Waste Reduction Model (WARM) Tool

User's Guide

WARM version: 15 (November 2020)
Software version: 1.5
Guide version: November 2020

Contents

United States
Environmental Protection
Agency

1. Introduction

The Waste Reduction Model (WARM) was created by the U.S. Environmental Protection Agency (EPA) to help solid waste planners and organizations estimate greenhouse gas (GHG) emission reductions and economic impacts from several different waste management practices. The purpose of this document is to provide guidance to WARM users in downloading, installing, and using the WARM Tool, including an overview of the tool's key functions and capabilities.

WARM calculates GHG emissions, energy, and economic impacts for baseline and alternative waste management practices, including source reduction, recycling, combustion, composting, and landfilling. The model calculates emissions in metric tons of carbon dioxide equivalent ($MTCO_2E$) and metric tons of carbon equivalent (MTCE), energy in millions of BTUs (MMBTU), wage impacts, tax impacts, and labor hours supported across a wide range of material types commonly found in municipal solid waste (MSW). The user can construct various scenarios by simply entering data on the amount of waste handled by material type and by management practice. WARM then automatically applies material-specific emission, energy, and economic factors for each management practice to calculate the GHG emissions, energy use, and economic impacts of each scenario. Several key inputs, such as landfill gas recovery practices and transportation distances to MSW facilities, can be modified by the user.

The GHG emission factors used in WARM are based on a life cycle perspective. The model documentation describes this methodology in detail. The WARM model was implemented in the free, open source life-cycle assessment (LCA) software called openLCA. The resulting openLCA database is used for the calculation of impacts in the WARM Tool described in this guide. The WARM version implemented in this software is WARM v15 (November 2020).

2. Installation

There are versions of the WARM Tool available for Windows (64 bit and 32 bit upon request) and Mac (64 bit and 32 bit upon request). In all cases, the tool is provided in a compressed file (*.zip, *.gz), which should be first downloaded and then its content extracted (i.e., right click on the file → Extract…).

A folder "WARM" will be then generated. The file "WARM.exe" contained in it should be run to get the application started.
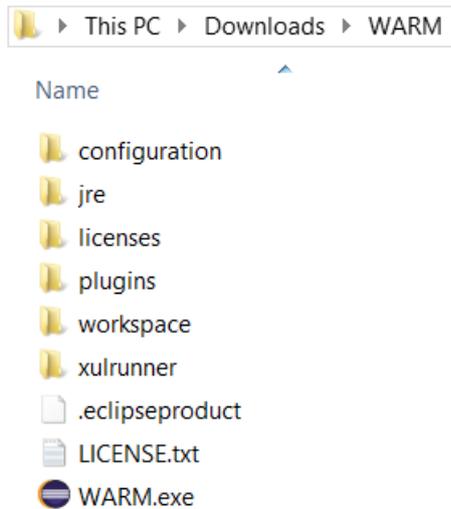
Figure 1. Content of WARM folder when extracted from the compressed file

2.1 Hardware and software requirements

Hardware:

- 1 GB RAM
- 140 MB (Windows), 64 MB (Mac) free hard disk space

Software:

- For MacOS users, Java version 8 is required to run the WARM tool. The official Oracle release of Java 8 may require a separate license agreement with Oracle. More details can be found here. The WARM tool may also be compatible with OpenJDK versions of Java 8. MacOS users may install OpenJDK free of charge by using the SDK command line tool. More information on SDK can be found here.

- Microsoft Visual C++ Runtime v10 needs to be installed on Windows 64 bit because the WARM Tool contains a browser engine for the display of modern HTML pages that requires this runtime. If you have not installed it before running the tool, a message like in Figure 2 would be shown. You can download this runtime here.

