COMPARATIVE STUDY OF GREENHOUSE GAS EMISSIONS FROM HAND TUNNELING AND PILOT TUBE METHOD UNDERGROUND CONSTRUCTION METHODS

Sadegh Mohit[1] MEng; Mahsa Ahmadian Nezhad Monfared[2] MSc; Chao Kang[3], PhD;
Alireza Bayat[4], PhD, PEng

ABSTRACT

The negative effects of greenhouse gas (GHG) emissions, such as climate change and global warming, have become major environmental concerns, especially for the construction industry, which is the third-highest source of GHG emissions among industrialized countries. Presently, underground utility projects are considered one of the most common types of construction, primarily due to aging infrastructure across North America and the subsequent rehabilitation of old pipelines and installation of new pipelines and facilities. Given the increasing demand being placed on the industry, the need to study airborne emissions associated with different underground construction technologies has risen, which will be helpful in selecting the most sustainable underground construction methods. This study investigates pollutant emission from two common trenchless methods used in underground construction, hand tunneling and pilot-tube method (PTM), through their varying GHG footprint sources and emissions measured by the United States Environmental Protection Agency (EPA). This paper analyzes a case from Edmonton, Canada, in which both PTM and hand tunneling were used by comparing the suggested indexes, including HC, CO, NO_x, PM, CO_2, and SO_2. In this case study, both methods were used in the installation of a new 68-cm diameter (27 in.) clay sewer line with an overburden depth of 12.9 m (42 ft) and length of 60 m (197 ft). Results indicated that the amount of airborne emissions was reduced between 17% and 36% through the use of PTM compared to the traditional hand tunnelling method.

KEYWORDS

Greenhouse Gases, CO_2 Emissions, Sustainable Development, Underground Construction, Hand Tunneling, Pilot-Tube Method

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[1] MEng Student, University of Alberta
[2] MSc Student, University of Alberta
[3] Postdoctoral Fellow, University of Alberta
[4] Associate Professor, University of Alberta, Innovation Centre for Engineering, abayat@ualberta.ca (corresponding author)

INTRODUCTION

Economic development powered by fossil fuels, population growth, and consumption increase have produced a substantial rise in carbon emissions, while the rate of natural carbon dioxide (CO_2) absorption has not changed (Sullivan 2012). According to the Intergovernmental Panel on Climate Change (IPCC), CO_2 is the reference gas for measuring greenhouse gas (GHG) effects on climate change as it is the primary component of GHG emissions (Xie and Atalah 2010). In the past 60 years, the total amount of CO_2 in the atmosphere has increased from 280 parts per million to more than 380 parts per million (Sullivan 2012) and based on the Global Greenhouse Gas Reference Network report, it is 409 parts per million. In Canada, World Bank data (2010) shows that the amount of CO_2 emission per capita has increased from 10.77 metric tons in 1960 to 14.7 metric tons in 2010. The harmful environmental effects of GHG emissions, such as global warming, are currently among the most significant concerns to society.

Many governments, industries, and organizations have tried to develop target plans to curb the amount of carbon emissions they are producing (Sihabuddin and Ariaratnam 2009a). In early 2010, the Canadian government adopted a national emissions target for 2020, the same commitment as the United States. This target has been set to a 17% reduction in emissions from 2005 and national annual emissions of 612 Mt by 2020. A variety of programs by the Government of Canada supports clean technologies. The Sustainable Development Technology Canada (SDTC) is one of the most important initiatives that finances and supports entrepreneurs in the development and demonstration of clean technologies. The Government of Canada also supports the efforts of provinces and territories to achieve their own GHG emissions reduction targets. Moreover, businesses and individuals are supported in lowering their respective emissions (Canada's Emissions Trends 2013). As of July 1, 2007, the Alberta government required all industrial facilities emitting more than 100,000 tonnes of GHG per year to decrease emissions by at least 12% (Government of Alberta 2008).

According to a report published by the EPA in 2008, construction activities are the third-highest source of GHG emissions in the United States (Truitt 2009). Furthermore, due to the large number of construction sites in the United States (more than 800,000), 131 million metric tons of CO_2 are released each year (Truitt 2009).

Due to North America's aging underground infrastructure and the need for rehabilitating and/or installing new pipelines and facilities, underground projects have become a major area of construction that contribute significantly to GHG emissions. Open-cut methods are traditionally used to install and rehabilitate underground infrastructure and have been associated with high environmental and social costs, mostly in densely populated areas (Sullivan 2012). Over the past 20 years, new technologies known as trenchless methods have been used increasingly over open-cut.

Pilot tube microtunneling (PTM) is a trenchless method primarily used for the installation of small-diameter gravity flow pipelines. PTM combines microtunneling, horizontal directional drilling (HDD), and auger boring. Although this method was originally used to install small-diameter pipes, it has also been used for large-diameter pipes. High accuracy, minimal footprint, low capital investment, small crew requirements, quick setup, and high production rate are some advantages associated with PTM (Gottipati 2011). The traditional PTM method consists of three steps, including pilot tubes installation, reaming and auger casings installation, and product pipe installation. The Eliminator, a new guided boring machine developed by the Ackerman Company, is the most recent PTM equipment. Pilot tube installation is not required to develop the preferred line and grade in this method. Therefore, the installation process is reduced to two steps: auger casings installation and pipe installation

Hand tunneling and the use of a tunnel boring machine (TBM) are two methods commonly used for pipe installation. Hand tunneling is completed using manpower resources and is mainly applied in short projects, while mechanized tunneling uses shielded mechanical moles and is suitable for longer projects. Tunneling consists of three steps: excavation, dirt removal, and tunnel support. The first step involves the excavation of a vertical shaft to the appropriate depth, followed by tunnel excavation, which starts in the shaft and is typically completed using a pneumatic hammer. The process continues with excavating the tunnel, disposing the dirt from the tunnel face, hoisting the dirt to the ground level, and lining the tunnel. (Ruwanpura et al. 2000).

