URBAN PLANNING TOOLS AS AGENTS OF CHANGE:

COLLABORATIVE SPATIAL DATA FOR SUSTAINABLE URBAN DEVELOPMENT IN INDONESIA


2020
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Quick-start guide

Urban Performance is a Geoportal extension which simplifies the process of urban growth scenario development. In simple terms, a scenario is a combination of spatial layers and numeric assumptions that describe possible conditions for a city. Scenarios can be used to compare public policy implementation, such as the construction of new transit lines, parks or other urban services. Urban Performance generates a range of indicators, which can be used to compare scenarios.

Using Urban Performance is straightforward:
1. Log in to the Geoportal.
2. Select Urban Performance from the Geoportal’s Tools menu icon in the top right corner.
3. Choose a study area.
4. Click on “Scenarios”, select which scenario-results to display and click “Calculate”.

In the results panel, you will find the results for up to 4 selected scenarios in tabular or graphical format.

Now, let’s have a more detailed look at each step and describe all required inputs.

In the example above we have considered that data is already available at the Geoportal, and that someone has set up Urban Performance before. In the following section we will describe how to set it up from scratch.

First, note that to use Urban Performance you will need:
A. Study area: A Geoportal layer which describes the study area for your analysis. Frequently this a state, a municipality or a metropolitan area boundary. You can select any name for this layer, as long as it contains the string “study area”.
B. Layers: A set of Geoportal layers with data to be analyzed. Layers must have at least two attributes, one with the MMU (minimum mapping unit) identifier and one with the numeric values which will be processed.
C. Assumptions: A set of numeric values which describe expected conditions, such as carbon emission factors and infrastructure costs.

Please note that depending on the indicators selected, Urban Performance will request specific layers and assumptions. Before using the tool we strongly recommend to explore which indicators are available and to identify which inputs will be required (See Section 1.1 of this manual).
If layers described in Section 1.1 are not yet available in the Geoportal, upload them. Please note that you do not need to upload all layers described in Section 1.1, but only those layers that are required for your selected indicators.

Once that you have all required layers in the Geoportal, follow these steps:

1. Log in to the Geoportal.
2. Select Urban Performance from the Geoportal’s Tools menu icon in the top right corner.
3. On “Create a new scenario”, type a name for the scenario and select a study area and choose which indicators should be included in the analysis.
4. Click on “Create”.
5. Depending on the indicators that you have selected, the tool will request specific data inputs. The main goal in this step is to match the attribute-names in the data sources with the Urban Performance requirements.
6. Click on “Scenarios”, select which scenario-results to display and click “Calculate”.
7. In the results panel, you will find the results for up to 4 selected scenarios in tabular or graphical format.

Dealing with messy data

You might need to use the “Clean data” icon at the mid-right of the Geoportal screen to perform basic cleanup operations to the Layer before importing to Urban Performance.
1.- Introduction

This document presents the methodology carried out to perform calculations in the Urban Performance tool. It also describes the inputs (spatial and numeric data), main sources of information and methods developed by the CPL-CAPSUS team to create the information needed for the tool.

In the Methodology section, we will go into deeper details about the Urban Performance tool, focusing on the calculation methods and indicators.
2.- Methodology

2.1 Urban Performance

The Urban Performance tool assesses the city’s present and future performance by modeling investment projects or policies in a range of indicators related to the Sustainable Development Goals (SDG), including aspects such as poverty reduction, water management, energy, infrastructure, public transportation, climate action, etc. Urban Performance models multiple scenarios and spatial solutions to test the effectiveness of their contributions to sustainable development. Scenarios can serve as a dialog platform between stakeholders, who can use them to assess synergies between initiatives, to develop integrated solutions, to understand interdependency of possible solutions, and/or to create a multilevel and multisectoral consensus, among others. The tool is able to support decision making for preparation and evaluation of RTR (spatial plans).

2.1.1 Inputs

The Urban Performance tool needs a set of information of different types and formats to perform properly. The data can be divided into spatial and numeric data. Spatial data consists of a set of georeferenced information layers that includes maps of the region or city where the assessment will take place, urban amenities or investment projects (schools, hospitals, public transportation lines, sources of employment, libraries, etc.) as well as territorial distribution of population and jobs, natural environments, and other topics.

On the other hand, numeric information in the tool consists of scalar values with important information/facts or assumptions about several urban aspects. This information helps to describe and understand the current situation of a city in regards to energy consumption and on key municipal expenditures on housing, public transport, waste management, among others.
2.1.1.2 Spatial information: Layers

Urban Performance and Suitability share most of the datasets mainly because their assessments are based on spatial data, such as urban amenities, public transportation, risks, heritage areas, slums, among others. Despite being complementary tools, Urban Performance estimates the contribution of public policies on sustainable development and its impact in terms of population. Data related to population distribution is contained on the population layers which were generated for the 6 pilot cities by intersecting three datasets.

The first dataset is the Global Human Settlements Layer created by the Joint Research Centre from the European Commission in 2018\(^1\), which reflects the built-up area in a pixel of 250 by 250 meters in terms of percentage.

This dataset was clipped by using the second dataset: the administrative boundaries at a village scale delineated by the Geospatial Information Agency (Badan Informasi Geospasial-BIG) of the Republic of Indonesia. These boundaries have been elaborated between 2015 to 2019.

The total amount of inhabitants that live in each village was retrieved from the census data gathered in 2010 by the Central Bureau of Statistics (BPS Badan Pusat Statistik) and joined to its administrative boundary generated by BIG. By doing this, it is possible to know how many people live in each village and also in the study area.

The population was distributed according to the following process:

- Adding up the built-up area identified in the GHSL grid at a village scale.
- By doing this the population and built-up area are at a village scale.

• The population must be distributed in the built-up area that each cell represents, based on the proportion or percentage of the total built-up area in the village.

For Urban Performance it is important to know how the jobs clustered along the city as they shape the mobility patterns of the urban area. To create this data, the Nighttime Lights layer\(^2\) was used in its latest version. The information is provided by NOA\(^3\) and it is an estimation of the jobs concentration based on an average of radiance.

To make the layer useful for Urban Performance it is necessary to do some processing in order to have an accurate number for each part of the city. The first step is to convert the radiance into the number of jobs located in a specific location. For that, an equivalence for each point was made in the original layer and multiplied by the corresponding value for each point. Then, it was divided into the analysis points that were in the same location. The result was a more accurate number of jobs for each analysis point.

To assess environmental indicators, it was necessary to gather data on water ecosystems, biodiversity, ecosystems, and agricultural land. These layers were retrieved for 6 cities (Denpasar, Semarang, Balikpapan, Banjarmasin, Solo and Bandung) from the Rupa Bumi Indonesia databases and were elaborated by the Geospatial Information Agency (BIG) between 2015 and 2018.

Layers uploaded to the geoportal should follow these recommendations for ease of use in Urban Performance:


\(^3\) National Oceanic and Atmospheric Administration.
● They should not have a ‘projection’ property per feature. This is because the ‘projection’ property is only expected to be applied to the whole layer, and not to every single feature that forms it.

● They should not have z-coordinates in their data, as Urban Performance expects coordinates for 2 dimensions, not 3; sending z-coordinates would therefore cause the tool to not work with layers that do not follow this.

2.1.1.2.1 Urban growth scenarios

It is also possible to model urban growth scenarios. For that, the future conditions of a city in terms of urban expansion and population growth must be forecasted. Then, future scenarios that integrate possible projects or policies can be developed.

Urban growth scenarios are “possible futures” of an urban area, which can be forecasted using statistical models and spatial data. Modeling urban scenarios helps to predict how an urban area would be like in the future and compare different options. Each scenario includes one or more investment projects or policies.

Future scenarios can be modeled to show how an urban area would perform in the future assuming either it replicates historical urban growth patterns (no other investment projects or policies are considered), or new investment projects or policies are implemented. In both cases, future scenarios consider population growth and urban expansion estimates. Population growth is estimated by using official projections or historical population growth rates. The result of these estimations is a projected number of inhabitants for each urban area in the horizon year and a polygon that defines the expansion areas that are more likely to become urban by the horizon (target) year, if the study area continues growing as it has been doing in the past.
Annex A elaborates on the methodology used to forecast the layer needed by the Urban Performance tool to develop future scenarios.

### 2.1.1.3 Numeric information: Assumptions

Assumptions compile many variables related to generation and management of waste, costs on public services such as public lighting waste collection, water supply, road maintenance, and greenhouse gases. These variables are useful to assess how the city is performing in terms of energy efficiency and its impacts on the environment, as well as the municipal expenditures.

Typically, assumptions are gathered beforehand for each city where Urban Performance is implemented, so they are loaded to the tool in advance to assess it, however, users can upload new assumptions if needed.

The assumptions must be compiled in a CSV file (comma-separated values), using the following structure:

- **Category**: indicates the class that the entry belongs to.
- **Name**: Identifier of the variable.
- **Value**: value identified for the variable.
- **Units**: measurement units in which the value is presented.
- **Description**: a brief explanation about what the variable represents.
- **Source**: reference to the paper, official dependencies, or research that measures the variable.

A detailed list of assumptions is shown in Annex B.

### 2.1.1.4 Numeric information: Indicators
An indicator is a parameter or value that provides information about a phenomenon. According to Huang et al., (2015), the basic components of an indicator are data. On the other hand, an indicator is the operational representation of an attribute of a system, whereas an index is a more complex aggregate variable that is composed of several indicators. Indicators can be seen as tools that help simplify complexity and provide guidance on sustainable development (Morse, 2015).

Indicators can help make better decisions and carry out more effective actions by simplifying, clarifying and making information available to decision-makers and policymakers. Indicators can incorporate knowledge of the physical and social sciences into decision making thereby helping to measure and recognize progress toward the SDG. Singh et al., (2009) summarize the utility that indicators can have to: “a) anticipate and assess conditions and trends, b) provide early warning information to prevent economic, social and environmental damage, c) formulate strategies and communicate ideas, and d) support decision-making.”

Indicators can describe the conditions of a city by simplifying the evaluation, monitoring and communication of the status of a city and are key for integrated urban planning. Indicators can be used to assess (or model) how a city is (or will be) dealing with a specific urban concern.

The Urban Performance tool integrates a set of 41 indicators related to any of the 17 Sustainable Development Goals (SDG) of the United Nations. These indicators assess issues such as energy consumption, greenhouse gas emissions, poverty, infrastructure, urban services, climate change and the environment.

For a detailed list of the 41 indicators integrated in the Urban Performance tool, its description and calculation methods please consult Annex C.
2.1.2 Outputs

The outputs of the tool are mainly tabular results obtained after assessing a pallet of indicators.

2.1.2.1 Ways to show information

The structure is made up of:

- Indicators assessed
- Measurement units
- Values

It is also possible to display the results in graphs which simplifies the comparison process between scenarios results.
References


Annexes

Annex A Modeling urban expansion and population

Urban growth expansion models are mathematical abstractions of the real world that combine statistics and computational tools to simulate and predict urban expansion patterns. Urban expansion models work with machine learning algorithms and are based on historical land use change data. This data is complemented with input variables that reflect the geographic, socioeconomic, or physical characteristics of the urban environment, in order to determine the drivers of urban expansion. Urban expansion models are a combination of mathematical and computational tools for the simulation and prediction of urban expansion patterns (Poelmans & Van Rompaey 2010). Urban expansion models work with machine learning algorithms and are based on trends in historical land use change data, for three moments in time. This data is then complemented with input variables that reflect the geographic, socioeconomic, or physical characteristics of the urban environment, in order to find a causality for change. These variables are also known as explanatory variables. The models “learn” about the perceived tendencies and are “trained” to forecast future changes in land use.

Urban growth expansion models are developed through the statistical computing language R outside of the Urban Performance tool. The programming language R is employed due to its ability for spatially explicit land use change modeling. Specifically, the LULCC package was used, since it allows the inclusion of methods to process and explore the model inputs, fit and evaluate predictive models, spatially allocate land use changes, validate the model, and visualize model outputs (Moulds et al., 2015).
To estimate urban growth, three different statistical algorithms can be used. Having three different algorithms provides greater robustness in the predictions, since the forecast with the highest degree of accuracy can be selected. Back-casting analysis is used to calibrate the models against historical growth patterns, in order to verify accuracy. The data of at least three points in time are necessary. The range between these points determines how far into the future can the forecast go. For example, if data is available for years 2005 and 2020 (15 years back in the past), it would be reasonable to make projections from 2020 to 2035. Going further into the future results in a reduction in the model’s accuracy. To train the model, the software divides the data for observation time $T_0$, as well as the data of explanatory variables, into two random sets. This generates a “training” sample and a “test” sample of land use pixels linked to their respective explanatory variables’ pixels. The next step is the creation of a matrix in which relationships between dependent and independent variables are identified. Once these relationships are defined, the model is adjusted using the training sample and three statistical algorithms.

The three statistical methods implemented for the growth models are Binary Logistic Regression (BLR), Random Forests (RF), and Recursive Partitioning and Regression Trees (RPRT). These three models work through machine learning algorithms and are based on historical trends in land use change. These algorithms try to identify how land uses have changed over time and if explanatory variables have driven or influenced these changes. The three algorithms can be described as follows:

- **Binary Logistic Regression (BLR):** It is a statistical model that seeks to establish a relationship between a dependent variable with respect to one or more independent variables. In BLR, the outcome or dependent variable is dichotomous, hence the goal of the model is to assess the probability of falling into one of the outcome categories based on a set of predictors (Maroof 2012). This model attempts to predict the likelihood that an observation
belongs to each of the two groups. To make sense of the cause and effect relationships, there must be several observations available.

- **Random Forests (RF):** The RF method is made up of a collection of decision trees that are used in order to control the variance. This method can be described as a set (collection) of models that use aggregated sampling bootstraps to construct different decision trees, to later combine these models in a final classification. Indeed, it is considered a classifier of reference due its excellent performance (Abellan et al., 2018). The Random Forests method has several advantages: it can handle a large number of variables, it is quickly trained, it is generally robust in the treatment of outlier data and noise, and provides a way to calculate the importance that each variable has in the model.

- **Recursive Partitioning and Regression Trees (RPRT):** Recursive partitioning is a step-by-step process, in which a decision tree is constructed by either splitting (or not) each tree node into two daughter nodes. An attractive feature of this method is that because the algorithm asks a sequence of hierarchical Boolean questions (e.g., is \( x_j \leq z_j \), where \( z_j \) is a threshold value), it is relatively simple to understand and interpret the results (Izenman 2013). In order to build a decision tree, the algorithm starts with the root node, which consists of the learning set. Using the “goodness-of-split” criterion for a single variable, the tree algorithm finds the best split at the root node for each of the variables, \( x_1 \) to \( x_r \).

The whole process can be simplified into these five steps, see Figure 1:

1. **Input data:** The model requires maps depicting land use for three different points in time \( (T_0, T_1, T_2) \), as well as maps of a series of explanatory variables that can be described as those conditions that influence observed land use changes over time. Some of the most frequently used explanatory variables include proximity to urban centers, roads and metro stations (Liu et al., 2014) or proximity to built-up areas, roads, industrial centers, schools, universities, hospitals, airports, downtown area of the urban area, topographic
characteristics, per capita income, altitude, average slope, and population density (Jiang & Jao 2010; Kamusoko & Gamba 2015).

2. Model training: Expansion models are built through artificial neural networks and different statistical algorithms, which “learn” how the explanatory variables relate to the observed land use changes. The result is a “trained model” that can predict future land use changes. It is important to note that two evaluations of the model are carried out. The first one is about the accuracy in the learning process of the mathematical model or its prediction ability. The second one assesses the precision in the spatial allocation of the forecasted areas.

3. Model training validation: The criteria for choosing the most precise model is based on its accuracy for predicting land use changes in a back-casting process. The prediction ability of each algorithm is assessed with a coefficient that measures the goodness of fit, that is, how well does the algorithm fit the observations. However, as these are statistical algorithms, there will be a degree of uncertainty. The coefficient can take values from 0 to 1.

4. Spatial validation: Spatial allocation performance is validated by comparing the initial land use map for time $T_2$ with the simulated land use map for the same time point ($T_2'$). This validation step, in which the model is ascertained against historical information, shows how precise the model is to spatially allocate pixels associated with urban growth or land use changes. The result of the validation is a coefficient that can take values from 0 to 1.

