DEVELOPMENT OF A MACHINE LEARNING-BASED PREDICTION MODEL FOR CONSTRUCTION AND ENVIRONMENTAL COSTS OF TRENCHLESS SPRAY-APPLIED PIPE LININGS, CURED-IN-PLACE PIPE, AND SLIPLINING METHODS IN LARGE DIAMETER CULVERTS

by

RAMTIN SERAJIANTEHRANI

Presented to the Faculty of the Graduate School of
The University of Texas at Arlington in Partial Fulfillment
of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

THE UNIVERSITY OF TEXAS AT ARLINGTON
JANUARY 2020
Arlington, Texas

Dedicated

to

My Dearest Parents,

Mr. Serajiantehrani and Mrs. Seyedinnour

and

My Dear Brother, Roozbeh

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Mohammad Najafi, professor and director of the Center for Underground Infrastructure Research and Education (CUIRE) at the University of Texas at Arlington (UTA) who has provided invaluable insight on my education in past five years. I was fortunate to assist Dr. Najafi in several courses and research projects over the last few years. He has fundamentally changed my thinking about education and research on more than one occasion. He have always inspired me to believe that, even in difficult times, all things are possible. There is no doubt that without his endless support and guidance, this milestone in my life would not have been achieved.

I also owe a debt of gratitude to Dr. Ardeshir Anjomani for trusted me at the first steps of this journey. I must also thank Dr. Melanie Sattler and Dr. Sharareh Kermanshachi for their input and guidance as members of my graduate advisory committee for their valuable comments, suggestions and contributions to my dissertation. I have been truly fortunate to work with such wonderful mentors and I look forward to continuing our relationships into the future.

I would like to thank Ohio DOT, New York State DOT, North Carolina DOT, Minnesota DOT, Pennsylvania DOT, Delaware DOT, and Florida DOT for funding and supporting this dissertation. Special thanks go to Mr. Jeffery Syar, P.E., Administrator, Ohio DOT Office of Hydraulic Engineering, for his leadership and supervision of this project. Without their assistance in providing data and insightful comments, this dissertation would not have been completed.

I thank God for blessing me with this opportunity to pursue my dreams and for always giving me the best options, the courage to choose, funneled me through the consequences, but at the same time, let me to enjoy the rewards. This journey would not have been possible without the dedicated support of my family, who I shall now thank as best as I am able: My father, Mr. Mohammad Serajiantehrani, my mother, Ms. Monir Seyedinnour, and my brother, Roozbeh whose supports and tireless and loving care everyday over the entire of my life has made this endeavor possible. My parents have supported my pursuits, research and otherwise, for many years and I cannot begin to give them the thanks that they deserve. This work, as with all of my work, belongs to you. I will love you, forever and for always, because you are my Dear Ones. I also thank all my aunts, uncles, cousins, and great family of Serajiantehrani and Seyedinnour for their help in caring for my parents in my absent over the past few years.

I would also like to acknowledge my colleagues, Dr. Seyed Jalalediny Korky, Dr. Reza Malek, and Dr. Vinayak Kaushal, my best friends and colleagues at CUIRE. We have grown together, throughout every step of this journey. I look forward to many more years of friendship and collaboration with them.

Last but not least, I would like to acknowledge help and support by CUIRE and Department of Civil Engineering staff and thank all the many friends I have gained while studying at the University of Texas at Arlington for their constant support and friendship.

December 6, 2019

ABSTRACT

DEVELOPMENT OF A MACHINE LEARNING-BASED PREDICTION MODEL FOR CONSTRUCTION AND ENVIRONMENTAL COSTS OF TRENCHLESS SPRAY-APPLIED PIPE LININGS, CURED-IN-PLACE PIPE, AND SLIPLINING METHODS IN LARGE DIAMETER CULVERTS

Ramtin Serajiantehrani, Ph.D.

The University of Texas at Arlington, 2020

Supervising Professor: Dr. Mohammad Najafi

According to U.S. Department of Transportation, Federal Highway Administration there are more than 4.1 million miles of road in total length, making it the world's longest and biggest road network with millions of culverts hidden underneath the road in the United States. The development of underground infrastructure, concerns about environmental impacts, and economic trends are influencing society, resulting in the advancement of technology for more environment-friendly and cost-effective pipeline rehabilitation.

Trenchless technologies employ innovative methods, materials, and equipment that require minimum surface excavation and access area for rehabilitation of old and deteriorated culverts. Trenchless technologies can be used when other conventional methods, such as open-cut methods, are not applicable or cost-effective. Life-cycle cost analysis (LCCA) is an analytical method used to evaluate long-term investment options, and facilitate the associated costs which consist of three main modules as construction, environmental, and social costs. The main objective of this dissertation is to develop a machine learning-based prediction model for the comprehensive construction and environmental costs of trenchless cementitious spray-applied pipe linings (SAPLs), cured-in-place pipe with polyester resin (CIPP), and sliplining with high density polyethylene (HDPE) pipe methods by evaluation and analysis of the construction and environmental costs based on the actual data. The secondary objective of this dissertation is to compare and analyze the results of construction and environmental costs for SAPL, CIPP, and sliplining in large diameter culverts.

Developing a model for construction and environmental costs of a pipeline renewal is an essential element when considering sustainable renewal and replacement of underground infrastructure. Project owners, decision-makers, design and consulting, and contractors commonly may take into consideration the construction costs only, and sometimes overlook the environmental aspects while making a choice among trenchless methods.

An actual bid data from 7 Departments of Transportation in the U.S. were used for this dissertation to evaluate and develop a prediction model for construction and environmental costs of large diameter trenchless SAPL, CIPP, and sliplining renewal methods.

The results of this dissertation shows that host pipe length, diameter, location, renewal material and thickness were the key factors to construction costs. Material components, the volume of materials, material transportation, project duration and location, and installation equipment were the main influencing factors to environmental costs.

Comparing environmental costs of SAPL, CIPP and sliplining, SAPL has the lowest and CIPP has the highest costs. The 60-in. diameter is the threshold for changing environmental cost difference between SAPL and the CIPP methods. Above 60-in. diameter, the environmental cost difference between CIPP and SAPL will increase by more than 50%. For diameters 78 in. to 108 in., the environmental costs of CIPP and sliplining are slightly the same and become twice SAPL application. In addition, the difference between mean construction costs of sliplining and SAPL in 72 in. diameter is 120 times more than that of 30 in. diameter. Diameter of culverts makes a significant difference for construction costs of SAPL and sliplining as increasing culvert diameter will make the sliplining more costly. It can be concluded that many quantifiable factors impact SAPL, CIPP, and sliplining construction and environmental costs for large diameter culverts. The prediction model developed in this dissertation provides a tool to compare and evaluate environmental and construction costs of SAPL, CIPP and sliplining for large diameter culverts and storm sewers.

Keywords: Trenchless Technology; Pipe Renewal; CIPP; SAPL; Sliplining; Machine Learning; Cost Prediction Model; Environmental Cost; Construction Cost

LIST OF ACRONYMS

ABS	Acrylonitrile Butadiene Styrene
ACH	Air Change per Hour
ASCE	American Society of Civil Engineers
ASTM	American Society of Testing and Materials
AWWA	American Water Works Association
CF	Carbon Footprint
CIPP	Cured-in-Place Pipe
CMP	Corrugated Metal Pipe
COD	Chemical Oxygen Demand
CP	Corrugated Plastic
CTU	Comparative Toxic Units
CUIRE	Center for Underground Infrastructure Research and Education
DI	Ductile Iron Pipe
DO	Dissolved Oxygen
DOT	Department of Transportation
EPA	Environmental Protection Agency
GHG	Greenhouse Gases
GRP	Fiber Reinforced Plastic Pipe
HDPE	High Density Polyethylene Pipe
ISO	International Organization for Standardization
KNN	K-nearest Neighbors
LCA	Life-cycle Analysis
LCCA	Life-cycle Cost Analysis

LCCATR	Life-cycle Cost Analysis of Trenchless Renewals
LCI	Life-cycle Inventory
LCIA	Life-cycle Impact Analysis
MJ	Megajoule
MPDM	Method Productivity Delay Model
MSW	Municipal Solid Waste
NASSCO	National Association of Sewer Service Companies
NASTT	North American Society for Trenchless Technology
NRCP	Non-reinforced Concrete Pipe
OD	Outside Diameter
OSHA	Occupational Safety and Health Administration
PCCP	Prestressed Concrete Cylinder Pipe
PVC	Polyvinyl Chloride
RCCP	Reinforced Concrete Cylinder Pipe
RCP	Reinforced Concrete Pipe
SAPL	Spray-applied Pipe Lining
SETAC	Society of Environmental Toxicology and Chemistry
SCC	Social Cost Calculator
TCM	Trenchless Construction Method
TCTT	Total Cost of Trenchless Technology
TO-15	Toxic Organics - 15
TOC	Total Organic Carbon
TRACI	The Tool for the Reduction and Assessment of Chemical and other Impact Categories
TRM	Trenchless Renewal Method

TT	Trenchless Technology
UNEP	United Nations Environment Program
UTA	The University of Texas at Arlington
UV	Ultraviolet
VCP	Vitrified Clay Pipe
VER	Vinyl Ester Resin

GLOSSARY

Acute Exposure Guideline Levels	Exposure guidelines designed to help responders deal with emergencies involving chemical spills or other catastrophic events where members of the public exposed to a hazardous airborne chemical.
Air Quality Monitoring	The systematic, long-term assessment of pollutant levels by measuring the quantity and types of certain pollutants in the surrounding, outdoor air.
Analysis of Variance	A statistical method in which the variation in a set of observations divided into distinct components.
Chemical Oxygen Demand	Measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrite.
Granular Activated Carbon	A highly porous adsorbent material, produced by heating organic matter, such as coal, wood and coconut shell, in the absence of air, which is then crushed into granules.
Lethal Concentration	The lethal concentration is the concentration of a chemical that will kill certain percent of the sample population under scrutiny.
Maximum Contaminant Level	Standards set by the United States Environmental Protection Agency (EPA) for drinking water quality.
Maximum Workplace Concentration	Maximum concentration of a chemical substance (as gas, vapor or particulate matter) in the workplace air which generally does not have known adverse effects on the health of the employee nor cause unreasonable annoyance even when the person is repeatedly exposed during long periods, usually for 8 hours daily but assuming on average a 40-hour working week.
Occupational Exposure Limits	An occupational exposure limit is an upper limit on the acceptable concentration of

	a hazardous substance in workplace air for a material or class of materials.
Permissible Exposure Limit	The limit for exposure of an employee to a chemical substance or physical agent.
Photoionization Detector	A type of gas detector to measure volatile organic compounds and other gases in concentrations from sub parts per billion to parts per million.
Precision Electro-Chemical Machining	Precision electrochemical machining is a nonconventional machining process that can help deliver complex and precise components quickly and accurately.
Quality Assurance	The maintenance of a desired level of quality in a service or product, especially by means of attention to every stage of the process of delivery or production.
Quality Control	A system of maintaining standards in manufactured products by testing a sample of the output against the specification.
Threshold Limit Value	A level to which a worker exposed day after day for a working lifetime without adverse effects.
Time Weighted Average	The average exposure over a specified period, usually a nominal eight hours.
Total Organic Carbon	The amount of carbon found in an organic compound and used as a non-specific indicator of water quality.
Vinyl Ester Resin	A resin produced by the esterification of an epoxy resin with an unsaturated monocarboxylic acid.
Volatile Organic Compound	The organic chemicals that have a high vapor pressure at ordinary room temperature referred as the Volatile Organic Compounds.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Introduction

According to U.S. Department of Transportation, there are approximately 4 million miles of roads and highways in the United States. The total length of US network, making it the world's biggest and longest road network with millions of culverts hidden underneath (Najafi, 2008).

A large proportion of underground infrastructure including culverts were installed in the 1950s and 1960s during a period of rapid economic growth in the United States and Canada (Hashemi et al., 2011). The Michigan Department of Transportation (MDOT) estimates that there are about 200,000 culverts in the state of Michigan (CUIRE, 2008). Each of these gravity conveyance conduit systems is susceptible to structural failure, blockages, and overflows (Figure 1-1) due to the aging of pipes, climate unexpected changes, and rapid urbanization (Tran et al., 2007).

There have been millions of water main breaks in the U.S. since January 2000, with an average of nearly 700 water main breaks every day (Alinizzi, 2013). Renewal and replacement of this aging and deteriorating underground infrastructure is a major obstacle faced by municipalities (Hashemi et al., 2011). Based upon the historical data, $271 billion is required for renewal of water infrastructure over the next 25 years. In addition, $51 billion is needed for conveyance systems repair (USEPA, 2012).

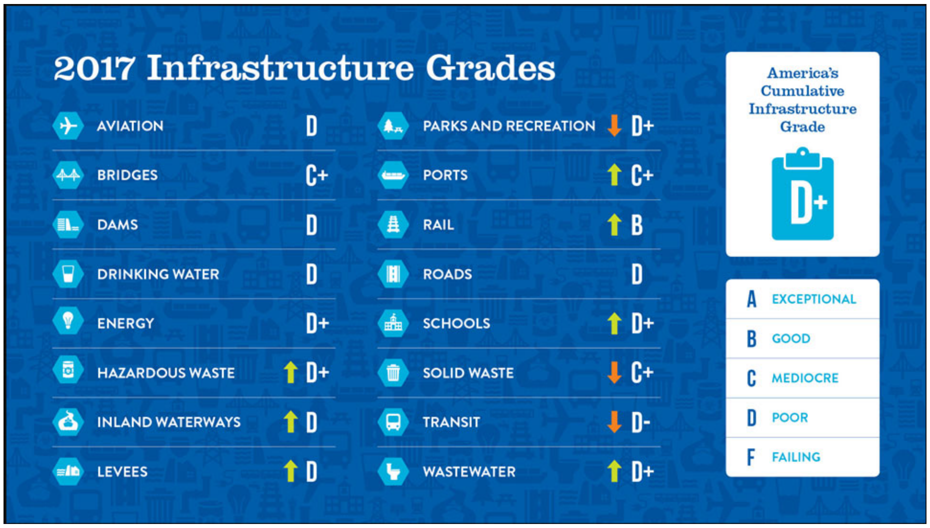
According to the American Society of Civil Engineers (ASCE) 2017 Infrastructure Report Card, a D+ grade has been assigned to the condition of U.S. wastewater infrastructure (Figure 1-2). Understandably, this expenditure, no matter how financed, will ultimately be passed on to rate payers per utility customers. Maximizing the benefit of every single dollar which is spent on collection system renewal and repair should be the target of every infrastructure and utility decision-maker. Too often, the only least initial investment is the main priority in the process of capital engineering and planning for collection system rehabilitation.

(a)

(b)

(c)

Figure 1-1 Culvert Failure Types: a. Structural Failure Source: Al Tenbusch, Available at: www.tenbusch.com b. Blockages Source: Martinez Beavers Available at: www.martinezbeavers.org c. Overflows Source: freeimages.co.uk Available at: www.freeimages.co.uk (Accessed December 12, 2019)



2017 Infrastructure Grades

AVIATION		D	PARKS AND RECREATION	↓	D+
BRIDGES		C+	PORTS	↑	C+
DAMS		D	RAIL	↑	B
DRINKING WATER		D	ROADS		D
ENERGY		D+	SCHOOLS	↑	D+
HAZARDOUS WASTE	↑	D+	SOLID WASTE	↓	C+
INLAND WATERWAYS	↑	D	TRANSIT	↓	D-
LEVEES	↑	D	WASTEWATER	↑	D+

America's Cumulative Infrastructure Grade

D+

A	EXCEPTIONAL
B	GOOD
C	MEDIOCRE
D	POOR
F	FAILING

Figure 1-2 ASCE 2017 Infrastructure Report Card
Source: ASCE Available at www.asce.org (Accessed December 12, 2019)

1.2 Culvert

Culverts as gravity conveyance conduit structures today are an important facet of an infrastructure, allowing moderate amount of water to flow under an embankment, such as, highways, roads, roadways, railroads, trails or any other obstruction with different size and shape definition as it must have derived from bridge. Following specified size and dimension based on three major US agencies are provided which shows the culverts span can be:

- Less than 10 ft. (Ohio DOT, 2017)
- Between 8 in. to 120 in. (USDA, 2005)
- Less than 20 ft. (FHWA, 1995)

Culvert Management Manual (2003) by Ohio Department of Transportation (ODOT) defines culverts as:

- A drainage infrastructure system to conveyance water under roadways.
- Any structure that conveys water or forms a passageway through an embankment.
- Designed to support a superimposed earth load or other fill material plus live load with a span, diameter, or multi-cell less than 10 ft when measured parallel to the centerline of the roadway.

1.2.1 Type, Material, and Shape

According to Howard (1996), a particular pipe type is usually considered as either a rigid or flexible pipe. Pipes have sometimes been referred to as semi-rigid, rigid, flexible or very flexible. Strength is the ability of a rigid pipe to resist stress that is created in the pipe wall due to internal pressure, live load, and longitudinal bending while stiffness is the ability of a flexible pipe to resist deflection.

Rigid pipes can be Vitrified Clay Pipe (VCP), Reinforced Concrete Pipe (RCP), Non-reinforced Concrete Pipe (NRCP), Reinforced Concrete Cylinder Pipe (RCCP), and Prestressed Concrete Cylinder Pipe (PCCP). Rigid pipes are designed to transmit the load on the pipe through the pipe walls to the foundation soil beneath.

Flexible pipes are designed to transmit part of the load on the pipe to the soil at the sides of the pipe. There are some types of flexible pipe such as Steel Pipe, Ductile Iron Pipe (DI), Corrugated Metal Pipe (CMP), Fiber Reinforced Plastic Pipe (GRP), Polyvinyl Chloride Pipe (PVC), High-Density Polyethylene Pipe (HDPE), and Acrylonitrile Butadiene Styrene Pipe (ABS). Host culvert can be made by Corrugated Metal Pipe (CMP), Reinforce Concrete Pipe (RCP), Corrugated Plastic (CP), and Concrete Box. (Najafi, 2011).

There are several types of shapes for culverts, but, the typical shapes of culverts can be categorized as circular, arch, box, and elliptical (Figure 1-3).

1.3 Trenchless Technology Methods (TTMs)

Trenchless technology methods (TTMs) employ innovative methods, materials, and equipment for inspection, stabilization, rehabilitation, renewal, and replacement of existing pipelines and installation of new pipelines with minimum surface and subsurface excavation (Najafi, 2016). Environmental and social costs, new and more stringent safety regulations, difficult underground conditions (containing natural or artificial obstructions, high water table, and etc.), and new developments in equipment have increased demand of trenchless technology. Because of the deterioration of municipal underground infrastructure systems and a growing population that demands a better quality of life, the efficient and cost-effective installation, renewal, and replacement of underground utilities is becoming an increasingly important issue (Serajaintehrani et al., 2020).


(a)

(b)

(c)

(d)

Figure 1-3 Culverts Shape Types: a. Circular b. Arch c. Box Source: Author d. Elliptical Source: ShiTeng Group Available at: www.stguardrail.com (Accessed December 12, 2019)

Trenchless technologies (TTs) as new innovative solutions are employed to address mentioned concerns. Trenchless technologies are including all methods of underground utility installation, replacement, and renewal without or with minimum surface excavation. These methods can be used to repair, upgrade, replace, or renovate underground infrastructure systems with minimum surface disruptions (Najafi and Gokhale, 2005).

TTMs are divided into two main categories (Figure 1-4); Trenchless Construction Methods (TCMs) which include all the methods for new utility and pipeline installation and Trenchless Renewal Methods (TRMs) which include all the methods of renewing, rehabilitating and renovating, an existing, utility system, or old or host pipeline (Mamaqani, 2014), such as:

- Oil and gas pipelines,
- Water distribution,
- Culverts, and
- Sewer collection systems (Najafi and Gokhale, 2005).

Trenchless technologies can be used when open-cut methods are not applicable or more costly (Najafi, 2013). Trenchless technologies have their own advantages and limitations. Advantages are low environmental impacts as well as low social costs and limitations are a high level of engineering skills needed as well as decreasing flow capacity of pipes or culverts which happen during the rehabilitation (Najafi and Gokhale, 2005). The total cost of every trenchless project varies with many factors such as pipe diameter size, pipe material, depth and length of the installation, project site, subsurface conditions, and trenchless method type or utility application.

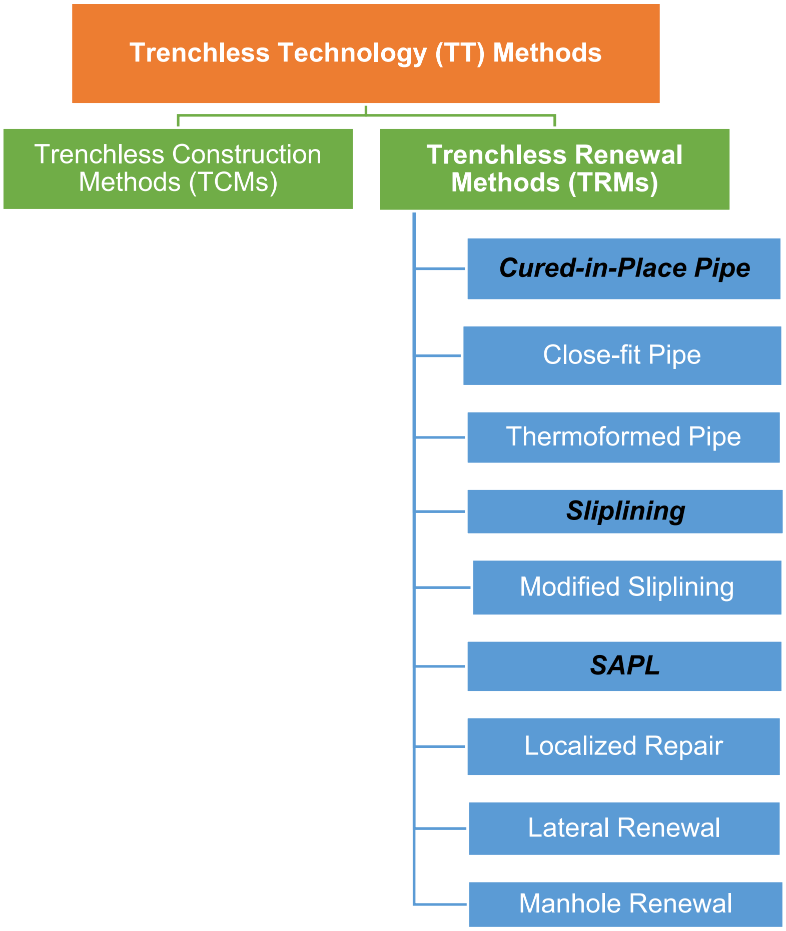


Figure 1-4 Trenchless Technology Methods
Adapted from Najafi and Gokhale, 2005

1.3.1 Trenchless Rehabilitation Methods (TRMs)

Trenchless methods of rehabilitation use the existing pipe as a host for a new pipe or liner. Trenchless culvert rehabilitation techniques offer a method of correcting pipe deficiencies that requires less restoration and causes less disturbance and environmental degradation than the traditional open-cut method. If the existing pipe is structurally sound enough to continue to maintain shape and carry the earth and live loads imposed on it, then several internal trenchless renewal lining techniques might be applicable, including:

- Spray-Applied Pipe Linings (SAPLs),
- Cured-In-Place Pipe (CIPP), and
- Sliplining.

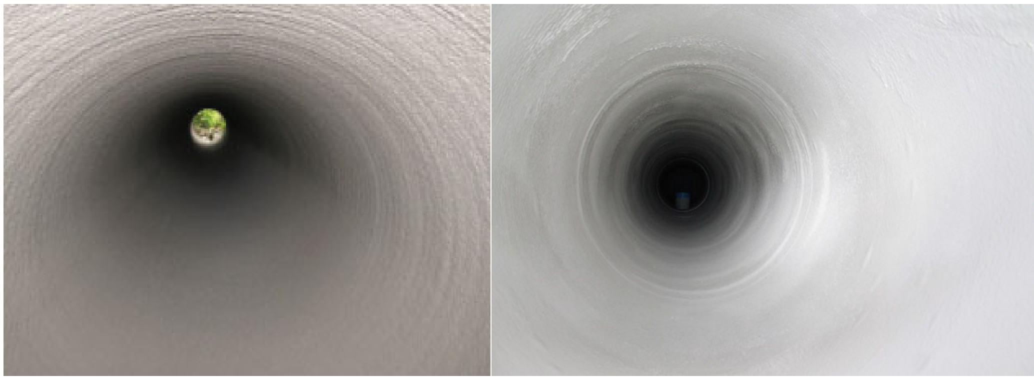
These alternative techniques must be fully understood before they are applied (EPA, 1999). These three culvert trenchless rehabilitation methods are described further in the following sections.

1.4 Spray-Applied Pipe Linings (SAPLs)

Spray Applied Pipe Linings (SAPLs) is a trenchless technology solution that is used when a culvert or pipe needs to be rehabilitated and/or repaired. SAPLs can be used for pipeline and conveyance conduit systems rehabilitation that prevent further deterioration, such as corrosion, abrasion, etc., and can provide structural support for severely damaged host pipes. This trenchless technology renewal method consists of spraying the following materials on the internal surface of the existing pipe (Najafi, 2013):

- Cementitious (thin cement mortar) and
- Polymer (polymer resin lining) (Figure 1-5).

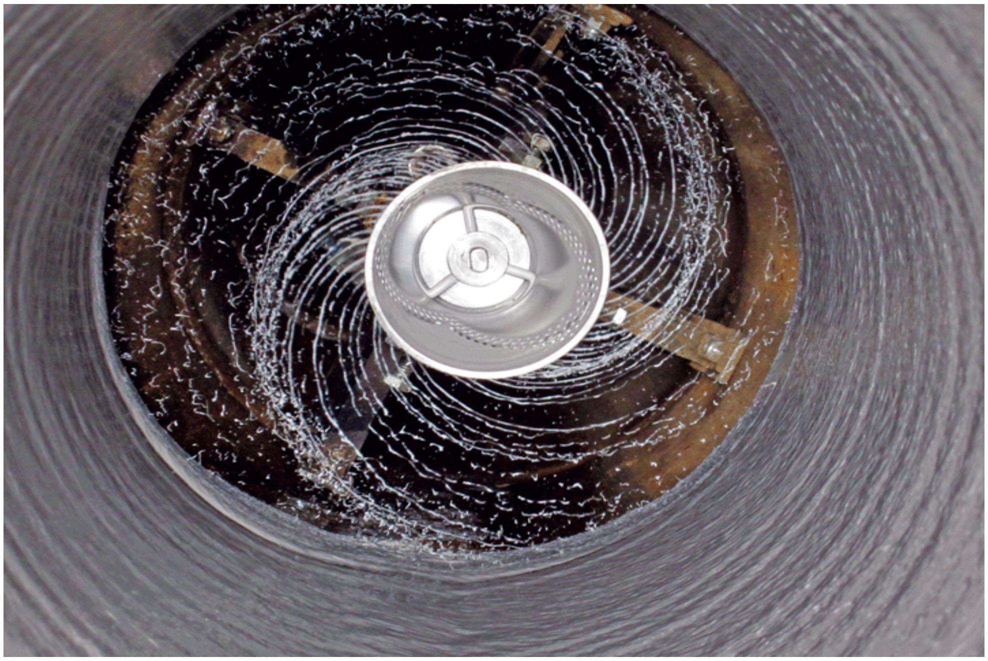
SAPL can be spray into the hoist pipe with two different methods: handheld spraying and spin-caster machine spraying (Figure 1-6). This trenchless renewal method can provide improved hydraulic characteristics and corrosion protection. It may enhance the structural integrity of the existing pipe and seal joints and leaks. SAPL is effective and widely used for renewing pressure pipes and gravity sewer (Najafi, 2013). Also, SAPL can be used for structural purposes (Najafi, 2011).



(a) (b)

Figure 1-5 SAPL Material Types: a. Cementitious Source: Milliken Inc. b. Polymer Source: Benassi Srl Available at: www.benassisrl.com

(a)



(b)

Figure 1-6 SAPL Spraying Methods: a. Handheld Spraying b. Spin-caster Machine Spraying Source: BENASSI SRL Available at: www.benassisrl.com (Accessed December 11, 2019)

Using of this trenchless renewal method has its advantages and limitations over other trenchless renewal methods which are listed as follows:

Advantages over other trenchless renewal methods are:

- Corrosion, abrasion, erosion resistance,
- Low cost (especially using cementitious lining),
- Ease of installation,
- Minimum thickness technique,
- Low hydraulic effect, and
- Applicable on any shape.

Limitations over other trenchless renewal methods are:

- Need to completely clean and dewater existing pipe before application,
- Tees and bends can pose installation difficulties,
- Minimum cure time is 16 hours, and
- Cement-mortar lining may result in high pH water (Najafi, 2013).

1.5 Cured-in-Place Pipe (CIPP)

Trenchless renewal method that a resin-impregnated fabric tube which is usually made of polyester or fiberglass-reinforced is inserted into an existing pipe (Figure 1-7) (Najafi, 2013). Among the different trenchless pipe rehabilitation techniques, cured-in-place pipe (CIPP) is considered a safe, cost-effective, efficient, and productive alternative. However, relining using CIPP is not a straightforward process and has a number of issues and challenges (Das et al., 2016). Cured-in-Place-Pipe (CIPP) installation was introduced in 1971 as an alternative to digging up and replacing water systems, and since then hundreds of millions of feet of renewed pipe have been installed around the world. Currently, CIPP is one of the most widely used methods of trenchless pipeline renewal and for both structural and nonstructural purposes.

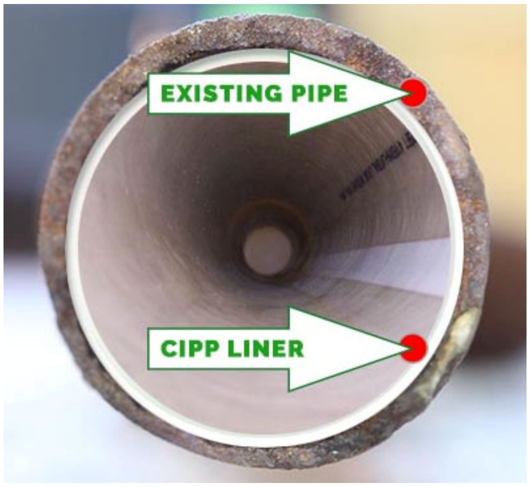
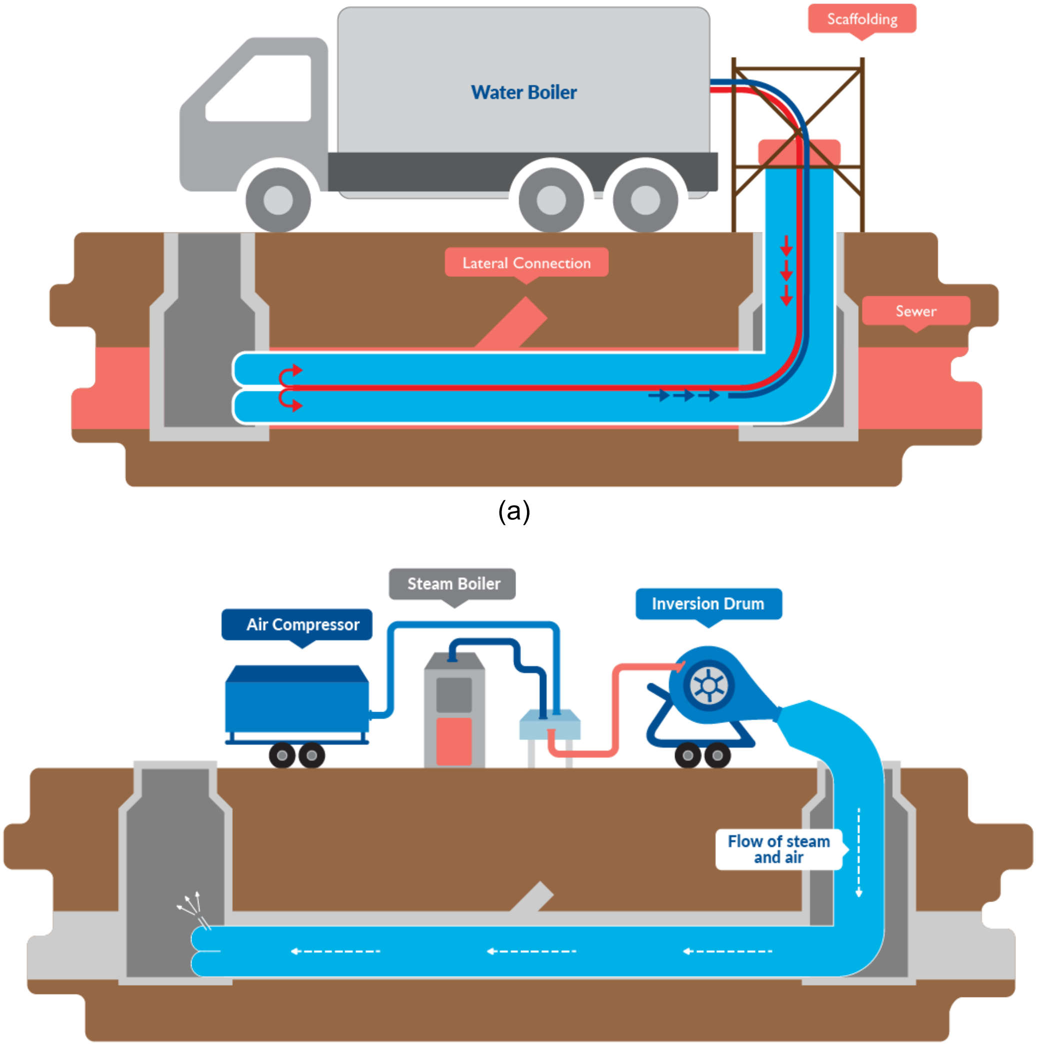


Figure 1-7 CIPP Trenchless Method Section Source: Dynamic Drain
Available at: www.dynamicdrain.net (Accessed December 12, 2019)

The CIPP process involves a liquid thermoset resin-saturated material which can be polyester, epoxy, or vinyl ester that is inserted into the existing pipeline by hydrostatic or air inversion, or by mechanically pulling-in and inflating. The liner material is cured-in-place using hot water, steam, or light-cured using UV light resulting in the CIPP product (Figure 1-8) (Kozman, 2013).



(a)

(b)

(c)

Figure 1-8 CIPP Curing Types: a. Hot Water b. Steam Source: Public Utilities Board of Singapore's National Water Agency Available at: www.pub.gov.sg c. UV Light Source: McAllister Group Available at: www.mcallistergroup.com (Accessed December 03, 2019)

This technique has its own advantages and limitation over other trenchless renewal methods as follows:

Advantages over other trenchless renewal methods are:

- Suitable for round pipes,
- Consistent in plant manufactured,
- Choice of resin to suit the application, and
- Can negotiate offsets, transitions, and multiple 90-degree bends (creating wrinkles).

Limitations over other trenchless renewal methods are:

- Large diameters require excavation or entry pits,
- Styrene based chemistries,
- Lateral require cutting and liner introducing possible failure points,

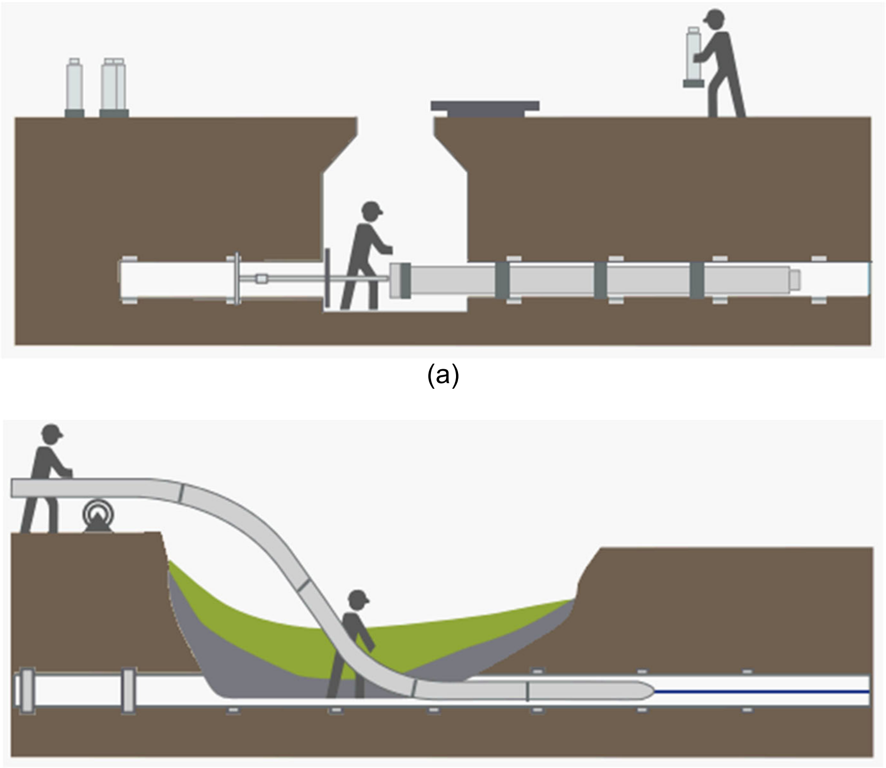
- Infiltration can move behind liner, and
- Pipes must be round (or close to round) (Najafi, 2013).

While the CIPP renewal method for wastewater industry has been used in the U.S. for more than 40 years (Matthews et al., 2012), CIPP mechanical properties have been the focus of nearly all past CIPP studies, not its environmental (Allouche et al., 2012). In 2011 and 2013, researchers compiled a number of environmental contamination incidents from the past 15 years associated with CIPP stormwater culvert and sanitary sewer installations (Whelton et al., 2013; Tabor et al., 2014).

These incidents involved the discharge of hot water and condensate from CIPP sites directly into waterways systems causing fish kills and activated sludge process inhibitions. Other incidents have involved chemical emission from nearby CIPP renewed pipes, which traveled through pipes and entered nearby residences through their premise plumbing. In some cases, emitted chemicals traveled above ground and entered building ventilation systems (Ajdari, 2016).

1.6 Sliplining

Sliplining is a well-established method of trenchless rehabilitation. This TRM is the practice of placing a new pipeline of smaller diameter into the existing pipe and usually the annulus space between the existing pipe and new pipe is grouted to prevent leaks and to provide structural integrity. Sliplining is mainly used for structural applications when the existing pipe does not have joint settlements or misalignments. This trenchless renewal method has two main categories as segmental sliplining and continuous sliplining (Figure 1-9) as well as three types of material as HDPE, PVC, and FRP (Figure 1-10) (Najafi, 2016).



(a)

(b)

Figure 1-9 Sliplining Installation: a. Segmental b. Continuous
Source: INFRA Available at: www.infra-sa.pl (Accessed December 12, 2019)

(a)

(b)

(c)

Figure 1-10 Sliplining Material Types: a. HDPE Source: C&L Water Solutions Available at: www.clwsi.com b. PVC Source: AEGION Available at: www.aegion.com c. FRP Source: HOBAS Available at: www.hobaspipe.com (Accessed December 12, 2019)

This technique has its own advantages and limitation over other trenchless renewal methods as follows:

Advantages over other trenchless renewal methods are:

- Not require costly specialized equipment,
- Simple technique,
- Applied to pressure and gravity pipelines,
- Structural and nonstructural purposes,
- Live insertion is possible, and
- Less expensive than the installation of a new line (Najafi, 2013).

Limitations over other trenchless renewal methods are:

- Reduction of the pipe diameter,
- Pit excavation is required if manhole access is not possible,
- For lateral connections, open-cut excavation is required,
- Grouting is recommended,
- Liner pipe cannot pass through and/or seal at significant inflection points, and
- Host pipes must be round (or close to round) (Najafi, 2013).

1.7 Life-cycle Cost Analysis (LCCA)

The Life-cycle Cost Analysis determines the total cost of a pipeline project by considering all of the phases a pipeline project experiences over its design life. These include production, installation, operation and maintenance, and end of life. Costs to the environment and the society during each phase of the pipeline project's life-cycle should be considered, as well. However, by using trenchless technology, the social costs of a renewal project can be significantly reduced and can be negligible (Serajiantehrani et al., 2020).

1.7.1 *Construction Cost Analysis*

The Life-cycle construction cost of a pipeline project is the category of costs including planning and engineering costs, direct and indirect costs, and operation and maintenance costs, which are associated with the entire life of the project (Najafi and Gokhale, 2005).

1.7.2 *Environmental Cost Analysis*

Glossary of Environment Statistics (GES) defines environmental cost as all costs are connected with the actual or potential deterioration of natural assets due to economic activities. More specifically, environmental cost analysis is a scientific method for assessment of the environmental impacts associated with the life-cycle of a product and then convert it to cost (UNEP/SETAC, 2009). In this process (Figure 1-11), the information about the raw materials, materials manufacture, product manufacture, are given as an input into the system to get the associated emissions and output wastes.

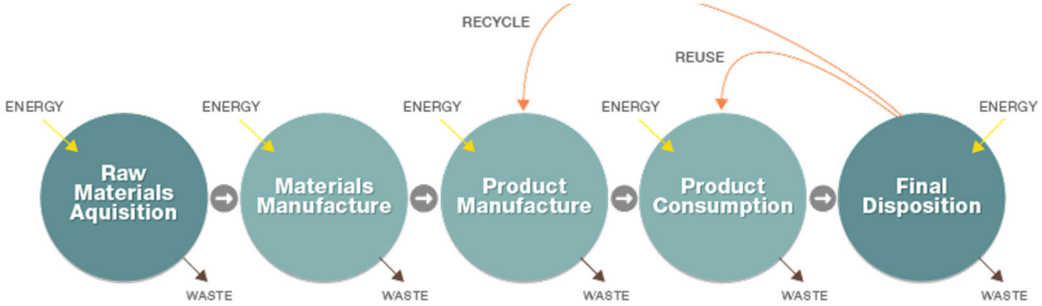


Figure 1-11 Environmental Impact Analysis Process Source: Elixir Environmental Available at: www.elixirenvironmental.com (Accessed December 12, 2019)

1.7.3 *Social Cost Analysis*

The social costs of pipeline renewal include inconvenience and disturbance to the society and general public and damage to surrounding and existing structures (Figure 1-13). Social costs are becoming more important as the public awareness grows and the needs to conserve and protect our environment and quality of life are more understood. These needs have resulted in identification and evaluation of social costs of utility and pipeline rehabilitation. Using trenchless renewal methods can significantly reduce social costs of the rehabilitation projects.

Social costs for the projects using trenchless technology (regardless of which method is used) consists approximately less than 5 percent of the total cost of the project Figure 1-12 (Najafi and Gokhale, 2005).

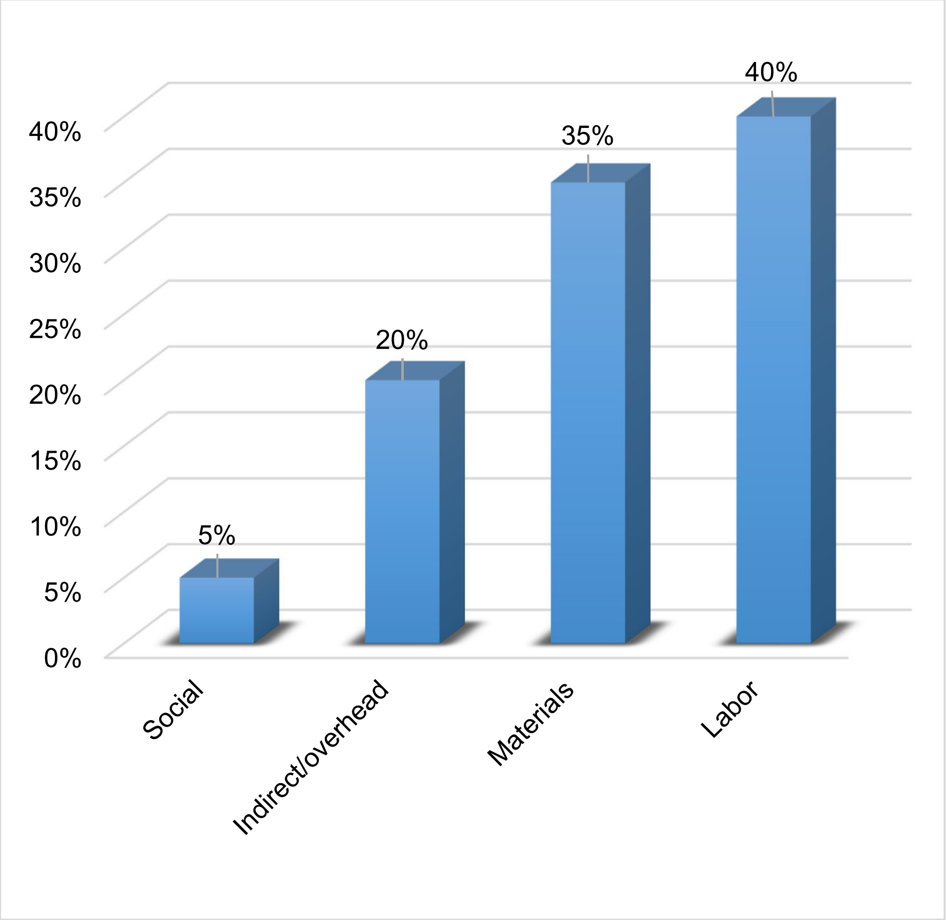


Figure 1-12 Cost Break-down of Trenchless Technology Methods
(Najafi and Gokhale, 2005)

Figure 1-13 Social Impact of an Underground Pipeline Project Source: City of Fort Wayne Available at: www.cityoffortwayne.org (Accessed December 03, 2019)

Najafi and Gokhale (2005) listed the most important factors which have significant impact to the society as follows:

- Vehicular traffic disruption,
- Fuel consumption due to traffic disruption,
- Road and pavement damage,
- Business and trade loss,
- Damage to detour roads, and
- Site and public safety.

Kaushal (2019) conducted a comparison of social and environmental costs of trenchless CIPP method and open-cut construction and concluded that less than 2% of the total cost of CIPP is associated to the social cost.

As a result, according to the literature review, the social costs of trenchless renewal projects can be negligible to evaluate the LCCA of trenchless renewal projects, thus it is not considered to analyze for this dissertation.

1.8 Need Statement

In response to the growing usage of SAPL installations, there has been a concern about potential health impacts associated with these new technology emissions and there is a lack of study of the life-cycle cost analysis for SAPL, CIPP, and sliplining trenchless methods (CUIRE, 2018). Also, nearly all past CIPP and sliplining renewal trenchless pipeline methods studies have focused on construction costs and the environmental costs of renewal methods are poorly investigated (Allouche et al., 2012).

Admittedly, there is a need to develop a prediction model that can determine the total construction and environmental costs of trenchless rehabilitation methods based on different pipe attributes and project locations (Kaushal, 2019). As a result, a comprehensive study of construction and environmental costs comparison for SAPL, CIPP, and sliplining will be a sustainable effective tool for decision making and planning in the design phase of a trenchless culvert renewal project (CUIRE, 2019).

1.9 Objectives

The main objective of this dissertation is to develop a machine learning-based prediction model for the comprehensive construction and environmental costs of trenchless cementitious spray-applied pipe linings (SAPLs), cured-in-place pipe with polyester resin (CIPP), and sliplining with high density polyethylene (HDPE) pipe methods by evaluation and analysis of the construction and environmental costs based on the actual data. The secondary objective of this dissertation is to compare and analyze the results of construction and environmental costs for SAPL, CIPP, and sliplining in large diameter culverts.

1.10 Scope of Work

Scope of work is defined based on the data sources and directed data which came from actual projects have been done all around the U.S. as following in Table 1-1.

Table 1-1 Scope of Study

TRM	Included	Not Included
SAPL, CIPP, and Sliplining	• Construction and environmental costs • Location: U.S. • Diameter: 30-108 in. • Time: Year 2010-2019 • SAPL material: Cementitious • CIPP material: Polyester Resin with Steam Curing • Sliplining material: HDPE	• Social costs • Soil condition • Depth of culvert • Watertable • SAPL polymeric material • SAPL installation methods • CIPP different resins • CIPP curing methods • Sliplining PVC and GRP material • Sliplining grout curing methods

1.11 Hypotheses

There are two main hypotheses which are addressed in this dissertation.

1.11.1 Hypothesis 1

Null Hypothesis (H0): The mean of environmental costs of SAPL trenchless method for large diameter culverts is lower than that of CIPP and sliplining trenchless methods.

Alternative Hypothesis (HA): The mean of the environmental costs of SAPL trenchless method for large diameter culverts is greater than that of CIPP and sliplining trenchless methods.

1.11.2 Hypothesis 2

Null Hypothesis (H0): The construction cost of SAPL trenchless method for large diameter culverts is lower than that of CIPP and sliplining trenchless methods.

Alternative Hypothesis (HA): The construction cost of SAPL trenchless method for large diameter culverts is greater than that of CIPP and sliplining trenchless methods.

1.12 Methodology

To accomplish the objectives of this dissertation, the below steps were followed:

1. A literature review was conducted on LCCA of SAPL, CIPP, and sliplining trenchless renewal methods.
2. The framework of the study was developed based on the literature review and data availability.
3. Required data to analyze construction and environmental costs of SAPL, CIPP, and sliplining was collected through several large diameter culvert renewal projects.
4. Data analysis was conducted using statistical analysis, mathematic analysis, and SimaPro software analysis
5. The construction and environmental costs prediction model of SAPL, CIPP, and sliplining in large diameter culverts was developed after testing and validation of the designed model.
6. Interpretation of the results and discussions was performed.
7. Conclusion and recommendation for future studies

Figure 1-14 shows a flowchart of the overall methodology for this dissertation.

1.13 Contribution to the Body of Knowledge

The key contributions of this dissertation are:

- A model to use for prediction of construction and environmental costs of trenchless SAPL, CIPP, and sliplining rehabilitation methods in large diameter culverts.
- An evaluation and comparison of construction and environmental costs per unit length of trenchless SAPL with CIPP and sliplining renewal methods.

- A methodology to analyze the life-cycle cost modules as construction and environmental costs of trenchless rehabilitation methods in underground utility and infrastructure.

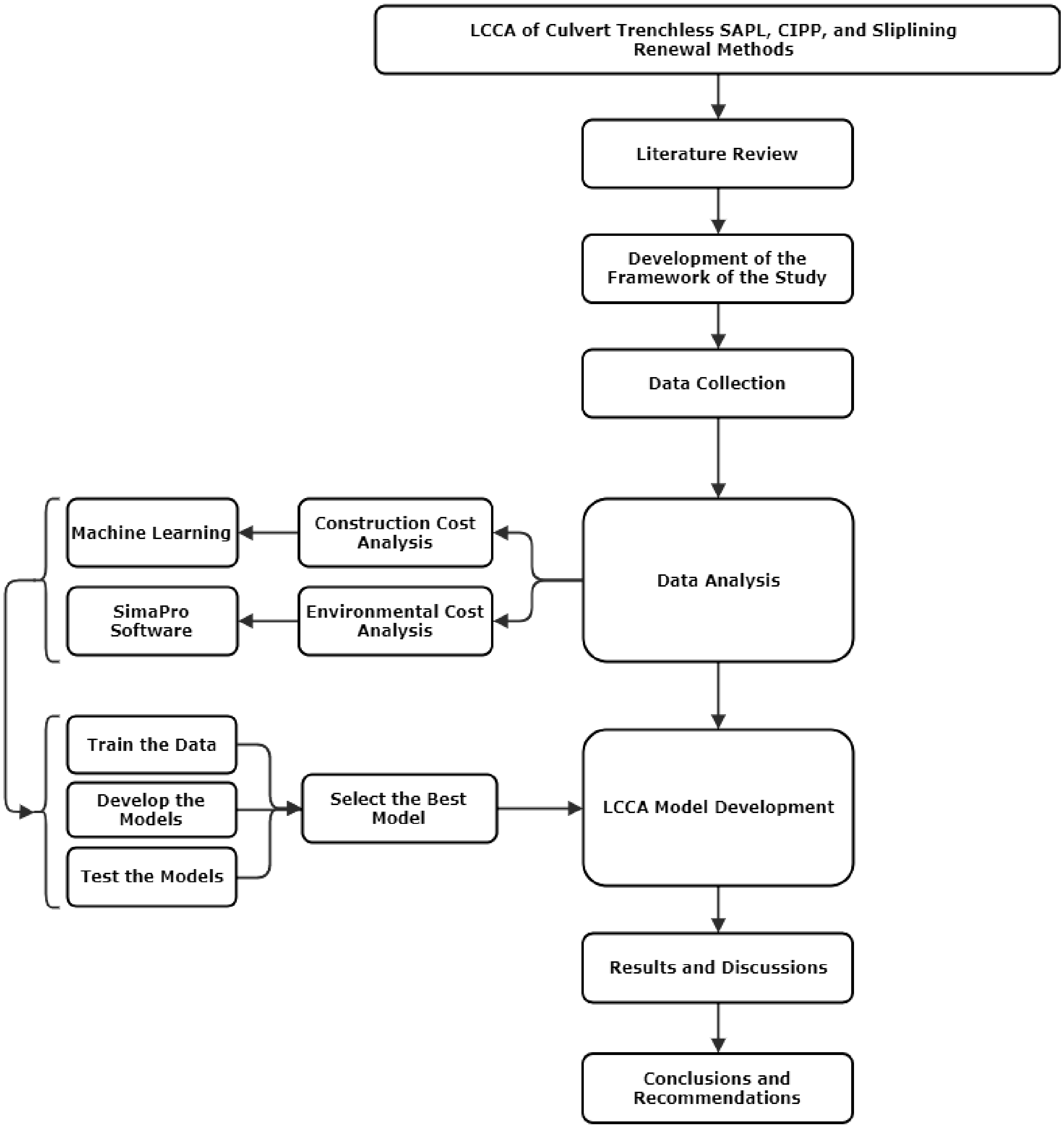


Figure 1-14 Overall Research Methodology

1.14 Dissertation Organization

This dissertation is categorized into 5 chapters. Followings are the brief descriptions of each organized chapter:

Chapter 1 presents the state of underground stormwater conveyance conduits in the US. It illustrates the problems and costs associated with the replacement and renewal of underground utilities. Chapter 1 also reviews attributes of culverts as well as a general background of trenchless technology. In addition, it discusses different types of culvert trenchless rehabilitation methods such as SAPL, CIPP, and sliplining. Admittedly, it highlights the concept of life-cycle cost analysis including its three main modules as construction and environmental, and social costs. Lastly, it presents the need statement, objectives, scope of the research, hypotheses, methodology, contribution to the body of knowledge, and organization of this dissertation respectively.

Chapter 2 highlights a comprehensive literature review of two modules as construction and environmental costs of life-cycle costs of trenchless SAPL, CIPP, and Sliplining renewal methods and briefly illustrates the reason behind not to account social costs for this dissertation. It also reviews LCCA application in the underground infrastructure and utility systems.

Chapter 3 depicts the developed methodology to achieve the comprehensive construction and environmental costs analysis for SAPL, CIPP, and Sliplining renewal methods in large diameter culverts.

Chapter 4 introduces the developed prediction construction and environmental costs of trenchless rehabilitation methods model (LCCATR) and its validation. In addition, it presents the results, analyses, and comparison of construction and environmental costs of SAPL, CIPP, and Sliplining.

Finally yet importantly, Chapter 5 presents conclusions and recommendations for future studies.

1.15 Chapter Summary

This chapter introduced the state of underground stormwater conveyance conduits in the US. Problems and costs associated with replacement and renewal of underground utilities were illustrated. Attributes of culverts, as well as a general background of trenchless technology, was presented. In addition, different types of culvert trenchless rehabilitation methods such as SAPL, CIPP, and sliplining were discussed. Admittedly, the concept of life-cycle cost analysis including its two main modules as construction and environmental costs were highlighted. Lastly, the need statement, objectives, scope of the research, hypotheses, methodology, contribution to the body of knowledge, and organization of this dissertation were presented respectively.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Generally speaking, each method of analysis of life-cycle of a project, focuses on one aspect, which can be either construction or environmental costs of that project, especially in the underground infrastructure and utility system projects. As stated in this chapter, most literature, even those with comprehensive life-cycle cost analysis, only addressed one category of life-cycle cost, being social, environmental or construction.

In this chapter, a literature review of LCCA of trenchless SAPL, CIPP, and sliplining renewal methods is presented. Additionally, this chapter reviews various analyses of life-cycle such as life-cycle assessment (LCA) and social costs as well as their application in the underground infrastructure and utility system.

2.2 Factors Affecting Failure of Pipelines

2.2.1 Introduction

Presently, an extensive research effort has been made to develop models for predicting the failure rate of pipelines. The factors utilized in these models can be classified into two clusters based on (1) whether these factors are static or dynamic through the lifecycle of pipelines and (2) whether these factors are physical or environmental or operational (Karimian, 2015).

After reviewing previous studies, it was observed that the second type of classification is more widely used in the recent research efforts.

2.2.2 Static and Dynamic Factors

Stone et al. (2002) categorized factors contributing to the failure of water pipelines into two groups: static factors and dynamic factors. The characteristics of static parameters do not depend on the time, but dynamic factors' specifications change over time. Static parameters include the diameter, length, soil type, pipe material, and etc.

On the other hand, the age, cumulative number of breaks, soil corrosivity, and water pressure are examples of dynamic factors influencing the pipe failure rate. Osman and Bainbridge (2011) studied the effect of time-dependent variables like pipe age, temperature and soil moisture on the deterioration of water pipes. Static factors such as soil type, length, wall thickness and diameter of the pipe were not considered in their study because of the unavailability of reliable data (Karimian, 2015).

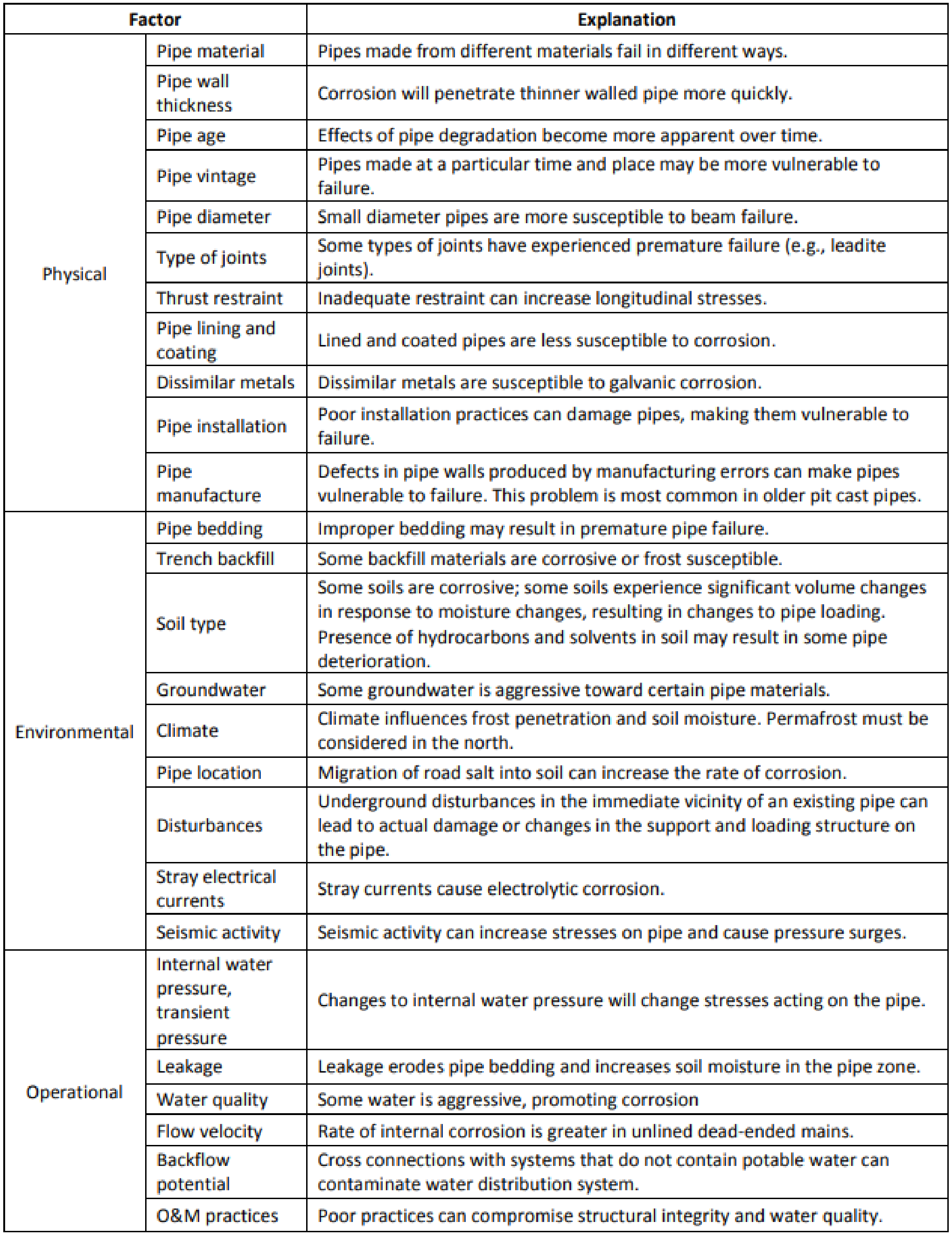
2.2.3 Physical, Environmental, and Operational Factors

InfraGuide (2003) classified the factors contributing to the failure of pipes to three main categories; physical, environmental and operational as shown in Table 2-1. According to InfraGuide (2003), physical factors include pipe material, pipe wall thickness, pipe age, pipe vintage, pipe diameter, type of joints, thrust restraint, pipe lining and coating, dissimilar metals, pipe installation, and pipe manufacture. In other researches, pipe length and buried depth are also known as physical factors.

InfaGuide (2003) considered pipe bedding, trench backfill, soil type, groundwater, climate, pipe location, disturbances, stray electrical currents, and seismic activity as the environmental factors. While, other researchers included rainfall, traffic and loading, and trench backfill as the environmental factors as well.

Kabir et al. (2015) studied the effect of soil type on the failure rate of water pipelines and highlighted that soil type can be classified further to major and minor factors. The five major soil factors include soil electrical resistivity, soil pH, redox potential, soil sulfide contents and soil moisture as the temperature of the soil, oxygen contents, presence of acids, sulfates, and sulfates reducing bacteria.

Table 2-1 Factors Affecting Pipe Failure (Karimian, 2015)



Factor		Explanation
Physical	Pipe material	Pipes made from different materials fail in different ways.
	Pipe wall thickness	Corrosion will penetrate thinner walled pipe more quickly.
	Pipe age	Effects of pipe degradation become more apparent over time.
	Pipe vintage	Pipes made at a particular time and place may be more vulnerable to failure.
	Pipe diameter	Small diameter pipes are more susceptible to beam failure.
	Type of joints	Some types of joints have experienced premature failure (e.g., leadite joints).
	Thrust restraint	Inadequate restraint can increase longitudinal stresses.
	Pipe lining and coating	Lined and coated pipes are less susceptible to corrosion.
	Dissimilar metals	Dissimilar metals are susceptible to galvanic corrosion.
	Pipe installation	Poor installation practices can damage pipes, making them vulnerable to failure.
	Pipe manufacture	Defects in pipe walls produced by manufacturing errors can make pipes vulnerable to failure. This problem is most common in older pit cast pipes.
Environmental	Pipe bedding	Improper bedding may result in premature pipe failure.
	Trench backfill	Some backfill materials are corrosive or frost susceptible.
	Soil type	Some soils are corrosive; some soils experience significant volume changes in response to moisture changes, resulting in changes to pipe loading. Presence of hydrocarbons and solvents in soil may result in some pipe deterioration.
	Groundwater	Some groundwater is aggressive toward certain pipe materials.
	Climate	Climate influences frost penetration and soil moisture. Permafrost must be considered in the north.
	Pipe location	Migration of road salt into soil can increase the rate of corrosion.
	Disturbances	Underground disturbances in the immediate vicinity of an existing pipe can lead to actual damage or changes in the support and loading structure on the pipe.
	Stray electrical currents	Stray currents cause electrolytic corrosion.
	Seismic activity	Seismic activity can increase stresses on pipe and cause pressure surges.
Operational	Internal water pressure, transient pressure	Changes to internal water pressure will change stresses acting on the pipe.
	Leakage	Leakage erodes pipe bedding and increases soil moisture in the pipe zone.
	Water quality	Some water is aggressive, promoting corrosion
	Flow velocity	Rate of internal corrosion is greater in unlined dead-ended mains.
	Backflow potential	Cross connections with systems that do not contain potable water can contaminate water distribution system.
	O&M practices	Poor practices can compromise structural integrity and water quality.

Karimian (2015) summarized the factors to predict the failure rate of pipelines. These factors included physical and operational, physical and environmental and physical, operational and environmental (Table 2-2).

Table 2-2 Factors Affecting Pipe Failure Rate by
Different Researchers (Karimian, 2015)

	Physical Factors													Environmental Factors										Operational Factors						
	Pipe Material	Pipe Wall Thickness	Pipe Age	Pipe Length	Pipe Vintage	Pipe Diameter	Type of Joint	Thrust Restraint	Pipe Lining and Coating	Dissimilar Metals	Depth Laid	Pipe Installation	Pipe Manufacture	Pipe Bedding	Trench Backfill	Soil Type	Groundwater	Climate	Pipe Location	Disturbances	Stray Electrical Currents	Traffic and Loading	Seismic Activity	Internal Water Pressure, Transient Pressure	Leakage	Water Quality	Flow Velocity	Backflow Potential	O&M Practices	Other Factors
Moglia et al. (2007)		✓	✓	✓		✓																		✓						corrosion rate
Berardi et al. (2008)			✓	✓		✓																								Number of Properties Supplies
Wang et al. (2009)	✓		✓	✓		✓					✓																			
Jafar et al. (2010)	✓	✓	✓	✓		✓										✓			✓					✓						
Wang et al. (2010)	✓		✓			✓			✓					✓	✓	✓					✓	✓		✓						
Xu et al. (2011)			✓	✓		✓																								
Asnaashari et al. (2013)	✓		✓	✓		✓			✓							✓														
Arsénio et al. (2014)			✓																											Ground Movement
Shirzad et al. (2014)			✓	✓		✓					✓													✓						
Aydogdu and Firat (2014)			✓	✓		✓																								
Nishiyama and Filion (2014)			✓	✓		✓										✓														
Kabir et al. (2014)		✓	✓	✓		✓										✓						✓		✓		✓				
Jenkins et al. (2014)			✓			✓																								
Francis et al. (2014)			✓													✓		✓	✓											
Kutyłowska (2015)	✓		✓	✓		✓																								
Kabir et al. (2015a)			✓	✓	✓	✓										✓			✓											Number of Connection for Each Pipe
Kimutai et al. (2015)	✓			✓		✓										✓		✓												Soil Resistivity, Freezing Index, and Rain Deficit
Kabir et al. (2015b)			✓	✓	✓	✓										✓														Soil Resistivity and Soil Corrosivity Index

2.3 Life-cycle Cost Analysis of Trenchless Renewal Methods

2.3.1 Introduction

The Federal Highway Administration (FHWA) (2002) defined LCCA as a tool which is used to compare possible alternatives based on total costs including initial construction, operation, maintenance, rehabilitation and other anticipated cost throughout the entire service life of pipeline rehabilitations and determine the most cost-effective way to perform the project (FHWA, 2002).

ASTM F1675 – 13 defines LCCA as a technique that measures the present value of all relevant costs to install, operate and maintain alternative drainage systems such as engineering, construction, maintenance, rehabilitation, or replacement over a specified period. The decision-maker, using the results of the LCCA can then identify the alternative(s) with the lowest estimated total cost based on the present value of all costs (Sompura, 2017).

ASCE (2019) defines LCCA as an analytical method used to evaluate long-term investment options and facilitate the associated construction and environmental costs. A clear understanding of all costs associated with SAPL, CIPP, and sliplining trenchless culvert renewal projects from inception to disposal which requires collecting, analyzing summarizing data. LCCA is a conceptual tool that engineers, planners, owners, and public officials can use to evaluate the potential impacts of a project and promote the sustainable planning, design, construction and operation of pipelines used in the water, wastewater and stormwater industry (ASCE, 2019).

2.3.2 Life-cycle Analysis Studies

Najafi and Kim (2004) presented an investigation of parameters involved in constructing underground pipelines with trenchless methods in urban centers in 34 comparisons with the open-cut method. Their study included a breakdown of the engineering and capital costs of the construction and the social costs for both methods. They considered the life-cycle cost of a project with the point of view of pre-construction, construction, and post-construction parameters. They asserted that considering the lifecycle costs of a project, innovative methods and trenchless technology are more cost-effective than traditional open-cut methods. Although the authors considered cost parameters for both trenchless and open-cut methods, they did not consider an actual cost data analysis for comparison of these two methods. Such an actual cost analysis is the main consideration of this thesis.

Shahata (2006) predicted the life-cycle cost for water mains, taking into consideration the uncertainty involved in determining its service life, discounted rate, and the cost of new installation or rehabilitation alternatives. Monte Carlo simulation was used to address the probability factor. Sensitivity analysis was performed to examine the effect of variability of cost information and deterioration on the LCCA. It was found that the open-cut pipeline method proved to be cost-effective for large diameter pipeline ranges (i.e. >30 in.) than the CIPP method.

Ariaratnam et al. (2014) provided a discussion on trenchless technologies, especially pipe bursting trends, for replacement and renewal of underground systems. The study included results from a survey questionnaire examining 886 projects from 2007 to 2010 in Canada and the United States, and the results supported the advantages of trenchless technologies.

Beaudet et al. (2019) presented a detailed description of the life-cycle cost methodology as it pertains to collection system rehabilitation decisions. A simple spreadsheet-based case study was provided for the collection system rehabilitation of lateral liners using CIPP lining. Many often overlooked variables influencing life-cycle rehabilitation costs were identified and methods to incorporate them into the LCC were described. These include not only initial capital and long-term operating costs but also a broad range of other evidence including job site tests, published reports, manufacturer product data, as well as historical local experience. They assumed three alternatives which are do nothing, CIPP lining using hydrophilic adhesive, and CIPP lining using molded Neoprene rubber gaskets. Beaudet et al. (2019) used data from site reports, published reports, manufacturer product data, and local experience for each of the alternatives to be considered and they employed net present value (NPV) with design life consideration to calculate the life-cycle cost of the alternatives. The result showed that CIPP lining using pre-engineered, molded rubber gaskets, ASTM F3240 compliant is the most cost-effective long-term alternative. This study concluded that the same method of LCC analysis can be used to compare alternatives for other collection system projects, including conveyance system projects.

2.4 Construction Cost Analysis of Trenchless Renewal Methods

2.4.1 Introduction

The Life-cycle construction cost of culvert projects is the category of costs including planning and engineering costs, direct and indirect costs, and operation and maintenance costs which are associated to the entire life of the project (Najafi and Gokhale, 2005). ASTM C1131 defines life-cycle cost as the sum of initial cost, repair and maintenance costs, and renewal cost of the project (Eq. 2-1).

$$LCC = C + M + N \qquad \text{Eq. 2-1}$$

Where LCC = Life-cycle cost,

C = initial cost,

M = repair and maintenance costs,

N = renewal cost.

