test case are:

topography is a key element that stirs the implementation of this system;

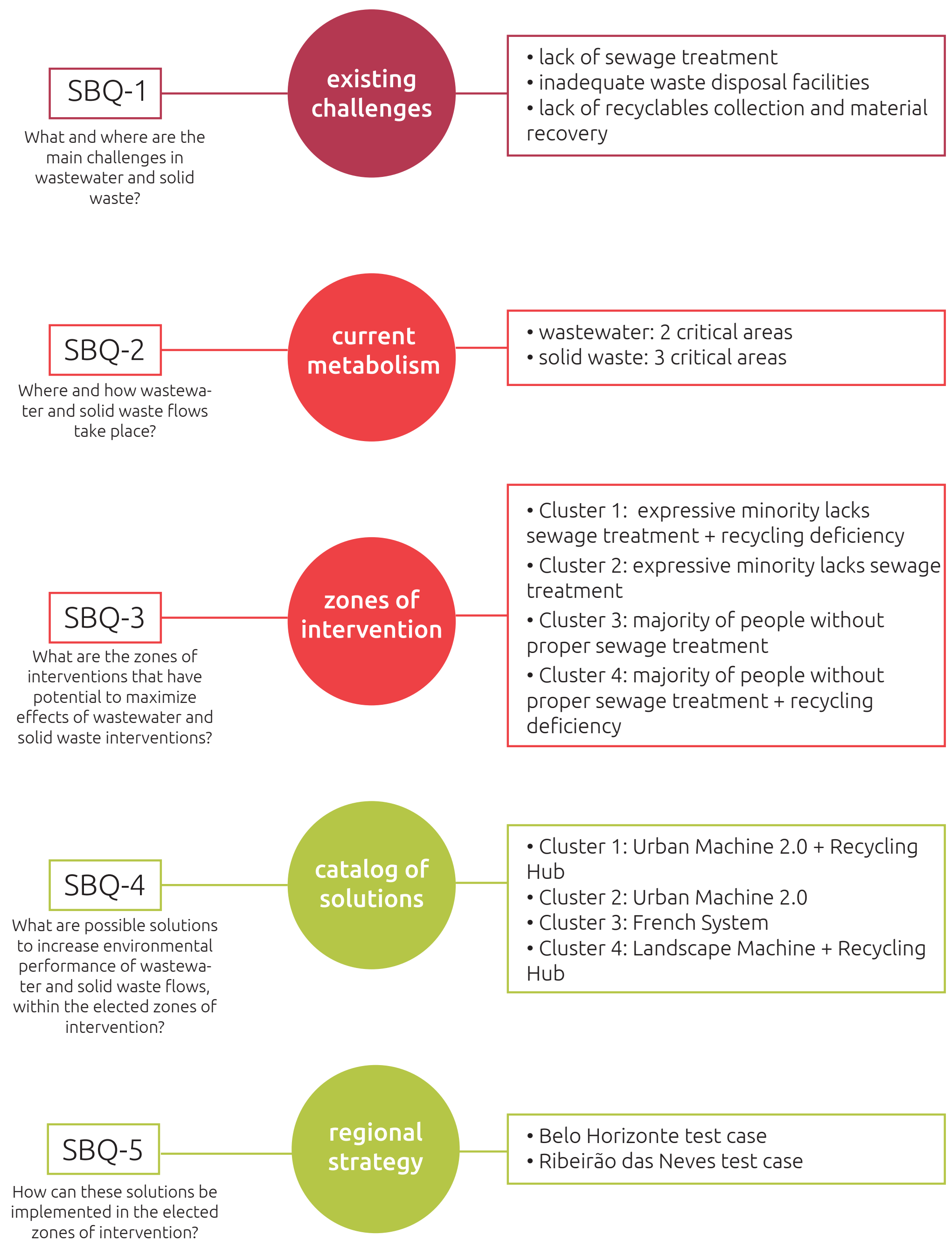
smaller systems are more flexible for dense areas and to adjust to local topography;

the implementation of this system might require additional proposals, such as housing, and therefore, requires the understanding of other dynamics rather than just wastewater treatment;

for the same reason, this system has a strong social aspect that has the potential to collaborate and improve not only the metabolism, but also urban-social relations;

