19/2021

Dworak, S.; Lee, R.D.; Centeno, C.; Galvan, E.; Fellner, J. (2021) “WAPLA – a user-friendly software for waste management planning in developing countries”, In: Proceedings “Sardinia 2021, 18th International symposium on waste management and sustainable landfilling”, E-paper 1439, CISA Publisher, Forte Village, S.M. Di Pula, Sardinia, Oct. 11th-15th 2021.

SARDINIA2021 HYBRID EVENT / 11-15 OCTOBER 2021 / CAGLIARI / ITALY
18TH INTERNATIONAL SYMPOSIUM ON WASTE MANAGEMENT AND SUSTAINABLE LANDFILLING

# WAPLA – A USER-FRIENDLY SOFTWARE FOR WASTE MANAGEMENT PLANNING IN DEVELOPING COUNTRIES

Sabine Dworak[1], Richard David Lee[1], Carmela Centeno[2], Erlinda Galvan[2], Johann Fellner[1]

[1] Institute for Water Quality and Resource Management, TU Wien, Vienna, Austria
[2] Industrial Pollution Mitigation Division, Department of Environment of UNIDO (United Nations Industrial Development Organization)

ABSTRACT: Communities, townships, municipalities, and regions in developing countries are facing increasing challenges with managing their waste. Even if waste regulations and competent municipal authorities tasked with waste management planning are in place, very often a holistic overview of the current waste management system (including information about waste flows, associated environmental impacts and economic costs) is missing. Information, which is, however, crucial to establish sustainable solid waste management. Hence, personnel responsible for the management and planning of solid waste at the municipal level need to be provided with the proper tools to evaluate their solid waste management systems.

Within the framework of a Global Environment Facility and United Nations Industrial Development Organization (GEF/UNIDO) funded project, a toolkit for waste management planning was developed and then implemented as a portable software (WaPla), which enables waste managers to assess and improve their waste management systems. The proposed model covers basic processes of waste management systems in developing countries, such as different modes of waste collection, formal landfilling and informal dumping, open burning and landfill fires. In addition, more sophisticated waste treatment processes, such as composting, material recovery facilities, and waste incineration plants, are also provided optionally. WaPla allows the user to model and display the waste flows of their system. Based on the waste flows and some further input data (e.g. climatic conditions, waste composition, fuel consumption, operating and investment costs), environmental impacts of the waste management system (unintentional persistent organic pollutant (uPOP), greenhouse gas (GHG) emissions), as well as the costs, can be estimated. WaPla's graphical interface is designed to support intuitive and easy use, while additional comments and explanation boxes provide further clarification. The results (waste flows, GHG and uPOP emissions, costs) are displayed in tables and figures, ready to download as high-resolution graphics and datasets, editable in common table calculation programmes.

*Keywords: Waste Management Plan, Unintentional Persistent Pollutant Emissions, Greenhouse Gas Emissions, Digital Planning Tool, Developing Countries*

## 1. INTRODUCTION

Communities, townships, municipalities, and regions in developing countries are facing increasing challenges with managing their waste. These leads to serious consequences, such as toxic emissions from open burning or contamination of soil and water (Gerstle and Kemnitz, 1967; Lemieux et al., 2004; Peter et al., 2019; Szewczyńska et al., 2008).

Even if waste regulations and competent municipal authorities tasked with waste management planning are in place, very often a holistic overview of the current waste management system (including information about waste flows, associated environmental impacts and economic costs) is missing. Information, which is, however, crucial to establish sustainable solid waste management. Hence, persons responsible for the management and planning of solid waste at the municipal level need to be provided with the proper tools to evaluate their solid waste management systems.

Hence, the proposed software tool aims to provide the means to visualize and understand the waste flows within basic waste management systems and estimate the emissions (greenhouse gases, unintentional persistent organic pollutants) as well as costs accompanying them. Thereby, the tool supports these communities in their ability to make knowledge-based decisions and enable sustainable waste management planning for the benefit of all stakeholders.

