METABOLIC FLOW ANALYSIS IN A 100 YEAR PLAN: THE CASE OF RECIFE, BRAZIL
Acknowledgements

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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ARIES</td>
<td>Agência Recife para Inovação e Estratégia (Recife Agency for Innovation and Strategy)</td>
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<tr>
<td>CGEE</td>
<td>Centro de Gestão e Estudos Estratégicos (Center for Management and Strategic Studies, Brazil)</td>
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<tr>
<td>ESIG</td>
<td>Informações Geográficas do Recife (Recife Geographic Information)</td>
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<tr>
<td>IBGE</td>
<td>Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics)</td>
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<tr>
<td>IEA</td>
<td>International Energy Agency</td>
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<tr>
<td>IO</td>
<td>Input-Output</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>ISOCARP</td>
<td>International Society of City and Regional Planners</td>
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<tr>
<td>LAC</td>
<td>Latin America and the Carribean</td>
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<tr>
<td>NUA</td>
<td>New Urban Agenda</td>
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<td>OSM</td>
<td>OpenStreetMap</td>
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<td>SDG</td>
<td>Sustainable Development Goal</td>
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<tr>
<td>SM</td>
<td>Spatial Microsimulation</td>
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<td>SMUM</td>
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<td>Urban Metabolism</td>
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<td>URBAN-LEDS</td>
<td>Urban Low Emission Development Strategies</td>
</tr>
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<td>UNEP</td>
<td>United Nations Environment Programme</td>
</tr>
</tbody>
</table>
# Table of Contents

Acknowledgements ............................................................................................................................ 3  
Acronyms ........................................................................................................................................... 4  
Introduction ........................................................................................................................................ 6  
Context ............................................................................................................................................. 6  
ARIES and Recife's 100 year plan ...................................................................................................... 6  
Describing City-Systems .................................................................................................................... 8  
Recife's challenges ............................................................................................................................ 8  
  Boundaries.................................................................................................................................... 8  
  Income Disparity........................................................................................................................... 9  
  Recife as a city system................................................................................................................... 10  
Simulation for Recife ........................................................................................................................ 10  
  Process overview ....................................................................................................................... 10  
  Identifying drivers of consumption ............................................................................................ 11  
  Measuring consumption ............................................................................................................. 11  
  Simulation results: electricity and water demand ........................................................................ 13  
Summary and conclusion ................................................................................................................. 14  
Consumption data in city planning and management ....................................................................... 14  
Bottom up planning is affordable ...................................................................................................... 14  
An argument for a compact city ......................................................................................................... 15  
The REC500 plan: towards an inclusive, resilient, and resource efficient city ................................. 15  
References ....................................................................................................................................... 16  
Annex 1: Consumption Table-Models ............................................................................................... 18
Introduction

Context

The Brazilian coastal city of Recife, the fourth largest urban agglomeration in Brazil, will be celebrating 500 years since its founding in 2037. Being among the most forward thinking cities in the country, Recife has embarked on an ambitious long-term planning process that will investigate pathways for the city’s sustainable growth in the next 100 years.

One of the objectives of the 100 year plan is to improve environmental sustainability in line with the 6 big transformations the city residents and its leaders envision (which are: 1) Global Connectivity – Conectividade Universal; 2. Dynamic City – Recife Cidade Viva; 3. Knowledge-Based Decision Making – Decisão Informada; 4. Waterfront City – Recife Cidade das Águas; 5. Connected City – Cidade dos Encontros; 6. Priority to Early Childhood – Primeiro a Infância). Working towards this environmental objective, Recife took part in the Urban-LEDS project, a climate change focused activity which was funded by the European Commission and implemented by UN-Habitat, ICLEI, and ISOCARP. Under this project, Recife’s city-wide master plan was reviewed and several low-carbon actions were recommended/started on the ground.

Following the project closure, Recife identified that low-carbon interventions needed to be complemented with behavioural change especially those that would reduce overall consumption and at the same time increase the efficiency of existing resource use. The United Nations Environment Programme (UNEP/UN Environment) has stepped in to help Recife address this gap.

This report focuses on how UN Environment’s approaches and strategies on sustainable consumption and production could support Recife in reaching its sustainability goals.