5. Simulation: The final step is to simulate urban growth in the horizon year ($T_3$). In this step, priority polygons can be defined to predict urban growth in scenarios where population establishment should happen first in certain zones, such as the expansion areas specified in the Master Plans.
Figure 1. Expansion model process
Annex B Assumptions

Complete list of assumptions and information gathered for Bandung City.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Units</th>
<th>Category</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average square meters permitted in construction licenses per year</td>
<td>1,138,378.03</td>
<td>m^2/year</td>
<td>constr_waste</td>
<td>construction_sq_m</td>
</tr>
<tr>
<td>Estimated generation of construction debris</td>
<td>19.5</td>
<td>kg/m^2</td>
<td>constr_waste</td>
<td>debris_construction</td>
</tr>
<tr>
<td>Estimated generation of total demolition debris</td>
<td>757</td>
<td>kg/m^2</td>
<td>constr_waste</td>
<td>debris_demoli</td>
</tr>
<tr>
<td>Estimated generation of refurbishing or remodeling debris</td>
<td>44.1</td>
<td>kg/m^2</td>
<td>constr_waste</td>
<td>debris_remod</td>
</tr>
<tr>
<td>Efficiency of the disposal site expressed in quantity of construction waste that can handle by hour</td>
<td>75</td>
<td>ton/h</td>
<td>constr_waste</td>
<td>disp_eff</td>
</tr>
<tr>
<td>Operation cost of the construction waste disposal site (electricity consumption per year)</td>
<td>7.2</td>
<td>MWh/year</td>
<td>constr_waste</td>
<td>elec_construct_waste</td>
</tr>
<tr>
<td>Operation cost of the construction waste disposal site (maintenance of the site and the trucks)</td>
<td>224,500</td>
<td>USD/year</td>
<td>constr_waste</td>
<td>maint_construct_waste</td>
</tr>
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<td>Efficiency of the disposal site truck</td>
<td>0.54</td>
<td>L/ton</td>
<td>constr_waste</td>
<td>truckcw_eff</td>
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<td>Average square meters permitted in refurbishing or remodeling licenses per year</td>
<td>1,868,950</td>
<td>m^2/year</td>
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<td>remod_sqm</td>
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<td>m^2/year</td>
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<td>demoli_sqm</td>
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<td>Parametric construction cost per m^2 of housing unit</td>
<td>250</td>
<td>USD</td>
<td>costs</td>
<td>param_hucost</td>
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<td>Cost electricity network construction per km (including piping, manholes, cables, excavations, transformers, etc.)</td>
<td>15,751.63</td>
<td>USD/km</td>
<td>costs</td>
<td>cost_elec</td>
</tr>
<tr>
<td>Cost public lighting construction per km (including cables, lights, poles, accessories, etc.)</td>
<td>16,086.23</td>
<td>USD/km</td>
<td>costs</td>
<td>cost_light</td>
</tr>
<tr>
<td>Cost primary road construction (including pavement, base course, sidewalks, etc.)</td>
<td>1,019,204.07</td>
<td>USD/km</td>
<td>costs</td>
<td>cost_prim_road</td>
</tr>
<tr>
<td>Cost secondary road construction (including pavement, base course, sidewalks, etc.)</td>
<td>780,834.07</td>
<td>USD/km</td>
<td>costs</td>
<td>cost_sec_road</td>
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<tr>
<td>Cost sewer network construction (including pumps, pipes, excavations, manholes, etc.)</td>
<td>209,157.14</td>
<td>USD/km</td>
<td>costs</td>
<td>cost_swge</td>
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<td>Cost water network construction (including pumps, pipes, excavations, etc.)</td>
<td>1,620.71</td>
<td>USD/km</td>
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<td>cost_watr</td>
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<td>Commercial cost per liter of diesel</td>
<td>0.68</td>
<td>USD/L</td>
<td>costs</td>
<td>diesel_cost</td>
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<tr>
<td>Cost that the municipality pays per kWh of electricity consumed for public lighting</td>
<td>0.44</td>
<td>USD/km</td>
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<td>Cost that the municipality pays per kWh of electricity consumed to provide potable water</td>
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<td>USD/kWh</td>
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<td>eWater_cost</td>
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<td>Electric network improvement</td>
<td>6,074,843.26</td>
<td>USD/km</td>
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<td>retro_elec</td>
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<td>Sewage network improvement</td>
<td>69,610.28</td>
<td>USD/km</td>
<td>costs</td>
<td>retro_swge</td>
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<td>Water network improvement</td>
<td>648.28</td>
<td>USD/km</td>
<td>costs</td>
<td>retro_watr</td>
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<td>Average primary roads maintenance costs for the municipality</td>
<td>477.80</td>
<td>USD/km</td>
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<td>road_maintenance</td>
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<td>405.82</td>
<td>USD/km</td>
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<td>Pedestrian roads total length in the city</td>
<td>224.17</td>
<td>km</td>
<td>general</td>
<td>ped_road_km</td>
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<tr>
<td>Description</td>
<td>Value</td>
<td>Unit</td>
<td>Code</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>-------------</td>
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<td></td>
</tr>
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<td>Primary roads total length in the city</td>
<td>39.24</td>
<td>km</td>
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<td>Secondary roads total length in the city</td>
<td>62.07</td>
<td>km</td>
<td>sec_road_km</td>
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<tr>
<td>Tertiary roads total length in the city</td>
<td>1,343.2</td>
<td>km</td>
<td>ter_road_km</td>
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<td>Diesel net caloric value (NET CV)</td>
<td>12.22</td>
<td>kWh/kg</td>
<td>diesel_cv</td>
<td></td>
</tr>
<tr>
<td>Diesel density</td>
<td>840</td>
<td>kg/m³</td>
<td>diesel_den</td>
<td></td>
</tr>
<tr>
<td>Average gasoline market price</td>
<td>0.54</td>
<td>USD/L</td>
<td>gasoline_cost</td>
<td></td>
</tr>
<tr>
<td>Gasoline net caloric value (NET CV)</td>
<td>12.87</td>
<td>kWh/kg</td>
<td>gasoline_cv</td>
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<td>Gasoline density</td>
<td>991</td>
<td>kg/m³</td>
<td>gasoline_den</td>
<td></td>
</tr>
<tr>
<td>Housing unit size: number of habitants per housing unit</td>
<td>3.7</td>
<td>Inhabitants/hu</td>
<td>hu_size</td>
<td></td>
</tr>
<tr>
<td>Exchange rate for 1 unit of the local currency to Mexican Peso (MXN per unit of the local currency)</td>
<td>19.57</td>
<td>MXN/USD</td>
<td>JDMXN_exrate</td>
<td></td>
</tr>
<tr>
<td>Average inflation from Dec 2010 to May 2018 in Mexico</td>
<td>4.1</td>
<td>%</td>
<td>avge_inflation</td>
<td></td>
</tr>
<tr>
<td>Assumed average socioeconomic level of population in deciles of income</td>
<td>7.88</td>
<td>decile</td>
<td>socioeco_level</td>
<td></td>
</tr>
<tr>
<td>Biogas units emissions factor</td>
<td>15,666.66</td>
<td>kgCO2/GWh</td>
<td>ghg_emissions bio_emi</td>
<td></td>
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<tr>
<td>Biogas units electricity generation per year</td>
<td>2.85</td>
<td>GWh/year</td>
<td>bio_gen</td>
<td></td>
</tr>
<tr>
<td>Greenhouse gases emissions per kWh of diesel</td>
<td>0.26</td>
<td>kgCO2eq/kWh</td>
<td>carbon_factor_d_iesel</td>
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</tr>
<tr>
<td>Greenhouse gases emissions per kWh of gasoline</td>
<td>0.26</td>
<td>kgCO2eq/kWh</td>
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</tr>
<tr>
<td>Emission factor of the national electricity grid</td>
<td>0.67</td>
<td>kgCO2/kwh</td>
<td>emission_fact</td>
<td></td>
</tr>
<tr>
<td>Hydro units emissions factor</td>
<td>0</td>
<td>kgCO2/GWh</td>
<td>hyd_emi</td>
<td></td>
</tr>
<tr>
<td>Hydro units electricity generation per year</td>
<td>1,428</td>
<td>GWh/year</td>
<td>hyd_gen</td>
<td></td>
</tr>
<tr>
<td>Emission factor of not clean local energy</td>
<td>1.05</td>
<td>kgCO2/GWh</td>
<td>local_factor_noclean</td>
<td></td>
</tr>
<tr>
<td>Percentage of the electricity consumed in the country that is produced at national level</td>
<td>70</td>
<td>%</td>
<td>nationalen_perc</td>
<td></td>
</tr>
<tr>
<td>Solar energy plants emissions factor</td>
<td>0.67</td>
<td>kgCO2/GWh</td>
<td>sol_emi</td>
<td></td>
</tr>
<tr>
<td>Solar energy units electricity generation per year</td>
<td>111.9</td>
<td>GWh/year</td>
<td>sol_gen</td>
<td></td>
</tr>
<tr>
<td>Total electricity consumption in the urban area per year</td>
<td>4.2</td>
<td>GWh/year</td>
<td>ua_consumpt</td>
<td></td>
</tr>
<tr>
<td>Wind units emissions factor</td>
<td>0.67</td>
<td>kgCO2/GWh</td>
<td>win_emi</td>
<td></td>
</tr>
<tr>
<td>Energy generated locally with non renewable sources</td>
<td>52.32</td>
<td>GWh/year</td>
<td>other_energy</td>
<td></td>
</tr>
<tr>
<td>Average energy consumption per household established as baseline</td>
<td>3,238.08</td>
<td>kWh/yr per hu</td>
<td>ener_baseline</td>
<td></td>
</tr>
<tr>
<td>Baseline water demand per housing unit</td>
<td>210.24</td>
<td>m³/yr per hu</td>
<td>HU_water0</td>
<td></td>
</tr>
<tr>
<td>Average rainwater harvested in a year per housing unit</td>
<td>23.04</td>
<td>m³/yr per hu</td>
<td>rwh</td>
<td></td>
</tr>
<tr>
<td>Current bulbs cost</td>
<td>35.71</td>
<td>USD</td>
<td>com_cost</td>
<td></td>
</tr>
<tr>
<td>Current bulb lifespan</td>
<td>8,500</td>
<td>hours</td>
<td>com_lifespan</td>
<td></td>
</tr>
<tr>
<td>Number of hours a day that the street lighting works</td>
<td>11.5</td>
<td>h</td>
<td>hours_day</td>
<td></td>
</tr>
<tr>
<td>Average distance between public lighting posts</td>
<td>35</td>
<td>m</td>
<td>interpost</td>
<td></td>
</tr>
<tr>
<td>Efficient bulbs cost (e.g. LED)</td>
<td>35.71</td>
<td>USD</td>
<td>led_cost</td>
<td></td>
</tr>
<tr>
<td>Efficient bulb lifespan (e.g. LED)</td>
<td>50,000</td>
<td>hours</td>
<td>led_lifespan</td>
<td></td>
</tr>
<tr>
<td>Voltage of the common bulbs used for street lighting</td>
<td>0.19</td>
<td>kW</td>
<td>volt_bulb</td>
<td></td>
</tr>
<tr>
<td><strong>Voltage of the efficient bulbs used for street lighting (e.g. LED)</strong></td>
<td>0.05</td>
<td>kW</td>
<td>public_lighting</td>
<td>volt_led</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------</td>
<td>----</td>
<td>----------------</td>
<td>----------</td>
</tr>
<tr>
<td><strong>Percent of diesel vehicles in the country</strong></td>
<td>0.40</td>
<td>%</td>
<td>transport_energy</td>
<td>diesel_transp_frac</td>
</tr>
<tr>
<td><strong>Percent of gasoline vehicles in the country</strong></td>
<td>0.59</td>
<td>%</td>
<td>transport_energy</td>
<td>gasoline_transp_frac</td>
</tr>
<tr>
<td><strong>Times the solid waste is collected per week</strong></td>
<td>2.3</td>
<td>times per week</td>
<td>waste</td>
<td>collections</td>
</tr>
<tr>
<td><strong>Efficiency of the collector truck compaction system</strong></td>
<td>541.66</td>
<td>L/m³</td>
<td>waste</td>
<td>comp_ef</td>
</tr>
<tr>
<td><strong>Average distance from the city center to the landfill(s) or dumpsite(s)</strong></td>
<td>45.4</td>
<td>km</td>
<td>waste</td>
<td>dist_land</td>
</tr>
<tr>
<td><strong>Average distance from the city center to the transfer station(s)</strong></td>
<td>1.5</td>
<td>km</td>
<td>waste</td>
<td>dist_ts</td>
</tr>
<tr>
<td><strong>Average distance from the transfer station(s) to the landfill(s) or dumpsite(s)</strong></td>
<td>25.24</td>
<td>km</td>
<td>waste</td>
<td>dist_tsland</td>
</tr>
<tr>
<td><strong>Efficiency of the landfill expressed in quantity of waste that can handle by hour</strong></td>
<td>1,800</td>
<td>ton/day</td>
<td>waste</td>
<td>land_ef</td>
</tr>
<tr>
<td><strong>Percentage of primary roads used by the collection truck</strong></td>
<td>0.42</td>
<td>%</td>
<td>waste</td>
<td>prim_road_fact</td>
</tr>
<tr>
<td><strong>Percentage of secondary roads used by the collection truck</strong></td>
<td>0.58</td>
<td>%</td>
<td>waste</td>
<td>sec_road_fact</td>
</tr>
<tr>
<td><strong>Percentage of tertiary roads used by the collection truck</strong></td>
<td>0</td>
<td>%</td>
<td>waste</td>
<td>ter_road_fact</td>
</tr>
<tr>
<td><strong>Average capacity of the solid waste containers</strong></td>
<td>6</td>
<td>m³/container</td>
<td>waste</td>
<td>swcont_cap</td>
</tr>
<tr>
<td><strong>Number of solid waste containers in the locality</strong></td>
<td>100</td>
<td>containers</td>
<td>waste</td>
<td>swcont_quant</td>
</tr>
<tr>
<td><strong>Solid waste operation cost (trucks and equipment maintenance)</strong></td>
<td>1,034,067.68</td>
<td>USD/year</td>
<td>waste</td>
<td>swmmain_cost</td>
</tr>
<tr>
<td><strong>Solid waste operation cost (workers’ salaries per year)</strong></td>
<td>114,085.71</td>
<td>USD/year</td>
<td>waste</td>
<td>swmwork_salary</td>
</tr>
<tr>
<td><strong>Capacity of the collection truck</strong></td>
<td>6</td>
<td>ton</td>
<td>waste</td>
<td>truck1_cap</td>
</tr>
<tr>
<td><strong>Efficiency of the collection truck</strong></td>
<td>0.54</td>
<td>km/L</td>
<td>waste</td>
<td>truck1_ef</td>
</tr>
<tr>
<td><strong>Number of collection trucks in the locality</strong></td>
<td>14</td>
<td>trucks</td>
<td>waste</td>
<td>truck1_quant</td>
</tr>
<tr>
<td><strong>Capacity of the transfer truck</strong></td>
<td>6</td>
<td>ton</td>
<td>waste</td>
<td>truck2_cap</td>
</tr>
<tr>
<td><strong>Efficiency of the transfer truck</strong></td>
<td>3.8</td>
<td>km/L</td>
<td>waste</td>
<td>truck2_ef</td>
</tr>
<tr>
<td><strong>Number of transfer trucks in the locality</strong></td>
<td>13</td>
<td>trucks</td>
<td>waste</td>
<td>truck2_quant</td>
</tr>
<tr>
<td><strong>Efficiency of the landfill truck (compactor)</strong></td>
<td>52.59</td>
<td>kWh/day</td>
<td>waste</td>
<td>truck3_ef</td>
</tr>
<tr>
<td><strong>Waste Density (compacted volume)</strong></td>
<td>160</td>
<td>kg/m³</td>
<td>waste</td>
<td>waste_density</td>
</tr>
<tr>
<td><strong>Total solid waste generated per person per day</strong></td>
<td>0.6</td>
<td>kg/day</td>
<td>waste</td>
<td>waste_per</td>
</tr>
<tr>
<td><strong>Energy needed to supply one m³ of water</strong></td>
<td>8</td>
<td>kWh/m³</td>
<td>water</td>
<td>water_factor</td>
</tr>
<tr>
<td><strong>Percentage of water that becomes wastewater</strong></td>
<td>80</td>
<td>%</td>
<td>water</td>
<td>ww_factor</td>
</tr>
<tr>
<td><strong>Cost per cubic meter of wastewater treated</strong></td>
<td>0.32</td>
<td>USD/m³</td>
<td>water</td>
<td>wwt_cost</td>
</tr>
<tr>
<td><strong>Average energy needed to treat one m³ of wastewater in Wastewater Treatment Plants</strong></td>
<td>1.596</td>
<td>kWh/m³</td>
<td>water</td>
<td>wwt_ener</td>
</tr>
<tr>
<td><strong>Wastewater treated in local treatment plants (WWTP)</strong></td>
<td>29,200,000</td>
<td>m³/year</td>
<td>water</td>
<td>wwtreated</td>
</tr>
<tr>
<td><strong>Water distribution loss</strong></td>
<td>0.48</td>
<td>m³/km per yr</td>
<td>water_loss</td>
<td>loss</td>
</tr>
<tr>
<td><strong>Maximum distance to a bus route or stop</strong></td>
<td>300</td>
<td>m</td>
<td>transit</td>
<td>bus</td>
</tr>
<tr>
<td><strong>Maximum distance to a mini_bus route or stop</strong></td>
<td>300</td>
<td>m</td>
<td>transit</td>
<td>mini_bus</td>
</tr>
<tr>
<td><strong>Maximum distance to a BRT stops</strong></td>
<td>800</td>
<td>m</td>
<td>transit</td>
<td>BRT</td>
</tr>
<tr>
<td><strong>Maximum distance to a light rail stops</strong></td>
<td>800</td>
<td>m</td>
<td>transit</td>
<td>light_rail</td>
</tr>
<tr>
<td><strong>Maximum distance to a collective taxi route or stop</strong></td>
<td>300</td>
<td>m</td>
<td>transit</td>
<td>collective_taxi</td>
</tr>
<tr>
<td>Description</td>
<td>Value</td>
<td>Unit</td>
<td>Category</td>
<td>Name</td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td>----------</td>
<td>-------</td>
<td>-------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Maximum distance to a bicycle lane</td>
<td>300</td>
<td>m</td>
<td>transit</td>
<td>cycle</td>
</tr>
<tr>
<td>Analysis distance for job density</td>
<td>1,000</td>
<td>m</td>
<td>jobs</td>
<td>job</td>
</tr>
<tr>
<td>Minimum desired job density</td>
<td>38</td>
<td>jobs/ha</td>
<td>jobs</td>
<td>job_min_dens</td>
</tr>
<tr>
<td>Analysis distance for intersections density</td>
<td>1,000</td>
<td>m</td>
<td>roads</td>
<td>intersections</td>
</tr>
<tr>
<td>Maximum distance to elementary school</td>
<td>700</td>
<td>m</td>
<td>amenities</td>
<td>elementary_school</td>
</tr>
<tr>
<td>Maximum distance to secondary school</td>
<td>2,000</td>
<td>m</td>
<td>amenities</td>
<td>secondary_school</td>
</tr>
<tr>
<td>Maximum distance to highschool</td>
<td>2,000</td>
<td>m</td>
<td>amenities</td>
<td>high_school</td>
</tr>
<tr>
<td>Maximum distance to university</td>
<td>5,000</td>
<td>m</td>
<td>amenities</td>
<td>university</td>
</tr>
<tr>
<td>Maximum distance to health facility</td>
<td>1,500</td>
<td>m</td>
<td>amenities</td>
<td>health</td>
</tr>
<tr>
<td>Maximum distance to nursery</td>
<td>700</td>
<td>m</td>
<td>amenities</td>
<td>nursery</td>
</tr>
<tr>
<td>Maximum distance to sports facility</td>
<td>1,000</td>
<td>m</td>
<td>amenities</td>
<td>sports</td>
</tr>
<tr>
<td>Maximum distance to market</td>
<td>700</td>
<td>m</td>
<td>amenities</td>
<td>market</td>
</tr>
<tr>
<td>Maximum distance to cultural facility</td>
<td>1,000</td>
<td>m</td>
<td>amenities</td>
<td>cultural_facility</td>
</tr>
<tr>
<td>Maximum distance to public services</td>
<td>2,000</td>
<td>m</td>
<td>amenities</td>
<td>public_service</td>
</tr>
<tr>
<td>Maximum distance to place of worship</td>
<td>1,000</td>
<td>m</td>
<td>amenities</td>
<td>worship</td>
</tr>
<tr>
<td>Maximum distance to parks and public spaces</td>
<td>400</td>
<td>m</td>
<td>amenities</td>
<td>public_space</td>
</tr>
<tr>
<td>Outreach of water borne hazards</td>
<td>700</td>
<td>m</td>
<td>risk</td>
<td>water_contamination</td>
</tr>
<tr>
<td>Outreach of sources of suspended particulate matter</td>
<td>1,000</td>
<td>m</td>
<td>risk</td>
<td>suspended_pm</td>
</tr>
<tr>
<td>Radius of the buffer within which population density will be calculated</td>
<td>1,000</td>
<td>m</td>
<td>mmu</td>
<td>pop_den_r</td>
</tr>
<tr>
<td>Radius of the buffer within which area of urban blocks will be calculated</td>
<td>1,000</td>
<td>m</td>
<td>mmu</td>
<td>area_den_r</td>
</tr>
<tr>
<td>Width used to create a buffer to display the roads in the geoportal for primary roads</td>
<td>10</td>
<td>m</td>
<td>roads</td>
<td>primary</td>
</tr>
<tr>
<td>Width used to create a buffer to display the roads in the geoportal for secondary roads</td>
<td>10</td>
<td>m</td>
<td>roads</td>
<td>secondary</td>
</tr>
<tr>
<td>Width used to create a buffer to display the roads in the geoportal for tertiary roads</td>
<td>10</td>
<td>m</td>
<td>roads</td>
<td>tertiary</td>
</tr>
</tbody>
</table>