Figure 2. Message displayed if the MS Visual C++ Runtime v10 is missing

3. First start and overview

When first running WARM, the Home page is shown providing some information and tips about the tool.
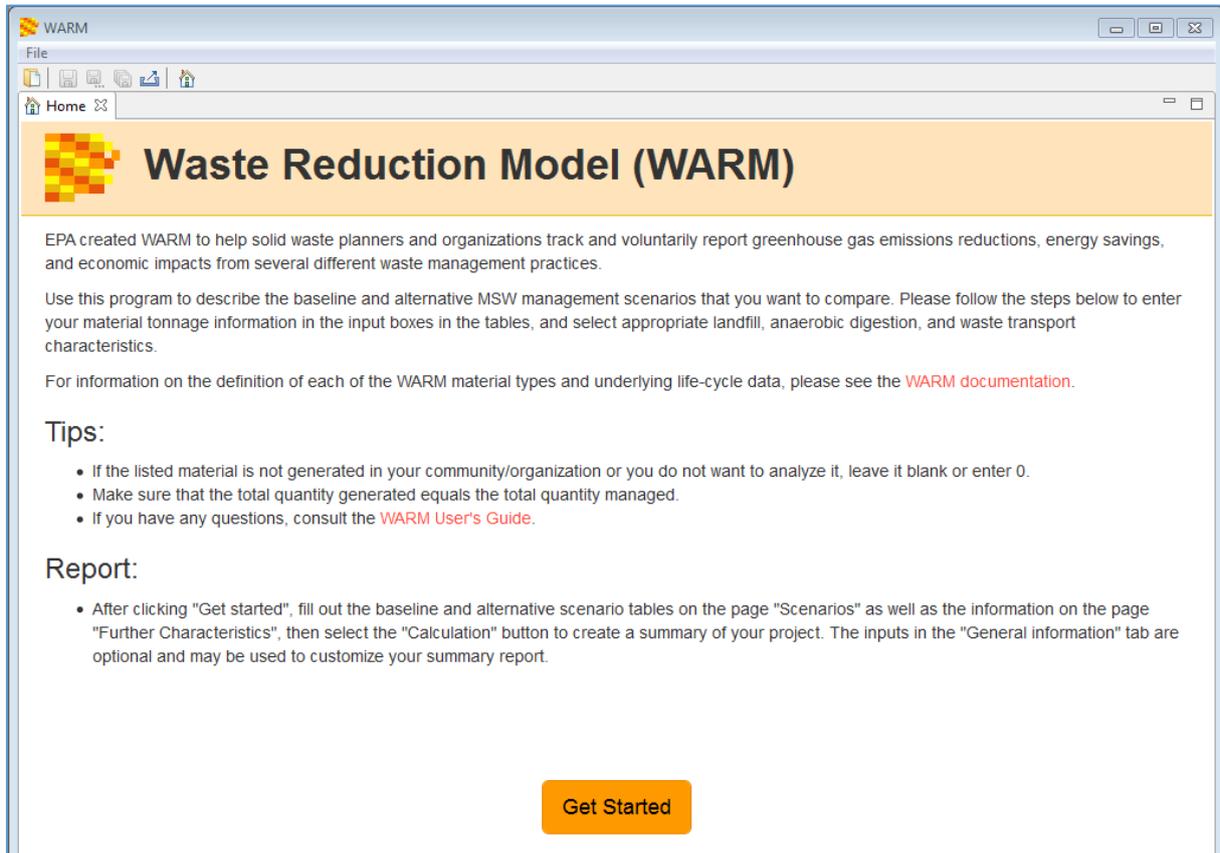
If you click the button "Get Started", a new tab "Data Entry" appears, where the data for the analysis should be entered by the user. This tab consists of four steps: Scenarios, Further Characteristics, General Information and Calculation. You can navigate through them by clicking on the buttons on the top of the tab or on the "Back"/ "Next" buttons on the bottom of the page. You can also use the scrollbar in the right of the window to see the full content of each page. Detailed information about the "Data Entry" tab is provided in section 4 of this guide.
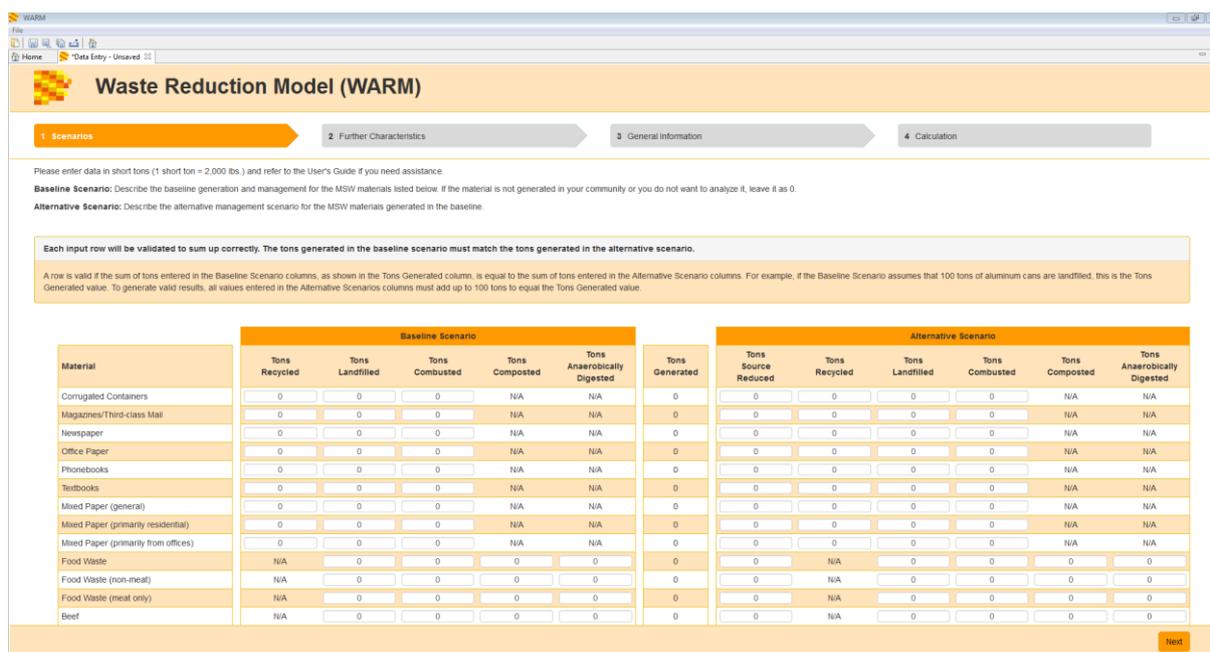
Figure 4. "Scenarios" step of the "Data Entry" tab

Several "Data Entry" tabs can exist at the same time in the software (i.e., various assessments); for creating new ones, just go to the Home tab and click "Get Started". If you had closed it, you can open it again by clicking on the icon 🏠 on the toolbar.

After the calculation for the entered data is finalized, results will be shown in a new tab "Report". Detailed information about the results analysis is provided in section 5 of this guide.

It is also possible to save the data entered in the "Data Entry" tab for future assessments, as explained in section 6 of this guide.

4. Data entry

4.1. Generate scenarios

Baseline and alternative scenarios can be constructed by simply entering data on the amount of waste handled by material type and by management practice. There are sixty material types[1] (rows) and six management practices available (columns): recycling, landfilling, combustion, composting, anaerobic digestion, and source reduction. This last practice is only included in the "Alternative Scenario", and refers to the decrease in waste generation compared to the waste handled in the baseline scenario.

There is an additional column "Tons generated" which is automatically updated by the tool and represents the total amount of waste handled in the baseline scenario, per material type. If data is introduced only for the alternative scenario, this field will remain as "0".

It is not necessary to enter data for all materials and management practices, only for those relevant for your assessment. When no data is added in a specific cell, the value remains as

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[1] For more information on the composition of mixed materials, please reference the model documentation chapters specific to each material type.

"0". In addition, not all management practices are available for all material types (e.g., food waste cannot be recycled). In those cases, "N/A" is written in the correspondent cell and no data can be entered by the user.

When scrolling down in the page view, the headers of the table columns will not be visible anymore. However, tooltips are available when typing in or hovering over each cell with information about the corresponding scenario and management practice.

Material	Baseline Scenario				
	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested
Corrugated Containers	0	0	0	N/A	N/A
Magazines/Third-class Mail	0	Base scenario - Tons landfilled	0	N/A	N/A
Newspaper	0	0	0	N/A	N/A
Office Paper	0	0	0	N/A	N/A

Figure 5. Entering data on the "Scenarios" step of the "Data Entry" tab

The following requirements exist for entering the data:

- Amounts should be entered in short tons[2]

- Only numbers can be entered (i.e., no formulas supported)

- "." should be used as decimal separator

- The total amount of waste handled in the baseline scenario has to equal the total amount of waste entered for the alternative scenario, per material. A validation is done for each material, and if there were divergences between the quantities generated in each scenario, that row is highlighted and an exclamation mark added to the left of the material's name.