ARIES and Recife’s 100 year plan

In 2014 the city of Recife, created the Recife Agency for Innovation and Strategy or Agência Recife para Inovação e Estratégia (ARIES). Since then, ARIES has been developing the strategic development plan for the city of Recife. The vision that ARIES promotes within its agency is the “cities-of-flows” (Cidades de Fluxos), alluding to Recife’s extensive river system which is at the heart of the city’s identity. The concept of cities as comprised of flows of people, goods, food, energy, water, data, cultural values, power, etc. is closely aligned with the vision of UN Environment for the systematic description of city-systems.

ARIES, under the leadership of the Mayor is drafting a 100-year plan, called the REC500 plan (referred to as the Plan throughout the document) that envisions Recife’s future with milestones in the next 25 and 50 years. A draft already exists but, since the Plan is a ‘living document’, it is continually being updated by ARIES and the local government. The Plan is a unique opportunity to create a systemic approach to urban planning to ensure both the environmental and social sustainability of the city. ARIES, in the development of this plan, has been instrumental in developing innovative data management strategies together with EMPREL.

“We believe that in the future, the performance of a city will be the direct result of how we design, adapt, build and sustain its structures of permanence. The proper management of these structures will result in a more effective and efficient flow of all city resources.”

Guilherme Cavalcanti / ARIES.
The implementation plan proposed by ARIES (2018) defines 12 guidelines grouped into 3 syntheses with 17 strategic pathways, targeting the following 6 big transformations:

1. Global Connectivity “Conectividade Universal”
2. Dynamic City “Recife Cidade Viva”
3. Knowledge Based Decision Making “Decisão Informada”
4. Waterfront City “Recife Cidade das Águas”
5. Connected City “Cidade dos Encontros”
6. Priority to Early Childhood “Primeiro a Infancia”

The Plan highlights the importance of urban resilience and infrastructure development. It also has a strong focus on equitable and inclusive development of urban services.

However, one of the main critiques of the Plan is that an explicit transformation targeting a more rational use of resources is not part of it. This is especially important in a city like Recife which has significant inequality and inconsistent delivery of basic services (for example, only 83% of the population has access to water and of this number, only 36.4% has access to sewage collection) (Aries, 2018c). In this report, UN Environment developed simulations of future scenarios that would support Recife in making decisions with regards to their overall consumption.

The methodology used illustrates one method for expanding the analysis and corresponding implementation plan to address the transition of the city towards more sustainable consumption of resources: implementing a hybrid Urban Metabolism model to represent resource flows and constructing a simple transition scenario for the city. The report presents the implementation of a micro-level simulation model for the description of city resource flows as complex, integrated systems and tests the application of the model as a contributor to the 500-year plan and as a means to improve overall environmental and social sustainability in Recife.

**EMPREL: A BEST CASE**

Recife has centralized much of their data management and storage into a single institution called EMPREL, which acts as an IT service provider for the city and provides services around data storage and management. The institute also hosts an open-data portal, but only a fraction of the data reaches this portal. Figure 1 shows the open-data platform for the city of Recife.

The efforts made by the city of Recife to centralize its data have been identified by UN Environment as a best case. The creation of an institution dedicated to the management of data is a clear advantage of the city of Recife, and other cities would benefit from developing knowledge-based policies to explore this alternative.

*Figure 1: The Open Data Portal of Recife.*

*Source: EMPREL – Dados Recife.*
Describing City-Systems

Developing the appropriate framework to describe Recife as a city system is one of the critical steps in the development of this report. Efforts were made to understand the issues that the city is facing in order to shape a framework that would support the city in its planning and management.

Recife’s challenges

Boundaries

Cities, due to their inherent character as centres of business and innovation, normally expand beyond their political boundaries. Recife is one such city where its urban agglomeration extends well beyond its jurisdiction. This poses a challenge in quantifying the city’s metabolic processes. In an ideal scenario, Recife’s, peripheral areas should be integrated into the analysis.

Figure 2 illustrates the urban footprint using the municipal administrative boundaries (in red) and the street layout (orange), demonstrating that the city system extends beyond its jurisdiction. Any Urban Metabolism analysis focusing exclusively on the city’s jurisdiction won’t be able to fully describe the metabolic performance of the city-system. Unfortunately, the city of Recife can only develop policies and collect data within its political jurisdiction and it is difficult to argue for budget for data collection beyond these borders.