According to the North American Society for Trenchless Technology (NASTT) terminology, a trenchless method is a technology with minimum excavation from the ground surface. For this reason, trenchless methods are more environmentally and socially friendly than open-cut procedures. Nevertheless, in spite of their reduced environmental impacts, trenchless methods can still produce significant amounts of GHG emissions. Given the increasing popularity of these techniques, it is necessary to evaluate those emissions to aid practitioners in selecting procedures that can be used to characterize the trenchless methods.

In order to quantify the amount of emissions produced by a construction process, several databases have been created. Some of them are regional, such as the California Off-Road Certification Database developed by the California Air Resources Board, and some are general, such as those developed by the EPA (2010a and b). The standard emission modeling method in North America is the method developed by the EPA and the method developed by Lewis (2009), both of which have been used in recent studies to evaluate the carbon emissions of underground construction.

Sihabbudin and Ariaratnam (2009a) estimated the emissions generated by equipment and transportation in horizontal directional drilling (HDD) by applying the EPA NONROAD model. In this model, estimating the emissions commences by the basic tool of emission factor, which is the weight of pollutant emitted per unit weight, volume, distance, or duration. After determination of each pollutant's emission factor, the emission of pollutant (CO_2, SO_2, NO_x, CO, PM, HC) can be calculated based on hours of use and average rated horsepower of equipment.

In a different study, Ariaratnam and Sihabbudin (2009) used the same model to compare the quantity of GHG generated in pipe bursting and open-cut operations. They found that the amount of emissions decreased by 80% when using the pipe bursting method instead of the traditional open-cut method.

Lewis (2009) analyzed seven types of diesel construction equipment: backhoes, bulldozers, excavators, motor graders, off-road trucks, track loaders, and wheel loaders. The engine operation of the defined equipment was categorized into ten levels, with level one defined as idling and level 10 defined as full load (Ahn et al. 2009). The emission factors (g/hr) of air pollutants for each duty cycle are calculated multiplying the manufacturer's estimated emission rate per unit of fuel consumed (g/gal) by the weighted-average fuel use rate (gal/hr) collected by the onboard portable emission monitoring system (PEMS) (Lewis 2009). Although the Lewis database is the only source that distinguishes between the emission factors for different duty cycles, the list of equipment included is not comprehensive. Thus, it requires further investigation to confirm its validity (Ahn et al. 2010).

This paper presents a comparative environmental evaluation of the emissions produced by traditional open-cut methods, specifically hand tunneling, and trenchless methods, specifically PTM. In this case study, both methods were used in a project that installed a new 68-cm diameter (27 in.) clay sewer line with an overburden depth of 12.9 m (42 ft) and length of 60 m (197 ft) during summer 2013 in Edmonton, Alberta. Six major airborne pollutants were considered in the investigation of GHG emissions from both construction methods: carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_X), sulfur oxide (SO_2), hydrocarbons (HC) and particulate matter (PM). The GHG emissions were evaluated by using the EPA NONROAD model to create a comprehensive decision-making model to determine which construction method is more effective for a given project in the future

RESEARCH METHODOLOGY

The research methodology is based on four main steps: data collection, analyze the collected data, calculate the amount of GHG emissions and comparison between the calculated amounts of emissions. The on-site data collection consists of detailed specifications of each equipment, hours of use, duration of the project, and site characteristics. After gathering the required data, the amounts of all pollutant emissions were calculated using the EPA standard emission model. Based on the calculated GHG emissions, hand tunneling and PTM pollutant emissions were compared.

The methodology for carbon footprint calculation divides construction (non-road) and transportation (road) equipment by emissions per source. The most commonly used reference for emission factor sources is the "Crankcase Emission Factors for Non-Road Engine Modeling-Compression-Ignition," published by the EPA (EPA 2010a) and which all emission factors in this research (HC, CO, NO_X, SO_2, PM, and CO_2) are based on. The research methodology is shown in Figure 1.

In this methodology, the main input for emission calculation is the emission factor. The emission factors for all pollutants are calculated for each equipment and transportation source. The equipment emission is calculated by multiplying the determined emission factor by load factor, horsepower, and hours of use, while the transportation emission is quantified by multiplying the haul and return distance by the transportation emission factor.

Construction equipment emissions

Construction machinery and equipment are among the largest sources contributing to carbon emission (Fabiano and Nobel 2012). The amount of gas emission produced by any piece of machinery can be calculated using Equation (1) detailed below, which was developed by the EPA (EPA 2010b) based on empirical observations:

$$\text{Emissions}_i = \text{EF}_\text{i} \times \text{HRS} \times \text{HP} \times \text{LF} \qquad (1)$$

where $\text{Emissions}_\text{i}$ is the emission amount generated by the equipment i (g), EF_i is the emission factor for the impact i (g/hp-hr), i is the type of pollutant (CO_2, SO_2, NO_X, CO, PM, HC), HRS is the hours of use, HP is the average rated horsepower of the equipment, and LF is the load factor (operating hp/maximum rated hp).

Table 1 shows the emission factor formulas used for construction equipment for different pollutants, including HC, CO, NO_x, PM, CO_2, and SO_2 (EPA 2010a and 2010b).

FIGURE 1. Schematic of research methodology used in the study.