The second test case was Ribeirão das Neves, with the goal of implementing Landscape Machine and Recycling Hub. Some of the conclusions from this test case are:

From an urban perspective, even



Conclusion summary.

though several areas fit the pre-defined principles for the Landscape Machine, those closer to the urban core give more opportunity for integration with the city and creating active public spaces.

The success of the Landscape Machine relies partially on the relation between different by-products. The system could function without them, but it would lose significantly its core intentions. This also means its implementation relies heavily on a successful interlocution among different stakeholders.

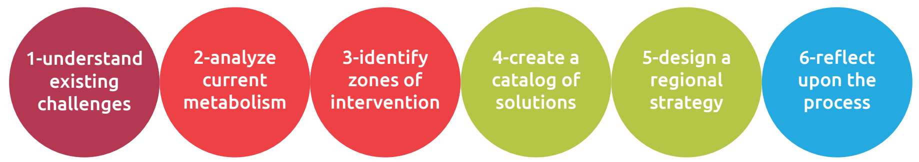
The Recycling Hub, on the other hand, given its small area requirement, is more flexible for implementation. Moreover, in a scenario where the collected recyclables are not cascaded back into the local context, they can still be taken to larger recycling plants and be recovered.

In conclusion, as showed in this section, by answering Sub-questions 1-5, it was possible also to develop a regional strategy for RMBH's wastewater and solid waste flows, thus answering the main research question of this thesis.

5.3 reflecting on the Metabolic Horizon

I started this thesis with open curiosity over Urban Metabolism (UM) topic and what it could offer to my hometown, Belo Horizonte, and its metropolitan region (RMBH). My motivation towards this topic arose after Q3-Studio, when I came across it for the first time. I saw UM as a non-traditional and holistic perspective that could shift the way planning is currently done in Brazil. Certainly, this relates to my personal understanding of what Brazilian urban planning is. I see it as a rigid framework that stumbles upon bureaucracy and simplistic perspectives of what are, in reality, complex relations. The result of this process is a lingering feeling of never achieving the desired goals. Therefore, my excitement of trying out something new, that would have a better chance of being successful, together with my personal perception of planning in Brazilian contexts, made a good match for this thesis. However, finding out my research question was not particularly easy. I started by looking at existing planning documents, which confirmed my intuitive feeling of planning gaps, but I still missed the answer to the question: "what is the problem of the region?". Only when I reacted to that questioning I could evolve to what is my research question now. Naturally, to go through this process, I needed to structure this research. Therefore, I developed a 6-step methodology:

The first step was to understand what the main challenges in the region are and where they take place. Since UM is highly related with resources and the urban and natural environment, these challenges were translated into environmental pressures. Here, two studies were crucial. The first was the historical evolution of the region, which led me to find out that the environmental pressures of today are (mostly) consequences of the rapid urbanization RMBH went through. The second was the study of the existing diagnosis from the PDDI. This thorough document allowed me to have a solid base of the metropolitan region, with an unquestionable source of data (especially given the role of the Federal University of Minas Gerais (UFMG) in its development). Even though I was happily surprise with such a detailed document, I still saw it attached to a rigid framework of zoning plans and policies that have little effectivity. Another drawback was that the document dates from 2010. Therefore, it disregards important events that influenced urban dynamics, such as the political and economic crisis Brazil has being going through since 2013. It also means it used data that can be outdated. With the purpose of minimizing this issue, I collected additional data to update the information, whenever possible. After producing this inventory, I was able to identify the part of the metabolism



(flows) that required urgent intervention: wastewater and solid waste. This finding led to my main research question "How to develop a feasible regional strategy for RMBH's wastewater and solid waste flows?" and to my hypothesis: studying RMBH through UM perspective would give me insights on how to deal with its current and future environmental challenges by managing better its resources related to wastewater and waste.