Our current inability to document data beyond Recife’s political borders will be a limitation in this simulation. Funding restrictions – both with the city and...

Figure 2: Recife municipality and urban agglomeration.
UN Environment – have not allowed collection of raw data beyond Recife’s jurisdiction which would have given more meaning to the metabolic flow analysis. The method used (described below), however, could be extended to include Recife’s periphery if given the opportunity to engage with those local governments in the development of similar simulation models.

Income Disparity

Income inequality is another issue that influenced the design of the simulation. Like many cities in Latin America and the Caribbean, a high level of inequality exists among Recife’s population. Figure 3 above shows a familiar picture of most cities in LAC. We see how low-income housing develops side by side with the high-income section of the city. With this high level of inequality in the city, implemented policies will have a different impact on both sections of the population.

The reality of income inequality makes it important to develop bottom-up simulation models considering that the ‘average’ citizen is not representative of a majority of the population. UN Environment developed a micro-level simulation model to quantify the impact with a better representation of the total population.

It is also due to income inequality that delivery of basic services such as water and electricity varies across different parts of the city. For this reason, we have chosen to focus on basic service delivery in the sample simulation below.
Recife as a city system

The concept of Urban Metabolism (UM), is perhaps the best framework to understand the city as a system especially from the perspective of consumption and production. UM implies a systemic approach to the analysis of cities and can be defined as: “the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste” (Kennedy, Cuddihy & Engel-Yan 2007).

UN Environment uses the UM methodology to help cities explore plausible evolution pathways of their urban systems and assess the impact of specific interventions in order to achieve long term sustainable urban development. For example, UM studies can provide insight on how government can manage and accelerate a transition toward a Circular Economy by analyzing the resource flows inside a city, their uses, and reintegration back into the system.

The first step for cities to channel the urban process towards a more sustainable development is to:

1. understand and quantify the resources flow of city-systems,
2. project these flows into the future, and
3. understand the impact of these pathways on their population.

Oftentimes, the data on the flow of resources available is at an aggregate level (i.e. for the city as a whole), which is enough to make evidence-based decisions on future infrastructure investment and policies targeting sustainable urban development. In order to understand the impact of city-level policies and investment strategies, cities need to understand 1) the drivers of consumption and 2) the plausible impact of these policies on their citizens. Thus, in order to get to this level of understanding, we propose in this paper the simulation of consumption intensities at a micro-level or with help of a “Spatial Microsimulation” (abbreviated in this paper as SM).

This report expands on the classic urban metabolism modelling process by incorporating Spatial Microsimulation (SM). A hybrid simulation model developed by UN Environment, the Spatial Microsimulation Urban Metabolism (SMUM), provides cities with an opportunity to not only understand its resource flows at the aggregate level but also develop bottom-up simulation that takes into consideration different parts of the population. This analytical framework addresses two of Recife’s key challenges: porous boundaries and income inequality. By describing the consumption intensities at the smallest level of detail possible (and implicitly their consumption drivers) cities have a tool to assess the impact at this micro-level (e.g. at municipal or district level), and take into consideration the socio-economic differences that lie within the city itself and make more appropriate, evidence-based responses to the challenges they face.

Simulation for Recife

Process overview

In the development of this simulation we look at delivery of electricity and water in the city of Recife, where both are referred to as ‘interventions’ that reach the population. ‘Interventions’ here is used to capture not only the built infrastructure for basic service delivery but also the policies regulating electricity and water delivery employed by the city.

In the absence of bottom-up data at local level, a synthetic population was developed using SMUM1 with real, national level demographic data used as a basis. We also defined the “sampling rules” in constructing the synthetic population. These rules defined, for example, who among the synthetic population (i.e. the simplified representation of the actual population) is more likely to adopt this technology. The selection rules are based on standard statistical assumptions and literature review. One scenario showed that a household headed by someone with a master’s degree level of education is 30 times more likely to adopt this technology than dwelling units with a household head with any other education level. The authors acknowledge that the use of synthetic population is not ideal but it also presents the opportunity of expanding beyond Recife’s borders in developing future scenarios.