The assumptions table is made up of five columns. The first column called "description" contains the synthetic description of the assumption. The second column "value" contains a scalar representing the value of the assumption. The third column "unit" contains the units. The fourth column "category" contains a label that represents the indicator that is affected by that assumption. Finally, the fifth column "name" contains a label that is used by the Urban Performance tool to carry out the calculations.

Users can use this table as a template. Please note that the only column to be modified will be "value". Users must enter the values that apply for their own city/study area for each of the assumptions in the list. The title of any column or any other field should not be modified.
Annex C Indicators

Population connected to the electricity network

**Description:** Percentage of population connected to the national electricity grid.

**Units:** Percentage [%]

**Methodology:** The percentage of the population that is connected to electricity (con_elec) is calculated as the sum of the population connected to the electricity network (pop_con_elec) divided by the total population then multiplied by 100.

\[
con_{elec} = \left( \frac{pop_{con\_elec}}{tot_{pop}} \right) \times 100
\]

To calculate pop_con_elec the percentage of connected population (con_elec) is multiplied by the population of each analysis point (pop) and then all the population obtained is added to obtain the pop_con_elec variable.

\[
pop_{con\_elec} = \sum pop_i \text{ if } con_{elec} \text{ is true}
\]

Where
- \( pop \) is the population connected to the electricity network.
- \( tot_{pop} \) is the total population of the study area.

**SDG goal:** 1

Population with access to potable water

**Description:** Percentage of population who has access to potable water.

**Units:** Percentage [%]

**Methodology:** The percentage of the population with access to potable water (water_acc) is calculated as the sum of the population that has access to potable water (pop_water_net) being connected to the network or access by wells or water spots (pop_water_well), divided by the total population and multiplied by 100.

\[
water_{acc} = \left( \frac{pop_{water\_net} + pop_{water\_well}}{tot_{pop}} \right) \times 100
\]
water_acc = (∑ pop_water_net + ∑ pop_water_well)/tot_pop*100

Where

- \( \text{pop} \) is the population that has access to potable water from the network in the study area.
- \( \text{pop} \) is the population that has access to potable water from wells or water spots in the study area.

SDG goal: 1

Population with access to potable water by water network

Description: Percentage of population who has access to potable water by water network.

Units: Percentage [%]

Methodology: The percentage of the population with access to potable water by water network (perc_water_net) is calculated as the sum of the population being connected to the water network (pop_water_network) divided by the total population and multiplied by 100.

\[
\text{perc}_\text{water}_\text{net} = \left( \frac{\text{pop}_\text{water}_\text{network}}{\text{tot}_\text{pop}} \right) * 100
\]

\[
\text{pop}_\text{water}_\text{net} = \sum \text{pop}_i \text{ if water}_\text{net} \text{ is TRUE}
\]

Where

- \( \text{pop} \) is the population that has access to potable water from the network in the study area.
- \( \text{tot}_\text{pop} \) is the total population of the study area.

SDG goal: 1

Population with access to potable water by wells or water spots
**Description:** Percentage of population who has access to potable water by wells or water spots.

**Units:** Percentage [%]

**Methodology:** The percentage of the population with access to potable water by wells or water spots (perc_water_well) is calculated as the sum of the population that access to potable water (pop_water_well) by wells or water spots divided by the total population and multiplied by 100.

To calculate it a buffer (buffer) of the maximum recommended distance (max_dist) is created from the center of each well or water spot, then if the analysis point is inside the buffer it is considered that the analysis point has 100% access to water.

$$\text{perc}_{\text{water\_well}} = (\text{pop}_{\text{water\_well}} / \text{tot}_{\text{pop}}) \times 100$$

$$\text{pop}_{\text{water\_well}} = \sum \text{pop} \mid \text{pop} \in \text{buffer}$$

$$\text{buffer} = \{ \text{circles of radius max\_dist around dwells} \in \text{fclass} \}$$

$$\text{max\_dist} = \text{criteria fclass dwells}$$

Where

- $\text{pop}$ is the population that has access to potable water from wells or water spots in the study area.
- $\text{tot}_{\text{pop}}$ is the total population of the study area.

**SDG goal:** 1

**Population connected to the sewage network**

**Description:** Percentage of population who have access to sewage.

**Units:** Percentage [%]
**Methodology**: The percentage of the population that is connected to the sewage network (con_sew) is calculated as the sum of the population connected to the sewage network (pop_con_sew) between the total population multiplied by 100.

\[
con\_sew = \left( \frac{pop\_con\_sew}{tot\_pop} \right) \times 100
\]

\[
pop\_con\_sew = \sum pop \text{ i if con\_sew is true}
\]

Where

- \(pop\) is the population connected to the sewage network.
- \(tot\_pop\) is the total population of the study area.

**SDG goal**: 1

**Population located in slums**

**Description**: Percentage of population that are located in areas considered as slums.

**Units**: Percentage [%]

**Methodology**: The percentage of the population that is located in slums (pop_slum) is obtained by adding all the population in all the analysis points inside the slums polygons divided by the total population (tot_pop) and multiplied by 100.

\[
pop\_slums = \left( \frac{\sum pop \in (slum \cap location\_population)}{tot\_pop} \right) \times 100
\]

Where

- \(slum \cap location\_population\) is the population in all the analysis points inside the slums polygons.
- \(tot\_pop\) is the total population of the study area.

**SDG goal**: 1

**Sustainable agriculture land**
**Description**: Percentage of agricultural area under productive and sustainable agriculture expressed as km\(^2\) of sustainable agriculture area per km\(^2\) of agricultural area.

**Units**: Percentage [%]

**Methodology**: Sustainable agricultural land (agric\_sustainable) is calculated as the percentage of agricultural land that is under productive and sustainable agriculture.

The first step is to define the polygon that acknowledges sustainable agricultural land (sustainable\_agri). Spatial information that delimits sustainable agricultural land is uploaded in the ‘Footprint’ table of the UP calculator with footprint\_id = sustainable\_agri. The percentage of sustainable agricultural land is calculated by comparing the hectares of sustainable agricultural land and the hectares of the agricultural polygon (polygon with footprint\_id = agricultural in the ‘Footprint’ table).

\[
\text{agric\_sustainable} = \left(\frac{\text{agricultur\_sus\_area}}{\text{agricultural\_area}}\right) \times 100
\]

\[
\text{agricultur\_sus} = \text{agricultural} \cap \text{sustainable\_agri}
\]

Where

- \(\text{sustainable}\_agri\) is the polygon that contains the sustainable agricultural land of the study area.
- \(\text{agricultural}\) is the polygon that contains the agricultural land of the study area.
- \(\text{agricultur\_sus\_area}\) is the area (km\(^2\)) that contains the sustainable agricultural land of the study area.
- \(\text{agricultural\_area}\) is the area (km\(^2\)) that contains the agricultural land of the study area.
- \(\text{tot\_pop}\) is the total population of the study area.

**SDG goal**: 2

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**Elementary school capacity**

**Description**: Maximum number of students that can be served by each elementary school.
Units: students/school

Methodology: The elementary school capacity (elementary_capacity) is calculated as the sum of the capacity of each elementary school (elemen_capacity).

\[
\text{elementary\_capacity} = \left( \sum \text{elemen\_capacity}_i \right)
\]

The elemen_capacity variable is calculated as the gross area of each school (gross_area) multiplied by the number of shifts of the school and then divided by the recommended area per student (student_area) to ensure a quality education.

\[
\text{elemen\_capacity} = \frac{\text{gross\_area} \times \text{shift}}{\text{elestudent\_area}}
\]

\[
\text{shift} = \text{amenities} \in \text{fclass\_elementary\_school}
\]

Where

- \( \text{gross\_area} \) is the gross area of each school within the study area.
- \( \text{shift} \) is the number of shifts in the schools of the study area.

SDG goal: 4

Elementary school ratio

Description: Percentage of students that can be served in comparison with the population in age of attending elementary school.

Units: Percentage [%]

Methodology: The percentage of students that can be served by the elementary schools (elemax_perc) is calculated as the division of the elementary school capacity (elementary_capacity) by the population that is in age of attending elementary schools (popElemen).

\[
\text{elemax\_perc} = \frac{\text{elementary\_capacity}}{\text{pop\_elemen}}
\]

To calculate the pop_elemen there are two options. The first, if there is information of population by age per analysis point, the calculation sums the population in age to attend elementary school (elepop) from each analysis point. The second option is to have a

---

4 To calculate this formula please consult “Elementary school capacity”.
global percentage of population in age to attend elementary school (elepop_perc), if this value is used, then to calculate pop_elemen is necessary to multiply elepop_perc by the total population (tot_pop).

\[
\text{if elepop\_perc = null} \\
\quad \text{then pop\_elemen} = \sum (\text{elepop}\_i) \\
\text{else pop\_elemen} = \text{tot\_pop} \times \text{elepop\_perc}
\]

elepop_perc = assumptions.elepop_perc

Where
- \text{elementary\_capacity} is the sum of the maximum number of students that can be served by each elementary school.
- \text{pop\_elemen} is the sum of the population that is in age of attending elementary schools.
- \text{elepop} is the population that is in age of attending elementary schools.
- \text{elepop\_perc} is the global percentage of the population that is in age of attending elementary schools and it is located in the assumptions table.
- \text{tot\_pop} is the total population of the study area.

SDG goal: 4

**High school capacity**

**Description**: Maximum number of students that can be served by each high school.

**Units**: students/school

**Methodology**: The high school capacity (highschool\_capacity) is calculated as the sum of the capacity of each elementary school (high\_capacity).

\[
\text{highschool\_capacity} = \sum (\text{high\_capacity})\_i
\]
The high_capacity variable is calculated as the gross area of each school (gross_area) multiplied by the number of shifts of the school and then divided by the recommended area per student (highstudent_area) to ensure a quality education.

\[
\text{high_capacity} = \frac{\text{gross_area} \times \text{shift}}{\text{highstudent_area}}
\]

\[
\text{shift} = \text{amenities} \in \text{fclass high_school}
\]

Where
- \( \text{gross}_{\text{area}} \) is the gross area of each school within the study area.
- \( \text{shift} \) is the number of shifts in the schools of the study area.
- \( \text{highstudent}_{\text{area}} \) is the recommended area per high school student.

**SDG goal: 4**

**High school ratio**

**Description:** Percentage of students that can be served in comparison with the population in age of attending high school.

**Units:** Percentage [%]

**Methodology:** The percentage of students that can be served by the highschools (highmax_perc) is calculated as the division of the highschool capacity (highschool_capacity) by the population that is in age of attending highschool (pop_high).

\[
\text{highmax}_\text{perc} = \frac{\text{highschool}_\text{capacity}}{\text{pop}_\text{high}}
\]

To calculate the pop_high there are two options. The first, if there is information of population by age per analysis point the calculation sums the population in age to attend highschool (highpop) from each analysis point. The second option is to have a global percentage of population in age to attend highschool (highpop_perc), if this value is used, then to calculate pop_high is necessary to multiply highpop_perc by the total population (tot_pop).

\[
\text{if highpop}_\text{perc} = \text{null}
\]

\[
\text{then pop}_\text{high} = \sum (\text{highpop}_i)
\]
else pop_high = tot_pop * highpop_perc

elepop_perc = assumptions.highpop_perc

Where

- \textit{highschool\_capacity} is the high school capacity in terms of number of students.
- \textit{pop\_high} is the population that is in age of attending high schools.
- \textit{highpop} is the population that is in age of attending high schools.
- \textit{highpop\_perc} is the global percentage of the population that is in age of attending high schools and it is located in the assumptions table.
- \textit{tot\_pop} is the total population of the study area.
- \textit{highpop\_perc}

SDG goal: 4

**Wastewater treated percentage**

**Description:** Percentage of wastewater treated.

**Units:** Percentage [%]

**Methodology:** The percentage of wastewater that receives treatment is calculated by dividing the volume of treated wastewater (wwtreated) by the total volume of wastewater generated in the city (ww). The result is multiplied by 100 to express it as a percentage. The total volume of wastewater includes both non-renewable water and renewable water (harvested rainwater) that requires treatment. This volume is estimated by multiplying a factor (ww\_factor) that describes the percentage of water that becomes wastewater, by the sum of the total volume of water consumed by the city (tot\_water*tot\_pop) and the total volume of rainwater harvested in the city. Since the factor (ww\_factor) is expressed as a percentage, it is divided by 100 to convert it to a decimal number. The total volume of rainwater harvested in the city is estimated by multiplying the number of new houses (HU\_new) by the percentage of the new houses implementing rainwater harvesting and water saving measures (GBC\_pen/100) and by the amount of rainwater harvested per household (rwh).
The number of new housing units (HU_new) is calculated as the difference between the total housing units in the horizon year (hu_tot) and the total housing units in the base year (HU_existing).

\[
ww\_pct = \left( \frac{ww\_factor}{100} \right) \times (\text{tot\_water} \times \text{tot\_pop} + \text{rwh} \times HU\_\text{new} \times \frac{GBC\_pen}{100})
\]

\[
HU\_\text{new} = hu\_\text{tot} - HU\_\text{existing}
\]

if wwtreated > ww

then wwt\_pct = 100

else

\[
wwt\_pct = \left( \frac{ww\_\text{treated}}{ww} \right) \times 100
\]

end if

Where

- \(ww\text{factor}\) is the percentage of water that becomes wastewater.
- \(\text{tot\_pop}\) is the total population of the study area.
- \(\text{tot\_water} \times \text{tot\_pop}\) is the total volume of water consumed by the city.
- \(HU\_\text{new}\) this variable represents new housing units.
- \(hu\_\text{tot}\) this variable represents the total housing units in the horizon year.
- \(HU\_\text{existing}\) this variable represents the total housing units in the base year.
- \(ww\_\text{treated}\) is the volume of treated wastewater.