Initial cost of the project is the original cost including the direct cost of materials and labor, mobilization, excavation, backfill, dewatering, surface restoration, traffic control, bypass, and indirect costs are such as general administrative and project management costs.

Maintenance cost is the future cost involved in, such as regularly inspection cost and/or minor repair of the culvert, which happens because of the lack of performance.

Renewal cost is the future cost of the project, which is including rehabilitation, and/or replacement of the culvert due to the failure of the culvert.

While construction cost analysis needs to evaluate the mentioned costs, contract cost of projects, as well as the bid cost, can represent the construction cost of projects for those with no or low repair, maintenance, and renewal costs (ASCE, 2019).

2.4.2 Construction Cost Analysis Studies

Zhao and Rajani (2002) studied the cost of construction and rehabilitation of buried pipes using different trenchless technologies including Reline (liner systems), CIPP, sliplining, and pipe bursting. They collected the cost data of trenchless technology projects from various sources. The data indicated that, in general, costs of the all trenchless methods increase with the increase in pipe size due to the increased level of complexity and difficulty of carrying out the renewal work (Figure 2-1). To demonstrate the range of costs in one location, the cost diameter relationship for the CIPP projects in Phoenix shows in Figure 2-2.

According to Piehl (2005), the cost for the CIPP method ranges from \$100 per linear foot for an 18-in. diameter pipe (\$5.50 per inch-per-foot) to \$800 or more per linear foot for the large-diameter pipe.

Lee (2006) presented the advantages in costs of trenchless technology, particularly pipe bursting, compared to the costs of traditional open-cut. A practical example of cost comparison of pipe bursting and open-cut methods was presented with the actual cases and a price range of the actual pipe bursting projects was worked-out to show the analysis of the different project costs in the price range.

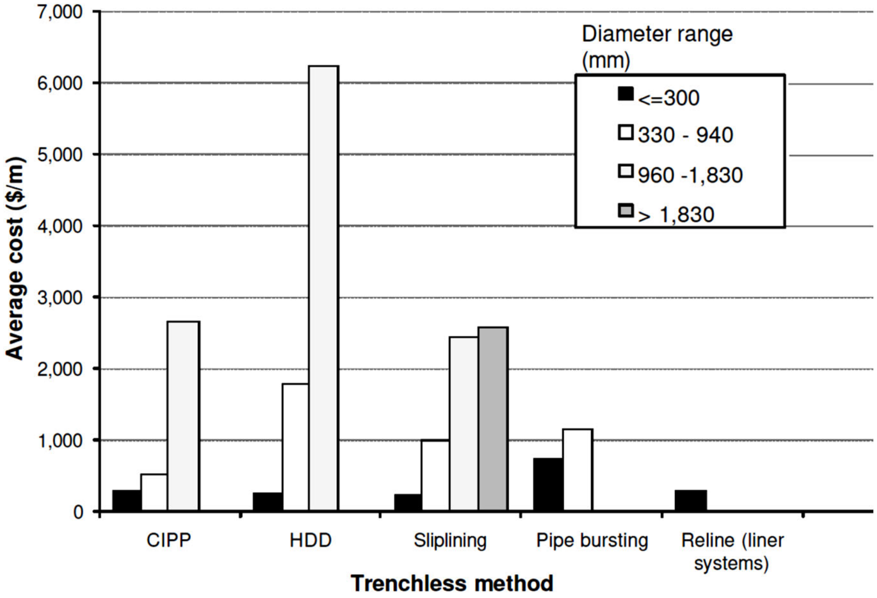


Figure 2-1 Average Cost of Trenchless Methods for Four Diameter Ranges (Adapted from Zhao and Rajani, 2002)

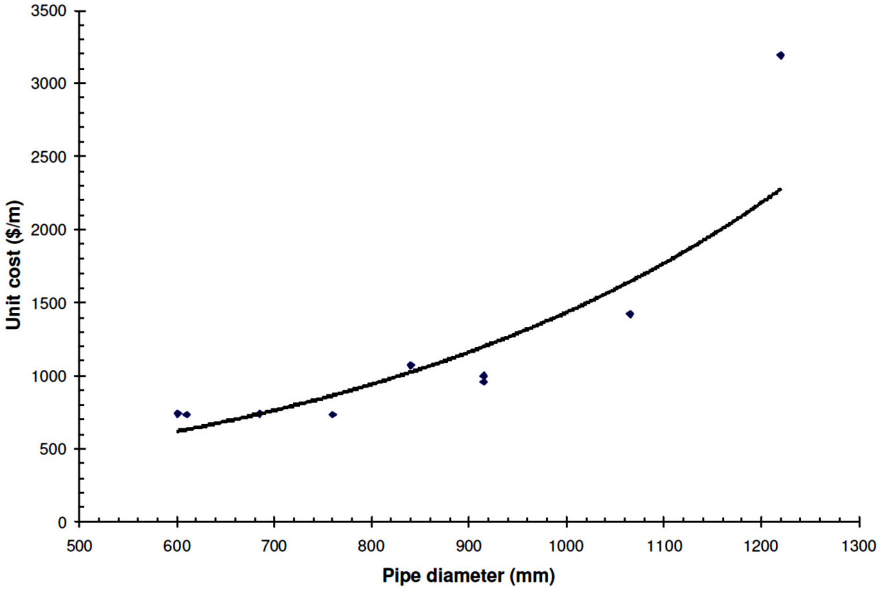


Figure 2-2 Increase of CIPP Rehabilitation with Pipe Diameter (Zhao and Rajani, 2002)

It was found that the pipe bursting method showed advantages in terms of cost, time, and minimum disruption to the environment compared to the open-cut method.

According to Jung and Sinha (2007), there are various costs related to a renewal pipeline project either with open-cut or pipe bursting. The authors considered some parameters related to these kinds of projects; namely, direct, social, and environmental. They asserted that the interrelation among these costs is becoming more important with growing public awareness of societal and environmental issues. They provided two general formulas for open-cut and trenchless methods as:

$$TCOC = C_{Direct} + C_{Social} + C_{Environmental} + C_{Other\ Factors}$$

$$TCTT = C_{Direct} + C_{Social} + C_{Environmental} + C_{Other\ Factors}$$

Where, TCOC = total cost of open-cut method,

TCTT = total cost of trenchless technology,

C_{Direct} = earthwork cost, restoration cost, overhead cost, and so on (including material, labor, and equipment cost),

C_{Social} = traffic delay cost, income loss of business, and so on,

$C_{Environmental}$ = noise pollution cost, air pollution cost, and so on, and

$C_{Other\ Factors}$ = productivity loss cost, safety hazard cost, structural behavior cost, and so on.

The authors concluded that with the above parameters, pipe bursting is a trenchless method would be less expensive than an open-cut technique. However, they did not consider any actual project data for the prediction of the pipe bursting or open-cut costs.

Hashemi (2008) conducted a cost comparison for pipe bursting and open-cut pipeline installations. This study included a case study as an example of a cost comparison for replacing sewer pipeline in the city of Troy, Michigan. The results of the study found that the pipe bursting method is much less expensive than the open-cut method for replacing the underground sewer pipelines. Also, the results from the case study found that the cost of installation per-inch-per-foot of pipe bursting is $11per-inch-per-foot while for open-cut is $18 per-inch-per-foot. Consequently, there is $7 per-inch-per-foot or about 40% saving by using a trenchless pipe bursting method.

Hashemi et al. (2011) evaluated the CIPP AWWA Class IV, pipe bursting, and open-cut methods based on cost, diameter size ability, and service re-connection to find out the best renewal option for water main distribution. They used statistical techniques to analyze the data for 6, 8, and 12 in. diameter pipes and found the average costs of open-cut and CIPP pipeline renewal as $750/ft and $325/ft, respectively.

2.5 Life-cycle Assessment of Trenchless Renewal Methods

2.5.1 Introduction

ISO 14040:2006 presents Life Cycle Assessment (LCA) as one of the techniques developed for understanding and addressing the possible environmental impacts associated with both manufactured and consumed products and services. “LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)” (ISO, 2006). LCA consists of four different phases including (i) scope definition, (ii) Life Cycle Inventory (LCI), (iii) Life Cycle Impact Analysis (LCIA), and (iv) interpretation. The methodologies for each of these phases can be found in ISO 14040 – 14044.

2.5.2 Life-cycle Assessment Studies

Kamat (2011) compared the generation of respirable suspended particulate matter (RSPM) between an open-cut and trenchless technology method to justify the need for replacing traditional open-cut methodologies with trenchless methods. He used the sampled filter paper to determine the amount of RSPM in each of the sampled sites to analyze the results. The detailed results were then compared with the EPA to check the allowed RSPM in the air from open-cut and trenchless methods. The average RSPM generated for an open-cut and trenchless technology sites were 59.45~60 and 34.28~35 micrograms/m^3, respectively.

As per Khan and Tee (2015), the carbon price is based on the social cost of carbon (SC-CO_2) which generally refers to the cost to mitigate climate change or the marginal social damage from one ton of emitted carbon. However, the actual carbon price is often determined by the market value.

Leuke et al. (2015) compared the estimated carbon footprint and greenhouse gas emissions during the rehabilitation of two asbestos cement water main projects by CIPP and Pipe bursting methods. The number of equipment utilized, cycle times, activity durations, and productivities of the crews were recorded. NASTT BC, Vermeer's E-Calc, and NASTT's carbon calculators were used to compare the emissions. It was found that emissions per 100 m (328 ft) length of pipe for CIPP method through NASTT, E-Calc, and NASTT BC were 3.11, 2.90, and 2.66 tones, respectively.

EPA (2016) and other federal agencies are using the estimates of the social cost of carbon to evaluate the climate impacts. The social cost of carbon is measured in dollars. The SC-CO_2 is meant to be a general estimate of climate change damages and includes, among other things, changes in net agricultural productivity, human health, property damages from increased flood risk and change in energy system costs, such as reduced cost for heating and increased costs for air conditioning.

Estimates of the SC-CO_2 are a helpful measure to assess the climate impacts of CO_2 emissions change. Table 2-3 Table 2-3 Social Cost (SC) of CO_2 Estimates from 2010 to 2050summarizes the Social Cost-CO_2 estimates for the years 2010 to 2050. The central value is the average of SC-CO_2 estimates based on the 3 percent discount rate. For purposes of capturing uncertainty around the SC-CO_2 estimates in regulatory impact analysis, the interagency working group emphasizes the importance of considering all four SC-CO_2 values (USEPA, 2016).

Table 2-3 Social Cost (SC) of CO_2 Estimates from 2010 to 2050
(in 2007 dollars per metric ton of CO_2) Source: USEPA, 2016

Year	5% discount rate average	3% discount rate average	2.5% discount rate average	High impact at 3% discount rate
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

Tavakoli et al. (2017) compared carbon footprint for conventional open-cut and trenchless technology methods, particularly tunneling in a rural area, and quantify carbon emissions produced by construction equipment for hauling excavated soils during pipeline construction. They estimated CO2 emissions for open-cut and tunneling methods for the UFT construction project. Statistical data was used to calculate the quantity of CO2 emissions to determine the magnitude of the environmental impacts of both methods. A potential UFT route is considered for 25-mile distance from Huntsville to Madisonville, Texas, in a rural area. Total CO2 produced using the trenchless technology method was 887 tons and for the open-cut method was 5,379 tons.

According to Monfared (2018), trenchless technologies provide cost-effective alternatives to traditional open-cut pipeline installations as these methods offer less trench and less footprint, and they are environmentally friendly.

2.6 Social Cost Analysis of Trenchless Renewal Methods

2.6.1 Introduction

Social costs which include pollution damage costs (costs due to emissions) and user costs are very difficult to determine. For calculation of pollution damages, Environmental Protection Agency (EPA) has developed some models to calculate emissions. For example, MOBILE6 is a model developed for calculation of emission from vehicles and NONROAD is a model developed for calculation of emission from construction equipment. Likewise, embodied energy models for different pipe materials can be used to calculate emissions during the manufacture of pipes.

The calculation of total emissions or pollution damages is the output of LCA. To be able to use it in LCCA, the dollar value for the damage must be determined. Many research works have been carried out to ascertain the pollution damage costs and have been summarized by Tol (2005). Tol (2005) analyzed 28 articles on pollution damage costs and found that the mean pollution cost from those 28 articles was $97 per metric ton of carbon (tC) emitted with a standard deviation of $203/tC. The mean for peer-reviewed articles was $50/tC. Therefore, it is found that there is a high level of uncertainty in determining the pollution damage costs.

2.6.2 Social Cost Analysis Studies

Tighe et al. (1999) studied traffic delay cost savings associated with trenchless technologies. This study focused on cost savings in trenchless methods due to the elimination of traffic disruptions associated with excavation and trenching in conventional open-cut methods. Tighe et al. suggested a methodology to consider the cost of traffic delays associated with open-cut trenching methods. The results showed that eliminating traffic disruption in trenchless technologies makes them an economical alternative to open-cut replacement.

Tighe et al. (2002) also performed a study to compare the overall project costs of traditional open-cut methods with trenchless technologies. They considered different factors, such as performance, future maintenance costs, and user-delay costs in the study. It was concluded that surface restoration costs were comparable and trenchless construction methods a feasible alternative to open trenching options, especially in developed urban areas. The results indicated that traditional open-cut methods reduce the life of a pavement by about 30 percent and increase the maintenance and rehabilitation costs 32 of pavement from \$690/ft^2 to \$1,185/ft^2. However, trenchless technologies have fewer costs associated with pavement disruptions.

Gangavarapu (2003) presented a case study to compare traffic and road disruption costs during utility construction when open-cut and trenchless construction methods are used. The author presented a breakdown of the social costs involved in utility construction. He investigated traffic flow rates and patterns during two sample utility construction projects to analyze the impact of construction on the traffic flow. Using traffic delay estimates obtained from the traffic flow and length of detoured roads, he developed a flow chart for estimating the costs of traffic disruption. He did not consider costs due to damage to pavement, environmental impacts, safety issues, and noise and dust in his study. Although he considered important social costs of a utility project, he did not compare the direct cost of open-cut with trenchless techniques which is the main subject of this thesis.

According to Allouche and Gilchrist (2004), communities that surround an operating construction site often found themselves subjected to negative impacts. Construction activities can have a significant effect on their surrounding environment, and the negative impacts are often called social cost as shown in Figure 2-3. Social cost, while widely acknowledged, is rarely considered in the design, planning, or bid evaluation phases of the construction project in North America.

Social cost can range from costs associated with traffic conditions (e.g., delays and increased on vehicle operation expenses), environmental costs (e.g., pollution), costs resulting from decreased safety (e.g., higher rate of traffic accidents and risk to pedestrians), accelerated deterioration of road surfaces (e.g., due to pavement cuts), lower business turnovers, decreased property values, and damage to existing utilities.

Maldikar (2010) investigated the loss in construction productivity due to surrounding outdoor noise conditions and found the relationship between the surrounding varying noise conditions and the rate of accidents. A case study was conducted under varying noise conditions at a construction job site. A total of 8 subcontractor crews were surveyed and studied, working simultaneously on 2 building sites, performing similar work, but under varying sound conditions using Method Productivity Delay Model (MPDM). Results were gathered, and data were analyzed to identify the problems. It was found that the rate of accidents was highest for sound levels above 90 dB with an average of 1.35 accidents per person per year.

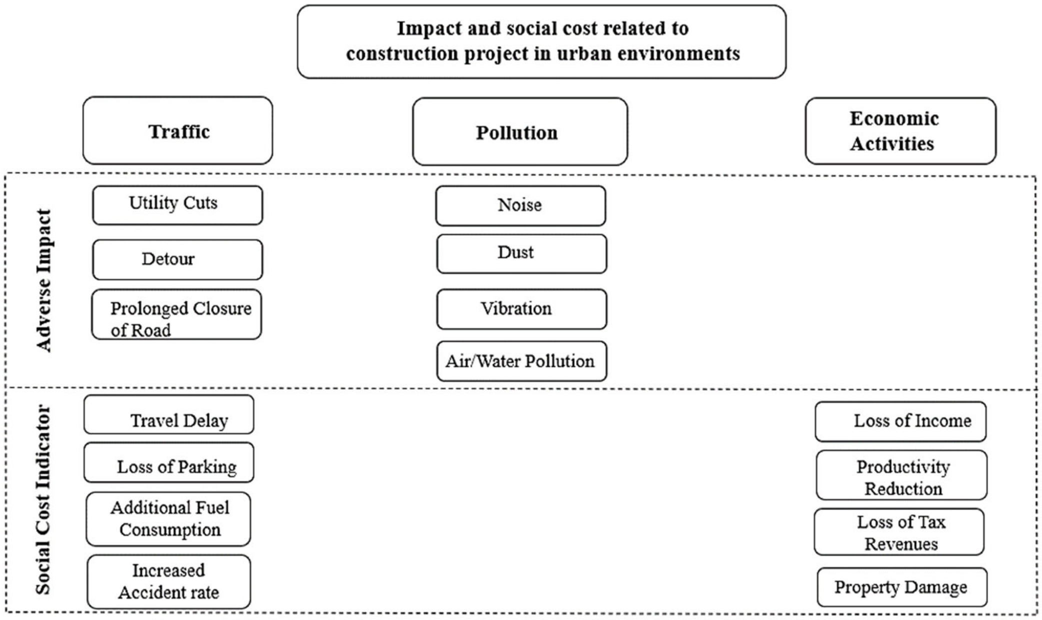


Figure 2-3 Potential Impacts and Social Cost Related to Pipeline Construction Projects (Allouche and Gilchrist, 2004)

In addition, it was moderate for sound levels ranging between 80 dB to 90 dB with an average of 0.33 accidents per person per year. Moreover, the least for sound levels below 80 dB with an average of 0.26 accidents per person per year.

Kamat (2011) compared the generation of respirable suspended particulate matter (RSPM) between an open-cut and trenchless technology method to justify the need for replacing traditional open-cut methodologies with trenchless methods. He used the sampled filter paper to determine the amount of RSPM in each of the sampled sites to analyze the results. Then, the detailed results were compared with the EPA to check the allowed RSPM in the air from open-cut and trenchless methods. The average RSPM generated for an open-cut and trenchless technology sites were 59.45~60 and 34.28~35 micrograms/m^3, respectively.

Islam et al. (2014) assessed social costs in trenchless projects, comparing them to traditional trenching methods through five case histories in different countries, including the United States, Austria, Italy, and Belgium. They used the Social Cost Calculator (SCC) developed in the Trenchless Technology Center (TTC) at Louisiana Tech University, and the results showed that the social cost of trenchless alternatives are significantly lower than the open-cut method, and trenchless methods reduce a project's associated social costs by less than 5 percent of the total calculated cost.

Whitehead et al. (2015) studied various challenges in constructing the underground pipeline in a heavily-populated area through the Southern Delivery System (SDS) in Colorado. The study identified some challenges with potential disruption to neighboring businesses, traffic control, safety, construction noise, vibration, and dust. Whitehead et al. found that trenchless technologies saved time and money in this project, and also facilitated a safer project with fewer social inconveniences.

Kaushal et al. (2019) conducted a comparison of social and environmental costs of trenchless CIPP method and open-cut construction and concluded that the social costs of open-cut are 10 times more than the social costs of the CIPP. In addition, the author found that the social costs of CIPP are less than 2% of the total cost of CIPP is associated with a social cost.

2.7 Cost Prediction Models

2.7.1 Introduction

One of the major challenges faced in trenchless renewal projects is the ability to successfully and accurately predict their cost at the early stages of the planning phase. Early and accurate cost prediction for these projects does not only assure the allocation of adequate budgets for their successful completion but also assists in the proper utilization of limited available resources (Shehab et al., 2010).

In an effort to predict the cost of trenchless culvert renewal projects, several cost prediction models by using information obtained from the project's cost databases have been developed by other researchers. Prediction models can perform an essential role to generate a comprehensive prioritization plan as they provide valuable information to forecast the initial cost and life-cycle cost of trenchless technology methods. Utility companies and municipalities can forecast the cost of their projects by generating prediction models to select the most cost-effective alternative among others. The primary objective of trenchless technology method prediction models is to apply an appropriate mathematical technique to estimate the cost of trenchless culvert renewal projects. Additionally, cost prediction models are capable to identify significant factors affecting the cost of trenchless technology projects.

Cost prediction models for trenchless renewal methods are classified into different categories such as deterministic, probabilistic, statistical, and artificial intelligence models. Cost prediction models of stormwater gravity conveyance conduits renewals are classified into two major categories: industry-standards and analytical methods which are the most common techniques developed by researchers. RSMeans is the most common approach used in an industry-standard category, while, deterministic, probabilistic, fuzzy method, statistical, and artificial intelligence models are used as analytical methods (Shahata, 2006 and Farooq, 2007).

2.7.2 Industry Standard

Selvakumar et al. (2002) presented the representative costs that can be used by utility managers to estimate order-of-magnitude budgetary costs for rehabilitation and replacement of distribution system pipelines. They reported cost per linear feet of various trenchless methods. Cost data were acquired from personnel who have experience in rehabilitation, from manufacturers and construction contractors, and from articles that appeared in journals and conference proceedings. Although Selvakumar et al. presented cost information pertinent to many trenchless technologies, such as cement mortar lining, sliplining, and microtunneling, its use is rather limited. Furthermore, the presented information is only used to estimate the cost of pipes and their installation. Other major cost items that were proven to highly impact sewer and water rehabilitation projects, such as valves and fire hydrants, were not considered (Shehab and Farooq 2009).

2.7.2.1 RSMeans

RSMeans data from Gordian is North America's leading construction cost database. A dynamic collection of data points actively monitored by experienced Cost Engineers, RSMeans data is used by construction professionals to create budgets, estimate projects, validate their own cost data and plan for ongoing facility maintenance. Localized, accurate and complete, RSMeans data is the construction industry standard (RSMeans, 2019).

In an effort to proceed with the cost estimation and prediction process of underground utility renewal projects, RSMeans considered only two parameters. These parameters are pipe diameter, length, and material. These three parameters do not reflect the large variations associated with this class of projects and neglect such factors as the technology of rehabilitation, the thickness of the material, location of the project, and etc. These factors may positively contribute to the accuracy of the estimation process, which is considered a significant advantage. Although not as widespread in practice, using statistical analyses and the newly evolving artificial intelligence techniques to automate the cost forecasting process at the project's early stages has been praised by several researchers (Adeli and Wu 1998, Adeli and Karim 2001, Farooq, 2007).

2.7.3 Analytical Methods

The deterministic, probabilistic, fuzzy method, statistical, and artificial intelligence models are categorized as analytical methods. Tran (2007) suggested statistical models as a model-driven type and artificial intelligence-based model as a data-driven type. Typically, the structure of model-driven is defined by the expert, while, the sample data demonstrates the structure of models in data-driven type.

Many researchers have developed a number of statistical and artificial intelligence cost estimation systems. In their developments, they utilized a two-step methodology:

1. Problem analysis
2. Problem modeling

Problem analysis is identifying the key factors that positively contribute to the accuracy of the estimation process, while, problem modeling is establishing a relationship between these key factors and the cost of the project.

Analytical models have been developed for different purposes in civil engineering fields such as structures, transportation, and geotechnical. These models were developed using a set of key attributes based on experience and questionnaires sent to end-users. The performance of these systems was evaluated in comparison to artificial neural networks. This comparison revealed the superior performance of neural networks (Farooq, 2007).

2.7.3.1 Deterministic Models

In the deterministic method, a discounted rate is used to compare all costs in the present value. It's assumed that all the cost components of the project to be well defined with a single value. It is based on the economic analysis of the time value of money. To find the total life-cycle cost of a project, it is just required to sum the present values of each kind of cost and subtract the present values of any positive cash flows such as a resale value (Boussabaine and Kirkham, 2004). Thus, the following formula applies (Eq. 2-2) (Riggs, 1986):

$$\mathrm{LCC} = \mathrm{C_p} + \sum\nolimits_{t=0}^{n} \frac{\mathrm{C_t}}{(1+d)^t} \qquad \text{Eq. 2-2}$$

Where, LCC = the present value of the total life-cycle cost,

Cp = the capital cost,

Ct = sum of the operation cost, maintenance and repair, replacement or rehabilitation, and the salvage value,

d = the discounted rate, and

n = the asset service life.

The deterministic method assumes that all the cost is identified by year and with certainty, where there is no probability in the identified values. The limitation of the deterministic method that it doesn't address can be a lack of having statistical significance and/or variability. Also, it is subject to manipulation, and there is a lack of credibility associated with the deterministic method (Gransberg et al., 2004).

2.7.3.2 Stochastic (Probabilistic) Models

The stochastic method deals with each element in the life-cycle cost equation as a probabilistic element which follows a probability distribution function. The stochastic method assumes that the cost center, discounted rate, and the service life of an asset are randomly distrusted according to different probability distribution functions (Frangopol et al., 2004). This assumption requires that each element be treated as an uncertain element from one year to another. Also, the output probability of the life-cycle cost is defined as the risk profile (Boussabaine and Kirkham, 2004). Thus, the following formula applies (Eq. 2-3) (Shahata, 2006):

$$f(PV) = f(\mathrm{C_p}) + \sum_{t=0}^{n} \frac{f(\mathrm{C_{ti}})}{(1+f(\mathrm{d}))^{t}} \qquad \text{Eq. 2-3}$$

Where, f(PV) = the present value of the probability distribution function of the life-cycle cost,

f(Cp) = the probability distribution function of the capital cost,

f(Cti) = the probability distribution function of the life-cycle cost element (i) in period t,

f(d) = the probability distribution function of the discounted rate, and

n = the asset service life.

2.7.3.3 *Fuzzy Models*

Expert judgment plays a major role in defining the cash flow of life-cycle costs. As uncertainty adopted by life-cycle costs does not usually fit the probability distribution functions. So the Fuzzy method was implanted to model the uncertainty with life-cycle cost elements. The formulas for the analyses of fuzzy present value, fuzzy equivalent uniform annual value, fuzzy future value, fuzzy benefit-cost ratio, and fuzzy payback period are developed by Kahraman et al., (2002) (Eq. 2-4):

$$PV = \left[\begin{array}{l} \sum_{t=0}^{n} \left(\frac{\max\left(P_t^{1(y)},0\right)}{\prod_{t'=0}^{t}\left(1+r_{t'}^{r(y)}\right)} + \frac{\min\left(P_t^{1(y)},0\right)}{\prod_{t'=0}^{t}\left(1+r_{t'}^{1(y)}\right)} \right), \\ \sum_{t=0}^{n} \left(\frac{\max\left(P_t^{r(y)},0\right)}{\prod_{t'=0}^{t}\left(1+r_{t'}^{1(y)}\right)} + \frac{\min\left(P_t^{r(y)},0\right)}{\prod_{t'=0}^{t}\left(1+r_{t'}^{r(y)}\right)} \right) \end{array} \right] \qquad \text{Eq. 2-4}$$

The substantial problem of this method is its formula which is not easy to be applied individually. In addition, there is no software available to calculate the life-cycle cost of underground renewal projects using this method.

Rajani et al. (2004) explains the difference between failure management of small-diameter mains in distribution systems and failure prevention in large-diameter transmission pipelines. He described the application of fuzzy logic to assess failure risk of large diameter transmission pipelines. Figure 2-4 illustrates the introduced framework for decision making in water mains by Rajani. He also addressed the effect of various cathodic protection measures on life-cycle costs of water mains. Despite the extensive research conducted by Rajani, new installation or rehabilitation methods were not covered.

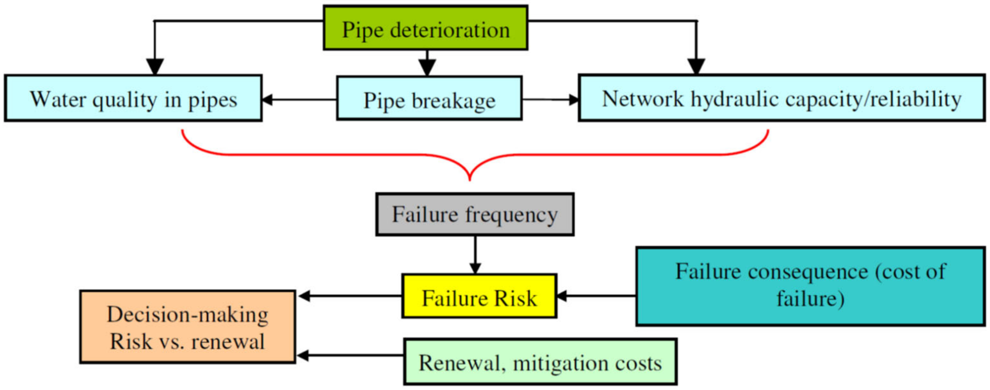


Figure 2-4 General Framework for Decision Making in
Water Distribution System (Rajani, 2004)

Ammar et al. (2012) proposed the first known model dedicated to the selection of methods for the repair of water mains. The model focuses on life-cycle cost analysis of commonly used technologies (e.g., open-cut, sliplining, etc.) to determine which option is most cost-effective. The site-specific inputs of the model include breakage data and deterioration curves, installation and maintenance costs, and service life. The critical gaps of the model include lack of validation by industry users and inability to take into account pipe specific parameters because the researchers concluded those parameters did not affect method ranking. Trial simulations provided similar rankings despite various diameters; however, physical pipe dimensions would affect the total cost in an actual cost analysis. The model has apparently not been implemented by U.S. utilities (Matthews et al., 2012).

2.7.3.4 Statistical Models

The basic explanation of a statistical model is a random variable X, which represents a quantity whose outcome is uncertain. In statistical models, the probabilistic nature of historical data is used to describe the model output as a random variable. In any statistical analysis, estimates are "best guesses" based on the condition of given historical data (Coles, 2011). Dasu and Johnson (2003) indicated that parametric density function is used in statistical models to measure the errors and identify probabilistic relationships between dependent and independent variables. The results and outcomes of statistical models can be presented in probability values and they are more applicable to predict the current and future cost of trenchless culvert renewals rather than deterministic models which provide quantitative results (Tran, 2007).

According to Tran (2007), predicting the ordinal data type and considering the probabilistic nature of the cost affecting factors can be the advantages of statistical models. While the sensitivity of statistical models to noisy data and the methodologies to measure the errors are disadvantages of these models. The sensitivity analysis by employing a Monte Carlo simulation, a powerful statistical analysis tool that is commonly used in both engineering and non-engineering fields and can assess the sensitivity of the output of the analysis with respect to each input variable (Habibzadeh-Bigdarvish et al., 2019).

Numerous statistical models, such as logistic regression, Markov chain, ordinal regression, and cohort survival model were used to predict the cost of culvert renewals in previous studies.

2.7.3.4.1 Regression Models

Regression is one of the most widely used techniques for analyzing multifactor data. Regression's usefulness results from the logical process of using an equation to express the relationship between two or more variables (Hashemi, 2008). The simplest linear regression model involves only one independent variable and the dependent variable can be predicted based on their relationship. The regression model states that the true mean of the dependent variable changes at a constant rate as the value of the independent variable increases or decreases. Therefore, the equation of a simple linear regression shows the functional relationship between the true mean of Y and X as shown in Eq. 2-5 (Rawlings, 1989).

$$Y = \beta_0 + \beta_1 X_1 + \epsilon \qquad \text{Eq. 2-5}$$

Where, i = facility index,

Y = dependent variable,

β_0 = intercept,

β_1 = parameter to be estimated,

X_1 = independent variable, and

ϵ = random error term.

A regression model that involves more than one independent variable (regressor) is called a multiple regression model. In general, the response Yi may be related to i regressor or predictor variables. Eq. 2-6 shows the multiple linear regression model with i variables (Hashemi, 2008):

$$Y_i = \beta_0 + \beta_{\mathrm{i}} X_i + \epsilon_i \qquad \text{Eq. 2-6}$$

Where, i = facility index,

Y_i = dependent variable for facility I,

β_0 = intercept,

β_i = parameters to be estimated,

X_i = independent variable, and

ϵi = random error term.

Clark et al. (2002) developed several linear regression models for water rehabilitation projects. The models estimate, individually, the cost of pipe materials, trenching, embedment, backfilling, valves, fittings, horizontal boring, shoring, pavement removal, traffic control, service connections, cement mortar lining, slip lining, and corrosion control. The cost of a project is calculated by adding up the results generated by all applicable models.

Clark et al. (2002) validated their regression models against data collected by Dickson (1972), for cement and mortar lined steel pipe. Although they used major cost elements in developing the regression models, many other important cost elements, such as inspection chambers, sidewalks, curbs, gutters, and abandonment of existing pipes, were not considered (Shehab and Farooq 2009). Moreover, the developed models calculate the direct cost of projects only. If the total cost is to be determined, other items, such as insurance and bonding costs, should be estimated by the user.

2.7.3.5 Artificial Intelligence Models

Warren McCulloch and Walter Pitts implemented the first artificial intelligence (AI) model in 1943. Three main sources of introducing the first artificial intelligence work were knowledge of the basic physiology and function of neurons in the brain, propositional logic, and Turing's theory of computation (Malek Mohammadi, 2019). Artificial intelligence can be defined as "the study of mental faculties through the use of computational models" (Charniak and McDermott, 1985). In other definition, AI is "The art of creating machines that perform functions that require intelligence when performed by people" (Kurzweil, 1990). According to Luger (2009), artificial intelligence can be decomposed into several categories as describes in below items:

- Game playing,
- Automated reasoning and theorem proving,
- Expert systems,
- Natural language understanding and semantics,
- Modeling human performance,
- Planning and robotics,
- Languages and environments for AI,
- Machine learning,
- Alternative representations: neural nets and genetic algorithms, and
- AI and philosophy.

In artificial intelligence models, the dependent variables are classified from a set of independent variables by learning from the available data. These models are appropriate to estimate ordinal condition ratings or nonlinear deterioration behavior, however, as a disadvantage; a large amount of data is needed to generate artificial intelligence models (Scheidegger et al., 2011). AI models are capable to handle complicated problems and processes. In recent years extensive studies have been done to model deterioration of infrastructures using neural nets and machine learning methodologies (Malek Mohammadi, 2019).

2.8 Chapter Summary

This chapter presented a comprehensive literature review of costs of trenchless cementitious SAPL, CIPP with polyester resin and steam curing, and sliplining with HDPE renewal methods. In this section, the complexity of the deterioration of pipes and the deterioration affecting factors was thoroughly explained. It was described that only one factor cannot be the cause of pipe deterioration. Numerous life-cycle cost analysis, life-cycle assessment, social cost analysis, and construction cost analysis from previous studies which emphasized such analyses as important tools in the decision-making process to choose an alternative trenchless culvert renewal method were presented in this chapter. Admittedly, these analyses provided excellent opportunities to identify the potential areas to minimize those costs. Moreover, various life-cycle prediction cost and construction estimation and prediction models of water main rehabilitation and stormwater renewals were presented in this chapter.

However, construction and environmental prediction models of trenchless SAPL, CIPP, and sliplining renewals for individual large diameter culverts have not been fully examined yet and the result of most studies reflected that it is possible to assess construction and environmental costs of a stormwater pipeline through new data analysis approaches. In nutshell, the objective of this dissertation is to model the two main life-cycle cost modules as construction and environmental costs of trenchless SAPL, CIPP, and sliplining in large diameter culverts and investigate the factors that influence construction and environmental costs of mentioned trenchless methods in general and in detail.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Based on what is discussed in the literature review chapter, there is a lack of study on the evaluation of comprehensive life-cycle cost analysis, which is including construction and environmental costs of the trenchless SAPL, CIPP, and sliplining. The majority of the previous studies of LCCA recommended an extensive construction and environmental costs implication for these trenchless renewal methods. This chapter presents the methodology adopted to analyze the construction and environmental costs of SAPL, CIPP, and sliplining trenchless renewals for this dissertation. The overall methodology was shown in Chapter 1 (Figure 1-14) which consists of the following elements:

- Literature review,
- Development of the framework of the study,
- Data Collection,
- Data analysis,
- LCCA Model development,
- Results and discussions, and
- Conclusions and recommendations.

In this chapter, the detailed and the procedure of the methodology employed to develop a comprehensive LCCA model for three trenchless renewal methods as SAPL, CIPP, and sliplining in large diameter culverts is presented.

3.2 Literature Review

There is no comprehensive LCCA model for trenchless renewal methods. LCCA models can be used to predict the future as well as evaluate the previous total costs including construction and environmental costs of trenchless renewal method projects by analyzing information obtained from previous databases. Prediction models play an essential role to generate decision making tools as they provide valuable information to forecast the short-term and long-term cost of different trenchless renewal alternatives in large diameter culverts. In general, utility companies and municipalities can forecast the future composited costs of their projects by following the same methodology and develop prediction models to identify the most cost-effective method considering the environmental impacts.

The primary objective of the LCCA prediction model is to apply appropriate artificial intelligence techniques which consist of statistical and mathematical methods to estimate future total costs of trenchless renewals. Admittedly, the LCCA prediction model is capable to identify the proportion of the contribution of each LCCA’s individual module to the total cost of SAPL, CIPP, and sliplining trenchless renewal projects. The current LCCA models are classified into two categories of statistical and artificial intelligence (AI) models.

The simple explanation of a statistical model term would be a mathematically-formalized representation to approximate reality and to predict the future outcome from this approximation. In some statistical models, the probabilistic nature of historical data is used to describe the model output as a random variable. The estimates produced by any statistical analysis are the "best guesses" based on the condition of given historical data.

The definition of artificial intelligence models is “the study of mental faculties through the use of computational models” (Charniak and McDermott, 1985). Artificial intelligence is a vast field, which its objective is to create intelligent machines, something that has been achieved many times, depending on how you define intelligence. Artificial intelligence represents powerful machine learning-based techniques, which are used to forecast an output based on learning through the input(s). In artificial intelligence models, the dependent variables are classified from a set of independent variables by learning from the available data.

3.3 Framework of the Prediction Model for Life-cycle Cost Analysis of Trenchless Renewals (LCCATR)

The objective of this dissertation is to develop an artificial intelligence model using a machine learning technique to predict two LCCA modules as construction and environmental costs of SAPL, CIPP, and sliplining as three widely-used trenchless methods for the renewal of aging culverts. To achieve this object, a model, which is named life-cycle cost analysis of trenchless renewals (LCCATR), is developed in this dissertation. The methodology to obtain the result of this model is described as follows.

First, LCCA of a project decomposed to its 2 modules as constriction and environmental costs and for each module, a specific method is used for analysis. Machine learning technique and SimaPro analysis two different methods are used to analyze the construction and environmental costs, respectively. Then, the outcomes of 2 different analyses are used as an input of the ASTM C1131 equation to achieve a comprehensive LCCA of a project. Lastly, the output of the ASTM C1131, which is the result of the LCCATR model, represents the two main modules of LCCA as construction and environmental costs of that trenchless renewal project.

After defining the framework of the study, a decision should be made to use either a deterministic or a probabilistic approach. The choice is usually based on whether the input parameters are deterministic or uncertain. For the deterministic approach, parameters are assumed to have a point value. The probabilistic approach uses a probability distribution function for all uncertain variables and therefore deals with the uncertainty in the model.

Most events in real life are a mixture of random and deterministic relationships. When something is part random and part deterministic, it is called a statistical relationship or probabilistic relationship. Both terms mean the same thing and can be used vice versa. Since in this framework, the output of the LCCATR model for construction and environmental costs has one uncertain output (from the machine learning-based model for the construction cost) and one is deterministic value (from the SimaPro analysis for the environmental costs), it is most suited to call the relationship of the input data to the LCCATR output as a probabilistic relationship. Figure 3-1 depicts a flow diagram of the above steps.

Each method that is employed to analyze of each module has its own procedure. In this chapter, the procedures, as well as the details and important properties of each method, are discussed in the following sections.

3.4 Data Collection

The data collection is conducted according to the literature review and data availability to meet all disciplines, which are required to analysis, evaluation, and determination of LCCA for trenchless rehabilitation projects. More than 500 trenchless SAPL, CIPP, and sliplining rehabilitation projects of large diameter culverts in 7 states of the US are selected from 7 Department of Transportations (DOTs) as following: Delaware, Florida, Minnesota, Ohio, New York, North Carolina, and Pennsylvania. Then the information is extracted which contains general information, attribute parameters, and cost data for each selected trenchless renewal project. In addition, rather than information associated with the selected projects, some general parameters including the general economic parameters such as the inflation rate are collected. Chapter 4 presents the details of all collected data and information used for analysis.

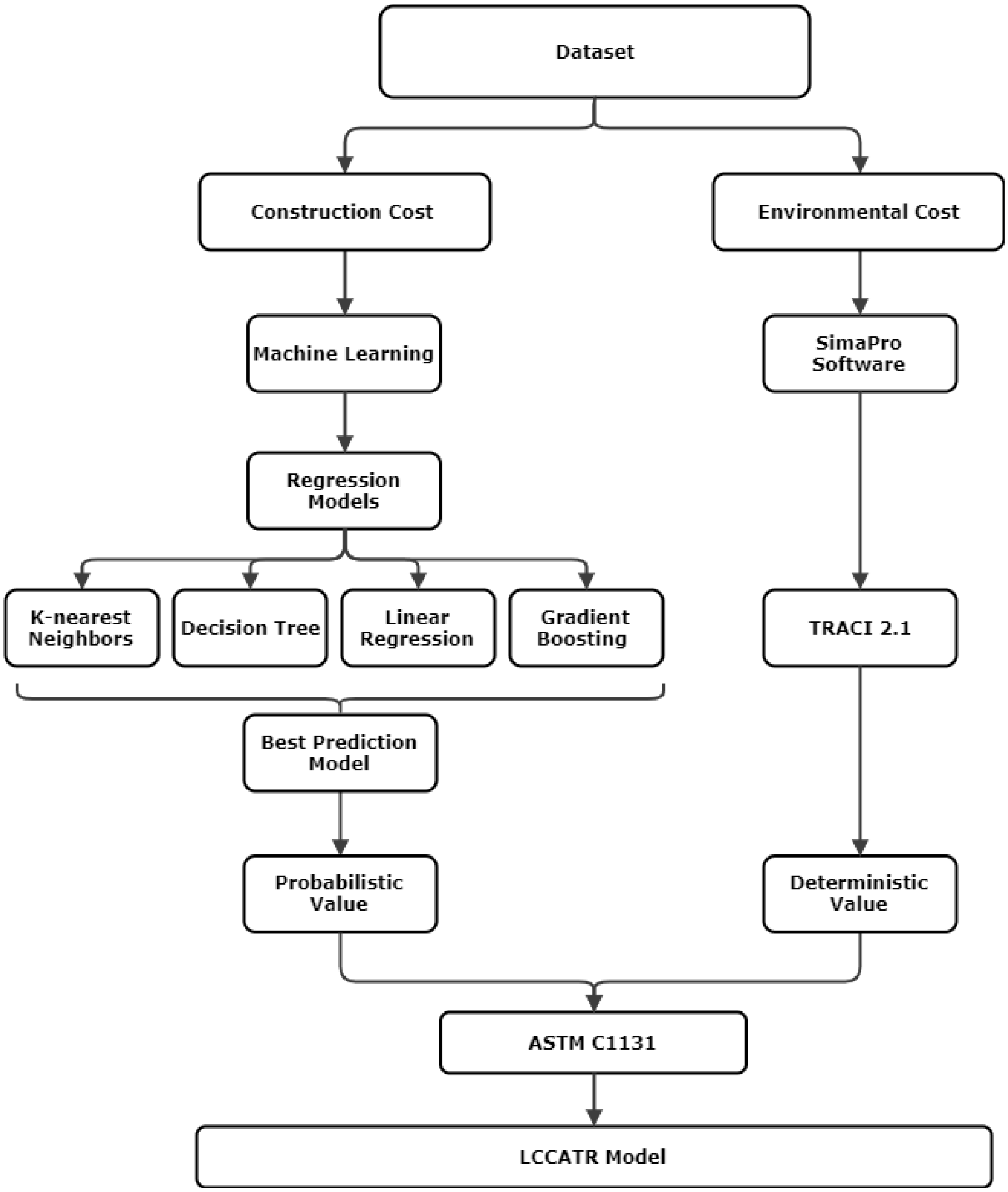


Figure 3-1 Framework of the LCCATR Model Methodology

3.5 Data Preparation

After data collection, the main data spreadsheet is created for data analysis. Each method; the machine learning method to evaluate the construction costs and SimaPro software to calculate the environmental costs, required specific input to run the analysis. However, the main data dataset included all the information needed for both methods about each of the selected projects.

The collected data needs to be prepared before developing artificial intelligence models. Below steps were conducted to prepare the dataset:

- Discover,
- Cleanse,
- Transform, and
- Store.

3.5.1 Discover Data

After collecting the data, it is important to discover each dataset. This step is required to know the data from all possible sources. Discovery is an important task and usually needs a preparation platform that offers visualization tools to help know the profile and browse the data. Technically, trying to check different sources to find the missing values is used to find missing values. However, in the end still, there were some data rows with missing values. Consequently, those rows with missing values need to be cleansed.

3.5.2 Cleanse Data

Traditionally after the data is collected, the first step which is cleaning up the data is the most time-consuming part of the data preparation process, however, it is crucial for removing faulty data and filling in gaps. The most important tasks in data cleaning are as follows:

- Removing extraneous data and outliers,
- Filling in missing values, and
- Masking private or sensitive data entries.

The next step after preparing the main dataset is to clean the data. Technically, there can be many rows in the dataset that one or more of the values are missing for some reason. Once data is cleansed, it is validated by testing for errors in the data preparation process. Often times, an error in the system become apparent during this step and needs to be resolved before moving forward.

3.5.3 Transform Data

Transforming data is the process of updating the format or value entries in order to reach an understandable well-defined result. Some values (such as cost or units) needed to transform to be able to be analyzed in one platform together (data transforming). For instance, cost data from different years should be all transform by cost adjustment using the commutative inflation rate to the current cost.

3.5.4 Store Data

Once data is prepared, the data can be stored or channeled into a third party application (business intelligence tool such as Python which is used in this dissertation) clearing the way for processing and analysis to take place.

3.6 Description and Visualization of Data

Subsequently, different data visualization techniques such as histogram, scatter plot, and pie or circle chart are used to visualize dataset, which represents large quantities of data coherently. The data visualization can contribute an understanding of data by leveraging the human visual system’s highly tuned ability to see trends, patterns, scatter, and identification of possible outliers. Admittedly, using data visualization techniques helps the user discern relationships in the data and prevent the dissertation from what the data has to say.

Finally yet importantly, the prepared visualized dataset is used as an input for two different methods, which are employed to analyze the two LCCA modules in this dissertation. Based on the literature review and data availability supervised machine learning found to be the best method to analyze and predict the construction cost of a trenchless project. Likewise, it is found that SimaPro software is the most suited and widely-used application to evaluate the environmental impacts of infrastructure and underground constructions. Following both of these methods and characteristics of the developed model are elaborated thoroughly.

3.7 Model Development

The most important process of any statistical analysis is to select the most-suited model. In this section, the two main methods to analyze the construction and environmental costs are presented.

To analyze the construction module of the LCCA, 4 machine learning models are employed to predict the construction cost of the SAPL, CIPP, and sliplining trenchless renewal projects. The selection of the models for culverts are dependent on various factors, such as the data availability, and number and type of independent and dependent variables. Then, one model is selected from 4 models as the prediction model of the construction cost.

The first model developed in this dissertation is K-nearest Neighbors (KNN) to predict the construction cost of trenchless renewals. Nearest neighbor method works based on identifying the labels of K-nearest patterns in data space and predict the dependent variable based on the distance of the data points. K-Nearest Neighbors is developed in this dissertation to satisfy the second objective of this dissertation about the diversity of the different statistical and artificial intelligence models and validating the result of logistic regression and gradient boosting tree models.

Additionally, KNN is used for regression and classification and the application of this method is not well studied in this area. Decision tree regression is the second developed model to forecast the construction cost of trenchless SAPL, CIPP, and sliplining renewal methods. Multi linear regression model is the third model developed in this dissertation as an artificial intelligence model. Gradient boosting is the last model developed in this dissertation, which is one of the most powerful learning techniques presented in past twenty years and it, is originally designed for classification problems. Gradient boosting is a machine learning technique for prediction and simulation with combining weak learners into a single strong learner (Hastie, 2017).

In this dissertation, since the goal was to find the most accurate prediction model, the most appropriate construction cost prediction model was selected based on the following reasons:

- The capability of the model to be trained by nominal variables such as type of trenchless technology and continuous variables such as pipe diameter and length,
- The performance of the model to predict continuous dependent variable (construction cost), and
- By using cross-validation to determine the root-mean-square error (RMSE) for each model. The one with the smallest RMSE is the one that is selected as the best prediction model.

To evaluate the environmental module of the LCCA, SimaPro software is used. Since there was a lack of complete information on selected trenchless renewal projects, a model is developed to work as a SimaPro software to be able to get the inputs and give the results without needing of using the software each time. To achieve this goal, it was needed to run the software several times and collect the results. Then, the output of the software is analyzed to develop a model to be able to calculate the environmental costs of SAPL, CIPP, and sliplining trenchless renewal projects.

The following, the detail and important properties of the two main methods to analyze the construction and environmental costs and 4 developed machine learning models in the purpose of construction cost analysis are presented.

3.7.1 Machine Learning

In 1959, Arthur Samuel defined machine learning as a “Field of study that gives computers the ability to learn without being explicitly programmed” (Simon, 2015). Also, machine learning can be defined as an automated process that extracts patterns and trends from a large number of data (Xinghua et al., 2019). In the field of predictive data analytics, machine learning is a method used to devise complex prediction algorithms and models (Mitchell, 1997; Kelleher et al., 2015).

These analytical models provide the capability for data analysts to uncover hidden insights, predict future values, and produce reliable, repeatable decisions through learning from historical relationships and trends in the data (SAS, 2018, Xinghua et al., 2019). Machine learning can learn directly from examples and experiences in the form of data, by exploring different prediction constructions and algorithms (Bishop, 2016). Typically, the predictive strength of machine learning models is used in industrial situations, especially when there is a requirement to have a vision of future data which is called a prediction approach based upon previous historical data (Malek Mohammadi, 2019).

Machine learning can be categorized into three broad classifications based on the nature of the learning as follows (Bishop, 2016):

- Supervised learning: in supervised learning models, the training data includes examples of input variables with their corresponding output variables (Figure 3-6).
- Unsupervised learning: application in which the training data comprises a set of input variables without any corresponding output variables (Figure 3-7).
- Reinforcement learning: same as unsupervised learning, the output variables are not given in the model and the targets should be predicted by trial and error (Figure 3-4).

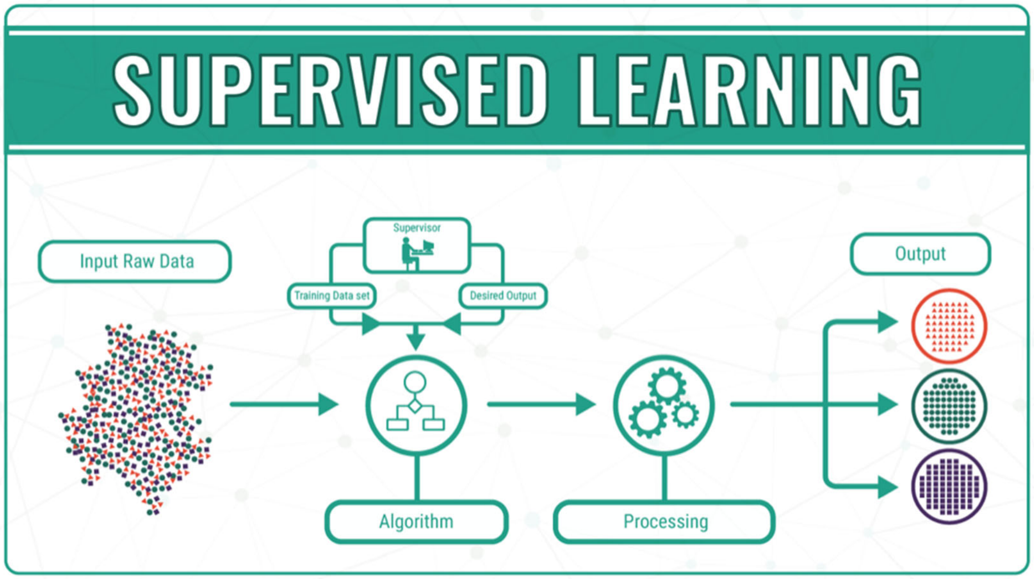


Figure 3-2 Supervised Machine Learning Source: Ronald van Loon Available at: www.bigdata-madesimple.com (Accessed December 01, 2019)

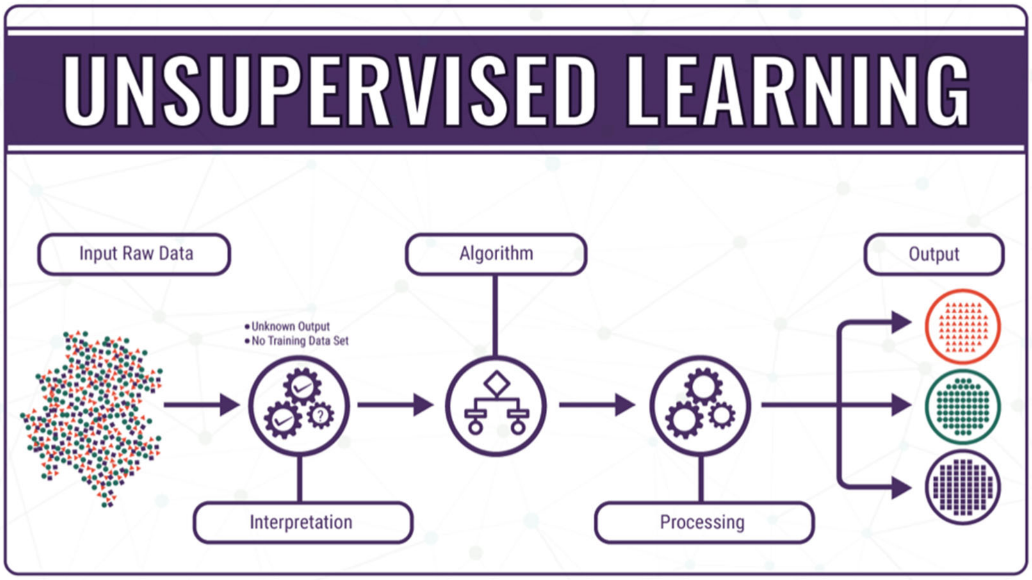


Figure 3-3 Unsupervised Machine Learning Source: Ronald van Loon Available at: www.bigdata-madesimple.com (Accessed December 01, 2019)

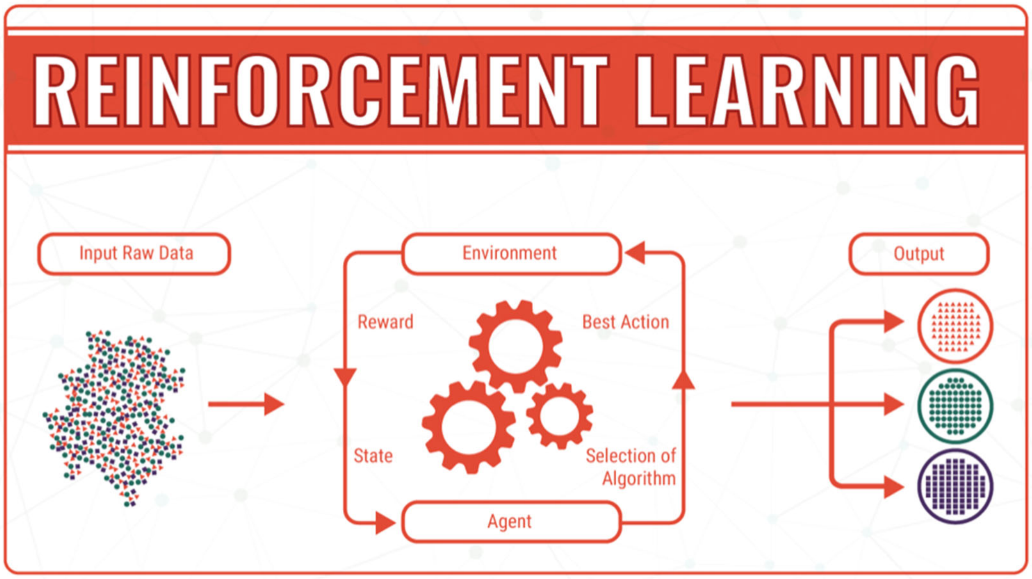


Figure 3-4 Reinforcement Machine Learning Source: Ronald van Loon Available at: www.bigdata-madesimple.com (Accessed December 01, 2019)

Another type of classification of machine learning can be based on the desired output of the modeling systems. Following definitions of these categories are presented:

- Classification: the outputs are divided into two or more classes and typically, supervised learning is used to model this class (Figure 3-5).
- Regression: in this category, the outputs are continuous rather than discrete and a supervised problem (Figure 3-5).
- Clustering: in clustering category, a set of inputs are classified into different groups. Unlike classification and regression, this is an unsupervised task.
- Density estimation: the distribution of inputs is found in some space in this category.
- Dimensionality reduction: simplifying the inputs by mapping them into a lower-dimensional space.

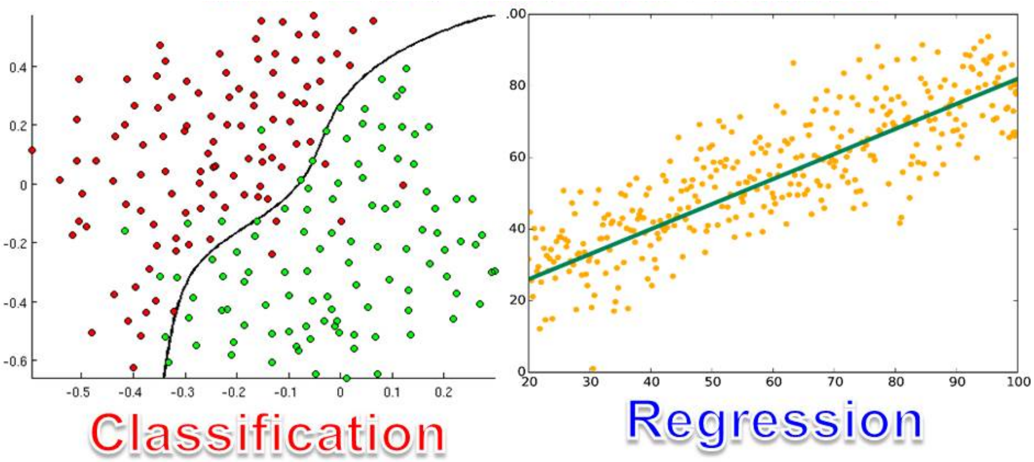


Figure 3-5 Difference between Classification and Regression Source: Kindsonthegenius Available at: www.kindsonthegenius.com (Accessed December 12, 2019)

Recently, the trend of taking advantage of using a machine learning method is rapidly growing in different fields of studies. Various machine learning models, such as linear regression, decision trees, and gradient boosting regression are used in the wastewater industry, to analyze and predict the construction costs and the life-cycle cost of pipelines.

In this dissertation, 4 regression-based machine learning models are employed. Regression is a form of supervised machine learning, which is where the data analyst teaches the machine by showing it features over and over and then showing it what the correct answer is in a repeatedly process to teach the machine. Once the machine is taught, the data analyst is able to test the machine on some new data points, where the data analyst still knows what the correct answer is, but the machine does not. The machine's answers are compared to the known answers, and in this way, the machine's accuracy can be measured. If the accuracy is high enough, the data analyst may consider actually employing the algorithm in the real world. In the following, the 4 regression algorithms and techniques of machine learning method are presented.

3.7.1.1 K-nearest Neighbor (KNN)

The K-nearest neighbor regressor (KNN) is one of the most widely used, non-parametric classification, and straightforward algorithms in machine learning method, however, it is limited due to memory consumption related to the size of the data, which is caused to not use for applying to large volumes of data (Salvador–Meneses et al., 2019). KNN is a type of instance-based learning, or lazy learning, which means that in the learning stage, it merely stores a set of the training set (input-output pairs).

When an output for a new query instance has to be determined, the algorithm finds K number of training which are the closest to the query point, using a similarity function usually based on the Euclidean distance. Then it performs local interpolation of the targets associated with the nearest neighbors (Amaral et al., 2019). In a simple word, KNN locates

K nearest neighbors in the predictor space to predict new value using the summary statistic which means this method is based on the principle that observations within a dataset are usually placed close to other observations that have similar attributes (García-Laencina et al., 2009). Given an observation from which it is in the purpose to predict the class to which it belongs, this method selects the closest observations (Figure 3-6) from the data in such a way to minimize this distance (Jerez et al., 2010).

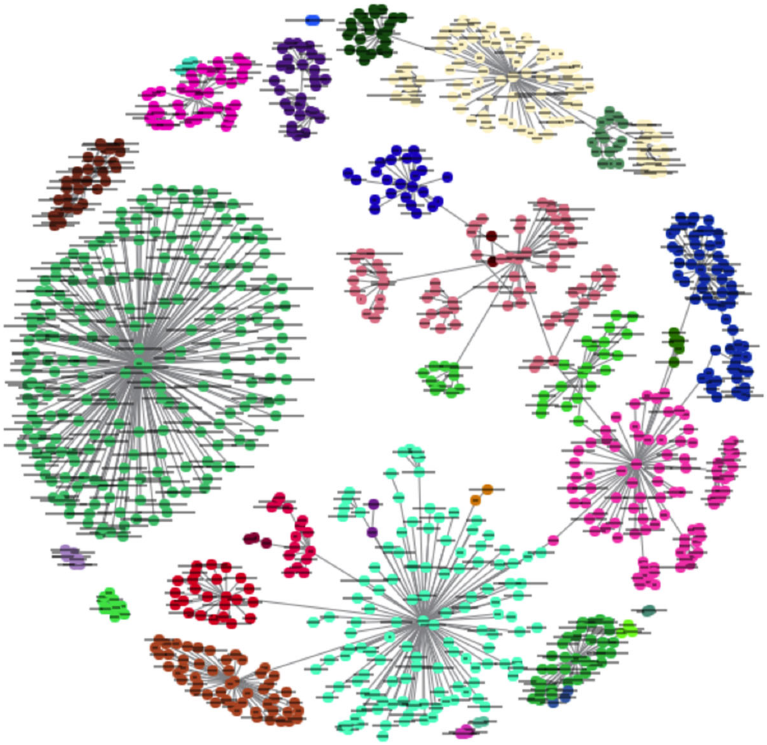
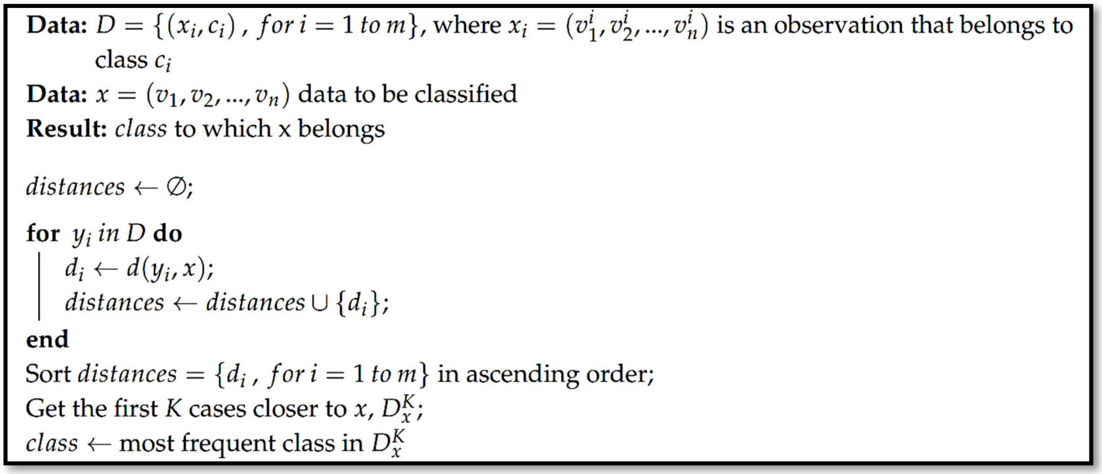


Figure 3-6 Schematic Illustration of the K-nearest Neighbors (KNN) Source: Aishwarya Singh Available at: www.analyticsvidhya.com (Accessed December 12, 2019)

3.7.1.1.1 KNN Algorithm

The algorithm of the basic scheme of the KNN method on a dataset with "m" observations shows in Figure 3-7. It should be emphasized that from the algorithm definition, it is required to determine the concept of distance between observations (Amaral et al., 2019).



```
Data: $D = \{(x_i, c_i)\ ,\ for\ i = 1\ to\ m\}$, where $x_i = (v_1^i, v_2^i, ..., v_n^i)$ is an observation that belongs to
        class $c_i$
Data: $x = (v_1, v_2, ..., v_n)$ data to be classified
Result: $class$ to which x belongs

$distances \leftarrow \emptyset$;

for $y_i$ in D do
    $d_i \leftarrow d(y_i, x)$;
    $distances \leftarrow distances \cup \{d_i\}$;
end
Sort $distances = \{d_i\ ,\ for\ i = 1\ to\ m\}$ in ascending order;
Get the first $K$ cases closer to $x$, $D_x^K$;
$class \leftarrow$ most frequent class in $D_x^K$
```

Figure 3-7 Algorithm of the K-nearest Neighbors (KNN) (Amaral et al., 2019)

The following paragraphs are presented to explain this algorithm in action with the help of a simple example. It is supposed that there is a dataset with two variables, which when plotted, looks like the one in Figure 3-8.

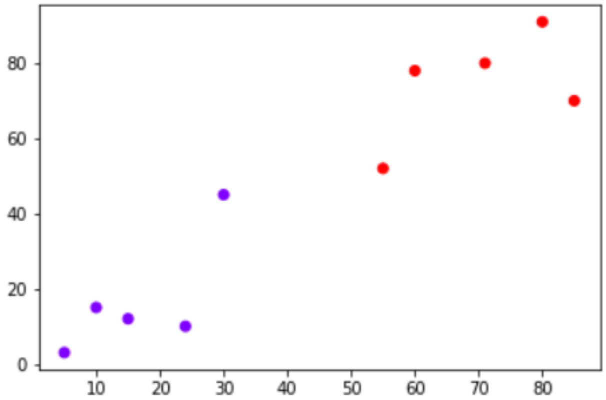


Figure 3-8 Plot of Dataset with 2 Variables Source: Scott Robinson, Available at: www.stackabuse.com (Accessed December 03, 2019)

This algorithm is applied to classify a new data point with 'X' into the "Blue" class or "Red" class. The coordinate values of the data point are x=45 and y=50. It is supposed that the value of K is 3. The KNN algorithm begins by calculating the distance of point 'X' from all the points. Subsequently, the 3 nearest points are found which have the least distance to point 'X'. Figure 3-9 illustrates the explained concept while the three nearest points are encircled.

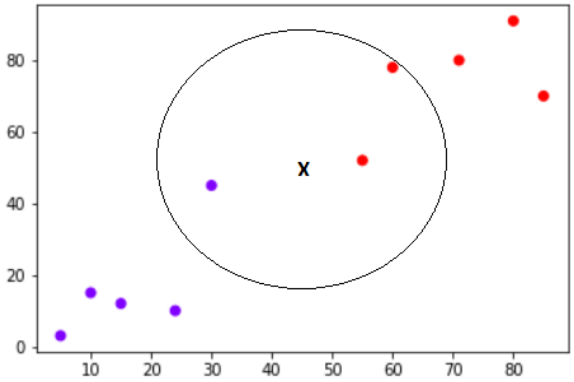


Figure 3-9 Plot of Dataset with 2 Variables Source: Scott Robinson, Available at: www.stackabuse.com (Accessed December 03, 2019)

The final step is to classify the 'X' point (assign a new point to the class (red or blue) to which the majority of the three nearest points belong). From Figure 3-9 it can be seen that the two of the three nearest points belong to the class "Red" while one belongs to the class "Blue". Consequently, the new data point 'X' can be classified as "Red".

3.7.1.1.2 Methods of Calculating Distance between Points

To use the KNN machine learning algorithm, it is required to calculate the distance between the new point and each training point. There are several methods to calculate this distance, but the most well-known methods for continuous variables are Euclidian and Manhattan and for categorical variables is Hamming distance.

1. Euclidean distance is calculated as the square root of the sum of the squared differences between a new point (x) and an existing point (y).

2. Manhattan distance is the distance between real vectors using the sum of their absolute difference (Figure 3-10).

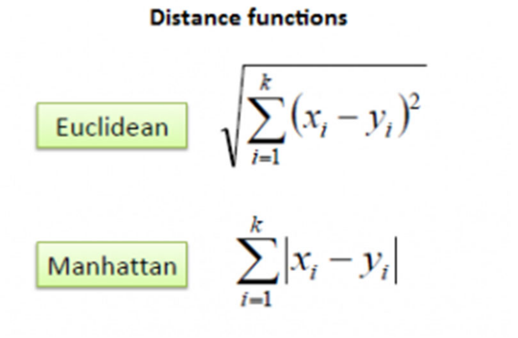


Figure 3-10 Euclidean and Manhattan KNN Distance Calculation Methods Source: Aishwarya Singh Available at: www.analyticsvidhya.com (Accessed December 03, 2019)

3. Hamming distance is used for categorical variables. If the value (x) and the value (y) are same, the distance is equal to 0, otherwise the distance is equal to 1 (Analyticsvidhya, 2018) (Figure 3-11).

$$D_H = \sum_{i=1}^{k} |x_i - y_i|$$

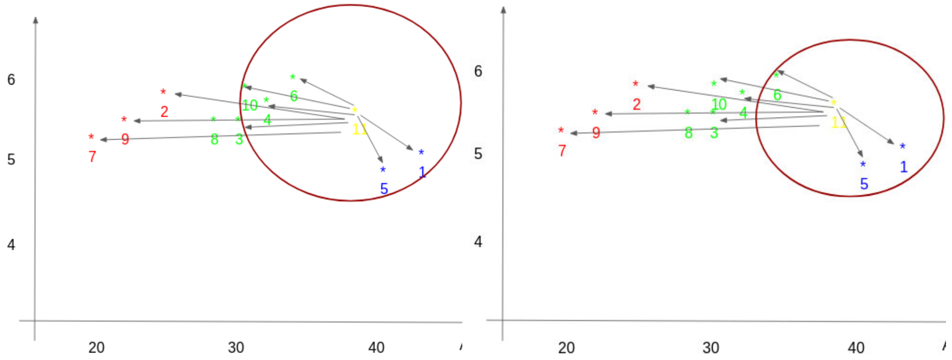
$$x = y \Rightarrow D = 0$$

$$x \neq y \Rightarrow D = 1$$

Figure 3-11 Hamming KNN Distance Calculation Method Source: Aishwarya Singh Available at: www.analyticsvidhya.com (Accessed December 03, 2019)

3.7.1.1.3 Determining the K Value in KNN

The important decision to be made in K nearest neighbor regression is to select the K value. This determines the number of neighbors it needs to consider when a value is assigned to any new observation. For instance, the following graph (Figure 3-12) is presented to show the difference between selecting a K value of 3 and 5.