Material	Baseline Scenario					Tons Generated	Alternative Scenario					
	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested		Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested
! Corrugated Containers	0	20	10	N/A	N/A	30	10	50	10	10	N/A	N/A
Magazines/Third-class Mail	0	0	0	N/A	N/A	0	0	0	0	0	N/A	N/A
! Newspaper	0	20	0	N/A	N/A	20	10	100	10	0	N/A	N/A
Office Paper	0	0	0	N/A	N/A	0	0	0	0	0	N/A	N/A
Phonebooks	75.5	15	0	N/A	N/A	90.5	10.5	75	5	0	N/A	N/A
! Textbooks	0	0	0	N/A	N/A	0	3	0	0	0	N/A	N/A

Figure 6. Error of validation for several materials in the "Scenarios" step (i.e., baseline total amount ≠ alternative total amount)

Once the data have been entered, you can continue to the next step clicking "2. Further Characteristics" (top of the page) or "Next" (bottom of the page). You can also navigate to other sections, like heading directly to the calculation if you want the keep all default options in the next sections. If the "Scenarios" step is left without having fixed possible invalid entries (i.e., total baseline ≠ total alternative), a warning message is displayed informing of the user that these amounts are not equal. The calculation can be run anyway, but the user should be aware of the existing differences in total quantities between scenarios.

[2] 1 short ton = 2,000 lbs = 907.18 kg
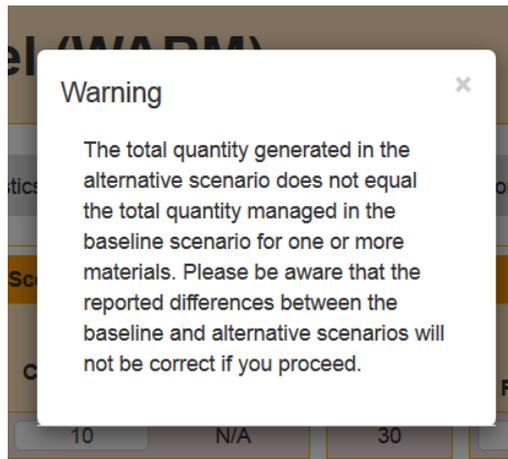
Figure 7. Warning message displayed if any material has invalid data entries

4.2. Further characteristics

Several key inputs affecting the GHGs and Energy results can be modified by the user. These are:

- Locations: they affect the emission factors for those management practices consuming/avoiding electricity. The specific regional grid mix is used depending on the state selected by the user in the drop-down menu. The value by default is "National Average".
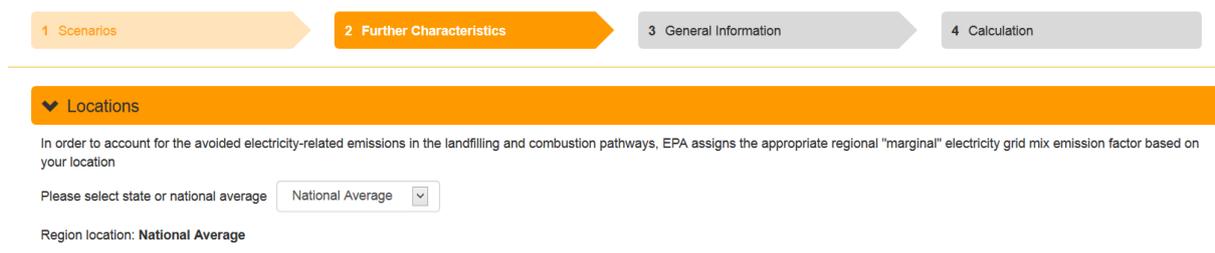
Figure 8. Locations options in "Further characteristics" section of the "Data Entry" tab

- Waste Transport Characteristics: the distances covered between the location where the waste was collected and the correspondent management facility can also be modified. The value by default is 20 miles. You can select the option "Define distance" to enter new values (also in miles).
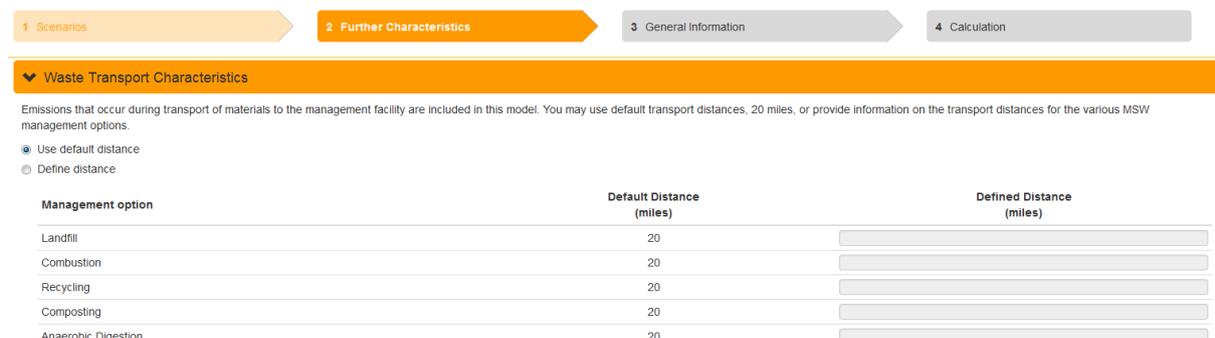
Figure 9. Waste transport options in "Further characteristics" section of the "Data Entry" tab

- Source reduction: you can decide whether the material that is source reduced would have been manufactured from the current mix of recycled and virgin materials or from 100% virgin materials. The option by default is "Current mix".
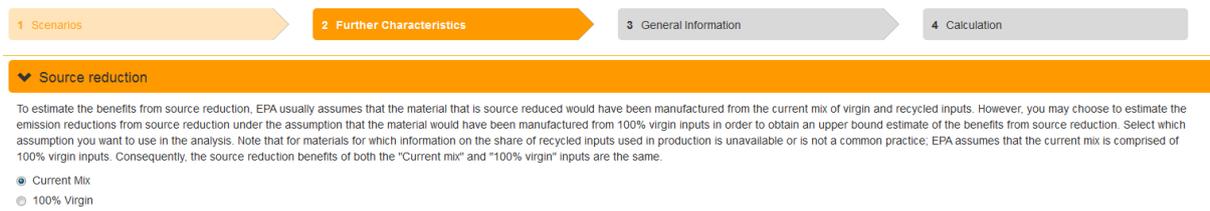

Figure 10. Source reduction options in "Further characteristics" section of the "Data Entry" tab

- Landfill characteristics: you can determine the:

I) Type of landfill: there are four options available: No landfill gas (LFG) recovery, LFG recovery for energy, LFG recovery and flared, and a "National Average" type which calculates emissions based on the proportions of the other three types in 2012. Depending on the selection, the other two options for landfill characteristics will be modifiable or not. For instance, if "No LFG Recovery" is selected, there are no further options to be chosen. On the other hand, if "National Average" is selected, the option "III) Moisture Conditions and Decay Rates" is also modifiable.
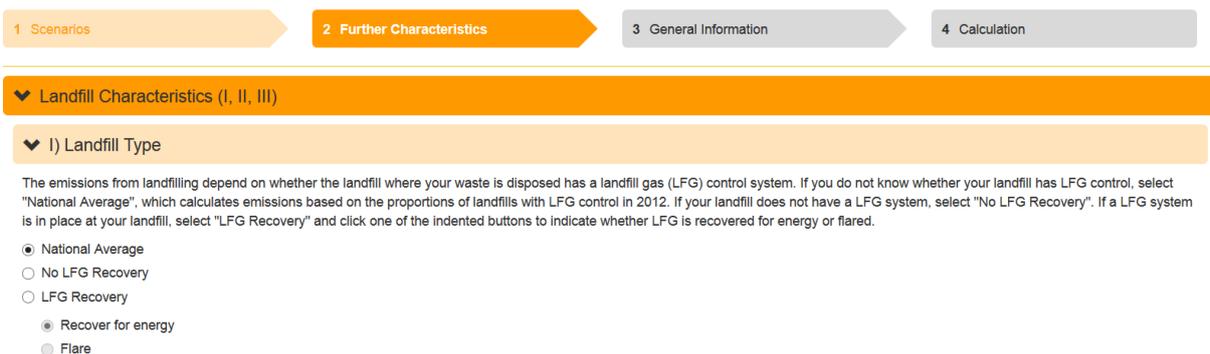
Figure 11. Landfill type options in "Further characteristics" section of the "Data Entry" tab

II) Landfill Gas Recovery: only relevant if any "LFG Recovery" option has been chosen previously. It represents four different gas collection efficiencies throughout the life of the landfill: typical, worst-case, aggressive, and California regulatory collections. Assumptions made for each option are explained in the tool.

1 Scenarios	2 Further Characteristics	3 General Information	4 Calculation

◉ LFG Recovery
  ◉ Recover for energy
  ○ Flare

❯ II) Landfill Gas Recovery

For landfills that recover gas, the landfill gas collection efficiency will vary throughout the life of the landfill. Based on a literature review of field measurements and expert discussion, a range of collection efficiencies was estimated for a series of different landfill scenarios. The "typical" landfill is judged to represent the average U.S. landfill, although it must be recognized that every landfill is unique and a typical landfill is an approximation of reality. The worst-case collection scenario represents a landfill that is in compliance with EPA's New Source Performance Standards (NSPS). The aggressive gas collection scenario includes landfills where the operator is aggressive in gas collection relative to a typical landfill. Bioreactor landfills, which are operated to accelerate decomposition, are assumed to collect gas aggressively. The California regulatory collection scenario allows users to estimate and view landfill management results based on California regulatory requirements.

◉ Typical operation - DEFAULT
○ Worst-case collection
○ Aggressive gas collection
○ California regulatory collection

Landfill gas collection efficiency (%) assumptions
Typical: Years 0-1: 0%; Years 2-4: 50%; Years 5-14: 75%; Years 15 to 1 year before final cover: 82.5%; Final cover: 90%
Worst-case: Years 0-4: 0%; Years 5-9: 50%; Years 10-14: 75%; Years 15 to 1 year before final cover: 82.5%; Final cover:
Aggressive: Year 0: 0%; Years 0.5-2: 50%; Years 3-14: 75%; Years 15 to 1 year before final cover: 82.5%; Final cover: 90%
California: Year 0: 0%; Year 1: 50%; Years 2-7: 80%; Years 8 to 1 year before final cover: 85%; Final cover: 90%

Figure 12. Landfill gas recovery options in "Further characteristics" section of the "Data Entry" tab

    III) Moisture Conditions and Decay Rates: relevant if "National Average" or any "LFG Recovery" option has been selected as landfill type. You can select here between five moisture conditions and associated bulk MSW decay rates (k) the one which best represents the conditions in your assessed landfill. The options are: National Average, dry (k=0.02), moderate (k=0.04), wet (k=0.06) and bioreactor (k=0.12). A higher average decay rate means that waste decomposes faster in the landfill.

1 Scenarios	2 Further Characteristics	3 General Information	4 Calculation

is in place at your landfill, select "LFG Recovery" and click one of the indented buttons to indicate whether LFG is recovered for energy or flared.

◉ National Average
○ No LFG Recovery
○ LFG Recovery
  ◉ Recover for energy
  ○ Flare

❯ II) Landfill Gas Recovery

❯ III) Moisture Conditions and Decay Rates

Which of the following moisture conditions and associated bulk MSW decay rate (k) most accurately describes the average conditions at the landfill? The decay rates, also referred to as k values, describe the rate of change per year (yr-1) for the decomposition of organic waste in landfills. A higher average decay rate means that waste decomposes faster in the landfill.

◉ National Average - DEFAULT
○ Dry (k = 0.02)
○ Moderate (k = 0.04)
○ Wet (k = 0.06)
○ Biorecator (k = 0.12)

Moisture condition assumptions
Dry (k=0.02): Less than 20 inches of precipitation per year
Moderate (k=0.04): Between 20 and 40 inches of precipitation per year
Wet (k=0.06): Greater than 40 inches of precipitation per year
Bioreactor (k=0.12): Water is added until the moisture content reaches 40 percent moisture on a wet weight basis
National average: Weighted average based on the share of waste received at each landfill type

Figure 13. Moisture conditions and decay rates options in "Further characteristics" section of the "Data Entry" tab

- Anaerobic Digestion characteristics: you can determine the:

    I)   Digestion Type: You can select either wet or dry digestion based on your digester type. Note that for grass, leaves, branches, yard trimmings and mixed organics, wet digestion is not applicable based on current technology and practices in the United States. Therefore, dry digestion is the only digestion type modeled in WARM for these materials. Only one type of digestion process (wet or dry) can be modeled at a time in WARM.
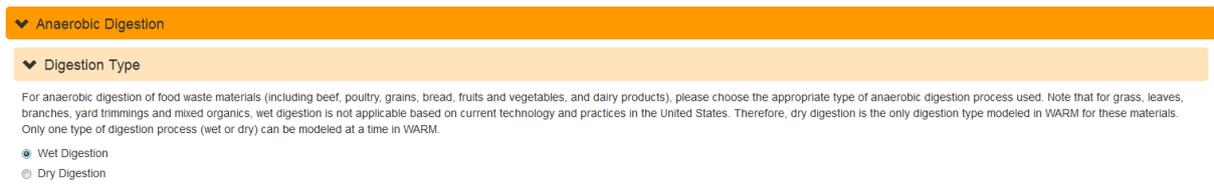
Figure 14: Digestion Type options in "Further characteristics" section of the "Data Entry" tab