**SDG goal: 6**

**Water ecosystems consumption**

**Description:** Amount of water related ecosystems land that is predicted to become urban human settlements, between the base year and the horizon year.

**Units:** Square kilometers \([\text{km}^2]\)
**Methodology**: Water related ecosystems land consumption (watereco_consumption) is calculated as the area of the urban footprint (in the horizon year) that was land a water related ecosystem in the base year.

\[
\text{watereco\_consumption} = 0.01 \times (\text{sum of area}_i \text{ if } i \in \text{water\_eco polygon} \land i \notin \text{footprint\_base polygon})
\]

The first step is to define the polygon that acknowledges these areas. Spatial information that delimits water related ecosystem land is uploaded in the ‘Footprint’ table of the UP calculator with footprint_id = water_eco. The land lost to urbanization is calculated by adding up the hectares of urban area (area) of each analysis point is located within the water_eco polygon and that was located outside the urban footprint in the base year (polygon with footprint_id = footprint_base in the ‘Footprint’ table).

Where

- \(\text{gross\_area}\) urban footprint (in the horizon year) that was land a water related ecosystem in the base year.

**SDG goal**: 6

**Energy consumption**

**Description**: Total average energy consumed per person during a year for public lighting, municipal water supply, solid waste management, electricity in dwellings, commuting by public transportation and private vehicles, and wastewater treatment. The solid waste management energy consumption involves collection, transportation to transfer stations and final disposal sites, transference, and final disposal in landfill (if applicable).

**Units**: Kilowatts hour per person per year [kWh/capita/annum]

**Methodology**: Total energy consumption (energy_consumption) takes into account the energy consumed by the city’s population for commuting (energy_transport), for water provision (energy_water), for public lighting (energy_lighting), to manage the solid waste produced by the city’s population (energy_swaste), to treat the wastewater generated by the city’s population (energy_wwt), and the electricity consumed to power homes (energy_buildings).
energy_consumption = energy_water + energy_lighting + energy_swaste +
energy_buildings + energy_transport + energy_wwt

Where

- \( energy_{transport} \) energy consumed by the city's population for commuting.
- \( energy_{water} \) energy consumed by the city's population for water provision.
- \( energy_{lighting} \) energy consumed by the city's population for public lighting.
- \( energy_{swaste} \) energy consumed to manage the solid waste produced by the city’s population.
- \( energy_{wwt} \) energy consumed to treat the wastewater generated by the city’s population.
- \( energy_{buildings} \) electricity consumed to power homes.

**Energy transport**

**Description:** Total average energy consumed per person during a year for commuting within the urban area, either by public transport or private vehicle.

**Measurement units:** Energy use (in kilowatt-hour) per capita per year [kWh/capita/annum]

**Methodology:** Energy consumption associated with transportation (energy_transport) is calculated by adding the energy consumed per type of fuel available for transportation vehicles in the urban area (energy_diese & energy_gasoline) divided by the total population (tot_pop). The overall consumption in the urban area, by type of fuel, is the sum of the energy consumed in all the analysis points \( i \) in the urban area.

The energy associated to transportation by fuel type in each analysis point was calculated by dividing the costs per person incurred in each type of fuel (transport_cost_diesel & transport_cost_gasoline) by the fuel's average cost (diesel_cost & gasoline_cost), and then multiplying by the population in the analysis point (pop_i) and by an energy conversion factor. This factor combines the calorific value (diesel_cv & gasolinel_cv) and the density (diesel_den & gasoline_den) of the fuels. The transport cost per person associated with each type of fuel was calculated by multiplying the transport cost per person (transport_cost_i) by the fraction each type of transport represents of the whole array (diesel_transp_fra & gasoline_transp_fra).

Transport costs were calculated per each analysis point (transport_cost_i) by applying a linear multivariable regression model developed with expenditure and income data from
Mexico. The model’s resulting units are costs incurred per household per trimester in Mexican pesos. As the units desired are the local currency per person per year, the result is multiplied by 4 trimesters in a year, the exchange rate to the desired currency (JDMXN_exrate), and the average inflation of the Mexican Peso from 2010 until the current date (avge_inflation), divided by the average household size in the urban area (hu_size). The regression model considers the distance from each analysis point to the nearest transit route (transit_distance), the job density around each analysis point (job_density_avge), population density around each analysis point (pop_density_avge), the average area of the observation units around the analysis point (avge_area), and the median income in each observation unit (socioeco_level).

\[
\text{energy}_\text{transport} = \left( \sum \text{energy}_\text{diesel} + \sum \text{energy}_\text{gasoline} \right) / \text{tot_pop}
\]

\[
\text{energy}_\text{diesel}_i = (\text{pop}_i) \left( \frac{\text{transport}_\text{cost}_\text{diesel}_i}{\text{diesel}_\text{cost}} \right) \left( \frac{\text{diesel}_\text{den}}{1000} \right) \left( \text{diesel}_\text{cv} \right)
\]

\[
\text{energy}_\text{gasoline}_i = (\text{pop}_i) \left( \frac{\text{transport}_\text{cost}_\text{gasoline}_i}{\text{gasoline}_\text{cost}} \right) \left( \frac{\text{gasoline}_\text{den}}{1000} \right) \left( \text{gasoline}_\text{cv} \right)
\]

\[
\text{transport}_\text{cost}_\text{gasoline} = \left( \frac{\left( \text{transport}_\text{cost}_i \right) \left( \text{diesel}_\text{transport}_\text{frac} \right)}{100} \right)
\]

\[
\text{transport}_\text{cost}_i = \max \left\{ 0 \left[ \frac{(4) \left( \frac{1}{\text{JDMXN}_\text{exrate}} \right) \left( 1 + \frac{\text{avge}_\text{inflation}}{100} \right) \left( -620.06 + \frac{3.06 \times \text{transit}_\text{distance}}{1000} \right) \left( 1 - 19.10 \times \text{job}_\text{density}_\text{avge} \right) + \left( -0.69 \times \text{pop}_\text{density}_\text{avge} \right) + 213.09 \times \frac{\text{avge}_\text{area} + 661.16 \times \text{socioeco}_\text{level}}{\text{hu_size}} \right] \right\} / \text{hu_size}
\]

\[
\text{transit}_\text{distance} = \text{distance from the analysis point } \text{i} \text{ to the closest public transport route}
\]

\[
\text{job}_\text{density}_\text{avge} = \sum \text{jobs within a circle of radius job} / \left( \pi \times \text{job}_\text{radius}^2 / 1000 \right)
\]

\[
\text{pop}_\text{density}_\text{avge} = \sum \text{population within a circle of radius pop}_\text{radius} / \left( \pi \times \text{pop}_\text{radius}^2 / 1000 \right)
\]

\[
\text{avge}_\text{area} = \text{average area of the analysis points within a circle of radius area}_\text{radius}
\]
In addition, individual energy consumption for gasoline (energy_gasoline) and diesel (energy_diesel) combustion are calculated in order to incorporate them into the calculation of the GHG emissions indicator.

\[
\text{energy}_{\text{gasoline}} = \frac{\sum \text{energy}_{\text{gasoline}i}}{\text{tot}_{\text{pop}}}
\]

\[
\text{energy}_{\text{diesel}} = \frac{\sum \text{energy}_{\text{diesel}i}}{\text{tot}_{\text{pop}}}
\]

Where

- \( \text{energy} \) is the annual energy consumption associated to diesel combustion for commuting and transportation [kWh/annum] in each analysis point \( i \).
- \( \text{energy} \) is the annual energy consumption associated to gasoline combustion for commuting and transportation [kWh/annum] in each analysis point \( i \).
- \( \text{tot}_{\text{pop}} \) is the total number of inhabitants in the urban area. It is calculated according to Section A.3 (Population density).
- \( \text{pop}_i \) is the population of the analysis point \( i \) in the scenario of analysis forecasted to the horizon year, in line with the selected population_level. This is spatial data.
- \( \text{transport} \) is the annual cost per capita associated to diesel combustion in the analysis point \( i \) [USD/capita/annum].
- \( \text{transport} \) is the annual cost per capita associated to gasoline combustion in the analysis point \( i \) [USD/capita/annum].
- \( \text{diesel}_{\text{den}} \) is the diesel’s density [km/m\(^3\)]. It is divided by 1,000 to convert it to kg/L. This is a numeric value.
- \( \text{diesel}_{\text{cv}} \) is the diesel’s net calorific value [kWh/kg]. This is a numeric value.
- \( \text{diesel}_{\text{cost}} \) is the average diesel market price [USD/L]. This is a numeric value.
- \( \text{diesel} \) is the percentage of diesel vehicles [%]. It is divided by 100 to convert the percentage to a decimal number. This is a numeric value.
- \( \text{gasoline}_{\text{den}} \) is the gasoline’s density [kg/km\(^3\)]. It is divided by 1,000 to convert it to kg/L. This is a numeric value.
- \( \text{gasoline}_{\text{cv}} \) is the gasoline’s net calorific value [kWh/kg]. This is a numeric value.
- \( \text{gasoline}_{\text{cost}} \) is the average gasoline market price [USD/L]. This is a numeric value.
- \( \text{gasoline} \) is the percentage of gasoline vehicles [%]. It is divided by 100 to convert the percentage to a decimal number. This is a numeric value.
- \( \text{transport} \) is the annual cost per capita associated to transportation in the analysis point \( i \) [USD/capita/annum].
- \( \text{JDMXN}_{\text{exrate}} \) is the exchange rate between the Mexican Peso (MXN) and the US Dollar (USD). This is a numeric value.
• $\textit{avg}_\textit{inflation}$ is the average inflation of the Mexican Peso from 2010 until the current date. It is divided by 100 to convert the percentage to a decimal number. This is a numeric value.

• $\textit{transit}_{\textit{distance}}$ is the distance [m] from each analysis point $i$ to the nearest public transport route. The value of $\textit{distance}$ is calculated by the UP calculator using spatial information on the location of public transport routes. Calculated by UP tool

• $\textit{job}$ is the job density [jobs/ha] in a radius of 1 km around each analysis point. It is calculated by the UP calculator by determining the number of jobs inside a circle of radius $\textit{job}$ (1000 m). This is spatial data.

• $\textit{job}$ is the analysis radio for job density. It is used to add up the number of employees in all the buildings within this radio. It has a value of 1000 m. This is spatial data.

• $\textit{pop}$ is the population density [inh/ha] in a radius of 1 km around each analysis point. It is calculated by the UP tool by adding up the value of the field ‘Population’ for each analysis point located within a radius of value (1000 m) and area of 314.16 ha.

• $\textit{pop}$ is the analysis distance for population density. It has a value of 1000 m. This is a numeric value.

• $\textit{avg}_\textit{area}$ is the average area [km$^2$] of the observation units inside a 1 km radius around each analysis point. It is calculated by the UP tool by averaging the area of each observation unit located within a radius of value $\textit{area}$ from the center of the analysis point $i$.

• $\textit{area}$ is the analysis distance for the average area. It has a value of 1000 m. This is a numeric value.

• $\textit{socioeco}_{\textit{level}}$ is the median socioeconomic level of the urban area’s population, expressed as deciles of income (1, 2, 3, ..., 10), therefore it is unitless. This is a numeric value.

• $\textit{hu}$ is the number of inhabitants per housing unit [inh/hu]. This is a numeric value.

• $\textit{energy}_{\textit{gasoline}}$ is the total average energy consumed per person during a year for commuting within the urban area, by public transportation or private vehicle that use gasoline as fuel [kWh/capita/annum]. Calculated by the UP tool.

• $\textit{energy}_{\textit{diesel}}$ is the total average energy consumed per person during a year for commuting within the urban area, by public transportation or private vehicle that use diesel as fuel [kWh/capita/annum]. Calculated by the UP tool.

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Energy water
Description: Per capita annual amount of energy required to supply the volume of water demanded by the urban area’s residential sector. Energy lost due to water losses derived from leakages in the network is included in the calculation.

Measurement units: Energy use (in kilowatt-hour) per capita per year [kWh/capita/annum]

Methodology: The total annual energy consumption for water distribution (energy_water) is calculated by multiplying the energy needed to supply and distribute one cubic meter of water (water_factor) by the sum of the total volume of water consumed by the urban area (tot_water*tot_pop) and the water lost through leakages.

Losses due to leakages are estimated based on the kilometers covered by the water network. The number of kilometers of roads in the horizon year is estimated by multiplying the forecasted area of the urban area in square kilometers (footprint_km2) by the road density in the base year, that is, the kilometers of primary, secondary, and tertiary roads per square kilometer of the urban area (prim_road_km2 + sec_road_km2 + ter_road_km2). This value is then multiplied by the volume of water lost per kilometer (loss). The total is then divided by the total population of the urban area (tot_pop).

\[
\text{energy_water} = (\text{water_factor}) \times ((\text{tot_water} \times \text{tot_pop}) + ((\text{footprint}_\text{km2}) \times (\text{prim_road}_\text{km2} + \text{sec_road}_\text{km2} + \text{ter_road}_\text{km2}) \times \text{loss})) \div \text{tot_pop}
\]

Where

- \(\text{water_factor}\) is the energy, in kilowatt-hour, needed to supply one cubic meter of water [kWh/m\(^3\)]. This is a numeric value.
- \(\text{tot_water}\) is the average volume of water consumed per person per year in the households of the urban area [m\(^3\)/capita/annum]. This value is calculated according to section A.7 (Water consumption).
- \(\text{tot_pop}\) is the total number of inhabitants in the urban area. It is calculated according to Section A.3 (Population density).
- \(\text{footprint}_\text{km2}\) is the urban footprint, in square kilometers [km\(^2\)], estimated in accordance with the levels (population_level) defined for the urban growth policy lever in each of the urban area’s scenarios. The footprint is calculated by adding up the area of all the analysis points that have population. This is spatial data.
- \(\text{prim}\) is the total number of kilometers of primary roads per square kilometer [km/km\(^2\)] of the urban area. This value is calculated by dividing the total length, in kilometers [km], of primary roads (\(\text{prim}\)) by the urban area’s footprint in the base year (\(\text{footprint}_\text{km2}\)).
- \(\text{sec}\) is the total number of kilometers of secondary roads per square kilometer [km/km\(^2\)] of the urban area. This value is calculated by dividing the total length, in
kilometers [km], of secondary roads (sec) by the urban area’s footprint in the base year (footprint_{km^2}).

- **ter** is the total number of kilometers of tertiary roads per square kilometer [km/km^2] of the urban area. This value is calculated by dividing the total length, in kilometers [km], of tertiary roads (ter) by the urban area’s footprint in the base year (footprint_{km^2}).

- **prim, sec** and **ter** are the total number of kilometers [km] of primary, secondary and tertiary roads in the urban area in the base year. This is a numeric value. This is a numeric value.

- **loss** is the value of annual water distribution losses, expressed in cubic meters per kilometer per year [m^3/km/annum]. This is a numeric value.

### Energy lighting

**Description:** Annual average per capita energy consumption due to public lighting.

**Measurement units:** Energy use (in kilowatt-hour) per capita per year [kWh/capita/annum]

**Methodology:** Annual energy consumption for public lighting (energy_lighting) is calculated considering the total number of bulbs in the urban area (tot_bulb), how many of these are LED bulbs (num_led), the voltage of conventional bulbs (volt_bulb) and LED bulbs (volt_led), the daily number of hours per day that the bulbs are on (hours_day) and the number of days in a year (365).