(a) (b)

Figure 3-12 Plot of Dataset with 2 Variables: a. K Value = 5 b. K Value = 3 Source: Aishwarya Singh Available at: www.analyticsvidhya.com (Accessed December 03, 2019)

When the size of neighborhoods is small, little and scattered neighborhoods appear in regions and the model tends to overfit. In contrast, a model in which the size of neighborhoods is high can potentially ignore the patterns which are in minority. Figure 3-13 illustrates a classification model with K = 1, 3, 5, and 7 on a two-dimensional data. It can be seen that for K = 1, several neighborhoods raised around the blue outliers located in the area of red data points. Understandably, the boundary gradually becomes smoother with the increasing value of K. For K = 7, the classifier technically ignored smaller patterns and the KNN search for the K-nearest patterns in the whole picture. It can be concluded that in larger neighborhood sizes, the risk of overfitting is lower, and the model yields a good approximation. Selecting an appropriate size of the neighborhood is an important part of developing K-nearest Neighbors models. Various techniques such as cross-validation can be used to select the best model and parameters in KNN models (Kramer, 2016).

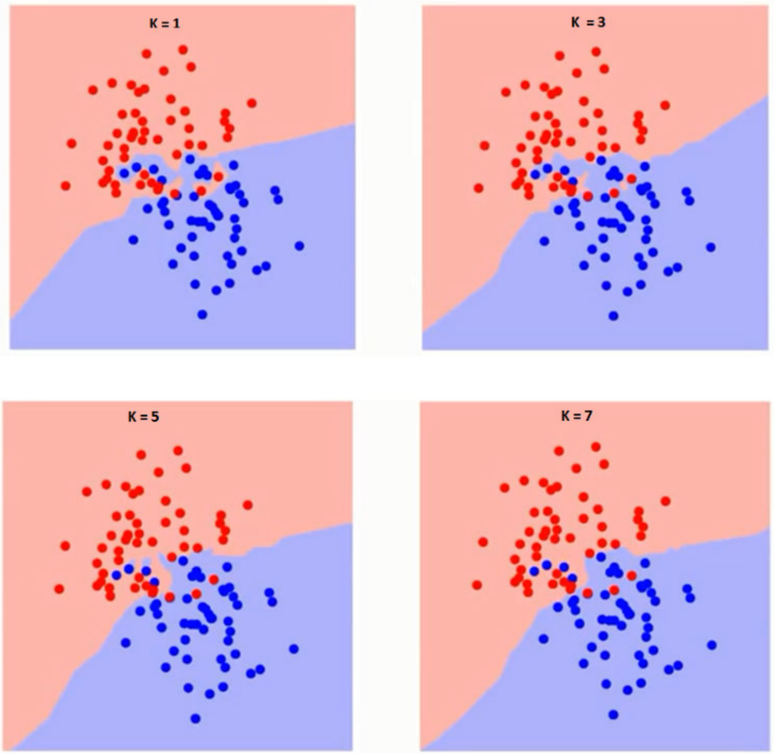


Figure 3-13 Comparison of Different K Value in KNN Classification Source: Aishwarya Singh Available at: www.analyticsvidhya.com (Accessed December 12, 2019)

3.7.1.1.4 Cross-Validation

Cross-validation is a strategy to avoid overfitting during training and testing machine learning models. In this method, the N observations $\{(xi, yi)\}^{N}_{i=1}$ split up into training, validation, and test set while the training set is used to learn the algorithm in the model. The validation set is used to evaluate the model and the test set is used to evaluate the final independent test set (Biau and Scornet, 2016).

K-fold cross-validation is one of the most widely-used and straightforward strategies to utilize to avoid overfitting. In this strategy, the learning process is repeated k times with different training and validation sets. To generate K-fold cross-validation, the model is trained using $k - 1$ sets which are employed for training. The remaining part of the data as the validation set is used to evaluate the model. For example, to split the data into 80% training and 20% testing, 5-fold cross-validation should be used during model development (Figure 3-14).

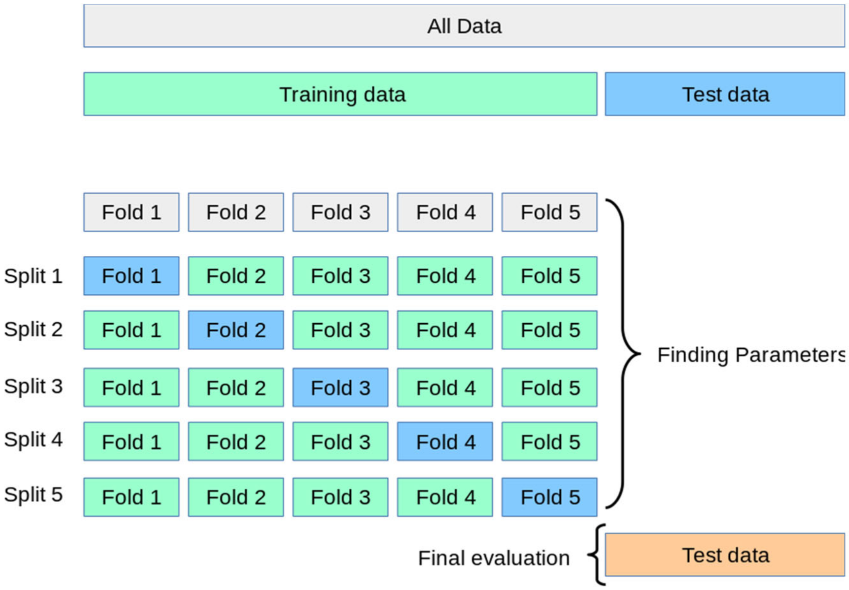


Figure 3-14 5-fold Cross-Validation Source: Scikit-learn Available at: www.scikit-learn.org (Accessed December 07, 2019)

The performance measure reported by k-fold cross-validation is then the average of the values computed in the loop. This approach can be computationally expensive but does not waste too much data (as is the case when fixing an arbitrary validation set), which is a major advantage in problems such as inverse inference where the number of samples is very small (Scikit-learn, 2019).

3.7.1.2 Decision Tree

The decision tree is a hierarchical data structure implementing the divide-and-conquer strategy. It uses a flowchart-like tree structure or is a model of decisions and all of their possible results, including outcomes, input costs, and utility. Decision-tree algorithm falls under the category of supervised learning algorithms. It is an efficient nonparametric method, which can be used for both regression and classification (Alpaydin, 2004). Decision tree regression is highly competitive with different machine learning algorithms and it is often applied as a machine learning model to solve many real-life problems (Czajkowski and Kretowski, 2016). The decision tree is a type of machine learning tools that can satisfy both good prediction accuracy and easy interpretation. Decision tree regression uses a tree-like model and it is built through an iterative process that splits each node into child nodes by certain rules unless it has a terminal node that the samples fall into. A regression model is fitted to each terminal node to get the predicted values of the output variables of new samples (Günaydin et al., 2019).

Decision tree regression is widely used to develop prediction models since it observes features of an object and trains a model in the structure of a tree to predict data in the future to produce meaningful continuous output. Continuous output means that the output/result is not discrete. In other words, the output is not represented just by a discrete, known set of numbers or values (in this dissertation the output is the cost, which is continuous, result).

In a simple word, the decision trees are used to fit a sine curve with addition to noisy observation. As a result, it learns local linear regressions approximating the sine curve. In decision tree regression, maximum depth parameter of the tree is a parameter, which allows the maximum distance from the training data in the model to learn from the data. If the maximum depth parameter is set too high, the decision trees learn too fine details of the training data and learn from the noise, which is cased overfitting. Figure 3-15 is presented to elaborate on a schematic concept of a decision tree regression.

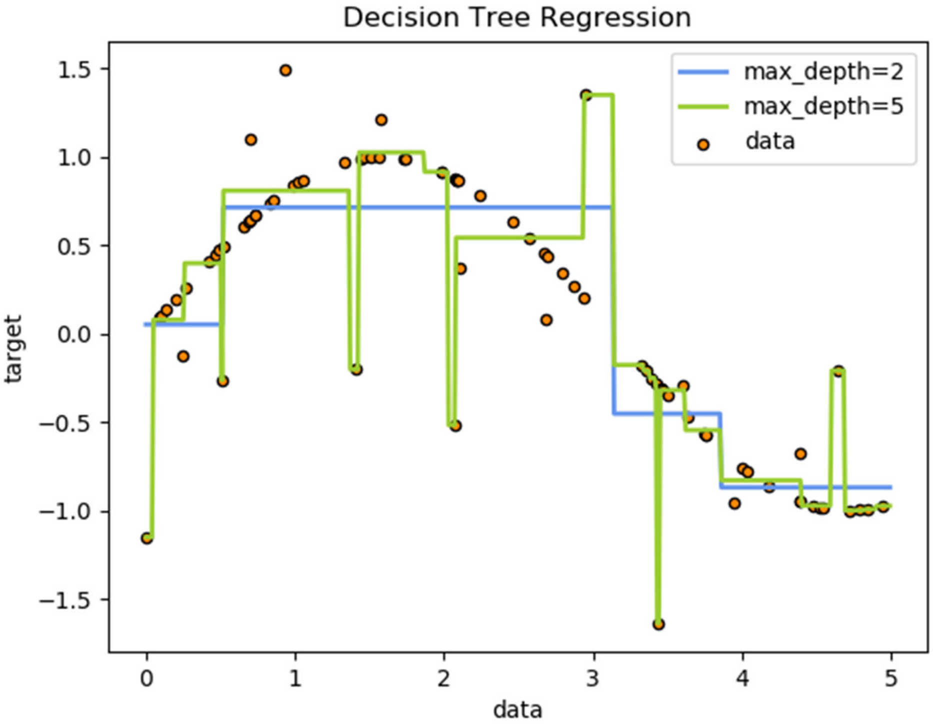


Figure 3-15 Decision Tree Regression Source: Scikit-learn Available at: www.scikit-learn.org (Accessed December 11, 2019)

3.7.1.3 Linear Regression

3.7.1.3.1 Simple Linear Regression

The "linearity" term in algebra means a linear relationship between two or more variables. If this relationship between two variables is drawn in a two-dimensional space, a straight line will be the output. Linear regression performs the task to predict a dependent variable value (y) based on a given independent variable (x). Thus, this machine learning-based regression technique finds out a relationship, which is linear between input (x) and output (y). If the independent variable (x) is plotted on the x-axis and dependent variable (y) on the y-axis, a straight line that best fits the data points is the linear regression as shown in the figure below (Figure 3-16).

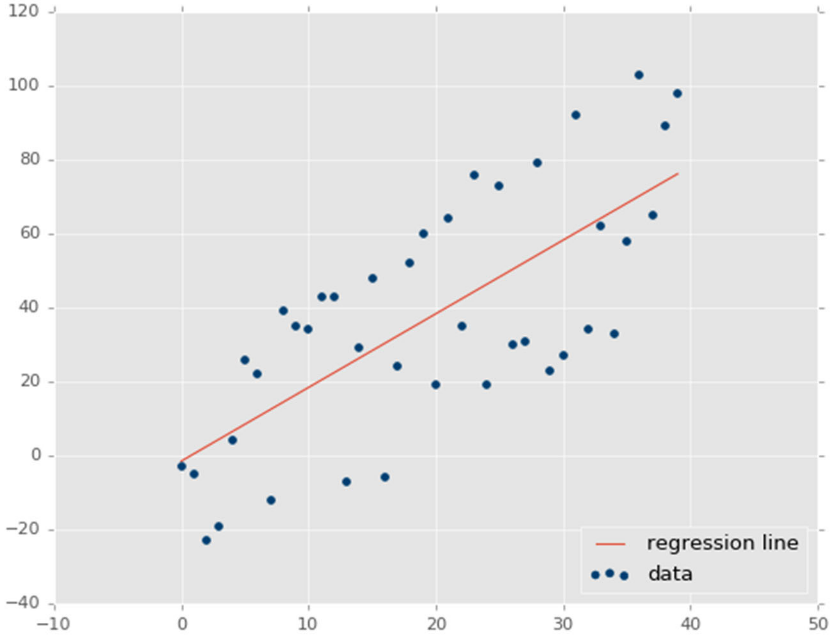


Figure 3-16 Linear Regression Source: Python Programming Available at: www. pythonprogramming.net (Accessed December 12, 2019)

The equation of the above line is:

$$y = mx + b. \qquad \text{Eq. 3-1}$$

Where (b) is the intercept and (m) is the slope of the line. Hence, in two dimensions, the linear regression algorithm results from the most optimal value for the intercept and the slope. The input (x) and output (y) variables remain the same, as they are the data features and cannot be changed. The values that can be controlled are the intercept (b) and slope (m). Always, there can be multiple straight lines to be drawn depending on the values of intercept and slope. Technically, the linear regression algorithm fits multiple lines on the dataset points and the result is the line which has the least error.

3.7.1.3.2 *Multiple Linear Regression*

The algorithm, which is discussed for the simple linear regression can be extended to cases where there are more than two variables, involve which is called multiple linear regression. For example, the multiple linear regression is applied if the objective is to predict the cost of a pipe installation based upon its material, method of the installation, location, soil specification, depth of the excavation, and so on. In this case, the dependent variable (target variable which in this example is the unit cost of a pipe installation) is dependent upon several independent variables. A regression model involving multiple variables can be presented as follows:

$$y = b_0 + m_1b_1 + m_2b_2 + m_3b_3 + \ldots \ldots + m_nb_n \qquad \text{Eq. 3-2}$$

The equation 3-2 is the equation of a hyperplane since a linear regression model in two dimensions is a straight line; in three dimensions it is a plane, and in more than three dimensions, a hyperplane. The concept of schematic hyperplane shows in Figure 3-17.

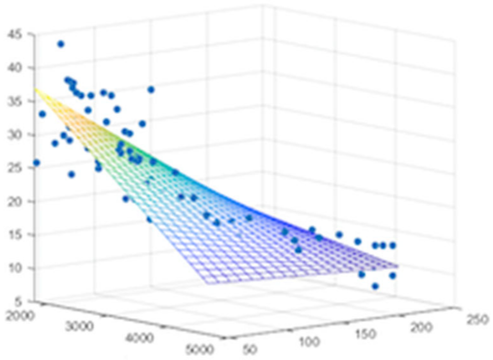


Figure 3-17 Multiple Linear Regression, Hyperplane Source: Python Programming Available at: www.pythonprogramming.net (Accessed December 12, 2019)

3.7.1.4 *Gradient Boosting*

Gradient boosting is a machine learning technique for regression and classification, which provides a prediction model by improving the performance of weak learners to create a strong predictive model. In this method, a weak learner is run repeatedly on various training data to develop classifiers. Then, the classifiers are combined into a single strong classifier to achieve a higher accuracy (Rokach and Maimon, 2015). In fact, gradient boosting tree is an ensemble model that employs the strengths of a collection of simpler base models to develop a prediction model (Friedman, J. 2001). In short, gradient boosting produces an ensemble of decision trees that, on their own, are weak decision models. Many recent machine learning approaches determined that the prediction of an ensemble of models works better than only a single prediction model. Gradient boosting models are becoming popular because of their effectiveness at classifying complex datasets.

There are two important parameters in the gradient boosting algorithm as estimator and tree depth. Data analysts are changing these two parameters to find the most-fitted model with the highest accuracy and lowest error. To elaborate on the concept of this algorithm, a gradient boosting regression with 1 estimator and a tree with a depth of 1 versus a simple linear regression of a two dimensions dataset is presented in Figure 3-18.

Figure 3-18 shows that the gradient boosting with 1 estimator and tree depth of 1 is not certainly the best model, but gradient boosting models are not supposed always to have just 1 estimator and a single tree split. The next figure shows the comparison between different numbers of estimators with a single tree split (Figure 3-19).

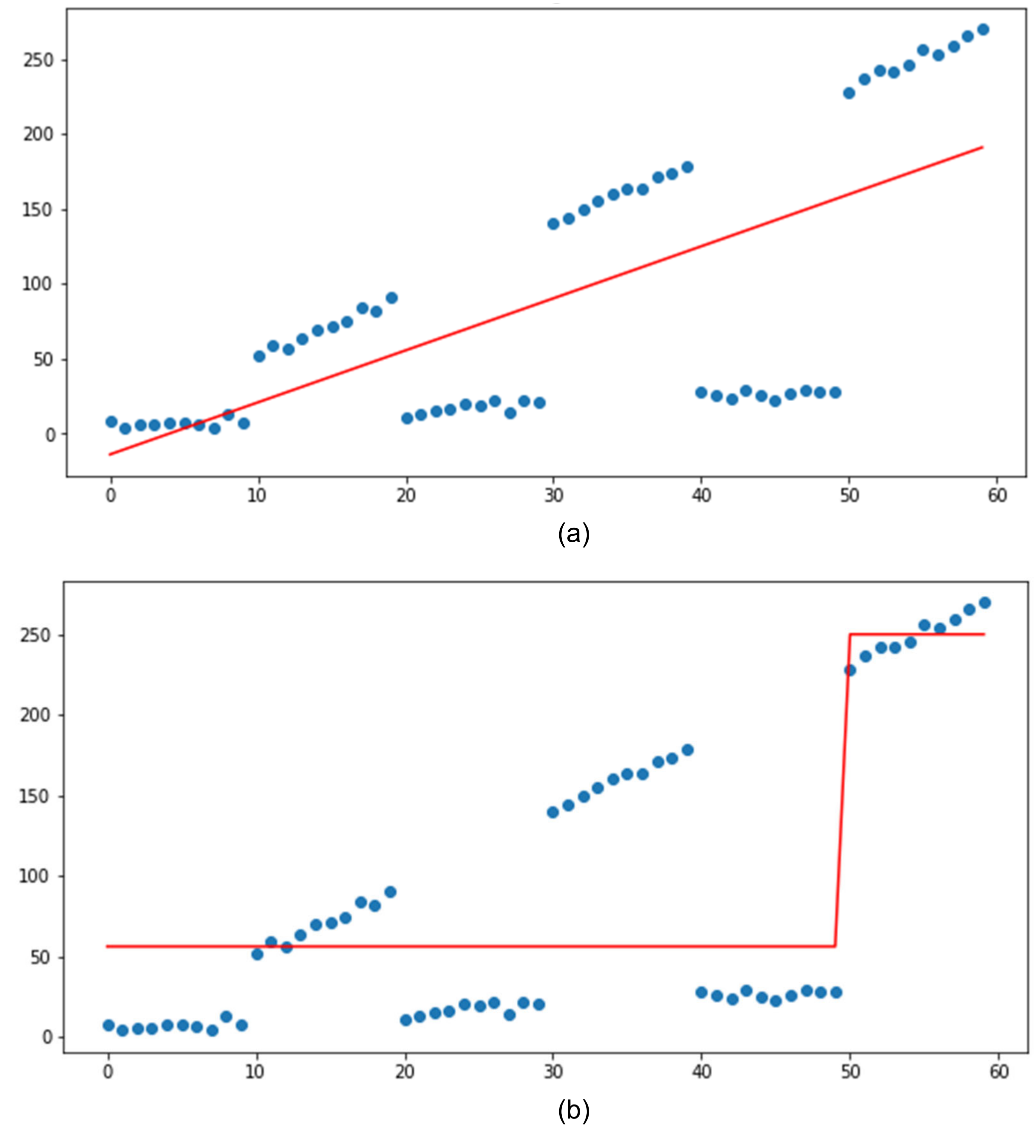


Figure 3-18 a. Liner Regression b. Gradient Boosting Regression Source: Ben Alex Keen Available at: www.benalexkeen.com (Accessed December 12, 2019)

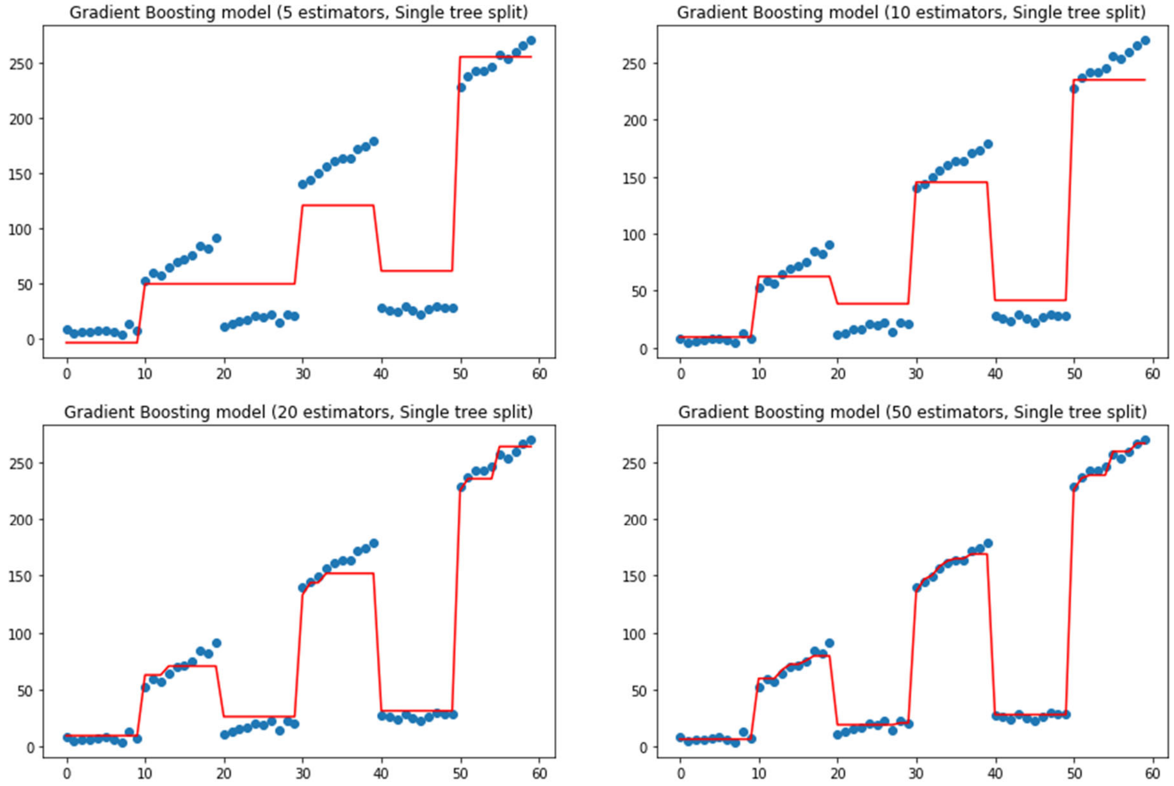


Figure 3-19 Gradient Boosting Regression with Different Estimators and Constant Tree Splits Source: Ben Alex Keen Available at: www.benalexkeen.com (Accessed December 12, 2019)

Understandably, with increasing the value of an estimator, the prediction model is getting closer to the cluster of variables. For estimator of 50, the classifier technically ignored smaller patterns and the gradient boosting regression search for the classification of the dataset, which may lead to overfitting. As another example, if the number of estimator keeps constant, with increasing the value of tree splits, the model is splitting in a way to cover all the single value of the dataset, which gives a better approximation of the output, however, again the model caused to overfitting. Following

Figure 3-20 is plotted to depict this concept of increasing the tree splits while keeping the estimators constant.

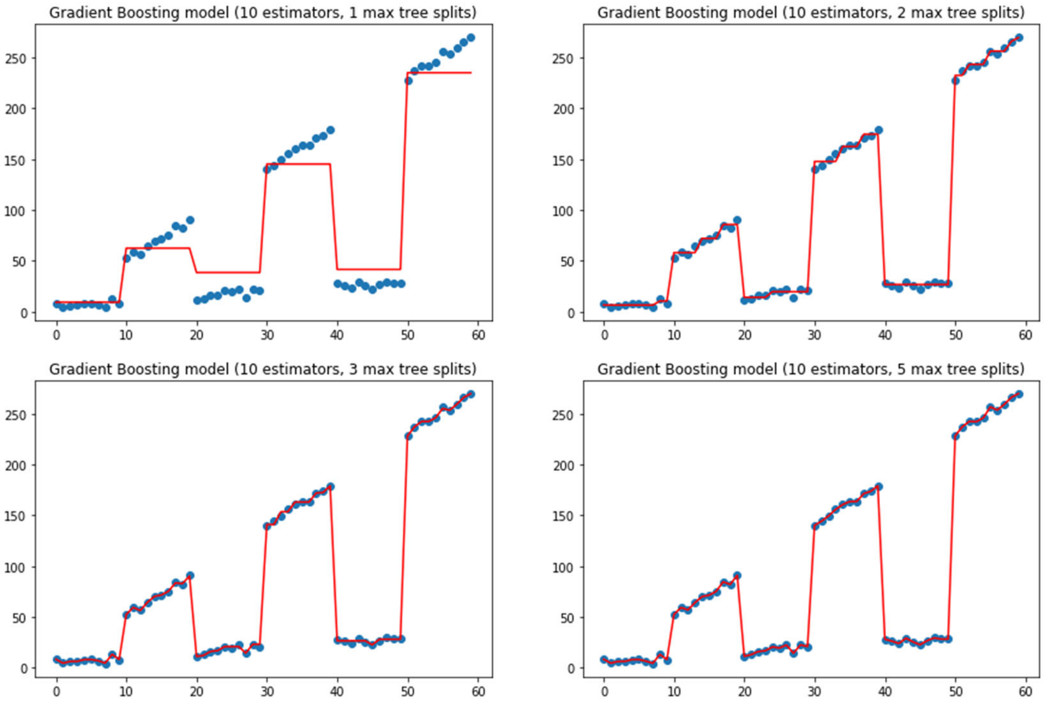


Figure 3-20 Gradient Boosting Regression with Different Tree Splits and Constant Estimators Source: Ben Alex Keen Available at: www.benalexkeen.com

Therefore, it is imperative to use validation splits/cross-validation, which is explained in section 3.7.1.1.4 to make sure the model is not overfitting the gradient boosting models.

3.7.2 SimaPro Software

3.7.2.1 Life-cycle Assessment (LCA)

Environmental impact assessment, also known as life-cycle assessment (LCA), is a systematic tool or framework used to identify and evaluate the environmental impacts associated with the energy and resources to create materials or services throughout the product's entire lifespan (ISO, 2006; Theis and Tomkin, 2013). Figure 3-21 shows the four steps as per ISO published framework that was followed for LCA.

The first most important step is to define the scope of the LCA. This involves setting clear boundaries of the investigated system, allowing the quantity and quality of inputs and outputs across this boundary to be measured. Thereafter, goals and scope are defined. The inventory analysis is the next step, which involves collecting data on the use of energy and materials for the product or service. The impact assessment uses the inventory data to sum the resources and energy consumed and wastes emitted by all processes in the system to estimate potential impacts on the environment. Interpretation of these results allows decisions to be made to reduce potential impacts by changing energy/material sources or updating processes or to decide between products/services (ISO, 2006; Theis and Tomkin, 2013).

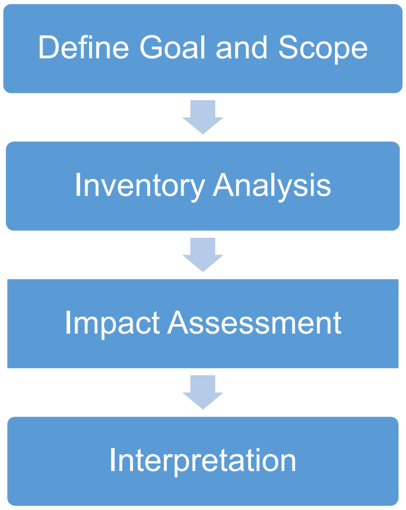


Figure 3-21 Framework for Life Cycle Environmental Analysis using SimaPro 2017 Software (Kaushal, 2019)

3.7.2.2 SimaPro Analysis

SimaPro is a software containing inventory databases and impact assessment methodologies to perform LCA studies (PRé, 2019). These installed databases contain the energy and material requirements and waste emissions for over 10,000 industrial and commercial processes (PRé, 2016) (Figure A-1, Appendix A).

SimaPro models the end-of-life phase through waste scenarios and waste treatment processes. Waste treatments document the emissions and impacts that arise from landfilling, burning, recycling, or composting of waste (PRé, 2016). The waste scenarios in SimaPro are based on material flow and do not observe product characteristics (PRé, 2016). For example, the waste treatment “Landfilling of municipal solid waste” gives the emissions and fuel requirements to landfill a unit mass of generic MSW and does not delineate the chemical composition of the MSW.

SimaPro has several pre-installed waste treatment scenarios that are useful in LCA, but does allow for the creation of custom waste treatment scenarios. Using data, the material, fuel, and energy inputs and corresponding emissions to air, the ground, and water can be defined for a specified waste. These inputs to construct custom waste treatment scenarios are in units of mass, meaning energy and fuel requirements and emissions are calculated as masses given the mass of the treated waste.

SimaPro uses the previously defined boundaries and pulls inventory data from its database to perform the impact assessment. An indicator substance is used in each impact category, and all emissions across material and fuel inputs and waste are converted to equivalents of these indicator substances (PRé, 2016). For example, to measure impacts on Global Warming, emissions from all steps or system processes are converted to equivalent masses of CO2 and totaled. This conversion and summation are performed for all categories to allow meaningful comparison between products or processes.

The outputs provided by SimaPro can then be displayed in an easy-to-read bar chart. For each impact category, the scenario with the largest impact will be scaled to 100, and the remaining processes will have their impact scaled off of the 100. For example, comparing two generic waste treatments 1 and 2 for impacts to global warming: If treatment 1 has 50kg CO_2 equivalent emissions and treatment 2 has 25kg CO_2 equivalents, treatment 1 will be represented by a bar with height 100, and treatment 2 with a bar height of 50. This is done for each impact category and all impact categories are shown on the same graph.

3.3.1.1 Method: Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) 2.1

The Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) is an environmental impact assessment tool created by the US Environmental Protection Agency (EPA) (EPA, 2016; PRé, 2016) (Figure A-2, Appendix A). TRACI calculates impact assessments based on ten impact categories:

1. Ozone depletion (measured in kg CFC-11 (Freon-11) equivalents)
2. Global warming (measured in kg CO_2 equivalents)
3. Smog (measured in kg O_3 equivalents)
4. Acidification (measured in kg SO_2 equivalents)
5. Eutrophication (measured in kg N equivalents)
6. Carcinogenics (measured in comparative toxic units (CTU) for morbidity (h))
7. Non-carcinogenics (measured in CTUh)
8. Respiratory effects (measured in kg particulate matter (PM) 2.5 equivalents)
9. Ecotoxicity (measured in CTU for aquatic ecotoxicity (CTUe))
10. Fossil Fuel Depletion (measured in MJ)

TRACI has factors for normalization to allow for comparison between impact categories. The normalization divides the calculated outputs for the individual impact categories by the averaged impact values of the US or Canadian citizen for each impact category for a year (PRé, 2016). This division will mean relative bar height is scaled off of how much more or less impact the scenario produces compared to the average citizen. A higher bar would mean more detrimental impacts than an average citizen, while lower bars mean relatively less detrimental impacts.

3.7.3 ASTM C1131

ASTM C1131 defines life-cycle cost as the sum of initial cost, repair and maintenance costs, and renewal cost of the project (Eq. 3-3).

$$LCC = C + M + N \qquad \text{Eq. 3-3}$$

Where, LCC = Life-cycle cost,

C = initial cost,

M = repair and maintenance costs, and

N = renewal cost.

The initial cost of the project is the original cost including the direct cost and indirect cost of the project. Maintenance cost is the future cost involved, such as regularly inspection cost and/or minor repair of the culvert, which happens because of the lack of performance. Renewal cost is the future cost of the project, which is including rehabilitation, and/or replacement of the culvert due to the failure of the culvert. While construction cost analysis needs to evaluate the above costs, the bid cost can represent the construction cost of projects for those with no or low repair, maintenance, and renewal costs (ASCE, 2019). In other words, since the life-cycle cost of renewal methods are investigated, and due to the data availability, the maintenance and renewal cost of the trenchless renewals can be assumed to be negligible. If the cost of the environmental impacts of a project adds to this equation, the adopted ASTM C1131 can be defined as the sum of the construction and environmental costs (Eq. 3-4).

$$LCCA = CC + LCA \qquad \text{Eq. 3-4}$$

Where LCCA = Life-cycle cost analysis,

CC = Construction costs, and

LCA = Environmental costs.

3.7.4 Life-cycle Cost Analysis of Trenchless Renewals (LCCATR)

After several explained models are developed, the one, which has the most accurate prediction with the least error, is selected as the final construction cost prediction model. The output of this model with the output of the SimaPro analysis and then the help of the ASTM C1131 created the LCCATR model. This artificial intelligence-based model is capable to predict the construction and environmental costs of life-cycle costs of SAPL, CIPP, and sliplining, which can be expanded to use for other trenchless renewal methods in case the required data is available.

3.8 Chapter Summary

In this chapter, the detail of KNN regression, decision tree regression, linear regression, and gradient boosting regression were comprehensively reviewed. The discussions in this chapter were reinforced the suitability of statistical and machine learning-based models to work as a regressor to predict the construction and environmental costs of trenchless renewals in large diameter culverts. Furthermore, the model selection process and various techniques for training and evaluation of the 4 developed models were widely explained. The source of a trenchless culvert renewal database and different steps of data preparation and data analysis, as well as model development, was presented in the following chapters.

CHAPTER 4

DATA PREPARATION AND ANALYSIS

4.1 Introduction

The required data for life-cycle cost analysis in this dissertation is collected from 7 U.S. Department of Transportations (DOTs) as Delaware, Florida, Minnesota, New York, North Carolina, Ohio, and Pennsylvania. Figure 4-1 is presented to show the location of the data points in the map.

Overall, 417 bid items (data points) of trenchless SAPL, CIPP, and sliplining renewal methods in large diameter[1] culverts from 2010 to 2019 of 7 DOTs are gathered and analyzed. All culverts are round and corrugated metal pipe (CMP).

Based on the literature review and data availability, several parameters from each bid item are collected as follows:

- Location of the culvert,
- Type of the trenchless renewal method,
- Letting year of the renewal,
- Diameter of the culvert,
- Length of the culvert,
- Thickness of the trenchless renewal method, and
- Unit cost of the trenchless renewal method.

Table 4-1 shows a summary of the included and excluded features in the dataset to analyze the comprehensive life-cycle cost analysis. In addition, a summary of the classification and the value of each parameter is shown in Table 4-2.

---

[1] Large diameter = 30 in. to 108 in.

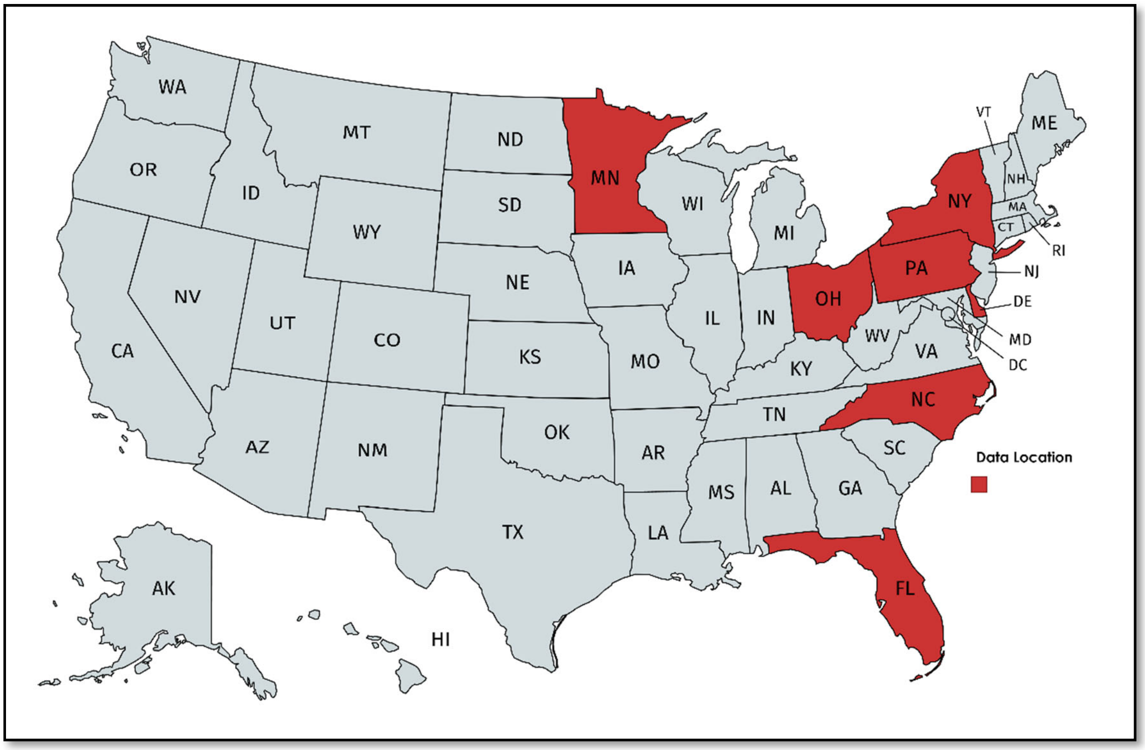


Figure 4-1 Location of the Data Points in the US Map

In addition, type of each variables can be found in Table 4-3. Finally, the sample of the raw collected data set is presented in Table 4-4. It should be noted that in this dissertation, data is collected and stored in Microsoft Excel 2016 and then Python 3.7 is used for data preparation, data analysis, and model development.

Table 4-1 Dataset Included Features

Feature	Included	Excluded
Culvert Shape	Round	Arch, Ellipse, Box
Culvert Material	CMP	Concrete
SAPL Material	Cementitious	Polymeric
CIPP Material	Polyester	Fiberglass Reinforced
Sliplining Material	HDPE	PVC and FRP

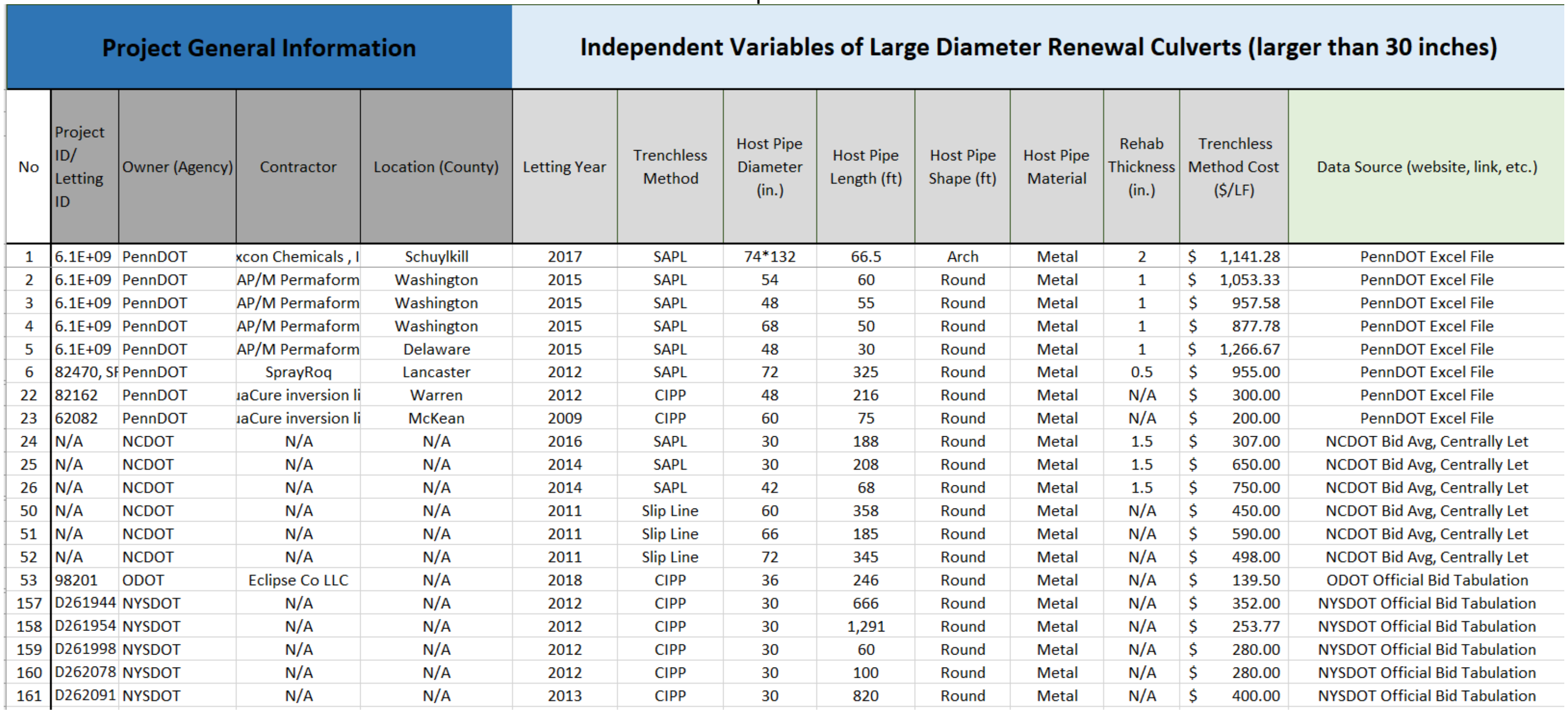
Table 4-2 Dataset Parameters Classification and Value

Parameter	Location	Time	Renewal Method	Rehab Thickness	Diameter	Length	Unit Cost
Unit/Type	State	Year	Trenchless	Inch (in.)	Inch (in.)	Feet (ft)	2019 Dollars ($)
Value/Classification	Delaware Florida Minnesota New York North Carolina Ohio Pennsylvania	2010 2011 2012 2013 2014 2015 2016 2017 2018 2019	SAPL CIPP Sliplining	0.5 1 1.5 1.75 2 2.25	30 36 42 48 54 60 66 72 78 84 90 96 102 108	5 – 46,950	105 – 1,275

Table 4-3 Type of Dataset Parameters

Parameter	Type
Location	Nominal Categorical
Renewal Method	
Time	Interval Continuous
Rehab Thickness	
Diameter	Ratio Continuous
Length	
Unit Cost	

Table 4-4 Sample of the Raw Dataset*



Project General Information					Independent Variables of Large Diameter Renewal Culverts (larger than 30 inches)								
No	Project ID/ Letting ID	Owner (Agency)	Contractor	Location (County)	Letting Year	Trenchless Method	Host Pipe Diameter (in.)	Host Pipe Length (ft)	Host Pipe Shape (ft)	Host Pipe Material	Rehab Thickness (in.)	Trenchless Method Cost ($/LF)	Data Source (website, link, etc.)
1	6.1E+09	PennDOT	xcon Chemicals , I	Schuylkill	2017	SAPL	74*132	66.5	Arch	Metal	2	$ 1,141.28	PennDOT Excel File
2	6.1E+09	PennDOT	AP/M Permaform	Washington	2015	SAPL	54	60	Round	Metal	1	$ 1,053.33	PennDOT Excel File
3	6.1E+09	PennDOT	AP/M Permaform	Washington	2015	SAPL	48	55	Round	Metal	1	$ 957.58	PennDOT Excel File
4	6.1E+09	PennDOT	AP/M Permaform	Washington	2015	SAPL	68	50	Round	Metal	1	$ 877.78	PennDOT Excel File
5	6.1E+09	PennDOT	AP/M Permaform	Delaware	2015	SAPL	48	30	Round	Metal	1	$ 1,266.67	PennDOT Excel File
6	82470, SF	PennDOT	SprayRoq	Lancaster	2012	SAPL	72	325	Round	Metal	0.5	$ 955.00	PennDOT Excel File
22	82162	PennDOT	uaCure inversion li	Warren	2012	CIPP	48	216	Round	Metal	N/A	$ 300.00	PennDOT Excel File
23	62082	PennDOT	uaCure inversion li	McKean	2009	CIPP	60	75	Round	Metal	N/A	$ 200.00	PennDOT Excel File
24	N/A	NCDOT	N/A	N/A	2016	SAPL	30	188	Round	Metal	1.5	$ 307.00	NCDOT Bid Avg, Centrally Let
25	N/A	NCDOT	N/A	N/A	2014	SAPL	30	208	Round	Metal	1.5	$ 650.00	NCDOT Bid Avg, Centrally Let
26	N/A	NCDOT	N/A	N/A	2014	SAPL	42	68	Round	Metal	1.5	$ 750.00	NCDOT Bid Avg, Centrally Let
50	N/A	NCDOT	N/A	N/A	2011	Slip Line	60	358	Round	Metal	N/A	$ 450.00	NCDOT Bid Avg, Centrally Let
51	N/A	NCDOT	N/A	N/A	2011	Slip Line	66	185	Round	Metal	N/A	$ 590.00	NCDOT Bid Avg, Centrally Let
52	N/A	NCDOT	N/A	N/A	2011	Slip Line	72	345	Round	Metal	N/A	$ 498.00	NCDOT Bid Avg, Centrally Let
53	98201	ODOT	Eclipse Co LLC	N/A	2018	CIPP	36	246	Round	Metal	N/A	$ 139.50	ODOT Official Bid Tabulation
157	D261944	NYSDOT	N/A	N/A	2012	CIPP	30	666	Round	Metal	N/A	$ 352.00	NYSDOT Official Bid Tabulation
158	D261954	NYSDOT	N/A	N/A	2012	CIPP	30	1,291	Round	Metal	N/A	$ 253.77	NYSDOT Official Bid Tabulation
159	D261998	NYSDOT	N/A	N/A	2012	CIPP	30	60	Round	Metal	N/A	$ 280.00	NYSDOT Official Bid Tabulation
160	D262078	NYSDOT	N/A	N/A	2012	CIPP	30	100	Round	Metal	N/A	$ 280.00	NYSDOT Official Bid Tabulation
161	D262091	NYSDOT	N/A	N/A	2013	CIPP	30	820	Round	Metal	N/A	$ 400.00	NYSDOT Official Bid Tabulation

*For more information about the complete set of data please contact author at Ramtin.serajiantehrani@mavs.uta.edu

4.2 Dataset Preparation

Data preparation creates higher quality data for analysis by eradicating errors and filling missing values before it is processed. Before developing artificial intelligence-based models by using Python data analysis software, the dataset needs to be well-prepared in Microsoft Excel. Data preparation is a combination of strategies and methods to work with the dataset for feeding pure data as an input to perform data analysis and model development and achieving higher accuracy for the models. Data preparation is not a completely automated process and several techniques should be applied to prepare the dataset (Pyle, 2007).

As per the methodology explained in chapter 3, data preparation is taken place by following the data preparation steps as data discovery, cleansing, transforming, and storing the final dataset. Prior to starting machine learning analysis of trenchless renewals dataset, several evaluations were performed by using filtering the data in Excel to find missing values and information. Admittedly, while project ID and/or letting ID were a well identification way to find the project but it was not available for some of the data points. Accordingly, a unique “No” was assigned to each data point with the intention to facilitate to identify and track individual projects. The following steps are implemented to enrich the dataset.

First, in the combination of the discovery and cleanse data steps, missing information was identified, analyzed, and cleansed based on the variables included in the dataset. Since the original dataset was collected from a variety of sources such as the Excel files received from DOTs, DOTs websites, and third-party databases such as bidexpress and bidnet websites, the parameters for each project were not similar and complete.

As a result, from 417 trenchless renewed culvert were available in the original dataset, there was a lack of the most important information as the unit cost for 18 of the project. By conducting a deep search on the internet and investigate from several sources, the 12 missing unit cost information was found and replaced to the dataset. However, the remaining 2 of the project with missing unit cost information were excluded from the dataset. Likewise, deep searching is conducted to find the other missing parameters as letting year, trenchless method, culvert diameter, culvert length, and rehabilitation thickness in the dataset. Much information for the projects with missing data was taken place to the dataset by finding from other sources rather than that project's original file.

Subsequently, projects with missing information on letting year, trenchless method, culvert diameter, and culvert length were excluded from the dataset. However, there was one exemption for the rehabilitation thickness parameter, which is only applied to the SAPL trenchless method. Since there were many SAPL projects with the missing rehabilitation thickness information, the missing values were filled by the average of the available data in Python. Admittedly, 8 projects were excluded since the culvert shape was an arch shape which was not in the scope of the work. At the end of this step, 401 data points are remained in the dataset to proceed for analysis. Understandably, it needs to emphasize that in the dataset the unit cost is the dependent variable and the rest parameters are independent variables.

Second, as the data transform step, the transformation was required for the cost data of the projects as the unit cost of the projects in the dataset were various from 2010 to 2019. Considering the inflation rate, by using the US Inflation Calculator website, all unit costs from 2010 to 2019 were transformed to present dollar value of their cost in 2019. Additionally, to enrich the data analysis, 2 columns as the “latitude” and “longitude” were added to the dataset to well represent the location of the projects in the analysis. Besides that, there was no need to transform any other value for other parameters at this stage.

Last but not least, according to the data storing step, the final dataset which was included 401 data points are stored as a CSV (Comma delimited) format file to be able to use it in Python software for further data analysis. The next section is provided to present the visualization of the prepared dataset. The sample of the final version of the prepared dataset is available in Table 4-5.

4.3 Dataset Preliminary Analysis

4.3.1 The Jupyter Notebook Platform

The prepared dataset is used as the main data frame to read by a modern and powerful web interface to Python, which is called Jupyter Notebook. The Jupyter Notebook as a web software ideal tool in which has the capability to create and share documents that contain live code, equations, and visualizations, as well as text, is used to gain the data science skills which is needed.

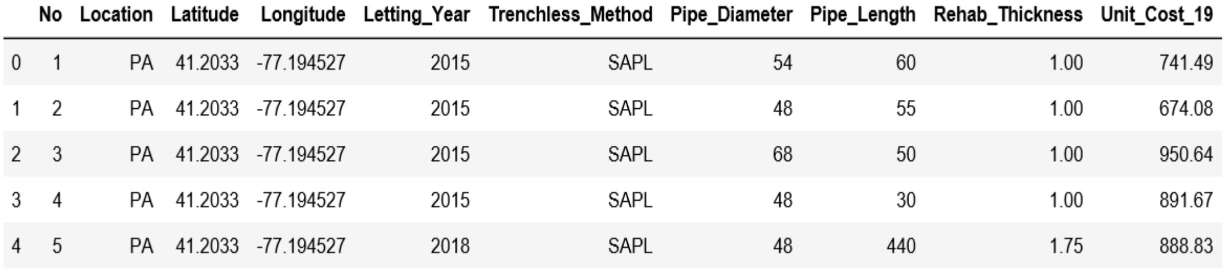
4.3.2 Dataset Reading in Jupyter Notebook

In this dissertation, Pandas, Numpy, and Matplot.pyplot libraries are imported in Jupyter Notebook to proceed the data description, analysis, and visualization. After reading the final prepared dataset in the software using the Panda library as it is presented in Table 4-6.

Table 4-5 Sample of the Final Dataset

No	Location	Latitude	Longitude	Letting_Year	Trenchless_Method	Pipe_Diameter	Pipe_Length	Rehab_Thick	Unit_Cost_19
1	PA	41.2033	-77.19453	2015	SAPL	54	60	1	741.49
2	PA	41.2033	-77.19453	2015	SAPL	48	55	1	674.08
3	PA	41.2033	-77.19453	2015	SAPL	68	50	1	950.64
4	PA	41.2033	-77.19453	2015	SAPL	48	30	1	891.67
5	PA	41.2033	-77.19453	2018	SAPL	48	440	1.75	888.83
6	PA	41.2033	-77.19453	2018	SAPL	60	450	2.25	1027.09
7	PA	41.2033	-77.19453	2016	CIPP	36	62		444.88
8	PA	41.2033	-77.19453	2016	CIPP	30	125		220.67
9	PA	41.2033	-77.19453	2016	CIPP	36	70		394.04
17	NC	35.7596	-80.79346	2016	SAPL	30	188	1.5	328.49
18	NC	35.7596	-80.79346	2014	SAPL	30	208	1.5	387.99
19	NC	35.7596	-80.79346	2014	SAPL	42	68	1.5	831.41
20	NC	35.7596	-80.79346	2014	SAPL	54	64	1.5	942.26
28	NC	35.7596	-80.79346	2015	CIPP	60	269		850.16
29	NC	35.7596	-80.79346	2017	CIPP	30	580		167.51
30	NC	35.7596	-80.79346	2019	CIPP	30	264		140
31	NC	35.7596	-80.79346	2019	Sliplining	32	211		250
33	NC	35.7596	-80.79346	2019	Sliplining	54	578		260
34	NC	35.7596	-80.79346	2011	Sliplining	30	452		492.96
35	NC	35.7596	-80.79346	2010	Sliplining	36	135		359.2

Table 4-6 Read the Dataset in Jupyter Notebook

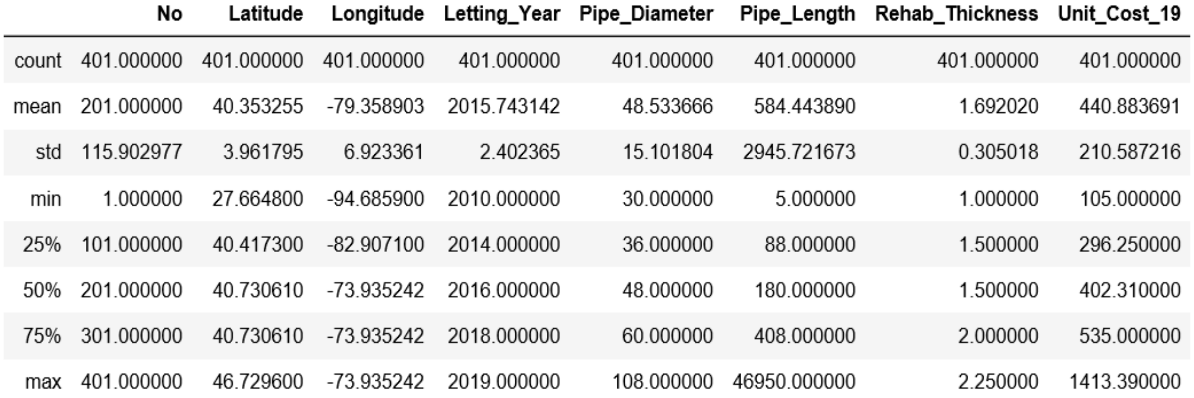


	No	Location	Latitude	Longitude	Letting_Year	Trenchless_Method	Pipe_Diameter	Pipe_Length	Rehab_Thickness	Unit_Cost_19
0	1	PA	41.2033	-77.194527	2015	SAPL	54	60	1.00	741.49
1	2	PA	41.2033	-77.194527	2015	SAPL	48	55	1.00	674.08
2	3	PA	41.2033	-77.194527	2015	SAPL	68	50	1.00	950.64
3	4	PA	41.2033	-77.194527	2015	SAPL	48	30	1.00	891.67
4	5	PA	41.2033	-77.194527	2018	SAPL	48	440	1.75	888.83

4.3.3 Dataset Description

After reading the dataset by the software, the description analysis of the numerical parameters in the dataset is conducted. This description can represent the number of each parameter (count), mean (mean), standard deviation (std), minimum value (min), the 25th, 50th, and 75th percentile (25%, 50%, 75%), and the maximum value (max) of each parameter which is shown in Table 4-7.

Table 4-7 Data Description



	No	Latitude	Longitude	Letting_Year	Pipe_Diameter	Pipe_Length	Rehab_Thickness	Unit_Cost_19
count	401.000000	401.000000	401.000000	401.000000	401.000000	401.000000	401.000000	401.000000
mean	201.000000	40.353255	-79.358903	2015.743142	48.533666	584.443890	1.692020	440.883691
std	115.902977	3.961795	6.923361	2.402365	15.101804	2945.721673	0.305018	210.587216
min	1.000000	27.664800	-94.685900	2010.000000	30.000000	5.000000	1.000000	105.000000
25%	101.000000	40.417300	-82.907100	2014.000000	36.000000	88.000000	1.500000	296.250000
50%	201.000000	40.730610	-73.935242	2016.000000	48.000000	180.000000	1.500000	402.310000
75%	301.000000	40.730610	-73.935242	2018.000000	60.000000	408.000000	2.000000	535.000000
max	401.000000	46.729600	-73.935242	2019.000000	108.000000	46950.000000	2.250000	1413.390000

4.4 Distribution of the Parameters (Histogram Analysis)

To do further analysis, it was crucial to understanding the distribution of each parameter. To achieve that, the histogram plot of each parameter was executed. The following sections are provided to illustrate the histogram analysis of each parameter.

4.4.1 Location

As it is explained, the dataset is gathered from 7 states in the U.S. The number of data points in each state is different from another. New York states is contributed to the dataset with 201 projects. Also, Delaware State with only 4 data had the least projects in the dataset. The histogram of the location distribution for 7 states is presented in Figure 4-2.

4.4.2 Letting Year

The letting year, which represents the year when the project is proceeding, is varied in the dataset from 2010 to 2019. Most of the collected projects were coming from 2018 with 95 data points and 2011 consists of the least collected data points with only 9 projects. The histogram of the letting year distribution of the dataset is presented in Figure 4-3.

4.4.3 Trenchless Method

The gathered trenchless methods of this dissertation were SAPL, CIPP, and sliplining. On one hand, sliplining is the most widely used trenchless renewal technology for years, thus, most projects with the number of 195 data points are sliplining projects in the dataset. On the other hand, SAPL is the newest method in the trenchless renewal technology field. As a result, fewer projects can be found for this technology. Only 53 of the collected projects were SAPL projects among 401 projects. The histogram of the trenchless method distribution is plotted in Figure 4-4.

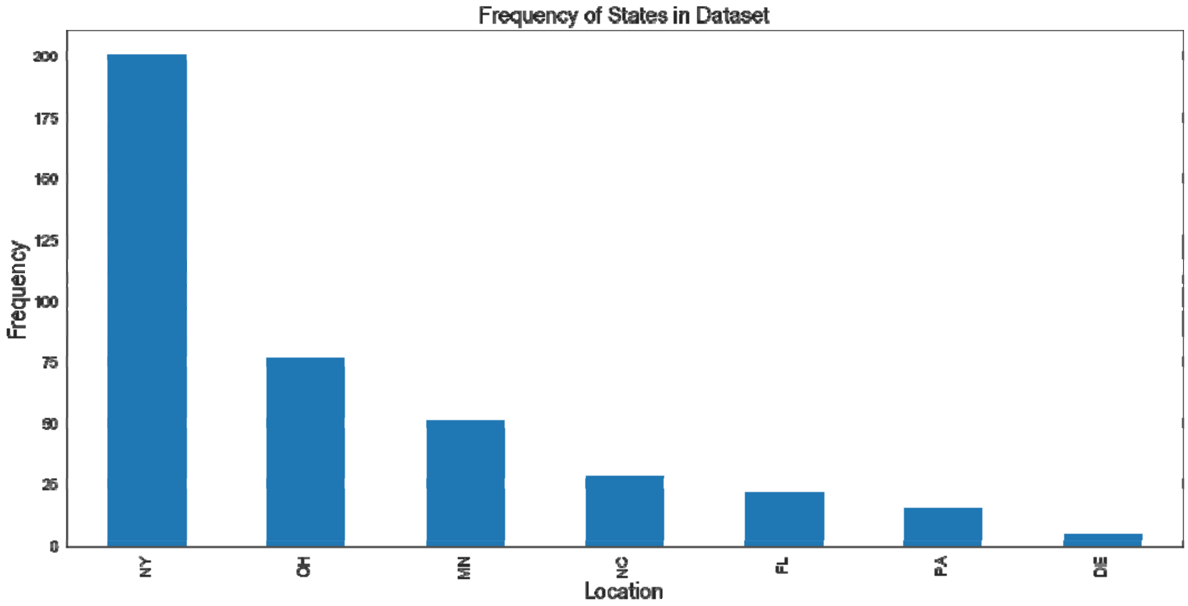


Figure 4-2 Frequency of Location Distribution

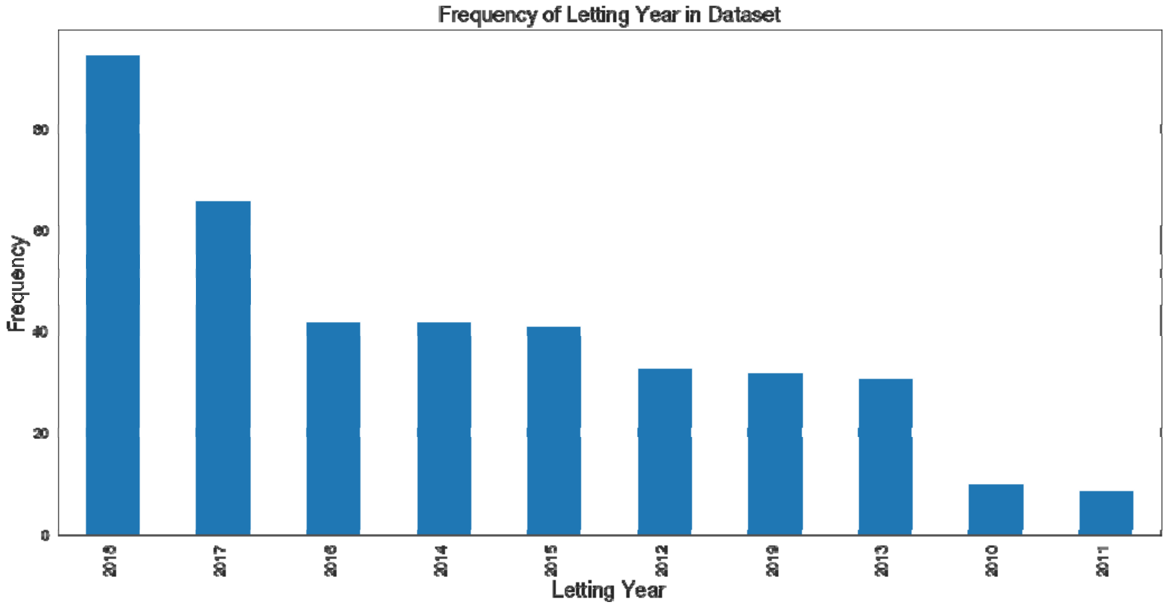


Figure 4-3 Frequency of Letting Year Distribution

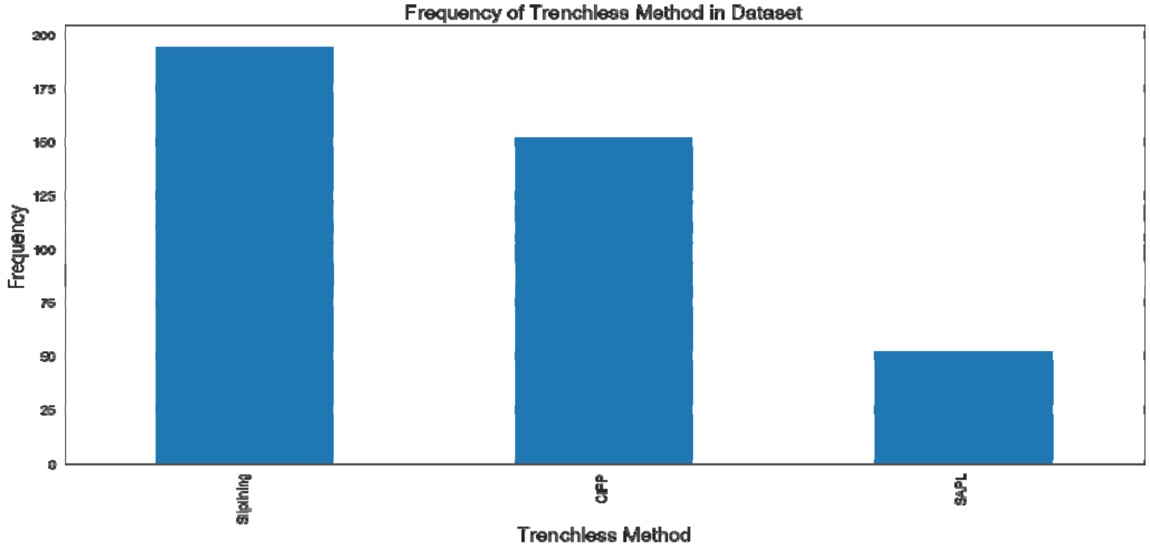


Figure 4-4 Frequency of Trenchless Method Distribution

4.4.4 Pipe Diameter

This dissertation is focused on large diameter culverts which include pipes with the diameter of 30 in. to 108 in. The wide range of the data points were pipes with 36, 48, and 60 inches of diameter and the least collected projects were including the pipes with 90, 102, and 108. The histogram of the pipe diameter distribution is illustrated in Figure 4-5.

4.4.5 Pipe Length

Pipe length is another independent variable, which is included in the dataset with the range of 5 ft to almost 5000 ft. The histogram of the pipe length distribution is depicted in Figure 4-6.

4.4.6 Rehab Thickness

The rehab thickness parameter, which represents the thickness of the SAPL renewal method is varied in the dataset from 0.5-in. to 2.25-in. Most of the collected projects were coming from 1.5-in. and 2-in. The histogram of the rehab thickness distribution is presented in Figure 4-7.

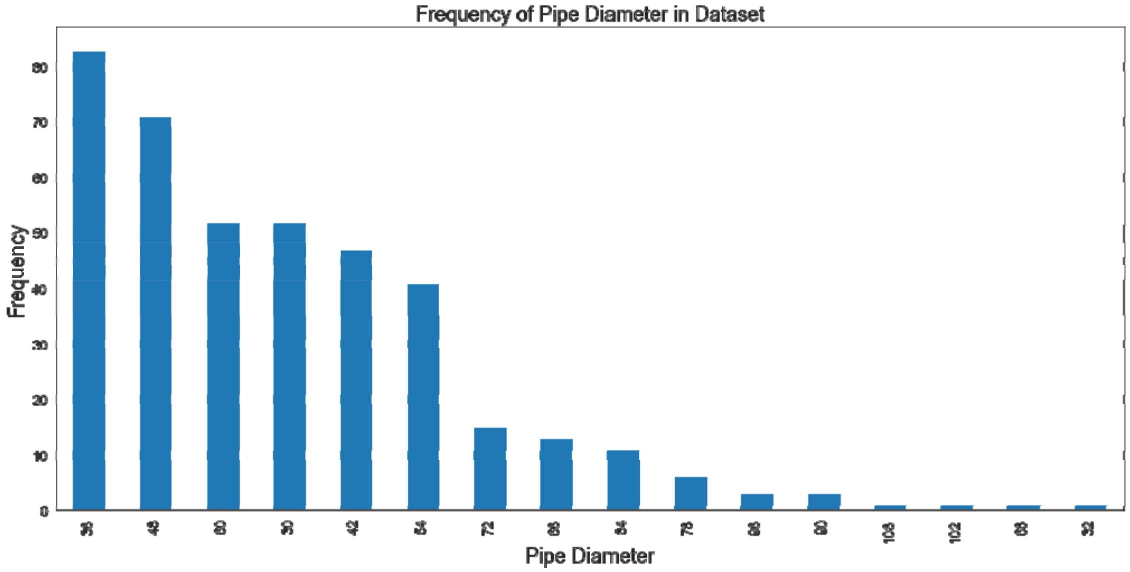


Figure 4-5 Frequency of Pipe Diameter Distribution

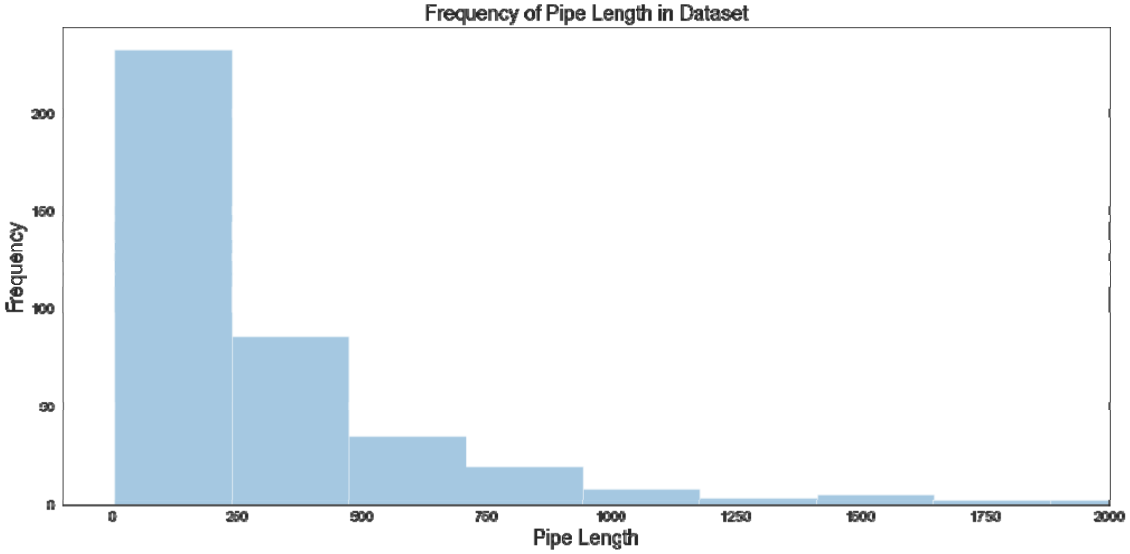


Figure 4-6 Frequency of Pipe Length Distribution

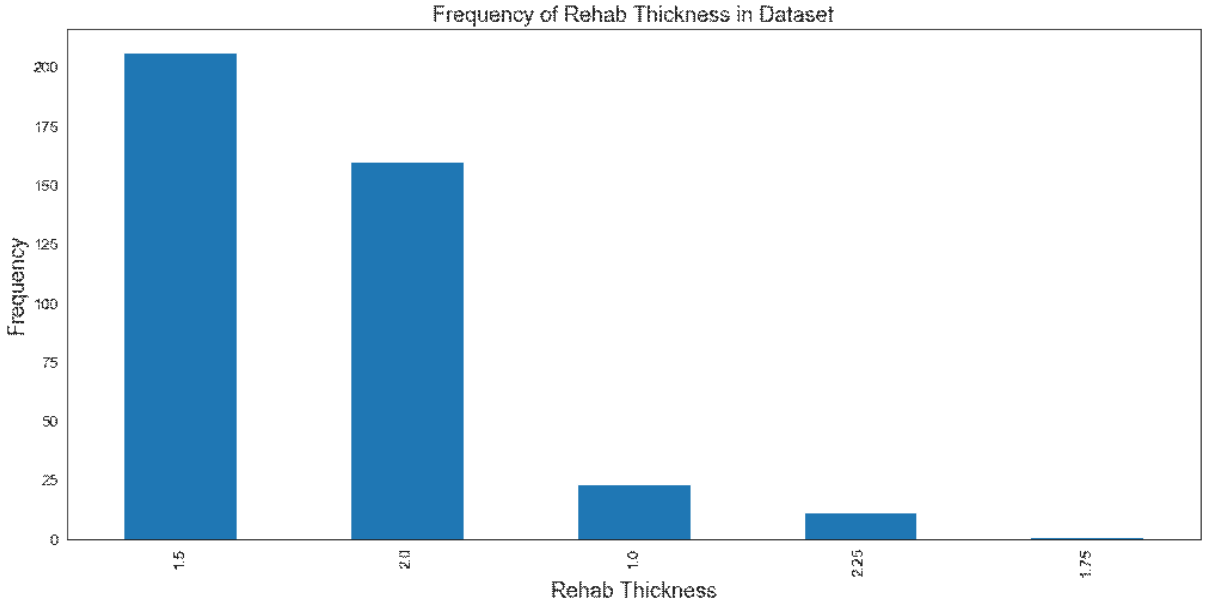


Figure 4-7 Frequency of Rehab Thickness Distribution

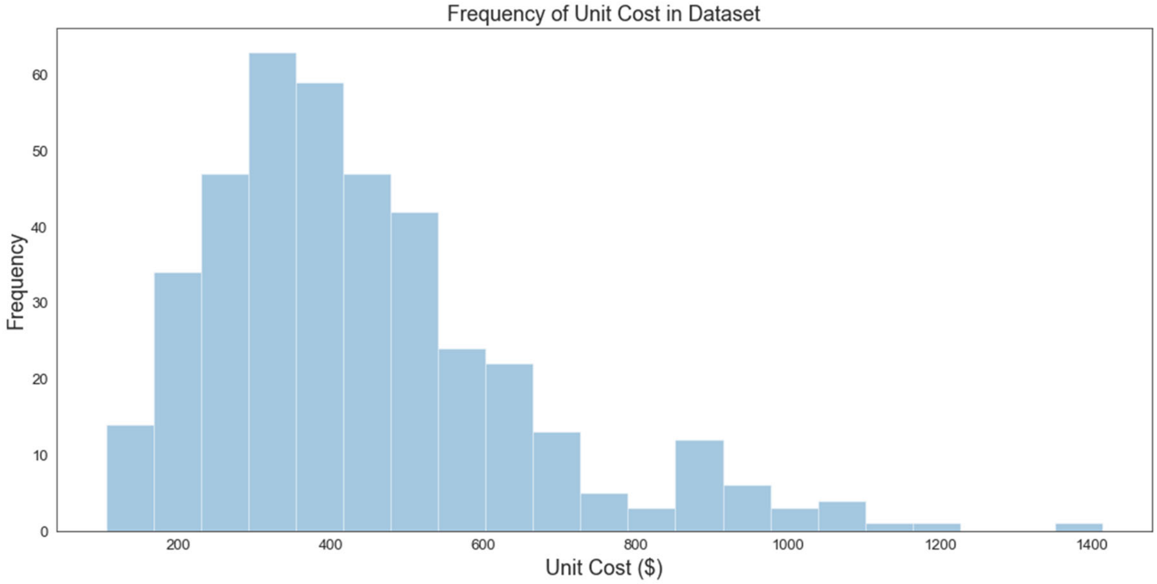


Figure 4-8 Frequency of Unit Cost Distribution

4.4.7 Unit Cost

Unit cost as the dependent variable in the dataset is the dollar value per linear feet of each trenchless culvert renewals. As it is mentioned earlier in the data preparation section (4.2), since the cost of projects was associated with their letting year which was varied from 2010 to 2019, all costs are adjusted to the equal dollar value in 2019. Figure 4-8 is presented to show the distribution of the unit costs of all projects in the dataset.

