STREET EXCAVATION EMISSION CALCULATOR

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1. Introduction

Urban areas, particularly those with aging infrastructure, frequently undergo road excavation for utility maintenance, new infrastructure installations, or road repairs. These activities commonly generate significant waste material and associated greenhouse gas (GHG) emissions. To quantify the impact of these excavations, a web-based "Street Excavation Emission Calculator" was designed to estimate GHG emissions associated with road excavation projects. The tool calculates emissions based on user provided excavation dimensions and location within New York City's boroughs. The tool dynamically adjusts the waste composition according to the excavation depth, following U.S. pavement design standards. The application also determines the nearest Construction and Demolition Waste (CDW) Transfer Station and landfill site, calculates the route to these facilities, and outputs affiliated emissions quantities.

2. Objective

The primary objective of the Street Excavation Waste Calculator was to provide a detailed estimation of the GHG emissions associated with road excavation activities. The tool achieves this by:

- Calculating the volume of waste generated based on user-defined excavation dimensions.
- Estimating GHG emissions from material production, equipment operation, and transportation.
- Identifying the nearest Construction and Demolition Waste (CDW) Transfer Station and landfill, providing the most efficient route and calculating the associated transportation emissions.
- Offering users a breakdown of emissions by source, thereby fostering informed decision-making for more sustainable construction practices.

3. Methodology

3.1 User Inputs

The tool requires the following inputs from the user:

Location: The user can either click on a map or enter a specific address to define the excavation site's location.

Excavation Dimensions: The user specifies the estimated length, width, and depth of the excavation in meters.

3.2 Geospatial Analysis

Geocoding: The input location is geocoded to obtain precise coordinates (latitude and longitude).

Borough Identification: Using GeoPandas, the application determines which New York City borough the excavation site falls within by analyzing the geospatial data of borough boundaries.

3.3 Dynamic Waste Composition Calculation

The waste composition generated from an excavation depends on the depth and standard pavement design. The application assumes that the pavement consists of multiple layers, each with a different material, following U.S. pavement design standards:

Layer Thicknesses:

Asphalt: 6 inches (0.1524 meters)

Concrete Base: 6 inches (0.1524 meters)

Underlying Materials (e.g., gravel, dirt): Depends on the depth beyond the asphalt and concrete layers.

The application dynamically calculates the waste composition based on the user-provided depth:

Full Layer: If the depth exceeds the thickness of a layer, the material is considered fully excavated.

Partial Layer: If the depth only partially covers a layer, the proportionate amount is calculated.

3.4 OD Matrix and Distance Calculation

a. **OD Matrix Creation:**

To accurately estimate the distance from the excavation site to the nearest CDW Transfer Station and from the Transfer Station to the nearest landfill, the tool uses precomputed Origin-Destination (OD) matrices. These matrices were created as part of this project using the centroids of census blocks and the transfer station and landfill locations. The process involved:

Census Block Centroids: Each census block's centroid was used as an origin point.

Transfer Stations and Landfills: The locations of transfer stations and landfills were used as destination points.

Two OD matrices were generated:

Census Blocks to Transfer Stations: This matrix calculates the network distance from each census block centroid to all nearby transfer stations.

Transfer Stations to Landfills: This matrix calculates the network distance from each transfer station to the nearest landfill.

b. **Distance Calculation Workflow:**

When a user selects an excavation location:

- The tool spatially determines which census block the location falls within by checking the spatial intersection with the census block geometries.
- Using the OD matrix, the tool identifies the closest transfer station based on the network cost (converted to miles) from the selected census block's centroid to the transfer stations.
- Similarly, the tool determines the closest landfill based on the distance from the identified transfer station to the available landfill sites.

3.4 Emission Calculation

The GHG emissions are calculated from EPA GHG Emission Factors Hub 2024, including material production, equipment operation, and transportation. The calculation steps are as follows:

a. Volume of Excavated Material:
The volume of the excavation (V) is calculated using the formula:

$$V = Length \times Width \times Depth \times 0.8$$

where 0.8 is a fill factor representing the portion of the excavated volume that is solid material.

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b. Waste Composition:

The previously calculated dynamic waste composition (see 3.3) is used to assigned an excavated volume to each of the excavated materials (e.g., asphalt, concrete).

c. Emission Factors:
Material Production: Emission factors for different materials are applied to calculate the emissions from the production of each material:

$$Emissions_{prod\_material} = V_{material} \times EF_{prod\_material}$$

where EF represents the emission factor for the production of the material in kg $CO2e/m^3$.