II)   Digestate Curing: You can select that the digestate is cured before land application or not cured.
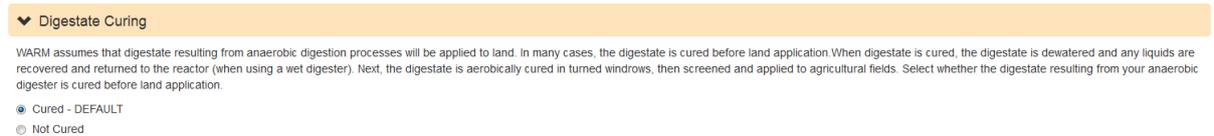

Figure 15: Digestate Curing in "Further characteristics" section of the "Data Entry" tab

You can collapse or expand each of these sections by clicking on the section's header area.

4.3. General Information

This page is included with documentation purposes. You can include your organization's name, your name, the reporting period and a description of the assessment in the existing text fields. The data typed in here will be shown in the report generated after the calculation.
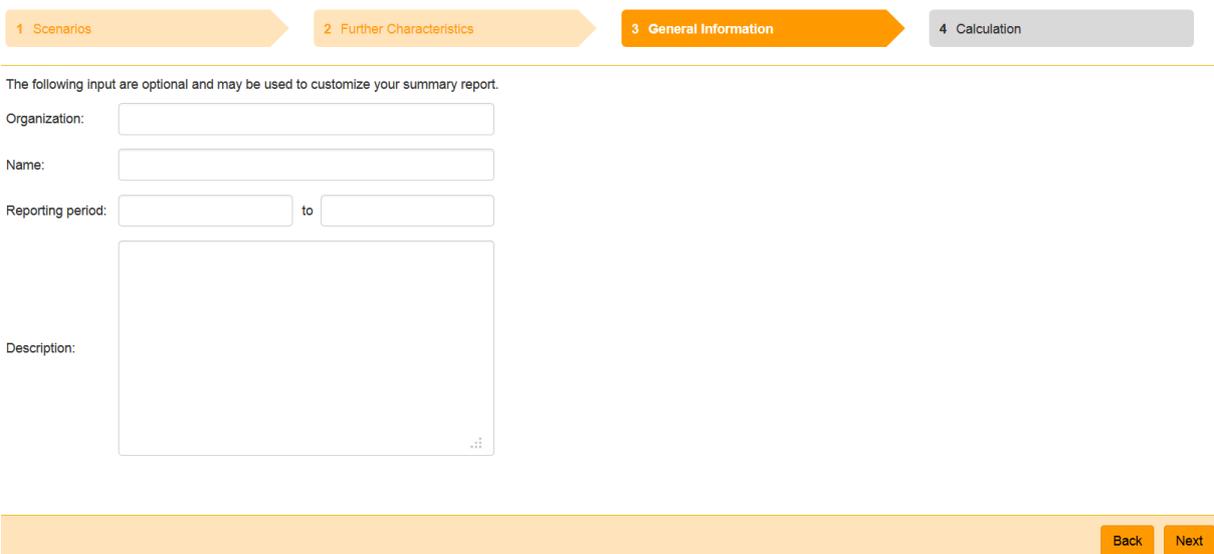
Figure 16. "General Information" section of the "Data Entry" tab

4.4. Calculation

Six types of calculations can be performed in the WARM tool:

- GHGs emissions in metric tons of carbon dioxide equivalent (MTCO2E)
- GHGs emissions in metric tons of carbon equivalent (MTCE)
- Energy consumed in million BTU
- Labor hours – employment supported by materials management
- Wages ($) – all forms of employment income from materials management

- Taxes ($) – taxes collected by the federal, state and local government from materials management
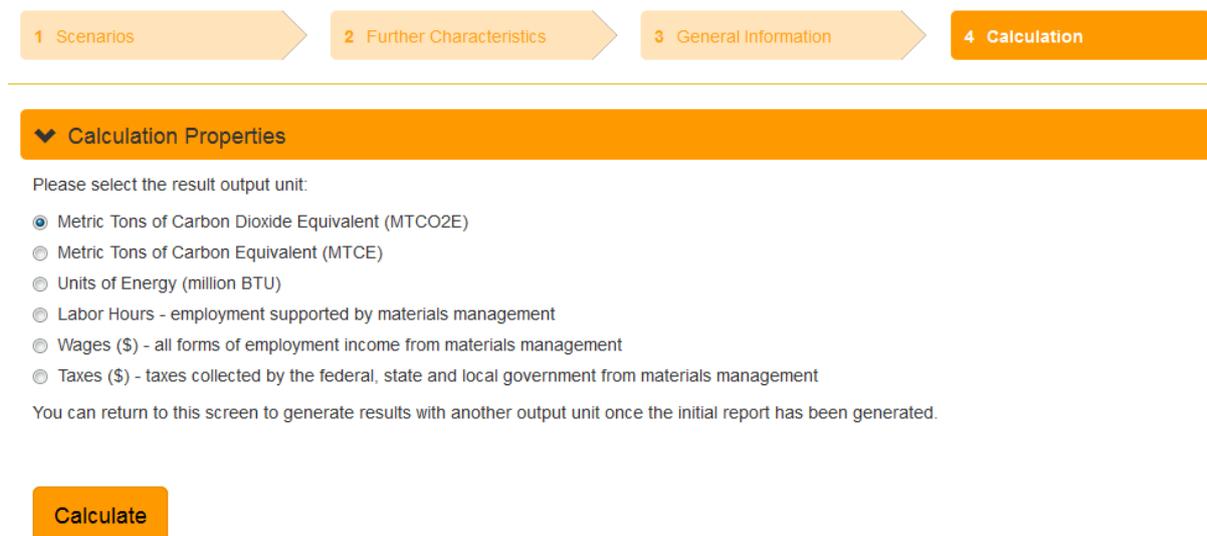
Figure 17. "Calculation" section of the "Data Entry" tab

After selecting the preferred calculation option, click on "Calculate" to get the results in a new tab "Report". You might need to wait a bit longer for the calculation to complete for the initial run.