4.5 Correlation Analysis

After watching the distribution and understanding the frequency of each independent as well as the dependent variable of the dataset, it was required to analyze the correlation between all the parameters. To achieve this objective, 2 correlation matrixes are analyzed; first without considering the categorical parameters and by focusing on continuous parameters and second by transforming categorical parameters to dummy variables for each category and involving them in the correlation matrix. The correlation matrixes are performed and ranked according to the dependent variable, which is the unit cost of each project. At the same time, this could not just reveal the contribution of each independent variable to the dependent variable, but also, it could show the possible impact of each independent variable to another which was needed to be considered. Figure 4-9 is presented to elaborate the correlation matrix according to the unit cost without considering categorical parameters and Figure 4-10 is plotted to highlights the correlation matrix according to the unit cost by including categorical parameters as dummy variables.

In the correlation matrix excluding categorical variables (Figure 4-9) it can be seen that the most contribution of the unit cost is the pipe diameter by 0.63 correlation and the least contributor to the dependent variable is the letting year. It should be noted that the actual value of the correlation is considered the high or low contribution of the parameter not the negative and positive sign of the correlations.

In addition, it is important to understand that even when categorical parameters were included in the analysis as it can be found in Figure 4-10, still the pipe diameter is the most contributor to the unit cost variable. However, since the level of impact of categorical parameters cannot be interpreted by their correlation factor, it cannot be concluded that the data associated with the New York state have the least contribution to the unit cost.

As the outcome of correlation matrixes, it could be clearly concluded that the diameter of pipe had the highest influence to the cost of a trenchless renewal project, thus, the graph that shows the unit cost of all projects in respect of their diameter is plotted categorized by trenchless methods in Figure 4-11.

Finally yet importantly, by observing the other correlations between other parameters together, it was failed to find any significant correlation within other parameters to themselves. That could cause multicollinearity, which is a state of very high intercorrelations or inter-association among the independent variables.

4.6 Data Visualization

In the previous sections (4.4.1 to 4.4.7), the distribution of each parameter was observed. After analysis, the correlation of parameters, the scatter of each independent variables and the dependent variable (unit cost) should be investigated.

Boxplot is a well-known simple graphical tool to display the variation of continuous data. Boxplot can identify the thresholds of the median, lower quartile, upper quartile, lower extreme, and upper extreme. The scatter boxplot is a type of boxplot, which shows more detail, particularly as the number of data points and groups, becomes larger. Scatter boxplot in Jupyter Notebook is employed by the Seaborn library to visualize the data parameters over each other and to identify the thresholds.

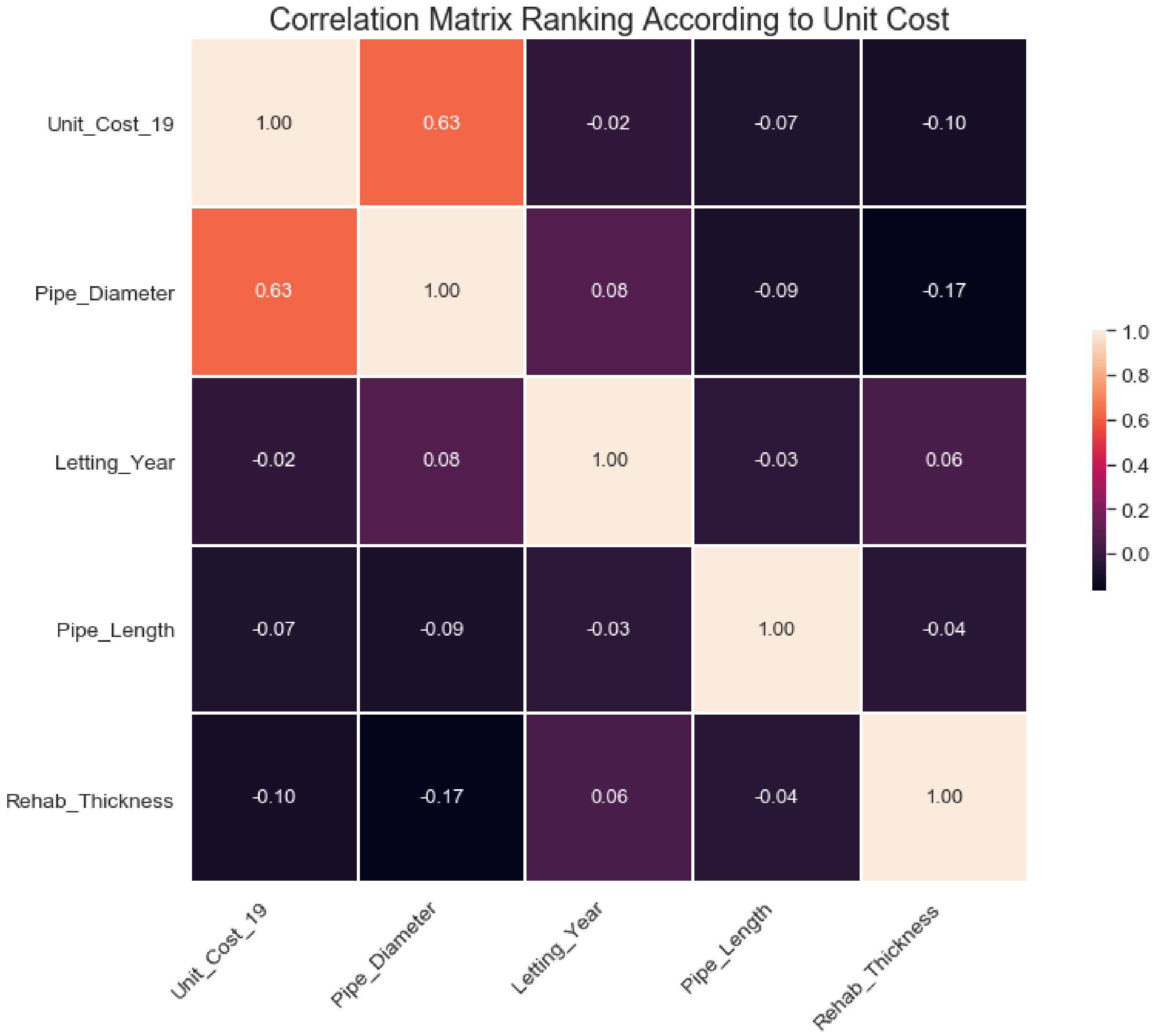
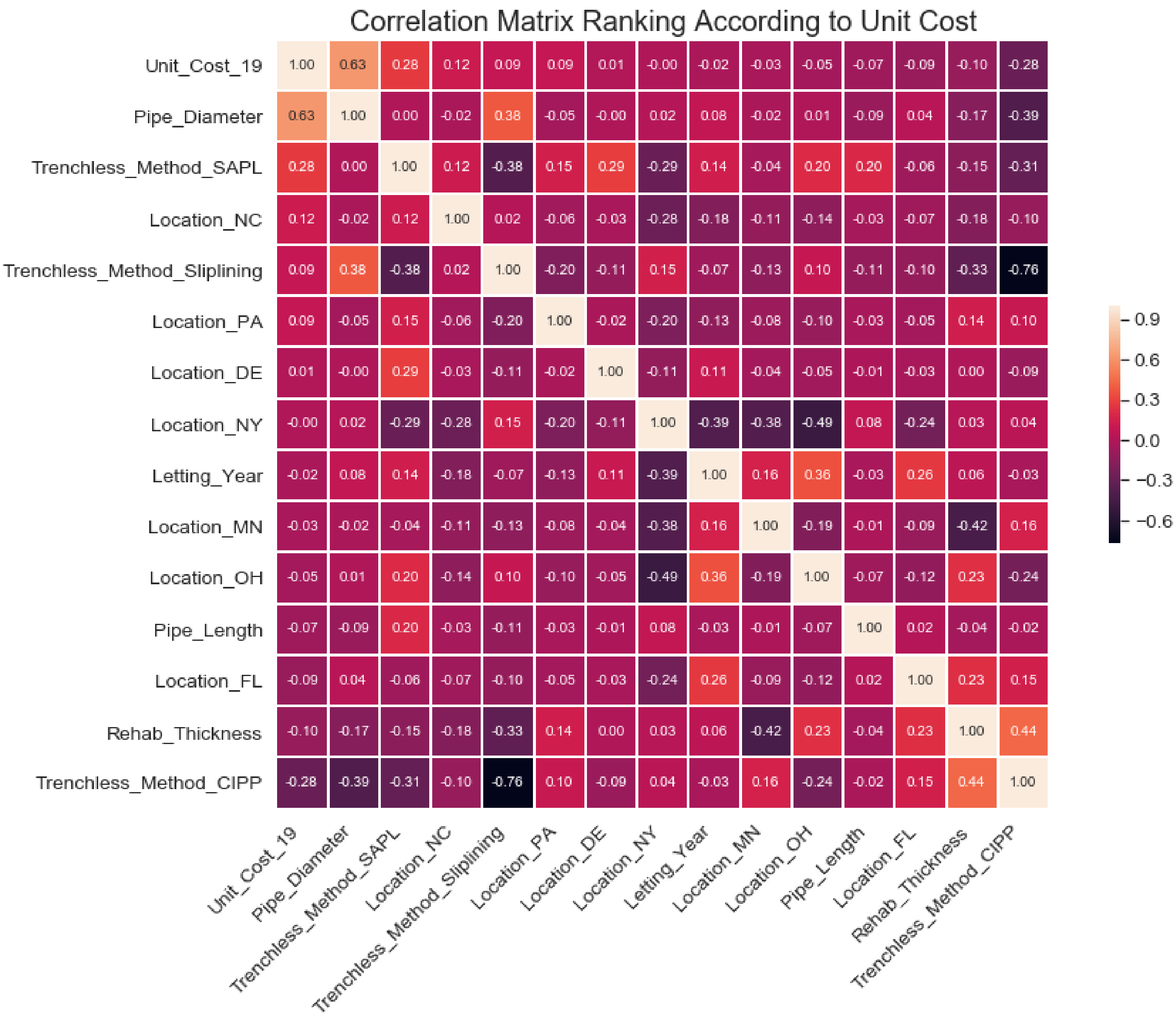


Figure 4-9 Correlation Matrix Excluding Categorical Parameters



	Unit_Cost_19	Pipe_Diameter	Trenchless_Method_SAPL	Location_NC	Trenchless_Method_Sliplining	Location_PA	Location_DE	Location_NY	Letting_Year	Location_MN	Location_OH	Pipe_Length	Location_FL	Rehab_Thickness	Trenchless_Method_CIPP
Unit_Cost_19	1.00	0.63	0.28	0.12	0.09	0.09	0.01	-0.00	-0.02	-0.03	-0.05	-0.07	-0.09	-0.10	-0.28
Pipe_Diameter	0.63	1.00	0.00	-0.02	0.38	-0.05	-0.00	0.02	0.08	-0.02	0.01	-0.09	0.04	-0.17	-0.39
Trenchless_Method_SAPL	0.28	0.00	1.00	0.12	-0.38	0.15	0.29	-0.29	0.14	-0.04	0.20	0.20	-0.06	-0.15	-0.31
Location_NC	0.12	-0.02	0.12	1.00	0.02	-0.06	-0.03	-0.28	-0.18	-0.11	-0.14	-0.03	-0.07	-0.18	-0.10
Trenchless_Method_Sliplining	0.09	0.38	-0.38	0.02	1.00	-0.20	-0.11	0.15	-0.07	-0.13	0.10	-0.11	-0.10	-0.33	-0.76
Location_PA	0.09	-0.05	0.15	-0.06	-0.20	1.00	-0.02	-0.20	-0.13	-0.08	-0.10	-0.03	-0.05	0.14	0.10
Location_DE	0.01	-0.00	0.29	-0.03	-0.11	-0.02	1.00	-0.11	0.11	-0.04	-0.05	-0.01	-0.03	0.00	-0.09
Location_NY	-0.00	0.02	-0.29	-0.28	0.15	-0.20	-0.11	1.00	-0.39	-0.38	-0.49	0.08	-0.24	0.03	0.04
Letting_Year	-0.02	0.08	0.14	-0.18	-0.07	-0.13	0.11	-0.39	1.00	0.16	0.36	-0.03	0.26	0.06	-0.03
Location_MN	-0.03	-0.02	-0.04	-0.11	-0.13	-0.08	-0.04	-0.38	0.16	1.00	-0.19	-0.01	-0.09	-0.42	0.16
Location_OH	-0.05	0.01	0.20	-0.14	0.10	-0.10	-0.05	-0.49	0.36	-0.19	1.00	-0.07	-0.12	0.23	-0.24
Pipe_Length	-0.07	-0.09	0.20	-0.03	-0.11	-0.03	-0.01	0.08	-0.03	-0.01	-0.07	1.00	0.02	-0.04	-0.02
Location_FL	-0.09	0.04	-0.06	-0.07	-0.10	-0.05	-0.03	-0.24	0.26	-0.09	-0.12	0.02	1.00	0.23	0.15
Rehab_Thickness	-0.10	-0.17	-0.15	-0.18	-0.33	0.14	0.00	0.03	0.06	-0.42	0.23	-0.04	0.23	1.00	0.44
Trenchless_Method_CIPP	-0.28	-0.39	-0.31	-0.10	-0.76	0.10	-0.09	0.04	-0.03	0.16	-0.24	-0.02	0.15	0.44	1.00

Figure 4-10 Correlation Matrix Including Categorical Parameters

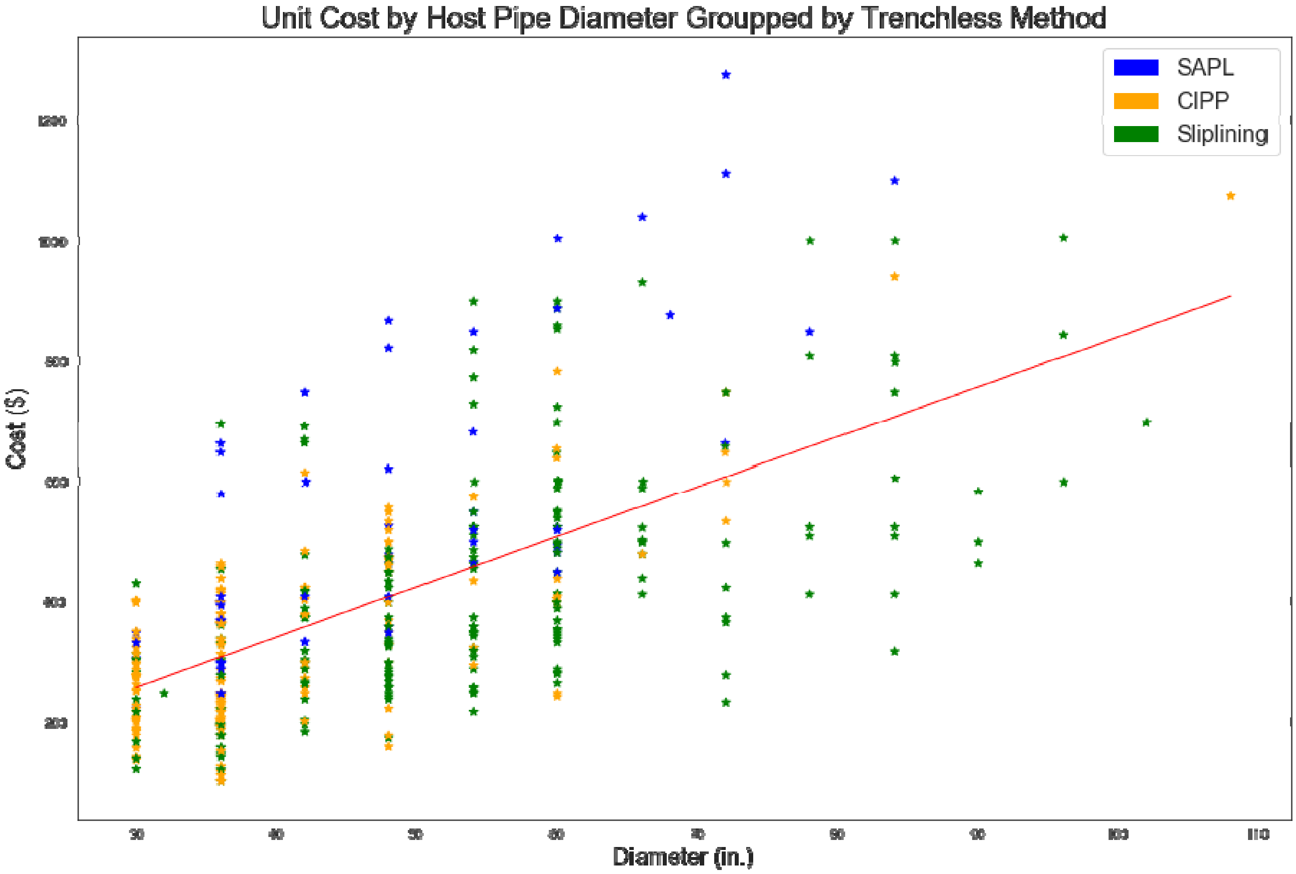


Figure 4-11 Scatter Plot of Unit Cost to Diameter Categorized by Trenchless Methods

Figure 4-12 shows the distribution of the unit cost and pipe diameter. This figure shows the thresholds of the median, lower quartile, upper quartile, lower extreme, and upper extreme of the unit cost for each pipe diameter. In addition, it shows that by increasing the pipe diameter, the unit cost of the project regardless of other factors are increased. Moreover, the congestion of data points for each diameter shows the range which the majority of the projects having the approximate same unit cost. Admittedly, it can be interpreted that there is considerable variation in the unit cost for the various pipe diameters. The medians vary from about 300 $/LF to 1100 $/LF. Lastly, it should be noted that there is some variation in the scale of the unit cost for each pipe diameter.

The distribution of the unit cost and trenchless method is shown in Figure 4-13. This figure shows that there is some variation in unit cost based on the trenchless method. The CIPP method, in particular, has the lowest median and the SAPL has the highest median. Moreover, there is some variation in the scale of the unit cost for three trenchless methods. Admittedly, it can be interpreted that there is some variation in the unit cost for the various trenchless methods. The medians vary from about 330 $/LF for the CIPP method to 520 $/LF for the SAPL renewal.

In addition, the congestion of data points for each diameter shows the range which the majority of the projects having the approximate same unit cost. The medians for different trenchless methods vary from about 320 $/LF to 510 $/LF. Lastly, it should be noted that there is some variation in the scale of the unit cost for each trenchless method, however, this variation for SAPL is much more than other methods.

Figure 4-14 shows the distribution of the unit cost with the location. This figure shows that Florida has the lowest and North Carolina has the highest unit cost median regardless of trenchless methods used. In addition, Pennsylvania, North Carolina, Ohio, New York, and Deleware have almost the same unit cost. The medians for different locations vary from about 250 $/LF to 510 $/LF. Lastly, there is some variation in the scale of the unit cost for each location, however, this variation for North Carolina and Minnesota is much more than other locations.

Figure 4-15 is plotted to show the scatter plot which shows the distribution of the pipe length over the unit cost. This figure shows several outlier in our data which needs to be removed. Also, it shows the range of the pipe length in our data set and can be concluded that majority of the length of the pipes are less than 5,000 ft.

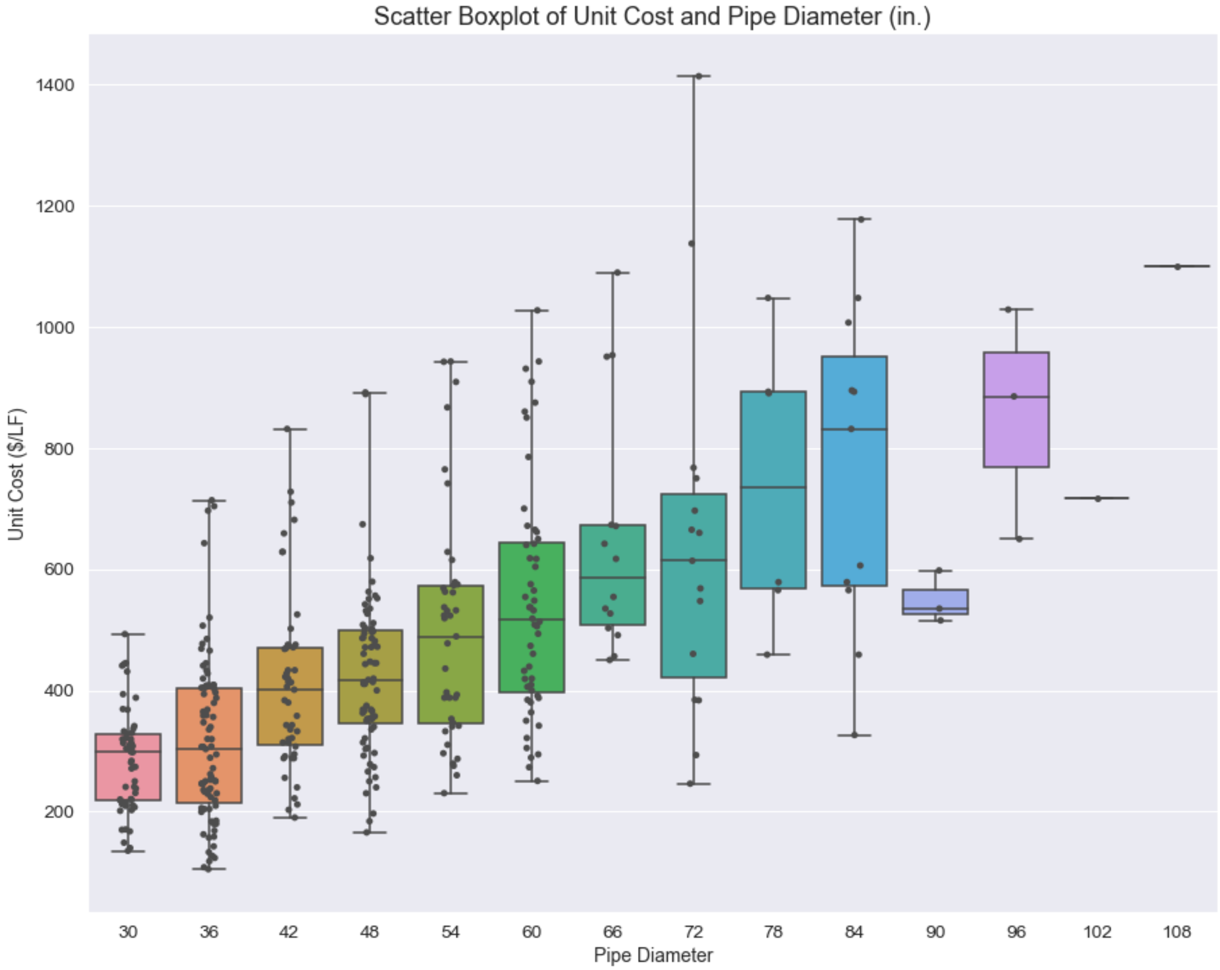


Figure 4-12 Scatter Boxplot of Unit Cost and Pipe Diameter

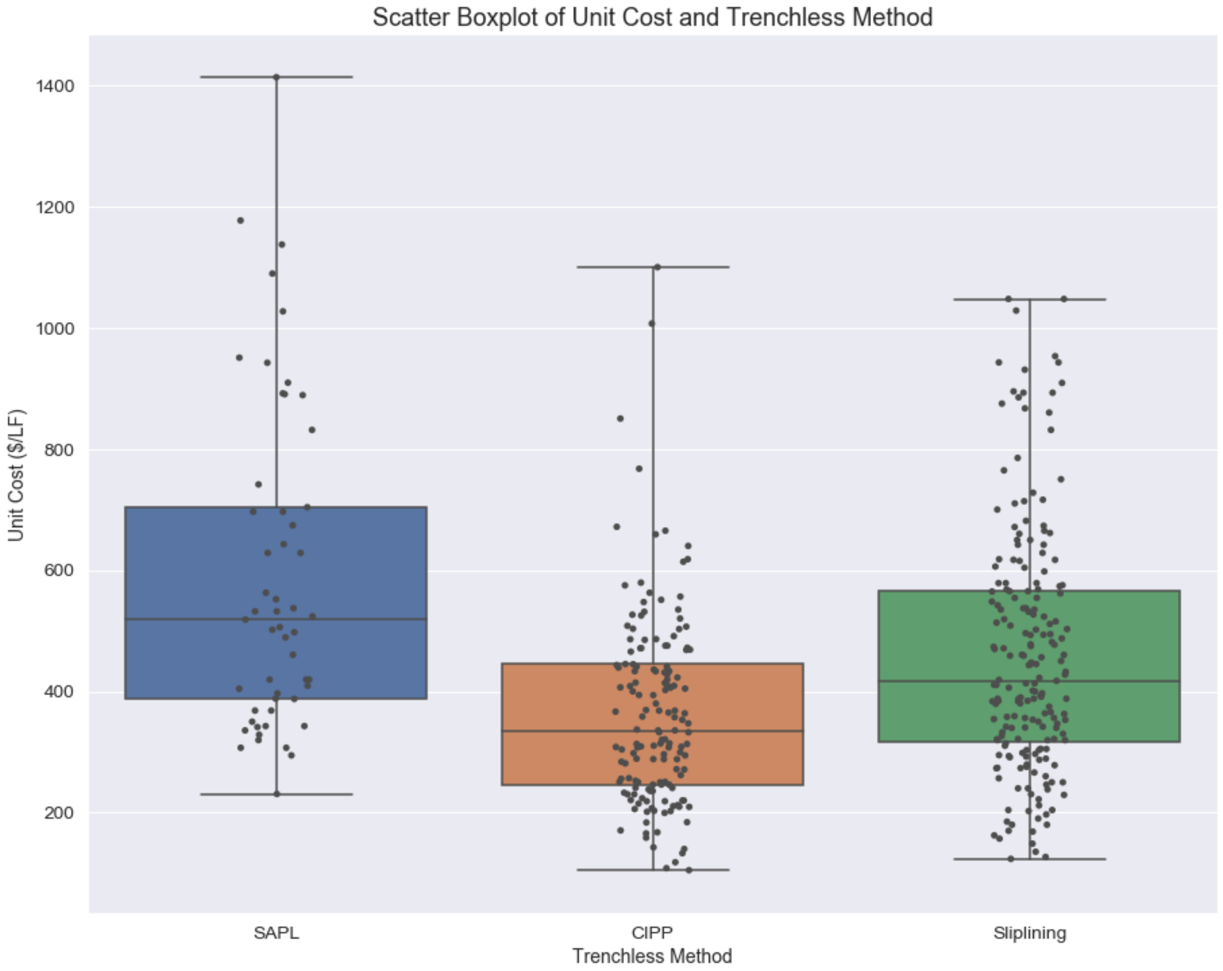


Figure 4-13 Scatter Boxplot of Unit Cost and Trenchless Method

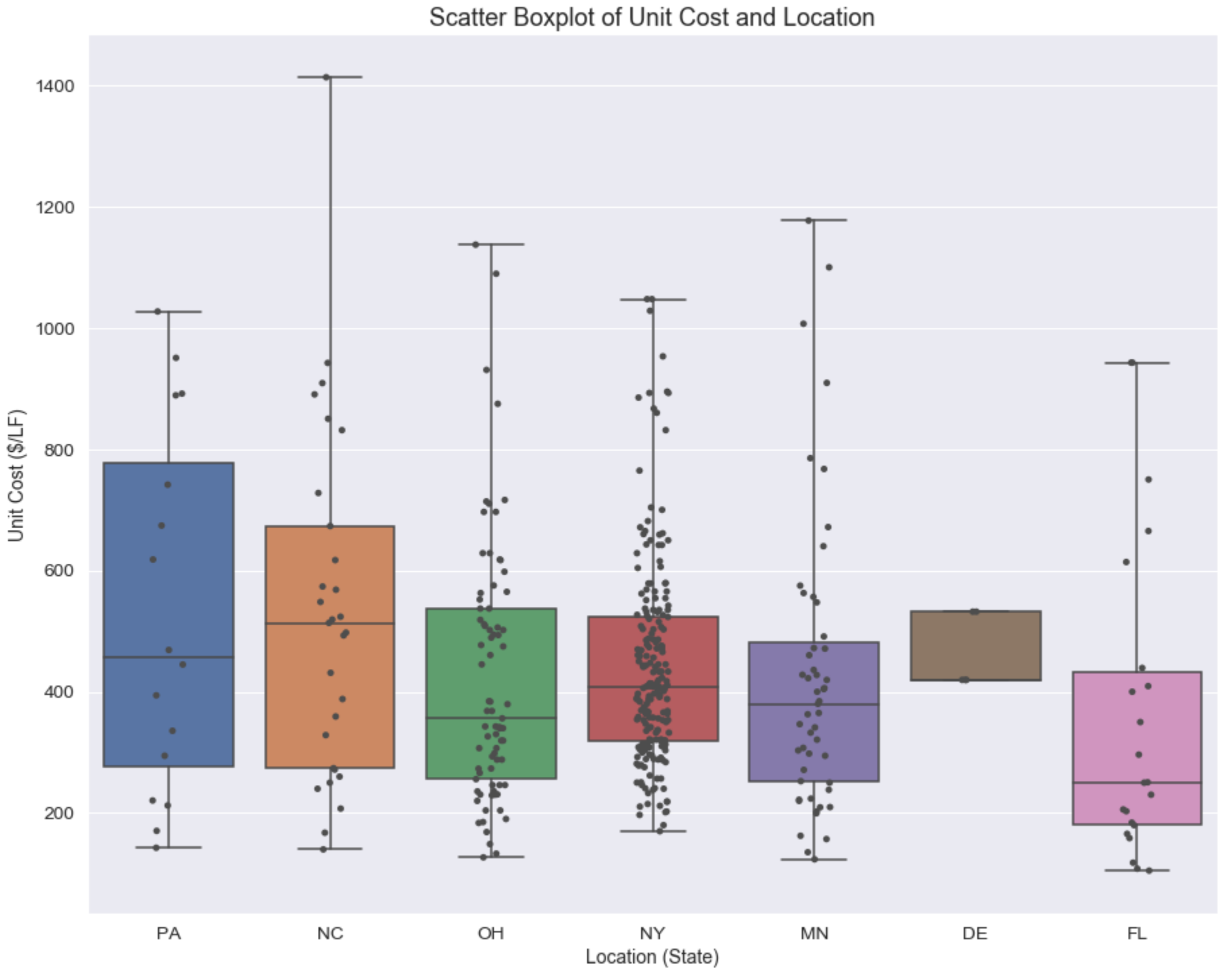


Figure 4-14 Scatter Boxplot of Unit Cost and Location

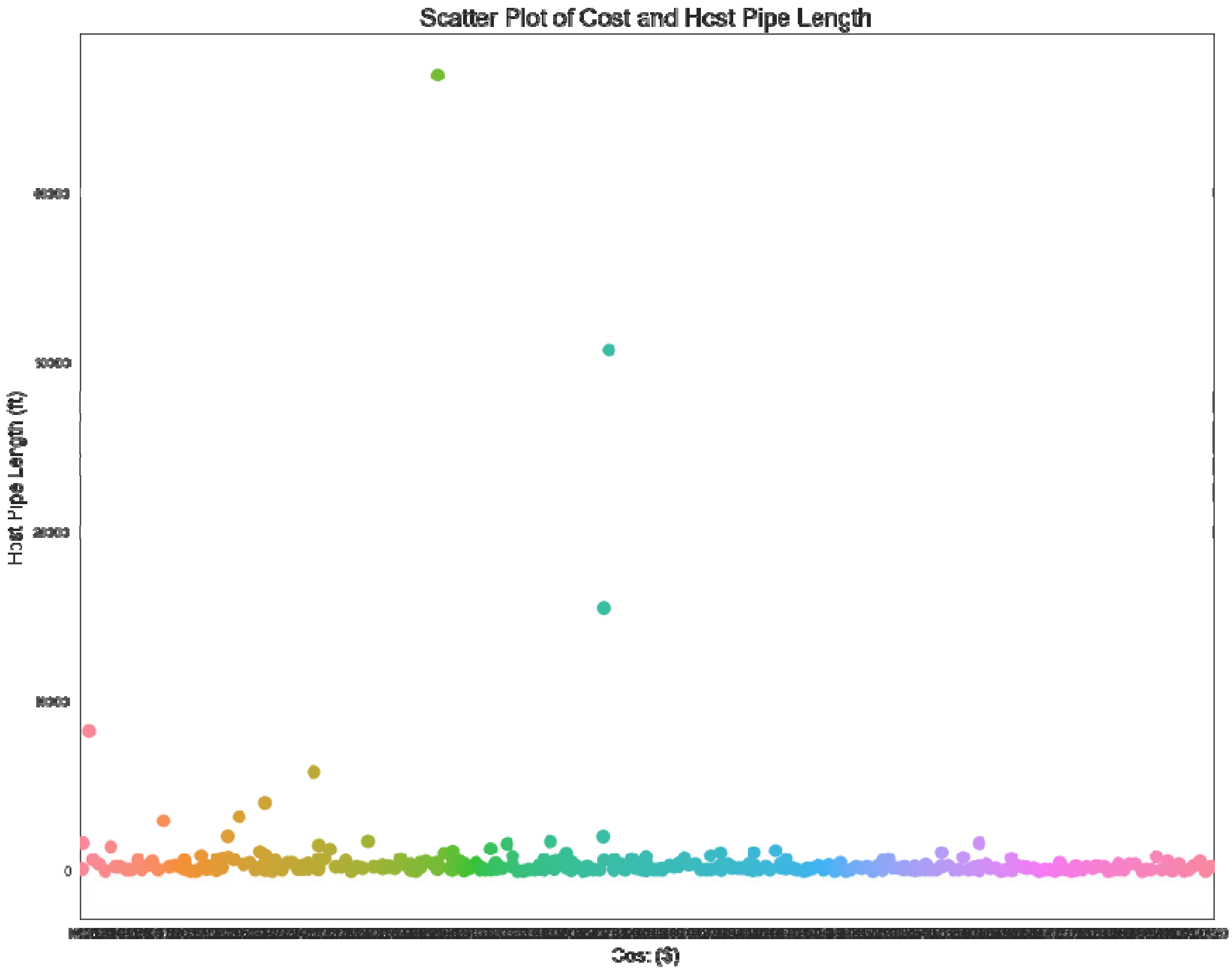


Figure 4-15 Scatter Plot of Pipe Length to Unit Cost

4.7 Chapter Summary

In this chapter, the data source of trenchless SAPL, CIPP, and sliplining renewal projects in large diameter culverts dataset was comprehensively reviewed. In addition, the detail of variables included in the model and data preparation techniques were explained thoroughly. The raw database was discovered, cleansed, transformed, and stored into a standardized format ready to insert to the software for the development of the models. The available parameters for the model development were identified and their relevance examined through machine learning analysis. The statistic descriptive as well as the histogram analysis of each parameter was presented in this chapter. Admittedly, two correlation matrixes were developed to investigate the correlation between all variables and to check the multicollinearity of independent variables in dataset. The detail of developing KNN, decision tree, linear regression, and gradient boosting tree regression models are presented in chapter 5.

CHAPTER 5

MODEL DEVELOPMENT AND RESULTS

5.1 Introduction

Based on what is discussed in the methodology section, to analyze the life-cycle cost of 3 trenchless renewals in culverts, 2 modules as construction and environmental costs are evaluated separately from a single dataset. In the previous chapter, the collected data is prepared, visualized, and analyzed.

In one hand, the data and parameters are prepared and ready to use as an input to develop a model for construction costs and independent variables are defined to predict the dependent variable as a unit cost ($/LF) of the trenchless method.

On the other hand, to evaluate the environmental costs, SimaPro software is employed for analysis. In this chapter, the analysis of environmental costs using SimaPro software is discussed. In addition, using a machine learning method, 4 models are developed and the best accurate model is selected to predict the construction costs of the trenchless renewal methods. Finally, by adding the results of SimaPro analysis as deterministic values to the outcome of the construction cost prediction model and then using ASTM C 1131, the machine learning-based model for construction and environmental costs in life-cycle cost analysis of trenchless SAPL, CIPP, and sliplining renewals in large diameter culverts (LCCATR) is introduced.

5.2 Environmental Costs Analysis

5.2.1 Environmental Inputs

To conduct the analysis of environmental costs, the data need to input to the SimaPro software. There are 2 categories of data which are needed by SimaPro software to calculate the life-cycle assessment of a trenchless renewal method; materials and equipment. The following sections are provided to discuss selecting materials and equipment and categorization of inputs for using in SimaPro software.

5.2.2 Materials Inputs

The materials data are calculated for each diameter of each trenchless method. In overall, 48 materials data are calculated to insert as material inputs in SimaPro software which is displayed in Table 5-1. As the average length of the pipes in the main dataset was about 500-ft, all materials data are calculated based on the requirement of a project with 500-ft length. In the end, the results in dollar values are divided by 500-ft to convert to dollar per linear feet ($/LF) unit.

Table 5-1 Pipe Diameters for Materials Input

Trenchless Method	Diameter (in.)													
SAPL, CIPP, & Sliplining	30	36	42	48	54	60	66	72	78	84	90	96	102	108

5.2.2.1 SAPL Properties

Based on the scope of the work of this dissertation, cementitious material with the physical properties of the structural cementitious liner according to the IOWA DOT and NASSCO rehabilitation guidelines is selected for analysis (www.iowadot.gov). Table 5-2 shows the physical properties of the selected cementitious material.

Table 5-2 Cementitious Lining Physical Properties Source: IOWA DOT Guide
Available at: www.iowadot.gov (Accessed December 12, 2019)

Property	Value
Unit Weight	125 pcf
Set Time at 70° F ASTM C 403 - Initial Set / Final Set	240 minutes / 440 minutes
Modulus of Elasticity ASTM C 469 - 24 hours / 28 days	180,000 psi / 1,150,000 psi
Flexural Strength ASTM C 293 24 - hours / 28 days	650 psi / 800 psi
Compressive Strength ASTM C 109 - 24 hours / 28 days	3,000 psi / 10,000 psi
Tensile Strength ASTM C 307	600 psi
Shear Bond ASTM C 882	>1,000 psi
Shrinkage ASTM C 157	None
Chloride Permeability ASTM C 1202	<550 Coulombs

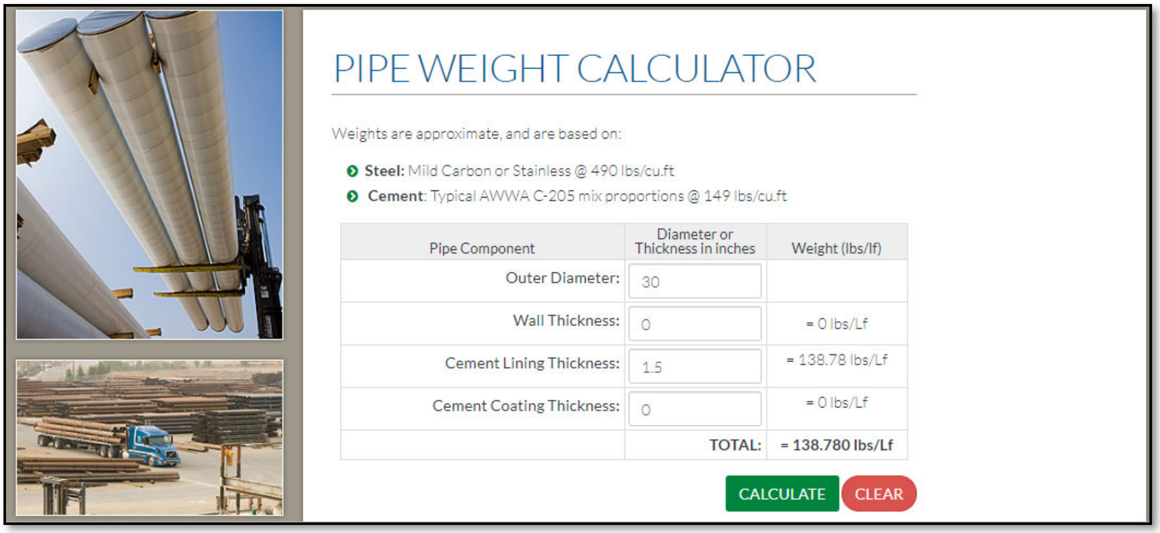
The specification for the structural cementitious liner is assumed for a SAPL cementitious product which is a high-strength, high-build, corrosion-resistant mortar, based on Portland cement fortified with micro silica with the minimum weight of 149 pcf. Mixed mortar is to have a paste-like consistency that may be sprayed, cast, pumped, or gravity-flowed into any area 0.5 in. and larger. In this dissertation, as the average thickness of the dataset for SAPL was 1.5 in., this thickness is selected for all diameter of the 500-ft length pipes. Also, a cement mortar with a unit weight of 149 pcf is assumed to calculate the weight of the cement used.

Subsequently, the weight of the cement mortar of various diameters is calculated by using a weight calculator in the Imperial Pipe website (www.imperialpipe.com) with respect to the SAPL wall thickness of 1.5 in. (Figure 5-1). Table 5-3 shows the results of weight for the SAPL technique material of a 149 pcf cement mortar for pipe diameter of 30 in. to 108 in.

Table 5-3 SAPL Material for Pipe with 500-ft length
and Diameter of 30 in. to 108 in.

Component	Wall Thickness	Portland cement, at plant/US*	
Diameter (in.)	Thickness (in.)	Weight per LF (lb/LF)	Weight (lb.)
30	1.5	138.78	69,390
36	1.5	168.00	84,000
42	1.5	197.21	98,605
48	1.5	226.43	113,215
54	1.5	255.65	127,825
60	1.5	284.86	142,430
66	1.5	314.08	157,040
72	1.5	343.30	171,650
78	1.5	372.51	186,255
84	1.5	401.73	200,865
90	1.5	430.95	215,475
96	1.5	460.16	230,080
102	1.5	489.38	244,690
108	1.5	518.60	259,300

*SimaPro software material code



PIPE WEIGHT CALCULATOR

Weights are approximate, and are based on:

- **Steel:** Mild Carbon or Stainless @ 490 lbs/cu.ft
- **Cement**: Typical AWWA C-205 mix proportions @ 149 lbs/cu.ft

Pipe Component	Diameter or Thickness in inches	Weight (lbs/lf)
Outer Diameter:	30	
Wall Thickness:	0	= 0 lbs/Lf
Cement Lining Thickness:	1.5	= 138.78 lbs/Lf
Cement Coating Thickness:	0	= 0 lbs/Lf
	TOTAL:	= 138.780 lbs/Lf

Figure 5-1 Sample of SAPL Cementitious Weight Calculation by Using Online Imperial Pipe Website (A Screenshot of www.imperialpipe.com) (Accessed December 12, 2019)

5.2.2.2 CIPP Properties

Based on the scope of the work for the CIPP method, an unsaturated polyester resin was used in this dissertation. It is a product of 1:1 maleic anhydride and propylene glycol with an average of 10.13 vinylene groups per molecule and an average molecular weight of 1580 g mole21, containing 35% by weight of styrene (Cao and Lee, 2013). After selecting the CIPP product, it is required to determine the thickness of CIPP to calculate the total weight of CIPP and its components respectively. Ra et al (2019) determined an average of 0.35 in. (9mm) for the unsaturated polyester resin. In addition, Ji et al (2018) reported 0.39 in. (9.83 mm) as an average wall thickness of the unsaturated polyester resin. The following equations (Eq. 4-1 and Eq. 4-2) are provided to calculate the thickness of CIPP X1 Design Considerations in ASTM F1216 Appendixes. Equation 4-1 is used for the partially deteriorated condition where groundwater pressure is loading pressure over the CIPP liner. Equation 4-2 is used for the fully deteriorated condition that the existing pipe is no longer supporting external loads including groundwater and surrounding soil.

When all other site conditions remain consistent, the CIPP liner thickness decreases proportionately to the one-third (1/3) fractional exponent of the value of E_L (Ji et al., 2018). According to ASTM F1216, the long-term modulus of elasticity (E_L) is recommended as a half value (50 percent) of short-term flexural modulus.

$$t = \frac{D}{\sqrt[3]{\frac{2kE_LC}{PN(1-v^2)}}+1} \qquad \text{Eq. 4-1}$$

$$t = 0.721D\sqrt[3]{\left[\frac{\left(\frac{Nq_t}{C}\right)^2}{E_LR_wB'E_s'}\right]} \qquad \text{Eq. 4-2}$$

Where, t = thickness of CIPP (in.),

D = mean inside diameter of original pipe (in.),

K = enhancement factor of the soil and existing pipe adjacent to the new pipe,

E_L = long-term modulus of elasticity for CIPP (psi),

C = ovality reduction factor,

P = groundwater load (lb),

N = factor of safety,

q_t = total external pressure on pipe (psi),

R_w = water buoyancy factor,

B' = Coefficient of elastic support, and

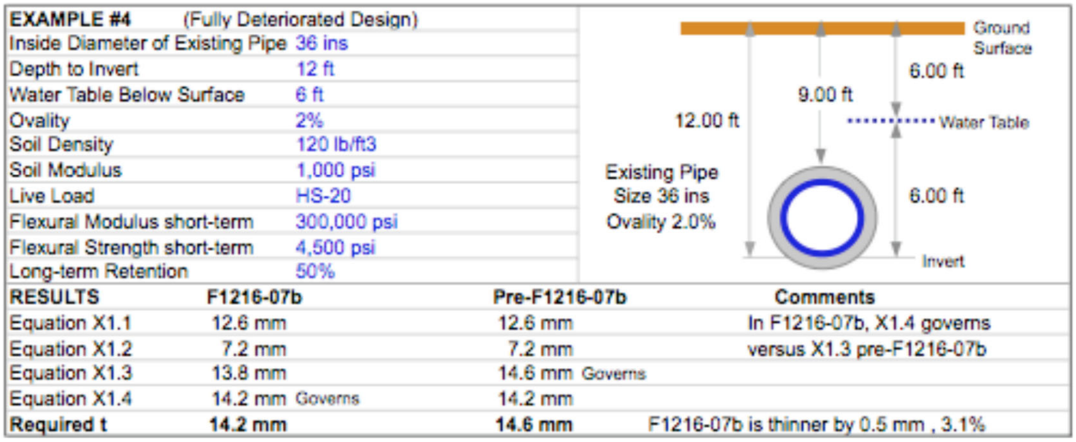
E'_s = modulus of soil reaction (psi).

To calculate the wall thickness of CIPP, it is assumed that the original pipe is fully deteriorated. Doherty (2008) calculated the CIPP wall thickness according to the ASTM F1216 regarding fully deteriorated pipes. Figure 5-2 to Figure 5-4 are presented to show the calculated t value for pipe diameter of 36 in., 48 in., and 60 in. as the CIPP wall thickness by Doherty (2008).

Based on the results of CIPP wall thickness reported by Doherty (2008), for the 36 in., 48 in., and 60 in of diameter, the CIPP wall thicknesses for other diameters from 30 in. to 108 in. are calculated. It is assumed the same CIPP wall thicknesses for diameters of 30 in. to 42 in., 48 in. to 54 in., 60 in. to 78 in., and 84 in. to 108 in. Also, based upon the proportion changing of the wall thickness from 30 in. to 48 in. (1.31) and 48 in. to 60 in. (1.38), by applying a factor of 1.45 (1.45 = 1.38 * [1.38 - 1.31]) to the wall thickness, which is associated with the 60 in. pipe liner, the CIPP wall thickness for the diameter of 84 in. is calculated.

Subsequently, the weight of unsaturated polyester resin of various diameters is calculated by using a weight calculator in the online metals website (www.onlinemetals.com) with respect to the CIPP wall thickness results (Figure 5-5).

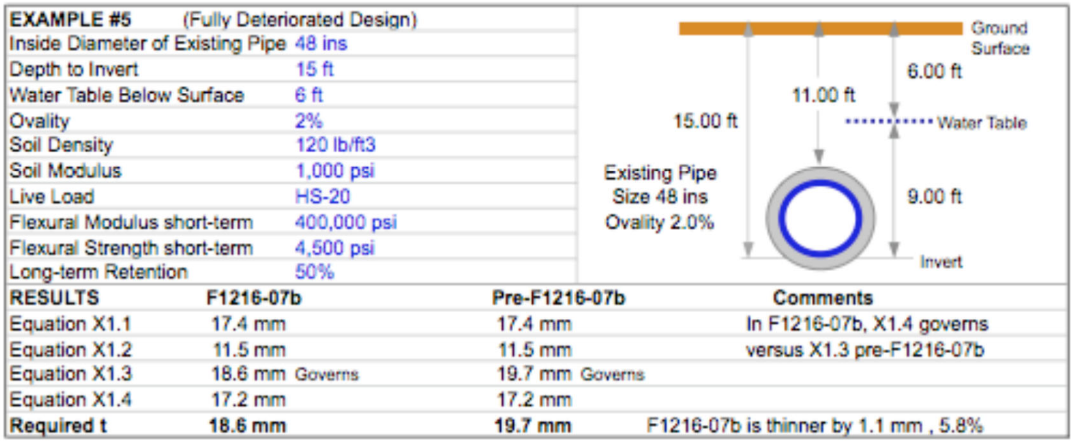
According to Cao and Lee (2013), 35% and McAlvin (2011), 38% of the total polyester resin weight is the weight of the styrene. As a result, 35% of the total weight of the polyester resin is allocated as the styrene weight. Moreover, according to Ajdari (2016), 1-5% of CIPP resins are consist of amorphous fumed silica, so, 3% of CIPP resin weight is accounted for amorphous fumed silica weight. Table 5-4 shows the weight of each component of the CIPP method with the material of unsaturated polyester resin for pipe diameter of 30 in. to 108 in.



EXAMPLE #4	(Fully Deteriorated Design)
Inside Diameter of Existing Pipe	36 ins
Depth to Invert	12 ft
Water Table Below Surface	6 ft
Ovality	2%
Soil Density	120 lb/ft3
Soil Modulus	1,000 psi
Live Load	HS-20
Flexural Modulus short-term	300,000 psi
Flexural Strength short-term	4,500 psi
Long-term Retention	50%

RESULTS	**F1216-07b**	**Pre-F1216-07b**	**Comments**
Equation X1.1	12.6 mm	12.6 mm	In F1216-07b, X1.4 governs
Equation X1.2	7.2 mm	7.2 mm	versus X1.3 pre-F1216-07b
Equation X1.3	13.8 mm	14.6 mm Governs	
Equation X1.4	14.2 mm Governs	14.2 mm	
Required t	**14.2 mm**	**14.6 mm**	F1216-07b is thinner by 0.5 mm , 3.1%

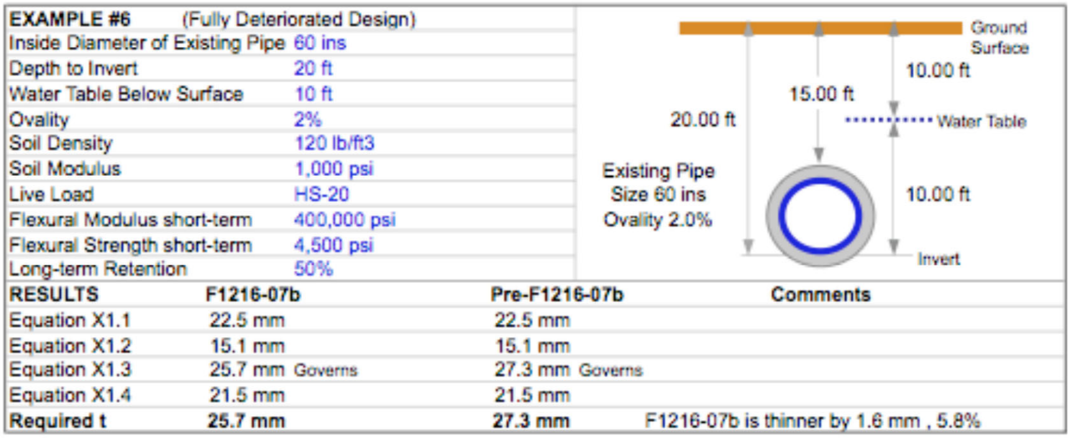
Figure 5-2 Fully Deteriorated Design for 36-in. Liner (Doherty, 2008)



EXAMPLE #5	(Fully Deteriorated Design)
Inside Diameter of Existing Pipe	48 ins
Depth to Invert	15 ft
Water Table Below Surface	6 ft
Ovality	2%
Soil Density	120 lb/ft3
Soil Modulus	1,000 psi
Live Load	HS-20
Flexural Modulus short-term	400,000 psi
Flexural Strength short-term	4,500 psi
Long-term Retention	50%

RESULTS	**F1216-07b**	**Pre-F1216-07b**	**Comments**
Equation X1.1	17.4 mm	17.4 mm	In F1216-07b, X1.4 governs
Equation X1.2	11.5 mm	11.5 mm	versus X1.3 pre-F1216-07b
Equation X1.3	18.6 mm Governs	19.7 mm Governs	
Equation X1.4	17.2 mm	17.2 mm	
Required t	**18.6 mm**	**19.7 mm**	F1216-07b is thinner by 1.1 mm , 5.8%

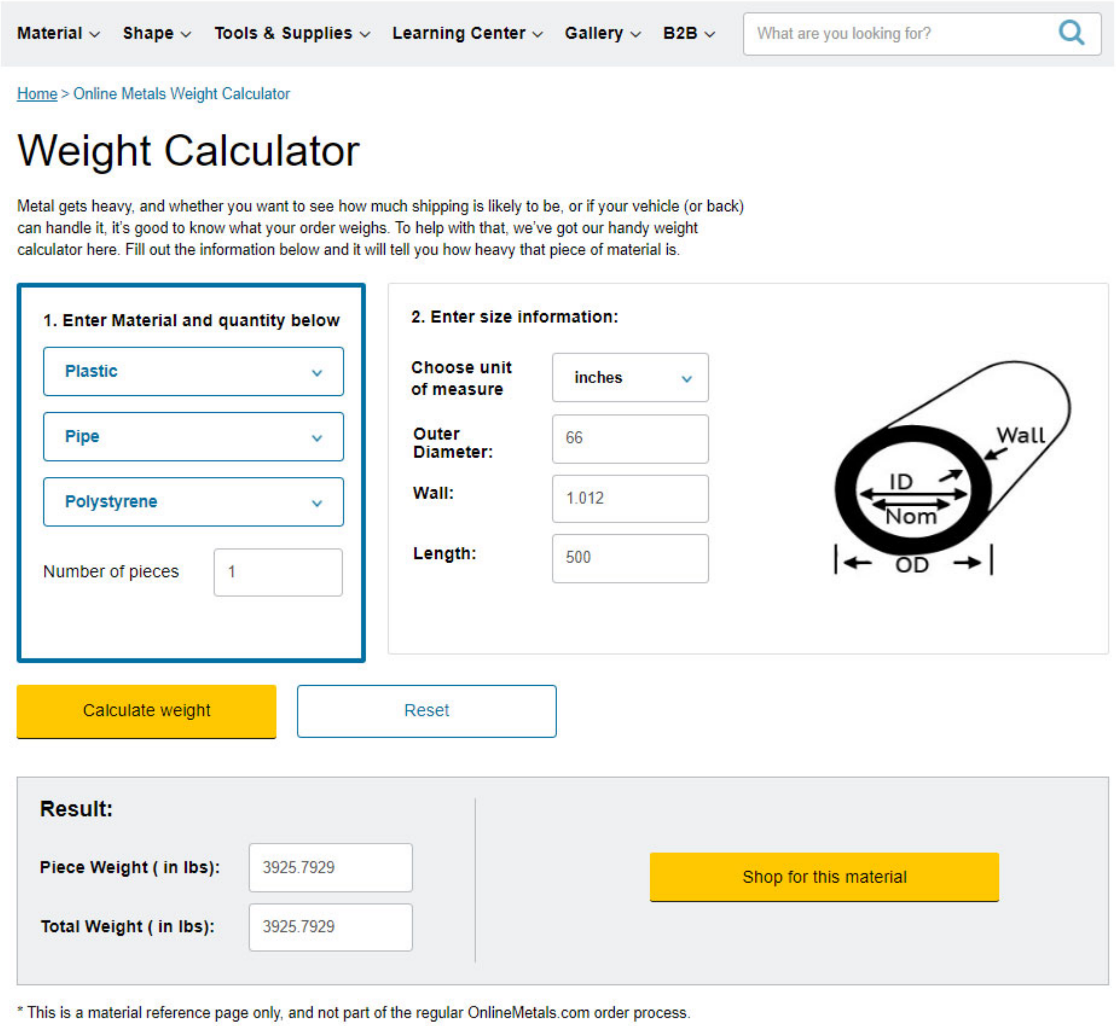
Figure 5-3 Fully Deteriorated Design for 48-in. Liner (Doherty, 2008)



EXAMPLE #6	(Fully Deteriorated Design)
Inside Diameter of Existing Pipe	60 ins
Depth to Invert	20 ft
Water Table Below Surface	10 ft
Ovality	2%
Soil Density	120 lb/ft3
Soil Modulus	1,000 psi
Live Load	HS-20
Flexural Modulus short-term	400,000 psi
Flexural Strength short-term	4,500 psi
Long-term Retention	50%

RESULTS	**F1216-07b**	**Pre-F1216-07b**	**Comments**
Equation X1.1	22.5 mm	22.5 mm	
Equation X1.2	15.1 mm	15.1 mm	
Equation X1.3	25.7 mm Governs	27.3 mm Governs	
Equation X1.4	21.5 mm	21.5 mm	
Required t	**25.7 mm**	**27.3 mm**	F1216-07b is thinner by 1.6 mm , 5.8%

Figure 5-4 Fully Deteriorated Design for 60-in. Liner (Doherty, 2008)



Weight Calculator

Metal gets heavy, and whether you want to see how much shipping is likely to be, or if your vehicle (or back) can handle it, it's good to know what your order weighs. To help with that, we've got our handy weight calculator here. Fill out the information below and it will tell you how heavy that piece of material is.

1. Enter Material and quantity below

Plastic
Pipe
Polystyrene
Number of pieces: 1

2. Enter size information:

Choose unit of measure: inches
Outer Diameter: 66
Wall: 1.012
Length: 500

Result:

Piece Weight (in lbs): 3925.7929
Total Weight (in lbs): 3925.7929

* This is a material reference page only, and not part of the regular OnlineMetals.com order process.

Figure 5-5 Sample of CIPP Weight Calculation by Using Online Metals Website Available at: www.onlinemetals.com (Accessed December 12, 2019)

Table 5-4 CIPP Material Proportioning for Pipe with 500-ft length and Diameter of 30 in. to 108 in.

Component	Wall Thickness	Polyester resin, unsaturated, at plant/US-US-EI U* (62%)	Styrene E* (35%)	Silica fume, densified {GLO}| market for | Alloc Rec, U* (3%)	Total
Reference	Doherty, 2018	Ji et al., 2018	Cao and Lee, 2013	Ajdari, 2016	www.onlinemetals.com
Diameter (in.)	Thickness (in.)	Weight (lb.)			
30	0.559	7,308.84	4,125.96	353.64	11,788.44
36	0.559	8,798.40	4,966.80	425.76	14,190.96
42	0.559	10,287.96	5,807.76	497.76	16,593.48
48	0.732	15,366.12	8,674.44	743.52	24,784.08
54	0.732	17,316.72	9,775.56	837.96	27,930.12
60	1.012	26,511.36	14,966.04	1,282.80	42,760.20
66	1.012	29,207.88	16,488.36	1,413.24	47,109.48
72	1.012	31,904.52	18,010.56	1,543.80	51,458.88
78	1.012	34,601.16	19,532.88	1,674.24	55,808.28
84	1.467	53,770.56	30,354.36	2,601.84	86,726.64
90	1.467	57,679.56	32,561.04	2,790.96	93,031.56
96	1.467	61,588.56	34,767.72	2,980.08	99,336.48
102	1.467	65,497.56	36,974.40	3,169.20	105,641.28
108	1.467	69,406.68	39,181.20	3,358.44	111,946.20

*SimaPro software material code

5.2.2.3 Sliplining Properties

Appropriate pipe stiffness is a function of the external loads and conditions, insertion compressive loads (multiple pipe pushing), grouting pressure, grouting deformation loads, and the blocking scheme. According to the scope of the work for sliplining application, the specifications of the Class DR 17 of HDPE pipes from Plastic Pipe Institute are used in this dissertation. Typically, DR 17 pipes have sufficient performance capability to safely withstand most controlled installations and are used most often. The table below lists the dimensions for the typical minimum wall, outside diameter, nominal pipe stiffness, minimum pipe thickness at gasket groove, safe compressive load pushing straight and weight per foot of the HDPE pipes from Plastic Pipe Institute official complete guide (Table 5-5). According to the HDPE DR 17 specification and based upon the minimum wall thickness and weight per foot of the pipe, the total weight of a 500-ft length HDPE pipe for various diameters is calculated and presented in Table 5-6.

Table 5-5 Adopted from DR 17 Plastic Pipe Institute Specification
(Plastic Pipe Institute Handbook, 2018)

Diameter (in.)	Wall Thickness (in.)
30	0.86
36	0.90
42	0.99
48	1.09
54	1.17
60	1.27
66	1.45
72	1.49
78	1.53
84	1.57
90	1.66
96	1.75
102	1.85
108	1.94

Table 5-6 Sliplining Material for Pipe with 500-ft length and Diameter of 30 in. to 108 in.

Component	Wall Thickness	HDPE Pipes E*	
Diameter (in.)	Thickness (in.)	Weight per LF (lb/LF)	Total Weight (lb)
30	0.86	87	43,500
36	0.90	110	55,000
42	0.99	140	70,000
48	1.09	175	87,500
54	1.17	210	105,000
60	1.27	251	125,500
66	1.45	315	157,500
72	1.49	352	176,000
78	1.53	393	196,500
84	1.57	430	215,000
90	1.66	491	245,500
96	1.75	547	273,500
102	1.85	628	314,000
108	1.94	695	347,500

*SimaPro software material code

5.2.3 Equipment Inputs

All the selected equipment for this dissertation is selected according to literature review (Tymkowicz, 1995; Jain, 2010), companies' installation manuals and guidelines (Plastic Pipe Institute, 2019) and interviews with representatives and several experts of various SAPL, CIPP, and sliplining providers[2]. Based on the data availability and expertise judgment, one set of equipment input as the required installation equipment for 30-in. diameter is selected for SAPL, CIPP, and sliplining renewals.

According to the literature review, by increasing the diameter of pipes, the installation time can considerably increase (Ramirez et al., 2010; Matthews, 2015). For instance, liner installation in the City of Los Angeles North Outfall Sewer (NOS), which is

---

[2] The names of vendors, which are participated in the interview and provided information regarding the SAPL, CIPP, and sliplining installation, is listed in acknowledgment part of this study.

78 in. of diameter took approximately seven days to complete which is almost two times rather than the common installation time for 30 in. of diameter (Hanks et al., 2010).

As there is no study that shows the exact proportion of increasing the installation time by increasing the diameter and based on the available related studies, it is assumed that by increasing one size of diameter (ex. from 30 in. to 36 in or from 36 in. to 42 in. and etc.) the installation time is increased by 5%.

The following sections are provided to determine all equipment needed for SAPL, CIPP, and sliplining installation at the job site for 30 in. of diameter. Then, for providing the data to use as inputs to the software, all the installation times are increased according to the assumption for the various diameter.

5.2.3.1 SAPL Installation

According to the author's observations and the interview with expertise, the equipment that is listed in Table 5-7 is assumed to install 500-ft length of SAPL renewal for the diameter of 30 in. It should be noted that the method of installation is assumed to apply by hand spraying based on the scope of the work.

Table 5-7 SAPL Installation Equipment for Pipe with 500-ft length and Diameter of 30 in.

Factor\Equipment	26-ft Truck[3]	40-kW Generator Set[4]	40-CFM Air Compressor[5]	Mix and Spray Pump[6]
Power type	Diesel	Diesel	Electric	Electric
Horsepower (hp)	325	65	10	15
Operating per day (hours)	8	8	8	8
Construction duration (days)	3	3	3	3
Total operating (hours)	24	24	24	24

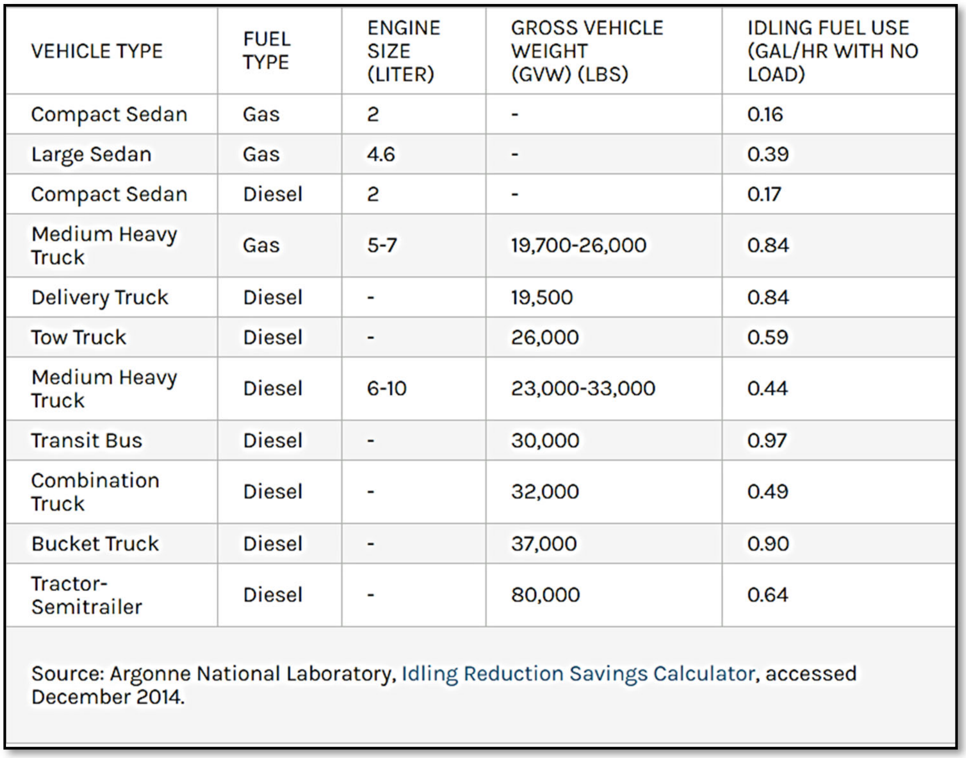
---

[3] International Durastar, 4300 Van, 2016, box truck – straight truck
[4] Industrial Power, diesel generator set - SD040 | 3.4L | 40 kW
[5] Schulz, L-Series 10120HL40X-3 10-HP 120-Gallon Two-Stage Air Compressor
[6] ChemGrout, CG-570, Thick Mix Series

There are some considerations involved to determining the inputs of SAPL (and CIPP and sliplining methods) installation for SimaPro software as follows:

- It is assumed that the average lifetime of equipment is 40,000 hours. Thus, according to the total operating hours of equipment in Table 5-7, 0.1% of total emissions from the production of each equipment is considered as the impact of them to the environment for renewal of a 500-ft length of pipe with 30 in. diameter.
- Transportation distance, which is the distance from the location where the materials are transported from to the job site, is assumed 50 miles (see section 5.2.4).
- The transportation of the material in the unit of ton-mile is calculated by multiplication of total material weights by transportation distance.
- The fuel consumption of the trucks with diesel engines is calculated for IDLE status at the job site according to a report from the US Office of Energy Efficiency and Renewable Energy (Fact #861) Figure 5-6.
- The fuel consumption of a generator set is calculated by using hardy diesel generator fuel consumption (www.hardydiesel.com). The screenshot of the website, which has been used to calculate the fuel consumption of a generator set, can be found in Figure 5-7.

Table 5-8 is provided to show the fuel consumption of all involved equipment. Also, the electricity consumptions which are shown in Table 5-9 are calculated by multiplication of kilowatt of the equipment and their operating hours.