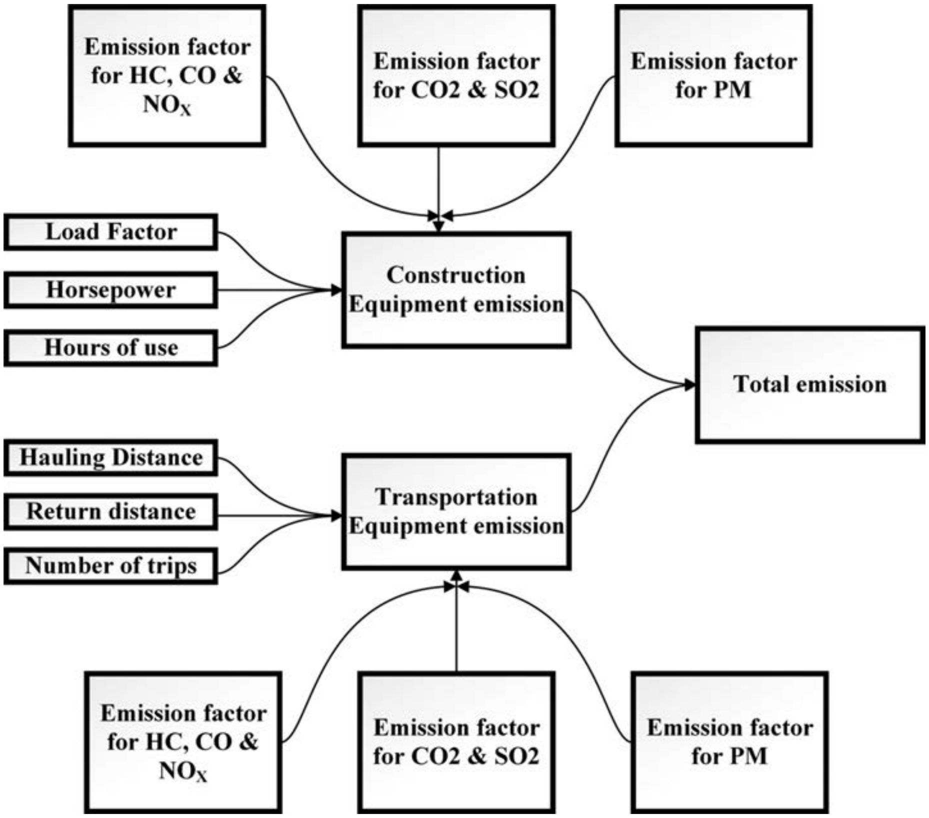


TABLE 1. The Construction Equipment Emission Factor Formulas.

Symbol	Description	Formula
EF(HC, CO, NO_x)	HC, CO, and NO_X emission factor	$EF_{SS} \times TAF \times DF$
EF(PM)	PM emission factor	$EF_{SS} \times TAF \times DF - S_{PMadj}$
EF(CO_2)	CO_2 emission factor	$\frac{44\ g\ CO_2}{12\ g\ C} 0.87(BSFCTAF453.6 - HC)$
EF(SO_2)	SO_2 emission factor	$\frac{64\ g\ SO_2}{32\ g\ S} 0.01\ SO_x\ dsl\left(BSFCTAF453.6\left(1 - SO_x conv\right) - HC\right)$

EFSS: Steady-state emission factor; TAF: Transient adjustment factor; DF: Deterioration factor; BSFC: Brake-specific fuel consumption; SPmadj: Sulfur content adjustment to PM emission factor; SOx dsl: Episodic fuel sulfur percentage; SOx conv: Fraction of fuel sulfur converted to PM.

Emissions from transporting materials to and from site

The second-most significant source of emissions is the transportation of materials to and from the work site. Hence, after calculating emission factors for construction equipment, the transportation footprint is calculated using Equation (2) (Ariaratnam and Sihabbudin 2009):

$$\text{Emissions}_{ti} = \text{EF}_i \times n \times (\text{D}_\text{O}+\text{D}_\text{R}) \tag{2}$$

where Emissions_{ti} is the transportation emission, EF_i is the transportation emission factor from pollutant i (g/mi), n is the number of trips required to transport materials and equipment, D_O is the one-way distance hauling to the site, and D_R is the return distance from the site.

The emission factor formulas of transportation are presented in Table 2 for different pollutants (EPA 2010a and 2010b).

RESULTS ANALYSIS AND DISCUSSION

Case description

This study investigated the magnitude of GHG emissions from two trenchless methods: PTM and hand tunneling. Hand tunneling and PTM are two common underground construction methods applied by the City of Edmonton for installing new pipes and replacing of old pipelines. A contractor employing both construction methods provided data for this paper, including a breakdown of activities by duration and information of the equipment used for each procedure.

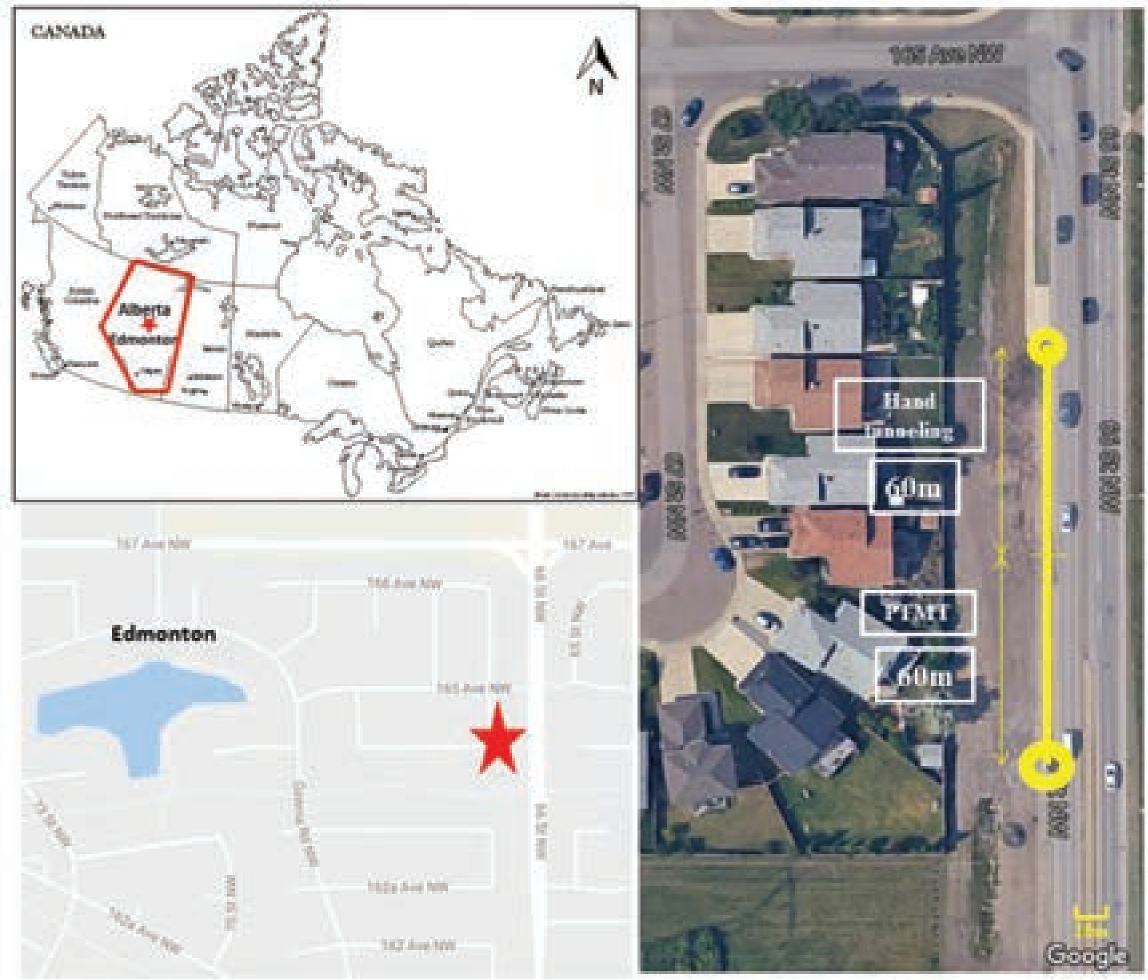
In this case study, both methods were used in a project that installed a new 68-cm diameter (27 in.) clay sewer line with an overburden depth of 12.9 m (42 ft) and length of 60 m (197 ft) in Edmonton, Alberta. The project location is shown in red in Figure 2.