Once I had defined my focus, I could move on to the second step, which was to understand the current metabolism regarding wastewater and solid waste. Here, using GIS to do the material flow analysis created an important differentiation with other analysis methods. GIS allowed me to go deep into the data, given the speed and information I could extract or combine. I could easily compare the current state of the cities, from both qualitative and quantitative perspectives. The result was a large map-set for each flow and a solid and deep understanding of the current situation. Steps 3 and 4 came naturally after this analysis. However, diverting from my methodology, the identification of zones of interventions was a result mainly from the metabolic analysis rather than from the "confrontation between the territorial analysis, the metabolic analysis and the existing policies". This diversion is probably due my initial reliance on the existing documents and the unknown expanse of data I would be able to find for the metabolic analysis. Moreover, since I could produce a detailed analysis, it had a heavier weight than the other two elements.

Apart from finding the zones of intervention from my analysis, one important conclusion was the reliance on centralized systems. This finding reinforced my vision of rigid frameworks, which led to my "decentralization investigation". This investigation resulted in a catalog of decentralized solutions for each flow. These solutions were assessed and elected for application in the zones of intervention. To develop this catalog, however, I had to learn several technical aspects (especially regarding wastewater treatment). Therefore, it could have been helpful to do a previous interview with a specialist to provide an overview of the existing solutions beforehand. Still, my intense literature review proved sufficient and accurate, a fact that I could confirm after my focus group, which I will discuss further.

After concluding the analysis, I could already verify my hypothesis. The metabolic approach proved to be appropriate for the purpose of this research. However, one of my motivations over this framework was to investigate if it could lead to better manage resources by interconnecting flows or creating synergies. The metabolic analysis allowed me to understand that Urban Metabolism does not point to synergies in particular, unless they already exist, since it can only unravel what is already part of the metabolism being studied. Yet, when searching for solutions that could potentially improve this metabolism, possible synergies became evident, since the flow perspective assured my understanding of all processes and elements associated to a specific solution. It should be noted, though, that the improvement of a metabolism through synergies does not necessarily imply on urban quality increase. Therefore, I developed a matrix of solutions, where I could define and compared the qualities I considered most important to urban life. In other words, UM did provide insights to deal with environmental pressures and better manage resources, but the association of these insights with urban values and qualities the urban planner/designer puts forward multiplied the potential of a successful urban proposal.

Having elected the zones of intervention and the solutions that match both metabolic and urban demands, I moved towards step 5: developing a regional strategy to apply these solutions in the elected areas. The transition between analysis and strategy was quite challenging. I struggled to find how decentralized solutions could be integrated into one strategy, also because I was attached to the idea of a "regional vision". I made several failed attempts, trying to combine all the requirements I had learned for implementing the elected solutions and looking for synergies at the same time. I could overcome this after I decided to, first, let the synergies for a later phase; and second, combine both flows and overlap their demands. After this step, I could see more clearly which combination of solutions were suitable for each cluster, leading to the creation of 4 different systems. For each system, I designed principles (technical and urban) that guarantee their implementation, putting all my gained knowledge regarding the solutions' requirements. Interestingly, when I started combining solutions, possible synergies arose naturally and I could incorporate them while defining the principles.