5. Results

There are three sub-tabs within the "Report" tab created after the calculation: summary, analysis, and charts (for GHG emissions and energy reports only). They can be found in the bottom left corner of the "Report" tab.
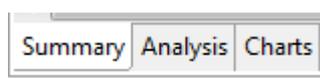
Figure 18. Detail of tabs found at the bottom of the "Report" screen

How to interpret the results presented in them? If a GHG emission value is negative, it means that those emissions have been avoided during the management of that specific material type and/or scenario. Likewise, if an energy consumption is negative, it means that the modelled scenario avoids the consumption of that amount of energy. If the total change between the alternative and baseline scenario is negative, then the alternative scenario will result in fewer GHG emissions, energy consumption, or economic impacts than the baseline, and vice versa.

Only those materials for which data has been entered on the "Scenarios" step will be presented in the results.

As in the "Scenarios" step, there are also tooltips for each cell/bar of the different results' tables containing information about the data displayed in them.

5.1. Summary

This sub-tab contains a table similar to the one in the "Scenarios" step but also includes the GHG emissions/Energy consumption/Economic impacts per material and scenario. In addition,

11

there is a column on the right side with the change between the two scenarios (i.e., Alternative minus Baseline) for the metric selected in the calculation properties.

Moreover, there are equivalencies in the bottom right of the page for the resulting total change. For example, WARM includes the amount of passenger vehicles' annual emissions equivalent to the total change in GHG Emissions. Depending on the sign of the total change, this equivalency will be presented as removal of annual emissions (if the sign is negative) or adding of emissions (if the sign is positive).
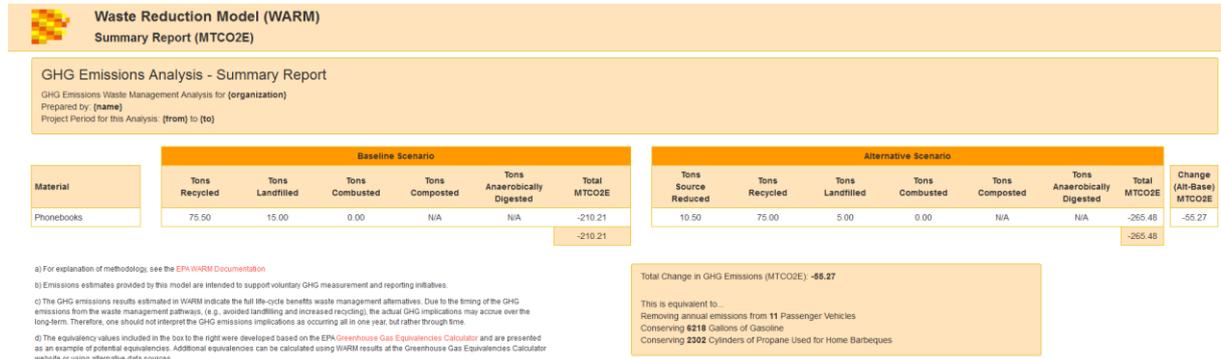
Figure 19. "Summary" sub-tab of the report

5.2. Analysis

This sub-tab contains four sections:

- Emission factors: this table contains the emission factors (in the selected metric) per relevant material type and management practice. The tons specified per material and management practice are multiplied by these factors to obtain the GHG emission/Energy consumption/Economic impact results.
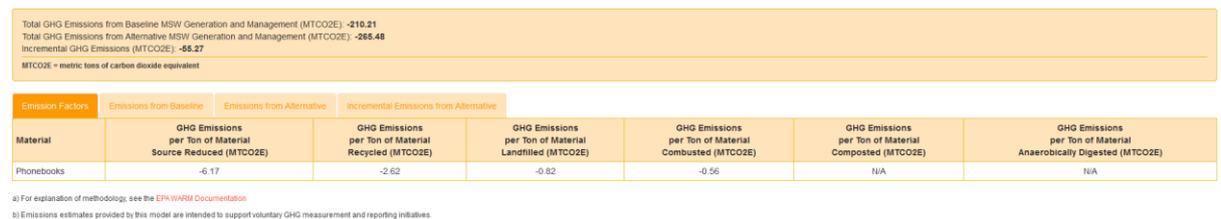
Figure 20. "Emission factors" section in the "Analysis" sub-tab of the report

- Emissions from Baseline: this table contains the tons managed and the resulting GHG emission/Energy consumption/Economic impact per relevant material and management practice, as well as the totals per material, for the baseline scenario.
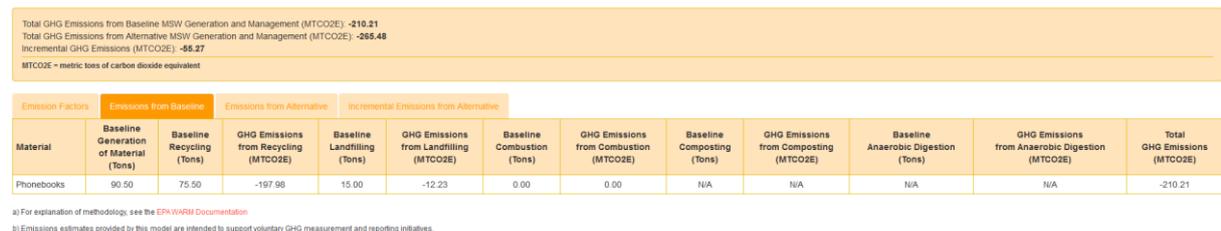
Figure 21. "Emissions from Baseline" section in the "Analysis" sub-tab of the report

- Emissions from Alternative: it contains the tons handled and the resulted GHG emission/Energy consumption/Economic impact per relevant material and management practice, as well as the totals per material, for the alternative scenario.

Figure 22. "Emissions from Alternative" section in the "Analysis" sub-tab of the report

- Incremental Emissions from Alternative: it contains the differences between the alternative and baseline scenario regarding tons handled and GHG emissions/Energy consumption/Economic impact per relevant material and management practice, as well as the total incremental results per material.