TABLE 2. The Transportation Emission Factor Formulas.

Symbol	Description	Formula
$\text{EF}_t(\text{HC, CO, NO}_x)$	HC, CO, and NO_X transportation emission factor	$\left\{\text{EF}_{\text{ZM(HC,CO,N}_{\text{ox}})} + \left(\text{D}\frac{\text{M}}{10{,}000}\right)\right\}\text{AFC}_\text{F}$
$\text{EF}_t(\text{PM})$	PM transportation emission factor	$\text{EF}_{\text{ZM(PM)}} + \left(\text{D}\frac{\text{M}}{10{,}000}\right)$
$\text{EF}_t(\text{CO}_2)$	CO_2 transportation emission factor	$\frac{44\text{ g CO}_2}{12\text{ g C}}0.87\left(\frac{\text{F}_\text{D}}{\text{F}_\text{E}}453.6 - \text{HC}\right)$
$\text{EF}_t(\text{SO}_2)$	SO_2 transportation emission factor	$\frac{64\text{ g SO}_2}{32\text{ g S}}0.01\text{ SO}_x\text{ dsl}\left(\frac{\text{F}_\text{D}}{\text{F}_\text{E}}453.6(1 - \text{SO}_x\text{conv}) - \text{HC}\right)$

EF_{ZM}: Zero-mile emission factor; D: Deterioration; M: Mileage; AF: Altitude adjustment factor; C_F: Conversion factor; F_D: Field density; F_E: Fuel economy.

FIGURE 2. Case study location (Google Earth).



As emissions produced from pavement and material were the same for both PTM and hand tunneling, these sources were not considered in this study. In addition, both methods were used in an off-road area adjacent to 66th Street. Therefore, emissions generated from traffic diversion were also disregarded in this case study. All other equipment and transportation emissions were considered for both methods.

PILOT TUBE METHOD

The PTM eliminator method was selected in this case study. The length of the project was 60 m and, due to the clayey soil conditions in Edmonton, the depth of the project was relatively deep at 12.5 m. The diameter of the launch shaft was 4.5 m with an exit shaft 3 m in diameter

Table 3 shows the instruments and non-road equipment used in each step of the project. The Tier category is specified based on the model and hours of power (hp) of the equipment engine. The total duration for PTM project was 15 days with average of 10 hours per day.

Following the application of equations presented in Table 1, the emission factors were calculated using the values from Table 3. Using the emission factors, each pollutant footprint was calculated according to Equation 1, and the results are given in Table 4.

TABLE 3. Non-Road Equipment Used in the PTM Project.

Equipment	Make	Model	Tier	HP	Cumulative Hours	Median Life Hours	Activity	LF	Hours of Use
Hydraulic Pilling Rig	CMV /TH 20	2006	2	250	3,262	4,667	Drilling launch and exit shaft	0.43	20
Generator	Wacker Neuson/G70	2006	2	100	2,366	4,667	Producing electricity	0.43	240
Crane (1)	TADANO/ GR-800 XL	2009	3	267	3,960	4,667	Carrying pipe and material in the site	0.43	160
Crane (2)	TADANO/ GR-300 XL	2009	3	215	3,960	4,667	Carrying pipe and material in/from the shaft	0.43	45
Power Pack	Ackerman/ P 275T	2012	3	275	790	4,667	Producing pneumatic pressure	0.56	130
Pump	Ackerman/ 2325D	2012	3	30	403	2,500	Injecting lubrication	0.43	70
Bobcat	Bobcat/ T 650	2009	3	74	4,368	4,667	Transferring pipe and material on the site	0.48	60

TABLE 4. Emission Factors and Footprint from Equipment Sources for the PTM Project.

	Emission Factor (g/hp-hr)						Emission (kg)					
Equipment	HC	CO	NO_X	PM	CO_2	SO_2	HC	CO	NO_X	PM	CO_2	SO_2
Hydraulic Pilling Rig	0.31	0.77	4.01	0.15	530.05	1.07	0.76	1.89	9.83	0.37	1,298.62	2.63
Generator	0.57	2.42	4.71	0.26	810.69	1.64	5.84	40.03	77.98	4.38	13,425.03	27.15
Crane (1)	0.19	0.79	2.51	0.18	530.45	1.07	3.41	14.49	46.06	3.23	9,744.21	19.71
Crane (2)	0.19	0.79	2.51	0.18	530.45	1.07	0.77	3.28	10.43	0.73	2,206.82	4.46
Power Pack	0.18	0.76	2.50	0.16	530.46	1.07	3.69	15.18	50.09	3.14	10,619.73	21.48
Pump	0.28	1.54	4.73	0.34	589.48	1.19	0.25	2.23	6.85	0.50	854.16	1.73
Bobcat	0.43	6.49	3.64	0.86	1,350.59	2.73	0.91	14.41	8.09	1.91	2,998.30	6.06
Total	-	-	-	-	-	-	15.63	91.51	209.33	14.27	41,146.87	83.22

Using the equations in Table 2, the emission factors for transportation equipment were calculated considering the values given in Table 5.