During the design phase, I also had the opportunity of doing a site visit, sponsored by the EFL Foundation. I organized a focus group, to be able to gather information regarding implementation phase. The choice of this method relied on pragmatic reasons. Given the lack of resources, short time and the difficulty to engage people from a distance, the focus group became the most feasible, and yet valuable, method to gather reliable information. My preparation beforehand, studying the premises of this method, allowed me to be precise on the topics that I wanted to learn more: general perception on waste flows; stakeholders and possible solutions. The results:

- confirmed my analysis and design intentions;
- gave me substantiation to choose my test cases;
- reminded me of the lack of awareness from the general population and the strong influence of political will in planning or design processes;

Thus, I believe the focus group was a good method that provided me with information I could incorporate into my strategy. I also conducted interviews to get a holistic perspective, which provided me different points of view from different stakeholders. The interviewees also shared updated information that I could not incorporate in this work. For example, I found out about on-going construction facilities for wastewater treatment that were not included on my data set. Therefore, the quantitative research presented here is not accurate with the current situation, as expected (since most of the data is from 2013). Nevertheless, these findings do not harm the overall problematic or relevance of this thesis. Lastly, I also did site visits, which supported my design decisions for my test cases. It should be mentioned that at the point of these visits I had pre-elected locations for one test case and not for the other. The insights gained from the visits were much larger on the pre-elected locations. Although I could count on digital tools such as Google Earth and Street View, I would have been able to fully grasp the existing scenarios if a second visit was possible.

Another issue that my design touched upon was the social impact of my proposals. In Ribeirão das Neves, it incentives a shift in the relations with a local prison, a topic that could create several tensions with the local population. In Belo Horizonte, it creates a tension between improvement of urban quality and provision of proper housing.

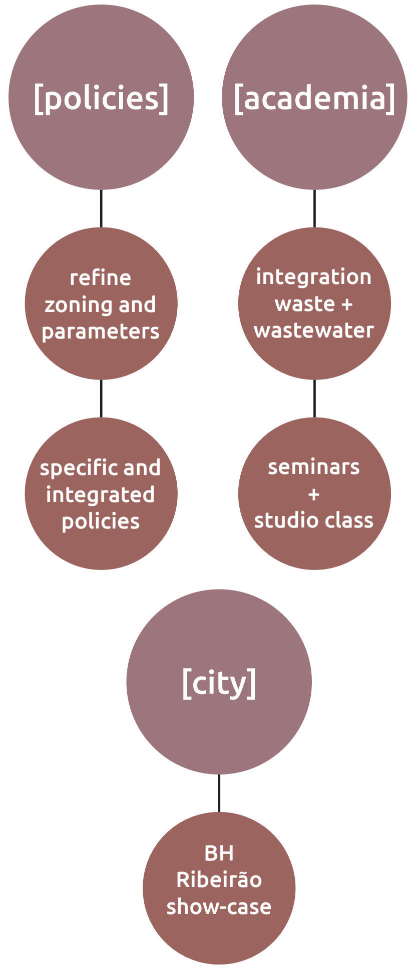
The proposals I put forward in this thesis target for a balance between interests, acting as the mediator an urban designer and planner aims to be. However, these aspects can become sources for further studies and, once in a participatory process, local social conditions could greatly affect the design outcome.

The last step – reflection – seeks to look back on the process and verify what was learned and how. From a methodological point of view, I believe the methods chosen were adequate and proved to be sufficient to answer my research question and sub-questions. I also believe that Urban Metabolism provided different insights than other frameworks could. The flows perspective allowed me to identify urgencies in the region in terms of territory and metabolism (for example, in the wastewater flow, I could identify the lack of sewage treatment as the main deficiency rather than the lack of sewage collection). This identification made my proposals coherent and increased their relevance. In the case of RMBH, it would be even possible to compare with the existing territorial approach, already studied in the PDDI. From my perspective, the policies in the PDDI do not incorporate aspects discussed in this thesis, such as decentralization (also seen as the desired approach by experts) and, thus, one might question how efficient their proposals will be. In terms of transferability, I find the sequence of steps I defined as the most valuable asset for initiating a different project, since the metabolic findings are site-specific. These steps allowed me a smooth evolution and transition between phases, providing me the substantiation I needed to move forward, without questioning the solid base I was always standing. Certainly, this smooth transition was stirred by my mentors, which constantly made sure I did not leave any gaps behind.