## 2. MATERIAL AND METHODS

### 2.1 Material Flow Analysis (MFA)

The present study uses Material Flow Analysis (MFA) as described by (Brunner and Rechberger, 2016) to map the flows and processes of waste management systems. MFA is a widely used method to investigate sources, stocks, and sinks of materials, as well as their connecting flows. The method is based on the law of conservation of matter and uses material balance to compare all inputs, stocks and outputs of processes. The mass balance formular is used to calculate unknown flows and stocks:

$$\sum_{i=1}^{k} \dot{m}_{IN,i} = \sum_{j=1}^{l} \dot{m}_{OUT,j} \pm \dot{m}_{STOCK,j}$$

with $\dot{m}$ given in mass of waste per time unit. $\sum_{i=1}^{k} \dot{m}_{IN,i}$ represents the total waste input $\dot{m}_{IN}$ of k input flows i, $\sum_{j=1}^{l} \dot{m}_{OUT,j}$ the total waste output $\dot{m}_{OUT}$ of i output flows j, and $\dot{m}_{STOCK}$ represents a potential flow from or to a stock located in the process itself. Otherwise, transfer coefficients can be used to calculate unknown flows:

$$TC_j = \frac{\dot{m}_{OUT,j}}{\sum_{i=1}^{k} \dot{m}_{IN,i}}$$

where the transfer coefficient $TC_j$ of an output flow j, $\dot{m}_{OUT,j}$ is its mass relative to the total mass input $\sum_{i=1}^{k} \dot{m}_{IN,i}$ of k flows i. The transfer coefficients can be calculated based on the same equation if all flows are known, which needs to be done by the user throw-out the system in this application.

### 2.2 Unintentional persistent organic pollutant (uPOP) and greenhouse gas (GHG) emissions

The tool has an implemented function to estimate emissions. GHG Emissions are estimated based on IPCC guidelines (IPCC, 2006), the assessment of the uPOP emissions is based on the Stockholm Convention on persistent organic pollutants (POPs) (UNEP, 2019). In Table 1, the emission factors applied are summarized. Further, substitutions factors for recycling (tonne $CO_{2eq}$/tonne recycled materials: paper & cardboard: -0.15; plastics: -1.5; metals: -1.8; glass: -0.3; waste incineration with energy recovery (-0.35 tonne $CO_{2eq}$/tonne waste incinerated) and RDF utilization (-0.35 t $CO_{2eq}$/t RDF utilized) were used. As results in the tool, the emissions are displayed as sum for each process.

Table 1: Emission factors used for the tool

| Process/Source | GHG emission factor | Comment GHG | uPOP emission factor |
|---|---|---|---|
| Transport | 0.0025 t $CO_{2eq}$/ liter fuel | - | - |
| Composting | 0.06-0.65 t $CO_{2eq}$/ t waste composted | Dependent on level of management of plant | To product:<br>Grey compost: 50<br>Clean compost: 5<br>in µg TEQ/t d.m. |
| Incineration | 0.18-0.0.5 t $CO_{2eq}$/t waste incinerated | Dependent on plastic content in waste | - |
| Open Burning | 0.12-0.35 t $CO_{2eq}$/t waste burned | Dependent on plastic content in waste | Air: 40<br>Land: 1<br>in µg TEQ/t material burned |
| Landfill/ dumpsites | 0.6-1.5 t $CO_{2eq}$/t waste landfilled | Dependent on biowaste content and level of management | To Water:<br>Hazardous wastes: 5<br>Mixed wastes: 0.5<br>Domestic wastes: 0.05<br>To Residue:<br>Hazardous wastes: 500<br>Mixed wastes: 50<br>Domestic wastes: 5<br>in µg TEQ/t material landfilled |
| Fires at landfills/ dumpsites | 0.12-0.35 t $CO_{2eq}$/t waste burned | Dependent on plastic content in waste | Air: 300<br>Land: 10<br>in µg TEQ/t material burned |

## 2.3 Structure and Implementation

The developed tool aims to support authorities and involved stakeholders to map and understand their waste management system, and thereby enable improved waste management planning. It is applicable for communities, municipalities, townships and cities up to 100,000 inhabitants. It requires input data for different levels of the system.