Figure 23. "Incremental Emissions from Alternative" section in the "Analysis" sub-tab of the report

5.3. Charts

GHG emission and energy results are also presented visually. Contributions per flow, material type, management practice and groups representing life cycle activities are presented as bar charts in four different sections:

- Flow contributions: in the GHG emissions calculation (i.e., MTCO2E, MTCE), the contribution per GHG flow assessed is presented for each scenario. The elementary flows displayed are:

    - Resources:
        - Carbon (forest storage)
        - Carbon (landfill storage)
        - Carbon (soil storage)
    - Air emissions:
        - Carbon dioxide
        - Dinitrogen monoxide
        - Ethane, hexafluoro, HFC-116
        - GHGs, unspecified
        - Methane
        - Methane, tetrafluoro, R-14

    In the Energy consumption calculation, a single flow is displayed "Energy, unspecified" (resource) for both scenarios.
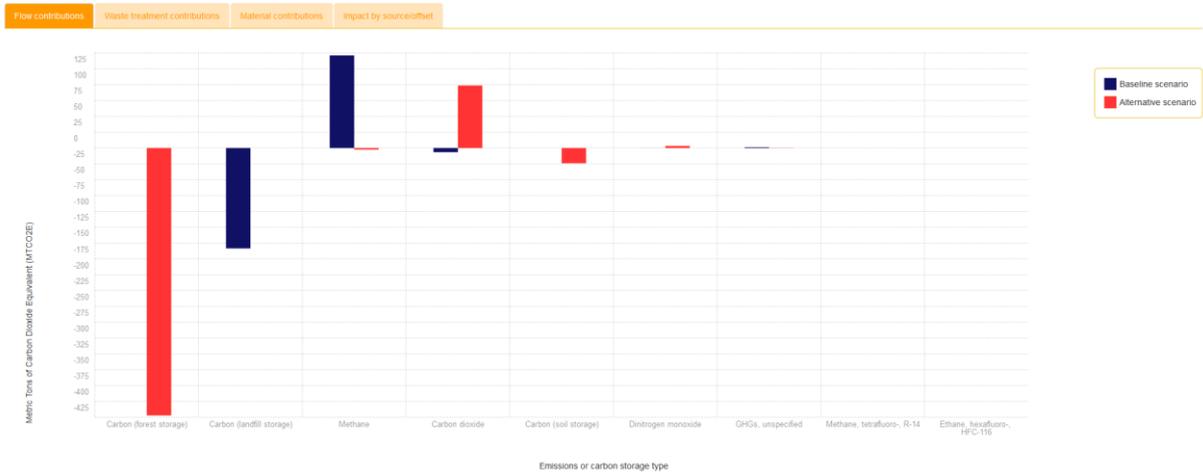
Figure 24. "Flow contributions" section in the "Charts" sub-tab of the report

- Waste treatment contributions: the GHG emissions/Energy consumption per waste management option is presented here for each scenario and a maximum of six materials. The materials to be displayed can be selected clicking on the "Select material filter" button. A pop-up window with the relevant materials will be shown; once the materials have been chosen, click on "Apply selection".
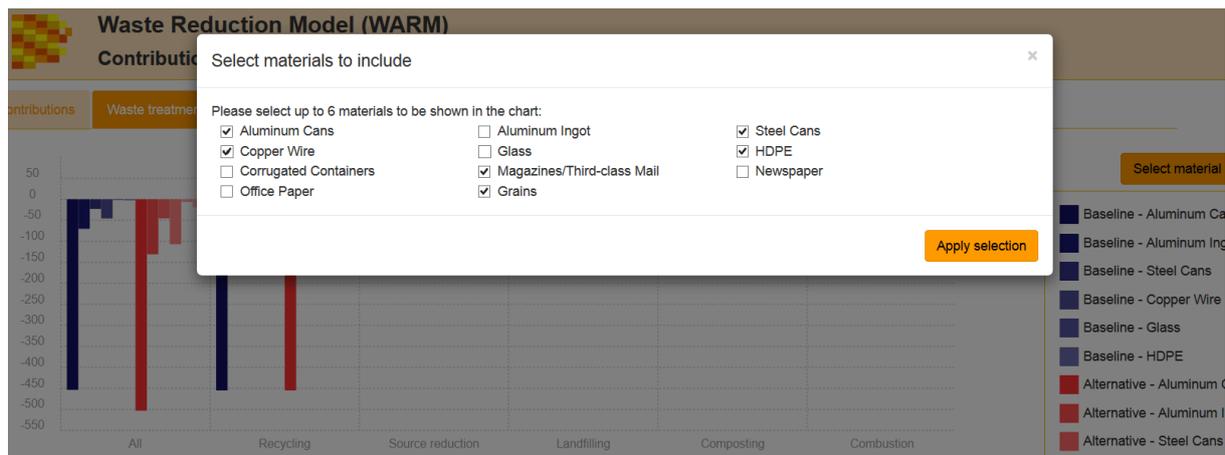

Figure 25. "Select materials filter" window in the "Waste treatment contributions" section of the "Charts" sub-tab of the report

- Material contributions: the GHG emissions/Energy consumption per material type is presented here for each scenario and management practice. As in the previous chart, only up to six materials can be presented simultaneously. The materials to be displayed can be selected clicking on the "Select material filter" button.
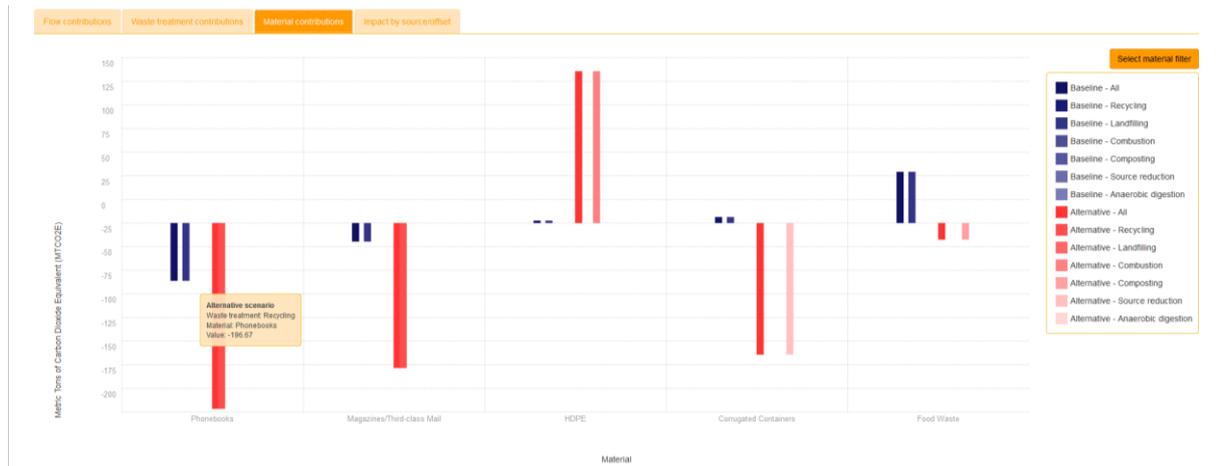
Figure 26. "Material contributions" section in the "Charts" sub-tab of the report

- Impact by source/offset: the GHG emissions/Energy consumption results per each pre-defined group of processes used in the WARM life cycle product system created in openLCA. The groups presented are:
    - Landfilling: impacts of methane emissions and benefits of carbon storage in landfills.