Lastly, I also see this work as a contribution for both academic and planning spheres. During the focus group, the participants mentioned their interest in seeing the final result of this research and the difficulty of reducing the gap between academia and reality. Given the close relation between UFMG (my former University) and current planning actions, I could possibly propose to present this work for students or in any other event related to regional urban planning, where the general public could also be involved. The design proposals could serve as base to a studio assignment and be further developed, or potentially inspire similar solutions in other locations. One advantage of this is the possibility to check the defined principles and test the proposed systems, possibly refining them. It should also be noted that this thesis only touches upon one fraction of RMBH's metabolism. This work could also trigger the study of other aspects, such as energy and food, to provide a more holistic view of the region. Therefore, by introducing this work within the academic sphere, Urban Metabolism framework could be presented as a possible planning tool, which contributes for enriching urban discussions.

In relation to the planning sphere, I see two different contributions. One is at the city scale, specifically the two used in the test cases: Belo Horizonte and Ribeirão das Neves. This work could be presented to those Municipalities, to trigger a debate or illustrate possibilities that, most likely, are not being considered within the existence governance. Certainly, this would require professionals and politicians to be interest in changing the current status quo. Nevertheless, the studies and analysis can contribute for the understanding of the current situation and support future changes. The second contribution is related to the PDDI and Macrozoning. As explained previously, the PDDI is a planning instrument composed of principles, guidelines and policies with structuring dimensions and integrating axes (Minas Gerais State, 2017). The Macrozoning, in turn, is an instrument part of the PDDI, to restructure the regional territory, using zoning and urban parameters to control urbanization (Minas Gerais State, 2017). This thesis relates to several policies and guidelines defined in the sustainability axis of the PDDI. However, the implementation of the proposed systems might be in conflict with the Macrozoning, considering that they require specific conditions and locations. Therefore, this work could be used as an additional layer to refine the proposed zoning areas and urban parameters. One example is to assure that areas that fit criteria such as closes to valleys and expansion areas are possible to be used for sanitation facilities and public spaces. Moreover, even though the territorial restructuring is the focus of the Macrozoning, it is also guided by other dimensions, such as sustainable development and environmental protection. Considering the by-products and synergies developed in this work, studying other aspects of the regions' metabolism, could contribute to better define zoning areas and integrate those goals. Lastly, since the PDDI creates one policy for each issue separately (for example one for drinking water, another for solid waste, etc.), this work relates to several of them at once. This condition points to two issues: generic and non-integrated policies. One proposition to create specific policies is to restrict the amount of waste sent to sanitary landfills, based on quantity and transport distance between municipality and landfill. This could be an addition to current practices, where municipalities that dispose their waste adequately, receive tax reduction in return. The government can increase the amount of tax reduction proportionally to the reduction of waste, for example. For the wastewater, given the urgency of water pollution in the region, a more severe restriction is necessary. One possibility is to define the maximum amount of BOD that can be discharged into the streams, proportionally to the city's population, fining those who do not comply. The measurements could be done using the existing measurement points and adding more, if necessary. Additionally, there could be a special incentive for those who integrate both solid waste and wastewater into one single system. This can benefit companies that can provide both services (for example, COPASA is also entering the solid waste market), and give incentive for innovative solutions, stepping out of the status quo. The requirements can be related to circularity (defined amounts of solid waste and wastewater that cascade back into the system) and the benefits can be the right to economically explore by-products and maybe even some subsidies from the government. All these proposals can potentially be discussed, since the PDDI has to be revised every 10 years (2021).

As for further scientific studies on this topic, I believe the interconnections between wastewater and solid waste can be further explored. Although there is already literature and investigations on this topic, through my research I could realize that the systems became more interesting once there was a connection between these flows. This connection implies on using more by-products, which in turn creates more opportunities for integrating urban and social functions, as well as increase the feasibility of the proposal.



Thesis contributions in three spheres: city scale, planning scale and academic scale.

6 |

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