### *2.3.1 User Interface and application*

The software application is written in RStudio (www.rstudio.com, language: R: www.r-project.org). Beside the default base package, the package shiny (shiny.rstudio.com) was used for app construction and packages from tidyverse (www.tidyverse.org) for data manipulation.

The user interface is designed to guide the user through the process while always providing further information regarding the required data and the processes, which are modified at the moment. The foremost left sidebar (grey) is used for general inputs, orientation and administration (calculating, saving/reloading projects) and is always visible. Further, a simplified plot of the system is shown while inputs are made. It shows which process is active at the moment to modify input data and so supports orientation while inputs are made.

The main panel consist of three tabs ("Inputs", Results", Summary"). "Inputs" serves as mask for all inputs, which are not covered by general data (grey sidebar) – see Figure 2. Each tab is categorized in "System Definitions", "Unintentional Persistent Organic Pollutant Emissions", "Greenhous Gas Emissions" and "Cost of Waste Management", selectable in the left-hand selection bar in the main panel. In each category tabs for all processes, where modifications are possible, are available. In the input masks, explanatory comments and supporting information are available, to assist the user while inputting the data. In "Results" various plots and tables are displayed and ready to be exported (graphs: .pdf, .png; data: .csv). They are categorized in the same fashion as "Inputs" (System, uPOP emissions, GHG emissions, costs). Last, the tab "Summary" shows data on all mass flows and transfer coefficients present in the system.

The application can be accessed for free at the following site https://owncloud.tuwien.ac.at/index.php/s/6yKkzmXnlz2Io1y

*2.3.2 Required Input Data:*

First (in the grey left sidebar), the city/region and the currency (if costs are calculated) shall be defined for proper outputs. Further, climatic conditions need to be defined to be able to propose various parameters (regarding landfill emissions).

The **waste management system** contains 11 pre-defined processes (Waste Generation, Waste Collection, Uncollected Waste, Separation of Recyclables in Households, Materials Recovery Facility, Composting, Open Burning, Informal Dumping, Landfill/Formal Disposal, Recycling, Incineration, Fires at Landfills/Dumpsites), whereas three are optional (Material Recovery Facility, Composting, Incineration) and can be inactivated if they are not present in the investigated system (see full system in Figure 1. The waste generated per year ([t/yr]) needs to be defined. The subsequent flows themself are defined via transfer coefficient in every process. These inputs are all defined in the tab “Inputs”, selection “System Definitions” (and according subtabs for each process) and determine the flows in the waste management system itself. Based on the system, uPOPs, GHG emissions and costs can be estimated. As a lot of data is required, where much of it might not be available, default values are defined to give a reasonable estimate, based on former studies and reports (Breeze, 2012; Cerda et al., 2018)

For the selections **Unintentional Persistent Organic Pollutant Emissions** and **Greenhous Gas Emissions** default values have been defined for the different waste management processes. This inputs concern waste composition and plant management, except for “Open Burning” and “Fires at Landfills / Dumpsites” in case of uPOPs, where the given emission factors may be adjusted (default based on Stockholm Convention on Persistent Organic Pollutants (UNEP, 2019), adjustment is not recommended). Default data is provided here as well. These data are used to calculate uPOP emissions to the environment and the products (compost, if applicable) and GHG emissions to air.

**Costs of Waste Management** allows to estimates costs and revenues of the waste management system. Due to price fluctuations, different price levels and different currencies, no default values are given. Nevertheless, in the comments displayed in the tool some reference points (in USD) are given if no original data is available.