A ‘business as usual’ scenario is used as a benchmark assuming that the population growth and demographic of the city remains in the same trajectory. Using the SMUM hybrid model, we defined the efficiency rates for electricity [Elec] and water [Water] to reach values of 40% and 20% by 2030 that would represent a net saving of about 400GWh or 200GWh of electricity and a net saving of 40 or 20 million of cubic meters of water in the residential sector. An absolute penetration rate [pr] for both of 30% by 2030 is also defined as part of the transition.

Because the simulation model is performed at a micro-level, we can aggregate the results using any of the attributes used within the simulation. The model looked at

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1 In the documentation on SMUM (see footnote 2 below), the word “technologies” is used instead of “interventions.”
2 Additional details on how to develop a synthetic population can be found in: https://resourceefficientcities.org/resources/smum/
the consumption of water and electricity by construction type: apartment (“Apartamento”) or detached house (“Casa”) for a simple transition scenario. Although the share of households in apartments is assumed to increase, single-family houses still have the largest consumption share.

The resource consumption shares by household type for the city of Recife allocates much of this consumption to households living in detached houses (“Casa”). This is the most common type of dwelling unit in the city. A denser urban agglomeration could potentially have a significant reduction in resource consumption. Nonetheless, the type of dwelling unit is not the only determinant of urban density but also floor space per household. Smaller more compact dwelling units will have significant reduction on the consumption intensities on the city.

Identifying drivers of consumption

To determine drivers of consumption such as population growth, we drew from national statistics. The model computed the growth rate for the federal state based on total population size from the national demographic census (1991) and projections from the national statistics office for the current year (2017). The estimated growth rate for Recife between 1991 and 2017 is 1.04 (4% population growth per year). This growth rate value is lower, compared to the growth rate of other cities in Brazil (e.g. Brasilia 1.06).

As a first step in the projection of consumption drivers, the aggregated demographic variables are simply extrapolated following the computation of the growth rate. As a second step, the model introduces bias to these projections. This bias, introduced into the projections, represents the baseline scenario. This scenario assumes:

1. An increase of dwelling units with 2 and 3 bathrooms.
2. An increase of dwelling units living in apartment buildings.
3. An increase of dwelling units connected to the water supply grid.
4. A 100% urban population.
5. No change in the sharer of household head gender.
6. No change in the age distribution of the city.
7. An increase in the head of family college and master education.
8. A share increase of smaller household size.

The assumptions made for the baseline scenario can be modified for the construction of alternative scenarios, but this method is not seen as the direct method for the construction of simulation scenarios.

Measuring consumption

A consumption table-model was used to describe the consumption patterns at a micro-level. Table-models calculated for Recife can be found in Annex 1. This micro-level consumption table-model simulated computations of the consumption value for each household in the city, making it possible to quantify the consumption per household.

For the case of Recife, we defined two simple consumption table-models: one for the estimation of water and one for the estimation of electricity. These two models share some of the required variables for the estimation of the consumption value. Regression analysis was used to properly downscale national data to make it relevant for local level computations.

The consumption table-models use the following variables:

1. Age of head of household: [age] (shared by both);
2. Dwelling unit type: [dutyp, Casa=Detached house] (shared by both);
3. Urbanization: [urban] (shared by both);
4. Household head gender: [sex] (shared by both);
5. Number of bathrooms per dwelling unit: [ban] (only water demand);
6. Water connection type: [connection] (only water demand);
7. Size of dwelling unit: [sqm] (only electricity demand);
8. Cooling Degree Days: [cdd, constant] (only for electricity demand);
9. Total household income: [income] (only for electricity demand); and
10. Highest education level of head of household: [edu] (only for electricity demand)

The model calibrates the values to known aggregates unique to each city. The representation of these known aggregates is based on a classical Urban Metabolism analysis, taking advantage of a well-established method in the urban science community, the input-output (IO) table. An example of an IO table for Recife can be found in Table 3. By defining table-models for the other resource flows, the analysis can be easily extended to them. All inputs into the system are balanced out through the definition of outputs (negative values). Any difference between input and output are allocated to the city system stocks. For example, if a city has a larger output of water resources than their inputs into the system it is assumed that the city-system is depleting their internal water resources (water stock). The only sector where the model does not integrate a stock is for the energy sector. All energy is assumed to be consumed and transform into CO2 emissions within the city-system even when the actual combustion has occurred outside the city-system. This accounting methodology is essential for any consumption-based accounting methodology.
Table 1: Resources consumption Input-Output table for the city of Recife