By applying Equation (2) and using the calculated emissions factors from Table 5, the total amount of transportation emissions for each pollutant were calculated and detailed in Table 6.

TABLE 5. Emission Factors for PTM Project Transportation.

Equipment	Model	Year	GVW	EF HC (g/mi)	EF CO (g/mi)	EF NO_X (g/mi)	EF PM (g/mi)	EF CO_2 (g/mi)	EF SO_2 (g/mi)
Dump Truck	International	2009	23,300	0.34	1.70	4.08	0.01	1,180.09	0.36

In summary, the total emission amounts associated with the PTM project are shown in Table 7.

HAND TUNNELING

The project included the installation of a 68-cm diameter (27 in.) pipe in a tunnel 2.06-m high by 1.22-m wide. The depth of the project was 12.5 m and the length was 60 m. Table 8 describes the equipment used in this project including model, power rate, and hours of use, load factor, tier, median life hours, cumulative hours and fuel type. The total duration for the hand tunneling project was 60 days with an average of 10 hours per day.

The emission factors were calculated using the equations in Table 1, and results are given in Table 9. Then, the pollutant footprint from each piece of equipment used was calculated using Equation (1) (Table 9).

The transportation emissions for the project were produced by the dump truck used to carry the excavated soil to the construction site. These emissions were calculated and are shown in Table 10.

Finally, the total footprint from transportation sources was calculated for different gases as presented in Table 11.

In summary, total emissions for the hand tunneling project are provided in Table 12.

TABLE 6. Footprint from Transportation Sources for the PTM Project.

Equipment	No. of Trips	DR (mi)	Do (mi)	HC Emission (kg)	CO Emission (kg)	NO_X Emission (kg)	PM Emission (kg)	CO_2 Emission (kg)	SO_2 Emission (kg)
Dump Truck	45	9.54	9.54	0.29	1.46	3.5	0.01	1,013.23	0.31

TABLE 7. Total Footprints for the PTM Project.

Emission Source	HC Emission (kg)	CO Emission (kg)	NO_x Emission (kg)	PM Emission (kg)	CO_2 Emission (kg)	SO_2 Emission (kg)
Equipment	15.63	91.51	209.33	14.27	41,146.87	83.22
Transportation	0.29	1.46	3.5	0.01	1,013.23	0.31
Total	15.92	92.97	212.83	14.28	42,160.10	83.53

TABLE 8. Non-Road Equipment Used in Hand Tunneling Project.

Equipment	Make	Model	Tier	HP	Fuel Type	Cumulative Hours	Median Life Hours	LF	Hours of Use
Air Compressor	DOSAN/XP 185	2006	2	72	Diesel	5,705	4,667	0.43	600
Crane	TADANO-GR-300 XL	2009	3	215	Diesel	3,960	4,667	0.43	650
Mini Loader	Bobcat-T 650	2009	3	74	Diesel	3,744	4,667	0.5	130
Hydraulic Pilling Rig	CMV /TH 20	2006	2	250	Diesel	3,262	4,667	0.43	25

TABLE 9. Emission Factor and Footprint from Equipment Sources for the Hand Tunneling Project.

Equipment	Emission Factor (g/hp-hr)						Emission (kg)					
	HC	CO	NO_X	PM	CO_2	SO_2	HC	CO	NO_X	PM	CO_2	SO_2
Air Compressor	0.37	2.49	4.72	0.30	589.18	1.19	6.94	46.27	87.72	5.57	15,837.06	32.03
Crane	0.19	0.79	2.51	0.18	530.45	1.07	11.14	47.39	150.67	10.57	29,652.32	59.97
Mini Loader	0.42	2.04	3.03	0.42	1,350.59	2.73	2.04	9.80	14.60	2.03	6,496.34	13.14
Hydraulic Pilling Rig	0.31	0.77	4.01	0.15	530.05	1.07	0.84	2.07	10.78	0.40	1,656.40	3.35
Total							20.97	105.54	263.77	18.57	53,642.12	108.49

TABLE 10. Emission Factors for Transportation Emissions in the Hand Tunneling Project.

Equipment	Model	Year	GVW	EF HC (g/mi)	EF CO (g/mi)	EF NO_X (g/mi)	EF PM (g/mi)	EF CO_2 (g/mi)	EF SO_2 (g/mi)
Dump Truck	International	2009	23,300	0.34	1.7	4.08	0.01	1,180.09	0.36

TABLE 11. Footprint from the Transportation Sources for the Hand Tunnel Project.

Equipment	No. of Trips	DR (mi)	Do (mi)	HC Emission (kg)	CO Emission (kg)	NO_X Emission (kg)	PM Emission (kg)	CO_2 Emission (kg)	SO_2 Emission (kg)
Dump Truck	95	9.54	9.54	0.61	3.09	7.4	0.02	2,139.04	0.66

TABLE 12. Total Footprint of the Hand Tunneling Project.

Emission Source	HC Emission (kg)	CO Emission (kg)	NO_X Emission (kg)	PM Emission (kg)	CO_2 Emission (kg)	SO_2 Emission (kg)
Equipment	20.97	105.54	263.77	18.57	53,642.12	108.49
Transportation	0.61	3.09	7.4	0.02	2,139.04	0.66
Total	21.58	108.63	271.17	18.59	55,781.16	109.15

Comparison of GHG emissions between hand tunneling and PTM

The comparison of GHG emissions between hand tunneling and PTM is depicted in Figure 3. The results reveal that the airborne emissions were reduced to approximately 28.82% with PTM compared to hand tunneling. CO_2, which is the main component of GHG emissions, was reduced by 32.31%. The amounts of HC, SO_2, and PM were decreased by 35.55%, 30.67%, and 30.18%, respectively, from hand tunneling to PTM. The lowest reductions occurred for NO_X and CO, which were 27.41% and 16.84%, respectively.