 

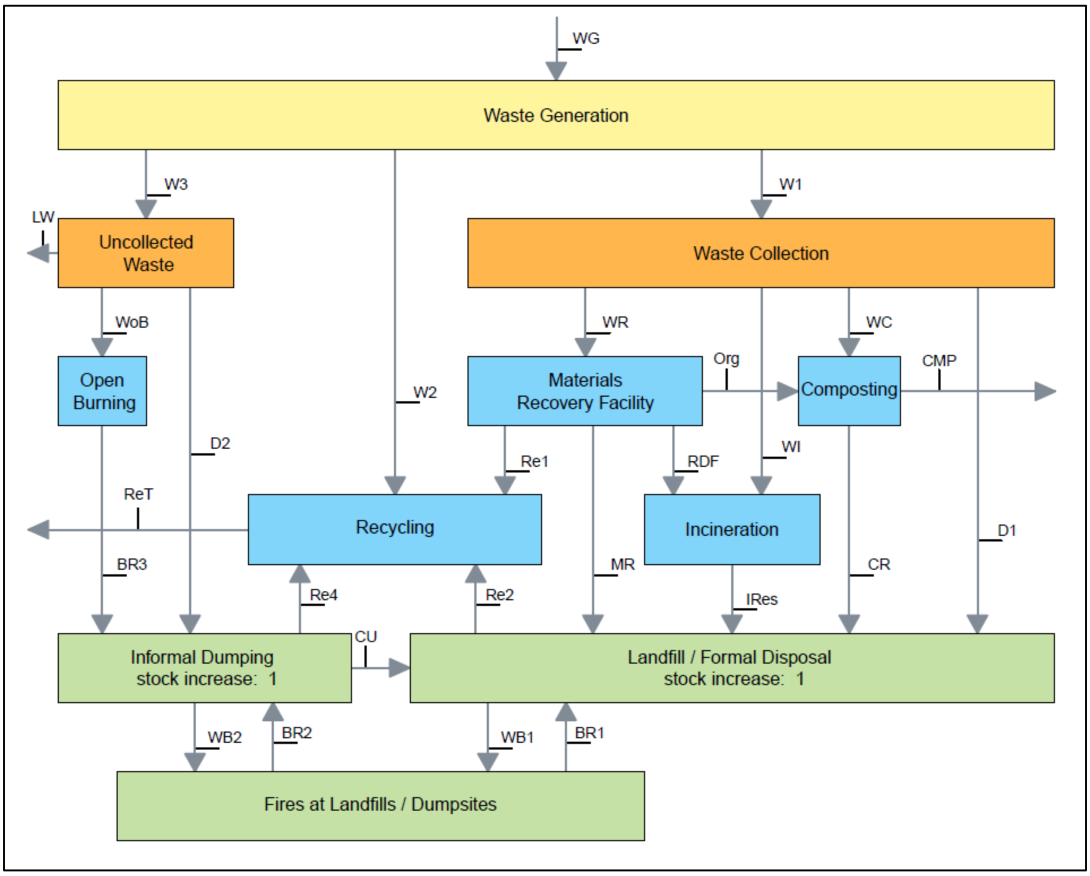


Figure 1: Waste Management Processes considered by the WaPla Tool

## 3. APPLICATION

### 3.1 Case Study

For demonstration, in the following, a case study is shown. All data of the case study can be downloaded at https://owncloud.tuwien.ac.at/index.php/s/ezlk6r0a5jsYpv4.

Inputs: A fictive Ugandan city is chosen with 1,700 mm/yr average precipitation and 22 °C average temperature. Besides waste collection, dumping and landfilling, a composting plant is present in the city, but no material recovery facility or incineration. The annual waste generation rate is estimated to 10,000 t/yr (see inputs on the left, Figure 2). The applied transfer coefficients are shown in Table 2. These are put in directly (e.g. share of waste collected of all waste generated), calculated based on mass conservation (as $\sum_{i=1}^{k} TC_i = 1$ for each process, one TC per process is calculated, e.g. share of waste not collected of all waste generated) or calculated based on the biodegradation rate of the waste in landfills/dumpsites.

The landfill and dumpsite are poorly managed (dumpsite with waste depth < 5m). Also, the compost plant is rather poorly managed. Costs are not considered in this case study.