Emission Factors Used:

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Asphalt Production: 85 kg $CO2e/m^3$

Concrete Production: 120 kg $CO2e/m^3$

Gravel Production: 20 kg $CO2e/m^3$

Dirt Production: 10 kg $CO2e/m^3$

d. Equipment Operation:

Excavation Equipment: Emissions from the operation of excavation equipment (e.g., excavator, bulldozer) are calculated based on usage rates and emission factors:

$$Emissions_{excavator} = V \times Usage\ Rate_{Excavator} \times EF_{excavator}$$

Usage Rates and Emission Factors:

Excavator Usage Rate: 0.1 $hours/m^3$

Bulldozer Usage Rate: 0.05 $hours/m^3$

Excavator Emission Factor: 25 kg CO2e/hour

Bulldozer Emission Factor: 70 kg CO2e/hour

e. Transportation:

Transport Emissions: Emissions from transporting waste to the recycling center and then to the landfill are calculated:

$$Emissions\ transport = Weight_{material} \times Distance \times EF_{transport}$$

Transportation Emission Factors:

Transport Emission Factor: 0.15 kg CO2e/ton-mile

f. Waste Management:

Emissions from landfill and recycling are calculated using their respective emission factors:

$$\text{Emissions}_{\text{landfill}} = \text{Weight total} \times \text{EF}_{\text{landfill}}$$

Waste Management Emission Factors:

Landfill Emission Factor: 5 kg CO2e/ton

Recycling Emission Factor: 3 kg CO2e/ton

g. Total Emissions:

The total emissions are calculated by summing up all the individual components:

$$\text{Total}_{\text{emissions}} = \sum \text{Emissions}_{\text{prod}} + \sum \text{Emissions}_{\text{transport}} + \text{Emissions}_{\text{excavator}} + \text{Emissions}_{\text{bulldozer}} + \text{Emissions}_{\text{landfill}} + \text{Emissions}_{\text{recycling}}$$

3.6 Routing and Distance Visualization

The tool uses the Open Source Routing Machine (OSRM) API to calculate the most efficient route from the excavation site to the nearest CDW Transfer Station.

The distance to the transfer station is used in the transportation emissions calculation.

The route is visualized on the front-end map, and the transfer station's location is marked. The popup for the transfer station includes the distance to the station and identifies it as the "Closest CDW Transfer Station."

3.6 Assumptions

Fill Factor: A fill factor of 0.8 is used to account for the solid material portion of the excavation.

Layer Thicknesses: Standard pavement layers are assumed to be 6 inches (0.1524 meters) for both asphalt and concrete.

Static Material Densities: Material densities are assumed to be constant, with values taken from typical construction materials.

Emission Factors: Emission factors are based on available literature and industry standards for GHG emissions from material production, equipment operation, and transportation.

Simplified Transportation Model: The model considers network distance within the five boroughs of NYC. Outside NYC, we assume a linear distance for transportation emissions and do not account for network distance.

4. User Interface and Experience

The application is designed to be user-friendly, offering an intuitive map interface where users can click to select the excavation site. The results are presented in a clear, organized manner, with a breakdown of emissions and a map showing the route to the nearest transfer station. An informational pop-up is available for users who wish to understand the methodology behind the calculations.

Example Use Case:

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Imagine a construction company planning an excavation project in Manhattan. The project requires cutting through 1 cubic meter of pavement. By entering the site location and excavation dimensions into the calculator, the company can:

- Understand the expected waste composition based on the depth of the excavation.
- Calculate the total GHG emissions associated with the project.
- Visualize the route to the nearest transfer station and landfill, ensuring compliance with local regulations and minimizing environmental impact.

4. Limitations

- **Excluded Emissions:** The tool does not account for emissions associated with the recycling processes beyond transportation. Additionally, emissions from the initial construction or any dismantling processes (e.g., cutting, drilling) are not considered.
- Simplified Routing: The routing model assumes straightforward transportation without accounting for possible delays, detours, or specific road conditions.
- **Circular Economy Focus:** The tool emphasizes minimizing waste to landfills in line with circular economy principles. As a result, only 10% of the waste is assumed to go to the landfill, which may not align with scenarios with higher landfill usage due to contamination or other factors.

Conclusions:

The Street Excavation Waste Calculator is a powerful tool for estimating the environmental impact of road excavation projects. By providing detailed emissions data and visualizing the waste disposal process, the tool helps stakeholders make informed decisions that align with sustainability goals. The dynamic nature of the waste composition calculation, coupled with real-time routing, ensures that the estimates are as accurate and relevant as possible.

This application is a valuable resource for construction companies, urban planners, and environmental consultants looking to assess and minimize the GHG emissions associated with their projects.