The result is divided by the total kilometers of primary, secondary, tertiary and pedestrian roads in the urban area (prim_road_km+sec_road_km+ter_road_km+ped_road_km) to obtain the energy required per street kilometer.

As the specific number of street kilometers that the urban area will have in future scenarios is uncertain (tot_road_km), this number is estimated by multiplying the total built-up area of the urban area (footprint_{km^2}) by the kilometers of primary, secondary and tertiary roads per square kilometer that the urban area had in the base year (prim_road_km2+sec_road_km2+ter_road_km2).

Finally, the energy required per kilometer of street is multiplied by the estimated kilometers of street (tot_road_km) and divided by the total population (tot_pop) to obtain the annual per capita energy consumption associated with public lighting.

Since the exact number of light bulbs is unknown, the value is estimated considering the average distance between light poles (interpost), assuming one light bulb per light pole.
The number of LED bulbs is calculated by multiplying the total number of light bulbs (tot_bulb) by the percentage of LED bulbs (led_pen).

\[
\text{energy_lighting} = \left( \frac{[(\text{tot_bulb} - \text{num}_\text{led}) \times (\text{volt_bulb}) + (\text{num}_\text{led}) \times (\text{volt}_\text{led})]}{(\text{hours}_\text{day}) \times (365)} \right) / (\text{prim}_\text{road}_\text{km} + \text{sec}_\text{road}_\text{km} + \text{ter}_\text{road}_\text{km} + \text{ped}_\text{road}_\text{km}) \times (\text{tot_road}_\text{km} / \text{tot_pop})
\]

\[
\text{tot_road}_\text{km} = (\text{prim}_\text{road}_\text{km}2 + \text{sec}_\text{road}_\text{km}2 + \text{ter}_\text{road}_\text{km}2) \times (\text{footprint}_\text{km}2)
\]

If \( \text{tot_bulb} = \text{null} \)

Then

\[
\text{tot_bulb} = (\text{prim}_\text{road}_\text{km} + \text{sec}_\text{road}_\text{km} + \text{ter}_\text{road}_\text{km} + \text{ped}_\text{road}_\text{km}) / (\text{interpost} / 1000)
\]

\[
\text{num}_\text{led} = \text{tot_bulb} \times (\text{led}_\text{pen} / 100)
\]

Where

- \( \text{volt}_\text{bulb} \) is the voltage, in kilowatts [kW], of the common bulbs used for street lighting. This is a numeric value.
- \( \text{volt}_\text{led} \) is the voltage, in kilowatts [kW], of the LED bulbs used for street lighting. This is a numeric value.
- \( \text{hours}_\text{day} \) is the average number of hours per day that the street lighting is on [h/day]. This is a numeric value.
- \( \text{prim} \) is the total number of kilometers of primary roads per square kilometer [km/km\(^2\)] of the urban area. This value is calculated by dividing the total length, in kilometers [km], of primary roads \( (\text{prim}) \) by the urban area’s footprint in the base year \( (\text{footprint}_{\text{km}2}) \). Calculated by UP tool.
- \( \text{sec} \) is the total number of kilometers of secondary roads per square kilometer [km/km\(^2\)] of the urban area. This value is calculated by dividing the total length, in kilometers [km], of secondary roads \( (\text{sec}) \) by the urban area’s footprint in the base year \( (\text{footprint}_{\text{km}2}) \). Calculated by UP tool.
Energy for solid waste management

**Description:** Average per capita energy consumed annually by the solid waste management system of the urban area, including energy for collection and transportation, as well as the energy consumed in the landfill and transfer stations.

**Measurement units:** Energy use (in kilowatt-hour) per capita per year [kWh/capita/annum]

**Methodology:** The energy consumption associated with solid waste management (energy_swaste) takes into account the sum of the energy consumed in every step of the management system: solid waste collection (collection_energy), its transportation to the transfer stations and/or landfills (transport_energy), the energy consumed in the transfer station (TS_energy) and the energy used in the landfill (landf_energy). The result of this sum is divided by the total population (tot_pop).

The first component is the energy used in the collection stage (collection_energy). The calculation considers the average efficiency of the collection trucks (truck1_ef) in liters of diesel consumed per kilometer, multiplied by the diesel’s density (diesel_den) and calorific value (diesel_cv) and the total kilometers traveled in a year, which are estimated by multiplying the kilometers of primary roads per square kilometer of built-up area (prim_road_km2) by the percentage of the primary roads that the truck uses (prim_road_fact), plus the kilometers of secondary roads per square kilometer of built-up area (sec_road_km2) by the percentage of the secondary roads that the truck uses (sec_road_fact), plus the kilometers of tertiary roads per square kilometer of built-up area (ter_road_km2) by the percentage of the tertiary roads that the truck uses (ter_road_fact), plus the kilometers of pedestrian roads per square kilometer of built-up area (ped_road_km2) by the percentage of the pedestrian roads that the truck uses (ped_road_fact), plus the distance, in meters [m], between the public lighting posts (interpost) divided by 1,000 to convert it to km. The energy used in the transfer station (TS_energy) and the energy used in the landfill (landf_energy) are calculated separately and added to the total energy consumption.
area (sec_road_km2) multiplied by the percentage of the secondary roads that the truck uses (sec_road_fact), plus the kilometers of tertiary roads per square kilometer of built-up area (ter_road_km2) multiplied by the percentage of the tertiary roads that the truck uses (ter_road_fact). This is multiplied by the number of times the truck collects garbage per week (collections) and the number of weeks (52) in a year. Then, this total is multiplied by the total built-up area (footprint_km2) to obtain the energy used by the truck per year. Additionally, it is important to add the average energy used by the trucks’ compactor systems; to calculate this, it is necessary to multiply the average compactor efficiency in cubic meters of diesel per cubic meter of garbage (comp_ef) by the diesel’s density (diesel_den) and calorific value (diesel_cv); the total is multiplied by the total population (tot_pop), the waste generation per person per day (waste_per) and the number of days (365) in a year, all divided by the waste density (waste_density).

The second component is the energy used to transport waste from the center of the urban area to the transfer stations and from the transfer stations to the landfill (transport_energy); if there are no transfer stations, it is assumed that the collection trucks transport the waste directly from the center of the urban area to the landfill’s location. The first part of the equation assumes that there are no transfer stations, and includes the average efficiency of the collection trucks (truck1_ef) converted to cubic meters of diesel per kilometer, multiplied by the diesel’s density (diesel_den) and calorific value (diesel_cv). This value is then multiplied by the total volume of waste that is collected annually, divided by the average capacity of the collection trucks (truck1_cap) and multiplied by the average distance from the center of the urban area to the landfill or landfills (dist_land); the total waste volume is calculated by multiplying the total population (tot_pop) by the waste generation per person per day (waste_per) and the number of days (365) in a year. If one or more transfer stations exist, the second part of the equation is the same than the first part, except the efficiency of the collection truck (truck_ef) is multiplied by the average distance from the center of the urban area to the transfer stations (dist_ts), plus the efficiency of the transfer station truck (truck2_ef) converted to cubic meters of diesel per kilometer, multiplied by the diesel’s density (diesel_den) and calorific value (diesel_cv), multiplied by the total volume of waste that is collected annually, divided by the capacity of the transfer station truck (truck2_cap), and multiplied by the average distance from the transfer stations to the landfill (dist_tsland).

The third component is the energy consumed in the transfer stations (TS_energy), which considers the multiplication of the total population (tot_pop) by the waste generated per person per day (waste_per), by the number of days in a year (365), and by the energy consumed by the waste segregation machinery per ton of waste that is processed (energy_tonTS).

The fourth and last component is the energy consumed in the landfill (landf_energy). This is obtained by multiplying the total population (tot_pop) by the waste generation per
person per day (waste_per) and by the number of days in a year (365); the volume of waste that is generated annually is then divided by the efficiency of the landfill in tons of waste that are processed per day (land_ef) and multiplied by the efficiency of the landfill trucks(truck3_ef).

\[
\text{energy\_swaste} = \frac{\text{collection\_energy} + \text{transport\_energy} + \text{TS\_energy} + \text{landf\_energy}}{\text{tot\_pop}}
\]

\[
\text{collection\_energy} = \frac{(\text{truck1\_ef} / 1000) (\text{diesel\_den}) (\text{diesel\_cv}) \left[\left((\text{prim\_road\_km2}) (\text{prim\_road\_fact}) / 100\right) + \left((\text{sec\_road\_km2}) (\text{sec\_road\_km2}) / 100\right) + \left((\text{ter\_road\_km2}) (\text{ter\_road\_fact}) / 100\right)\right] \times (\text{collections}) (52) (\text{footprint\_km2})}{(\text{tot\_pop}) (\text{waste\_per}) (365)) / (\text{waste\_density})}
\]

\[
\text{transport\_energy} = \frac{(\text{truck1\_ef} / 1000) (\text{diesel\_den}) (\text{diesel\_cv}) \left[\left((\text{tot\_pop}) (\text{waste\_per}) (365) / 1000\right) (\text{dist\_lan} / \text{truck1\_cap}) + \left((\text{truck1\_ef} / 1000) (\text{diesel\_den}) (\text{diesel\_cv}) \left((\text{tot\_pop}) (\text{waste\_per}) (365) / 1000\right) (\text{dist\_ts/truck1\_cap})\right)\right]}{(\text{dist\_tsland} / \text{truck2\_cap})}
\]

\[
\text{TS\_energy} = ((\text{tot\_pop}) (\text{waste\_per}) (365) / 100) (\text{energy\_tonTS})
\]

\[
\text{landf\_energy} = ((\text{tot\_pop}) (\text{waste\_per}) (365) / 1000) (\text{truck3\_ef} / \text{land\_ef})
\]

Where

- \text{collection\_energy} is the energy consumed annually during the solid waste collection step [kWh/annum].
- \text{transport\_energy} is the energy consumed annually during the transportation to the transfer stations and/or landfills [kWh/annum].
- \text{TS\_energy} is the energy consumed annually in the transfer station [kWh/annum].
- \text{landf\_energy} is the energy consumed annually in the landfill [kWh/annum].
- \text{tot\_pop} is the total number of inhabitants in the urban area. It is calculated according to Section A.3 (Population density). Calculated by UP tool.
• $footprint_{km2}$ is the urban footprint, in square kilometers [$km^2$], estimated in accordance with the levels (population_level) defined for the urban growth policy lever in each of the urban area’s scenarios. The footprint is calculated by adding up the area of all the analysis points that have population. This is spatial data.

• $diesel_{den}$ is the diesel’s density [$kg/m^3$]. This is a numeric value.

• $diesel_{cv}$ is the diesel’s net calorific value [ $kWh/kg$]. This is a numeric value.

• $prim$ is the total number of kilometers of primary roads per square kilometer [$km/km^2$] of the urban area. This value is calculated by dividing the total length, in kilometers [km], of primary roads ($prim$) by the urban area’s footprint in the base year ($footprint_{km2}$). Calculated by UP tool.

• $prim$ is the percentage of primary roads used by the collection truck. It is divided by 100 to convert the percentage to a decimal number. This is a numeric value.

• $sec$ is the total number of kilometers of secondary roads per square kilometer [$km/km^2$] of the urban area. This value is calculated by dividing the total length, in kilometers [km], of secondary roads ($sec$) by the urban area’s footprint in the base year ($footprint_{km2}$). Calculated by UP tool.

• $sec$ is the percentage of secondary roads used by the collection truck. It is divided by 100 to convert the percentage to a decimal number. This is a numeric value.

• $ter$ is the total number of kilometers of tertiary roads per square kilometer [$km/km^2$] of the urban area. This value is calculated by dividing the total length, in kilometers [km], of tertiary roads ($ter$) by the urban area’s footprint in the base year ($footprint_{km2}$). Calculated by UP tool.

• $ter$ is the percentage of tertiary roads used by the collection truck. It is divided by 100 to convert the percentage to a decimal number. This is a numeric value.

• $prim$, $sec$, and $ter$ are the total number of kilometers [km] of primary, secondary, and tertiary roads in the urban area during the base year. This is a numeric value.

• $collections$ is the number of times solid waste is collected per week by each truck. This is a numeric value.

• $truck_{1ef}$ is the efficiency of the collection truck, in liters of diesel per km [$L/km$]. It is divided by 1,000 to convert it to $m^3/km$. This is a numeric value.

• $truck_{2ef}$ is the efficiency of the transfer truck, in liters of diesel per km [$L/km$]. It is divided by 1,000 to convert it to $m^3/km$. This is a numeric value.

• $truck_{3ef}$ is the daily efficiency of the landfill truck (compactor) [$kWh/day$]. This is a numeric value.

• $truck_{1cap}$ is the capacity of the collection truck, in tons [t]. This is a numeric value.

• $truck_{2cap}$ is the capacity of the transfer truck, in tons [t]. This is a numeric value.

• $comp_{ef}$ is the efficiency of the collector truck’s compaction system, in liters of diesel per cubic meter of garbage [$L/m^3$]. It is divided by 1,000 to convert it to cubic meters of diesel per cubic meters of garbage. This is a numeric value.
- $waste_{per}$ is the total solid waste generated per person per day [kg/capita/day]. It is divided by 1,000 to convert it to tons per capita per day [t/capita/day]. This is a numeric value.
- $waste_{density}$ is the waste's density (compacted volume) [$kg/m^3$]. This is a numeric value.
- $dist_{land}$ is the average distance [km] from the urban area’s center to the landfill or dumpsite. This is a numeric value.
- $dist_{ts}$ is the average distance [km] from the urban area’s center to the transfer station. This is a numeric value.
- $dist_{tsland}$ is the average distance [km] from the transfer station to the landfill or dumpsite. This is a numeric value.
- $energy_{tonTS}$ is the average energy used by the transfer station to process one ton of solid waste [kWh/t]. This is a numeric value.
- $land_{ef}$ is the landfill's efficiency expressed as the quantity of waste, in tons, that can be processed per day [t/day]. This is a numeric value.

**Energy for buildings**

**Description:** Average per capita electricity consumed annually to power homes and dwellings.

**Measurement units:** Energy use (in kilowatt-hour) per capita per year [kWh/capita/annum]

**Methodology:** The annual electricity consumed per person in housing units (energy_buildings) reflects the savings expected from implementing energy efficiency measures in the houses to be built between the base year and the horizon year (HU_new). These measures can be the result of implementing building standards or regulations like a Green Building Code (GBC). It is estimated by multiplying the number of housing units existing in the base year (HU_existng) by the average energy consumption per household established as baseline (ener_baseline), plus the multiplication of the new houses (HU_new) by the penetration percentage of the green building code (GBC_pen/100) by the reduced energy consumption per household (GBC_ener), plus the multiplication of the new houses (HU_new) by the percentage that do not implement the green building code (1 - GBC_pen/100) by the baseline housing unit energy consumption (ener_baseline). This value is then divided by the total population (tot_pop) to obtain the annual housing energy consumption per capita.
The number of new housing units (HU_new) is calculated as the difference between the total housing units in the horizon year (hu_tot) and the total housing units in the base year (HU_existing).

\[
\text{Energy\_buildings} = ( (\text{HU\_existing}) (\text{ener\_baseline}) + [(\text{HU\_new}) ((1-(\text{GBC\_pen} / 100)) (\text{ener\_baseline}) + (\text{HU\_new}) (\text{GBC\_pen} / 100) / \text{GBC\_ener})]) / \text{tot\_pop}
\]

\[
\text{HU\_new} = \text{hu\_tot} - \text{HU\_existing}
\]

Where

- \(\text{HU\_existing}\) is the number of housing units existing in the base year. It is calculated by adding up the housing units of each analysis point in the base year. This is spatial data.
- \(\text{hu\_tot}\) is the number of housing units in the scenario of analysis. It is calculated by adding up the housing units of each analysis point. Calculated by UP tool.
- \(\text{ener\_baseline}\) the average electricity consumption per household established as baseline, expressed as energy use (in kilowatt-hour) per year per housing unit [kWh/annum/hu]. This is a numeric value.
- \(\text{GBC\_ener}\) is the reduced electricity consumption per household when energy efficiency measures are implemented in the new houses (HU_new). It is expressed as energy use (in Kilowatt-hour) per year per housing unit [kWh/annum/hu]. This is a numeric value.
- \(\text{GBC\_pen}\) is the penetration percentage of the energy efficiency measures or GBC, that is, the percentage of new houses that will implement the efficiency measures. It is divided by 100 to convert the percentage to a decimal number. This is a numeric value.
- \(\text{tot\_pop}\) is the total number of inhabitants in the urban area. It is calculated according to Section A.3 (Population density). Calculated by UP tool.