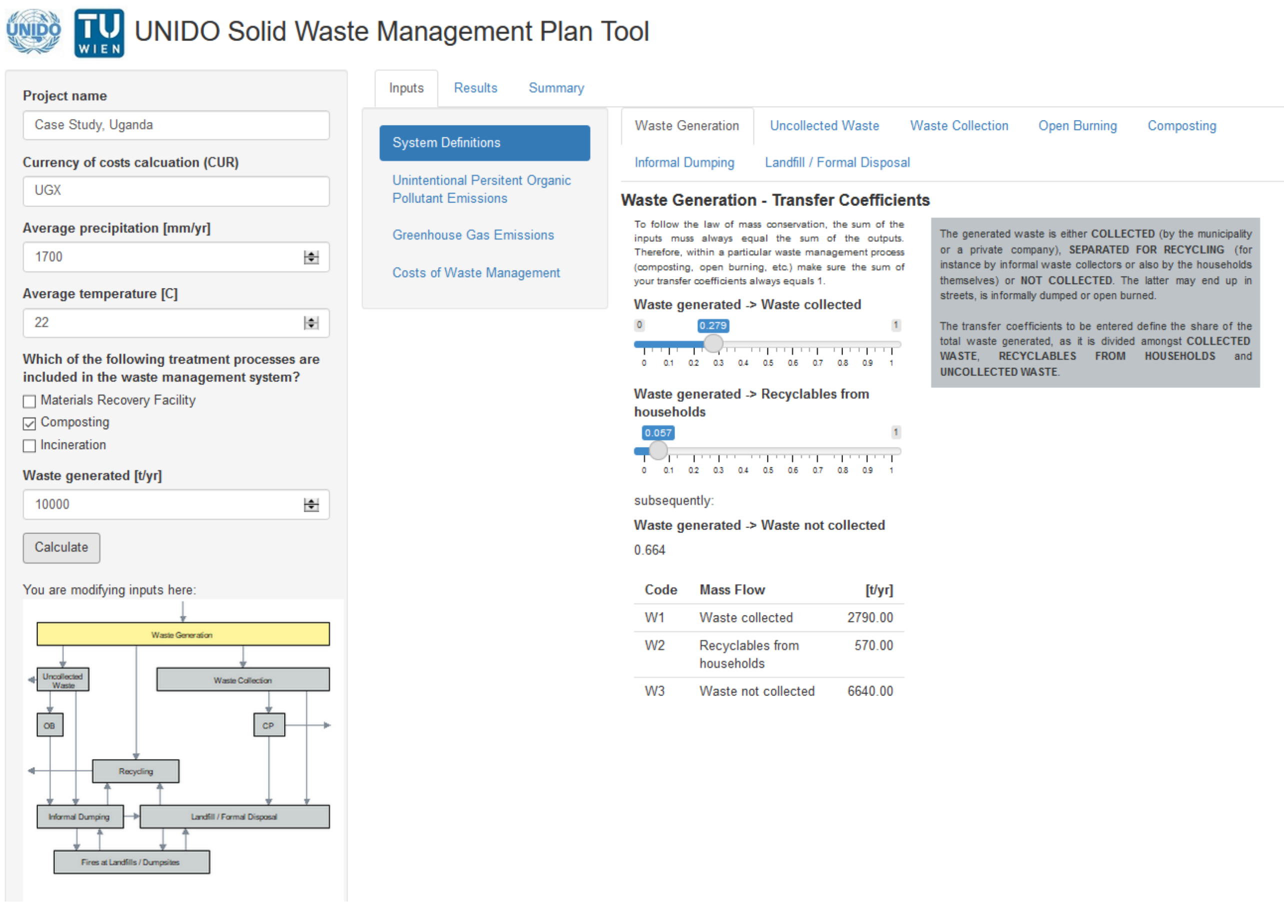


Figure 2: Input mask of WaPla for the case study city

Table 2: Applied transfer coefficients for the case study city

| Process | Mass Flow | TC |
|---|---|---|
| Composting | Plant input -> Compost | 0.15 |
| Composting | Plant input -> Gaseous and liquid composting losses | 0.71 |
| Composting | Plant input -> Composting residuals | 0.14 |
| Fires at Landfills / Dumpsites | Waste burned at formal landfills -> Burning residuals | 0.3 |
| Fires at Landfills / Dumpsites | Waste burned at dumpsites -> Burning residuals | 0.3 |
| Fires at Landfills / Dumpsites | Plant input -> Emissions from fires at landfills / dumpsites | 0.7 |
| Informal Dumping | Input -> Waste burned at dumpsites | 0.4 |
| Informal Dumping | Input -> Dumpsite emissions | 0.3 |
| Informal Dumping | Input -> Waste to dump stock | 0.3 |
| Informal Dumping | Input -> Recyclables from dumpsites | 0 |
| Informal Dumping | Input -> Clean-up of dumpsites | 0 |
| Landfill / Formal Disposal | Plant input -> Waste burned at formal landfills | 0.25 |
| Landfill / Formal Disposal | Plant input -> Recyclables from landfills | 0 |
| Landfill / Formal Disposal | Plant input -> Landfill emissions | 0.345 |
| Landfill / Formal Disposal | Plant input -> Waste to landfill stock | 0.405 |
| Open Burning | Waste to open burning -> Burning residuals | 0.2 |