VEHICLE TYPE	FUEL TYPE	ENGINE SIZE (LITER)	GROSS VEHICLE WEIGHT (GVW) (LBS)	IDLING FUEL USE (GAL/HR WITH NO LOAD)
Compact Sedan	Gas	2	-	0.16
Large Sedan	Gas	4.6	-	0.39
Compact Sedan	Diesel	2	-	0.17
Medium Heavy Truck	Gas	5-7	19,700-26,000	0.84
Delivery Truck	Diesel	-	19,500	0.84
Tow Truck	Diesel	-	26,000	0.59
Medium Heavy Truck	Diesel	6-10	23,000-33,000	0.44
Transit Bus	Diesel	-	30,000	0.97
Combination Truck	Diesel	-	32,000	0.49
Bucket Truck	Diesel	-	37,000	0.90
Tractor-Semitrailer	Diesel	-	80,000	0.64

Source: Argonne National Laboratory, Idling Reduction Savings Calculator, accessed December 2014.

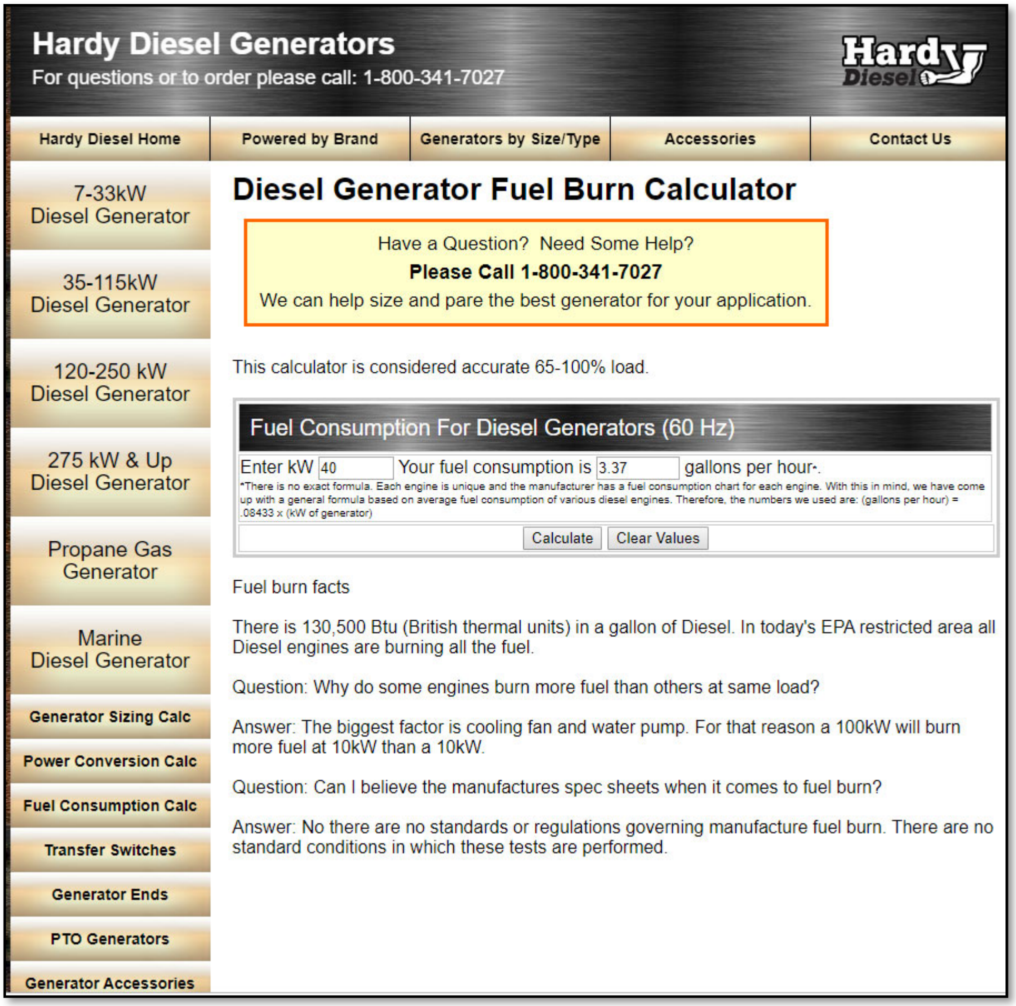
Figure 5-6 Fuel Consumption for Gasoline and Diesel Vehicles in IDLE Status
Source: US Office of Energy Efficiency and Renewable Energy
Available at www.energy.gov (Accessed December 1, 2019)

Table 5-8 Fuel Consumption of SAPL Equipment at the Jobsite for Pipe with 500-ft length and Diameter of 30 in.

Equipment	Diesel Consumption (gal/hour)	Operation (hour)	Diesel (gal)
26-ft Truck (IDLE)	0.84	24	20.16
40-kW Generator Set	3.37	24	80.88
Total			101.04

Table 5-9 Electricity Consumption of SAPL Equipment at the Jobsite for Pipe with 500-ft length and Diameter of 30 in.

Equipment	Kilowatt (kW)	Operation (hour)	Electricity (kWh)
40-CFM Air Compressor	7.5	24	120
Mix and Spray Pump	12	24	288
Total			408



Diesel Generator Fuel Burn Calculator

Have a Question? Need Some Help?
Please Call 1-800-341-7027
We can help size and pare the best generator for your application.

This calculator is considered accurate 65-100% load.

Fuel Consumption For Diesel Generators (60 Hz)

Enter kW 40 Your fuel consumption is 3.37 gallons per hour*.

*There is no exact formula. Each engine is unique and the manufacturer has a fuel consumption chart for each engine. With this in mind, we have come up with a general formula based on average fuel consumption of various diesel engines. Therefore, the numbers we used are: (gallons per hour) = .08433 x (kW of generator)

Fuel burn facts

There is 130,500 Btu (British thermal units) in a gallon of Diesel. In today's EPA restricted area all Diesel engines are burning all the fuel.

Question: Why do some engines burn more fuel than others at same load?

Answer: The biggest factor is cooling fan and water pump. For that reason a 100kW will burn more fuel at 10kW than a 10kW.

Question: Can I believe the manufactures spec sheets when it comes to fuel burn?

Answer: No there are no standards or regulations governing manufacture fuel burn. There are no standard conditions in which these tests are performed.

Figure 5-7 Fuel Consumption for Diesel Generators Source: Hardy Diesel Guide Available at: www.hardydiesel.com (Accessed December 11, 2019)

Considering the calculated materials for SAPL and the assumptions, the equipment datasheet to input in SimaPro software for environmental impact analysis is provided for all diameters from 30 in. to 108 in. (Table 5-10). It should be emphasized that since there was no generator set in the software with 40-kW, 3 sets of 18.5-kW generator sets are considered.

Table 5-10 SAPL Process Inputs in SimaPro Software for Pipe with 500-ft Length and Diameters from 30 in. to 108 in.

Processes	Transport, lorry 20-28t, fleet average/US US-EI U*	Diesel-electric generating set, 18.5kW {GLO}| market for | Alloc Def, U*	Air compressor, screw-type compressor, 4 kW, at plant/US-/I US-EI U*	Diesel, combusted in industrial equipment/US*	Electricity, medium voltage {US}| market group for | Alloc Def, U*
Diameter (in.)\Unit	tmi[7]	Piece	Piece	gal	kWh
30	1,734.75	0.003	0.001	101.04	408.00
36	2,100.00	0.003	0.001	106.09	428.40
42	2,465.13	0.003	0.001	111.40	449.82
48	2,830.38	0.003	0.001	116.97	472.31
54	3,195.63	0.004	0.001	122.81	495.93
60	3,560.75	0.004	0.001	128.96	520.72
66	3,926.00	0.004	0.001	135.40	546.76
72	4,291.25	0.004	0.001	142.17	574.10
78	4,656.38	0.004	0.001	149.28	602.80
84	5,021.63	0.005	0.002	156.75	632.94
90	5,386.88	0.005	0.002	164.58	664.59
96	5,752.00	0.005	0.002	172.81	697.82
102	6,117.25	0.005	0.002	181.45	732.71
108	6,482.50	0.006	0.002	190.53	769.34

*SimaPro software process code

---

[7] tmi = ton-mile; 1 tmi transports 1 ton over 1 mile

5.2.3.2 CIPP Installation

According to the recent study by Kaushal (2019) and the interview with expertise, the equipment which is needed for CIPP installation of a pipe with 500-ft length is assumed and listed in Table 5-11. The list of equipment for CIPP renewal is considered for the diameter of 30 in. It should be emphasized that the method of curing is assumed to be steam based on the scope of the work.

Table 5-11 CIPP Installation Equipment for Pipe with
500-ft length and diameter of 30 in.

Factor\Equipment	Utility 26-ft Truck[8]	40-kW Generator Set[9]	750-CFM Air Compressor[10]	Refrigeration Truck[11]	Steam Truck[12]	Curing Unit[13]
Power type	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
Horsepower (hp)	325	65	300	260	325	8
Operating per day (hours)	8	8	8	8	8	8
Construction duration (days)	4	4	4	4	4	4
Total operating (hours)	32	32	32	32	32	32

The next step after the equipment that is required for CIPP application was determined, was to prepare the list of the inputs to use in SimaPro software based on the equipment and the weight of the materials for each diameter from 30 in. to 108 in. Following is the list of the assumptions involved to calculate the inputs of SimaPro software.

- Transportation distance, which is the distance from the location where the materials are transported from is assumed 50 miles (see section 5.2.4).

---

[8] International Durastar, 4300 Van, 2016, Box truck – Straight truck

[9] Industrial Power, diesel generator set - SD040 | 3.4L | 40 kW

[10] The Sullair, 750, double axle rotary screw portable air compressor, delivers 750 cfm

[11] International Durastar, 4300 Van, 2012, Refrigerated Truck

[12] International Chassis, 26-ft, 56k GVW

[13] epros® SteamGen, M150, Steam Unit

- The transportation of the material in the unit of ton-mile is calculated by multiplication of total material weights by transportation distance.
- The fuel consumption of the 26-ft tuck with diesel engine is calculated for IDLE status at the job site according to report from the US Office of Energy Efficiency and Renewable Energy (Fact #861) available at www.energy.gov
- The fuel consumption of generator set is calculated by using hardy diesel generator fuel consumption (www.hardydiesel.com).

Table 5-12 is provided to show the fuel consumption of all involved equipment.

Table 5-12 Fuel Consumption of CIPP Equipment at the Jobsite

Equipment	Diesel Consumption (gal/hour)	Operation (hour)	Diesel (gal)
26-ft Truck	0.84	32	26.88
40-kW Generator Set	3.37	32	107.84
Refrigerator Truck	0.84	32	26.88
Steam Truck	0.84	32	26.88
Curing Unit	0.50	32	16.00
750-CFM Air Compressor	11.30	32	361.6
Total			566.08

The following table is provided to present the process inputs of SimaPro software for all diameter from 30 in. to 108 in for a culvert with 500-ft length (Table 5-13). It should be emphasized that since there was no generator set in the software with 40-kW, 3 sets of 18.5-kW generator sets are considered.

Table 5-13 CIPP Process Inputs in SimaPro Software for Pipe with 500-ft Length and Diameters from 30 in. to 108 in.

Processes	Transport, lorry 20-28t, fleet average/US US-EI U*	Diesel-electric generating set, 18.5kW {GLO}| market for | Alloc Def, U*	Air compressor, screw-type compressor, 300 kW, at plant/US-/I US-EI U*	Transport, freight, lorry with refrigeration {GLO} | Alloc Def, U *[14]	Transport, lorry 20-28t, fleet average/US US-EI U[15]*	On-site steam average[16]	Diesel, combusted in industrial equipment U*
Diameter (in.)\Unit	tmi	Piece	Piece	tmi	tmi	lb	gal
30	294.71	0.003	0.001	12.50**	12.50**	11,788.44	566.08
36	354.77	0.003	0.001	13.13	13.13	14,190.96	594.38
42	414.84	0.003	0.001	13.78	13.78	16,593.48	624.10
48	619.60	0.003	0.001	14.47	14.47	24,784.08	655.31
54	698.25	0.004	0.001	15.19	15.19	27,930.12	688.07
60	1,069.01	0.004	0.001	15.95	15.95	42,760.20	722.48
66	1,177.74	0.004	0.001	16.75	16.75	47,109.48	758.60
72	1,286.47	0.004	0.001	17.59	17.59	51,458.88	796.53
78	1,395.21	0.004	0.001	18.47	18.47	55,808.28	836.36
84	2,168.17	0.005	0.002	19.39	19.39	86,726.64	878.18
90	2,325.79	0.005	0.002	20.36	20.36	93,031.56	922.08
96	2,483.41	0.005	0.002	21.38	21.38	99,336.48	968.19
102	2,641.03	0.005	0.002	22.45	22.45	105,641.28	1,016.60
108	2,798.66	0.006	0.002	23.57	23.57	111,946.20	1,067.43

* SimaPro software process code

** It is assumed that the truck carries 500 lb of utilities and tools (12.50 tmi = 500(lb)/2000(lb/tn)*50(mile))

---

[14] Refrigerator Truck

[15] Steam Truck

[16] Curing

5.2.3.3 Sliplining Installation

Installation and field guide of Plastic Pipe Institute Pipe along with the author's observations led to account the required equipment for HDPE pipe installation in sliplining trenchless method. The equipment for installation of 500-ft length of HDPE pipe for the diameter of 30 in. are assumed. The complete package of the hydraulic jacking machine is assumed to use for installation as the main equipment of sliplining. All required equipment, which is assumed for sliplining installation, can be found in Table 5-14.

Table 5-14 Sliplining Installation Equipment for Pipe with 500-ft length and diameter of 30 in.

Factor\Equipment	Winch Truck[17]	Forklift[18]	Crane[19]	Hydraulic Jacking Machine[20]
Power type	Diesel	Diesel	Diesel	Diesel
Horsepower (hp)	500	69	130	215
Operating per day (hours)	4	4	4	16
Construction duration (days)	1	1	3	3
Total operating (hours)	4	4	12	48

There are some considerations involved in determining the inputs of sliplining installation for SimaPro software as follows:

- Consider that just a fraction of the lifetime of the winch truck, crane and forklift is used for sliplining setting up, these equipment environmental impacts were assumed to be almost negligible, so detailed modeling in SimaPro software were not accounted for them.

---

[17] KENWORTH C550, 2021, Winch Truck
[18] MANITOU, MT5519, 2018 Forklift
[19] Grove, YB7725, 25-Ton, Carry Deck Crane
[20] Akkerman, SLS 50/100, Hydraulic Jacking Machine with a 60-Ton pushing capacity

Table 5-15 is provided to show the fuel consumption of all involved equipment in sliplining installation.

Table 5-15 Fuel Consumption of Sliplining Equipment at the Jobsite

Equipment	Diesel Consumption (gal/hour)	Operation (hour)	Diesel (gal)
Winch Truck	0.84	4	3.36
Forklift	4.21	4	16.84
Crane	8.18	12	98.16
Total			118.36

After the equipment which is required for sliplining application was determined, the list of the inputs is prepared to use in SimaPro software based on the equipment and the weight of the materials for each diameter from 30 in. to 108 in. (Table 5-16).

5.2.4 Transportation of Materials

To analyze the total environmental costs for SAPL, CIPP, and sliplining trenchless renewals, it is necessary to account for the transportation of materials to the job site. The unit of transportation in SimaPro analysis is ton-mile, which considers the two main factors of transportation; the weight of the material (ton) and the distance that materials need to be hauled (mile).

It is assumed that on average, the materials were transported to the job site from 50 miles. In other words, the manufacturing plant location has in the average 50-mile distance to the job site for all three methods and for all different diameters. Then, by multiplying the weight of materials to 50-mile, the transportation input for SimaPro software can be calculated.

Table 5-16 Sliplining Process Inputs in SimaPro Software for Pipe with 500-ft Length and Diameters from 30 in. to 108 in.

Processes	Transport, truck >20t, EURO4, 80%LF, empty return/GLO Economic*[21]	Machine operation, diesel, >= 74.57 kW, steady-state {GLO}| machine operation, diesel, >= 74.57 kW, steady-state | Alloc Def, U*[22]	Cable yarding {RER}| yarding, mobile cable yarder on trailer | Alloc Def, U	Diesel, combusted in industrial equipment/US*
Diameter (in.)\Unit	tmi[23]	hr	hr	gal
30	1087.50	48.00	12.00	118.36
36	1375.00	50.40	12.60	124.28
42	1750.00	52.92	13.23	130.49
48	2187.50	55.57	13.89	137.02
54	2625.00	58.34	14.59	143.87
60	3137.50	61.26	15.32	151.06
66	3937.50	64.32	16.08	158.61
72	4400.00	67.54	16.89	166.54
78	4912.50	70.92	17.73	174.87
84	5375.00	74.46	18.62	183.62
90	6137.50	78.19	19.55	192.80
96	6837.50	82.10	20.52	202.44
102	7850.00	86.20	21.55	212.56
108	8687.50	90.51	22.63	223.19

*SimaPro software process code

---

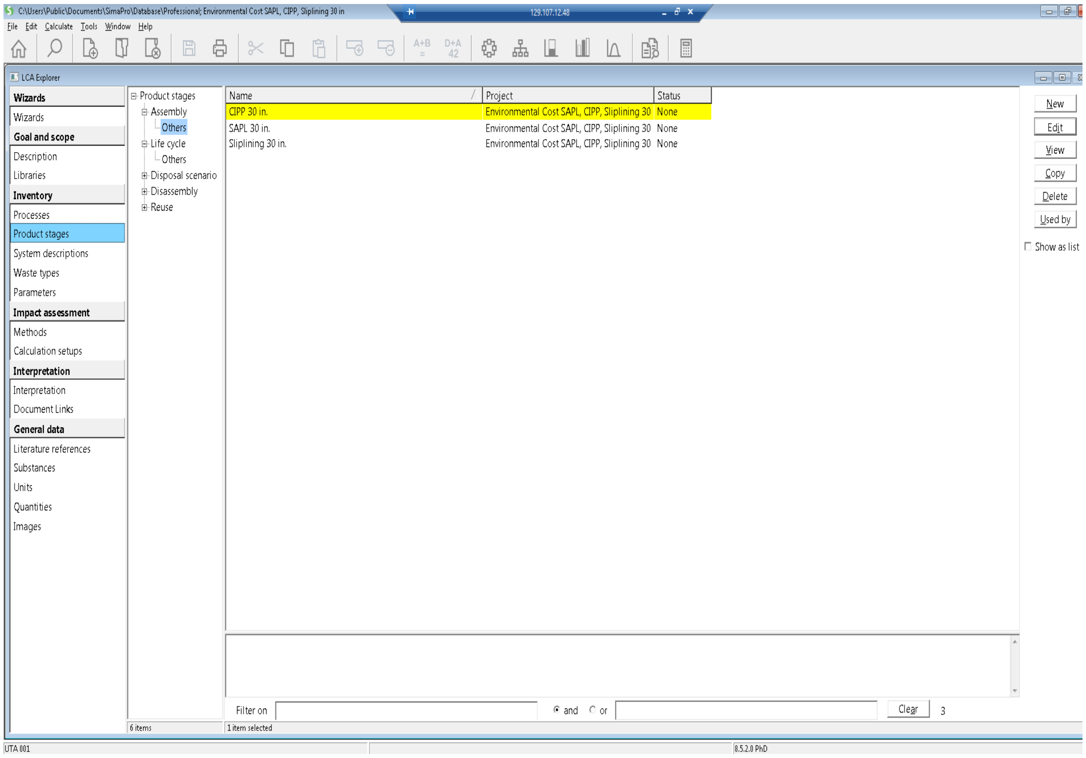
[21] Winch Truck

[22] Hydraulic Jacking Machine

[23] tmi = ton-mile; 1 tmi transports 1 ton over 1 mile

5.3 Environmental Costs Results

After the preparation of materials and equipment for all three trenchless renewal methods to analyze the total environmental costs, the inputs are transferred into the SimaPro software. The results are analyzed and plotted in the following sections in terms of environmental emissions and the associated costs. To have a view of how the SimaPro software is working a screenshot of the software is presented in Figure 5-8. This figure presents the main page of the SimaPro software where the materials (assembly) and equipment (process) is defined to conduct the life-cycle assessment.


C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 30 in

Name	Project	Status
CIPP 30 in.	Environmental Cost SAPL, CIPP, Sliplining 30	None
SAPL 30 in.	Environmental Cost SAPL, CIPP, Sliplining 30	None
Sliplining 30 in.	Environmental Cost SAPL, CIPP, Sliplining 30	None

Figure 5-8 Screenshot of the Main Page of SimaPro Software

5.3.1 Impact Category

The substantial output of the SimaPro is an impact category list, which consists of 10 major environmental impacts. All of the impacts listed in the impact category and their decryptions are provided in the following sections.

5.3.1.1 Ozone Depletion

“Ozone within the stratosphere provides protection from radiation, which can lead to increased frequency of skin cancers and cataracts in the human populations. Additionally, ozone has been documented to have effects on crops, other plants, marine life, and human-built materials. Substances which have been reported and linked to decreasing the stratospheric ozone level are chlorofluorocarbons (CFCs) which are used as refrigerants, foam blowing agents, solvents, and halons which are used as a fire extinguishing agents (USEPA, 2008).

Over 20 years ago, the United States signed the Montreal Protocol to reduce CFC production, and later implemented even more stringent reductions, which have led to a complete end of production of CFCs (by 1996) and halons (by 1994). Levels of total inorganic chlorine have been declining since 1998, and recovery of the ozone layer is expected in about 50 years (USEPA, 2008).

There is an international consensus on the use of ozone depletion potentials (ODPs), a metric proposed by the World Meteorological Organization (WMO) (Solomon and Albritton, 1992; WMO, 1999), for calculating the relative importance of substances expected to contribute significantly to the breakdown of the ozone layer. The USEPA maintains websites listing various options for ODPs (USEPA, 2008). These options are consistent with the US and WMO documents used internationally (WMO, 2003; USEPA,

1992; USEPA, 2003; WMO, 1999; USEPA, 2008). Within TRACI 2.1, the most recent sources of ODPs were used for each substance" (TRACI 2.1, 2012).

5.3.1.2 Global Warming

"Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human-induced. In common usage, global warming often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities (USEPA, 2008).

The current trend is to use the phrase 'climate change' instead of global warming to denote the other changes which may occur in addition to temperature change (USEPA, 2008). During the last 200 years, the sources of greenhouse gases have increased (mostly caused from the increased combustion of fossil fuels (USEPA, 2008)), while the sinks have decreased (e.g., deforestation and land-use changes)" (TRACI 2.1, 2012).

"The U.S. is keeping track of the greenhouse gas emissions (USEPA, 2008h; USEPA, 2008) and has a policy in place for greenhouse gas reductions (USEPA, 2008). TRACI 2.1 utilizes global warming potentials (GWPs) for the calculation of the potency of greenhouse gases relative to CO2 (IPCC (Intergovernmental Panel on Climate Change) 2001). Consistent with the guidance of the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 2003), the USEPA uses GWPs with 100-year time horizons.

TRACI 2.1 expands the list of substances found within the original version of TRACI and utilizes a hierarchy of data sources consistent with international acceptance.

This hierarchy of sources includes the most current GWPs published by the IPCC (Solomon, 2011; Solomon et al, 2007; IPCC, 2001; IPCC, 1996)" (TRACI 2.1, 2012).

5.3.1.3 Smog

"Ground-level ozone is created by various chemical reactions, which occur between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues including increasing symptoms of bronchitis, asthma, and emphysema. Permanent lung damage may result from prolonged exposure to ozone. Ecological impacts include damage to various ecosystems and crop damage. The primary sources of ozone precursors are motor vehicles, electric power utilities and industrial facilities (USEPA, 2008)" (TRACI 2.1, 2012).

"Modifications were made in the development of TRACI 2.1 when compared to the original version of TRACI. First, the MIRs were updated to include the latest work of Carter (Carter, 2010). More chemicals were added and the total number of pollutants now quantified in this category is nearly 1200 substances.

Second, to be consistent with the presentation and units of other impact categories a reference substance was adopted. Thirdly, those twelve substances, which have a negative MIR, were set to zero. While it may be true there is a slightly beneficial effect to the reduction of ozone concentrations upon the increased concentration of these pollutants, it was decided that providing "credit" for the additional release of pollutants was not generally a good practice. This is consistent with other recommendations in which negative MIRs were not given credits (Carter, 2003)" (TRACI 2.1, 2012).

5.3.1.4 Acidification

"Acidification is the increasing concentration of hydrogen ion (H+) within a local environment. This can be the result of the addition of acids (e.g., nitric acid and sulfuric acid) into the environment, or by the addition of other substances (e.g., ammonia) which increase the acidity of the environment due to various chemical reactions and/or biological activity, or by natural circumstances such as the change in soil concentrations because of the growth of local plant species" (TRACI 2.1, 2012).

"Acidifying substances are often air emissions, which may travel for hundreds of miles prior to wet deposition as acid rain, fog, or snow or dry deposition as dust or smoke particulate matter on the soil or water. Sulfur dioxide and nitrogen oxides from fossil fuel combustion have been the largest contributors to acid rain (USEPA, 2008)" (TRACI 2.1, 2012).

"Substances, which cause acidification, can cause damage to building materials, paints, and other human-built structures, lakes, streams, rivers, and various plants and animals. The sensitivity of various environments can depend on a number of factors including the local buffering capacity, the local plant and animal species, and the existing acidity within the environment (USEPA, 2008)" (TRACI 2.1, 2012).

"Consistent with the focus on providing midpoint assessments, TRACI 2.1 uses an acidification model which incorporates the increasing hydrogen ion potential within the environment without incorporation of site-specific characteristics such as the ability for certain environments to provide buffering capability (Wenzel et al., 1997; Wenzel and Hauschild, 1997)" (TRACI 2.1, 2012).

5.3.1.5 Eutrophication

"Eutrophication is the "enrichment of an aquatic ecosystem with nutrients (nitrates, phosphates) that accelerate biological productivity (growth of algae and weeds) and an undesirable accumulation of algal biomass" (USEPA, 2008). Although nitrogen and phosphorus play an important role in the fertilization of agricultural lands and other vegetation, excessive releases of either of these substances may provide undesired effects on the waterways in which they travel and their ultimate destination.

While phosphorus usually has a more negative impact on freshwater lakes and streams (U.S. Environmental Protection Agency, 2008), nitrogen is often more detrimental to coastal environments (Ecological Society of America, 2000)" (TRACI 2.1, 2012).

"Some of the major substances which have a role in this impact category are difficult to characterize including emissions from wastewater treatment plants, decaying plant life pulp and paper mills, food processing plants, and fertilizers used in agricultural, commercial, and individual household locations (US Environmental Protection Agency 1997). For example, the majority of fertilizer (when utilized correctly) provides the benefits for which it was purchased.

However, depending on the slope of the fields, the precipitation, and the volatilization of the fertilizer, some of this product may go beyond the originally intended boundaries and cause unintended consequences downstream. It is these unintended consequences that are considered to be the emission in this case; whereas, the portion of the application that achieved its goal of fertilizing fields was considered to be a useful product (US Department of Energy - National Renewable Energy Laboratory, 2008)" (TRACI 2.1, 2012).

"The original methodology utilized in TRACI allowed site-specific characterization, which is not supported, in the current version. Additional substances, which have the potential to cause eutrophication, have been added to TRACI 2.1" (TRACI 2.1, 2012).

5.3.1.6 Carcinogenics and Non-Carcinogenics (Human Toxicity)

"During the development of the original TRACI, human health was represented by three impact categories based on the current structure of the EPA regulations and the chemical and physical behaviors of the pollutants of concern. CalTOX was determined to be the best model for human health cancer and noncancer (McKone, 1993), and the input parameters were selected to be consistent with the EPA Risk Assessment Guidelines and the Exposure Factors Handbook (USEPA, 1997; USEPA, 1989, USEPA, 1989). Research was conducted to determine the source of the major uncertainties and influence of site-specific parameters on the human toxicity potentials (Hertwich et al., 1999)" (TRACI 2.1, 2012).

The probabilistic research showed that for the majority of the TRI substances, chemical data (e.g., toxicity and half-life) had the most significant impact on data variability/uncertainty and that site-specific parameters had little effect on the relative human toxicity potentials (Hertwich et al., 1999). This dissertation supported later development of global toxicity potentials for human health cancer and noncancer" (TRACI 2.1, 2012).

5.3.1.7 Respiratory effects

"This impact category as respiratory effects are caused by inorganic substances. The CFs are given for emissions into air only (as it is not very likely that these pollutants will be emitted into soil or water)" (Quantis, 2002). "Although this category may be called the human health criteria pollutants category, it deals with a subset of the criteria pollutants, i.e., particulate matter and precursors to particulates. Particulate matter is a collection of small particles in ambient air which have the ability to cause negative human health effects including respiratory illness and death (USEPA, 2008).

Numerous epidemiology studies show an increased mortality rate with elevated levels of ambient particulate matter (USEPA, 2008). Particulate matter may be emitted as particulates, or may be the product of chemical reactions in the air (secondary particulates).

The most common precursors to secondary particulates are sulfur dioxide (SO2) and nitrogen oxides (NOx). Common sources of primary and secondary particulates are fossil fuel combustion, wood combustion, and dust particles from roads and fields (USEPA, 2008)" (TRACI 2.1, 2012).

"Particulate matter is divided into two major groups of concern: "inhalable coarse particles" which are between 2.5 micrometers and 10 micrometers in diameter, like dust from roadways, and "fine particles" which are smaller than or equal to 2.5 micrometers in diameter, and are often the products of combustion (USEPA, 2008). Sensitive populations such as children, the elderly, and people with asthma are more susceptible to experiencing higher consequences (USEPA, 2008). Although national US standards have existed since 1971, even more stringent standards were placed in 2006 (USEPA, 2006)" (TRACI 2.1, 2012).

5.3.1.8 Ecotoxicity

"Over the course of a series of workshops and numerous communications, model results from the original models were compared to determine the most influential parameters and largest sources of differences between the models using 45 organic substances, which were selected for their diversity in environmental partitioning, exposure pathway, persistence, and air transport. The USEtox model adopted many of the best features of the above-named models and was used to develop human health cancer and noncancer toxicity potentials and freshwater ecotoxicity potentials for over 3000 substances including organic and inorganic substances" (TRACI 2.1, 2012).

"The USEtox model has been selected to replace the CalTOX model as the basis for the TRACI impact categories of human health cancer, noncancer, and ecotoxicity. It should be noted that some of the characterization factors included within the USEtox model are recommended while others are simply interim and should be used with caution (Rosenbaum et al., 2008; Hauschild et al., 2008)" (TRACI 2.1, 2012).

5.3.1.9 Fossil fuel depletion

"This impact category indicator is related to the use of fossil fuels. Fossil fuels provide a valuable source of energy and feedstock for materials such as plastics. Although there are alternatives, these are only able to replace a small proportion of the current usage. Fossil fuels are a finite resource and their continued consumption will make them unavailable for use by future generations" (BRE, 2019).

5.3.2 Impact Category Cost

The SimaPro has the environmental language and presents the midpoints of each impact in the impact category. However, there are environmental costs corresponded to the impact category results of SimaPro software. To translate this language to the cost, Using SimaPro software analysis the environmental impact results for 30 in. to 108 in. the diameter of SAPL, CIPP, and sliplining renewal methods are evaluated. In the following sections, the results of the environmental analysis are provided. It should be noted that for each renewal method, only the detail of analysis for 30 in. diameter and the result for all the diameters are plotted. The detailed analyses for all diameters from 30 in. to 108 in. can be found in Appendix A.

Table 5-17 and Figure 5-9 are provided the unit cost of each obtained environmental impact to convert them to environmental costs for the purpose of analyses and comparisons. To be able to use all impact categories cost and translate the environmental impacts to the cost, all the costs were transformed to the costs in 2019 by using US Inflation Calculator.

Moreover, to have a better perspective on the influence of each impact category in environmental cost analysis, Figure 5-10 is presented. In this pie chart, the percentage and proportion of each environmental impact category is depicted. It can be seen that respiratory effects, ozone depletion, Ecotoxicity, and acidification have the most contribution to environmental costs, respectively.

5.3.3 Environmental Impact Results

Using SimaPro software analysis the environmental impact results for 30 in. to 108 in. the diameter of SAPL, CIPP, and sliplining renewal methods are evaluated. In the following sections, the results of the environmental analysis are provided. It should be noted that for each renewal method, only the detail of analysis for 30 in. diameter and the result for all the diameters are plotted. The detailed analyses for all diameters from 30 in. to 108 in. can be found in Appendix A.

Table 5-17 Costs of Environmental Impact Categories (CE Delft, 2018)

Impact category	Unit	Cost \$ (€) per Unit in 2018 Dollars	Cost \$ per Unit in 2019 Dollars
Ozone depletion	kg CFC-11 eq	33.03 (30.4)	33.86
Global warming	kg CO2 eq	0.063 (0.057)	0.065
Smog	kg O3 eq	2.20 (2.00) (Ecochain, 2018)	2.26
Acidification	kg SO2 eq	5.47 (4.97)	5.61
Eutrophications	kg N eq	2.05 (1.86)	2.10
Carcinogenic and Non carcinogenics	CTUh[24]	0.2 (0.22)	0.21
Respiratory effects	kg PM2.5 eq	63.34 (57.51) (AEAT, 2005)	64.92
Ecotoxicity	CTUe	14.59 (16.049)	14.95
Fossil fuel depletion	MJ surplus[25]	0.0098 (0.0089)[26]	0.01

---

[24] The unit “CTUh” (Comparative Toxic Unit for Humans) expresses the estimated increase in morbidity in the total human population due to different types of emissions entering into the environment. The calculation is based on USEtox (USEtox is a well-known model for characterising the toxic impact of chemical emissions), which is a model that describes chemical fate, exposure, effect and optionally severity of emissions (Rosenbaum et al., 2008) = 1.84 * kg 1,4 DB-eq (Environmental Sustainability Assessment of Bioeconomy Products and Processes – Progress Report 1, 2015)

[25] 1 barrel of oil equivalent (59°F) (BOE) of energy equals to 6,120.00 megajoules (MJ) in energy

[26] The cost is based on Brent crude oil spot prices averaged \$60 per barrel (b) in October, 2019

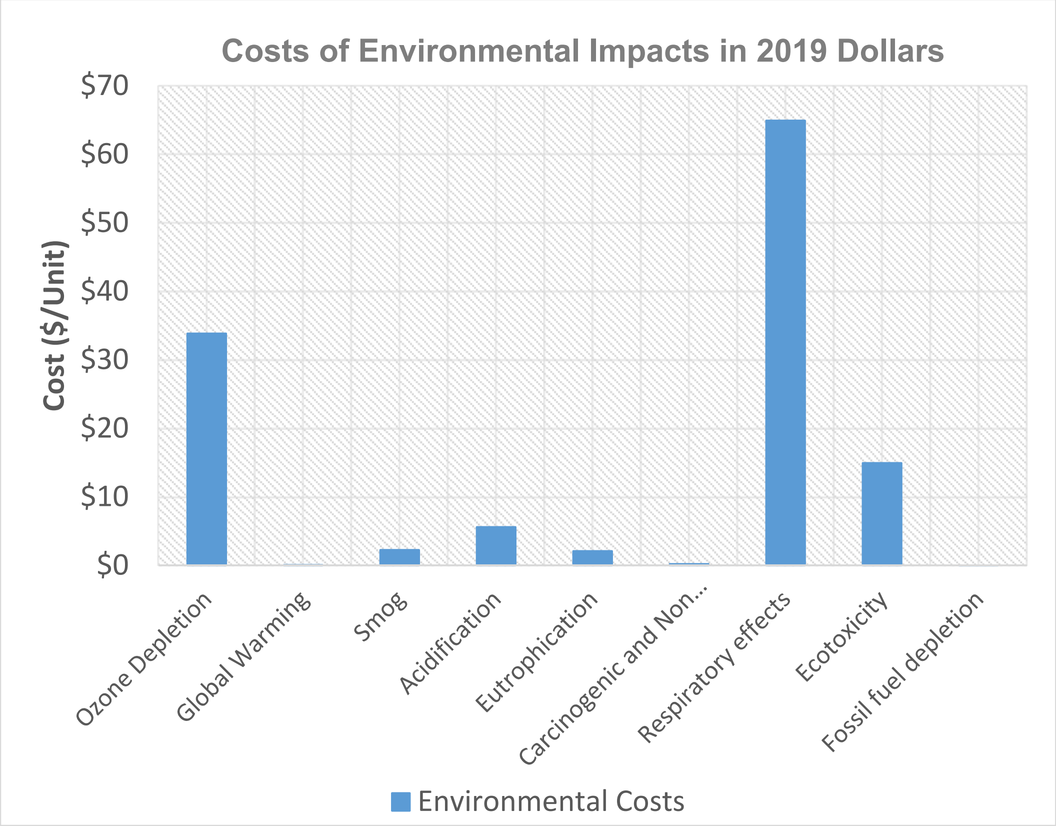


Figure 5-9 Environmental Costs of Each Impact Category

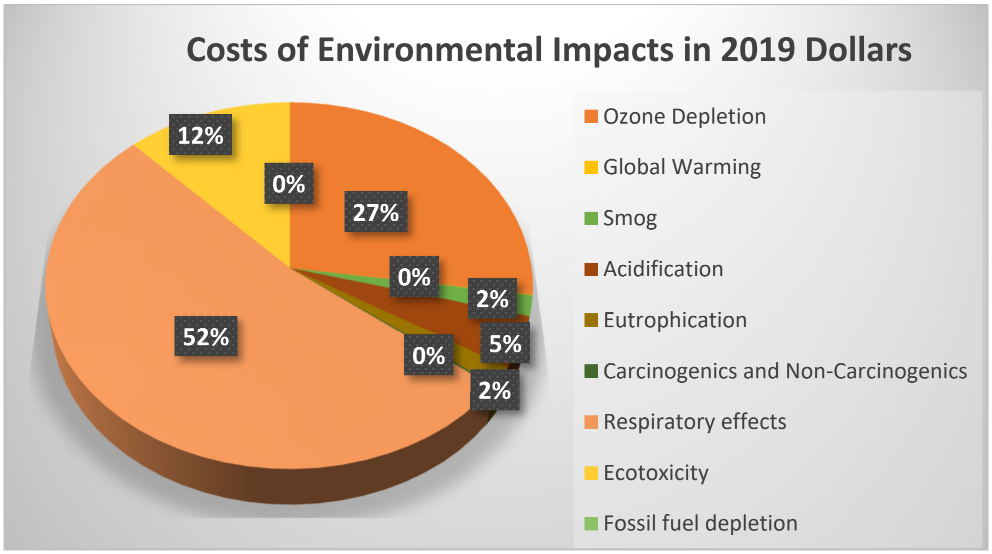
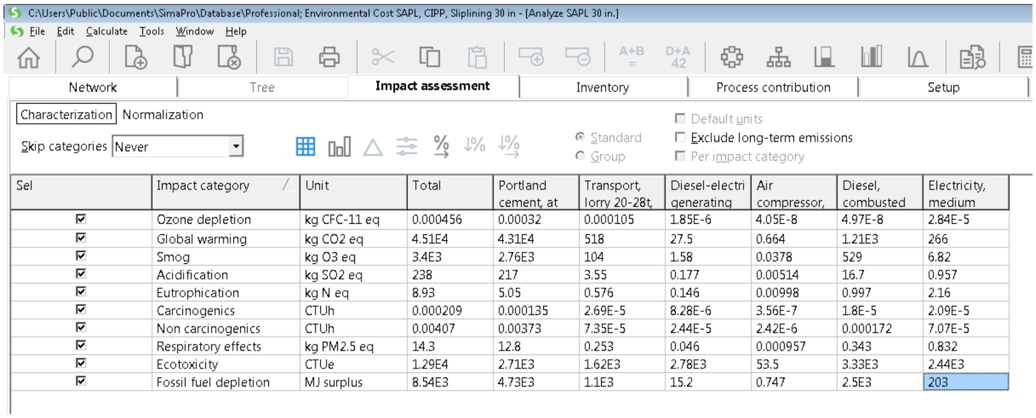


Figure 5-10 Portion of Cost of Each Impact in Impact Category

5.3.3.1 *SAPL Environmental Analysis*

The screenshot of the impact assessment table is presented for SAPL renewal of 500-ft length and 30 in. diameter culvert in Figure 5-11.



Skip categories Never

● Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.000456	0.00032	0.000105	1.85E-6	4.05E-8	4.97E-8	2.84E-5
☑	Global warming	kg CO2 eq	4.51E4	4.31E4	518	27.5	0.664	1.21E3	266
☑	Smog	kg O3 eq	3.4E3	2.76E3	104	1.58	0.0378	529	6.82
☑	Acidification	kg SO2 eq	238	217	3.55	0.177	0.00514	16.7	0.957
☑	Eutrophication	kg N eq	8.93	5.05	0.576	0.146	0.00998	0.997	2.16
☑	Carcinogenics	CTUh	0.000209	0.000135	2.69E-5	8.28E-6	3.56E-7	1.8E-5	2.09E-5
☑	Non carcinogenics	CTUh	0.00407	0.00373	7.35E-5	2.44E-5	2.42E-6	0.000172	7.07E-5
☑	Respiratory effects	kg PM2.5 eq	14.3	12.8	0.253	0.046	0.000957	0.343	0.832
☑	Ecotoxicity	CTUe	1.29E4	2.71E3	1.62E3	2.78E3	53.5	3.33E3	2.44E3
☑	Fossil fuel depletion	MJ surplus	8.54E3	4.73E3	1.1E3	15.2	0.747	2.5E3	203

Figure 5-11 Screenshot of the Impact Assessment Table from SimaPro Software for 30 in. Diameter SAPL

The environmental results as a chart that shows the contribution of each used material and equipment to each environmental impact (characterization chart) for 30 in. SAPL renewal is presented in Figure 5-12.

From the impact category indicator result, it cannot be interpreted based on the actual amount of each impact that one impact is high rather than the other or not. Whether a figure is high can only be determined by comparing it with a reference (a normal value). SimaPro software provides the normalized value for each impact category to put the results into perspective, and the software does this by dividing the result by the normalized value. After that, it can be seen that if an impact is relatively high compared to the other impact categories or not (which does not say that they are important or not; that is just a weighting issue). After normalization, the units for all the impacts are all the same. People mostly think normalization results have no units, but when emissions per year are used, strictly speaking, the unit of a normalized value is a year (SimaPro, 2016). Consequently, to have a better perspective of all environmental impacts and their relative together, the normalization chart of environmental impact assessment of 30 in SAPL is provided in Figure 5-13. In addition, the pie chart is developed for a better comparison of all components in the impact category which can be found in Figure 5-14.

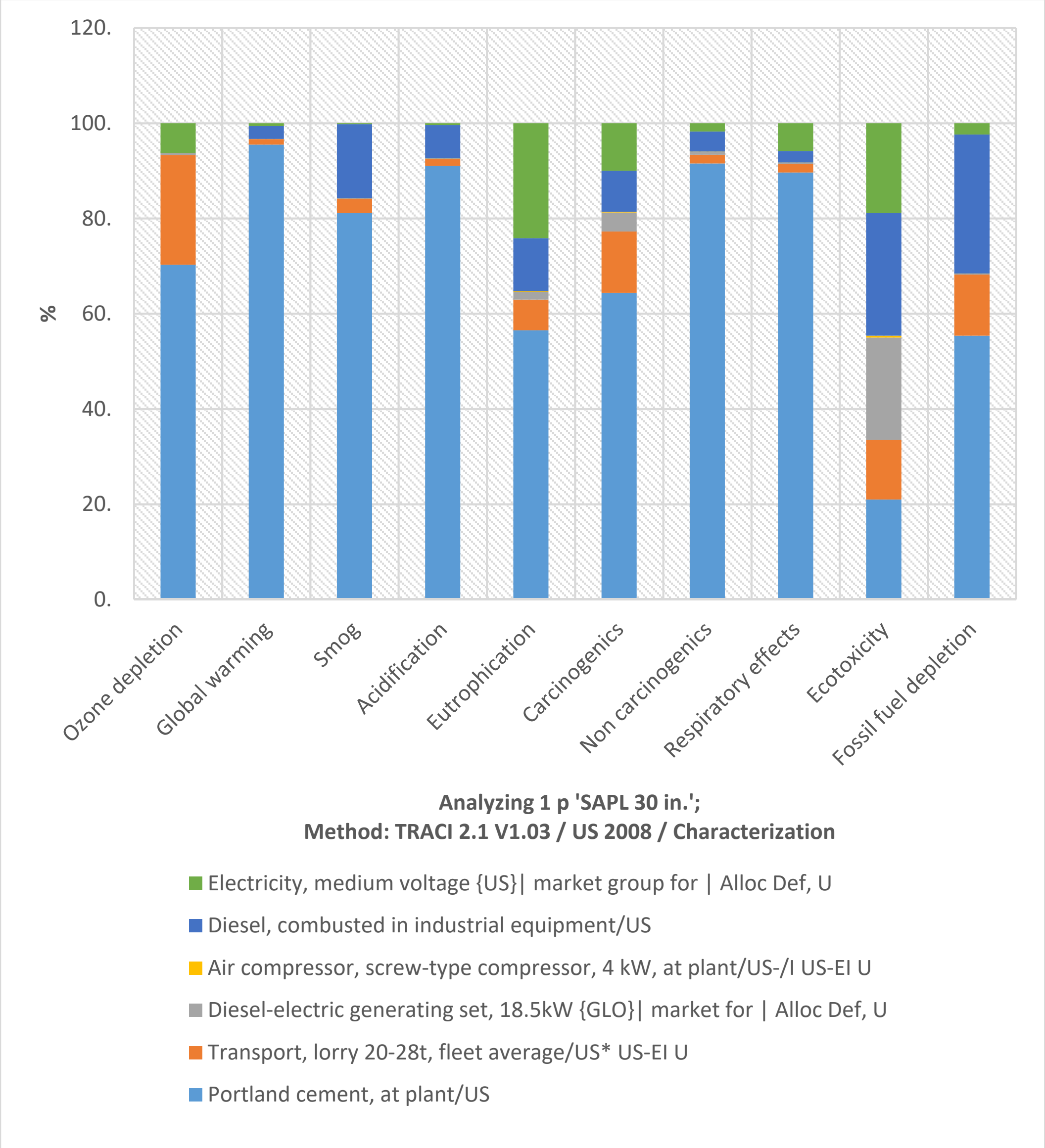


Figure 5-12 Environmental Impact Assessment of 30 in. Diameter SAPL Renewal Method

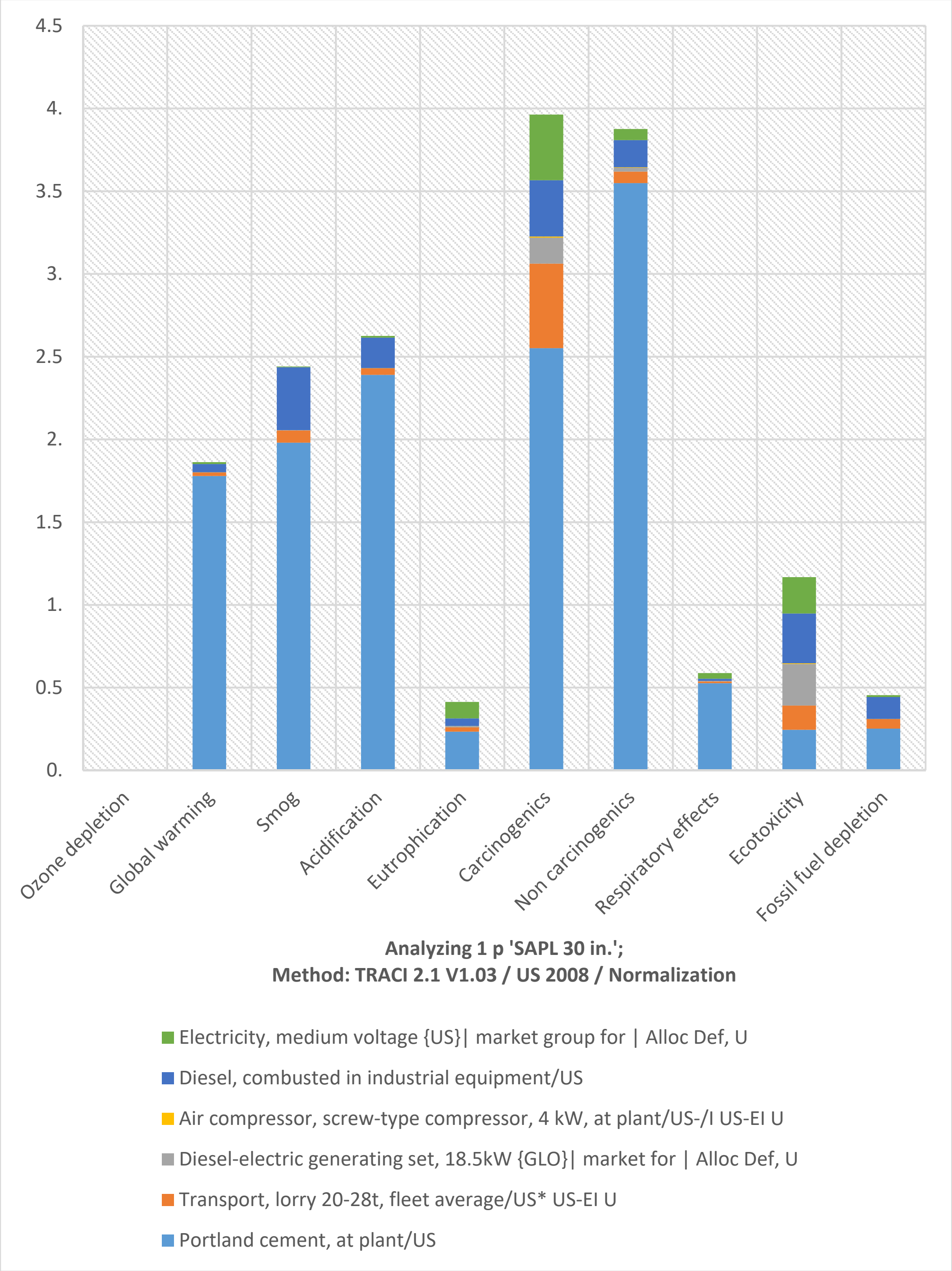


Figure 5-13 Normalized Environmental Impact Assessment of 30 in. Diameter SAPL Renewal Method

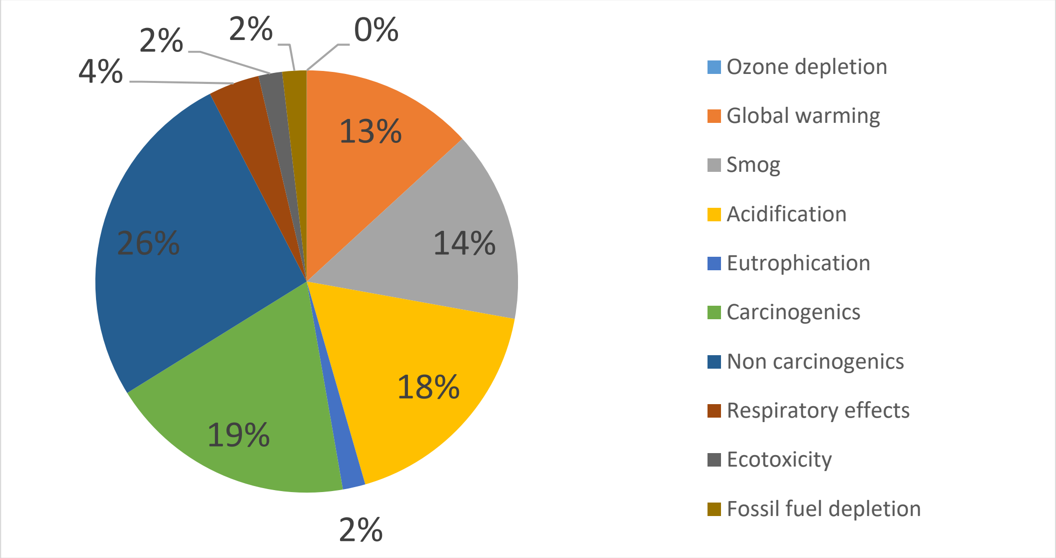


Figure 5-14 Percentage of Normalized Environmental Impact Assessment of 30 in. Diameter SAPL Renewal Method

Table 5-18 is presented to show the total emissions for each impact category for the life-cycle of 30 in. diameter of SAPL renewal. In this table, the actual amount of several environmental impacts as Ozone depletion, Global warming, Smog, Acidification, Eutrophication, Carcinogenic, Non carcinogenic, Respiratory effects, Ecotoxicity, and Fossil fuel depletion are evaluated and presented. In addition, the normalized number of all impacts is provided for the purpose of better understanding and comparison in Table 5-19. Finally, Table 5-20 is plotted to highlight the cost which is associated with each impact category according to the unit cost of each impact category.

Table 5-18 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.000456	0.00032	0.000105	1.85E-06	4.05E-08	4.97E-08	2.84E-05
Global warming	kg CO2 eq	45103.9	43077.08	518.4345	27.46688	0.664274	1214.308	265.9476
Smog	kg O3 eq	3397.351	2755.492	1.04E+02	1.58E+00	3.78E-02	5.29E+02	6.82E+00
Acidification	kg SO2 eq	238.4524	217.0942	3.55E+00	1.77E-01	5.14E-03	16.6709	9.57E-01
Eutrophication	kg N eq	8.93074	5.046063	0.575572	0.146058	0.00998	0.997238	2.155829
Carcinogenics	CTUh	0.000209	0.000135	2.69E-05	8.28E-06	3.56E-07	1.80E-05	2.09E-05
Non carcinogenics	CTUh	0.004071	0.003727	7.35E-05	2.44E-05	2.42E-06	0.000172	7.07E-05
Respiratory effects	kg PM2.5 eq	14.2503	12.77515	0.252966	0.046028	0.000957	0.343103	0.832093
Ecotoxicity	CTUe	12927.25	2710.66	1619.718	2777.057	53.52642	3325.583	2440.703
Fossil fuel depletion	MJ surplus	8543.921	4731.404	1096.634	15.17393	0.746784	2497.024	202.9381

Table 5-19 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.002825	0.001985	0.000651	1.14E-05	2.51E-07	3.08E-07	0.000176
Global warming	-	1.861975	1.778304	0.021402	0.001134	2.74E-05	0.050129	0.010979
Smog	-	2.440779	1.979645	0.074783	0.001133	2.71E-05	0.380294	0.004898
Acidification	-	2.625263	2.390117	0.039065	0.001946	5.66E-05	0.18354	0.010538
Eutrophication	-	0.413158	0.233444	0.026627	0.006757	0.000462	0.046135	0.099734
Carcinogenics	-	3.962496	2.551472	0.510488	0.157095	0.006752	0.340648	0.396042
Non carcinogenics	-	3.875633	3.548698	0.069989	0.023204	0.0023	0.164105	0.067338
Respiratory effects	-	0.58769	0.526854	0.010432	0.001898	3.95E-05	0.01415	0.034316
Ecotoxicity	-	1.167778	0.244866	0.146317	0.250864	0.004835	0.300415	0.22048
Fossil fuel depletion	-	0.453972	0.251398	0.058268	0.000806	3.97E-05	0.132677	0.010783

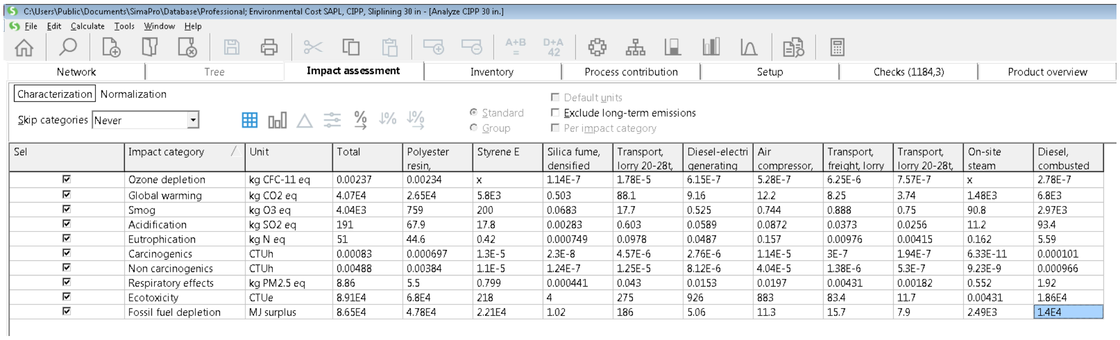
Table 5-20 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 30 in. Culvert in 2019 Dollars

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.000456	$0.02
Global warming	kg CO2 eq	45103.9	$3,060.04
Smog	kg O3 eq	3397.351	$8,048.86
Acidification	kg SO2 eq	238.4524	$1,404.62
Eutrophication	kg N eq	8.93074	$19.72
Carcinogenics	CTUh	0.000209	$0.00
Non carcinogenics	CTUh	0.004071	$0.04
Respiratory effects	kg PM2.5 eq	14.2503	$972.02
Ecotoxicity	CTUe	12927.25	$570.77
Fossil fuel depletion	MJ surplus	8543.921	$90.17
Total			$13,483.64

5.3.3.2 CIPP Environmental Analysis

The screenshot of the impact assessment is presented for CIPP renewal of 500-ft length and 30 in. diameter culvert in Figure 5-15. In addition, the environmental results chart shows the proportion of each material and equipment in the environmental impact category for 30 in. CIPP renewal is presented in Figure 5-16. For the purpose of having a broader view of all environmental impacts and their relative, the normalization chart of environmental impact assessment of 30 in CIPP is provided in Figure 5-17. In addition, the pie chart is developed for a better comparison of all components in the impact category which can be found in Figure 5-18.

Moreover, Table 5-21 is presented to show the total emissions for each impact category for the life-cycle of 30 in. diameter of CIPP renewal. In this table, the actual amount of several environmental impacts as Ozone depletion, Global warming, Smog, Acidification, Eutrophication, Carcinogenic, Non carcinogenic, Respiratory effects, Ecotoxicity, and Fossil fuel depletion are plotted. Admittedly, the normalized number of all impacts is provided for the purpose of a better understanding and comparison in Table 5-22. Last but not least, Table 5-23 is depicted to illustrate the cost which is associated with each impact category according to the unit cost of each impact category.



Skip categories: Never

○ Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00237	0.00234	x	1.14E-7	1.78E-5	6.15E-7	5.28E-7	6.25E-6	7.57E-7	x	2.78E-7
☑	Global warming	kg CO2 eq	4.07E4	2.65E4	5.8E3	0.503	88.1	9.16	12.2	8.25	3.74	1.48E3	6.8E3
☑	Smog	kg O3 eq	4.04E3	759	200	0.0683	17.7	0.525	0.744	0.888	0.75	90.8	2.97E3
☑	Acidification	kg SO2 eq	191	67.9	17.8	0.00283	0.603	0.0589	0.0872	0.0373	0.0256	11.2	93.4
☑	Eutrophication	kg N eq	51	44.6	0.42	0.000749	0.0978	0.0487	0.157	0.00976	0.00415	0.162	5.59
☑	Carcinogenics	CTUh	0.00083	0.000697	1.3E-5	2.3E-8	4.57E-6	2.76E-6	1.14E-5	3E-7	1.94E-7	6.33E-11	0.000101
☑	Non carcinogenics	CTUh	0.00488	0.00384	1.1E-5	1.24E-7	1.25E-5	8.12E-6	4.04E-5	1.38E-6	5.3E-7	9.23E-9	0.000966
☑	Respiratory effects	kg PM2.5 eq	8.86	5.5	0.799	0.000441	0.043	0.0153	0.0197	0.00431	0.00182	0.552	1.92
☑	Ecotoxicity	CTUe	8.91E4	6.8E4	218	4	275	926	883	83.4	11.7	0.00431	1.86E4
☑	Fossil fuel depletion	MJ surplus	8.65E4	4.78E4	2.21E4	1.02	186	5.06	11.3	15.7	7.9	2.49E3	1.4E4

Figure 5-15 Screenshot of the Impact Assessment Table from SimaPro Software for 30 in. Diameter CIPP

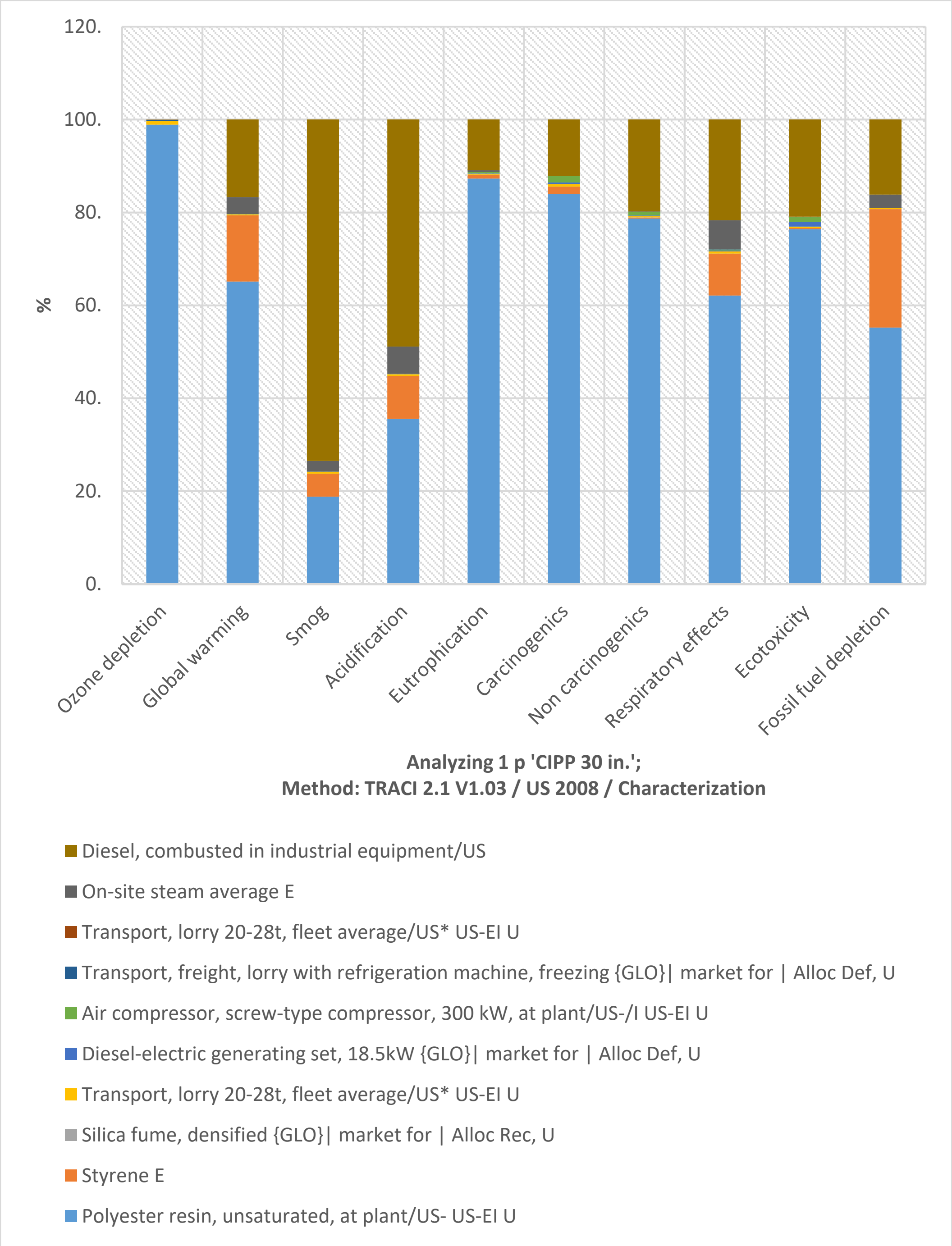


Figure 5-16 Environmental Impact Assessment of 30 in. Diameter
CIPP Renewal Method

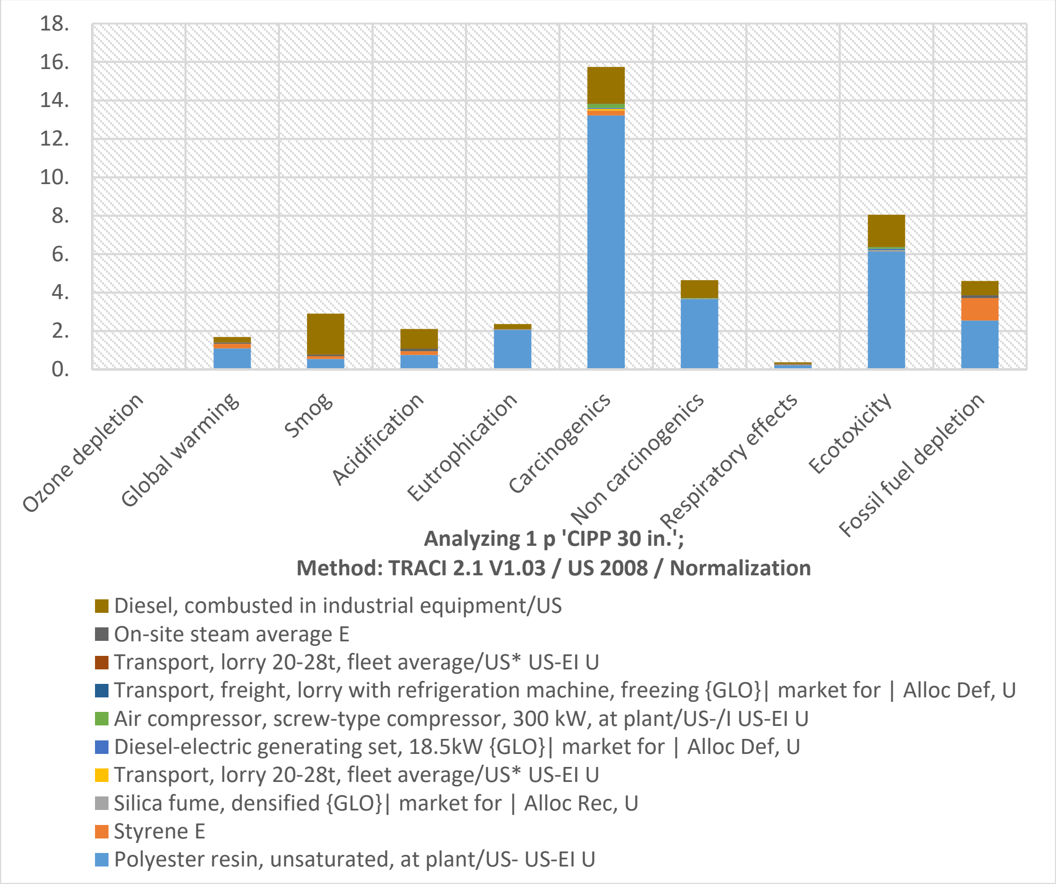


Figure 5-17 Normalized Environmental Impact Assessment of 30 in. Diameter CIPP Renewal Method

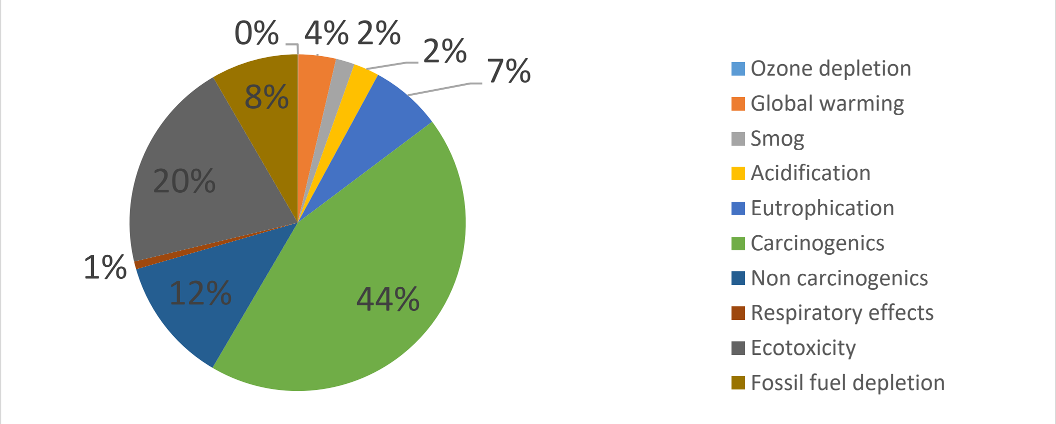


Figure 5-18 Percentage of Normalized Environmental Impact Assessment of 30 in. Diameter CIPP Renewal Method

Table 5-21 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.002368	0.002342	0	1.14E-07	1.78E-05	6.15E-07	5.28E-07	6.25E-06	7.57E-07	0	2.78E-07
Global warming	kg CO2 eq	40723.04	26522.55	5795.396	0.502756	88.07484	9.155625	12.19125	8.253799	3.735657	1479.977	6803.199
Smog	kg O3 eq	4035.44	758.5147	199.8396	0.068273	17.68366	0.525497	0.744435	0.888006	0.750045	90.80566	2965.62
Acidification	kg SO2 eq	191.0955	67.9045	17.76294	0.00283	0.602797	0.058932	0.087169	0.037294	0.025567	11.21423	93.39929
Eutrophication	kg N eq	51.04978	44.56274	0.41974	0.000749	0.097782	0.048686	0.156728	0.009765	0.004147	0.162383	5.587062
Carcinogenics	CTUh	0.00083	0.000697	1.30E-05	2.30E-08	4.57E-06	2.76E-06	1.14E-05	3.00E-07	1.94E-07	6.33E-11	0.000101
Non carcinogenics	CTUh	0.004878	0.003839	1.10E-05	1.24E-07	1.25E-05	8.12E-06	4.04E-05	1.38E-06	5.30E-07	9.23E-09	0.000966
Respiratory effects	kg PM2.5 eq	8.862105	5.504925	0.798746	0.000441	0.042975	0.015343	0.019726	0.004311	0.001823	0.55157	1.922245
Ecotoxicity	CTUe	89065.04	68032.24	217.7601	3.996024	275.1676	925.6858	883.4641	83.35973	11.67112	0.004306	18631.69
Fossil fuel depletion	MJ surplus	86541.85	47775.83	22058.38	1.018046	186.3029	5.057976	11.34395	15.68626	7.901959	2490.664	13989.66

Table 5-22 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.014686	0.014523	0	7.05E-07	1.11E-04	3.81E-06	3.28E-06	3.87E-05	4.69E-06	0	1.73E-06
Global warming	-	1.681125	1.094901	0.239245	2.08E-05	3.64E-03	0.000378	0.000503	0.000341	0.000154	0.061096	0.280849
Smog	-	2.899206	0.544944	0.143572	4.91E-05	1.27E-02	0.000378	0.000535	0.000638	0.000539	0.065238	2.130608
Acidification	-	2.103883	0.7476	0.195563	3.12E-05	6.64E-03	0.000649	0.00096	0.000411	0.000281	0.123464	1.028288
Eutrophication	-	2.361691	2.061584	0.019418	3.46E-05	0.004524	0.002252	0.007251	0.000452	0.000192	0.007512	0.258472
Carcinogenics	-	15.7368	13.21619	0.247249	0.000437	0.086725	0.052365	0.215978	0.005684	0.003678	1.20E-06	1.90849
Non carcinogenics	-	4.644769	3.654916	0.010426	0.000118	0.01189	0.007735	0.038459	0.00131	0.000504	8.78E-06	0.919402
Respiratory effects	-	0.365478	0.227026	0.032941	1.82E-05	1.77E-03	0.000633	0.000814	0.000178	7.52E-05	0.022747	0.079274
Ecotoxicity	-	8.045655	6.145665	0.019671	0.000361	0.024857	0.083621	0.079807	0.00753	0.001054	3.89E-07	1.683086
Fossil fuel depletion	-	4.598306	2.538516	1.172048	5.41E-05	9.90E-03	0.000269	0.000603	0.000833	0.00042	0.132339	0.743325

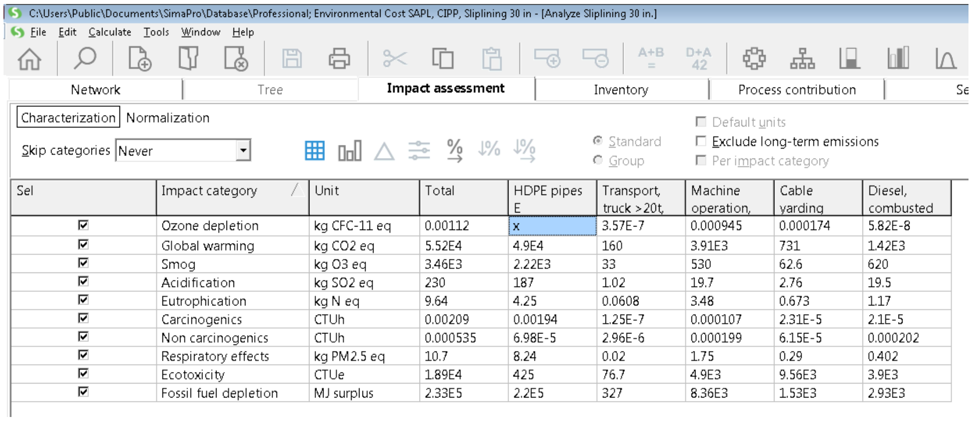
Table 5-23 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 30 in. Culvert in 2019 Dollars

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.002368	$0.08
Global warming	kg CO2 eq	40723.04	$2,629.69
Smog	kg O3 eq	4035.44	$9,099.92
Acidification	kg SO2 eq	191.0955	$1,071.42
Eutrophication	kg N eq	51.04978	$107.27
Carcinogenics	CTUh	0.00083	$0.00
Non carcinogenics	CTUh	0.004878	$0.04
Respiratory effects	kg PM2.5 eq	8.862105	$575.36
Ecotoxicity	CTUe	89065.04	$3,742.96
Fossil fuel depletion	MJ surplus	86541.85	$869.31
Total			$18,096.05

5.3.3.3 *Sliplining Environmental Analysis*

The screenshot of the impact assessment is presented for sliplining renewal of 500-ft length and 30 in. diameter culvert in Figure 5-19. In addition, the environmental results chart illustrates the proportion of each impact for 30 in. sliplining renewal is presented in Figure 5-20. To have a broader view of all environmental impacts and their relative, the normalization chart of environmental impact assessment of 30 in CIPP is provided in Figure 5-21. In addition, the pie chart is developed for better comparison of all components in the impact category which can be found in Figure 5-22.