    - Combustion: impacts of carbon dioxide and dinitrogen monoxide emissions during combustion.

    - Recycling: benefits of steel recycling from combustion of tires.

    - Source reduction: benefits of avoiding new product manufacturing due to recycling or source reduction of waste. Transport emissions/energy consumption occurred during the manufacturing are accounted in the group "transport".

    - Composting: impacts of methane and dinitrogen monoxide emissions produced during the composting and benefits of carbon storage due to applying compost in soils.

    - Anaerobic digestion: impacts of digester operation and land application.

    - Electricity: avoided utility GHG emissions/energy consumption due to combustion and landfilling of waste.

    - Heavy equipment for landfilling: impacts of carbon dioxide emissions/energy consumption during landfill operations.

    - Heavy equipment for composting: impacts of carbon dioxide emissions/energy consumption due to turning compost piles.

    - Transport: impacts of GHG emissions/energy consumption due to transportation of waste to management facilities, within the management facilities or to retailer; and benefits of avoiding GHG emissions/energy consumption by avoiding transportation for new products manufacturing due to recycling and source reduction.

- Forest carbon sequestration: benefits of avoiding timber harvesting due to recycling or source reduction of some material types (e.g., textbooks).

- Other: impacts of carbon dioxide and methane emissions due to wood chipping in combustion facilities.

5.4. Report export

All the content of the "Report" tab can be exported as HTML by clicking on the icon of the toolbar. The exported file can then be opened in any modern web browser. The only difference with the view in the WARM Tool is that the report's sub-tabs, "Summary" and "Analysis", are included in the exported file as buttons in the top-right of the page.


Figure 27. WARM Report exported as HTML opened in a web browser

6. Saving data

All the entered data and selected options from the "Data Entry" tab can be saved in a file with the extension *.warm and be opened again in the tool for further assessments. To do this, select "File" in the menu bar and choose between any of the existing options (i.e., "Save", "Save as", "Save all"). For opening an existing file, select the option "Open…". The files with extension *.warm can only be opened from within this WARM Tool.
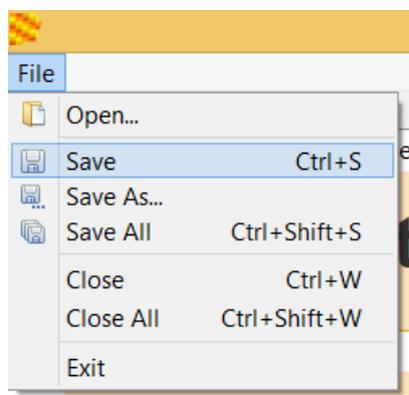

Figure 28. "File" menu options

The save/open functions are also available in the toolbar.

All the tabs that remain opened when closing the application will be displayed again the next time the tool is run. If you want to close permanently any tab, use the "Close" and "Close All" options of the "File" menu or click on the white cross in the right of the tab's header.

7. Other features

You can display several tabs at the same time in the tool by dragging and dropping the tabs into different positions in the window. Please, note that if the size of the window is too small, some elements might not be displayed properly (e.g., data entry tab).
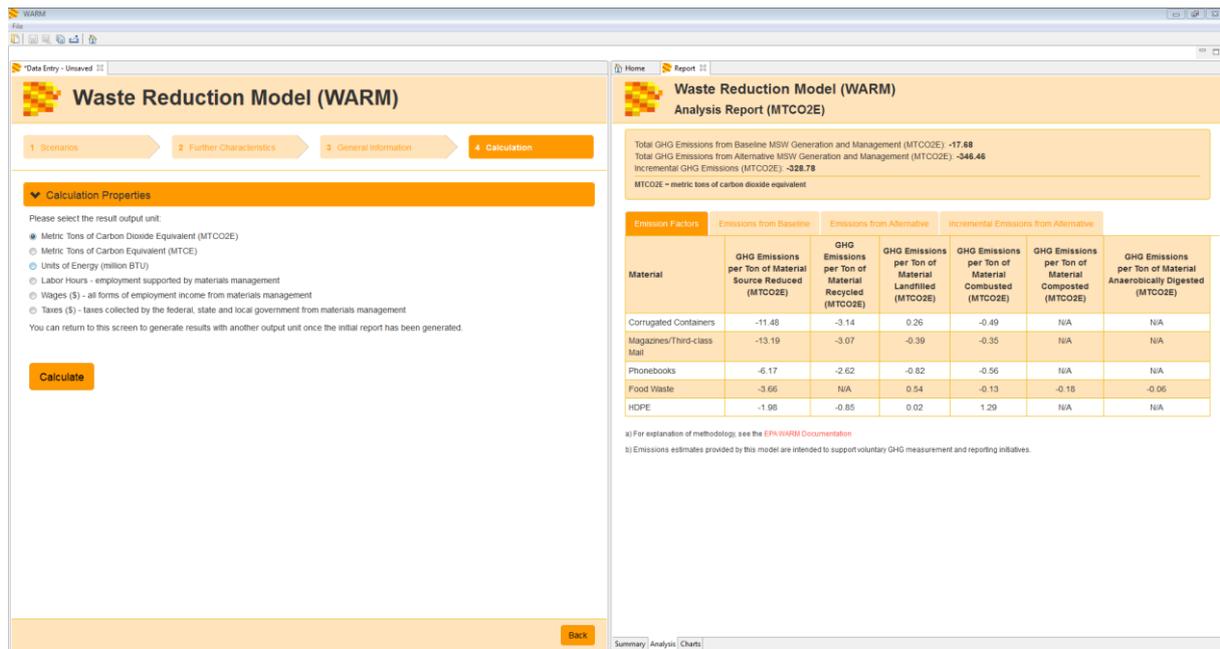

Figure 29. Display of two tabs simultaneously in WARM

8. Contact

If you need additional assistance with using WARM, please email orcrWARMquestions@epa.gov.