| Open Burning | Waste to open burning -> Open burning emissions | 0.8 |
| Recycling | Plant input -> Total recyclables | 1 |
| Uncollected Waste | Waste not collected -> Waste to dumping | 0.534 |
| Uncollected Waste | Waste not collected -> Waste to open burning | 0.466 |
| Uncollected Waste | Waste not collected -> Leakage to waters | 0 |

 

| | | |
|---|---|---|
| Waste Collection | Waste collected -> Direct waste disposal | 0 |
| Waste Collection | Waste collected -> Waste to composting | 1 |
| Waste Generation | Waste generated -> Waste collected | 0.279 |
| Waste Generation | Waste generated -> Recyclables from households | 0.057 |
| Waste Generation | Waste generated -> Waste not collected | 0.664 |

<u>Results:</u> The tool provides the possibility to display graphs and tables with results. In Figure 3 the waste management system is displayed with all waste management processes and all solid flows of waste. It shows all flows with their abbreviations and values (in t/yr) in Sankey style. This visualisation helps the user to understand the distribution of solid waste flows in relation to each other.

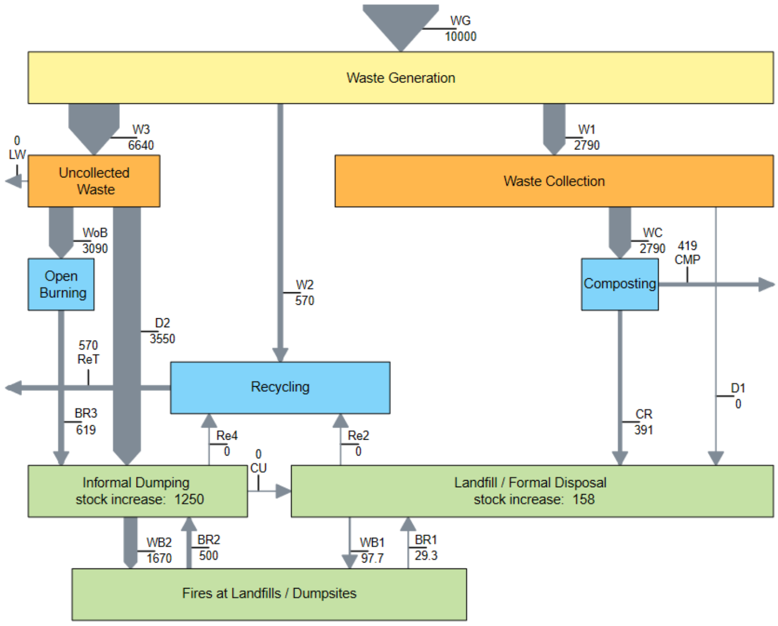


Figure 3: Waste management system, displaying all solid flows (liquid and gaseous flows are not displayed) - output of the WaPla tool.