**Energy associated with wastewater treatment**

**Description:** Average energy consumed annually per capita to treat the wastewater generated by the urban area’s population.
Measurement units: Energy use (in kilowatt-hour) per capita per year [kWh/capita/annum]

Methodology: Average energy consumption per capita for wastewater treatment depends on the volume of wastewater generated in the urban area (ww). If the volume of wastewater that receives treatment in the urban area (wwtreated) is less than the volume of generated wastewater (ww), then the annual energy consumed per person to treat the wastewater generated inside an urban area is estimated by multiplying the volume of wastewater treated annually (wwtreated) by the average energy needed to treat one cubic meter of wastewater (wwt_en). The result is then divided by the total population of the urban area (tot_pop) to obtain the average energy consumption per capita.

Otherwise, if the volume of wastewater treated by the urban area’s WWTPs is greater than the volume of wastewater generated in the urban area, then annual per capita energy consumption for wastewater treatment is the result of multiplying the volume of wastewater generated in the urban area (ww) by the average energy needed to treat one cubic meter of wastewater (wwt_en) and divided by the total population (tot_pop). This distinction is established because an urban area may provide treatment to more wastewater than the volume generated by its population.

If

\[ \text{ww} > \text{wwtreated} \]

Then

\[ \text{energy}_\text{wwt} = \frac{(\text{wwt}_\text{ener} \cdot \text{wwtreated})}{\text{tot}_\text{pop}} \]

Else

\[ \text{energy}_\text{wwt} = \frac{(\text{wwt}_\text{ener} \cdot \text{ww})}{\text{tot}_\text{pop}} \]

Where

- \(\text{wwt}_\text{ener}\) is the average energy needed to treat one cubic meter of wastewater [kWh/m\(^3\)]. This is a numeric value.
- \(\text{wwtreated}\) is the annual volume of wastewater generated in an urban area [m\(^3\)/annum]. This is a numeric value.
- \(\text{ww}\) is the annual volume of wastewater that is generated in an urban area [m\(^3\)/annum].
- \(\text{tot}_\text{pop}\) is the total number of inhabitants in the urban area. It is calculated according to Section A.3 (Population density). Calculated by UP tool.
SDG goal: 7

**Renewable energy**

**Description:** The percentage of the total energy consumption in the city that is generated locally through renewable sources.

**Units:** Percentage [%]

**Methodology:** The indicator of renewable energy (ren_energy) reflects the amount of energy from a city’s total energy consumption that is generated locally through renewable sources. The percentage is estimated by dividing the local renewable energy generation (localren_energy) by the total energy consumption in the city (ua_consumpt). The result is then multiplied by 100 to express it as a percentage.

\[
\text{ren_energy} = \left( \frac{\text{localren_energy}}{\text{ua_consumpt}} \right) \times 100
\]

Local renewable energy generation is the sum of the individual energy generation by each renewable source, including biogas (bio_gen), solar (sol_gen), wind (win_gen), and hydroelectric energy (hyd_gen).

\[
\text{localren_energy} = \text{bio_gen} + \text{sol_gen} + \text{win_gen} + \text{hyd_gen}
\]

Where
- \(\text{localren_energy}\) local renewable energy generation.
- \(\text{ua_consumpt}\) total energy consumption in the city.
- \(\text{bio_gen}\) local renewable energy generation through biogas.
- \(\text{sol_gen}\) local renewable energy generation through solar energy.
- \(\text{win_gen}\) local renewable energy generation through wind energy.
- \(\text{hyd_gen}\) local renewable energy generation through hydroelectric energy.

SDG goal: 7

**Financial services proximity**
**Description**: Percentage of the population with accessibility to banks and ATM's.

**Units**: Percentage [%]

**Methodology**: The proximity (amen_proxi) is calculated for each amenity class (fclass) by dividing the population (pop_prox_ami) that lives within the maximum distance recommended for that type of amenity (max_dist), by the total population (tot_pop) and multiplied by 100.

The first step is to create a buffer (bufferi) of the maximum recommended distance (max_dist) from the center of each amenity. Spatial information on the location of amenities and urban services can be found in the ‘Amenities’ table of the UP calculator. Next, the population (pop) of all the analysis points contained in the buffer is added up to obtain the population that has access to a particular amenity (pop_prox_ami). Finally, this population is divided by the total population of the city (tot_pop) and multiplied by 100 to obtain the percentage of the population that lives within the recommended distance for that type of amenity (amen_proxi). In the UP calculator, the values for max_dist are included in the ‘Assumptions’ table and can be identified by their ‘critiera_id’. The ‘critiera_id’ must match the ‘fclass’ field in the ‘Amenities’ table for the tool to be able to generate buffers adequately and calculate the indicators.

\[
\text{amen_proxi} = \left( \frac{\text{pop_prox_ami}}{\text{tot_pop}} \right) \times 100
\]

\[
\text{pop_prox_ami} = \sum \text{pop} \mid \text{pop} \in \text{buffer i}
\]

\[
\text{buffer i} = \{ \text{circles of radius max_dist i around amenities} \in \text{fclass i} \}
\]

\[
\text{max_dist} = \text{criteria fclass atm}
\]

Where

- \( \text{tot_pop} \) is the total population of the study area.

**SDG goal**: 8

**Road proximity**

**Description**: Percentage of the population who live near an all-season road.
**Units**: Percentage [%]

**Methodology**: The percentage of the population who lives near an all season road (allseason_prox) is calculated as the population with proximity to an all season road (pop_prox_allseason) divided by the total population (tot_pop) and multiplied by 100.

\[
\text{allseason}_\text{prox} = \left( \frac{\text{pop}_\text{prox}_\text{allseason}}{\text{tot}_\text{pop}} \right) \times 100
\]

To calculate the pop_prox_allseason the first step is to create a buffer (bufferi) of the maximum recommended distance (max_dist_allseason) from each all season road. Then the population (pop) of all the analysis points contained in the buffer is added up to obtain the population that has an all season road.

\[
\text{pop}_\text{prox}_\text{allseason} = \sum \text{pop}_i \mid \text{pop} \in \text{buffer}_i \text{ if road.allseason is true}
\]

\[
\text{buffer} = \{ \text{buffer}_i \}
\]

\[
\text{buffer}_i = \{ \text{circles of radius max_dist_allseason around all season roads} \in \text{season} \}
\]

Where

- \( \text{tot}_\text{pop} \) is the total population of the study area.

**SDG goal**: 9

**Population located in not safe settlements**

**Description**: Percentage of urban population living in slums, informal settlements or inadequate housing.

**Units**: Percentage [%]

**Methodology**: The percentage of population that is located in not safe settlements (percent_notsafe) is calculated as the division of the population in not safe areas (pop_nosafe) by the total population (tot_pop) multiplied by 100.

\[
\text{percent}_\text{notsafe} = \frac{\text{pop}_\text{nosafe}}{\text{tot}_\text{pop}} \times 100
\]

The pop_nosafe variable is calculated as the sum of the population that is located inside the union of the polygons of slums (slums), informal settlements (informar_set) and inadequate housing (inadeq_hu).
\[ \text{pop}_{\text{nosafe}} = \left\{ \sum \text{pop} \cdot \text{population} \mid \text{population} \in (\text{not_safe} \cap \text{location} \cdot \text{population}) \right\} \]

\[ \text{not_safe} = \text{slums} \cup \text{infor} \cup \text{inadeq} \]

\[ \text{slums} = \text{polygon} \cdot \text{slum} \]

\[ \text{infor} = \text{polygon} \cdot \text{informal} \]

\[ \text{inadeq} = \text{polygon} \cdot \text{inaaq} \]

Where
- \( t_{\text{tot}} \cdot \text{pop} \) is the total population of the study area.

**SDG goal: 11**

### Population located in informal settlements

**Description:** Percentage of urban population living in informal settlements.

**Units:** Percentage [%]

**Methodology:** The percentage of the population living in informal settlements (\( \text{percent}_{\text{informalset}} \)) is calculated as the sum of the population located in informal settlements (\( \text{pop}_{\text{informalset}} \)) divided by the total population (\( \text{tot}_{\text{pop}} \)) and multiplied by 100.

\[ \text{percent}_{\text{informalset}} = \frac{\text{pop}_{\text{informalset}}}{\text{tot}_{\text{pop}}} \times 100 \]

The \( \text{pop}_{\text{informalset}} \) variable is calculated as the sum of the population that is located inside the informal settlements polygon (\( \text{informal} \cdot \text{set} \)).

\[ \text{pop}_{\text{informalset}} = \left\{ \sum \text{pop} \cdot \text{population} \mid \text{population} \in (\text{informal} \cdot \text{set} \cap \text{location} \cdot \text{population}) \right\} \]

\[ \text{informal} = \text{polygon} \cdot \text{informal} \]

Where
- \( t_{\text{tot}} \cdot \text{pop} \) is the total population of the study area.

**SDG goal: 11**
**Population located in inadequate housing**

**Description:** Percentage of urban population living in inadequate housing.

**Units:** Percentage [%]

**Methodology:** The percentage of the population living in inadequate housing (percent_inade) is calculated as the sum of the population located in inadequate housing (pop_inade) divided by the total population (tot_pop) and multiplied by 100.

\[
\text{percent_inade} = \frac{\text{pop_inade}}{\text{tot_pop}} \times 100
\]

The pop_inade variable is calculated as the sum of the population that is located inside the inadequate housing polygon (inadequate_hu).

\[
\text{pop_inade} = \sum \{ \text{pop.population} \mid \text{population} \in (\text{inadequate_hu} \cap \text{location.population}) \}
\]

inadequate_hu = polygon.inadequate

Where
- \( \text{tot_pop} \) is the total population of the study area.

**SDG goal:** 11

**Population located in sea flood areas**

**Description:** Percentage of urban population living in areas prone to floods due to sea rising levels.

**Units:** Percentage [%]

**Methodology:**

The percentage of the population living in sea flood areas (percent_sflood) is calculated as the sum of the population located in areas prone to floods due to sea rising levels (pop_sflood) divided by the total population (tot_pop) and multiplied by 100.

\[
\text{percent_sflood} = \frac{\text{pop_sflood}}{\text{tot_pop}} \times 100
\]
\[
\text{percent\_sflood} = \frac{\text{pop\_sflood}}{\text{tot\_pop}} \times 100
\]

The `pop\_sflood` variable is calculated as the sum of the population that is settled inside the sea flood areas polygon (`sea\_floods`).

\[
\text{pop\_sflood} = \{ \sum \text{pop\_population} \mid \text{population} \in (\text{sea\_floods} \cap \text{location\_population}) \}
\]

\[
\text{sea\_floods} = \text{polygon\_sea\_floods}
\]

Where

- `tot\_pop` is the total population of the study area.

**SDG goal: 11**

**Public transport proximity**

**Description:** Percentage of the population that lives within walking distance from a public transport station.

**Units:** Percentage [%]

**Methodology:**

Public transport proximity (`transit\_prox`) is calculated by dividing the population (`pop\_prox\_transit`) that lives within the maximum recommended distance to a public transport route or stop (`max\_dist\_transiti`), by the total population (`tot\_pop`) and multiplied by 100.

First, a buffer (`buffer`) of the maximum recommended distance (`max\_dist\_transiti`) is created from the center of each public transport route or stop, according to the type of transportation (`fclassi`). Spatial information that defines the distribution of the different types of transport systems in the city is loaded in the ‘Transit’ table of the UP calculator. The maximum recommended distance varies according to the type of transportation system: for example, walking distance is 800 meters for structured transport systems like a BRT or subway, and 300 meters for buses and similar systems.

Second, the population (`pop`) of all the analysis points contained in the buffer is added up to obtain the population that lives close to public transport (`pop\_prox\_transit`).

Third, this population is divided by the total population of the city (`tot\_pop`) and multiplied by 100 to obtain the percentage of the population that lives close to public transport (`transit\_prox`).
transit_prox = ( pop_prox_transit / tot_pop ) * 100

pop_prox_transit = \( \sum \text{pop} \mid \text{pop} \in \text{buffer} \)

buffer = \{ \text{buffer i} \}

buffer i = \{ \text{circles of radius max_dist_transit around transit routes or stops} \in \text{fclass i} \}

Where

- \( \text{tot}_\text{pop} \) is the total population of the study area.

**SDG goal:** 11

**Land consumption**

**Description:** Amount of land predicted to change from natural habitats or agricultural uses into urban human settlements, between the base year and the horizon year.

**Units:** Square kilometers \([\text{km}^2]\)

**Methodology:**

Land consumption (land_consumption_km) is calculated as the difference between the city footprint in the horizon year (fp_horizon) and the footprint in the base year (fp_base). The city footprint refers to the total built-up area of a city, including streets, open space and inner vacant land.

\[
\text{land_consumption_km} = \text{fp}_\text{horizon} - \text{fp}_\text{base}
\]

Where

- \( \text{fp}_\text{horizon} \) is the city footprint in the horizon year.
- \( \text{fp}_\text{base} \) is the city footprint in the base year.

**SDG goal:** 11

**Heritage area consumption**
**Description:** Amount of land predicted to change from heritage areas into urban human settlements, between the base year and the horizon year.

**Units:** km²

**Methodology:**

Heritage area consumption (heritage_consumption) is calculated as the area of the urban footprint (in the horizon year) that was heritage land in the base year. This includes heritage areas. The first step is to define the polygon that acknowledges the areas considered as heritage land. Spatial information that delimits heritage land is uploaded in the ‘Footprint’ table of the UP calculator with footprint_id = heritage. The heritage land lost to urbanization is calculated by adding up the hectares of urban area (area) of each analysis point is located within the heritage polygon and that was located outside the urban footprint in the base year (polygon with footprint_id = footprint_base in the ‘Footprint’ table).

\[
\text{heritage\_consumption} = 0.01 \times (\sum \text{of area}_i \text{if } i \in \text{heritage polygon} \land i \notin \text{footprint\_base polygon})
\]

Where

- \(\text{footprint\_base\ polygon}\) is the polygon that represents the study area in the base year.
- \(\text{heritage\ polygon}\) is the polygon that represents the heritage land.

**SDG goal:** 11

**Solid waste management coverage**

**Description:** The coverage of the solid waste management system, expressed as the percentage of solid waste that can be collected and processed by the landfill with respect to the total solid waste generation in the city.

**Units:** Percentage [%]

**Methodology:**

There are two components that determine the capacity of the solid waste management system to cope with the volume of solid waste generated in the city (solidw_coverage): the landfill’s coverage (landfill_coverage) and the collection trucks’ coverage.
(truck_coverage). To measure the coverage of the system as a whole, the weakest link in the process must be identified. If both the landfill and the collection trucks can handle the whole waste generation, then there is complete coverage. However, if either the landfill or the collection trucks cannot handle the generated waste, then the system's coverage will be equal to the capacity of the component that has the largest deficiency.

The landfill is said to have complete coverage (landfill_coverage=100) when the quantity of waste it can handle in a week (land Ef*7) is greater than the city’s waste generation per week, which is equal to the waste generation per person per day (waste_per) multiplied by the total population (tot_pop) and by the number of days in a week (7). Otherwise, the landfill’s coverage is equal to the quantity of waste that the landfill can handle in a week (land Ef*7) divided by the city’s total waste generation (waste_per*tot_pop*7). The result is multiplied by 100 to express it as a percentage.

The truck coverage is assessed based on the collection capacity of the entire truck fleet (truckcol_cap) multiplied by the number of weekly collections (collections) that each truck carries out. If this number is greater than the city's waste generation per week (waste_per*tot_pop*7), there is complete coverage by the collection trucks (truck_coverage=100). Otherwise, the collection truck’s coverage is equal to the daily collection capacity of the entire truck fleet (truckcol_cap) multiplied by the number of times waste is collected each week (collections), and divided by the city’s total waste generation (waste_per*tot_pop*7). The result is multiplied by 100 to express it as a percentage.

The daily collection capacity of the entire truck fleet (truckcol_cap) is estimated as the multiplication of the number of trucks available for solid waste collection (truck1_quant) by the average capacity of an individual collection truck (truck1_cap).

\[
\text{if landfill_coverage} = 100 \text{ and truck_coverage} = 100 \\
\quad \text{then solidw_coverage} = 100 \\
\quad \text{else} \\
\quad \quad \text{if truck_coverage} < \text{landfill_coverage} \\
\quad \quad \quad \text{then solidw_coverage} = \text{truck_coverage} \\
\quad \quad \text{else solidw_coverage} = \text{landfill_coverage} \\
\quad \text{end if} \\
\text{if (land Ef*7*1000) > (waste_per*tot_pop*7)}
\]
then landfill_coverage = 100

else landfill_coverage = (((land_ef*7*1000)/(waste_per*tot_pop*7)))*100

end if

if (7*(waste_per*tot_pop)) < (truckcol_cap*collections)

then truck_coverage = 100

else truck_coverage = (truckcol_cap*collections/((7)*(waste_per*tot_pop)))*100

end if

truckcol_cap = truck1_quant*truck1_cap*1000

Where

- landfill_coverage is the landfill coverage within the study area. The landfill is said to have complete coverage when the quantity of waste it can handle in a week is greater than the city’s waste generation per week.