Moreover, Table 5-24 is presented to show the total emissions for each impact category for the 30 in. diameter of CIPP renewal. In this table, the actual amount of several environmental impacts as Ozone depletion, Global warming, Smog, Acidification, Eutrophication, Carcinogenics, Non carcinogenics, Respiratory effects, Ecotoxicity, and Fossil fuel depletion are plotted. Admittedly, the normalized number of all impacts is provided for a better understanding and comparison in Table 5-25. Yet importantly, Table 5-26 is highlighted the cost, which is associated with each impact category according to the unit cost of each impact category.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 30 in - [Analyze Sliplining 30 in.]

Skip categories Never

● Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00112	x	3.57E-7	0.000945	0.000174	5.82E-8
☑	Global warming	kg CO2 eq	5.52E4	4.9E4	160	3.91E3	731	1.42E3
☑	Smog	kg O3 eq	3.46E3	2.22E3	33	530	62.6	620
☑	Acidification	kg SO2 eq	230	187	1.02	19.7	2.76	19.5
☑	Eutrophication	kg N eq	9.64	4.25	0.0608	3.48	0.673	1.17
☑	Carcinogenics	CTUh	0.00209	0.00194	1.25E-7	0.000107	2.31E-5	2.1E-5
☑	Non carcinogenics	CTUh	0.000535	6.98E-5	2.96E-6	0.000199	6.15E-5	0.000202
☑	Respiratory effects	kg PM2.5 eq	10.7	8.24	0.02	1.75	0.29	0.402
☑	Ecotoxicity	CTUe	1.89E4	425	76.7	4.9E3	9.56E3	3.9E3
☑	Fossil fuel depletion	MJ surplus	2.33E5	2.2E5	327	8.36E3	1.53E3	2.93E3

Figure 5-19 Screenshot of the Impact Assessment Table from SimaPro Software for 30 in. Diameter Sliplining

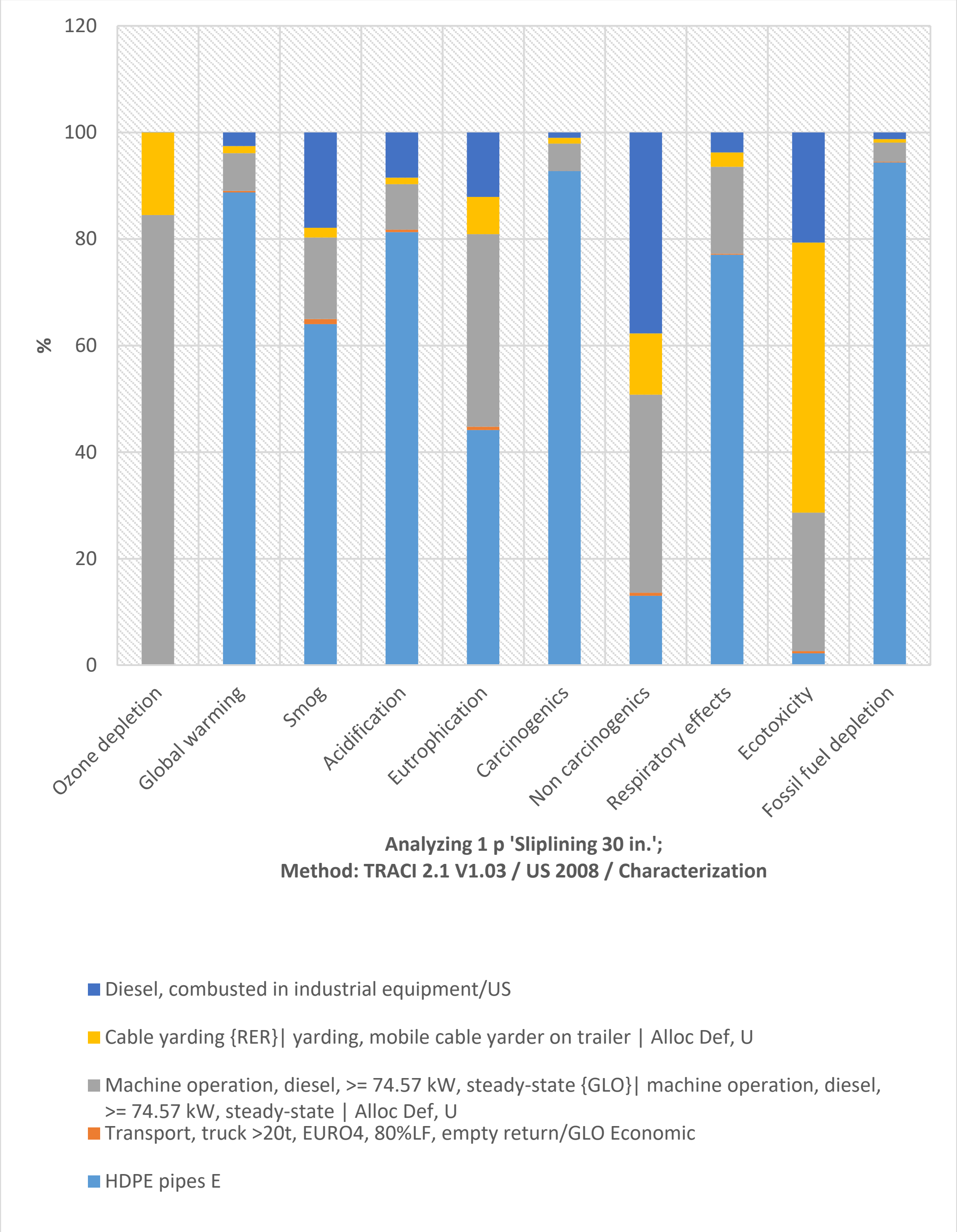


Figure 5-20 Environmental Impact Assessment of 30 in. Diameter Sliplining Renewal Method

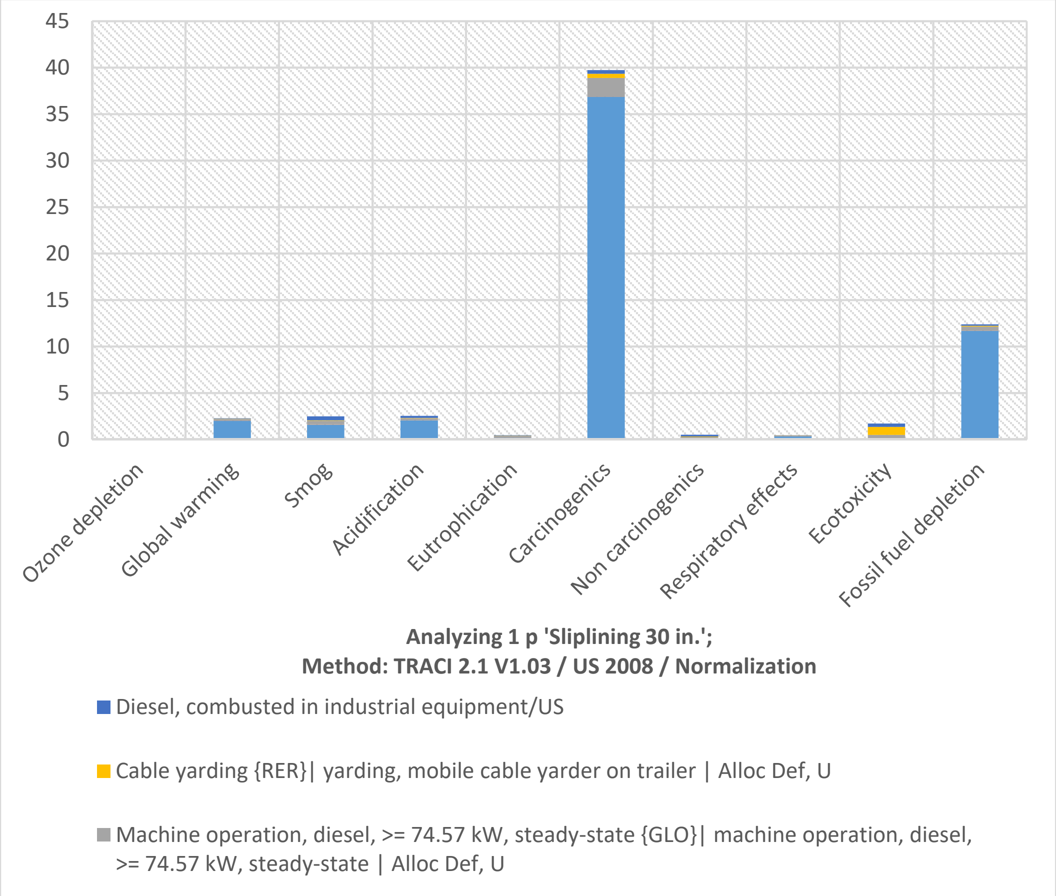


Figure 5-21 Normalized Environmental Impact Assessment of 30 in. Diameter Sliplining Renewal Method

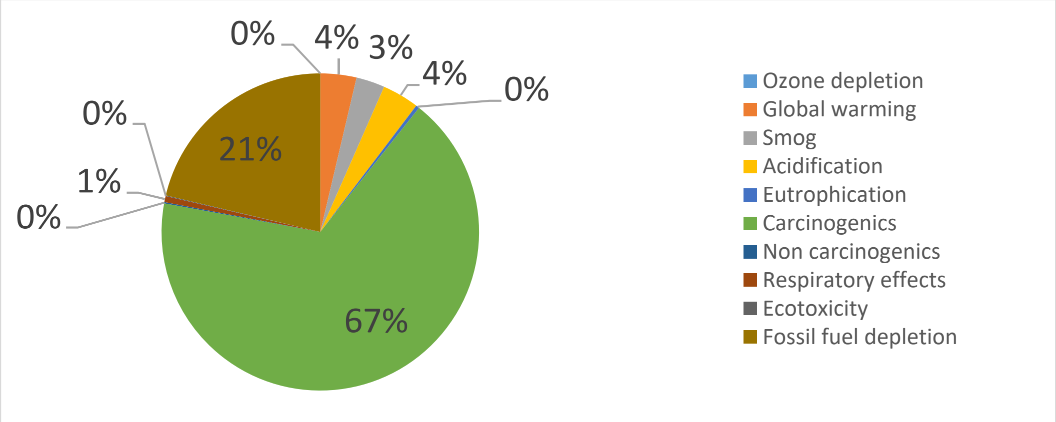


Figure 5-22 Percentage of Normalized Environmental Impact Assessment of 30 in. Diameter Sliplining Renewal Method

Table 5-24 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001118908	0	3.57E-07	0.000945	0.000173517	5.82E-08
Global warming	kg CO2 eq	55187.897	48964.181	159.71979	3910.769	730.7669	1422.4608
Smog	kg O3 eq	3463.482	2217.5895	33.036982	530.1696	62.613045	620.07283
Acidification	kg SO2 eq	229.67119	186.71033	1.0204896	19.65103	2.7607659	19.528582
Eutrophication	kg N eq	9.6373066	4.2543714	0.060775291	3.481051	0.67292678	1.1681824
Carcinogenic	CTUh	0.00209478	0.001943649	1.25E-07	0.000107	2.31E-05	2.10E-05
Non carcinogenic	CTUh	0.000535174	6.98E-05	2.96E-06	0.000199	6.15E-05	0.000201906
Respiratory effects	kg PM2.5 eq	10.698694	8.2415422	0.019983223	1.74525	0.29000252	0.40191654
Ecotoxicity	CTUe	18853.253	424.93699	76.715815	4898.033	9557.9216	3895.6456
Fossil fuel depletion	MJ surplus	233051.6	219917.93	326.64655	8355.063	1526.9038	2925.0568

Table 5-25 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit[27]	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.006938228	0	2.21E-06	0.00586	0.001075958	3.61E-07
Global warming	-	2.2782613	2.0213344	0.006593537	0.161444	0.030167446	0.058721884
Smog	-	2.4882902	1.5931962	0.023734957	0.380893	0.044983466	0.44548264
Acidification	-	2.5285847	2.0556034	0.011235168	0.21635	0.03039489	0.2150016
Eutrophication	-	0.44584597	0.19681789	0.002811617	0.161042	0.031131281	0.054043046
Carcinogenic	-	39.734811	36.868084	0.002379472	2.026471	0.4388357	0.3990405
Non carcinogenic	-	0.50954093	0.066497077	0.002819926	0.189448	0.058541086	0.19223507
Respiratory effects	-	0.44122005	0.33988575	0.000824119	0.071975	0.011959864	0.01657526
Ecotoxicity	-	1.7031011	0.038386513	0.006930093	0.442462	0.86341103	0.35191158
Fossil fuel depletion	-	12.38294	11.685097	0.017356005	0.443937	0.081130355	0.15541968

---

[27] As the impacts are normalized, they do not have any unit

Table 5-26 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 30 in. Culvert in 2019 Dollars

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.002392	$0.04
Global warming	kg CO2 eq	41425.06	$3,563.76
Smog	kg O3 eq	4198.951	$7,810.15
Acidification	kg SO2 eq	198.0497	$1,287.71
Eutrophication	kg N eq	54.14167	$20.25
Carcinogenic	CTUh	0.001017	$0.00
Non carcinogenic	CTUh	0.005524	$0.00
Respiratory effects	kg PM2.5 eq	9.577679	$694.60
Ecotoxicity	CTUe	124757.5	$792.30
Fossil fuel depletion	MJ surplus	87462.82	$2,341.01
Total			$16,509.82

5.3.4 Environmental Costs Results

The analysis of environmental impacts for the 500-ft length of trenchless SAPL, CIPP, and sliplining was taken place for each diameter from 30 in. to 108 in. and the amount of each impact in the impact category is collected thoroughly. According to what is discussed in 5.3.3, there is a cost associated with each impact. To translate the results of environmental analysis, by using information in Table 5-17 and by using unit cost conversion factor in 2019 dollars, the environmental cost results of 30 in. to 108 in. diameter of renewal methods was calculated. Table 5-27 illustrates the final environmental costs of the 500-ft length trenchless SAPL, CIPP, and sliplining methods in large diameter culverts.

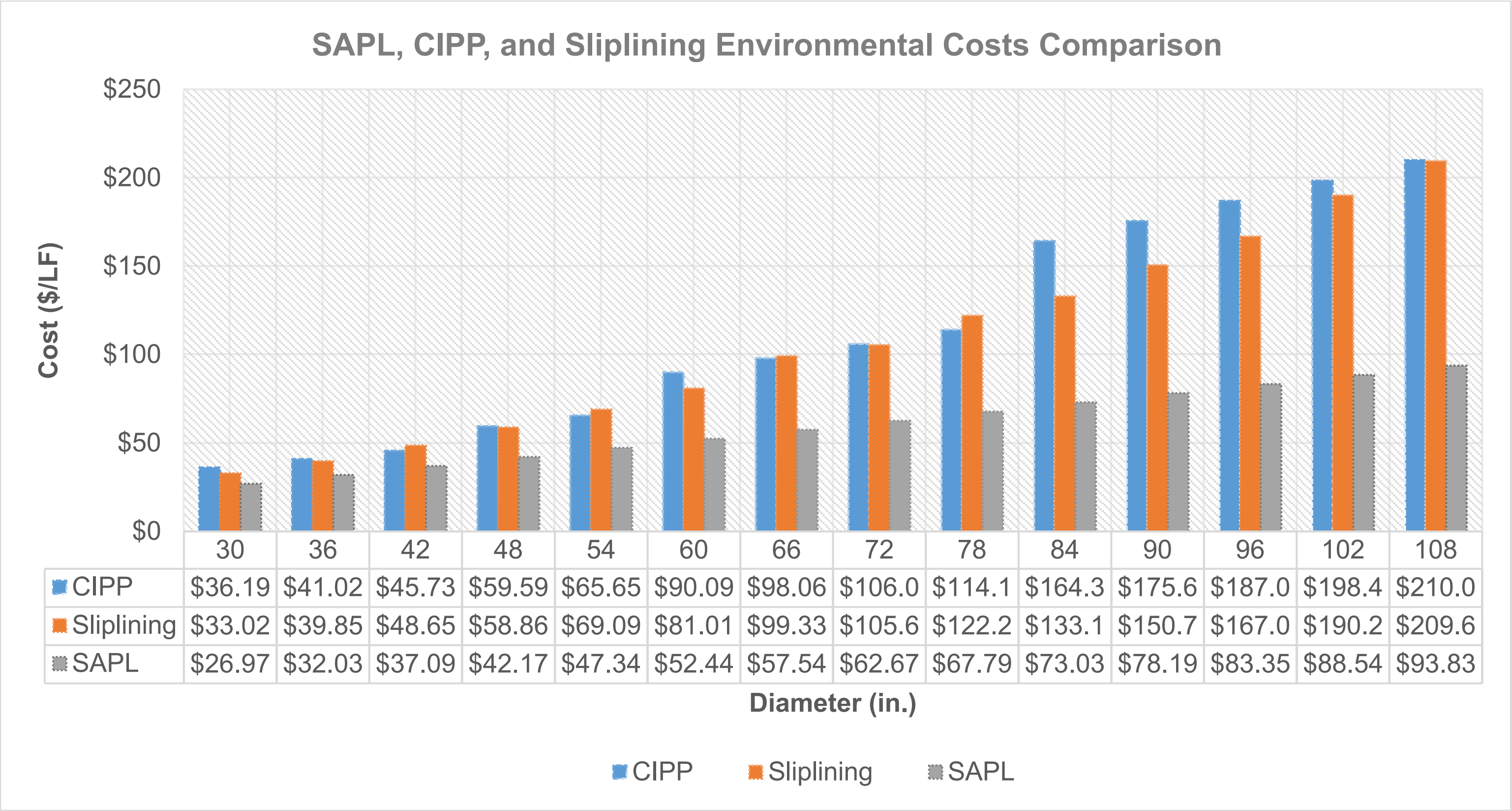
Subsequently, due to the objective of this dissertation, there is a need of having a spreadsheet in unit cost for environmental results of trenchless SAPL, CIPP, and sliplining methods. The result which is plotted in Table 5-28 can be used as the reference for the life-cycle environmental costs of SAPL, CIPP, and sliplining trenchless renewals. By having a diameter, length, and type of trenchless renewal it is possible to obtain the associated environmental cost from the result table. In addition, Figure 5-23 is plotted to show the change of environmental cost by increasing the diameter for each trenchless renewal. Admittedly, the comparison of environmental cost of trenchless SAPL, CIPP, and sliplining methods for different diameters from 30 in. to 108 in. can be observed.

Table 5-27 Environmental Costs of 500-ft Length of Trenchless SAPL, CIPP, and Sliplining Methods in Large Diameter Culverts in 2019 Dollars

Diameter (in.)\Trenchless Method	SAPL	CIPP	Sliplining
30	$13,483.64	$18,096.06	$16,509.82
36	$16,013.52	$20,510.06	$19,924.65
42	$18,547.09	$22,861.63	$24,322.31
48	$21,086.00	$29,798.50	$29,426.01
54	$23,671.79	$32,825.18	$34,541.70
60	$26,219.93	$45,044.83	$40,503.39
66	$28,773.98	$49,029.48	$49,664.28
72	$31,333.76	$53,042.10	$52,797.40
78	$33,898.60	$57,084.02	$61,109.50
84	$36,515.17	$82,183.20	$66,573.83
90	$39,093.39	$87,829.14	$75,386.78
96	$41,677.69	$93,509.13	$83,522.15
102	$44,269.97	$99,224.55	$95,146.80
108	$46,912.02	$105,019.56	$104,846.89

Table 5-28 Environmental Costs Per Linear Feet ($/LF) of Trenchless SAPL, CIPP, and Sliplining Methods in Large Diameter Culverts in 2019 Dollars

Diameter (in.)\Trenchless Method	SAPL	CIPP	Sliplining
30	$26.97	$36.19	$33.02
36	$32.03	$41.02	$39.85
42	$37.09	$45.73	$48.65
48	$42.17	$59.59	$58.86
54	$47.34	$65.65	$69.09
60	$52.44	$90.09	$81.01
66	$57.54	$98.06	$99.33
72	$62.67	$106.09	$105.60
78	$67.79	$114.16	$122.22
84	$73.03	$164.37	$133.15
90	$78.19	$175.65	$150.78
96	$83.35	$187.02	$167.04
102	$88.54	$198.45	$190.29
108	$93.83	$210.04	$209.69



	30	36	42	48	54	60	66	72	78	84	90	96	102	108
CIPP	$36.19	$41.02	$45.73	$59.59	$65.65	$90.09	$98.06	$106.0	$114.1	$164.3	$175.6	$187.0	$198.4	$210.0
Sliplining	$33.02	$39.85	$48.65	$58.86	$69.09	$81.01	$99.33	$105.6	$122.2	$133.1	$150.7	$167.0	$190.2	$209.6
SAPL	$26.97	$32.03	$37.09	$42.17	$47.34	$52.44	$57.54	$62.67	$67.79	$73.03	$78.19	$83.35	$88.54	$93.83

Figure 5-23 Environmental Costs of 500-ft Length of Trenchless SAPL, CIPP, and Sliplining Methods in Large Diameter Culverts in 2019 Dollars

5.4 Development of Models for Construction Costs

Four different machine learning-based models are developed to predict the construction costs of SAPL, CIPP, and sliplining trenchless renewals for large diameter culverts. The following sections are provided to present the details of developed models.

5.4.1 K-neighbor Nearest Model

To develop a model by using KNN regression, the dataset is divided to train set and test set by using Scikit-Learn library in Jupyter Notebook. 80% of the dataset is randomly picked as training set to develop the model and the remaining 20% is allocated as testing set to test the model. The first KNN model is developed by using K value of 6. The Statsmodels.api library is used to make a statistical output of the model. Table 5-29 is presented to show the summary of the developed model. Figure 5-24 is presented to determine the optimum value of K in KNN regression model. In this graph, different RMSEs for different K values are plotted. The optimum value for K can be determined based upon the lowest RMSE or according to the chart based on the shortest bar. It can be found from below Figure that K value of 4 is the best to develop the KNN model.

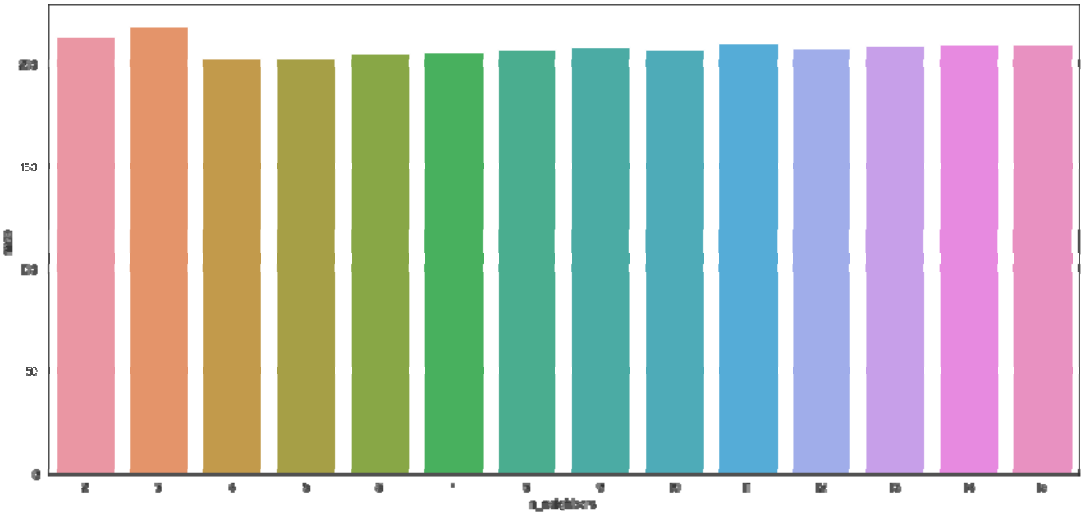


Figure 5-24 K Value Determination

Table 5-29 The Statistic Summary of the KNN Model

Dep. Variable:	Unit_Cost_19	R-squared:	0.420
Model:	KNN	Adj. R-squared:	0.401
Method:	Least Squares	F-statistic:	25.42
Date:	Tue, 12 Nov 2019	Prob (F-statistic):	3.77e-43
Time:	22:09:47	Log-Likelihood:	-2030.6
No. Observations:	320	AIC:	4087.
Df Residuals:	307	BIC:	4136.
Df Model:	12		
Covariance Type:	nonrobust		

Table 5-30 shows the coefficient (coef), standard deviation (std err), t-test (t), and P value (P>|t|) of the KNN cost predicted model.

Table 5-30 The KNN Model Coefficients' Values

	coef	std err
Pipe_Diameter	9.0181	0.593
Pipe_Length	-0.0049	0.003
Rehab_Thickness	102.8325	40.592
Letting_Year	0.7698	3.997
Location_DE	-629.4699	2423.642
Location_FL	-623.5030	2425.209
Location_MN	-451.5451	2418.754
Location_NC	-413.3676	2408.460
Location_NY	-473.1560	2411.723
Location_OH	-531.4441	2422.189
Location_PA	-462.9684	2408.989
Trenchless_Method_CIPP	-1258.9203	5639.392
Trenchless_Method_SAPL	-1065.6360	5640.017
Trenchless_Method_Sliplining	-1260.8977	5637.784

The developed model is validated using the test set. Figure 5-25 shows the residual distribution and presents the difference of the predicted values and the actual values which is the residual.

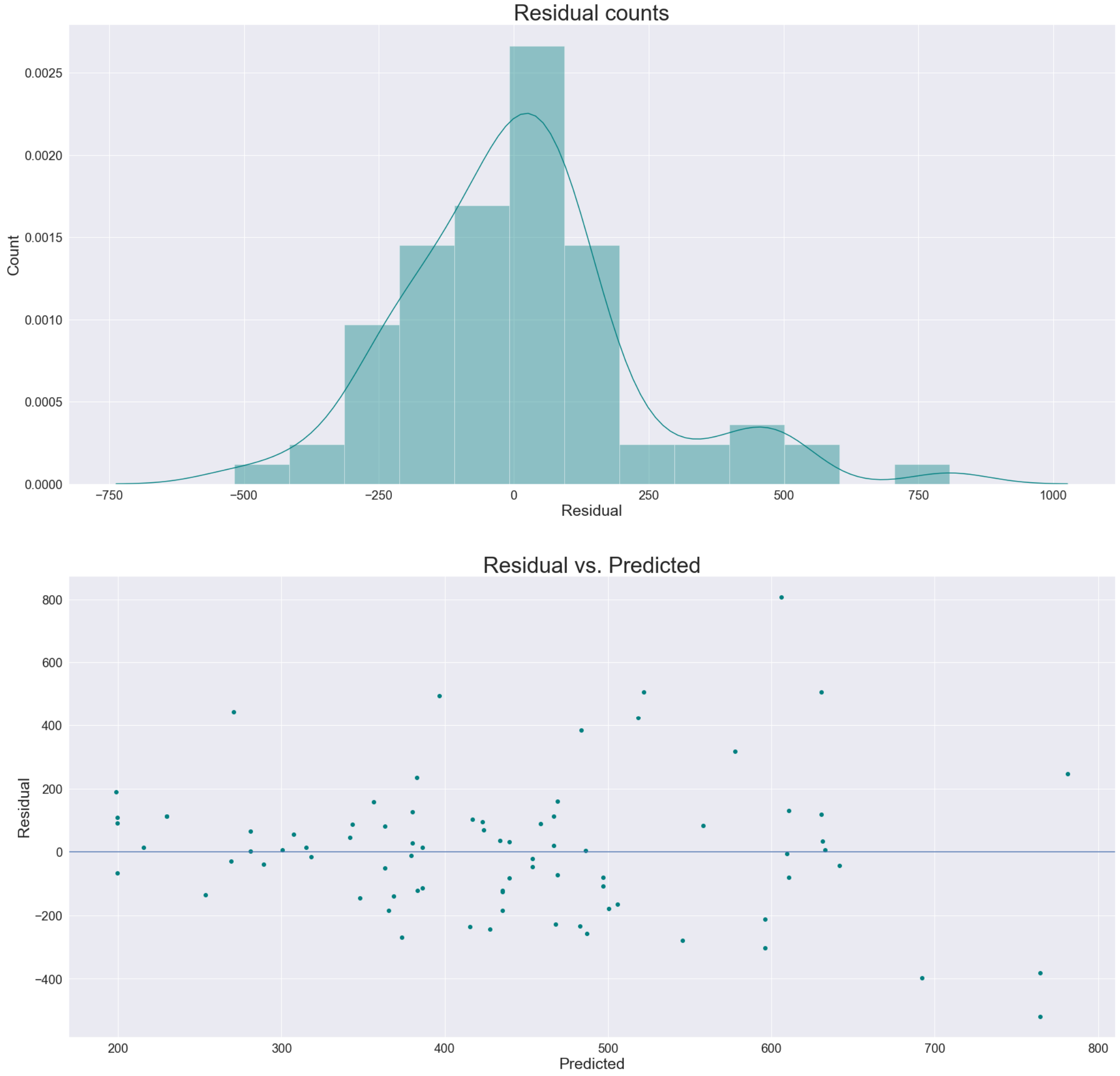


Figure 5-25 KNN Predicted Values and Residuals

5.4.2 Decision Tree Model

To develop a model by using decision tree regression, the dataset is divided to train set and test set by using Scikit-Learn library in Jupyter Notebook. 80% of the dataset is randomly picked as to be trained and model development and the remaining 20% is assigned to be tested by the developed model. The Statsmodels.api library is used to make a statistical output of the model.

Table 5-29 is presented to show the summary of the developed model.

Table 5-31 The Statistic Summary of the Decision Tree Model

Dep. Variable:	Unit_Cost_19	R-squared:	0.375
Model:	DT	Adj. R-squared:	0.353
Method:	Least Squares	F-statistic:	28.53
Date:	Mon, 25 Nov 2019	Prob (F-statistic):	3.77e-43
Time:	19:21:12	Log-Likelihood:	-2030.6
No. Observations:	320	AIC:	4087.
Df Residuals:	307	BIC:	4136.
Df Model:	12		
Covariance Type:	nonrobust		

Table 5-32 shows the coefficient (coef), standard deviation (std err), t-test (t), and P value (P>|t|) of the decision tree cost predicted model.

Table 5-32 The Decision Tree Model Coefficients' Values

	coef	std err
Pipe_Diameter	9.0181	0.593
Pipe_Length	-0.0049	0.003
Rehab_Thickness	102.8325	40.592
Letting_Year	0.7698	3.997
Location_DE	-629.4699	2423.642
Location_FL	-623.5030	2425.209
Location_MN	-451.5451	2418.754
Location_NC	-413.3676	2408.460
Location_NY	-473.1560	2411.723
Location_OH	-531.4441	2422.189
Location_PA	-462.9684	2408.989
Trenchless_Method_CIPP	-1258.9203	5639.392
Trenchless_Method_SAPL	-1065.6360	5640.017
Trenchless_Method_Sliplining	-1260.8977	5637.784

The developed model is validated using the test set. Figure 5-26 shows the residual distribution and presents the difference of the predicted values and the actual values which is the residual.

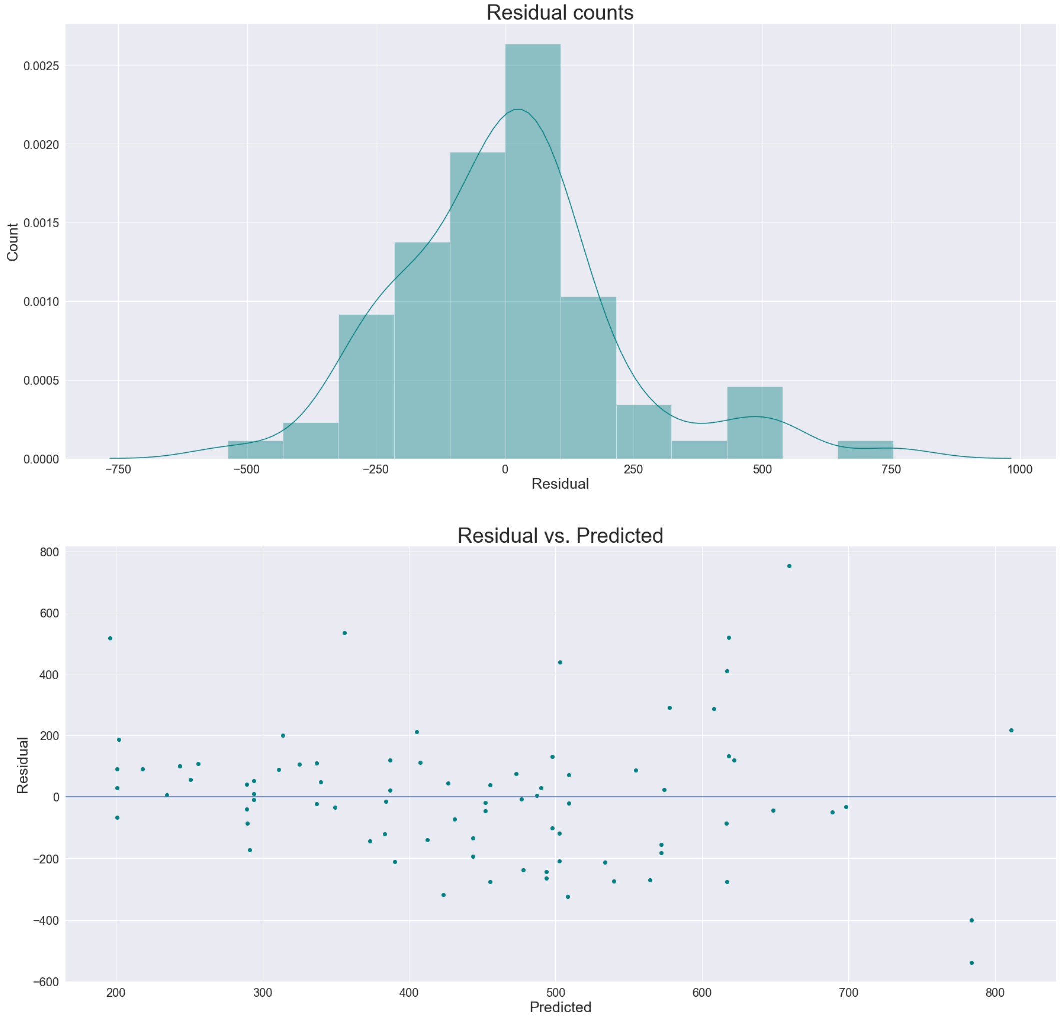


Figure 5-26 Decision Tree Predicted Values and Residuals

5.4.3 *Multi-linear Regression Model*

To develop a model by using multi-linear regression, the dataset is divided to train set and test set by using Scikit-Learn library in Jupyter Notebook. 80% of the dataset is randomly picked as to be trained and model development and the remaining 20% is assigned as to be tested by the developed model. The Statsmodels.api library is used to make a statistical output of the model. Table 5-33 is presented to show the summary of the developed model.

Table 5-33 The Statistic Summary of the Multi-linear Regression Model

Dep. Variable:	Unit_Cost_19	R-squared:	0.627
Model:	MLR	Adj. R-squared:	0.609
Method:	Least Squares	F-statistic:	38.42
Date:	Mon, 25 Nov 2019	Prob (F-statistic):	3.77e-43
Time:	10:34:36	Log-Likelihood:	-2030.6
No. Observations:	320	AIC:	4087.
Df Residuals:	307	BIC:	4136.
Df Model:	12		
Covariance Type:	nonrobust		

The Table 5-34 shows the coefficient (coef) and standard deviation (std err) of the multi-linear regression cost predicted model.

Table 5-34 The Multi-linear Regression Model Coefficients' Values

	coef	std err
Pipe_Diameter	8.0161	0.593
Pipe_Length	-0.0049	0.003
Rehab_Thickness	92.8325	40.592
Letting_Year	0.7698	3.997
Location_DE	-529.4699	2423.642
Location_FL	-423.5030	2425.209
Location_MN	-551.5451	2418.754
Location_NC	-613.3676	2408.460
Location_NY	-373.1560	2411.723
Location_OH	-531.4441	2422.189
Location_PA	-462.9684	2408.989
Trenchless_Method_CIPP	-1258.9203	5639.392
Trenchless_Method_SAPL	-1065.6360	5640.017
Trenchless_Method_Sliplining	-1260.8977	5637.784

The developed model is validated using the test set. Figure 5-27 shows the residual distribution and presents the difference of the predicted values and the actual values which is the residual.

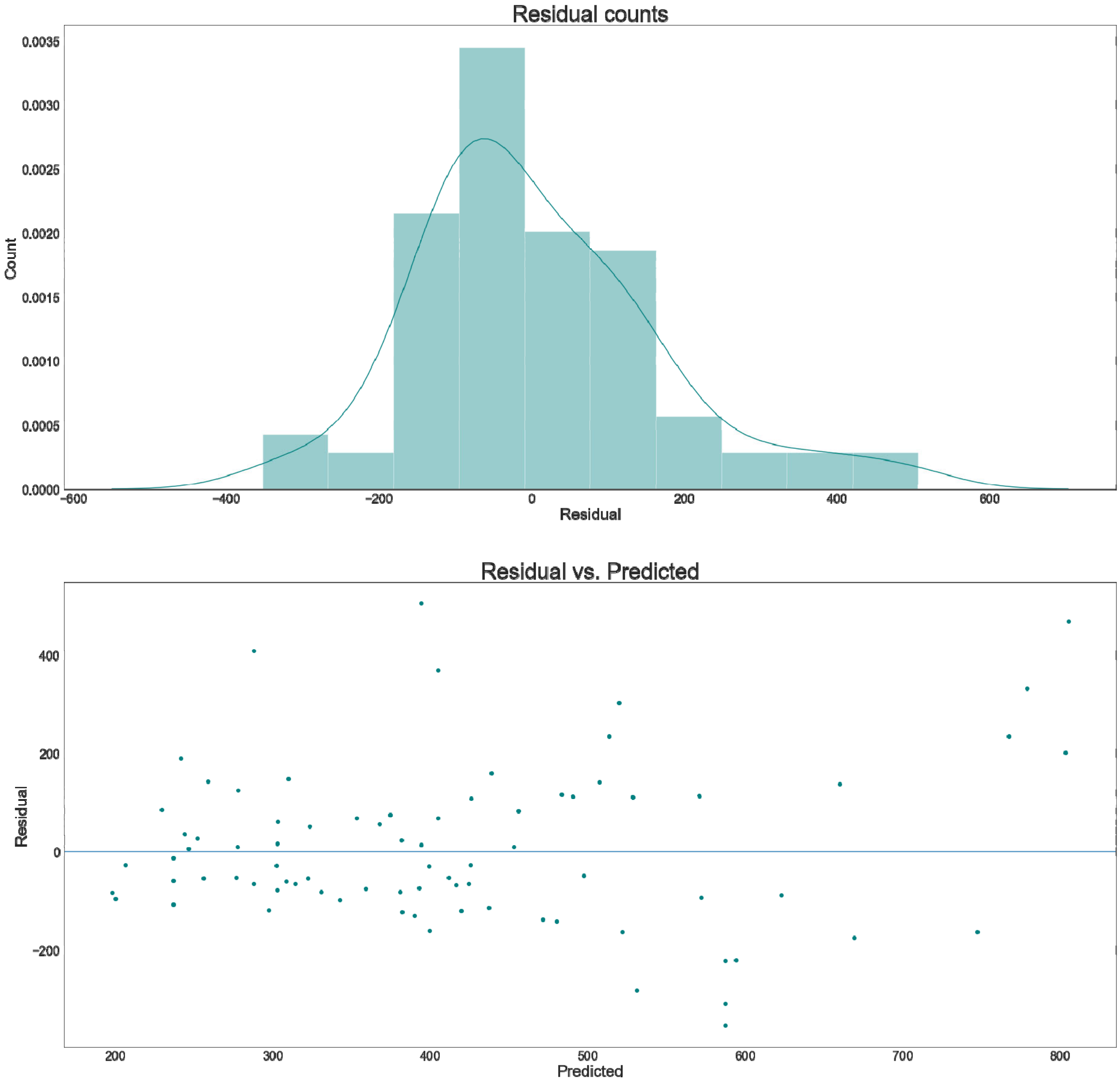


Figure 5-27 Multi-linear Regression Predicted Values and Residuals

5.4.4 Gradient Boosting Model

The model developed by using gradient boosting regression, the dataset is divided to train set and test set using Scikit-Learn library in Jupyter Notebook. 80% of the dataset is randomly picked to be trained and model development and the remaining 20% is assigned as to be tested by the developed model. The Statsmodels.api library is used to make a statistical output of the model.

Table 5-29 is presented to show the summary of the developed model.

Table 5-35 The Statistic Summary of the Gradient Boosting Regression Model

Dep. Variable:	Unit_Cost_19	R-squared:	0.540
Model:	GBR	Adj. R-squared:	0.503
Method:	Least Squares	F-statistic:	25.36
Date:	Mon, 25 Nov 2019	Prob (F-statistic):	3.77e-43
Time:	10:34:36	Log-Likelihood:	-2030.6
No. Observations:	320	AIC:	4087.
Df Residuals:	307	BIC:	4136.
Df Model:	12		
Covariance Type:	nonrobust		

Table 5-36 shows the coefficient (coef) and standard deviation (std err) of the gradient boosting cost predicted model.

Table 5-36 The Gradient Boosting Regression Model Coefficients' Values

	coef	std err
Pipe_Diameter	8.0181	0.593
Pipe_Length	-0.0049	0.003
Rehab_Thickness	102.8325	40.592
Letting_Year	0.7698	3.997
Location_DE	-629.4699	2423.642
Location_FL	-623.5030	2425.209
Location_MN	-451.5451	2418.754
Location_NC	-413.3676	2408.460
Location_NY	-473.1560	2411.723
Location_OH	-531.4441	2422.189
Location_PA	-462.9684	2408.989
Trenchless_Method_CIPP	-1258.9203	5639.392
Trenchless_Method_SAPL	-1065.6360	5640.017
Trenchless_Method_Sliplining	-1260.8977	5637.784

In addition, Figure 5-11 is presented to determine the optimum value of depth for developing the gradient boosting regression model.

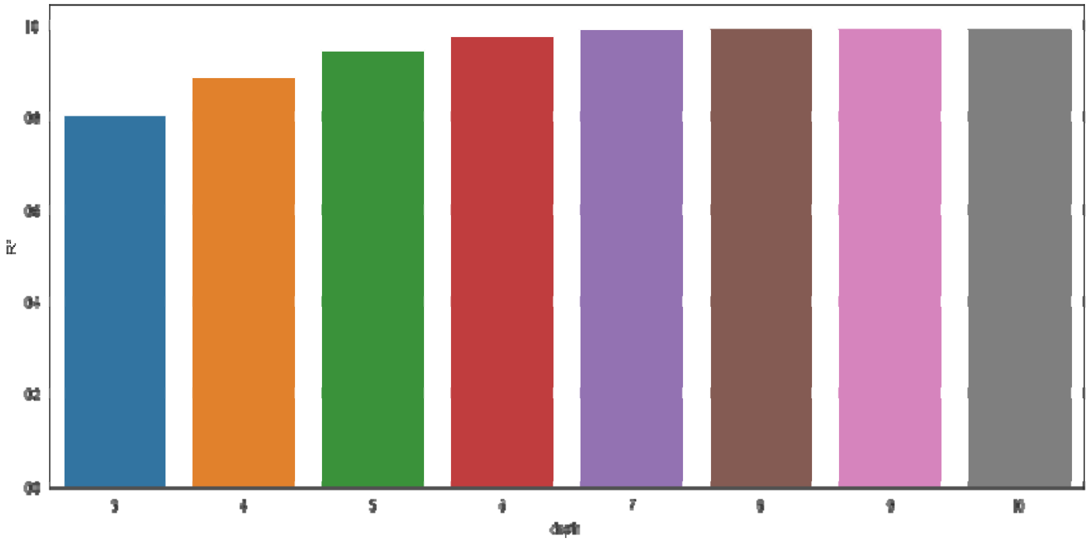


Figure 5-28 Gradient Boosting Regression Depth Value Determination

The developed model is validated by using the test set. Figure 5-29 shows the residual distribution and presents the difference of the predicted values and the actual values which is the residual.

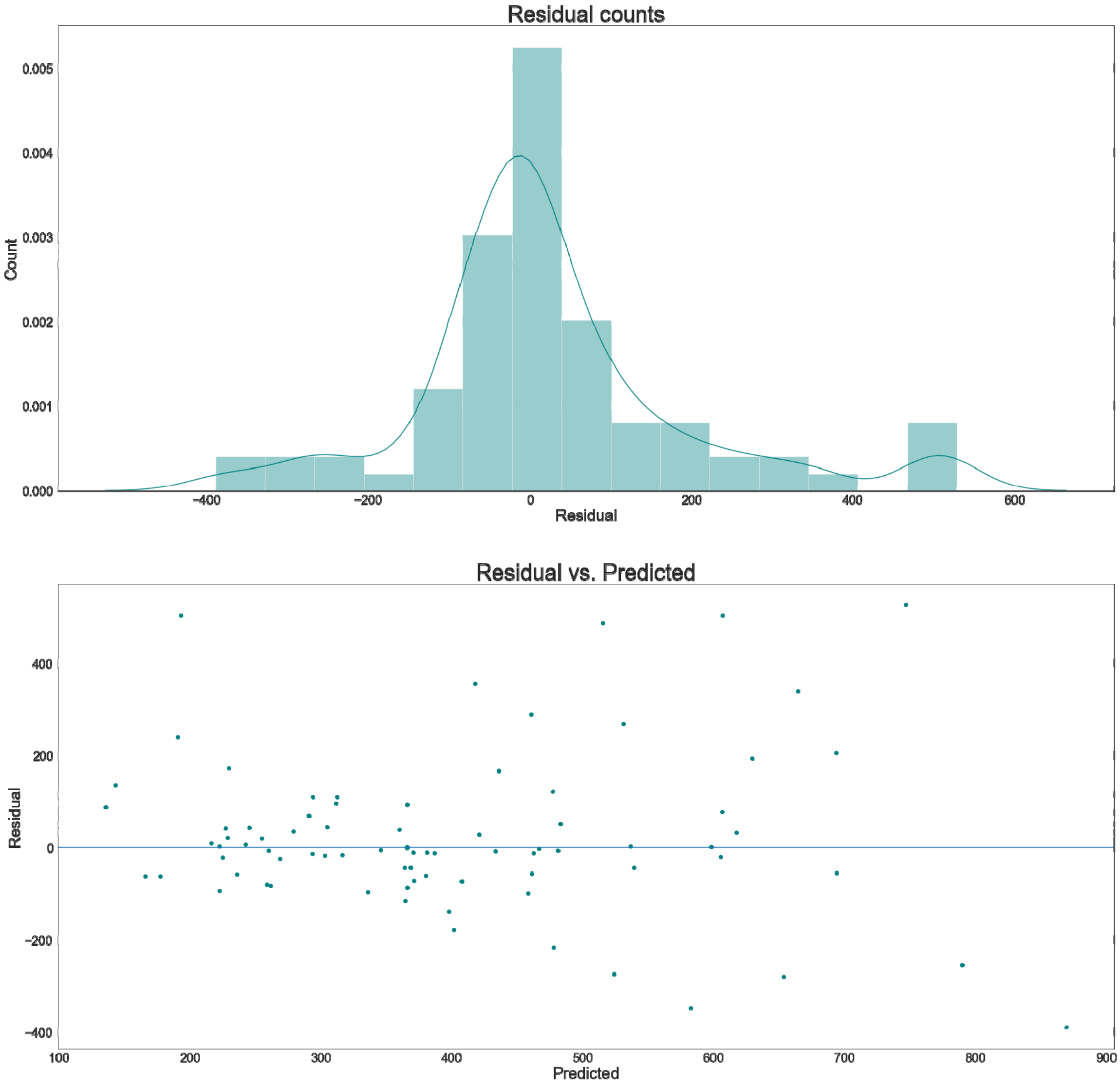


Figure 5-29 Gradient Boosting Regression Predicted Values and Residuals

5.5 Construction Costs Model Selection

To select the best prediction model the Root Mean Square Error (RMSE) of all four developed model are compared and the model with the least RMSE which was the multi-linear regression model is selected among all models as the most accurate prediction model in the purpose of predicting construction costs of SAPL, CIPP, and sliplining in large diameter culverts.

Table 5-37 The Gradient Boosting Regression Model Coefficients' Values

	RMSE	Accuracy
KNN Regression	202.46	42.0%
Decision Tree Regression	226.73	37.5%
Multi-linear Regression	153.273	62.7%
Gradient Boosting Regression	173.036	54.0%

The prediction performance of the models to predict the construction costs is shown in Figure 5-30.

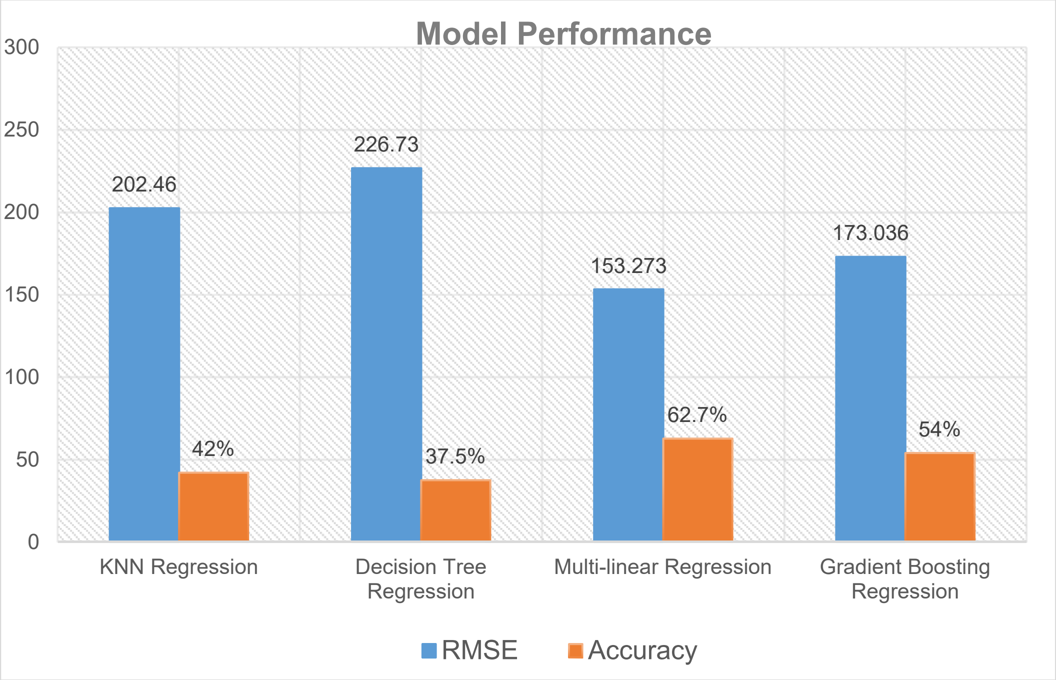


Figure 5-30 Multi-linear Regression Model Actual and Predicted Values

The accuracy of the selected model is 62.7% and Figure 5-31 is plotted to show the difference between actual values and predicted values by using this model.

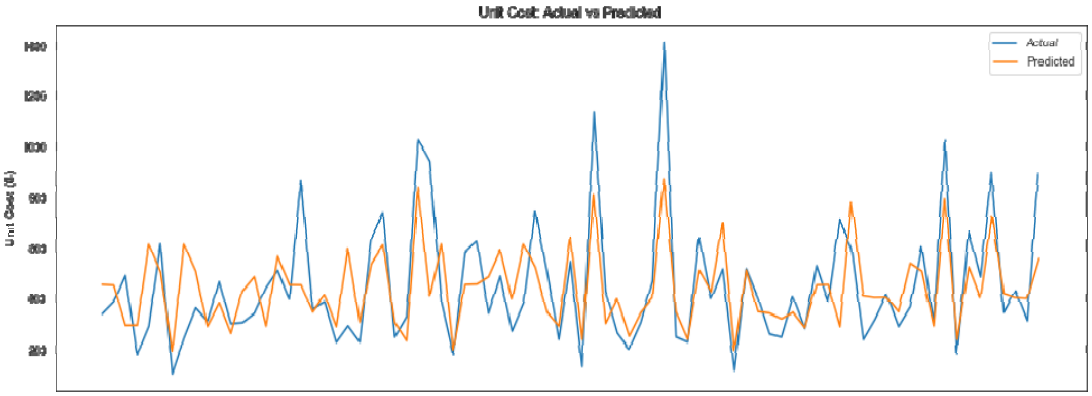


Figure 5-31 Multi-linear Regression Model Actual and Predicted Values

5.6 LCCATR Development

As it is discussed in the methodology of developing the LCCATR model, by using the results of environmental costs as deterministic value and the output of the construction cost prediction model as probabilistic value, the comprehensive life-cycle cost of three trenchless renewals for large diameter culverts is developed. To predict the life-cycle cost of SAPL, CIPP, and sliplining renewal methods the following independent variables are needed as it is shown in Table 5-38.

Table 5-38 LCCATR Model Required Inputs

Parameter	Range of Value
Pipe Diameter (ft)	30 – 108
Pipe Length (in.)	0 – 10000
Rehab Thickness (in.)	0.25 – 2.25
Letting Year	2010 – 2030
Location	Delaware – Florida – Minnesota – North Carolina – New York – Ohio – Pennsylvania
Trenchless Method	SAPL – CIPP – Sliplining

After preparing the above parameters to analyze the life-cycle cost using the LCCATR model, it is required to input all parameters to the machine learning-based construction cost model. Figure 5-32 illustrates the screenshot of the construction cost software which predicts the construction cost by analyzing the independent variables. It should be notified that the predicted value will be in 2019 dollars.

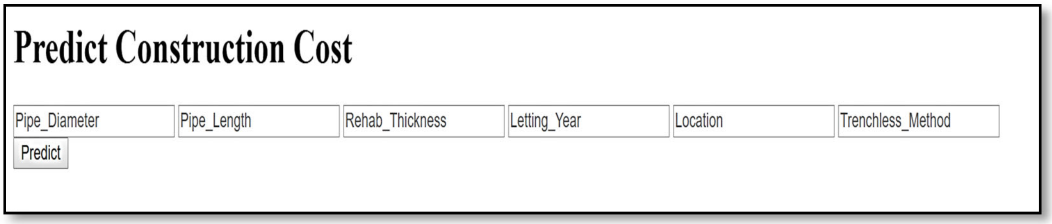

Predict Construction Cost

Figure 5-32 Construction Cost Prediction Model Available at: www.lccatr2019.herokuapp.com (Accessed December 12, 2019)

A sample of the Python codes and all libraries which are used to develop this construction cost prediction software can be found in Appendix B.

After having the predicted value from the construction cost prediction software, the environmental costs prediction table needs to be used to find the unit cost per linear feet. To achieve the total environmental costs of a trenchless project, the obtained unit cost has to multiple by the length of that project. According to the adopted equation obtained from ASTM C1131 (Eq. 5-1), by adding the total environmental costs and constriction costs, the result represents the comprehensive life-cycle cost of that project.

$$LCCA = CC + LCA + SC \qquad \text{Eq. 5-1}$$

Where LCCA = Life-cycle cost analysis,

CC = Construction costs,

LCA = Environmental costs, and

SC = Social costs.

5.7 Comparison of Results

The comprehensive analysis has been done to be able to have a comparison of the sum of environmental and construction costs of SAPL, CIPP, and sliplining and its modules as construction costs and environmental costs are shown the mean construction costs comparison of SAPL, CIPP, and sliplining in diameter of 30 in. to 108 in.

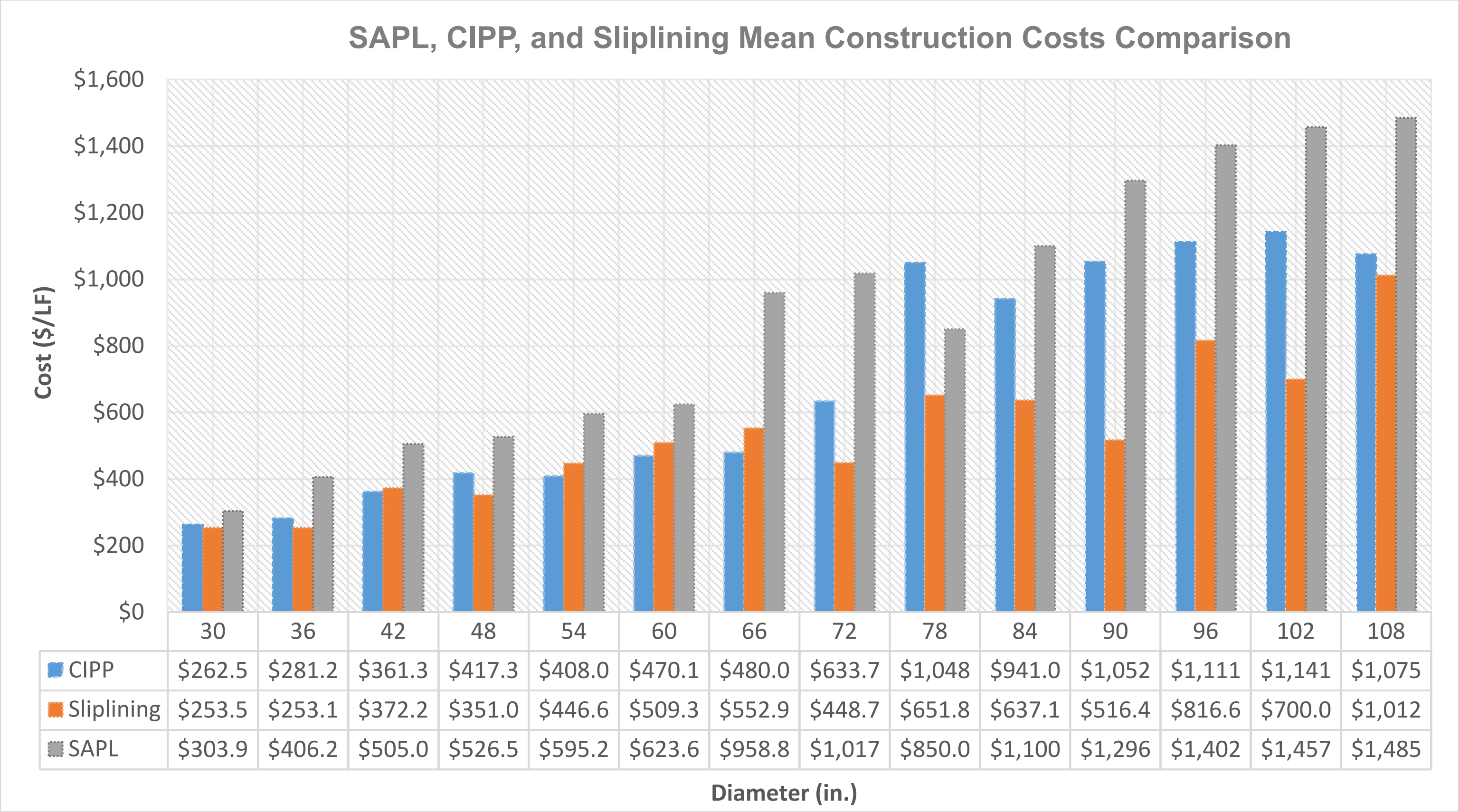
In addition, Figure 5-34 is presented to show the comparison of the environmental costs of all three applications for large diameter culverts. It should be noted that there are some assumptions behind the environmental costs analysis which can be found earlier in this chapter in environmental cost results.

Moreover, the life-cycle costs which consist of environmental and construction costs for a diameter of 30 in. to 108 in. for SAPL, CIPP, and sliplining renewals are presented in Figure 5-35.

In this result, the sum of environmental and construction costs corresponded to each diameter for each method is calculated based on the sum of the mean construction costs corresponded for each diameter of each trenchless method with the estimated environmental costs for each diameter of each method.

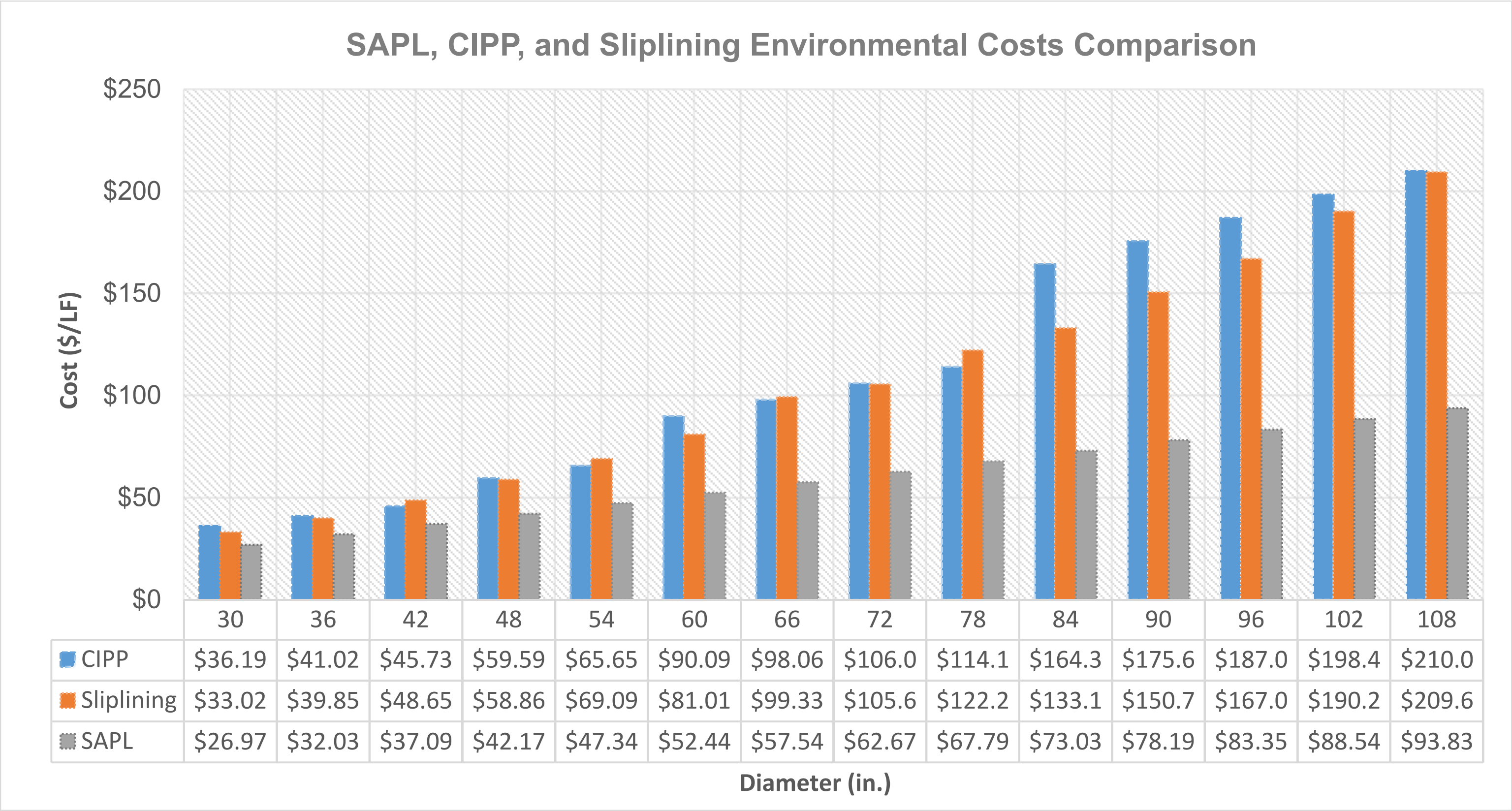
The result shows that by accounting the environmental costs into the total costs of SAPL, CIPP, and sliplining trenchless culvert rehabilitations, the environmental and construction costs of all applications for the diameter of 30 in. to 66 in. will be almost the same. In addition, although the environmental costs of SAPL are less than other methods, still the sum of environmental and construction costs of SAPL for diameter of 84 in. and larger are higher than the other two methods.

Finally, Figure 5-36, Figure 5-37, and Figure 5-38 are presented to illustrate the proportion of environmental costs and construction costs in the life-cycle cost of SAPL, CIPP, and sliplining for diameter of 30 in. to 108. In 2019 dollars.