In Figure 4, the emissions are displayed. In the upper part, the uPOP emissions to air, water, land, product (compost) and residue are displayed, as well as the total uPOP emissions. The biggest share are uPOP emissions to air originating from open burning and fires at landfills and dumpsites. The remaining uPOP emissions are rather insignificant.

The lower part shows the GHG emissions per process and the total GHG emissions. The calculated emissions for each process are displayed. Recycling of waste results in a reduction of GHG emissions due to the substitution of primary resources.

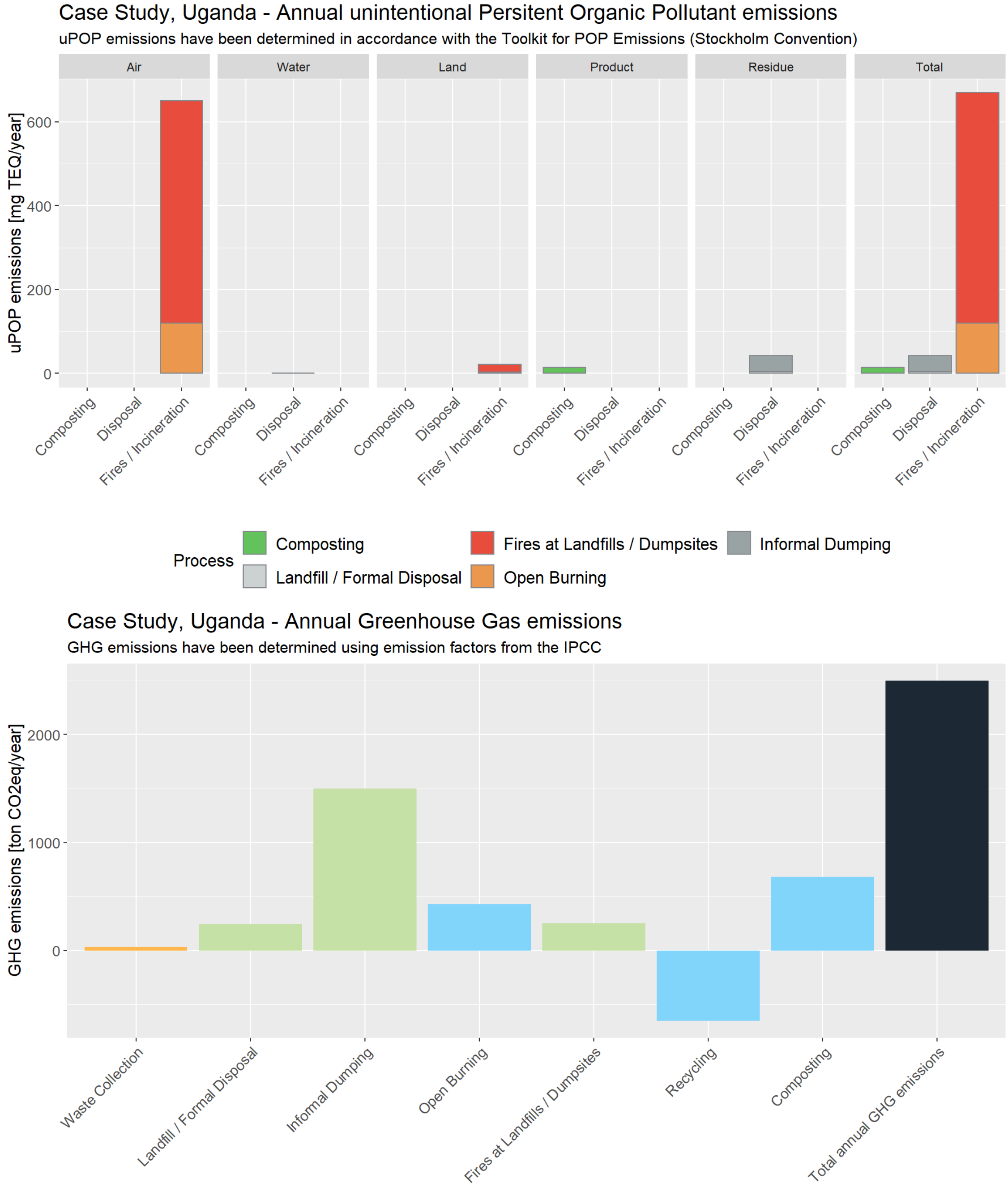


Figure 4: Results plots for uPOP-emissions (upper part) and GHG emissions (lower part)