FIGURE 3. Comparison of GHG emissions between two utility installation methods.

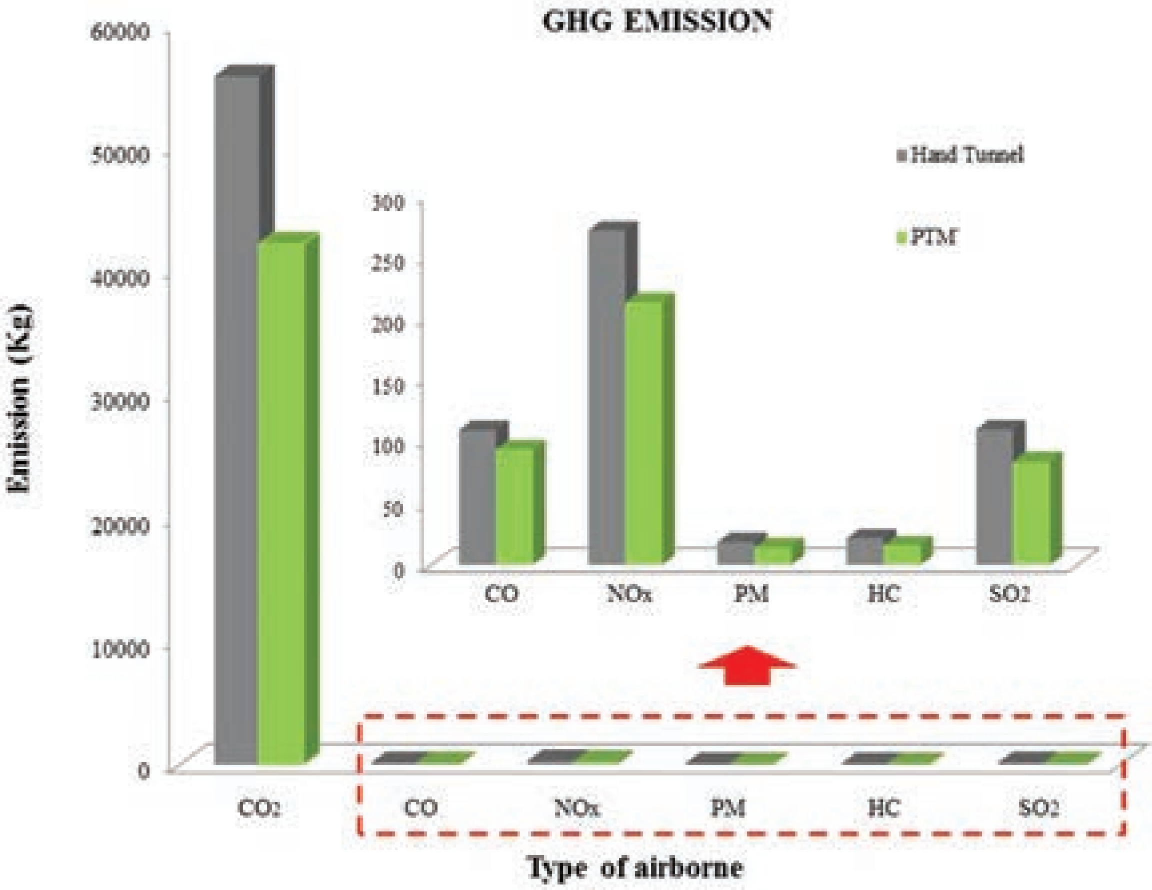
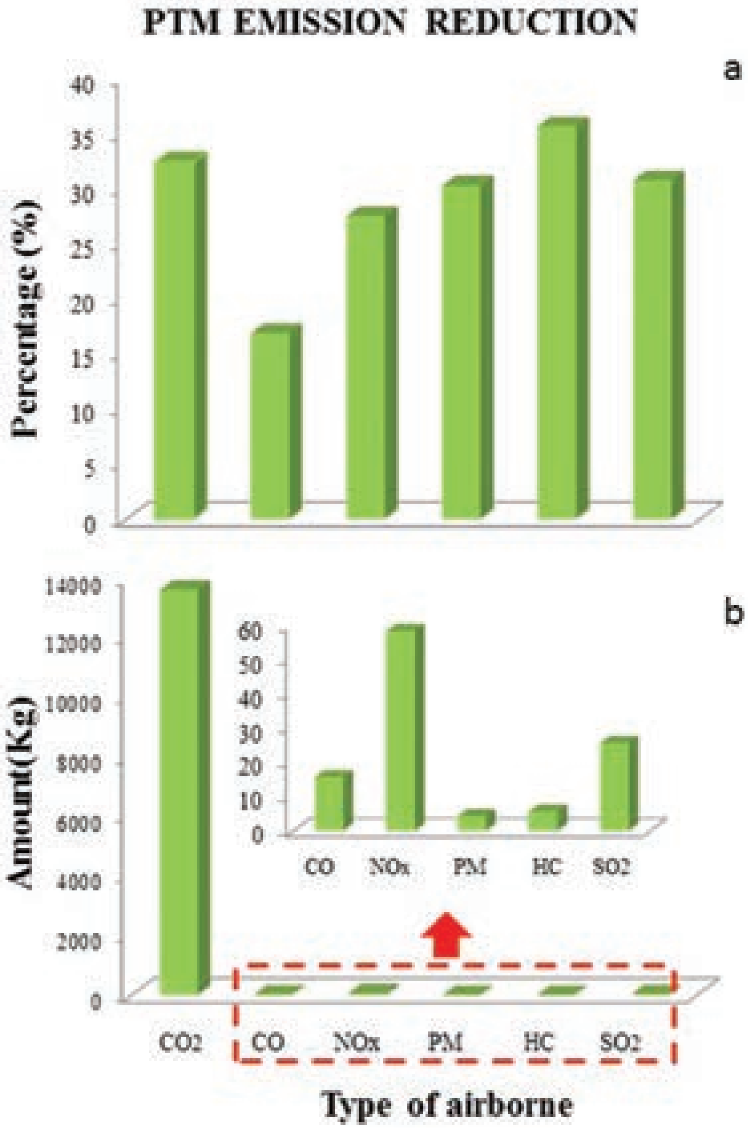


Figure 4 shows the emission reduction by PTM. It can be seen that the carbon dioxide emissions govern the emissions reductions from the quantity point of view. It should be noted that nitrogen oxide and sulfur dioxide emissions reductions are also considerable. Consequently, the PTM method enables more environmentally friendly construction by the major reduction in GHG emission compared to hand tunneling.