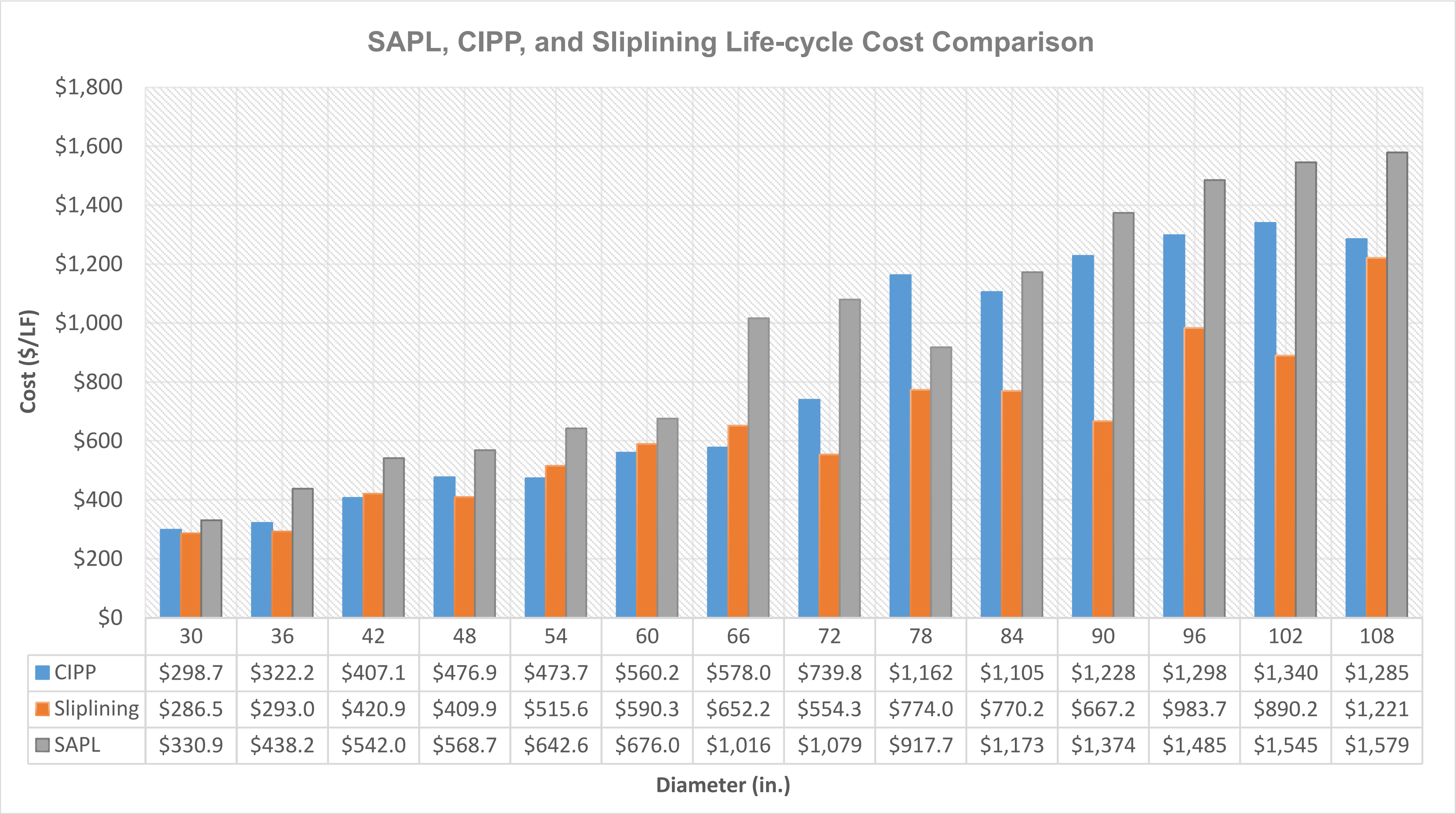
	30	36	42	48	54	60	66	72	78	84	90	96	102	108
🟦 CIPP	$262.5	$281.2	$361.3	$417.3	$408.0	$470.1	$480.0	$633.7	$1,048	$941.0	$1,052	$1,111	$1,141	$1,075
🟧 Sliplining	$253.5	$253.1	$372.2	$351.0	$446.6	$509.3	$552.9	$448.7	$651.8	$637.1	$516.4	$816.6	$700.0	$1,012
▨ SAPL	$303.9	$406.2	$505.0	$526.5	$595.2	$623.6	$958.8	$1,017	$850.0	$1,100	$1,296	$1,402	$1,457	$1,485

Figure 5-33 Mean Construction Costs Comparison
of SAPL, CIPP, and sliplining in 2019 Dollars



	30	36	42	48	54	60	66	72	78	84	90	96	102	108
CIPP	$36.19	$41.02	$45.73	$59.59	$65.65	$90.09	$98.06	$106.0	$114.1	$164.3	$175.6	$187.0	$198.4	$210.0
Sliplining	$33.02	$39.85	$48.65	$58.86	$69.09	$81.01	$99.33	$105.6	$122.2	$133.1	$150.7	$167.0	$190.2	$209.6
SAPL	$26.97	$32.03	$37.09	$42.17	$47.34	$52.44	$57.54	$62.67	$67.79	$73.03	$78.19	$83.35	$88.54	$93.83

Figure 5-34 Environmental Costs Comparison
of SAPL, CIPP, and sliplining in 2019 Dollars



	30	36	42	48	54	60	66	72	78	84	90	96	102	108
🟦 CIPP	$298.7	$322.2	$407.1	$476.9	$473.7	$560.2	$578.0	$739.8	$1,162	$1,105	$1,228	$1,298	$1,340	$1,285
🟧 Sliplining	$286.5	$293.0	$420.9	$409.9	$515.6	$590.3	$652.2	$554.3	$774.0	$770.2	$667.2	$983.7	$890.2	$1,221
⬜ SAPL	$330.9	$438.2	$542.0	$568.7	$642.6	$676.0	$1,016	$1,079	$917.7	$1,173	$1,374	$1,485	$1,545	$1,579

Figure 5-35 Life-cycle Cost Comparison of SAPL, CIPP, and Sliplining in 2019 dollars

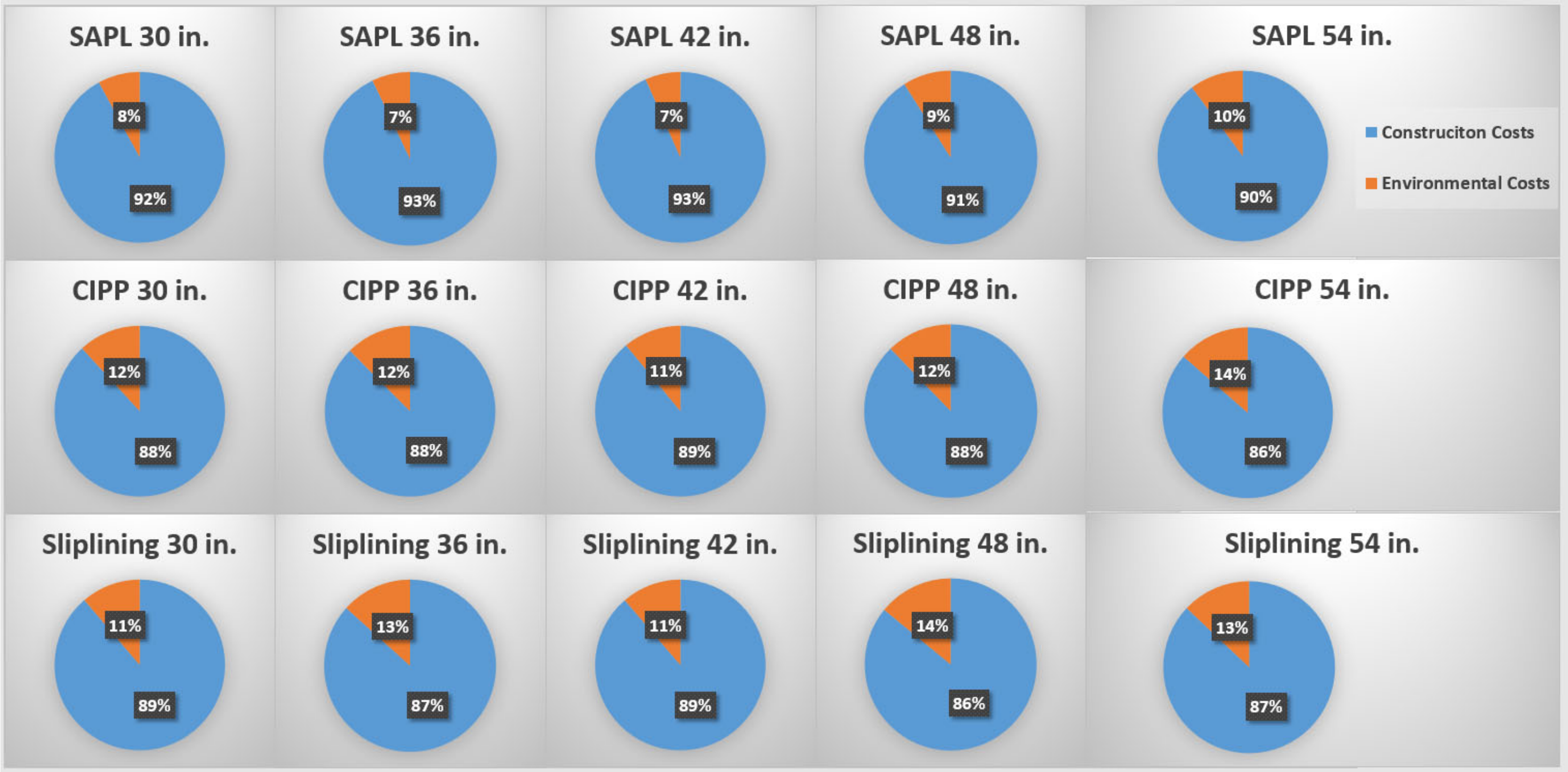


Figure 5-36 Life-cycle Cost Proportioning Comparison of SAPL, CIPP, and sliplining for Diameter of 30 in. to 54 in.

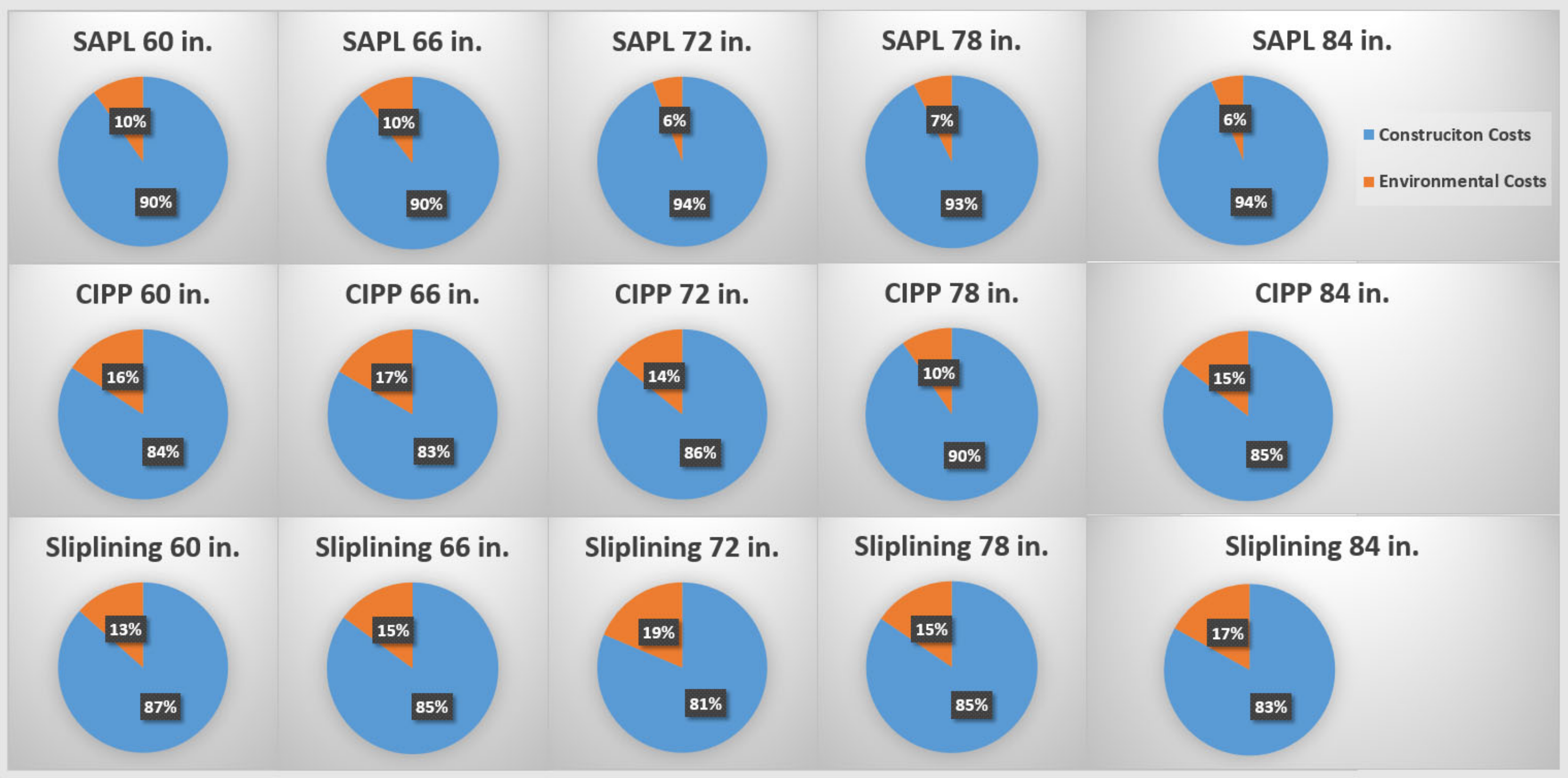


Figure 5-37 Life-cycle Cost Proportioning Comparison of SAPL, CIPP, and sliplining for Diameter of 60 in. to 84 in.

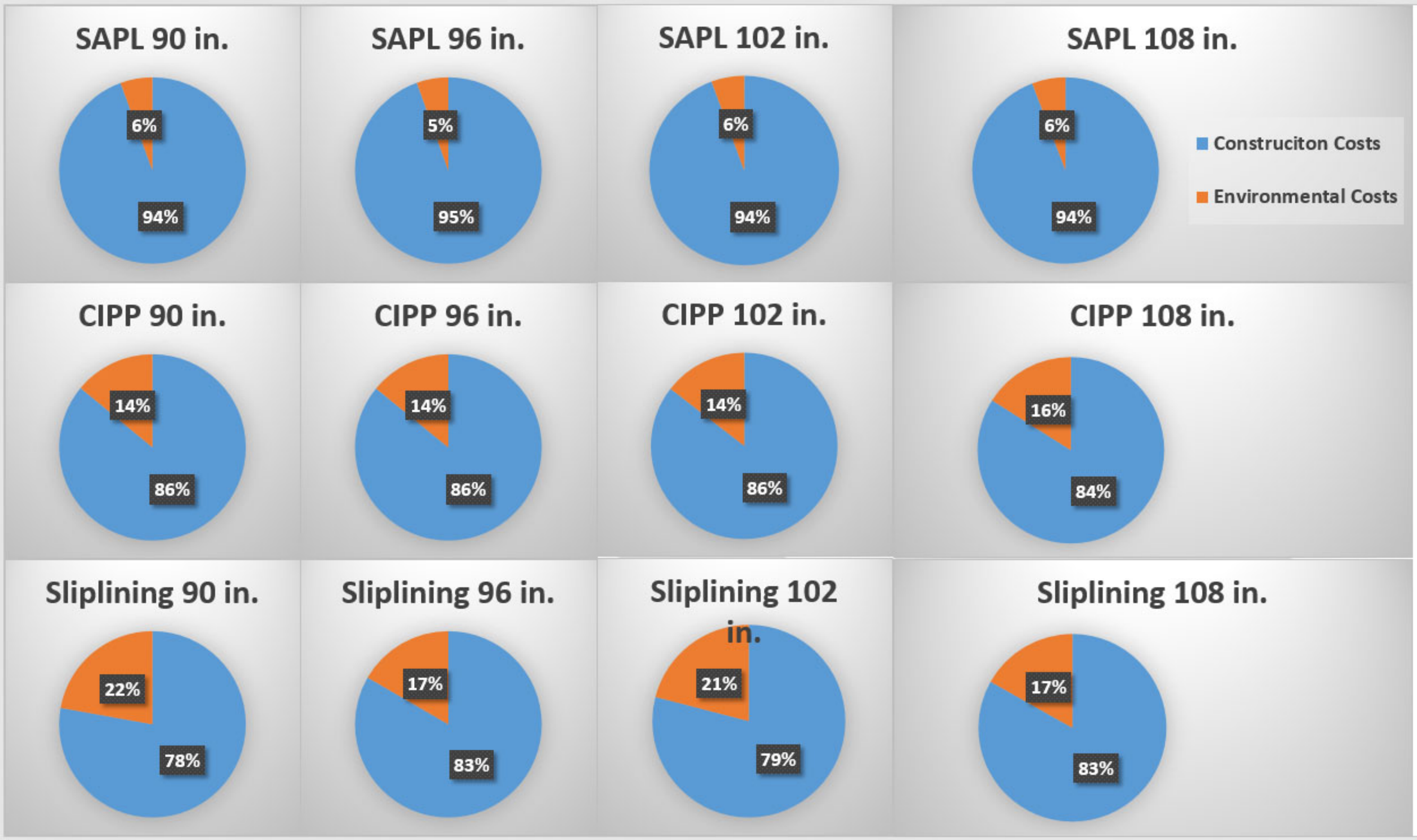


Figure 5-38 Life-cycle Cost Proportioning Comparison of SAPL, CIPP, and sliplining for Diameter of 90 in. to 108 in

5.8 Discussion of Results

In this section, the machine learning-based model (LCCATR) is developed to predict the construction and environmental costs as two main modules of the life-cycle cost of cementitious SAPL, CIPP with polyester resin and steam curing, and sliplining with HDPE pipe in large diameter culverts. Based on the obtained results, the following statements can be noticed:

- Imposing the environmental costs to the analysis of the total cost of SAPL, CIPP, and sliplining renewals can play a significant role in decision-making phase especially in large diameters.
- From the diameter of 60 in., the difference between the trenchless SAPL method with the lowest environmental costs and the trenchless CIPP method with the highest environmental cost is started to increase by more than 50%.
- From 78 in. to 108 in. of diameter, the environmental costs of CIPP and sliplining are almost the same. Moreover, the environmental costs of both CIPP and sliplining are twice rather than SAPL application.
- The difference between mean construction costs of sliplining and SAPL in 72 in. diameter is 120 times more than that of 30 in. diameter. It shows the significant difference in construction costs within SAPL and sliplining exist by increasing the diameter of the culverts.
- The difference between mean construction costs of CIPP and SAPL in 72 in. diameter is 500% more than that of 30 in. diameter. It shows the significant difference in construction costs within CIPP and SAPL by increasing the diameter of the culverts.

5.9 Limitations of this Study

Every research will have limitations. The limitations of this dissertation are listed below:

- There was a lack of enough data corresponding to various diameters in different locations for SAPL projects. By adding more data for SAPL projects, the accuracy of the entire developed model can be improved significantly.
- There was a lack of information about the thickness of each trenchless renewals. Therefore, the contribution of the trenchless thickness as an independent variable to the unit cost is not significant in the LCCATR model. Also, it reduced the accuracy of the model. This issue can be solved by having more data regarding the thickness of each trenchless renewals and add it to the model.
- In the procedure of analysis of environmental costs, many parameters such as material thickness, equipment, and especially project duration are assumed due to the lack of actual data. Also, one type of material for each renewal method is investigated. This can be improved by adding more data for each trenchless renewal.

5.10 Chapter Summary

This chapter discussed the results of LCCA modules as environmental and construction costs for cementitious SAPL, CIPP with polyester resin and steam curing, and sliplining with HDPE pipe trenchless applications for large diameter culverts were presented. SimaPro software was employed to the analysis of environmental costs based on the collected and evaluated required materials and equipment inputs. In addition, four machine learning-based models were developed to predict the construction costs and the most-fitted model with the highest accuracy was selected.

A comparison of construction and environmental costs between SAPL, CIPP, and sliplining methods as stated above was performed for culverts with a diameter of 30 in. to 108 in. Most importantly, the LCCATR model, which represents a comprehensive life-cycle construction and environmental costs model and its methodology were developed and introduced. Finally, the limitations of this dissertation were discussed.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

6.1 Conclusions

This dissertation provided a comprehensive environmental and construction costs analysis of trenchless cementitious SAPL, CIPP with polyester resin and steam curing, and sliplining with HDPE pipe renewal methods in large diameter culverts. The LCCA modules were construction, environmental, and social costs. As the selected trenchless renewals may have a short period of installation with comparable traffic disruptions, the social costs of these methods were assumed to be negligible. Therefore, this analysis focused on construction and environmental costs for these trenchless renewals.

The data of different projects were collected and prepared from various sources. The analysis to provide midpoint environmental impact potentials for specific SAPL, CIPP, and sliplining renewals including ozone depletion, smog, acidification, eutrophication, carcinogenic and non-carcinogenic human toxicity, respiratory effects, ecotoxicity, and fossil fuel depletion was conducted. These impact potentials, calculated for SAPL, CIPP, and sliplining as the major renewal applications for large diameter culverts in the trenchless technology field, compared favorably together.

Conclusions and contribution to the body of knowledge of this dissertation can be summarized as follow:

- Sometimes project owners, designers and contractors consider only the construction costs of the projects. These organizations may overlook the environmental impacts and costs at the decision making phase of the trenchless renewal selection.

- Analysis of environmental costs of trenchless renewals in culverts is an essential factor in the decision-making phase when considering sustainable development of underground infrastructure.
- Construction costs of more than 400 trenchless projects were analyzed and modeled. Four different machine learning models were developed and the most accurate one was selected. Furthermore, a model to predict the construction costs of cementitious SAPL, CIPP with polyester resin and steam curing, and sliplining with HDPE pipe renewals were developed.
- The major contribution of this dissertation was the inclusion of LCCATR methodology in the LCCA analyses for trenchless renewals. This methodology, while location-based in this dissertation, it can be generalized and applied to all other trenchless renewals based on data availability.
- The other contributions of this dissertation were the analyses and the comparisons between environmental costs of three major rehabilitation applications in the trenchless technology field for large diameter culverts. These comparisons confirmed some literature that state CIPP produces greater environmental impacts than the other trenchless renewals, especially when using a polyester resin with styrene and steam curing. According to this dissertation, CIPP has the highest environmental costs for the culvert with the diameter of 30 in. to 108 in. compared to SAPL and sliplining. In addition, the environmental costs of CIPP for the diameter of 84 in. to 108 in. is twice than SAPL.
- SimaPro software and its embedded databases yielded a comparable global warming for trenchless renewal projects (especially CIPP) to previously environmental-focused studies, which have used single-impact focused data. This

process confirms use of SimaPro for estimating and predicting midpoint in environmental impacts for these trenchless renewal applications.

- The other contribution of this dissertation centered on the approach to predict the construction costs of trenchless renewals by using a machine learning technique. The models developed and trained from actual data and validated by testing sets, which is called the train-test split approach to algorithm evaluation. Numerous structures were tested and the best architecture was selected as the main cost prediction model.

6.2 Recommendation for Future Research

According to the results and conclusions of this dissertation, followings are the recommendations for future research on two main LCCA modules (construction and environmental costs) of trenchless SAPL, CIPP, and sliplining renewals:

- In this dissertation, only one material from each trenchless method was considered for the analyses and comparisons. There is a need to obtain the project data for all other types of materials for each trenchless method to improve the model as well as to have a better comparison between these three applications.
- The methodology used in this dissertation can be expanded to other diameters, locations, trenchless renewal methods as well as open-cut construction.
- There are some assumptions behind environmental costs analysis. There is a need to improve the analysis by obtaining more actual data and run the same methodology to evaluate the environmental costs.
- The environmental cost analysis was conducted by SimaPro software. There is a need to have a study to collect and measure the actual emissions at the installation

phases of SAPL, CIPP, and sliplining and compare them with the results of this dissertation as the midpoints of potential environmental impacts.

- Due to the objective of this dissertation, the environmental impacts have been translated to the cost. More research is needed to evaluate and compare the environmental impacts of trenchless applications and to focus on environmental aspects rather than costs.
- Since the SAPL concept for large diameter gravity culverts is a more recent technique rather than CIPP and sliplining, fewer projects are conducted with this method until now. Currently, there are many ongoing projects, which are using the SAPL method for the culvert renewal. Therefore, there is a need to obtain new data from these latest SAPL projects and utilize them to improve accuracy of the developed LCCATR model.
- Environmental and construction costs analysis play an essential role in the decision-making tool to select the most appropriate trenchless method for culvert renewals. At the same time, there are other factors involved in designing and decision making phase of trenchless method selection. There can be a study to investigate the influence of other factors, such as social costs, in addition to construction and environmental costs considered in this dissertation.

References

Ajdari, E. (2016). Volatile Organic Compound (VOC) Emission during Cured-in-Place-Pipe (CIPP) Sewer Pipe Rehabilitation. *Ph.D. Dissertation*, University of New Orleans, LA, in in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Amaral, J., Silva, J. R. C., de Andrade, D. S. M., Ferreira, L. T., Quirino, T. M., & Quirino, J. (2019). Machine Learning Algorithms Applied to the Inference of the Flow Rate in a Non-intrusive Thermal Flow meter. *Proc.* 4th International Symposium on Instrumentation Systems, Circuits and Transducers (INSCIT) (pp. 1-6). IEEE.

Allouche, E. N., & Gilchrist, A. (2004). Quantifying construction related social costs. *Proc.* NASTT No-Dig Conference, 2004.

Allouche, E., Alam, S., Simicevic, J. and Sterling, R. (2012). A Retrospective Evaluation of Cured-In-Place Pipe (CIPP) Used in Municipal Gravity Sewers. *Environmental Protection Agency*. Trenchless Technology Center at Louisiana Tech University, Battelle Memorial Institute, Jason Consultants, Inc., New Jersey and Ohio, 2012.

Alinizzi, M. F. (2013). A Framework for Coordinating Water Distribution System and Pavement Infrastructure M&R Based on LCCA. *Master's Thesis*, Purdue University, West Lafayette, IN.

Alpaydin, E., (2004). Introduction to Machine Learning. Cambridge, Massachusetts London, England.

Alsadi, A. (2019). Evaluation of Carbon Footprint During the Life-Cycle of Four Different Pipe Materials. *Ph.D. Dissertation*, Louisiana Tech, 2019.

American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF). (2000). Standard Methods for the

Examination of Water and Wastewater. 22nd Ed., American Public Health Association (APHA), Baltimore, MD.

ASCE. (2019). Guidelines for the Sustainable Design of Pipelines. Reston, VA (Under Print).

ASCE. (2010). Trenchless Renewal of Culverts and Storm Sewers. *Manuals and Reports on Engineering Practice No. 120.*, Reston, VA.

ASTM International. (2009). Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube.

Atalah, A. (2004). Ground movement in hard rock conditions related to Pipe bursting. *Proc.* ASCE Pipelines 2004.

Baik, H. S., Abraham, D. M., & Gipson, D. J. (2004). Impacts of Deteroriation Based Life Cycle Cost Analysis (LCCA) on the Assessment of Values of Wastewater Infrastructure Assets. *Proc.* Pipeline Engineering and Construction.

Bauer, G., and McCartney, D. (2004). Odor Control-More than Sewage When Installing Cured-In-Place Sewer Pipe Liners. *Proc.* of the North American Society for Trenchless Technology (NASTT) No-Dig Conference, New Orleans, LA.

Bartlett, S., Cisneros, H., Decker, P., Heartwell, G., Warnock, A., Nellenbach, M., and Campanelli, B. (2017). Executive Council on Infrastructure Water Task Force.

Beaudet, B. A., Tobey, B., and Harder, S. (2019). Life Cycle Cost Analysis for Decision Making in Collection System Rehabilitation. *Proc.* NASTT No-Dig Show, Chicago, IL, Mar 17-20, 2019.

Caltrans Division of Research and Innovation-Preliminary Investigation (2012). Environmental Effects of Cured-in-Place Pipe Repairs. Produced by *CTC & Associates LLC*, August 2012.

Carbon Trust. (2007). Carbon footprinting: An introduction for organizations. London: Carbon Trust.

Cao, X., and Lee, L. J. (2003). Control of Shrinkage and Residual Styrene of Unsaturated Polyester Resins Cured at Low Temperatures: Effect of Curing Agents. Polymer, 44(6), 1893-1902.

Delft, C. E. (2017). Van use in Europe and their environmental impact. *CE Delft, Delft*.

Chilana, L. (2011). Carbon footprint analysis of a large diameter water transmission pipeline installation. *Master's Thesis*, The University of Texas at Arlington, 2011.

Chilana, L., A. H. Bhatt, M. Najafi, and M. Sattler (2016). Comparison of carbon footprints of steel versus concrete pipelines for water transmission. *Journal of the Air & Waste Management Association*, vol. 66, no. 5, pp. 518–527, May 016.

Crawford, S., & Lungu, C. T. (2011). Influence of Temperature on Styrene Emission from a Vinyl Ester Resin Thermoset Composite Material. *Science of the Total Environment*, 409(18), 3403-3408.

CUIRE. (2018). Evaluation of Potential Release of Organic Chemicals in the Steam Exhaust and Other Release Points during Pipe Rehabilitation Using the Trenchless Cured-In-Place Pipe (CIPP) Method. *Final Report*, NASSCO's Phase 1 CIPP Steam Emissions Study, 2018.

De Matos, C. T., Garcia, J. C., Aurambout, J. P., & Manfredi, S. (2015). Environmental sustainability assessment of bioeconomy products and processes—progress report 1. European Commission Report EUR 27356 EN.

Currier, B. (2017). Water Quality of Flow through Cured-In-Place Pipe (CIPP). *Final Report*; Office of Water Programs, California State University Sacramento: Sacramento, CA, 2017 (prepared for California Department of Transportation, Sacramento, CA).

Czajkowski, M., and Kretowski M. The role of decision tree representation in regression problems; an evolutionary perspective. Apple Soft Computer. J., vol. 48, pp. 458–475, 2016.

Das, S., (2016). Evaluation of Cured-in-Place Pipe Lining Installations. *Master's Thesis*, University of Alberta, Canada.

Das, S., Bayat, A., Gay, L., Salimi, M., & Matthews, J. (2016). A Comprehensive Review on the Challenges of Cured-in-Place pipe (CIPP) Installations. *Journal of Water Supply: Research and Technology-Aqua*, 65(8), 583-596.

Dayal, P. (2011). Worcester day care center evacuated. *Worcester Telegram and Gazette*, Oct. 28.

Doherty, I. J. (2008). CIPP Liner Thickness Change Under F1216-07b, *Proc.* NASTT, Dallas, Texas, April 27 – May 2, 2008.

Donaldson B. (2012). Water Quality Implications of Culvert Repair Options: Vinyl Ester Based and Ultraviolet Cured-in-Place Pipe Liners. *Virginia Center for Transportation Innovation & Research*, Virginia, 2012.

Donaldson, B. M., and A. Baker. (2008). The Environmental Implications of Cured-in-Place Pipe Rehabilitation. VTRC 08-CR12, *Virginia Transportation Research Council*, Charlottesville, 2008.

Dusseldorp, A.; and Schols, E. (2006). Rioolrenovatie Met Kousmethoden-Achtergronden Bij Het Informatieblad. RIVM rapport 609021038/2006, Bilthoven, RIVM-Rijksinstituut voor Volksgezondheid en Milieu.

García-Laencina, P. J., Sancho-Gómez, J. L., Figueiras-Vidal, A. R., Verleysen, M. K. (2009). Nearest Neighbours with Mutual Information for Simultaneous

Classification and Missing Data Imputation. Neurocomputing 2009, 72, 1483–1493.

Gao, X., Pishdad-Bozorgi, P., Dennis, R., Shelden, A., and Tang, S. (2018). Machine Learning-based Life-cycle Cost Analysis. Educational Facilities.

Glossary of Environment Statistics. (1997). Studies in Methods, Series F, No. 67. United Nations, New York.

Gowen, A. (2004). Fumes from Va. sewer work cited in illnesses: Alexandria Officials Reevaluating Effects of Styrene Vapor on Residents. *Washington Post*, May 12, B08.

GÜNAYDIN, O., ÖZBEYAZ, A., SÖYLEMEZ, M. (2017). Estimating California Bearing Ratio Using Decision Tree Regression Analysis Using Soil Index and Compaction Parameters.

Habibzadeh-Bigdarvish, O., Yu, X., Lei, G., Li, T., & Puppala, A. J. (2019). Life-Cycle cost-benefit analysis of Bridge deck de-icing using geothermal heat pump system: A case study of North Texas. Sustainable Cities and Society, 47, 101492.

Heinselman, W. (2012). The History of Cured-in-Place-Pipe Lining in the United States, *Express Sewer & Drain*, 2012.

Holland, M., Pye, S., Watkiss, P., Droste-Franke, B., & Bickel, P. (2005). Damages per Tonne Emission of PM2. 5. NH3, SO2, NOx and VOCs from each EU25 Member State (Excluding Cyprus) and Surrounding Seas, AEAT, Published by EC.

Howard, A. (1996). Pipeline Installation. *Relativity Publishing*. Lake Wood, Colorado.

InfraGuide (2003). Coordinating Infrastructure Works. DMIP Best Practice, *National Research Council of Canada*, Ottawa, Canada.

International Organization for Standardization (ISO). (2006). Environmental management - Life cycle assessment - Principles and framework. *ISO 14040*, Geneva.

Islam, A., Allouche, E. and Matthews, J. (2014). Assessment of social cost savings in trenchless projects. *Proc.* North American Society for Trenchless Technology

Jahren, C., & Civil, C. (2011). Development of Updated Specifications for Roadway Rehabilitation Techniques. *Iowa State University, Final Report*.

(NASST), Orlando, FL.

Jain, A. A. (2010). Evaluation of Trenchless Renewal Methods for Potable Water Distribution Pipes. *Ph.D.'s Dissertation.* The University of Texas at Arlington. Arlington, Texas, USA.

Jalalediny Korky, S., Homing Ni, A., Najafi, M., Malek Mohammadi, M., and Serajiantehrani, R. (2019). Design and installation of water pipeline renewals. North American Society for Trenchless Technology (NASTT) No-Dig Show, Chicago, IL.

Jerez, J. M., Molina, I., García-Laencina, P.J., Alba, E., Ribelles, N., Martín, M., Franco, L. (2010). Missing Data Imputation Using Statistical and Machine Learning Methods in a Real Breast Cancer Problem. Artificial Intelligence Medium. Vol. 50, 105–115.

Ji, H., Yoo, S., Kim, J., & Koo, D. (2018). The Mechanical Properties of High Strength Reinforced Cured-in-Place Pipe (CIPP) Liner Composites for Urban Water Infrastructure Rehabilitation. *Water*, *10*(8), 983.

Jung, Y., Sinha, S. (2007). Evaluation of Trenchless Technology Methods for Municipal Infrastructure System. *Journal of Infrastructure Systems*, Vol. 13, No. 2, pp. 144-156.

Kabir, G., Tesfamariam, S., & Sadiq, R. (2015). Predicting water main failures using bayesian model averaging and survival modelling approach. *Reliability Engineering & System Safety*, 142, 498-514.

Kamat, S. M. (2011). Comparison of Dust Generation from Open Cut And Trenchless Technology Methods for Utility Construction. *Master's Thesis*, The University of Texas at Arlington.

Kampbell, E. (2009). Understanding Environmental Implications of CIPP Rehab Technology. *Rehabilitation Technology, Underground Technology Cutting Edge Technical Information for Utility Construction and Rehabilitation*, 2009.

Karimian, S. F. (2015). Failure Rate Prediction Models of Water Distribution Networks. *Master's Thesis*, Concordia University, 2015.

Kaushal, V., Iyer, G., Najafi, M., Sattler, M., and Schug, K. (2019). Review of Literature for Cured-in-Place Pipe (CIPP) Chemical Emissions and Worker Exposures. *Proc.* Transportation Research Board Annual Meeting, Washington, D.C., 2019.

Kaushal, V., Najafi, M., and Serajiantehrani, R., (2019). A Comparison of Environmental and Construction Costs of Trenchless Cured-in-Place Pipe (CIPP) Method with Open-Cut Pipeline Installation. Proc. ICPTT, Changhai, China, 2019.

Kaushal, V., Najafi, M., and Serajiantehrani, R., (2020). A Comparison of Construction Cost of Trenchless Cured-in-Place Pipe (CIPP) Method with Open-Cut Pipeline Installation. Proc. The Third European and Mediterranean Structural Engineering and Construction Conference, Limassol, Cyprus, June 22-27, 2020.

Kaushal, V., Najafi, M., and Serajiantehrani, R., (2019). Development of a Methodology to Compare Environmental and Social Costs of Trenchless Cured-in-Place Pipe

Renewal Method with Open-cut Pipeline Replacement for Sanitary Sewers. Journal of Pipeline Systems Engineering and Practice, ASCE.

Kaushal, V., Najafi, M., and Serajiantehrani, R. (2019). Environmental Impacts of Conventional Open-cut Pipeline Installation and Trenchless Technology Methods: A State-of-the-Art Review. Journal of Pipeline Systems Engineering and Practice, ASCE.

Kaushal, V., Najafi, M., and Serajiantehrani, R., (2019). Environmental Impact Analysis of Trenchless Cured-in-Place Pipe Renewal Method with Open-cut Pipeline Replacement for Sanitary Sewers. Journal of Tunneling and Underground Space Technology.

Kaushal, V., Najafi, M., Sattler, M., and Schug, K. (2019a). Evaluation of Potential Release of Organic Chemicals in the Steam Exhaust and Other Release Points during Pipe Rehabilitation Using the Trenchless Cured-In-Place Pipe (CIPP) Method. *Proc.* North American Society for Trenchless Technology-No-Dig Conference, Chicago, IL.

Kaushal, V., Najafi, M., Sattler, M., and Schug, K. (2019b). Review of Literature on Chemical Emissions and Worker Exposures Associated with Cured-In-Place Pipe (CIPP) Installation. *Proc.* ASCE Pipelines 2019, Nashville, TN.

Kaushal, V., Serajiantehrani, R., Najafi, M., and Hummel, M. (2019). Seismic Hazards Estimation for Buried Infrastructure Systems: Challenges and Solutions. Proc. 2nd International Conference on Natural Hazards & Infrastructure, 23-26 June 2019, Chania, Greece.

Kaushal, V., Najafi, M., Serajiantehrani, R., & Malek Mohammadi, M. (2020). Social Cost Comparison of CIPP with Open-cut. Proc. ASCE Pipelines 2020, San Antonio, TX.

Kendall, A., Keoleian, G. A., and Helfand G. E. (2008). Integrated Life-Cycle Assessment and Life-Cycle Cost Analysis Model for Concrete Bridge Deck Applications. *Journal of Infrastructure Systems*, 14(3), 214-222.

Khan, L. R. and Tee, K.F. (2015). Quantification and comparison of carbon emissions for flexible underground pipelines. *Canadian Journal of Civil Engineering*, 42(10), pp.728-736.

Kleiner, Y., Adams, B. J., & Rogers, J. S. (2001). Water distribution network renewal planning. *Journal of Computing in Civil Engineering*, 15(1), 15-26.

Kozman, D. P. (2013). Evaluation of Cured-in-Place Pipe Allows Structural Renewal of Drinking Water Pipe. *R S Technik LLC*, USA, 2013.

Lee, R. K. (2008). Risk Associated with CIPP Lining of Stormwater Pipes and the Release of Styrene. *Proc.* North American Society for Trenchless Technology (NASTT) NO-DIG Conference, NASTT, Dallas, TX, 2008; Paper E-1-05.

Loendorf, T., & Waters, D. (2009). Styrene Removal Adds to the Challenges of Rehabilitating Sewer Pipeline in Reno, Nevada. *Proc.* of the North American Society for Trenchless Technology (NASTT) No-Dig Conference. Liverpool, NY.

Lueke, J. S., Matthews, J. C., Stowe, R., and Lamont, C. (2015). Comparing Carbon Footprints of Trenchless Water Main Renewal Technologies. *Proc.* NASTT No-Dig Show, 2015, Denver, Co.

McAlvin, J. E. (2011). Green Composites Through the Use of Styrene-Free Resins and Unsaturated Polyesters Derived from Renewable and Recycled Raw Materials. *Proc.* Composites. February 2-4, 2011, Ft. Lauderdale, FL, USA.

Maldikar, S. (2010). An Investigation of Productivity Loss Due to Outdoor Noise Conditions. *Master's Thesis*, The University of Texas at Arlington, 2010.

Malek Mohammadi, M. (2019). Development of Condition Prediction Models for Sanitary Sewer Pipes. *Doctoral Dissertation*, University of Texas, Arlington, TX.

Malek Mohammadi, M., Najafi, M., Kaushal, V., Serajiantehrani, R., Salehabadi, and N., Ashoori, T. (2019). Sewer Pipes Condition Prediction Models: A State-of-the-Art Review. Infrastructures, MDPI. 4(4), 64.

Malek Mohammadi, M., Najafi, M., Korky, S., and Serajiantehrani, R. (2019). Development of a Framework for Design and Installation of a New Lining Material for Water Pipeline Renewal. Proc. ASCE Pipelines 2019, Nashville, TN, (pp. 125-134).

Malek Mohammadi, M., Najafi, M., Serajiantehrani, R., and Kaushal, V. (2020). Prediction Condition of Sanitary Sewer Pipes with Random Forest. Proc. ASCE Pipelines 2020, San Antonio, TX.

Mamaqani, B. (2014). Numerical Modeling of Ground Movements Associated with Trenchless Box Jacking Technique. *Ph.D. Dissertation*. The University of Texas at Arlington, TX.

Matthews, J. C. (2015). Large-Diameter Sewer Rehabilitation Using a Fiber-Reinforced Cured-in-Place Pipe. Practice Periodical on Structural Design and Construction, 20(2), 1-5.

Matthews, J. C., Allouche, E. N., & Sterling, R. L. (2015). Social Cost Impact Assessment of Pipeline Infrastructure Projects. *Environmental Impact Assessment Review*, 50, 196-202.

Matthews, J., Condit, W., Wensink, R., and Lewis, G. (2012). Performance Evaluation of Innovative Water Main Rehabilitation Cured-in-Place Pipe Lining Product in Cleveland, Ohio. Battelle Memorial Institute, EPA (Environmental Protection Agency). NJ and OH, 2012.

Milousi, M. (2018). Stochastic Life Cycle Assessment and Cost analysis in Renewable Energy Systems. *Master's Thesis*, School of Production Engineering and Management, Technical University of Crete, Chania, Greece.

Mohit, S., Monfared, M. A. N., Kang, C., and Bayat, A. 2017. Comparative study of greenhouse gas emissions from hand tunneling and pilot tube method underground construction methods. *Journal of Green Building*, 12(4), 54-69.

Monfared, M. A. N. (2018). Comparison of Trenchless Technologies and Open Cut Methods in New Residential Land Development. *Master's Thesis*, University of Alberta, Canada.

Najafi, M. and Gokhale, S.B. (2005). *Trenchless Technology: Pipeline and Utility Design, Construction, and Renewal*, New York: McGraw-Hill; 2005.

Najafi, M. (2011). *Pipeline Rehabilitation Systems for Service Life Extension* - *Chapter 10*. University of Texas at Arlington, USA, 2011.

Najafi, M. (2016). *Pipeline Infrastructure Renewal and Asset Management*, New York: McGraw-Hill Education; 2016.

National Ready-Mixed Concrete Association. (2008). Concrete CO_2 Fact Sheet, 2008.

Osman, H., & Bainbridge, K. (2010). Comparison of statistical deterioration models for water distribution networks. *Journal of Performance of Constructed Facilities*, 25(3), 259-266.

Pandey, D., Agrawal, M., and Pandey, J. S. 2011. Carbon footprint: current methods of estimation. *Environmental monitoring and assessment*, 178(1-4), 135-160.

Piehl, R. (2005). Summary of trenchless technology for use with USDA Forest Service culverts. US Department of Agriculture, *Forest Service*, San Dimas Technology and Development Center.

Ra, K., Sendesi, S. M. T., Nuruddin, M., Zyaykina, N. N., Conkling, E. N., Boor, B. E., & Whelton, A. J. (2019). Considerations for emission monitoring and liner analysis of thermally manufactured sewer cured-in-place-pipes (CIPP). Journal of hazardous materials, 371, 540-549.

Ramirez, P. R., Fee, T. K., and Perez, C. S. (2010). Design Rehabilitation Challenges for Large Diameter Pipes. *Proc.* No-Dig Show 2010, NASTT, May 2-7, Chicago, IL, Paper D–3–01.

Rosenbaum R. K., Bachmann T. M., Gold L. S., Huijbregts A. J., Jolliet O., Juraske R., Koehler A., Larsen H. F., MacLeod M., Margni M., McKone T. E., Payet J., Schuhmacher M., van de Meent D. and Hauschild M. Z. (2008). USEtox - The UNEP-SETAC Toxicity Model: Recommended Characterisation Factors for Human Toxicity and Freshwater Ecotoxicity in Life Cycle Assessment. International Journal of Life Cycle Assessment, 13(7), pp. 532-546.

RSMeans (2019) Heavy Construction Cost Data, 33th Annual Edition, Reed Construction Data

Salvador–Meneses, J., Ruiz–Chavez, Z., Garcia–Rodriguez, J. (2009). Compressed kNN: K-nearest Neighbors with Data Compression. Neurocomputing 2009.

Sendesi, S., K. Ra, E. Conkling, B. Boor, M. Nuruddin, J. Howarter, J. Youngblood, L. Kobos, J. Shannahan, C. Jafvert, and A. Whelton. (2017). Worksite chemical air emissions and worker exposure during sanitary sewer and stormwater pipe rehabilitation using cured-in-place-pipe (CIPP). *Environmental Science & Technology Letters*, 4(8), 325-333, 2017.

Serajiantehrani, R., Najafi, M., Kaushal, V. & Malek Mohammadi, M. (2020). Environmental Impact Assessment of Trenchless Spray-applied Pipe Linings (SAPLs) in Water Mains. Proc. EWRI 2020, Henderson, NV.

Serajiantehrani, R., Najafi, M., Kaushal, V. and Malek Mohammadi, M. (2020). Framework for Life-Cycle Cost Analysis of Trenchless Renewal Methods for Large Diameter Culverts. Proc. ASCE Pipelines 2020, San Antonio, TX,

Serajiantehrani, R., Janbaz, S., Najafi, M., Korky, S., and Mohammadi, M. M. (2019). Impact of Tunnel Boring Machine Advance Rate for Pipeline Construction Projects. *Proc.* Pipelines 2019, pp. 650-660, Reston, VA.

Shahata, K. (2006). Stochastic Life Cycle Cost Modelling Approach for Water Mains. Master's Thesis, Concordia University, Montreal, Canada.

Shehab, T., Farooq, M., Sandhu, S., Nguyen, T., and Nasr, E., (2010). Cost Estimating Models for Utility Rehabilitation Projects: Neural Networks versus Regression, ASCE Pipeline 2010.

Sihabuddin, S. and Ariaratnam, S.T., 2009a. Quantification of carbon footprint on underground utility projects. *Proc.* Construction Research Congress 2009: Building a Sustainable Future (pp. 618-627).

Sihabuddin, S.S. and Ariaratnam, S.T., 2009b. Methodology for estimating emissions in underground utility construction operations. *Journal of Engineering, Design and Technology*, 7(1), pp. 37-64.

Sompura, S. J. (2017). Life Cycle Cost Analysis of Precast Concrete Pavement. *Master's Thesis*, California State University, Fullerton, CA.

Stone, S. L., Dzuray, E. J., Meisegeier, D., Dahlborg, A., Erickson, M., & Tafuri, A. N. (2002). Decision-support tools for predicting the performance of water distribution and wastewater collection systems US Environmental Protection Agency, Office of Research and Development. EPA/600/R-02/029.

Tabor, M. L. (2014). The Influence of Rehabilitated Stormwater Infrastructure on Water Quality and Daphnia magna Toxicity: A Field and Laboratory Investigation. *Master's Thesis*, University of South Alabama, 2014.

Tabor, M., D. Newman, and A. Whelton. (2014). Stormwater Chemical Contamination Caused by Cured-in-Place Pipe (CIPP) Infrastructure Rehabilitation Activities. *Environmental Science & Technology*, 2014.

Tafuri, A. and Selvakumar, A. (2001). Wastewater Collection System Infrastructure Research Needs in the USA. *Urban Water*, USA, 2001.

Theis, T., & Tomkin, J. (2013). Sustainability - A Comprehensive Foundation. U of I Open Source Textbook Initiative.

Tighe, S., Lee, T., McKim, R., and Haas, R. (1999). Traffic delay cost savings associated with trenchless technology. *Journal of infrastructure systems*, 5(2), 45-51.

Tighe, S., Knight, M., Papoutsis, D., Rodriguez, V., & Walker, C. (2002). User cost savings in eliminating pavement excavations through employing trenchless technologies. *Canadian Journal of Civil Engineering*, 29(5), 751-761.

Tymkowicz, S., (1995). Pipe Rebabilitatioh with Polyetbylere Pipe Lirers Construction Report for Iowa Highway Rese, Arch Board Project Br-370, March 1995

Tol, R. S. J. (2005). The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties. *Journal of Energy Policy*, 33 2064-2074.

Tran, D. H., Ng, A. W. M., & Perera, B. J. C. (2007). Neural networks deterioration models for serviceability condition of buried stormwater pipes. Engineering Applications of Artificial Intelligence, 20(8), 1144-1151.

UNEP/SETAC (2009). Life Cycle Management: How business uses it to decrease footprint, create opportunities and make value chains more sustainable. UNEP/SETAC, 2009.

United States Department of Agriculture (USDA). (2005). Summary of Trenchless Technology for Use with USDA Forecast Service Culverts. USA

USEPA. (1999). Collection Systems O7M Fact Sheet. USA

USEPA, NR-009d (2010). Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling Compression Ignition. Document No. EPA-420-R-10-018, Office of Transportation and Air Quality, *U.S. Environmental Protection Agency*, Washington D.C.

USEPA. NR-005d. (2010). Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling. Document No. EPA-420-R-10-016, Office of Transportation and Air Quality, *U.S. Environmental Protection Agency*, Washington D.C.

USEPA. (2012). Clean Watersheds Needs Survey. 2012 Report to Congress, EPA-830-R-15005, January 2012.

US Environmental Protection Agency EPA (2016). Social Cost of Carbon. EPA, 2016.

Visentin, C., da Silva Trentin, A. W., Braun, A. B., & Thomé, A. (2019). Lifecycle Assessment of Environmental and Economic Impacts of Nano-Iron Synthesis Process for Application in Contaminated Site Remediation. *Journal of Cleaner Production.*

Whelton, A. J., M. Salehi, M. Tabor, B. Donaldson, and J. Estaba, J. (2013). Impact of Infrastructure Coating Materials on Storm-Water Quality: Review and

Experimental Study. *Journal of Environmental Engineering*, 139(5), 746-756, 2013.

Whitehead, B., B. Williams, B. Robless, and D. Bryden. (2015). Minimizing Community Impacts and Reducing Costs through Trenchless Pipe Installation. *Proc.* North American Society for Trenchless Technology (NASTT), Denver, CO.

Willett, M. (2017). Industrial Hygiene Evaluation: CIPP-Styrene Exposure. Prince William County Service Authority, Woodbridge, VA, 2017.

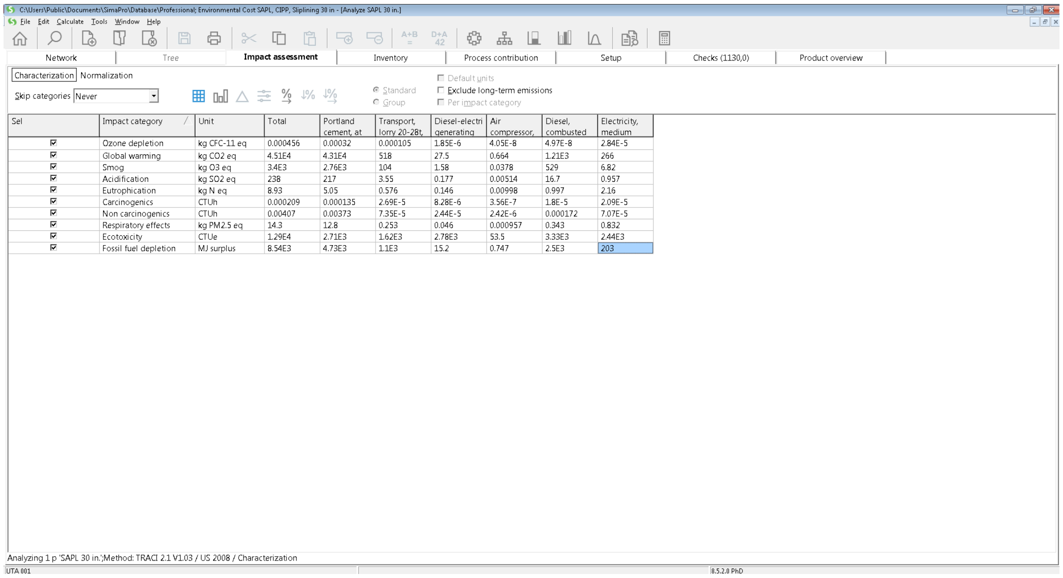
Zhao, J. Q. and Rajani, B. (2002). Construction and Rehabilitation Costs for Buried Pipe With a Focus on Trenchless Technologies. *Final Report*, Institute for Research in Construction National Research Council Canada, Ottawa, Canada.

Appendix A SIMAPRO RESULTS

A.1 SAPL Environmental Costs Results

In this Appendix, all the SimaPro analysis and results for SAPL method are presented.

A.1.1 SAPL 30 in.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 30 in - [Analyze SAPL 30 in.]

Skip categories: Never

☐ Exclude long-term emissions

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.000456	0.00032	0.000105	1.85E-6	4.05E-8	4.97E-8	2.84E-5
☑	Global warming	kg CO2 eq	4.51E4	4.31E4	518	27.5	0.664	1.21E3	266
☑	Smog	kg O3 eq	3.4E3	2.76E3	104	1.58	0.0378	529	6.82
☑	Acidification	kg SO2 eq	238	217	3.55	0.177	0.00514	16.7	0.957
☑	Eutrophication	kg N eq	8.93	5.05	0.576	0.146	0.00998	0.997	2.16
☑	Carcinogenics	CTUh	0.000209	0.000135	2.69E-5	8.28E-6	3.56E-7	1.8E-5	2.09E-5
☑	Non carcinogenics	CTUh	0.00407	0.00373	7.35E-5	2.44E-5	2.42E-6	0.000172	7.07E-5
☑	Respiratory effects	kg PM2.5 eq	14.3	12.8	0.253	0.046	0.000957	0.343	0.832
☑	Ecotoxicity	CTUe	1.29E4	2.71E3	1.62E3	2.78E3	53.5	3.33E3	2.44E3
☑	Fossil fuel depletion	MJ surplus	8.54E3	4.73E3	1.1E3	15.2	0.747	2.5E3	203

Analyzing 1 p 'SAPL 30 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-1 Screenshot of the Impact Assessment Table from SimaPro Software for 30 in. SAPL

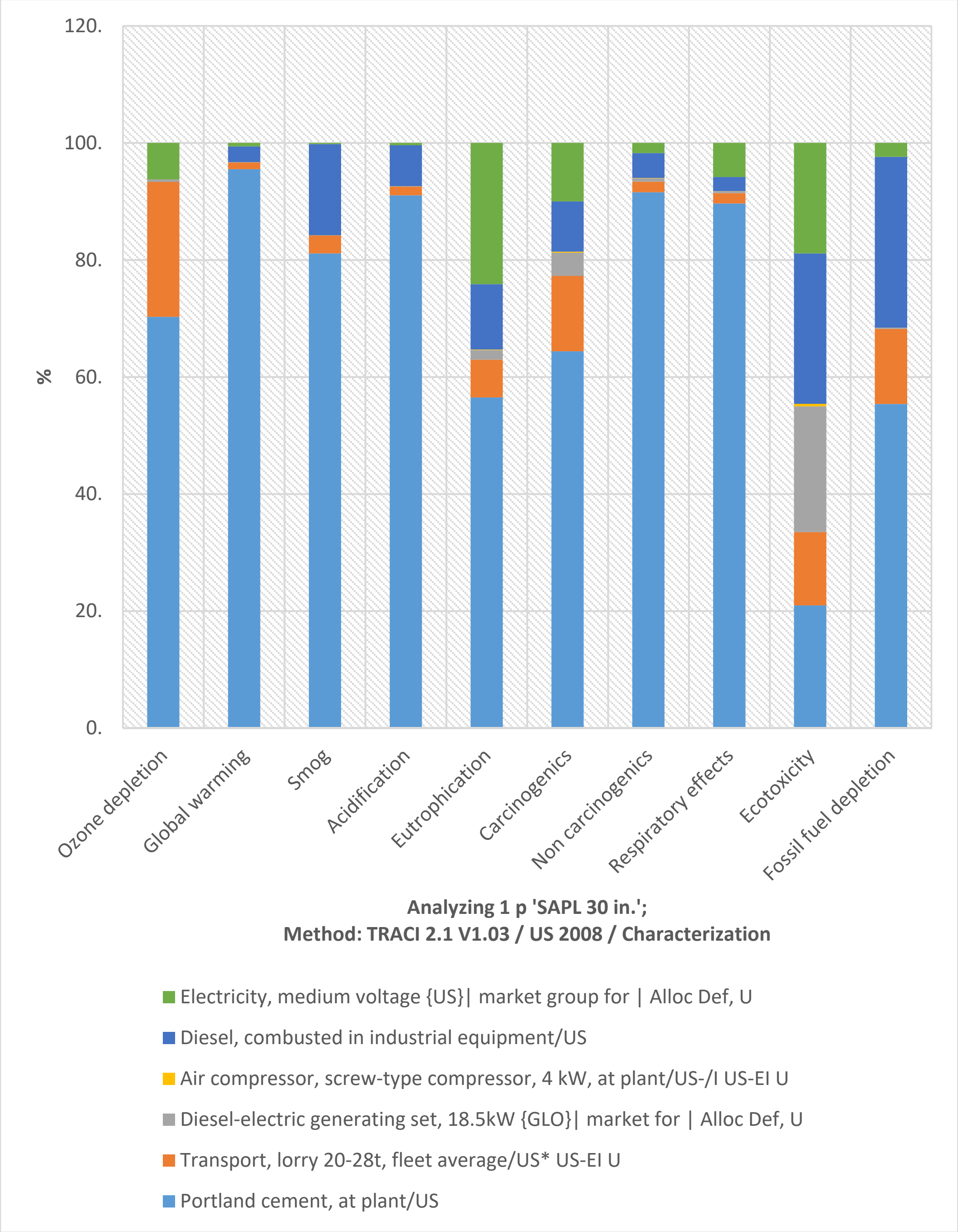


Figure B-2 Environmental Impact Assessment of 30 in. Diameter SAPL Renewal Method

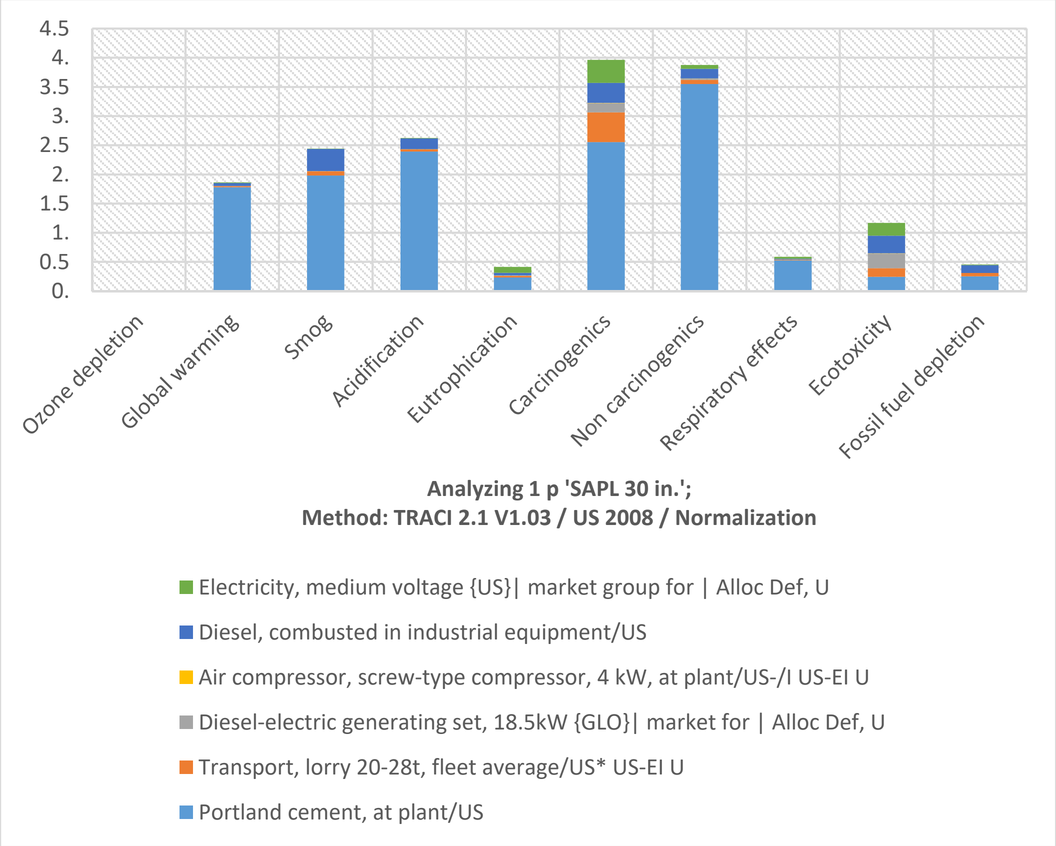


Figure B-3 Normalized Environmental Impact Assessment of 30 in. Diameter SAPL Renewal Method

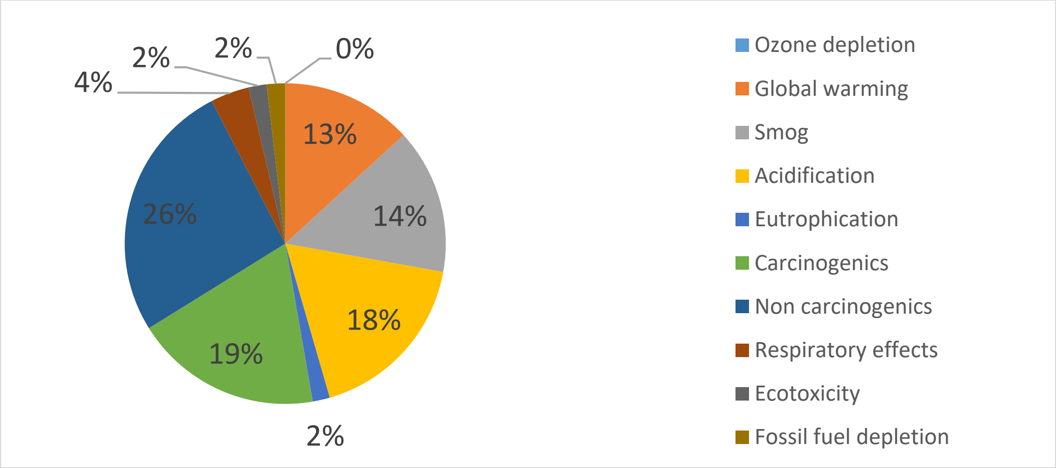


Figure B-4 Percentage of Normalized Environmental Impact Assessment of 30 in. Diameter SAPL Renewal Method

Table B-1 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.000456	0.00032	0.000105	1.85E-06	4.05E-08	4.97E-08	2.84E-05
Global warming	kg CO2 eq	45103.9	43077.08	518.4345	27.46688	0.664274	1214.308	265.9476
Smog	kg O3 eq	3397.351	2755.492	1.04E+02	1.58E+00	3.78E-02	5.29E+02	6.82E+00
Acidification	kg SO2 eq	238.4524	217.0942	3.55E+00	1.77E-01	5.14E-03	16.6709	9.57E-01
Eutrophication	kg N eq	8.93074	5.046063	0.575572	0.146058	0.00998	0.997238	2.155829
Carcinogenics	CTUh	0.000209	0.000135	2.69E-05	8.28E-06	3.56E-07	1.80E-05	2.09E-05
Non carcinogenics	CTUh	0.004071	0.003727	7.35E-05	2.44E-05	2.42E-06	0.000172	7.07E-05
Respiratory effects	kg PM2.5 eq	14.2503	12.77515	0.252966	0.046028	0.000957	0.343103	0.832093
Ecotoxicity	CTUe	12927.25	2710.66	1619.718	2777.057	53.52642	3325.583	2440.703
Fossil fuel depletion	MJ surplus	8543.921	4731.404	1096.634	15.17393	0.746784	2497.024	202.9381

Table B-2 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.002825	0.001985	0.000651	1.14E-05	2.51E-07	3.08E-07	0.000176
Global warming	-	1.861975	1.778304	0.021402	0.001134	2.74E-05	0.050129	0.010979
Smog	-	2.440779	1.979645	0.074783	0.001133	2.71E-05	0.380294	0.004898
Acidification	-	2.625263	2.390117	0.039065	0.001946	5.66E-05	0.18354	0.010538
Eutrophication	-	0.413158	0.233444	0.026627	0.006757	0.000462	0.046135	0.099734
Carcinogenics	-	3.962496	2.551472	0.510488	0.157095	0.006752	0.340648	0.396042
Non carcinogenics	-	3.875633	3.548698	0.069989	0.023204	0.0023	0.164105	0.067338
Respiratory effects	-	0.58769	0.526854	0.010432	0.001898	3.95E-05	0.01415	0.034316
Ecotoxicity	-	1.167778	0.244866	0.146317	0.250864	0.004835	0.300415	0.22048
Fossil fuel depletion	-	0.453972	0.251398	0.058268	0.000806	3.97E-05	0.132677	0.010783

Table B-3 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.000456	0.02
Global warming	kg CO2 eq	45103.9	2,841.55
Smog	kg O3 eq	3397.351	7,474.17
Acidification	kg SO2 eq	238.4524	1,304.33
Eutrophication	kg N eq	8.93074	18.31
Carcinogenic	CTUh	0.000209	0.00
Non carcinogenic	CTUh	0.004071	0.04
Respiratory effects	kg PM2.5 eq	14.2503	902.61
Ecotoxicity	CTUe	12927.25	530.02
Fossil fuel depletion	MJ surplus	8543.921	83.73
Total			13,154.77

Table B-4 Inventory Results for SAPL Renewal Method of 500-ft Length and Diameter of 30 in. Culvert[28]

Substance	Compartment	Unit	Total	Portland cement	Transport, lorry	Generating set	Air compressor	Diesel	Electricity
1-Butanol	Air	5g	1.772144	0	0.166628	0.115733	0.000918	0	1.488865
1-Butanol	Water	5g	997.4689	0	752.9757	195.1595	0.206202	0	49.12752
1-Pentanol	Air	5g	1.038226	0	0.074289	0.047128	0.000516	0	0.916294
1-Pentanol	Water	5g	2.491774	0	0.178296	0.113108	0.001238	0	2.199132
1-Pentene	Air	5g	1.189297	0	0.056139	0.164789	0.00039	0	0.967979
1-Pentene	Water	5g	1.882994	0	0.134736	0.085474	0.000935	0	1.661849
1-Propanol	Air	fg	5449.035	0	14.5086	5226.771	0.058322	0	207.6973
1-Propanol	Water	5g	8.715703	0	0.327491	0.371756	0.00226	0	8.014195
1,4-Butanediol	Air	5g	7.699215	0	2.939445	2.587967	0.003309	0	2.168495
1,4-Butanediol	Water	5g	10.93906	0	1.175786	4.983198	0.001324	0	4.778756
2-Aminopropanol	Air	5g	1.029053	0	0.096835	0.054172	0.000559	0	0.877488
2-Aminopropanol	Water	5g	2.479289	0	0.237817	0.130203	0.001348	0	2.10992
2-Butene, 2-methyl-	Air	5g	2.040638	0	1.25E-05	2.02576	8.65E-08	0	0.014866
2-Butene, 2-methyl-	Water	5g	4.897605	0	2.99E-05	4.861895	2.07E-07	0	0.03568
2-Chloroacetophenone	Air	fg	11794.54	11794.51	0.009694	0	5.55E-05	0.028388	0
2-Hexanone	Water	fg	21365.63	12589.62	0.568682	0	0.00326	8775.443	0
2-Methyl-1-propanol	Air	5g	2.48648	0	0.246983	0.112424	0.001649	0	2.125425
2-Methyl-1-propanol	Water	5g	5.967451	0	0.592748	0.269812	0.003958	0	5.100933
2-Methyl-4-chlorophenoxyacetic acid	Air	5g	0.221066	0	0	0.005599	0	0	0.215466
2-Methyl-4-chlorophenoxyacetic acid	Water	5g	0.51279	0	0	0.012997	0	0	0.499793
2-Methyl-4-chlorophenoxyacetic acid	Soil	5g	47.47992	0	0	1.444438	0	0	46.03548

---

[28] Please contact the author for complete sets of inventory for all SAPL, CIPP, and sliplining methods with various diameters at Ramtin.serajiantehrani@mavs.uta.edu

2-Nitrobenzoic acid	Air	5g	1.633207	0	0.197281	0.069785	0.001286	0	1.364855
2-Propanol	Air	fg	91366	0	44440.91	45375.74	11.06842	0	1538.289
2-Propanol	Water	5g	15.19428	0	0.97958	1.256365	0.006944	0	12.95139
2,4-D	Air	5g	43.47019	0	0	1.975851	0	0	41.49433
2,4-D	Soil	fg	5730.713	0	248.1574	267.7269	0.079846	0	5214.748
2,4-D amines	Water	5g	0.695923	0	0	0.017584	0	0	0.67834
2,4-D amines	Soil	5g	22.23917	0	0	0.561905	0	0	21.67727
2,4-D ester	Air	5g	1.301713	0	0	0.032889	0	0	1.268824
2,4-D ester	Water	5g	0.153103	0	0	0.003869	0	0	0.149234
2,4-D ester	Soil	5g	5.979851	0	0	0.151097	0	0	5.828754
2,4-D, dimethylamine salt	Air	5g	0.111499	0	0	0.002817	0	0	0.108682
2,4-DB	Water	5g	0.267709	0	0	0.007886	0	0	0.259823
4-Methyl-2-pentanol	Water	5g	2.11E-06	0	0	1.80E-06	0	0	3.13E-07
4-Methyl-2-pentanone	Air	5g	0.015146	0	0	0.0129	0	0	0.002246
4-Methyl-2-pentanone	Water	fg	14055.08	8102.956	132.7666	3.336959	0.761482	5648.029	167.2292
5-methyl Chrysene	Air	5g	51.06212	50.87695	3.05E-05	0	1.74E-07	0.185137	0
Acenaphthene	Air	fg	1197.274	1179.412	3.224706	0.526252	0.012508	4.291697	9.806603
Acenaphthene	Water	5g	50.73563	0	49.90957	0.266754	0.012761	0	0.546542
Acenaphthylene	Air	5g	580.3625	578.1477	0.000346	0.034574	1.98E-06	2.103833	0.076066
Acenaphthylene	Water	5g	3.173016	0	3.121354	0.016683	0.000798	0	0.034181
Acephate	Air	5g	4.620613	0	0	0.210021	0	0	4.410593
Acephate	Soil	fg	1109.941	0	0	46.07502	0	0	1063.866
Acetaldehyde	Air	m3/g	14.96398	1.057546	9.006489	0.005915	8.37E-05	4.878578	0.015364
Acetaldehyde	Water	fg	2955.325	0	1453.452	1011.632	44.47679	0	445.7644
Acetamide	Air	5g	1.137437	0	0	0.0517	0	0	1.085737
Acetamide	Soil	5g	126.4474	0	0.229797	5.379722	0.001073	0	120.8368
Acetic acid	Air	fg	397784.1	0	207160.6	19752.8	889.2119	0	169981.5
Acetic acid	Water	fg	20124.24	0	13455.22	5043.187	649.8999	0	975.9297
Acetochlor	Soil	5g	358.2256	0	13.51367	19.56018	0.063103	0	325.0886
Acetone	Air	fg	182415.6	0	61148.63	106547.9	61.6027	0	14657.48
Acetone	Water	fg	33539.97	19281.1	316.9992	79.83408	1.818157	13439.37	420.8618
Acetonitrile	Air	5g	688.8748	0	215.2741	35.41714	0.143943	0	438.0396

Acetonitrile	Water	5g	1.300519	0	0.065907	0.060676	0.000423	0	1.173512
Acetophenone	Air	fg	25274.02	25273.94	0.020773	0	0.000119	0.060831	0
Acetyl chloride	Water	5g	1.957448	0	0.140064	0.088854	0.000972	0	1.727558
Acidity, unspecified	Water	fg	23750.86	0	13063.41	1533.566	103.6113	0	9050.282
Acids, unspecified	Water	fg	1036.484	1022.759	0	0	0	13.72532	0
Acifluorfen	Air	5g	0.634292	0	0	0.02883	0	0	0.605461
Acifluorfen	Soil	5g	0.027189	0	0	0.001236	0	0	0.025953
Aclonifen	Soil	5g	468.5631	0	466.4866	1.704117	0.073424	0	0.298966
Acrolein	Air	m3/g	1.045548	0.445452	0.001961	0.001094	8.00E-06	0.590801	0.006233
Acrylate	Water	5g	281.3058	0	272.2334	8.824455	0.068255	0	0.179685
Acrylic acid	Air	5g	118.8573	0	115.0241	3.728509	0.028839	0	0.075921
Actinides, radioactive, unspecified	Air	eBq	50027502	0	12100718	2014812	46330.63	0	35865643
Actinides, radioactive, unspecified	Water	eBq	1451926	0	45751.98	27089.44	1969.12	0	1377116
Aerosols, radioactive, unspecified	Air	eBq	630230.7	0	609866.2	5083.75	2659.071	0	12621.73
Alachlor	Air	5g	4.48875	0	0	0.204027	0	0	4.284722
Alachlor	Soil	5g	40.81853	0	0.941037	11.97988	0.004394	0	27.89321
Aldehydes, unspecified	Air	m3/g	20.55143	5.870473	0.009569	0.001586	4.25E-05	14.64783	0.021928
Aldicarb	Soil	fg	2981.969	0	26.40663	123.8028	0.240134	0	2831.519
Aldrin	Soil	5g	910.5361	0	2.960744	549.7174	0.006819	0	357.8512
Allyl chloride	Water	5g	2.492759	0	0	1.652994	0	0	0.839764
Alpha-cypermethrin	Soil	5g	5.687573	0	0	0.227869	0	0	5.459704
Aluminium	Raw	kgCOD	1.499489	0	0.259032	1.189277	0.016677	0	0.034502
Aluminium	Air	m3/g	22.11911	0	7.768741	2.238002	0.206861	0	11.9055
Aluminium	Water	kgCOD	1.066215	0.109576	0.080003	0.563293	0.003138	0.116221	0.193985
Aluminium	Soil	m3/g	3.724223	0	3.255023	0.04261	0.00141	0	0.425181
Ametryn	Soil	5g	116.8576	0	0	4.681828	0	0	112.1758
Amidosulfuron	Soil	5g	0.029344	0	0	0.002444	0	0	0.0269
Amitraz	Soil	5g	154.2604	0	0	6.180351	0	0	148.0801
Ammonia	Air	oz	6.280396	5.489277	0.272021	0.041899	0.003013	0.259692	0.214495
Ammonia	Water	oz	1.86804	0.97928	5.85E-05	0	3.36E-07	0.888701	0