## 3.2 Chances and Limitations

The tool is designed to support mapping and understanding of waste management systems and thereby promote well informed and sustainable waste management planning for communities up to 100,000 inhabitants in developing countries. The tool aims to balance the usability (as easy and straight forward with as little data needed as possible) and the accuracy (coverage of applied treatment processes, realistic estimates of emissions/costs). This involves, that many common waste management processes are modelled in a very simplified way, as the data for more precise calculations and most probably the technology itself might not be available in developing countries. Bigger communities, like major cities, would need a more flexible planning tool (more treatment possibilities, multiple plants per category, more detailed specification of applied technologies/management etc.), which requires much more know how to navigate.

 

Even though still quite some data is required, the tool provides the user with reasonable default values if no data is available. In that way, the tool also points out to the user which data would be required to improve the display of the investigated waste management system.

## 4. CONCLUSIONS

We designed a tool, which supports small communities (up to 100,000 inhabitants) in development countries to map and understand their waste management system. This understanding gives the users (municipalities and/or authorities responsible for waste management) a tool to improve their waste management, not only from an environmental point of view, but also to estimate the accompanying costs of it.

The user interface is designed to support intuitive handling and thereby guides the user through the process of data input. In this way, the tool supports the planning of data gathering campaigns, as the user is made aware which data would be required to model the waste management system more precise.

The tool is kept simple, to overcome inhabitations and ensure easy handling. The tool provides exporting and saving options, which allow further processing and communication with people not familiar with the tool.

## ACKNOWLEDGEMENTS

The software was developed by Vienna University of Technology (TU Wien) for the United Nations Industrial Development Organization (UNIDO), under the projects 'Promotion of BAT/BEP to reduce uPOPs releases from waste open burning in participating African countries of SADC' and 'Demonstration of BAT and BEP in open burning activities in response to the Stockholm Convention on POPs. The project was funded by the Global Environment Facility (GEF).

## REFERENCES

Breeze, R., 2012. Municipal Solid Waste Management in Dar Es Salaam. World Bank J.

Brunner, P.H., Rechberger, H., 2016. Handbook of Material Flow Analysis for Enviromental, Resource, and Waste Engineers, 2nd ed. CRC Press - Taylor & Francis Group.

Cerda, A., Artola, A., Font, X., Barrena, R., Gea, T., Sánchez, A., 2018. Composting of food wastes: Status and challenges. Bioresour Technol. https://doi.org/10.1016/j.biortech.2017.06.133

Gerstle, R.W., Kemnitz, D.A., 1967. Atmospheric emissions from open burning. J Air Pollut Control Assoc 17. https://doi.org/10.1080/00022470.1967.10468988

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies (IGES) for the IPCC.

Lemieux, P.M., Lutes, C.C., Santoianni, D.A., 2004. Emissions of organic air toxics from open burning: A comprehensive review. Prog Energy Combust Sci. https://doi.org/10.1016/j.pecs.2003.08.001

Peter, A.E., Shiva Nagendra, S.M., Nambi, I.M., 2019. Environmental burden by an open dumpsite in urban India. Waste Manag 85. https://doi.org/10.1016/j.wasman.2018.12.022

Szewczyńska, M., Dobrzyńska, E., Pośniak, M., 2008. Qualitative analysis of highly toxic organic compounds emitted from uncontrolled combustion sources using GC-MS/MS. Chem Analityczna 53.

UNEP, 2019. STOCKHOLM CONVENTION ON PERSISTENT ORGANIC POLLUTANTS (POPS), reviesed 2019.

 