<table>
<thead>
<tr>
<th>Group</th>
<th>Indicator</th>
<th>Sector</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Residential</td>
<td>Commercial</td>
</tr>
<tr>
<td>Energy</td>
<td>Electricity</td>
<td>1 168.97</td>
<td>1 466.95</td>
</tr>
<tr>
<td></td>
<td>Natural Gas</td>
<td>6.88</td>
<td>30.16</td>
</tr>
<tr>
<td></td>
<td>Fuel Oil</td>
<td>0.00</td>
<td>0.14</td>
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<tr>
<td></td>
<td>LPG</td>
<td>548 537.52</td>
<td>54 853.75</td>
</tr>
<tr>
<td></td>
<td>CO$_2$eq</td>
<td>-202 164.00</td>
<td>-122 957.00</td>
</tr>
<tr>
<td>Water</td>
<td>Water Consumption</td>
<td>104.79</td>
<td>50.87</td>
</tr>
<tr>
<td></td>
<td>Waste Water</td>
<td>-104.79</td>
<td>-50.87</td>
</tr>
<tr>
<td>Materials</td>
<td>Steel</td>
<td>55 135.85</td>
<td>26 764.89</td>
</tr>
<tr>
<td></td>
<td>Cement</td>
<td>220 543.41</td>
<td>107 059.55</td>
</tr>
<tr>
<td></td>
<td>Sand</td>
<td>385 950.97</td>
<td>187 354.22</td>
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<td></td>
<td>Aggregates</td>
<td>441 086.82</td>
<td>214 119.10</td>
</tr>
<tr>
<td></td>
<td>CDW</td>
<td>-36 757.23</td>
<td>-17 843.26</td>
</tr>
</tbody>
</table>

Sources: Prefeitura Municipal do Recife 2016 & Prefeitura Municipal do Recife 2016a, EMPREL.
These simple input-output tables give a basic overview of the resources flow of Recife at an aggregated level. These IO tables can grow in size and complexity as required by the city, and can be balanced by economic sector derived from downscaled national monetary IO tables.

A clear advantage of using input-output tables for the description of resource flows is that monetary input-output tables can be used for the representation of physical input-output tables, (see Zhang et al. 2014 and Liu & Zhang 2012). Many countries have detailed input-output tables either at a national or a regional level, though they are not yet common in many cities. National or regional monetary input-output tables can be downscaled to a city level. Nonetheless, this will assume that the national-industrial symbiosis is the same as the city-industrial symbiosis. The method for accurately downsizing this type of IO tables needs to be further developed.

Simulation results: electricity and water demand

Figure 4 shows the simulation results for water and electricity. It demonstrates a simulation baseline (blue line), representing a business as usual scenario, in which there are no policy interventions, and a simple transition scenario (orange line) which only takes into account minimal intervention that seeks to improve service delivery. In this ‘orange’ trajectory, the local government intervention plan would be solely to meet the residents’ needs but does not make an effort to introduce resource efficiency measures. A more advanced scenario could integrate expected behaviour changes as part of the baseline scenario.

One unsurprising result of the simulation is the large increase in required resources due to expected population growth. Water demand is expected to increase by about 20% until the year 2030. Infrastructure investment strategies that are designed to meet demand are only able to reduce this increase to about a 10% increase of water demand. Similarly for electricity consumption, using an ambitious 40% target, the city could start reducing its demand growth from 2024 onwards and could only reach electricity consumption levels of the benchmark year (2016) by 2030.

Figure 4: Simulation results for Recife.
Summary and conclusion

Consumption data in city planning and management

As mentioned in the introduction, UN Environment, in collaboration with ARIES, seeks to demonstrate the potential and necessity of resource efficiency measures to meet Recife’s future consumption needs. Considering resource efficiency is critical to the medium and long term planning and management of the city and should be an important factor in the city’s 100 year plan.

The importance of future consumption planning seen from the lens of long-term resilience, resource scarcity, and increasing climate change impacts is underacknowledged by many cities. However, these types of scenarios are essential for the planning of a city, especially for investment in urban infrastructure. Meeting the demand (in a business as usual scenario), is simply not enough.