Although the comparison shows that PTM is a better underground construction method from an environmental point of view, there are some ways to improve this method to reduce GHG emissions more, such as using brand new equipment, following a regular equipment maintenance schedule, substituting fuels with more environmentally friendly fuels, and creating better project schedules. Therefore, in this study, the emissions are re-calculated to evaluate

FIGURE 4. The reduction of emission using PTM comparing to Hand-Tunnel. (a) Reduction of emission in percentage. (b) The amount of emission reduced.



their impacts after improvements were made in two cases: replacing the machine with a newer model, and creating a better work schedule.

Case 1: Replacing the model 2006 driller and generator with model 2011. This project was completed in 2013, and this replacement would change the machines' tier type from 2 to 3, which decreases their emissions factors except for CO_2 and SO_2 emissions. The emissions factors for CO_2 and SO_2 are calculated based on the BSFC and TAF, which are the same for all types of tiers in one category of engine power. The carbon that utilizes HC emissions are also subtracted to correct for the correlation for unburned fuel features. The emission comparison is shown in Figure 6. It shows that CO, NOx, PM, and HC emissions decreased to approximately 24%. The amounts of CO and HC were decreased by 40% and 25%, respectively, from an older group of equipment to a newer one. The lowest reduction was 8% for PM. It is also observed that both groups of equipment have the same level of CO_2 and SO_2 emissions as expected.

Case 2: In this case study, to understand the effect of work scheduling, the emission analysis was calculated by reducing the total hours in the project by 5%, 10%, 15%, 20%, 25%, and 30%, which can be achieved by using new models of equipment, saving idle time and proper work planning.

Figure 7 shows the trend of changing the emission percentage by reducing the total project time. For example, it is seen that when the hours of a project are reduced by 10%, the CO

FIGURE 5. Comparison of GHG emissions between two PTMs.

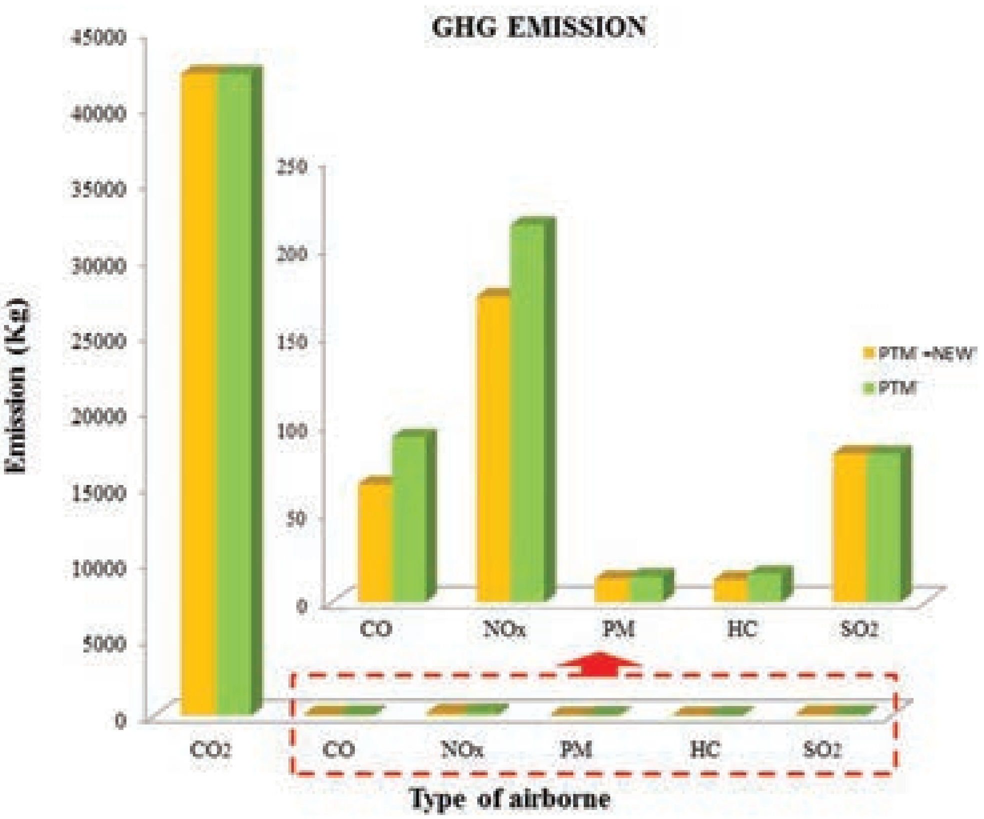
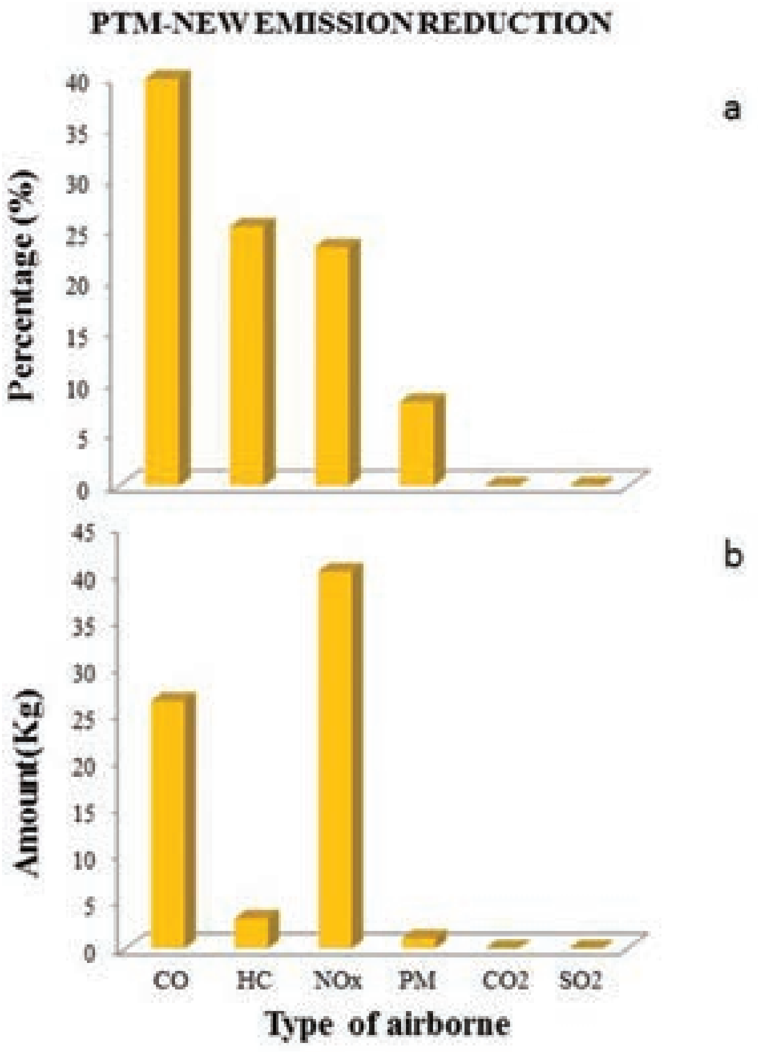