- truck_coverage is the coverage by the collection trucks within the study area. It is assessed based on the collection capacity of the entire truck fleet multiplied by the number of weekly collections that each truck carries out and divided by the city’s total waste generation.

- solidw_coverage is the capacity of the solid waste management system to cope with the volume of solid waste generated in the city.

- truckcol_cap represents the entire truck fleet.

- tot_pop is the total population of the study area.

- waste_per is the waste generation per person per day.

SDG goal: 11

Public space proximity

Description: Percentage of the population with accessibility to urban public services, public buildings, cultural spaces and public spaces.

Units: Percentage [%]
Methodology:

The proximity (amen_proxi) is calculated for each amenity class (fclassi) by dividing the population (pop_prox_ami) that lives within the maximum distance recommended for that type of amenity (max_disti), by the total population (tot_pop), all by 100.

The first step is to create a buffer (bufferi) of the maximum recommended distance (max_disti) from the center of each amenity. Spatial information on the location of amenities and urban services can be found in the ‘Amenities’ table of the UP calculator. Next, the population (pop) of all the analysis points contained in the buffer is added up to obtain the population that has access to a particular amenity (pop_prox_ami). Finally, this population is divided by the total population of the city (tot_pop) and multiplied by 100 to obtain the percentage of the population that lives within the recommended distance for that type of amenity (amen_proxi). In the UP calculator, the values for max_disti are included in the ‘Assumptions’ table and can be identified by their ‘criteria_id’. The ‘criteria_id’ must match the ‘fclass’ field in the ‘Amenities’ table for the tool to be able to generate buffers adequately and calculate the indicators.

\[
\text{amen_proxi} = \left( \frac{\text{pop_prox_ami}}{\text{tot_pop}} \right) \times 100
\]

\[
\text{pop_prox_ami} = \sum \text{pop.population} \mid \text{pop} \in \text{buffer i}
\]

buffer i = \{ circles of radius max_disti around amenities \in fclass i \}

Where

- \( \text{tot}_{pop} \) is the total population of the study area.

SDG goal: 11

**Educational infrastructure in risk areas**

**Description:** Total number of educational infrastructure located in risk areas.

**Units:** unit

**Methodology:**
The total number of educational infrastructure in risk areas (edu_risk) is calculated as the sum of all the amenities with the fclass related to educational infrastructure (as school, elementary_school, highschool) that are inside the risks polygons located in the footprint table.

\[
edu\_risk = \text{riskedu\_tot}
\]

\[
\text{riskedu\_tot} = \{ \text{count (location.amenities)} | \text{location.amenity} \in \text{risk.polygon} \land \text{fclass.amenities = school, elementary\_school, high\_school} \}
\]

Where
- \text{fclass.amenities} is the type of amenity a city can have.
- \text{risk.polygon} risks polygons located in the footprint table.

**SDG goal: 11**

**Health infrastructure in risk areas**

**Description:** Total number of health infrastructure located in risk areas.

**Units:** unit

**Methodology:**

The total number of health infrastructure in risk areas (health_risk) is calculated as the sum of all the amenities with the fclass related to health infrastructure (as hospital, clinics, etc) that are inside the risks polygons located in the footprint table.

\[
\text{health\_risk} = \text{health\_tot}
\]

\[
\text{health\_tot} = \{ \text{count (location.amenities)} | \text{location.amenity} \in \text{risk.polygon} \land \text{fclass.amenities = clinic, doctors, hospital, nursery} \}
\]

Where
- \text{fclass.amenities} is the type of amenity a city can have.
- \text{risk.polygon} risks polygons located in the footprint table.

**SDG goal: 11**
**Roads infrastructure in risk areas**

**Description:** Total number of kilometers that are in risk areas.

**Units:** Linear kilometers [km]

**Methodology:**

The total number of kilometers of roads infrastructure in risk areas (roads_risk) is calculated as the sum of the length of the roads that are inside the risks polygons located in the footprint table divided.

\[ \text{road\_risk} = \text{risk\_road\_tot} \]

\[ \text{risk\_road\_tot} = \left\{ \sum \text{length.roads} \mid \text{location.roads} \in \text{risk.polygon} \right\} \]

Where
- \( \text{risk}\_\text{polygon} \) risks polygons located in the footprint table.

**SDG goal:** 11

**Telecommunications infrastructure in risk areas**

**Description:** Total number of telecommunications infrastructure in risk areas.

**Units:** unit

**Methodology:**

The total number of telecommunications infrastructure in risk areas (telecom_risk) is calculated as the sum of all the elements inside the telecommunications table that are inside the risks polygons located in the footprint table.

\[ \text{telecom\_risk} = \text{telecom\_tot} \]
telec_tot = \{ \text{count (location.amenities)} \mid \text{location.amenity} \in \text{risk.polygon} \land \\
\quad \text{fclass.amenities} = \text{telecom} \}\)

Where

- \textit{fclass.amenities} is the type of amenity a city can have.
- \textit{risk.polygon} risks polygons located in the footprint table.

**SDG goal: 11**

**Solid waste recycled**

**Description:** Percentage of the solid waste generated that is sorted or recycled in transfer stations.

**Units:** Percentage [%]

**Methodology:**

The percentage is obtained by dividing the solid waste collected by the trucks (\textit{trucks\_collect}) by the recycling capacity of the transfer stations (\textit{rec\_cap}).

The solid waste collected by the truck is obtained by multiplying the trucks coverage (\textit{truck\_coverage}) by the solid waste generation per person (\textit{waste\_per}) by the total population (\textit{tot\_pop}).

\[
\text{waste\_recycled} = \frac{\text{trucks\_collect}}{\text{rec\_cap}}
\]

\[
\text{trucks\_collect} = \text{truck\_coverage} \times \text{waste\_per} \times \text{tot\_pop}
\]

Where

- \textit{trucks\_collect} this variable represents the solid waste collected by the trucks.
- \textit{rec\_cap} this variable represents the recycling capacity of the transfer stations.
- \textit{truck\_coverage} coverage by the collection trucks within the study area. Is assessed based on the collection capacity of the entire truck fleet multiplied by the number of weekly collections that each truck carries out.
- \textit{waste\_per} is the waste generation per person per day.
● \( t_{\text{ot pop}} \) is the total population of the study area.

**SDG goal: 12**

**Green land consumption**

**Description**: Amount of valuable natural land that is predicted to become urban human settlements, between the base year and the horizon year. This includes forest, natural reserves or other areas that provide environmental services.

**Units**: Square kilometers \([\text{km}^2]\)

**Methodology**:  
Green land consumption \((\text{greenland}\_\text{consumption})\) is calculated as the area of the urban footprint (in the horizon year) that was land with high environmental value in the base year. This includes forests, natural reserves, etc. The first step is to define the polygon that acknowledges the areas with high environmental value. Spatial information that delimits high-value environmental land is uploaded in the ‘Footprint’ table with footprint\_id = green\_land. The green land lost to urbanization is calculated by adding up the hectares of urban area (area) of each analysis points\_i located within the green\_land polygon and that was located outside the urban footprint in the base year (polygon with footprint\_id = footprint\_base in the ‘Footprint’ table).

\[
\text{greenland}\_\text{consumption} = 0.01 \times (\sum \text{area\_i if i \in green\_land\ polygon} \land i \notin \text{footprint\_base\ polygon})
\]

Where

- \( \text{footprint\_base\ polygon} \) is the polygon that represents the study area in the base year.

**SDG goal: 15**

**Green land availability**

**Description**: Percentage of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type.
Units: Percentage [%]

Methodology:

Green land availability (greenland_availability) is calculated dividing the protected areas that are land with high environmental value by the total area of protected zones. The result is multiplied by 100 to express it as a percentage. This includes forests, natural reserves, etc.

The first step is to define the polygon that acknowledges the areas with high environmental value. Spatial information that delimits high-value environmental land is uploaded in the ‘Footprint’ table with footprint_id = green_land. Then it is necessary to define the protected areas polygon, spatial information that delimits the protected areas is uploaded in the ‘Footprint’ table with footprint_id = protected.

\[
greenland\_availability = (\text{green\_land}\text{.area} / \text{protected}\text{.area}) \times 100
\]

Where
- \(\text{land}\text{.area}\) this variable represents the protected areas with high environmental value.
- \(\text{protected}\text{.area}\) this variable represents the total area of protected zones.

SDG goal: 15

Biodiversity land consumption

Description: Amount of high-biodiversity value land that is predicted to become urban human settlements, between the base year and the horizon year. This includes biodiversity areas.

Units: Square kilometers [km²]

Methodology:

Biodiversity land consumption (biodiversity_consumption) is calculated as the area of the urban footprint (in the horizon year) that was land with high biodiversity value in the base year. This includes biodiversity areas.
The first step is to define the polygon that acknowledges the areas with high biodiversity value. Spatial information that delimits high-value biodiversity land is uploaded in the ‘Footprint’ table of the UP calculator with footprint_id = biodiversity. The biodiversity land lost to urbanization is calculated by adding up the hectares of urban area (area) of each analysis point i located within the biodiversity polygon and that was located outside the urban footprint in the base year (polygon with footprint_id = footprint_base in the ‘Footprint’ table).

\[
\text{biodiversity\_consumption} = 0.01 \times (\sum \text{area}_i \text{ if } i \in \text{biodiversity polygon} \land i \notin \text{footprint\_base polygon})
\]

Where

- \text{footprint\_base polygon} is the polygon that represents the study area in the base year.

**SDG goal:** 15

**Mountain land consumption**

**Description:** Amount of mountain value land that is predicted to become urban human settlements, between the base year and the horizon year. This includes all mountain ecosystems.

**Units:** Square kilometers [km²]

**Methodology:**

Mountain land consumption (mountain\_consumption) is calculated as the area of the urban footprint (in the horizon year) that was land with mountain value in the base year. The first step is to define the polygon that acknowledges the areas with mountain value. Spatial information that delimits mountain value land is uploaded in the ‘Footprint’ table of the UP calculator with footprint_id = mountain. The mountain land lost to urbanization is calculated by adding up the hectares of urban area (area) of each analysis point i located within the mountain polygon and that was located outside the urban footprint in the base year (polygon with footprint_id = footprint_base in the ‘Footprint’ table).

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mountain_consumption = 0.01 * ( \sum \text{area } i \text{ if } i \in \text{mountain_land polygon} \land i \notin \text{footprint_base polygon})

Where

- $footprint_{base\ polygon}$ is the polygon that represents the study area in the base year.

SDG goal: 15
Annex D Classification

Since the layers can be uploaded by the user into the Geoportal without processing them and considering that the calculation methods for each indicator works based on specific variables that may not exist in the user data, here is where the classification table comes into play. The aforementioned table is meant to be a pivot between the data that the user imports from the Geoportal to UP through the Manage data Module.

The table is composed by three columns:

- **Name**: This column contains the values imported from the user layers by using the Manage Data Module.
- **Category**: This column indicates the name of the tables in which the data is imported (amenities, footprint, mmu, mmu_info, jobs, etc.).
- **Fclass**: This column will store the identifier that UP is expecting to carry out the assessment of the indicator. By default, it automatically copies the same value from the 'name' column but should be edited in order to match it with the variables awaited.

The user therefore must adjust the fclass to match what the indicators are expecting in order for UP to run its evaluations correctly. The identifiers expected by UP for each indicator can be found in Annex C of this document.

Example: The user creates a scenario that evaluates the proximity to health facilities, so it will require the location of these facilities. The layer from which they are imported categorizes them as hospital, health_facility, clinic, etc. Values that will be stored in the classification table in the name column.

As specified above, the fclass column will initially have the same value as the name. However, due to the indicator requiring these facilities to be categorized as health, none of the previously imported data would work during the assessment.

However, by simply adjusting the fclass value in the classification table to health for each of the fields (hospital, etc.), UP will be able to use said data during its calculations.
Annex E Matching data

The following annex lists important information regarding the Manage Data module in UP, as well as the data that is required for indicators to run their calculations properly.

Important: When importing data to the Minimum Mapping Units (MMU) and MMU Attributes tables, the same Layer must be used for this process.

Some indicators require the existence of a baseline scenario for the corresponding study area, as they take the values of the baseline scenario to compare against other scenarios.

When an indicator has dependencies, it means that said indicator requires results obtained from its corresponding dependencies.

Most indicators have at least one dependency. If there is required data in common between the indicator and its dependencies, this doesn’t mean that the matching process for said data must be repeated.

Glossary

**Base Footprint:** This represents a layer with the current conditions of a city (base area), in terms of the urban footprint.

**Footprint layer:** This layer contains information related to the spatial location where the analysis will take place.

**Tables:** Set of attributes related to spatial and tabular information that the Urban Performance tool needs to carry out the calculations correctly.

- **Amenities:** This table requires spatial location for amenities.
● **Assumptions:** Contains important tabular information related to a place/town/city. For more information about the Assumptions table, please consult Annex B of this document.

● **Footprint:** This table requires information related to the urban footprint where the analysis will take place.

● **Jobs:** This table requires spatial information regarding the radius of influence for job coverage.

● **MMU:** Minimum Mapping Units. This represents the minimum units of analysis into which a spatial information layer can be divided for its study, for example, Kelurahan, Kabupaten, blocks, etc. Typically, the area of each MMU is the information needed.

● **MMU Attributes:** Minimum Mapping Units Attributes. It contains information related to each single MMU, such as area, population census, urban services, etc.

● **Risk:** This table requires spatial information related to risk areas (slums, tsunami, volcano, droughts, etc.).

● **Roads:** This table requires spatial location for roads.

● **Transit:** This table requires spatial location for transit and public transportation.

**Study Area layer:** This layer contains information related to the spatial location where the analysis will take place. This layer is bigger than the Footprint layer as, in addition to containing the urban footprint, it contains other land uses.

**Scenario:** This concept represents the configuration of a set of investment projects or public policy actions that together could help to understand the current or future conditions of a city in terms of indicators.

According to the selected indicator(s) and/or module(s), data must be imported from the geoportal’s layers into the UrbanPerformance tools to do its evaluations. Listed below is the data that is expected for each indicator.

**General Calculus**
This module performs the calculation or updating of the following values: the area of the footprint polygons, the total population of the scenario, the area of the mmu, the number
of housing units in the scenario, the number of vacant housing units in the scenario, the area increment inside of the vacant base footprint, the vacant housing units rate, the population settled inside of the base footprint, the population outside of the base footprint, the population area density, pop_density_avge

Dependencies:

- N/A

Baseline required: **No**

Required tables:

- Assumptions
- Footprint
- MMU
- MMU Attributes

Type of data required:

- **Assumptions**: use data from the assumptions table related to the **Study Area** that the current **Scenario** belongs to.
- **Footprint**: requires the name (fclass*) of the classification and spatial location (geometry*), which will be retrieved from the **Base Footprint** layer and from the **Study Area** layer that the current **Scenario** belongs to; this implies that the same 'matching' process must be done once for each of these layers.
- **MMU**: requires the name of the classification and spatial location for the MMU. This data can be found in layers pertaining to population.
- **MMU Attributes**: require the values for population and area of each MMU for the **Study Area** that the current **Scenario** belongs to. This data can be found in layers pertaining to population. Since only one column can be imported at a time, the same 'matching' process must be done once for each value.

Buffers for urban amenities, Buffers for each job unit, Buffers for risk areas, Buffers for roads, Buffers for public transportation
These modules perform the calculation or updating of the following values respectively: amenities.buffer, risk.buffer, roads.buffer, transit.buffer.

Dependencies:
- N/A

Baseline required: No

Required tables:
- **Amenities** for Buffers for urban amenities
- **Assumptions** for any of the Buffers modules
- **Jobs** for Buffers for each job unit
- **Risk** for Buffers for risk areas
- **Roads** for Buffers for roads
- **Transit** for Buffers for public transportation

Type of data required:
- **Amenities**: requires the name of the classification and spatial location for amenities. This data can be found in layers pertaining to amenities.
- **Assumptions**: uses data from the assumptions table related to the Study Area that the current Scenario belongs to.
- **Jobs**: This table requires spatial information regarding the radius of influence for job coverage.
- **Risk**: requires the name of the classification and spatial location for risk areas. This data can be found in layers pertaining to risks.
- **Roads**: requires the name of the classification and spatial location for roads. This data can be found in layers pertaining to roads.
- **Transit**: requires the name of the classification and spatial location for transit and public transportation. This data can be found in layers pertaining to transit and public transportation.

**Access to electricity network**
For more information about this indicator please go to Annex C of this document.
Access to potable water by dwellings

Access to potable water by dwellings

For more information about this indicator please go to Annex C of this document.

Dependencies:
- Buffers
- General Calculus

Baseline required: No

Required tables:
- Amenities
- MMU

Type of data required:

Access to potable water by dwellings

For more information about this indicator please go to Annex C of this document.