One example of future consumption planning is illustrated in the World Bank’s 2012 case study of Bogota, Colombia. The city was suffering from water supply issues coupled with a burgeoning population. Initially, the city tried to address this through an increase in infrastructure investments (from the construction of dams and water treatment plants, to inter-basin transfers - from the Chingaza basin to Bogota). These interventions solved the long-term water supply issue (but they succeeded because they coupled this with an increase in tariffs set forth by the city’s water and sanitation authority, thus reflecting more accurately reflecting the environmental impact of water use and increasing efficiency incentives for the water utility company. These measures encouraged more responsible water use in the city, touted as one of the lowest in the continent, at 130 L of water per day, as opposed to 250 L /day on average in Latin America (going up to 400 L / day in some cities) (World Bank, 2012).

Bottom up planning is affordable

This report shows that science-based action does not require a perfect data set or a high price tag. Synthetic populations can be a stand-in for raw data and can provide robust numbers that can be used in decision making. The method presented in this paper uses the type of data that is available for many cities around the world and is thus something that can be replicated.

The spatial microsimulation urban metabolism analytical framework can be expanded to other resources and locations, because it makes use of data readily available at the national level.
An argument for a compact city

One key finding from the research and subsequent simulations is the environmental impact of the current preferred residence in Recife, which is dominated by stand-alone, single-family dwellings. Even under the assumption that the types of buildings would change at the city level and that efficiency measures are adopted at a household level, the dominant influence in the city’s urban form is single-family houses. The city of Recife needs to dedicate further analysis into possible urban development strategies that favour a compact city with smaller dwelling units.

Following this, policies promoting the reduction of floor space per household may reduce the consumption of resources and should be assessed at a micro-level, though impact on increased inequality should be considered. One strategy could be a reform of the property taxes scheme to be inclusive of all sections of the population. An assessment tool able to account for the impact on each household strata in their city would be essential in this intervention.

The REC500 plan: towards an inclusive, resilient, and resource efficient city

Shared prosperity is one of the goals of the REC500 plan (Aries, 2018a) and so is building environmental and urban resilience. The city’s vision mirrors the global aspiration that UN Environment and the New Urban Agenda supports.

A microsimulation analysis, similar to the one presented in this report, provides an opportunity to integrate marginalized households, which are less visible in other analytical frameworks. Bottom-up analysis of resource flows through microsimulation provides a snapshot of resource consumption as it stands at a given point in time.

Resource flow analysis would enrich the development of inclusive urban policies. Should the city choose to pursue this path, its experience would serve as an example to the country and the rest of Latin America, a region unfortunately identified with its large inequality with some of the highest Gini coefficients in the world (see Figure 5).

It is also clear – even just from looking at water and electricity consumption – that future shifts in demographic, environmental, and socio-economic factors will challenge Recife’s resilience.

To ensure the city’s sustainability into the future, it is important to understand future consumption needs and how policies put into place now could impact different sections of the population in the future.

Recife has taken a significant, bold step by looking at a 100 year time frame for its planning process. It is even more inspiring that it wishes to ensure social inclusion and an equitable network of city services for the next generations of Recifenses.3 This report hopes to contribute to Recife’s aspirations.

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3 Rephrased from the city’s “Vision of the Future” (Aries, 2018a) and “Timeline” (Aries, 2018b).
References


Annex 1: Consumption Table-Models

Table 1 shows the water input table used to run the simulation. The SMUM model needs this input in order to define the water consumption table-model. In order to define the consumption table-model, SMUM needs some information on the variable distribution, defined by a prior distribution [dis] and its corresponding parameters [either mu and sd or p]. The other two values in the table represent the regression coefficients. These coefficients are used for the computation of consumption values and describe the consumption behaviour at a micro-level. The regression coefficients are defined through its mean value [co_mu] and its standard deviation [co_sd]. The standard deviation represents the induced uncertainty in the simulation model, making it an inherent stochastic (i.e. random) model.