FIGURE 6. The reduction of PTM emission using new equipment. (a) Reduction of emission in percentage. (b) The amount of emission reduced.

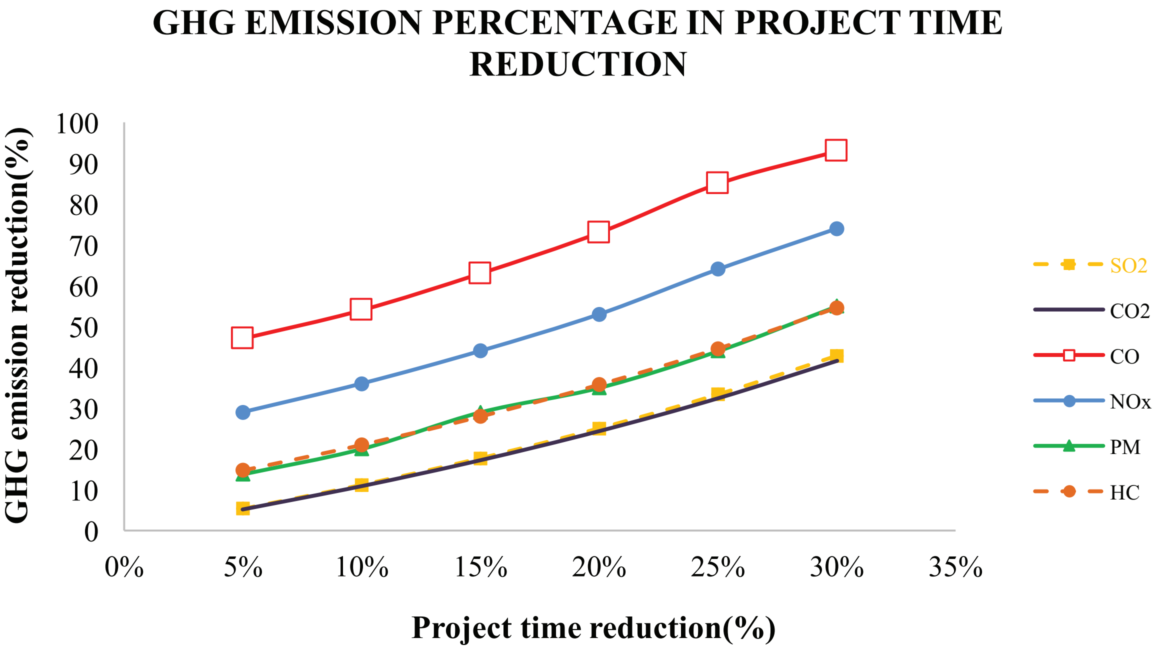


emission is reduced by 54%. The biggest changes in percentage are in CO amounts from 47% to 93% by reducing the project time from 5% to 30%, respectively. The lowest changes are in CO_2 percentage of emission reduction. Decreasing project time by 5% reduces CO2 emissions by 5.24%, and decreasing project time by 30% reduces CO_2 emissions by 41.55%. As the CO_2 emission is the highest emission from the quantity point of view, each percentage of reduction in emission means a great improvement in the construction method.

CONCLUSION

This paper explored a project conducted by the City of Edmonton that used two utility installation methods, hand tunnelling and PTM. In this study, this project was evaluated in terms of GHG emissions by using the EPA NONROAD model. This methodology is a guide for contractors to determine which equipment produces the lowest GHG emissions in the preplanning phase.

FIGURE 7. Effect of work scheduling on PTM emission reduction.



Due to the smaller project duration and underground excavation amount for the PTM, the total amount of GHG emissions released into the environment was significantly reduced. The highest reductions were 35% for HC and 32% for CO_2, and the lowest reduction was 16% for PM. In the scale of city projects, this amount of emissions reduction means tons of GHG emissions savings, which may lead to achieving the goal of global movement in protecting the environment.

Improving common applications of trenchless technologies like PTM is another way to preserve the environment from GHG emissions. This study shows that updating construction equipment and tools in these kinds of projects effectively reduces the amount of emissions. It also shows that CO, NOx, PM, and HC emissions decreased to approximately 24% by replacing two machines in this project.

Effective project scheduling is another necessary aspect in reducing the emissions studied. The emission analysis was calculated by reducing the total hours of using new equipment in the project by 5%, 10%, 15%, 20%, 25%, and 30 %, and the results show changes of 5% to 93% in different GHG emissions by time reduction.

Finally, it is suggested that to create a comprehensive decision-making model to determine which method is more effective for a given project, other factors, such as cost and time, must be analyzed and incorporated into this environmental analysis.

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