Dependencies:
- Buffers
- General Calculus

Baseline required: No

Required tables:
- Amenities
- MMU

Type of data required:
- **Amenities**: requires the name of the classification and spatial location for water wells. This data can be found in layers pertaining to amenities.
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.

**Access to potable water by network and dwells**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**
- **Access to potable water by water network**
- **Access to potable water by dwells**

Baseline required: **No**

Required tables:
- N/A

Type of data required:
- **Results**: this data is gathered from the results of this indicator’s dependencies.

**Access to potable water by water network**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- MMU
- MMU Attributes
Type of data required:
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **MMU Attributes**: requires the values for **population with access to potable water from the network** of each MMU for the **Study Area** that the current **Scenario** belongs to. This data can be found in layers pertaining to population.

**Access to sewage network**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- **MMU**
- **MMU Attributes**

Type of data required:
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **MMU Attributes**: requires the values for the **population** and the **percentage of the population connected to the sewage network** of each MMU for the **Study Area** that the current **Scenario** belongs to. This data can be found in layers pertaining to population.

**Consumption of green land**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**
Baseline required: **No**

Required tables:
- Footprint
- MMU
- MMU Attributes

Type of data required:
- **Footprint**: requires the name of the classification and spatial location of greenlands. This data can be found in greenlands layers.
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **MMU Attributes**: requires the values for the area of each MMU for the **Study Area** that the current **Scenario** belongs to. This data can be found in layers pertaining to population.

**Consumption of heritage land**
For more information about this indicator please go to Annex C of this document.

**Dependencies**:
- **General Calculus**

Baseline required: **No**

Required tables:
- Assumptions
- Footprint

Type of data required:
- **Assumptions**: uses data from the assumptions table related to the **Study Area** that the current **Scenario** belongs to.
- **Footprint**: requires the name of the classification and spatial location of heritage areas. This data can be found in heritage areas layers.
Consumption of high biodiversity land
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- Amenities
- MMU
- MMU Attributes

Type of data required:
- **Footprint**: requires the name of the classification and spatial location of high biodiversity land and the base footprint. This data can be found in biodiversity and base footprint layers, respectively.
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **MMU Attributes**: requires the values for the area of each MMU for the Study Area that the current Scenario belongs to. This data can be found in layers pertaining to population.

Consumption of mountain land
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
● Footprint
● MMU
● MMU Attributes

Type of data required:
● **Footprint:** requires the name of the classification and spatial location of mountains. This data can be found in mountain layers.
● **MMU:** requires the spatial location for the MMU. This data can be found in layers pertaining to population.
● **MMU Attributes:** requires the values for the area of each MMU for the Study Area that the current Scenario belongs to. This data can be found in layers pertaining to population.

**Coverage of the solid waste management system**
For more information about this indicator please go to Annex C of this document.

Dependencies:
● **General Calculus**

Baseline required: **No**

Required tables:
● **Assumptions**

Type of data required:
● **Assumptions:** uses data from the assumptions table related to the Study Area that the current Scenario belongs to.

**Distance to transportation systems**
For more information about this indicator please go to Annex C of this document.

Dependencies:
● **General Calculus**
Baseline required: No

Required tables:
- MMU
- MMU attributes
- Transit
- Transit attributes

Type of data required:
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **MMU Attributes**: require the values for the population of each MMU for the Study Area that the current Scenario belongs to. This data can be found in layers pertaining to population.
- **Transit**: requires the spatial location for transit and public transportation. This data can be found in layers pertaining to transit and public transportation.
- **Transit attributes**: requires the name of the classification for transit and public transportation. This data can be found in layers pertaining to transit and public transportation.

**Educational infrastructure in risk areas**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- N/A

Baseline required: No

Required tables:
- Amenities
- Risk
Type of data required:

- **Amenities**: requires the name of the classification and spatial location of educational infrastructure. This data can be found in layers pertaining to amenities.
- **Risk**: requires the name of the classification and spatial location for risk areas. This data can be found in layers pertaining to risks.

**Elementary school capacity**

For more information about this indicator please go to Annex C of this document.

Dependencies:

- **General Calculus**

Baseline required: **No**

Required tables:

- **Amenities**
- **Amenities attributes**
- **Assumptions**

Type of data required:

- **Amenities**: requires the name of the classification for amenities. This data can be found in layers pertaining to amenities.
- **Amenities attributes**: requires the shifts and gross area of elementary schools. This data can be found in layers pertaining to amenities.
- **Assumptions**: uses data from the assumptions table related to the **Study Area** that the current **Scenario** belongs to.

**Elementary school ratio**

For more information about this indicator please go to Annex C of this document.

Dependencies:

- **General Calculus**
- **Elementary school ratio**

  Baseline required: **No**

  Required tables:
  - Assumptions
  - MMU
  - MMU attributes

  Type of data required:
  - **Assumptions**: uses data from the assumptions table related to the **Study Area** that the current **Scenario** belongs to.
  - **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
  - **MMU Attributes**: require the values for the elementary school population of each MMU for the **Study Area** that the current **Scenario** belongs to. This data can be found in layers pertaining to population.
  - **Results**: this data is gathered from the results of its dependencies

  **Energy consumption associated to buildings**

  For more information about this indicator please go to Annex C of this document.

  Dependencies:
  - **General Calculus**

  Baseline required: **Yes**

  Required tables:
  - **Assumptions**

  Type of data required:
  - **Assumptions**: uses data from the assumptions table related to the **Study Area** that the current **Scenario** belongs to.
• **Results:** this data is gathered from the results of its dependencies

**Energy consumption associated to public lighting**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**
- **Roads density**

Baseline required: **Yes**

Required tables:
- **Assumptions**

Type of data required:
- **Assumptions:** uses data from the assumptions table related to the Study Area that the current Scenario belongs to.
- **Results:** this data is gathered from the results of this indicator’s dependencies.

**Energy consumption associated to solid waste mgm**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**
- **Roads density**

Baseline required: **Yes**

Required tables:
- **Assumptions**

Type of data required:
• **Assumptions:** uses data from the assumptions table related to the *Study Area* that the current *Scenario* belongs to.

• **Results:** this data is gathered from the results of this indicator’s dependencies.

**Energy consumption associated to transportation**

For more information about this indicator please go to Annex C of this document.

Dependencies:

- **General Calculus**
- **Distance to transportation systems**

Baseline required: **Yes**

Required tables:

- Assumptions
- MMU
- MMU Attributes

Type of data required:

- **Assumptions:** uses data from the assumptions table related to the *Study Area* that the current *Scenario* belongs to.
- **MMU:** requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **MMU Attributes:** requires the values for the *population, area, transit distances* and *energy variables* of each MMU for the *Study Area* that the current *Scenario* belongs to. This data can be found in layers pertaining to population.
- **Results:** this data is gathered from the results of this indicator’s dependencies.

**Energy consumption associated to wastewater treatment**

For more information about this indicator please go to Annex C of this document.

Dependencies:
- General Calculus
- Percentage of wastewater treated

Baseline required: Yes

Required tables:
- Assumptions

Type of data required:
- **Assumptions**: uses data from the assumptions table related to the Study Area that the current Scenario belongs to.
- **Results**: this data is gathered from the results of this indicator’s dependencies.

**Energy consumption associated with water distribution & MGMT**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- General Calculus
- Water consumption per capita
- Roads density

Baseline required: Yes

Required tables:
- Assumptions

Type of data required:
- **Assumptions**: uses data from the assumptions table related to the Study Area that the current Scenario belongs to.
- **Results**: this data is gathered from the results of this indicator’s dependencies.

**Health infrastructure in risk areas**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- **Amenities**
- **Risk**

Type of data required:
- **Amenities**: requires the spatial location and the name of the classification for health infrastructure. This data can be found in layers pertaining to amenities.
- **Risk**: requires the name of the classification and spatial location for risk areas. This data can be found in layers pertaining to risks.

**High biodiversity value protected areas**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- **Footprint**

Type of data required:
- **Footprint**: requires the name of the classification and spatial location of greenlands and protected areas. This data can be found in greenlands and
protected areas layers; this implies that the same ‘matching’ process must be done once for each of these layers.

High school capacity
For more information about this indicator please go to Annex C of this document.

Dependencies:
- General Calculus

Baseline required: No

Required tables:
- Amenities
- Amenities attributes
- Assumptions

Type of data required:
- **Amenities**: requires the name of the classification for amenities. This data can be found in layers pertaining to amenities.
- **Amenities attributes**: requires the shifts and gross area of high schools. This data can be found in layers pertaining to amenities.
- **Assumptions**: uses data from the assumptions table related to the Study Area that the current Scenario belongs to.

High school ratio
For more information about this indicator please go to Annex C of this document.

Dependencies:
- General Calculus
- High school ratio

Baseline required: No
Required tables:
- Assumptions
- MMU
- MMU attributes

Type of data required:
- **Assumptions**: uses data from the assumptions table related to the Study Area that the current Scenario belongs to.
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **MMU Attributes**: require the values for the high school population of each MMU for the Study Area that the current Scenario belongs to. This data can be found in layers pertaining to population.
- **Results**: this data is gathered from the results of its dependencies

**Job density**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- Assumptions
- Jobs
- Jobs attributes
- MMU

Type of data required:
- **Assumptions**: uses data from the assumptions table related to the Study Area that the current Scenario belongs to.
- **Jobs**: requires the spatial location for job coverage. This data can be found in layers pertaining to job coverage.
• **Jobs attributes**: requires the job density average. This data can be found in layers pertaining to job coverage.
• **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.

**Land consumption**
For more information about this indicator please go to Annex C of this document.

Dependencies:
• **General Calculus**

Baseline required: **Yes**

Required tables:
• Footprint
• MMU
• MMU attributes

Type of data required:
• **Footprint**: requires the name of the classification and spatial location of the study area. This data can be found in study area layers.
• **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
• **MMU Attributes**: require the values for the area of each MMU for the Study Area that the current Scenario belongs to. This data can be found in layers pertaining to population.

**Percentage of wastewater treated**
For more information about this indicator please go to Annex C of this document.

Dependencies:
• **General Calculus**
• **Water consumption per capita**
Baseline required: **Yes**

**Required tables:**
- **Assumptions**
- **MMU Attributes**

**Type of data required:**
- **Assumptions:** uses data from the assumptions table related to the Study Area that the current Scenario belongs to.
- **MMU Attributes:** require the values for the housing units of each MMU for the Study Area that the current Scenario belongs to. This data can be found in layers pertaining to population.

**Population density**
For more information about this indicator please go to Annex C of this document.

**Dependencies:**
- **General Calculus**

Baseline required: **No**

**Required tables:**
- N/A

**Type of data required:**
- **Results:** this data is gathered from the results of this indicator’s dependencies.

**Population living in areas prone to sea floods**
For more information about this indicator please go to Annex C of this document.

**Dependencies:**
• General Calculus

Baseline required: No

Required tables:
• MMU
• Risk

Type of data required:
• **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
• **Risk**: requires the name of the classification and spatial location for areas prone to sea floods. This data can be found in layers pertaining to risks.

**Population living in inadequate housing**
For more information about this indicator please go to Annex C of this document.

Dependencies:
• General Calculus

Baseline required: No

Required tables:
• MMU
• Risk

Type of data required:
• **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
• **Risk**: requires the name of the classification and spatial location for inadequate housing. This data can be found in layers pertaining to slums.

**Population living in informal settlements**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- **MMU**
- **Risk**

Type of data required:
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **Risk**: requires the name of the classification and spatial location for informal settlements. This data can be found in layers pertaining to slums.

**Population living in not safe settlements**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- **MMU**
- **Risk**

Type of data required:
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **Risk**: requires the name of the classification and spatial location for unsafe settlements. This data can be found in layers pertaining to slums.

**Population living in slums**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- MMU
- Risk

Type of data required:
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **Risk**: requires the name of the classification and spatial location for areas considered as slums. This data can be found in layers pertaining to slums.

**Proximity to all season roads**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- MMU
- MMU attributes
- Roads
● Roads: attributes

Type of data required:

● **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.

● **MMU Attributes**: require the values for the population of each MMU for the **Study Area** that the current **Scenario** belongs to. This data can be found in layers pertaining to population.

● **Roads**: requires the spatial location for roads. This data can be found in layers pertaining to roads.

● **Roads attributes**: Requires data that confirms whether or not a road is considered all-seasons. This data can be found in layers pertaining to roads.

**Proximity to public transport systems**

For more information about this indicator please go to Annex C of this document.

Dependencies:

● **Buffers**

● **General Calculus**

Baseline required: **No**

Required tables:

● **MMU**

● **MMU Attributes**

● **Transit**

Type of data required:

● **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.

● **MMU Attributes**: require the values for the population of each MMU for the **Study Area** that the current **Scenario** belongs to. This data can be found in layers pertaining to population.
• **Transit**: requires the name of the classification and spatial location for transit and public transportation. This data can be found in layers pertaining to transit and public transportation.

**Proximity to urban amenities**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**
- **Buffers**

Baseline required: **No**

Required tables:
- Amenities
- MMU
- MMU Attributes

Type of data required:
- **Amenities**: requires the name of the classification, spatial location and buffers for amenities. The name and spatial location can be found in layers pertaining to amenities. The buffers are provided by the **Buffers** module.
- **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.
- **MMU Attributes**: require the values for the population of each MMU for the **Study Area** that the current **Scenario** belongs to. This data can be found in layers pertaining to population.

**Roads density**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**
Baseline required: **Yes**

Required tables:
- Assumptions
- Footprint

Type of data required:
- **Assumptions**: uses data from the assumptions table related to the *Study Area* that the current *Scenario* belongs to.
- **Footprint**: requires the name of the classification and spatial location of base footprint. This data can be found in base footprints layers.

**Road infrastructure in risk areas**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- N/A

Baseline required: **No**

Required tables:
- Risk
- Roads

Type of data required:
- **Risk**: requires the name of the classification and spatial location for risk areas. This data can be found in layers pertaining to risks.
- **Roads**: requires the name of the classification and spatial location for roads. This data can be found in layers pertaining to roads.

**Solid waste recycled in transfer stations**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- General Calculus
- Coverage of the solid waste management system

Baseline required: No

Required tables:
- Assumptions

Type of data required:
- Assumptions: uses data from the assumptions table related to the Study Area that the current Scenario belongs to.

Sustainable agricultural land
For more information about this indicator please go to Annex C of this document.

 Dependencies:
- General Calculus

Baseline required: No

Required tables:
- Footprint

Type of data required:
- Footprint: requires the name of the classification and spatial location of agricultural areas and sustainable agricultural areas. This data can be found in agricultural areas and sustainable agricultural areas layers; this implies that the same ‘matching’ process must be done once for each of these layers.
Telecommunication infrastructure in risk areas

For more information about this indicator please go to Annex C of this document.

Dependencies:
  - General Calculus

Baseline required: No

Required tables:
  - Amenities
  - Risk

Type of data required:
  - Amenities: requires the name of the classification and spatial location for telecommunication infrastructure. This data can be found in layers pertaining to amenities.
  - Risk: requires the name of the classification and spatial location for risk areas. This data can be found in layers pertaining to risks.

Total energy consumption

For more information about this indicator please go to Annex C of this document.

Dependencies:
  - General Calculus
  - Energy consumption associated to buildings
  - Energy consumption associated with water distribution & MGMT
  - Energy consumption associated to public lighting
  - Energy consumption associated to solid waste MGM
  - Energy consumption associated to transportation
  - Energy consumption associated to wastewater treatment

Baseline required: Yes
Required tables:
- N/A

Type of data required:
- **Results**: this indicator depends on the results obtained by its dependencies; this implies that no user input is required outside of following the requirements for said dependencies.

**Total energy generated by renewable sources**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **No**

Required tables:
- **Assumptions**

Type of data required:
- **Assumptions**: uses data from the assumptions table related to the Study Area that the current Scenario belongs to.

**Water consumption per capita**
For more information about this indicator please go to Annex C of this document.

Dependencies:
- **General Calculus**

Baseline required: **Yes**

Required tables:
● Assumptions

Type of data required:

● **Assumptions**: uses data from the assumptions table related to the **Study Area** that the current **Scenario** belongs to.

**Water ecosystem consumption**

For more information about this indicator please go to Annex C of this document.

Dependencies:

● **General Calculus**

Baseline required: **No**

Required tables:

● MMU
● MMU Attributes
● Risk

Type of data required:

● **MMU**: requires the spatial location for the MMU. This data can be found in layers pertaining to population.

● **MMU Attributes**: require the values for the **area** of each MMU for the **Study Area** that the current **Scenario** belongs to. This data can be found in layers pertaining to population.

● **Risk**: requires the name of the classification and spatial location for water ecosystems. This data can be found in layers pertaining to risks
COLLABORATIVE SPATIAL DATA FOR SUSTAINABLE URBAN DEVELOPMENT IN INDONESIA

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