Table 1: Water demand table-model for Recife (benchmark year 2016)

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<th></th>
<th>co_mu</th>
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<td>-</td>
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<td>-</td>
<td>-</td>
<td>Bernoulli</td>
</tr>
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<td>0.09</td>
<td>3.70</td>
<td>0.54</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>Categorical</td>
</tr>
<tr>
<td>connection</td>
<td>1, ..., 151.17</td>
<td>0, ..., 5.73</td>
<td>0.02, ..., 0.88</td>
<td>-</td>
<td>-</td>
<td>Categorical</td>
</tr>
</tbody>
</table>

The consumption table-models are imputed into the simulation table-model as listed in Table 1 and Table 2. The demographic variables, as explained before, are constructed with help of a distribution function and their required parameters. The age of the household head is sampled from a Gamma distribution with a mean value of 42.32 years of age and a standard deviation of 15.04. Dwelling unit type, urbanization and gender are sampled from a Bernoulli distribution 4 distribution while the number of bathrooms and water connection type are sampled as categorical variables with a sampling probability vector p. With this approach, the model is able to construct all kinds of input variables, even variables for which we don’t have data. On the simulation itself, these variables are benchmarked to known aggregates. If the aggregate value is unknown, we can express any of these variables as a function of other variables or computed by another independent table-model.

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4 A Bernoulli Distribution is a distribution in which a random variable can only have two possible values. One example of this is the distribution of coin tossing (with either a heads or tails outcome).
Table 2: Electricity demand table-model for Recife (benchmark year 2016)

<table>
<thead>
<tr>
<th></th>
<th>co_mu</th>
<th>co_sd</th>
<th>p</th>
<th>mu</th>
<th>sd</th>
<th>dis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-</td>
<td>-</td>
<td>3,329.17</td>
<td>-</td>
<td>-</td>
<td>Deterministic</td>
</tr>
<tr>
<td>dutyp</td>
<td>1,963.17</td>
<td>154.10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>None*</td>
</tr>
<tr>
<td>urban</td>
<td>-3,561.35</td>
<td>147.73</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>None*</td>
</tr>
<tr>
<td>sex</td>
<td>-201.80</td>
<td>116.63</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>None*</td>
</tr>
<tr>
<td>sqm</td>
<td>15.87</td>
<td>0.57</td>
<td>-</td>
<td>111.9</td>
<td>36.97</td>
<td>Normal</td>
</tr>
<tr>
<td>cdd</td>
<td>-</td>
<td>-</td>
<td>6,394</td>
<td>-</td>
<td>-</td>
<td>Deterministic</td>
</tr>
<tr>
<td>income</td>
<td>0.04</td>
<td>0.00</td>
<td>-</td>
<td>732.6</td>
<td>7.33</td>
<td>Gamma</td>
</tr>
<tr>
<td>hhsizesg</td>
<td>976.95</td>
<td>39.84</td>
<td>-</td>
<td>3.56</td>
<td>1.35</td>
<td>Normal</td>
</tr>
<tr>
<td>edu</td>
<td>1, ..., -625.98</td>
<td>0,..., 204.25</td>
<td>0.33, ..., 0.64</td>
<td>-</td>
<td>-</td>
<td>Categorical</td>
</tr>
</tbody>
</table>

* The sampling of this variable is not performed as this was sampled on the previous consumption table-model for water demand (see Table 1)

For the estimation of electricity demand at a household level, the simulation requires a consumption demand table-model able to explain electricity consumption patterns at a micro level. Because there is no available electricity consumption data at this level, we use data from the US. Residential Energy Consumption Survey (EIA, 2009). The results from this regression model are calibrated to the city of Recife by means of the Cooling Degree Days (CDD) variable. The use of this data-set for the estimation of electricity demand is suboptimal. The use of a local survey on electricity consumption would improve the performance of the table-model.

The definition of the electricity table-model is almost identical to the definition of the water table-model with some small differences. Apart from the use of different variables for the estimation of electricity demand, this table-model does not define any prior distribution for some of the input variables (dutyp, urban and sex). The reason for not defining a prior distribution for these variables is because they have been previously sampled on the water table-model. The model used the sample variables from the water table-model for the estimation of electricity, this is essential in order to maintain the consistency of the generated synthetic population sample.
METABOLIC FLOW ANALYSIS IN A 100 YEAR PLAN: THE CASE OF RECIFE, BRAZIL