Ammonia, as N	Water	5g	520.5326	513.6396	0	0	0	6.892996	0
Ammonium carbonate	Air	5g	99.13232	0	39.48295	9.683137	0.74938	0	49.21685
Ammonium chloride	Air	m3/g	1.833544	1.809292	0	0	0	0.024253	0
Ammonium, ion	Water	oz	1.145373	1.066153	0.049894	0.003312	0.000144	0.000183	0.025687
Anhydrite	Raw	fg	6325.959	0	5613.92	388.0359	93.98161	0	230.0212
Aniline	Air	5g	21.83085	0	2.915065	0.855735	0.023829	0	18.03623
Aniline	Water	5g	52.45691	0	7.030374	2.055075	0.057238	0	43.31422
Anthracene	Air	5g	487.4119	485.6444	0.000291	0	1.66E-06	1.767224	0
Anthranilic acid	Air	5g	1.265309	0	0.149496	0.054237	0.000996	0	1.06058
Anthraquinone	Soil	5g	7.296336	0	0	0.240258	0	0	7.056078
Antimony	Air	fg	67562.16	41626.62	2997.198	12678.71	511.3413	151.4758	9596.814
Antimony	Water	fg	473720.6	42277.45	109087.4	120366.5	8975.69	72488.99	120524.5
Antimony	Soil	5g	2.605214	0	0.259202	1.407264	0.051918	0	0.88683
Antimony-122	Water	eBq	51030.99	0	22.81411	613.2799	0.073936	0	50394.82
Antimony-124	Air	5Bq	93.85963	0	0.056588	0.905644	0.000183	0	92.89722
Antimony-124	Water	eBq	49679026	0	9367.52	2096715	407.4636	0	47572536
Antimony-125	Air	eBq	1320.935	0	0.590542	15.87472	0.001914	0	1304.468
Antimony-125	Water	eBq	2414481	0	11437.55	31843.97	563.7432	0	2370635
AOX, Adsorbable Organic Halogen as Cl	Water	fg	23492.16	0	8441.138	11887.75	39.14642	0	3124.126
Argon	Raw	m3/g	6.692795	0	0	4.875427	0	0	1.817368
Argon-40	Air	m3/g	2.097754	0	0	1.772702	0	0	0.325052
Argon-41	Air	eBq	37460615	0	177018.4	2993284	401.2443	0	34289911
Arsenic	Air	fg	876958.4	800069.2	25336.9	18202.13	3923.095	4925.481	24501.52
Arsenic	Water	m3/g	2.493441	0.463611	0.404148	0.281514	0.027345	0.368462	0.948359
Arsenic	Soil	fg	1566.426	0	1315.787	57.55538	0.580077	0	192.5035
Arsine	Air	5g	0.001385	0	0.001341	4.33E-05	3.36E-07	0	8.84E-07
Asulam	Soil	5g	2.989927	0	0	0.256948	0	0	2.732979
Atrazine	Air	5g	4.387769	0	0	0.186265	0	0	4.201504
Atrazine	Water	5g	4.723687	0	0	0.140394	0	0	4.583293
Atrazine	Soil	fg	1044.661	0	22.87605	241.1983	0.104983	0	780.4812
Azinphos-methyl	Soil	5g	8.969423	0	2.524153	0.257306	0.022954	0	6.165011
Azoxystrobin	Air	5g	2.099056	0	0	0.095408	0	0	2.003647

Azoxystrobin	Soil	5g	53.78287	0	12.48214	1.679384	0.113509	0	39.50784
Barite	Raw	EU	1.24645	0	1.153342	0.011201	0.000361	0	0.081545
Barite	Water	m3/g	20.28004	0	19.97415	0.137845	0.006453	0	0.161599
Barium	Air	fg	44304.56	0	4258.791	13875.12	77.88129	0	26092.77
Barium	Water	kgCOD	2.60906	0.982704	0.01707	0.000561	6.78E-05	1.590676	0.017982
Barium	Soil	m3/g	1.794738	0	1.618808	0.014242	0.000679	0	0.161008
Barium-140	Air	eBq	57751.76	0	38.41388	502.5875	0.124492	0	57210.64
Barium-140	Water	eBq	150232.2	0	99.93784	1307.249	0.323879	0	148824.7
Basalt	Raw	oz	1.768	0	1.211146	0.274217	0.00183	0	0.280807
Benfluralin	Soil	5g	791.4725	0	0	31.70987	0	0	759.7627
Benomyl	Soil	5g	0.635504	0	0.460361	0.09808	0.000308	0	0.076754
Bentazone	Air	5g	1.950139	0	0	0.088582	0	0	1.861556
Bentazone	Water	5g	0.06934	0	0	0.002749	0	0	0.066591
Bentazone	Soil	5g	242.0649	0	238.0732	1.136857	0.037472	0	2.817384
Benzal chloride	Air	5g	0.094405	0	0.022284	0.000664	0.000128	0	0.071329
Benzaldehyde	Air	fg	1366.059	0	25.31394	665.1045	0.142986	0	675.4974
Benzene	Air	oz	6.100867	5.699742	0.08597	0.011982	0.000218	0.209764	0.093193
Benzene	Water	m3/g	6.280705	3.234586	0.683438	0.026233	0.001213	2.254565	0.08067
Benzene, 1-methyl-2-nitro-	Air	5g	1.41031	0	0.170363	0.060261	0.00111	0	1.178576
Benzene, 1-methyl-4-(1-methylethyl)-	Water	5g	326.9846	192.6766	0.008703	0	4.99E-05	134.2992	0
Benzene, 1,2-dichloro-	Air	5g	9.456718	0	0.604919	0.420051	0.003984	0	8.427764
Benzene, 1,2-dichloro-	Water	fg	14405.53	0	328.2251	11881.27	0.115701	0	2195.917
Benzene, chloro-	Air	fg	37068.57	37068.45	0.030467	0	0.000174	0.089219	0
Benzene, chloro-	Water	fg	27574.05	0	6760.742	17458.35	2.27885	0	3352.678
Benzene, ethyl-	Air	fg	364553.2	158383.4	199748.9	1402.031	188.5412	0.381209	4829.936
Benzene, ethyl-	Water	fg	511397.5	181953.1	195580.3	1104.416	66.36311	126824.7	5868.606
Benzene, hexachloro-	Air	5g	141.2838	0	122.2952	14.97645	1.069087	0	2.943022
Benzene, pentachloro-	Air	5g	2.404314	0	1.690808	0.598132	0.038526	0	0.076848
Benzene, pentachloronitro-	Soil	5g	92.45507	0	26.01847	2.652262	0.236604	0	63.54773

Benzene, pentamethyl-	Water	5g	245.2397	144.507	0.006527	0	3.74E-05	100.7262	0
Benzenes, alkylated, unspecified	Water	fg	100643.1	37046.66	4.280976	0	0.024543	63592.08	0
Benzo(a)anthracene	Air	5g	185.6821	185.0066	0.000111	0.000668	6.34E-07	0.673218	0.001469
Benzo(a)pyrene	Air	fg	4850.173	87.87853	1170.198	2578.137	40.99422	0.319784	972.6459
Benzo(b)fluoranthene	Air	5g	0.002527	0	0	0.00079	0	0	0.001738
Benzo(b,j,k)fluoranthene	Air	5g	255.3106	254.3848	0.000152	0	8.72E-07	0.925683	0
Benzo(g,h,i)perylene	Air	5g	62.66751	62.4401	3.74E-05	4.86E-05	2.14E-07	0.227216	0.000107
Benzo(k)fluoranthene	Air	5g	0.001828	0	0	0.000571	0	0	0.001257
Benzoic acid	Water	m3/g	3.319394	1.955972	8.83E-05	0	5.07E-07	1.363333	0
Benzyl chloride	Air	m3/g	1.179454	1.179451	9.69E-07	0	5.55E-09	2.84E-06	0
Beryllium	Air	fg	42739.64	41672.62	232.5964	71.41093	2.561125	240.6454	519.8129
Beryllium	Water	fg	504318.6	21845.87	60994.19	59924.7	3584.782	20510.33	337458.7
Bifenox	Soil	5g	2.301448	0	0	0.075068	0	0	2.226381
Bifenthrin	Soil	5g	1.305274	0	0.04924	0.071272	0.00023	0	1.184532
Biphenyl	Air	fg	3945.719	3931.411	0.002354	0	1.35E-05	14.30615	0
Biphenyl	Water	fg	6516.243	2398.654	0.277174	0	0.001589	4117.31	0
Bitertanol	Soil	5g	0.6899	0	0	0.02288	0	0	0.66702
BOD5, Biological Oxygen Demand	Water	kgCOD	1.943642	0.340006	1.304076	0.021887	0.001158	0.24586	0.030655
Borate	Water	fg	1785.229	0	24.62326	119.4728	0.16624	0	1640.967
Borax	Raw	fg	82362.13	0	2108.067	21749.27	6.480797	0	58498.32
Boric acid	Air	5g	0.006959	0	0	0.006313	0	0	0.000646
Boron	Air	m3/g	1.921682	0	0.018541	0.093566	0.000738	0	1.808837
Boron	Water	m3/g	25.11125	6.05164	5.120644	5.559617	0.713939	4.21816	3.447249
Boron	Soil	fg	49124.86	0	37143.87	886.1354	68.24703	0	11026.6
Boron trifluoride	Air	5g	46.63035	0	1.83E-05	42.30141	4.60E-09	0	4.328919
Bromacil	Soil	fg	1182.94	0	0	47.39378	0	0	1135.546
Bromate	Water	fg	66378.94	0	37524.22	25461.13	884.6342	0	2508.951
Bromide	Water	EU	1.542561	0.909016	4.57E-05	2.14E-06	2.68E-07	0.633454	4.26E-05
Bromine	Raw	fg	24618.1	0	2164.489	1080.785	14.94708	0	21357.88
Bromine	Air	fg	112785.2	0	1840.325	38317.84	100.1678	0	72526.84

Bromine	Water	m3/g	21.47833	0	12.55269	0.235788	0.04995	0	8.639905
Bromine	Soil	5g	19.74769	0	0	10.99597	0	0	8.751714
Bromoform	Air	fg	65712.46	65712.25	0.054009	0	0.000309	0.158161	0
Bromoxynil	Air	5g	0.12283	0	0	0.003117	0	0	0.119713
Bromoxynil	Water	5g	0.776247	0	0	0.019617	0	0	0.75663
Bromoxynil	Soil	5g	35.54727	0	0.14772	1.061662	0.00069	0	34.3372
Bromuconazole	Soil	5g	0.047478	0	0	0.001485	0	0	0.045993
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	Air	oz	4.199055	4.026856	0	0	0	0.172199	0
Butadiene	Air	fg	253682.2	4951.91	17.95805	0.389365	0.10048	248709	2.861542
Butane	Air	m3/g	10.23441	0	8.952699	0.094661	0.003622	0	1.18343
Butene	Air	fg	203214.8	0	198847.1	1963.973	92.55785	0	2311.157
Butene	Water	fg	2356.191	0	191.5669	2025.166	117.1756	0	22.28169
Butyl acetate	Water	fg	1291.373	0	978.3537	253.4525	0.26521	0	59.30115
Butyric acid, 4-(2,4-dichlorophenoxy)-	Air	5g	0.64154	0	0	0.018859	0	0	0.622682
Butyric acid, 4-(2,4-dichlorophenoxy)-	Soil	5g	10.01234	0	0	0.294835	0	0	9.717502
Butyrolactone	Air	5g	2.774443	0	0.696058	1.797752	0.000207	0	0.280426
Butyrolactone	Water	5g	6.658784	0	1.670571	4.314684	0.000496	0	0.673034
Cadmium	Raw	m3/g	1.970666	0	0.895401	0.848769	0.001227	0	0.225269
Cadmium	Air	fg	219275.5	193531	12588.89	5504.588	1304.219	1213.991	5132.826
Cadmium	Water	fg	594663.3	71971.49	138534.5	139818.3	16587.41	54414.18	173337.5
Cadmium	Soil	5g	955.8746	0	836.5079	14.56768	0.063204	0	104.7358
Calcite	Raw	kgCOD	17.64571	0	13.9233	0.915217	0.041681	0	2.765516
Calcium	Air	fg	765597.1	0	175558.6	58947.47	1252.056	0	529839
Calcium	Water	kgCOD	16.85459	6.19677	0.997808	0.385583	0.031729	4.317337	4.925367
Calcium	Soil	m3/g	16.03013	0	13.0467	0.286978	0.005758	0	2.690692
Captan	Soil	fg	3371.168	0	0	135.0638	0	0	3236.104
Carbaryl	Air	5g	0.569109	0	0	0.025251	0	0	0.543858
Carbaryl	Water	5g	0.000554	0	0	1.65E-05	0	0	0.000538

Carbaryl	Soil	5g	1.608882	0	0.407805	0.046787	0.003543	0	1.150746
Carbendazim	Soil	5g	3.960069	0	0	0.540941	0	0	3.419128
Carbetamide	Soil	5g	126.7123	0	48.2592	34.2598	0.007598	0	44.18568
Carbofuran	Soil	5g	363.8863	0	256.7646	54.21632	0.20814	0	52.69723
Carbon	Air	5g	17.70537	0	0	9.974806	0	0	7.730562
Carbon	Water	5g	60.58652	0	0	34.13311	0	0	26.45341
Carbon	Soil	m3/g	11.05478	0	9.892334	0.110556	0.004541	0	1.047352
Carbon-14	Air	eBq	3.19E+09	0	32915701	56432001	1189214	0	3.10E+09
Carbon-14	Water	eBq	5280586	0	0	230428.9	0	0	5050157
Carbon dioxide	Air	tn.lg	11.58566	11.58565	9.45E-06	3.80E-07	5.41E-08	0	4.28E-07
Carbon dioxide, biogenic	Air	kgCOD	67.8803	63.53474	0.514328	0.475426	0.003294	0.85263	2.499876
Carbon dioxide, fossil	Air	tn.lg	31.73462	29.82772	0.485972	0.023559	0.000563	1.147486	0.249321
Carbon dioxide, in air	Raw	kgCOD	68.79065	63.53474	0.738065	0.606068	0.00463	0.85263	3.054517
Carbon dioxide, land transformation	Air	oz	8.614006	0	0.146776	2.971084	0.000213	0	5.495935
Carbon disulfide	Air	m3/g	1.344376	0.219041	0.47224	0.400507	0.088198	5.27E-07	0.164389
Carbon disulfide	Water	5g	34.64156	0	1.898011	2.605479	0.019293	0	30.11877
Carbon monoxide	Air	kgCOD	34.6282	34.62795	2.84E-05	0	1.63E-07	0.000219	0
Carbon monoxide, biogenic	Air	m3/g	5.536759	0	0.359062	2.024232	0.008641	0	3.144824
Carbon monoxide, fossil	Air	kgCOD	25.47505	13.80521	1.278633	0.146973	0.003748	10.14677	0.09372
Carbon monoxide, land transformation	Air	fg	273552.8	0	0	20463.24	0	0	253089.6
Carbon, organic, in soil or biomass stock	Raw	m3/g	12.89217	0	0.318798	1.128519	0.000213	0	11.44464
Carbonate	Water	fg	281193	0	119142.9	80955.53	1299.348	0	79795.27
Carbonyl sulfide	Air	fg	12342.35	0	0	1156.854	0	0	11185.49
Carboxylic acids, unspecified	Water	oz	1.188394	0	1.168635	0.006399	0.000307	0	0.013053

Carfentrazone-ethyl	Air	5g	0.058226	0	0	0.002647	0	0	0.05558
Carfentrazone-ethyl	Soil	5g	0.079345	0	0	0.002638	0	0	0.076707
Carnallite	Raw	fg	49207.75	0	0	35387.38	0	0	13820.38
Cerium	Raw	fg	3118.395	0	0	2988.297	0	0	130.0977
Cerium-141	Air	eBq	13998.91	0	9.312401	121.8118	0.03018	0	13867.76
Cerium-141	Water	eBq	63323.55	0	39.9568	583.9591	0.129492	0	62699.5
Cerium-144	Water	eBq	27209	0	12.16416	326.9922	0.039422	0	26869.81
Cesium	Water	fg	8156.854	0	8024.047	42.88646	2.05165	0	87.86851
Cesium-134	Air	5Bq	670.4578	0	0.446004	5.834002	0.001445	0	664.1764
Cesium-134	Water	eBq	689217.6	0	10665.37	18928.23	566.3545	0	659057.7
Cesium-136	Water	eBq	15862.51	0	7.091552	190.6324	0.022982	0	15664.76
Cesium-137	Air	eBq	12019.81	0	7.906198	105.9535	0.025622	0	11905.93
Cesium-137	Water	eBq	1.86E+08	0	5277839	3309380	226958.2	0	1.78E+08
Chloramine	Air	5g	9.439493	0	0.480449	0.422352	0.003187	0	8.533504
Chloramine	Water	5g	84.32367	0	4.338752	3.770639	0.02851	0	76.18577
Chlorate	Water	fg	518691.5	0	294021.4	196249	6812.338	0	21608.75
Chlorfenvinphos	Soil	5g	49.35081	0	0	1.97721	0	0	47.3736
Chloridazon	Soil	5g	4.23715	0	0	0.132517	0	0	4.104633
Chloride	Air	5g	49.34408	48.69066	0	0	0	0.653424	0
Chloride	Water	kgCOD	149.3495	92.53438	5.577099	0.224777	0.010489	48.5377	2.465071
Chloride	Soil	EU	1.763917	0	1.754427	0.006903	5.07E-05	0	0.002535
Chlorides, unspecified	Water	fg	849362.9	0	0	81266.67	0	0	768096.3
Chlorimuron-ethyl	Air	5g	1.059395	0	0	0.048153	0	0	1.011242
Chlorimuron-ethyl	Soil	5g	23.33453	0	16.44983	0.273021	0.002588	0	6.609094
Chlorinated solvents, unspecified	Air	5g	187.0683	0	0	6.688204	0	0	180.3801
Chlorinated solvents, unspecified	Water	fg	9912.595	0	222.2504	6606.574	5.859041	0	3077.911
Chlorine	Air	fg	301712.7	0	170948.8	89641.97	4014.811	0	37107.05
Chlorine	Water	fg	5054.448	0	3973.187	421.2868	37.07258	0	622.9016
Chlorine	Soil	5g	513.9307	0	0	286.1686	0	0	227.7621
Chlormequat	Soil	5g	40.58315	0	0	2.298245	0	0	38.28491
Chloroacetic acid	Air	5g	61.48472	0	28.85314	1.843882	0.015947	0	30.77176

Chloroacetic acid	Water	5g	691.3499	0	110.2061	45.84663	0.227379	0	535.0698
Chloroacetyl chloride	Water	5g	3.306554	0	0.317167	0.173649	0.001798	0	2.813939
Chloroform	Air	fg	102586	99410.83	696.6985	565.8476	2.886136	0.239269	1909.451
Chloroform	Water	5g	18.34612	0	15.46289	0.84797	0.005425	0	2.029829
Chlorosilane, trimethyl-	Air	5g	27.56689	0	19.02873	2.822522	0.026154	0	5.689485
Chlorosulfonic acid	Air	5g	1.912336	0	0.096109	0.101854	0.000618	0	1.713756
Chlorosulfonic acid	Water	5g	4.729224	0	0.239663	0.220642	0.00154	0	4.267379
Chlorothalonil	Soil	fg	2588.726	0	375.7574	167.5229	3.416155	0	2042.029
Chlorpyrifos	Air	5g	21.13408	0	0	0.960608	0	0	20.17347
Chlorpyrifos	Soil	fg	2461.282	0	53.98844	101.3579	0.013432	0	2305.922
Chlorsulfuron	Soil	5g	0.065452	0	0	0.002047	0	0	0.063405
Chlortoluron	Soil	5g	11.38747	0	0	1.147595	0	0	10.23988
Choline chloride	Soil	5g	9.02328	0	0	0.282204	0	0	8.741076
Chromium	Raw	oz	2.609863	0	0.941652	1.110758	0.181508	0	0.375945
Chromium	Air	fg	799338	513963	108206.1	111289.8	17801.78	3529.629	44547.69
Chromium	Water	m3/g	4.2451	1.10068	0.050568	0.003402	0.000193	3.065059	0.025198
Chromium	Soil	fg	22983.05	0	20104.85	283.3951	7.305389	0	2587.505
Chromium-51	Air	5Bq	897.0477	0	0.596737	7.805679	0.001934	0	888.6434
Chromium-51	Water	eBq	11146281	0	14627.41	99428.46	447.7215	0	11031778
Chromium III	Water	m3/g	1.045269	0.814796	0	0	0	0.230473	0
Chromium IV	Air	5g	3.09E-05	0	0	1.74E-05	0	0	1.35E-05
Chromium VI	Air	fg	192772.6	182693.8	2773.759	2898.024	444.4348	664.7999	3297.746
Chromium VI	Water	m3/g	4.997827	0.004631	2.420136	0.73097	0.028034	0.012897	1.801158
Chromium VI	Soil	fg	74402.33	0	26793.5	3384.804	308.7465	0	43915.28
Chrysene	Air	5g	232.1015	231.2596	0.000138	7.29E-05	7.92E-07	0.84154	0.00016
Chrysotile	Raw	fg	17297.21	0	7394.605	8843.065	164.4971	0	895.0453
Cinidon-ethyl	Soil	5g	0.035569	0	0	0.002963	0	0	0.032607
Cinnabar	Raw	5g	804.2754	0	654.1283	119.2033	15.68698	0	15.2569
Clay	Raw	kgCOD	4.134076	0	4.127005	0	0.007071	0	0
Clay, bentonite	Raw	oz	8.773714	0	7.578858	0.582876	0.034502	0	0.577478
Clay, unspecified	Raw	tn.lg	1.849756	1.849367	0	0.00019	0	0	0.000198
Clethodim	Air	5g	3.134231	0	0	0.14246	0	0	2.991771
Clethodim	Soil	5g	33.53215	0	23.54283	0.396562	0.003983	0	9.588778

Clodinafop-propargyl	Soil	5g	0.968582	0	0	0.030292	0	0	0.93829
Clomazone	Soil	5g	1.861962	0	0	0.112723	0	0	1.749239
Clopyralid	Soil	5g	0.870551	0	0.042114	0.027454	2.60E-05	0	0.800956
Cloquintocet-mexyl	Soil	5g	0.233967	0	0	0.007317	0	0	0.22665
Cloransulam-methyl	Air	5g	0.551765	0	0	0.025079	0	0	0.526685
Cloransulam-methyl	Soil	5g	10.0215	0	7.061794	0.117395	0.001111	0	2.841201
Coal, 26.4 MJ per kg	Raw	tn.lg	5.27704	5.25813	3.16E-06	0	1.81E-08	0.018907	0
Coal, brown	Raw	kgCOD	105.0992	0	0.244961	2.167388	0.013686	0	102.6731
Coal, hard	Raw	kgCOD	85.18122	0	27.88833	7.886652	0.162963	0	49.24328
Cobalt	Raw	fg	5527.833	0	3380.711	1178.506	1.227391	0	967.3891
Cobalt	Air	fg	289824.4	266215	8034.958	2993.704	231.6109	7124.798	5224.271
Cobalt	Water	m3/g	6.734206	0.042718	0.943035	0.627481	0.064989	0.029775	5.026209
Cobalt	Soil	5g	123.9458	0	9.427047	18.84434	0.033159	0	95.64126
Cobalt-57	Water	eBq	503535.9	0	225.1126	6051.391	0.729547	0	497258.6
Cobalt-58	Air	eBq	1552.786	0	0.83098	16.58175	0.002693	0	1535.37
Cobalt-58	Water	eBq	66917752	0	94203.82	817329	3470.392	0	66002749
Cobalt-60	Air	eBq	12436.73	0	7.340938	122.3898	0.023791	0	12306.97
Cobalt-60	Water	eBq	49152523	0	74749.53	536309	2629.295	0	48538835
Cobalt, Co 5.0E-2%, in mixed ore, in ground	Raw	5g	277.9629	0	0	169.8562	0	0	108.1067
COD, Chemical Oxygen Demand	Water	kgCOD	2.527192	0.583534	1.386901	0.045476	0.00248	0.466789	0.042012
Colemanite	Raw	m3/g	1.735211	0	0.58751	0.853085	0.140143	0	0.154473
Copper	Air	fg	617838.5	4194.681	489439.8	61247.56	14391.32	62.68828	48502.48
Copper	Water	oz	1.941207	0.024688	0.055752	1.405847	0.004982	0.013501	0.436437
Copper	Soil	fg	102276	0	70426.83	2386.168	195.6066	0	29267.37
Copper, 0.52% in sulfide, Cu 0.27% and Mo 8.2E-3% in crude ore	Raw	m3/g	9.75781	0	0	6.746098	0	0	3.011712
Copper, 0.59% in sulfide, Cu 0.22% and Mo 8.2E-3% in crude ore	Raw	m3/g	7.078051	0	0	5.158279	0	0	1.919772

Copper, 0.97% in sulfide, Cu 0.36% and Mo 4.1E-2% in crude ore	Raw	m3/g	2.939935	0	0	2.502653	0	0	0.437282
Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore	Raw	m3/g	17.35763	0	4.344623	7.865682	0.993508	0	4.153821
Copper, 1.13% in sulfide, Cu 0.76% and Ni 0.76% in crude ore	Raw	fg	477987.1	0	0	305026.2	0	0	172960.9
Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore	Raw	oz	1.362211	0	0.836525	0.238851	0.19408	0	0.092754
Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore	Raw	m3/g	8.772676	0	6.290765	0.666237	1.459502	0	0.356172
Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore	Raw	oz	1.497137	0	1.120115	0.08003	0.255222	0	0.041771
Copper, Cu 0.2%, in mixed ore	Raw	fg	7648.814	0	0	6824.344	0	0	824.4693
Copper, Cu 0.38%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Pb 0.014%, in ore	Raw	m3/g	11.8157	0	0	8.128414	0	0	3.687288
Copper, Cu 3.2E+0%, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0% in ore	Raw	fg	442748.8	0	0	302380.2	0	0	140368.5
Copper, Cu 5.2E-2%, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2% in ore	Raw	fg	7560.78	0	0	6164.507	0	0	1396.273
Copper, Cu 6.8E-1%, in mixed ore, in ground	Raw	fg	3779.894	0	0	2309.799	0	0	1470.095

Cu-HDO	Water	5g	0.009657	0	0	0.000542	0	0	0.009115
Cumene	Air	fg	56201.23	8930.126	43125.53	1495.762	323.5254	0.021494	2326.267
Cumene	Water	fg	113275.4	0	103553.5	3581.578	777.1336	0	5363.188
Cyanide	Air	m3/g	4.296463	4.212324	0.019501	0.007735	0.000338	1.01E-05	0.056555
Cyanide	Water	fg	135953.3	142.3573	87450.76	36861.6	3753.646	97.03766	7647.873
Cyanoacetic acid	Air	5g	1.553115	0	0.078708	0.072461	0.000506	0	1.401441
Cyclohexane	Air	5g	1.393496	0	0	0.855879	0	0	0.537617
Cycloxydim	Soil	5g	0.002629	0	0	0.002237	0	0	0.000392
Cyfluthrin	Air	5g	0.110604	0	0	0.005027	0	0	0.105577
Cyfluthrin	Soil	5g	13.5403	0	1.731289	0.490719	0.015693	0	11.30259
Cyhalothrin, gamma-	Air	5g	1.269301	0	0	0.057694	0	0	1.211607
Cyhalothrin, gamma-	Soil	5g	0.054414	0	0	0.002473	0	0	0.051941
Cymoxanil	Soil	5g	172.6738	0	1.164974	6.870971	0.010594	0	164.6272
Cypermethrin	Air	5g	0.268392	0	0	0.012199	0	0	0.256193
Cypermethrin	Soil	5g	182.3343	0	35.64571	14.55663	0.023867	0	132.1081
Cyproconazole	Soil	5g	1.060074	0	0	0.057423	0	0	1.002651
Cyprodinil	Soil	5g	382.4612	0	0	15.30805	0	0	367.1532
Decane	Water	fg	95382.4	56203.94	2.538744	0	0.014555	39175.91	0
Deltamethrin	Soil	5g	0.217846	0	0	0.009571	0	0	0.208276
Detergent, oil	Water	m3/g	2.975884	1.846346	7.25E-05	0	4.16E-07	1.129465	0
Diatomite	Raw	fg	1482.086	0	330.5997	918.4729	0.012701	0	233.0009
Diazinon	Soil	5g	565.4072	0	9.569383	22.26582	0.087021	0	533.485
Dibenz(a,h)anthracene	Air	5g	0.001188	0	0	0.000371	0	0	0.000817
Dibenzofuran	Water	5g	622.1862	366.626	0.01656	0	9.49E-05	255.5436	0
Dibenzothiophene	Water	5g	524.2147	304.4481	0.014273	0	8.18E-05	219.7522	0
Dicamba	Air	5g	2.535414	0	0	0.080944	0	0	2.45447
Dicamba	Water	5g	0.500674	0	0	0.014881	0	0	0.485793
Dicamba	Soil	5g	32.27208	0	0.393916	1.681195	0.001839	0	30.19513
Dichlorprop	Air	5g	0.15971	0	0	0.004035	0	0	0.155674
Dichlorprop	Water	5g	0.16708	0	0	0.004222	0	0	0.162858
Dichlorprop	Soil	5g	6.630703	0	0	0.167541	0	0	6.463161
Dichlorprop-P	Soil	fg	2296.517	0	645.9047	65.95311	5.873659	0	1578.786
Dichromate	Water	fg	2156.607	0	699.6277	120.3484	15.43013	0	1321.201
Diclofop	Soil	5g	11.37258	0	0	0.374891	0	0	10.99769

Diclofop-methyl	Soil	5g	11.62969	0	0	0.383065	0	0	11.24662
Dicrotophos	Soil	5g	157.5923	0	0	6.608473	0	0	150.9838
Diethyl ether	Air	5g	0.036334	0	0	0.033587	0	0	0.002747
Diethylamine	Air	5g	10.14269	0	1.331637	0.408092	0.010714	0	8.392244
Diethylamine	Water	5g	24.34282	0	3.195978	0.979435	0.025713	0	20.1417
Diethylene glycol	Air	5g	0.493923	0	0	0.448018	0	0	0.045905
Difenoconazole	Soil	5g	701.6855	0	0	25.32701	0	0	676.3585
Diflubenzuron	Air	5g	0.058226	0	0	0.002647	0	0	0.05558
Diflubenzuron	Soil	fg	3788.26	0	0	150.1389	0	0	3638.121
Diflufenican	Soil	5g	139.4019	0	0	3.884039	0	0	135.5179
Diflufenzopyr-sodium	Soil	5g	1.160217	0	0.043768	0.063351	0.000204	0	1.052893
Dimethachlor	Soil	5g	4.547219	0	0	0.275288	0	0	4.27193
Dimethenamid	Air	5g	0.136488	0	0	0.004057	0	0	0.132431
Dimethenamid	Water	5g	0.048775	0	0	0.00145	0	0	0.047325
Dimethenamid	Soil	5g	50.50446	0	1.143463	5.050325	0.005339	0	44.30534
Dimethoate	Soil	5g	339.0458	0	6.615838	13.44756	0.060162	0	318.9223
Dimethomorph	Soil	5g	129.3888	0	0.249643	5.173789	0.00227	0	123.9631
Dimethyl malonate	Air	5g	1.947619	0	0.098701	0.090866	0.000634	0	1.757417
Dimethylamine	Air	5g	0.15173	0	0	0.12589	0	0	0.025841
Dimethylamine	Water	5g	36.12768	0	3.774501	1.83373	0.026677	0	30.49277
Dinitrogen monoxide	Air	kgCOD	1.296537	1.253887	0.007438	0.000617	1.85E-05	0.026859	0.007718
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air	fg	3142.293	3141.789	0.196051	0.075642	0.001519	0.022631	0.208135
Dipropylamine	Air	5g	5.899677	0	0.794582	0.230082	0.006527	0	4.868487
Dipropylamine	Water	5g	14.15935	0	1.907013	0.552201	0.015665	0	11.68448
Dipropylthiocarbamic acid S-ethyl ester	Soil	5g	367.56	0	103.4378	10.54421	0.940632	0	252.6373
Diquat	Soil	5g	71.53939	0	19.9718	2.072787	0.181617	0	49.31318
Diquat dibromide	Soil	5g	67.01901	0	0	2.760449	0	0	64.25856
Dithianone	Soil	5g	514.9095	0	0	20.64222	0	0	494.2672
Diuron	Soil	fg	2299.64	0	0	92.5846	0	0	2207.055

DOC, Dissolved Organic Carbon	Water	EU	1.991869	0.955574	0.96016	0.039432	0.001987	9.27E-11	0.034715
Docosane	Water	fg	3501.477	2063.267	0.093195	0	0.000534	1438.117	0
Dodecane	Water	fg	180972.9	106638.9	4.816802	0	0.027615	74329.22	0
Dolomite	Raw	oz	2.50304	0	0.982437	1.000929	0.004818	0	0.514856
Eicosane	Water	fg	49826.69	29360.61	1.326189	0	0.007603	20464.74	0
Electricity usage	Raw	Therms	2.637668	0	2.62761	0	0.010058	0	0
Endosulfan	Soil	5g	816.9941	0	8.654128	32.04306	0.078698	0	776.2182
Endothall	Soil	5g	0.375336	0	0.125032	0.010953	0.000753	0	0.238598
Energy, gross calorific value, in biomass	Raw	kg-DZ	1.001497	0	0.176033	0.135101	0.001079	0	0.689284
Energy, gross calorific value, in biomass, primary forest	Raw	kcal	35.73628	0	5.280623	3.293067	0.003531	0	27.15906
Energy, kinetic (in wind), converted	Raw	kg-NO	1.334797	0	0.245576	0.016542	0.000941	0	1.071738
Energy, potential (in hydropower reservoir), converted	Raw	Therms	1.782496	0	0.276961	0.261867	0.007552	0	1.236116
Energy, solar, converted	Raw	MJ elec	1.905823	0	1.795319	0.100969	0.006872	0	0.002663
Epoxiconazole	Soil	5g	2.304475	0	0	0.094682	0	0	2.209793
Esfenvalerate	Air	5g	0.661472	0	0	0.030066	0	0	0.631406
Esfenvalerate	Soil	5g	5.060704	0	1.414629	0.145955	0.012864	0	3.487255
Ethalfluralin	Soil	5g	2.988633	0	1.47172	0.091779	0.00091	0	1.424224
Ethane	Air	m3/g	5.415912	0	3.055582	0.347493	0.004062	0	2.008775
Ethane, 1,1-difluoro-, HFC-152a	Air	fg	17781.16	0	387.6799	16892.52	1.483949	0	499.4721
Ethane, 1,1,1-trichloro-, HCFC-140	Air	fg	34228.15	33710.73	116.9878	19.44419	0.44798	33.89143	346.6494
Ethane, 1,1,1-trichloro-, HCFC-140	Water	5g	0.000116	0	0	0.000106	0	0	1.08E-05
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	m3/g	1.019999	0	1.018225	0.000934	1.86E-05	0	0.000822

Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	5g	209.2139	0	5.458997	74.55362	0.001369	0	129.1999
Ethane, 1,2-dibromo-	Air	fg	2021.922	2021.915	0.001662	0	9.51E-06	0.004866	0
Ethane, 1,2-dichloro-	Air	fg	90987.37	67397.18	3510.213	13023.8	180.7473	0.162217	6875.272
Ethane, 1,2-dichloro-	Water	5g	504.2297	0	133.9074	131.4496	1.320062	0	237.5526
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	fg	10604.98	0	1090.165	145.3951	4.731039	0	9364.687
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	Air	5g	186.3987	0	0	60.12855	0	0	126.2702
Ethane, chloro-	Air	fg	70767.26	70767.03	0.058164	0	0.000333	0.170327	0
Ethane, hexafluoro-, HFC-116	Air	fg	12934	0	6522.153	5852.909	392.972	0	165.9625
Ethanol	Air	fg	68124.84	0	11057.68	40391.79	88.9317	0	16586.43
Ethanol	Water	fg	5590.68	0	1768.566	3295.224	0.863061	0	526.0273
Ethene	Air	fg	812194.4	0	695876.2	76323.62	2804.003	0	37190.56
Ethene	Water	fg	39903.65	0	38138.22	788.9445	111.5898	0	864.8923
Ethene, chloro-	Air	fg	11382.33	0	1198.54	6855.324	92.05102	0	3236.417
Ethene, chloro-	Water	5g	100.9	0	10.99772	60.52543	0.119439	0	29.25742
Ethene, tetrachloro-	Air	fg	264463.5	100282.3	254.4815	162651.5	0.979736	441.1581	832.9931
Ethephon	Air	5g	5.86E-06	0	0	1.83E-07	0	0	5.68E-06
Ethephon	Water	5g	3.89E-07	0	0	1.22E-08	0	0	3.77E-07
Ethephon	Soil	5g	405.6622	0	0	17.54026	0	0	388.1219
Ethofumesate	Soil	fg	1237.025	0	0	43.43221	0	0	1193.593
Ethoprop	Soil	5g	85.16004	0	23.96552	2.44299	0.217935	0	58.53359
Ethyl acetate	Air	fg	422582.1	0	207393.3	213615.5	56.27556	0	1516.997
Ethyl acetate	Water	5g	23.99064	0	3.290347	1.098896	0.056731	0	19.54467
Ethyl cellulose	Air	5g	865.4254	0	417.5466	444.916	0.104531	0	2.858207
Ethylamine	Air	5g	6.419268	0	0.378312	0.54142	0.002869	0	5.496667
Ethylamine	Water	5g	15.40642	0	0.907957	1.299425	0.006887	0	13.19215
Ethylene diamine	Air	5g	9.324069	0	2.073116	1.87441	0.004302	0	5.37224

Ethylene diamine	Water	5g	22.46556	0	5.018163	4.533626	0.010353	0	12.90342
Ethylene oxide	Air	fg	2729.769	0	657.4679	2011.67	2.284028	0	58.34665
Ethylene oxide	Water	5g	398.829	0	143.4402	218.7262	0.113256	0	36.54934
Ethyne	Air	fg	28368.32	0	11972.91	12131.9	235.7707	0	4027.735
Europium	Raw	5g	7.81268	0	0	7.486739	0	0	0.325941
Feldspar	Raw	5g	590.5733	0	19.34581	419.9409	0.159354	0	151.1273
Fenamiphos	Soil	5g	645.9429	0	0	25.87931	0	0	620.0635
Fenbuconazole	Soil	5g	0.076694	0	0	0.006388	0	0	0.070306
Fenoxaprop	Air	5g	0.865816	0	0	0.039354	0	0	0.826462
Fenoxaprop	Soil	5g	20.00998	0	14.0959	0.234382	0.002218	0	5.677481
Fenoxaprop-P ethyl ester	Soil	5g	0.463775	0	0	0.015401	0	0	0.448374
Fenoxaprop ethyl ester	Soil	5g	0.947701	0	0	0.03124	0	0	0.91646
Fenoxycarb	Soil	5g	36.10637	0	0	1.44658	0	0	34.65979
Fenpiclonil	Soil	5g	41.22435	0	18.69995	4.088343	0.026271	0	18.40978
Fenpropidin	Soil	5g	24.66776	0	0	0.874329	0	0	23.79344
Fenpropimorph	Soil	5g	345.8066	0	0	12.56601	0	0	333.2406
Fentin hydroxide	Soil	5g	14.73569	0	4.146881	0.422723	0.03771	0	10.12838
Fipronil	Soil	5g	943.7133	0	0.065654	39.59572	0.000307	0	904.0516
Florasulam	Soil	5g	0.174169	0	0	0.005775	0	0	0.168394
Fluazifop-p-butyl	Air	5g	1.24239	0	0	0.05647	0	0	1.185919
Fluazifop-P-butyl	Soil	5g	192.8938	0	4.707863	7.629465	0.000741	0	180.5557
Flucarbazone sodium salt	Soil	5g	0.004091	0	0	0.000128	0	0	0.003963
Fludioxonil	Soil	5g	77.31052	0	0	3.149201	0	0	74.16131
Flufenacet	Air	5g	0.465829	0	0	0.021173	0	0	0.444656
Flufenacet	Soil	5g	7.233843	0	0	0.239642	0	0	6.994202
Flumetsulam	Air	5g	0.108989	0	0	0.004954	0	0	0.104036
Flumetsulam	Soil	5g	2.035111	0	0.076596	0.11108	0.000358	0	1.847077
Flumiclorac-pentyl	Air	5g	0.186493	0	0	0.008477	0	0	0.178016
Flumiclorac-pentyl	Soil	5g	0.007991	0	0	0.000363	0	0	0.007628
Flumioxazin	Air	5g	1.886459	0	0	0.085745	0	0	1.800714
Flumioxazin	Soil	5g	11.72542	0	8.224913	0.139154	0.001294	0	3.360058
Fluoranthene	Air	fg	1647.938	1641.942	0.000983	0.006084	5.63E-06	5.974924	0.013386

Fluorene	Air	fg	2112.123	2104.447	0.00126	0.005525	7.21E-06	7.657803	0.012156
Fluorene, 1-methyl-	Water	5g	372.4006	219.4374	0.009912	0	5.68E-05	152.9533	0
Fluorenes, alkylated, unspecified	Water	fg	5832.53	2146.974	0.248092	0	0.001422	3685.307	0
Fluoride	Air	oz	2.651858	2.651831	2.18E-06	0	1.25E-08	2.55E-05	0
Fluoride	Water	oz	2.116334	0.221955	1.071692	0.517532	0.04919	0.002975	0.25299
Fluoride	Soil	fg	229919.1	0	179995.2	3715.689	276.527	0	45931.71
Fluorine	Raw	fg	977332.8	0	377302.5	460709.4	2969.678	0	136351.2
Fluorine	Air	fg	94737.45	0	24978.79	3345.86	570.6718	0	65842.12
Fluorine	Water	fg	2976.578	1157.942	0.12213	0	0.0007	1818.514	0
Fluorine, 4.5% in apatite, 3% in crude ore	Raw	fg	446179.2	0	194019.7	156613.1	1327.04	0	94219.34
Fluorspar	Raw	m3/g	25.04671	0	10.24674	11.22878	0.266452	0	3.304735
Fluosilicic acid	Air	fg	37432.22	0	7171.759	28979.59	459.1256	0	821.7525
Fluosilicic acid	Water	fg	71600.7	0	12909.17	56274.8	826.426	0	1590.312
Flupyrsulfuron-methyl	Soil	5g	0.006351	0	0	0.000199	0	0	0.006152
Fluquinconazole	Soil	5g	0.066692	0	0	0.005555	0	0	0.061137
Fluroxypyr	Soil	5g	3.138085	0	0	0.103274	0	0	3.03481
Flurtamone	Soil	5g	330.4287	0	0	8.99335	0	0	321.4354
Flusilazole	Soil	5g	1.040403	0	0	0.047963	0	0	0.99244
Flutolanil	Soil	5g	16.75615	0	4.715474	0.480684	0.042881	0	11.51711
Folpet	Soil	5g	249.8939	0	0	10.01185	0	0	239.882
Fomesafen	Air	5g	7.013896	0	0	0.318803	0	0	6.695093
Fomesafen	Soil	5g	76.75478	0	54.00196	0.903168	0.008497	0	21.84116
Foramsulfuron	Soil	5g	0.217544	0	0.008207	0.011879	3.83E-05	0	0.19742
Formaldehyde	Air	oz	1.299847	0.43846	0.587209	0.001199	2.45E-05	0.266864	0.006089
Formaldehyde	Water	fg	7682.785	0	6547.067	423.6618	37.57343	0	674.4833
Formamide	Air	5g	1.898815	0	0.135867	0.086192	0.000943	0	1.675812
Formamide	Water	5g	4.557216	0	0.326086	0.206864	0.002264	0	4.022003
Formic acid	Air	fg	4875.11	0	1698.18	496.7684	1.027346	0	2679.134
Formic acid	Water	5g	1.322924	0	0.094659	0.060051	0.000657	0	1.167557
Formic acid, thallium(1+) salt	Water	5g	945.7319	0	50.82009	68.1597	0.373912	0	826.3782
Fosetyl-aluminium	Soil	fg	3079.555	0	0	124.3116	0	0	2955.243

Fungicides, unspecified	Soil	5g	57.19293	0	0	1.98875	0	0	55.20418
Furan	Air	fg	13037.65	2.859189	408.8761	944.4621	0.273489	0.038313	11681.14
Furathiocarb	Soil	fg	10769.12	0	0	295.0819	0	0	10474.04
Gadolinium	Raw	5g	19.49831	0	0	18.68485	0	0	0.813459
Gallium	Raw	5g	3.550412	0	2.925014	0.526637	0.011196	0	0.087565
Gangue, bauxite, in ground	Raw	kgCOD	12.99835	0	0	12.63196	0	0	0.366391
Gas, mine, off-gas, process, coal mining/m3	Raw	Bales	7.355487	0	2.603989	0.89459	0.016162	0	3.840746
Gas, natural/m3	Raw	MCF	18.91077	16.36415	0.739544	0.044944	0.002453	0.699775	1.059902
Glufosinate	Soil	5g	14.47263	0	2.323441	0.60122	0.019931	0	11.52804
Glufosinate ammonium	Soil	5g	140.5628	0	0	5.631563	0	0	134.9312
Glutaraldehyde	Water	fg	2503.709	0	2465.944	17.01792	0.796639	0	19.95045
Glyphosate	Air	fg	1403.399	0	0	63.76925	0	0	1339.629
Glyphosate	Water	5g	9.70908	0	0	0.295256	0	0	9.413824
Glyphosate	Soil	fg	47862.4	0	32484.23	970.2707	9.219617	0	14398.68
Gold	Raw	fg	2683.222	0	898.0885	1771.977	2.05266	0	11.10397
Gold, Au 1.0E-7%, in mixed ore, in ground	Raw	5g	0.057341	0	0	0.035039	0	0	0.022301
Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore	Raw	5g	750.3049	0	409.0299	337.7126	0.934874	0	2.627609
Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore	Raw	fg	1348.586	0	750.0721	593.0528	1.714356	0	3.746848
Gold, Au 1.8E-4%, in mixed ore	Raw	5g	9.129302	0	0	8.14525	0	0	0.984052
Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore	Raw	fg	1503.903	0	1371.735	128.2192	3.135222	0	0.812979
Gold, Au 4.3E-4%, in ore	Raw	5g	688.7647	0	339.9716	345.8488	0.777035	0	2.167237
Gold, Au 4.9E-5%, in ore	Raw	fg	2561.68	0	814.2754	1734.673	1.861098	0	10.87021
Gold, Au 5.4E-4%, Ag 1.5E-5%, in ore	Raw	5g	9.870811	0	0	9.8025	0	0	0.068311
Gold, Au 6.7E-4%, in ore	Raw	fg	3125.401	0	1260.631	1850.294	2.881282	0	11.59474

Gold, Au 6.8E-4%, Ag 1.5E-4%, in ore	Raw	5g	13.41352	0	0	13.32069	0	0	0.092828
Gold, Au 7.1E-4%, in ore	Raw	fg	2286.801	0	1421.492	856.692	3.248944	0	5.368399
Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore	Raw	5g	373.2654	0	85.17877	198.0505	0.194684	0	89.84151
Gold, Au 9.7E-5%, Ag 7.6E-5%, in ore	Raw	5g	48.52614	0	0	48.19031	0	0	0.335824
Granite	Raw	5g	2.13549	0	0.374367	0.877808	0.000829	0	0.882486
Gravel	Raw	kgCOD	572.78	0	561.6199	3.041176	0.091285	0	8.02766
Gypsum	Raw	tn.lg	1.905153	1.905127	1.57E-06	6.63E-06	9.56E-09	0	1.77E-05
Haloxyfop- (R) Methylester	Soil	5g	46.64939	0	0	1.272333	0	0	45.37705
Heat, waste	Air	MWh	1.96522	0	1.962107	0.000428	0.002367	0	0.000318
Heat, waste	Water	Therms	2.026366	0	2.01369	0.003516	0.005988	0	0.003172
Heat, waste	Soil	kWp	1.039818	0	1.037204	0	0.002614	0	0
Helium	Air	fg	834099.2	0	812799	2339.466	116.6318	0	18844.15
Heptane	Air	m3/g	2.031726	0	1.989516	0.017899	0.000445	0	0.023865
Herbicides, unspecified	Soil	5g	28.87214	0	0	0.888291	0	0	27.98385
Hexadecane	Water	fg	197531.2	116395.2	5.257567	0	0.030142	81130.68	0
Hexane	Air	m3/g	5.661285	0.11289	4.523425	0.062621	0.001907	2.72E-07	0.960442
Hexanoic acid	Water	fg	687411.9	405059.6	18.29625	0	0.104895	282333.8	0
Hexazinone	Soil	5g	108.2546	0	0	4.337154	0	0	103.9174
Hydramethylnon	Soil	5g	2.494874	0	0	0.099956	0	0	2.394918
Hydrazine, methyl-	Air	fg	286438.9	286438	0.235424	0	0.001347	0.68942	0
Hydrocarbons, aliphatic, alkanes, cyclic	Air	fg	59623.55	0	13555.38	34299.58	106.7924	0	11661.8
Hydrocarbons, aliphatic, alkanes, unspecified	Air	m3/g	4.145254	0	2.291235	1.456914	0.009685	0	0.38742
Hydrocarbons, aliphatic, alkanes, unspecified	Water	m3/g	1.060391	0	1.043126	0.005575	0.000267	0	0.011423
Hydrocarbons, aliphatic, unsaturated	Air	fg	352531	0	19924.71	40785.76	381.3796	0	291439.1

Hydrocarbons, aliphatic, unsaturated	Water	fg	97895.92	0	96289.44	515.1443	24.62659	0	1066.709
Hydrocarbons, aromatic	Air	m3/g	4.006145	0	0.591483	0.127038	0.004826	0	3.282798
Hydrocarbons, aromatic	Water	m3/g	4.342224	0	4.271087	0.022963	0.001093	0	0.047081
Hydrocarbons, chlorinated	Air	fg	38856.77	0	5826.9	23112.31	309.9083	0	9607.658
Hydrocarbons, unspecified	Air	m3/g	10.58434	10.44256	0	8.19E-05	0	0.139976	0.001721
Hydrocarbons, unspecified	Water	fg	508109	3.929566	451271.1	29573.04	695.7985	0.052734	26565.05
Hydrocarbons, unspecified	Soil	fg	1478.965	0	0	87.24819	0	0	1391.717
Hydrogen	Air	fg	645256	0	421126.7	108286.1	4703.291	0	111140
Hydrogen-3, Tritium	Air	eBq	1.08E+10	0	5.60E+09	1.65E+08	28170019	0	5.00E+09
Hydrogen-3, Tritium	Water	eBq	7.29E+11	0	4.09E+10	1.91E+10	6.35E+08	0	6.68E+11
Hydrogen carbonate	Water	fg	260025.7	0	0	215514.6	0	0	44511.16
Hydrogen chloride	Air	kgCOD	3.887695	3.836421	0.009107	0.004157	5.31E-05	0.010876	0.027082
Hydrogen chloride	Water	fg	82626.58	0	0	7744.629	0	0	74881.95
Hydrogen fluoride	Air	oz	9.921641	9.544615	0.043043	0.144702	0.000505	0.04452	0.144256
Hydrogen peroxide	Air	5g	731.6719	0	310.024	332.6186	86.61014	0	2.419221
Hydrogen peroxide	Water	fg	6082.024	0	2689.966	2909.961	304.7543	0	177.3418
Hydrogen sulfide	Air	m3/g	1.216134	1.57E-06	1.059803	0.049546	0.005995	2.11E-08	0.100789
Hydrogen sulfide	Water	fg	211690.2	0	53508.46	73798.97	255.8687	0	84126.88
Hydroxide	Water	fg	24584.49	0	8912.67	9014.469	3.566096	0	6653.784
Hypochlorite	Water	fg	25276.2	0	4359.078	3150.61	62.28328	0	17704.23
Imazamox	Air	5g	0.278977	0	0	0.01268	0	0	0.266297
Imazamox	Soil	5g	10.03436	0	7.061794	0.117631	0.001111	0	2.853821
Imazapyr	Soil	5g	0.029006	0	0.001094	0.001584	5.11E-06	0	0.026323
Imazaquin	Air	5g	0.889408	0	0	0.040426	0	0	0.848981
Imazaquin	Soil	5g	0.038115	0	0	0.001732	0	0	0.036382
Imazethapyr	Air	5g	1.84071	0	0	0.083666	0	0	1.757044
Imazethapyr	Soil	5g	25.15545	0	17.64447	0.299701	0.002794	0	7.208487
Imidacloprid	Soil	5g	949.3926	0	6.82371	39.46238	0.062052	0	903.0445
Indeno(1,2,3-cd)pyrene	Air	5g	141.583	141.0691	8.45E-05	0.000146	4.83E-07	0.513349	0.000321

Indium	Raw	fg	32989.8	0	15068.45	14145.93	21.00422	0	3754.429
Insecticides, unspecified	Soil	5g	0.007402	0	0	0.00022	0	0	0.007182
Iodide	Water	fg	822908.9	0	804600.1	4491.274	220.1398	0	13597.41
Iodine	Raw	fg	7360.315	0	879.3585	300.7422	6.812103	0	6173.402
Iodine	Air	fg	70500.17	0	751.0327	19748.83	37.71506	0	49962.6
Iodine-129	Air	eBq	893890.5	0	28167.58	16677.84	1212.305	0	847832.7
Iodine-131	Air	eBq	3912815	0	617887.8	757045.6	2260.314	0	2535622
Iodine-131	Water	eBq	9823289	0	1829.688	409517.6	80.54323	0	9411861
Iodine-133	Air	eBq	2370947	0	2259602	1234.701	8651.536	0	101458.6
Iodine-133	Water	eBq	102013.8	0	62.73877	965.5518	0.203324	0	100985.3
Iodine-135	Air	eBq	4919563	0	4900799	0	18764.18	0	0
Iodosulfuron	Soil	5g	0.004446	0	0	0.00037	0	0	0.004076
Iodosulfuron-methyl-sodium	Soil	5g	0.003963	0	0	0.000124	0	0	0.003839
Ioxynil	Soil	5g	232.506	0	0	9.50244	0	0	223.0036
Iprodione	Soil	fg	1335.328	0	8.446348	40.41401	0.076808	0	1286.391
Iron	Raw	kgCOD	16.45027	0	14.5123	1.230071	0.075266	0	0.632626
Iron	Air	m3/g	1.902232	0	0.566192	0.142179	0.004533	0	1.189329
Iron	Water	kgCOD	1.486048	0.228872	0.099077	0.306689	0.006714	0.231606	0.61309
Iron	Soil	m3/g	13.66596	0	10.49843	0.283538	0.105325	0	2.778671
Iron-59	Water	eBq	43097903	0	17.24823	1879564	0.055898	0	41218321
Iron ore	Raw	kgCOD	424.9098	424.9095	0.000348	0	1.99E-06	0	0
Isocyanic acid	Air	fg	11692.45	0	371.2	3003.095	1.759814	0	8316.394
Isophorone	Air	fg	977262.2	977259.1	0.803212	0	0.004596	2.35214	0
Isoprene	Air	kgCOD	1.617339	1.595922	1.90E-08	3.15E-09	1.27E-11	0.021417	3.89E-08
Isopropylamine	Air	5g	2.744273	0	0.176924	0.226915	0.001254	0	2.339179
Isopropylamine	Water	5g	6.586317	0	0.42462	0.544602	0.00301	0	5.614086
Isoproturon	Soil	5g	62.6883	0	0	4.652805	0	0	58.0355
Isoxaflutole	Soil	5g	3.48071	0	0.131306	0.190057	0.000613	0	3.158734
Kaolinite	Raw	m3/g	6.621916	0	4.799716	0.757741	0.047624	0	1.016835
Kerosene	Air	fg	878134.5	866519.3	0	0	0	11615.2	0
Kieserite	Raw	fg	99581.48	0	84325.46	8988.784	35.62473	0	6231.618
Kresoxim-methyl	Soil	5g	0.668467	0	0	0.04473	0	0	0.623737

Krypton	Raw	5g	645.5208	0	0	527.7654	0	0	117.7554
Krypton-85	Air	eBq	1.58E+08	0	580879.4	9596790	1343.53	0	1.48E+08
Krypton-85m	Air	eBq	1.01E+09	0	560434.5	10774608	1807.561	0	1.00E+09
Krypton-87	Air	eBq	1.84E+08	0	128581	1679446	410.106	0	1.83E+08
Krypton-88	Air	eBq	2.44E+08	0	166934.6	2190435	535.8399	0	2.42E+08
Krypton-89	Air	eBq	1.04E+08	0	69558.09	910561.4	224.9946	0	1.03E+08
Lactic acid	Air	5g	4.621482	0	0.622431	0.180233	0.005113	0	3.813705
Lactic acid	Water	5g	11.09162	0	1.493843	0.432563	0.012271	0	9.152939
Lactofen	Air	5g	0.895687	0	0	0.040712	0	0	0.854975
Lactofen	Soil	5g	0.038384	0	0	0.001745	0	0	0.036639
Lambda-cyhalothrin	Air	5g	1.86E-07	0	0	5.80E-09	0	0	1.80E-07
Lambda-cyhalothrin	Water	5g	9.39E-11	0	0	2.94E-12	0	0	9.10E-11
Lambda-cyhalothrin	Soil	5g	40.10431	0	2.359939	1.525038	0.000398	0	36.21894
Lanthanum	Raw	5g	934.8506	0	0	895.8492	0	0	39.00146
Lanthanum-140	Air	eBq	4935.315	0	3.283084	42.94474	0.01064	0	4889.076
Lanthanum-140	Water	eBq	169173.6	0	106.4421	1564.733	0.344958	0	167502
Lead	Raw	oz	2.884612	0	2.252964	0.498985	0.000228	0	0.132435
Lead	Air	m3/g	6.594785	6.30397	0.162793	0.061976	0.01161	0.0054	0.049035
Lead	Water	m3/g	2.841163	0.7868	0.285524	0.67415	0.013658	0.774377	0.306655
Lead	Soil	fg	33507.2	0	32718.39	166.384	1.066599	0	621.3637
Lead-210	Air	eBq	36794998	0	4925419	9033351	46671.69	0	22789557
Lead-210	Water	eBq	44714134	0	19147111	1676574	113751.7	0	23776697
Lead-210/kg	Water	5g	0.00034	0.0002	9.05E-09	0	5.19E-11	0.00014	0
Lead, Pb 0.014%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, in ore	Raw	m3/g	1.428056	0	0	0.982407	0	0	0.445649
Lead, Pb 3.6E-1%, in mixed ore	Raw	fg	13767.41	0	0	12283.42	0	0	1483.996
Lenacil	Soil	5g	56.25456	0	0	2.253805	0	0	54.00075
Limestone	Raw	tn.lg	42.43945	42.43942	3.47E-05	0	1.99E-07	0	0
Linuron	Soil	fg	2538.884	0	6.307685	208.0238	0.052383	0	2324.5
Lithium	Raw	fg	624882.6	0	3.93072	620326.3	0.027291	0	4552.349
Lithium	Air	5g	0.003024	0	0	0.001704	0	0	0.00132

Lithium	Water	kgCOD	1.723094	1.576453	0.033946	0.000856	0.000195	0.068768	0.042876
Lithium	Soil	5g	1.28789	0	0	0.717127	0	0	0.570763
m-Xylene	Air	fg	4300.853	0	171.1761	866.2097	0.776347	0	3262.691
m-Xylene	Water	fg	101338.4	58419.63	959.5932	24.27753	5.504057	40718.56	1210.785
Magnesite	Raw	oz	7.430285	0	6.362694	0.851887	0.054243	0	0.161461
Magnesium	Raw	fg	6799.152	0	6776.891	0	22.26113	0	0
Magnesium	Air	m3/g	26.1072	25.43848	0.159258	0.084181	0.00208	0.092568	0.330638
Magnesium	Water	kgCOD	5.233394	1.211418	0.393518	0.214716	0.018573	0.843998	2.551171
Magnesium	Soil	m3/g	3.05957	0	2.600221	0.042211	0.001123	0	0.416015
Malathion	Soil	5g	62.06158	0	0.38246	3.967667	0.00344	0	57.70801
Maleic hydrazide	Soil	5g	93.14584	0	26.21287	2.672079	0.238372	0	64.02252
Mancozeb	Soil	fg	11527.45	0	446.8863	547.127	4.062721	0	10529.38
Mandipropamid	Soil	5g	0.075554	0	0	0.003027	0	0	0.072527
Maneb	Soil	5g	2.168443	0	0.610238	0.062206	0.005549	0	1.49045
Manganese	Raw	oz	1.626932	0	0.411129	1.064472	0.019909	0	0.131423
Manganese	Air	m3/g	1.039674	0.933993	0.031297	0.015253	0.001756	0.007421	0.049954
Manganese	Water	oz	10.26081	1.141131	1.071606	0.861421	0.071752	0.05267	7.062227
Manganese	Soil	fg	257833.7	0	132906.6	13213.52	69.26632	0	111644.3
Manganese-54	Air	5Bq	459.3878	0	0.305595	3.997372	0.00099	0	455.0838
Manganese-54	Water	eBq	3010435	0	6118.967	29871.47	238.0494	0	2974207
MCPB	Air	5g	0.21933	0	0	0.005542	0	0	0.213788
MCPB	Water	5g	0.507713	0	0	0.012828	0	0	0.494885
MCPB	Soil	5g	35.0821	0	0	14.01145	0	0	21.07066
Mecoprop	Soil	5g	3.736742	0	0	0.116867	0	0	3.619875
Mecoprop-P	Soil	5g	2.019972	0	0	0.37069	0	0	1.649281
Mefenpyr	Soil	5g	1.908773	0	0	0.063593	0	0	1.84518
Mefenpyr-diethyl	Soil	5g	0.927575	0	0	0.030802	0	0	0.896772
Mepiquat chloride	Soil	5g	27.87955	0	0	1.111128	0	0	26.76842
Mercaptans, unspecified	Air	oz	12.8971	12.89706	1.06E-05	0	6.07E-08	2.91E-05	0
Mercury	Air	m3/g	4.255007	4.224932	0.017985	0.003166	0.000142	0.000933	0.007849
Mercury	Water	fg	83585	1241.168	9671.014	2971.301	104.7612	1277.5	68319.26
Mercury	Soil	5g	3.340913	0	1.14655	0.318549	0.00309	0	1.872723

Mesosulfuron-methyl (prop)	Soil	5g	0.02186	0	0	0.000684	0	0	0.021177
Mesotrione	Soil	5g	9.427211	0	0.355631	0.514754	0.001661	0	8.555166
Metalaxil	Soil	5g	48.24848	0	13.48089	1.567732	0.122591	0	33.07727
Metalaxyl-M	Soil	5g	490.7971	0	0	19.66349	0	0	471.1337
Metaldehyde	Soil	5g	779.2421	0	0.000438	45.97188	1.03E-06	0	733.2698
Metallic ions, unspecified	Water	5g	48.62173	47.97788	0	0	0	0.643859	0
Metals, unspecified	Air	5g	0.182977	0.180554	0	0	0	0.002423	0
Metam-sodium dihydrate	Soil	fg	15168.96	0	4268.554	435.6375	38.81692	0	10425.95
Metamitron	Soil	fg	4565.225	0	0	158.7475	0	0	4406.478
Metamorphous rock, graphite containing	Raw	m3/g	11.448	0	0.392763	10.99614	0.024146	0	0.034947
Metazachlor	Soil	5g	606.0236	0	0	24.49966	0	0	581.524
Metconazole	Soil	5g	0.626039	0	0	0.038668	0	0	0.587371
Methane	Air	kgCOD	25.32864	23.82023	9.86E-05	3.32E-08	5.65E-07	1.508308	2.82E-08
Methane, biogenic	Air	m3/g	4.166889	0	0.671417	1.732003	0.004817	0	1.758653
Methane, bromo-, Halon 1001	Air	fg	269589.6	269588.7	0.226673	0.000152	0.001297	0.648866	0.016316
Methane, bromochlorodifluoro-, Halon 1211	Air	5g	507.6299	0	34.98642	19.8165	0.231288	0	452.5957
Methane, bromotrifluoro-, Halon 1301	Air	fg	7328.52	0	6427.249	50.91197	1.338743	0	849.021
Methane, chlorodifluoro-, HCFC-22	Air	fg	4534.288	0	351.7188	2117.411	1.187776	0	2063.97
Methane, dichloro-, HCC-30	Air	fg	735562.1	720707.2	1701.956	303.3344	6.554031	7788.819	5054.147
Methane, dichloro-, HCC-30	Water	fg	85385.05	0	78771.91	690.0639	22.14252	0	5900.935
Methane, dichlorodifluoro-, CFC-12	Air	5g	470.1164	15.01992	15.63657	270.7331	6.490725	41.82591	120.4102
Methane, dichlorofluoro-, HCFC-21	Air	5g	0.355582	0	0.040909	0.258069	2.94E-05	0	0.056575

Methane, fossil	Air	kgCOD	2.563454	1.198142	0.807604	0.097764	0.002174	0.107812	0.349958
Methane, land transformation	Air	fg	71456.86	0	0	3584.415	0	0	67872.44
Methane, monochloro-, R-40	Air	fg	905821.2	893012.6	3098.826	514.9743	11.8752	2.149369	9180.764
Methane, monochloro-, R-40	Water	5g	131.7069	77.60868	0.003506	0	2.01E-05	54.09473	0
Methane, tetrachloro-, CFC-10	Air	5g	565.7698	1.501992	253.502	255.1499	5.137524	4.182591	46.29568
Methane, tetrafluoro-, CFC-14	Air	fg	141284.8	0	55247.69	80226.38	3535.674	0	2275.054
Methane, trichlorofluoro-, CFC-11	Air	5g	0.572095	0	0.066413	0.41482	4.77E-05	0	0.090815
Methane, trifluoro-, HFC-23	Air	5g	113.1398	0	13.01637	82.11283	0.009356	0	18.00126
Methanesulfonic acid	Air	5g	1.569469	0	0.079537	0.073224	0.000511	0	1.416197
Methanol	Air	fg	169199.3	0	116571.9	14303.96	494.7045	0	37828.75
Methanol	Water	fg	8731.099	0	6770.726	1184.231	145.0546	0	631.0879
Methomyl	Air	5g	2.01E-05	0	0	6.27E-07	0	0	1.94E-05
Methomyl	Water	5g	3.13E-07	0	0	9.78E-09	0	0	3.03E-07
Methomyl	Soil	5g	6.32E-05	0	0	1.98E-06	0	0	6.12E-05
Methoxyfenozide	Soil	5g	63.4707	0	0	2.542915	0	0	60.92778
Methyl acetate	Air	5g	0.378169	0	0.045683	0.016159	0.000298	0	0.316029
Methyl acetate	Water	5g	0.907605	0	0.109637	0.038781	0.000715	0	0.758473
Methyl acrylate	Air	5g	134.8398	0	130.5054	4.215647	0.032721	0	0.086061
Methyl acrylate	Water	fg	2634.135	0	2549.461	82.3539	0.63921	0	1.681234
Methyl borate	Air	5g	0.955523	0	0.035487	0.044553	0.000242	0	0.875241
Methyl ethyl ketone	Air	m3/g	1.079746	0.657122	0.207432	0.213622	5.64E-05	1.58E-06	0.001511
Methyl ethyl ketone	Water	5g	263.4041	155.2114	0.007011	0	4.02E-05	108.1857	0
Methyl formate	Air	5g	1.900706	0	0.541872	0.787747	0.000375	0	0.570712
Methyl formate	Water	5g	0.758842	0	0.216338	0.314502	0.00015	0	0.227852
Methyl lactate	Air	5g	5.073586	0	0.683322	0.197865	0.005613	0	4.186786

Methyl methacrylate	Air	fg	33698.7	33698.59	0.027697	0	0.000158	0.081108	0
Methylamine	Air	5g	3.230073	0	0.838648	0.725428	0.000633	0	1.665364
Methylamine	Water	5g	7.752009	0	2.012691	1.740997	0.00152	0	3.996801
Metiram	Soil	5g	63.27947	0	17.80795	1.815301	0.16194	0	43.49428
Metolachlor	Air	5g	14.89824	0	0	0.673849	0	0	14.22439
Metolachlor	Water	5g	0.656905	0	0	0.019476	0	0	0.637429
Metolachlor	Soil	5g	934.8606	0	190.5795	92.16497	0.33766	0	651.7785
Metosulam	Soil	5g	0.012521	0	0	0.000392	0	0	0.01213
Metribuzin	Air	5g	5.809181	0	0	0.264045	0	0	5.545136
Metribuzin	Soil	5g	254.8953	0	100.1587	9.810207	0.40592	0	144.5204
Metsulfuron-methyl	Soil	5g	0.920305	0	7.70E-05	0.423858	4.76E-08	0	0.49637
Mineral oil	Soil	fg	3570.22	0	0	143.0387	0	0	3427.181
Molybdenum	Raw	fg	608445.7	0	260778.2	285414.9	12382.8	0	49869.75
Molybdenum	Air	fg	8776.068	0	2873.868	1424.951	8.987685	0	4468.261
Molybdenum	Water	m3/g	1.642151	0.044324	0.252847	0.1611	0.016984	0.030895	1.136002
Molybdenum	Soil	5g	28.87973	0	4.543363	4.565497	0.01465	0	19.75622
Molybdenum-99	Water	eBq	55279	0	36.69895	482.1345	0.118934	0	54760.04
Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore	Raw	fg	824845.4	0	590120.1	65879.25	134460.9	0	34385.11
Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore	Raw	fg	122783.8	0	82629.7	13673.56	19170.67	0	7309.922
Molybdenum, 0.016% in sulfide, Mo 8.2E-3% and Cu 0.27% in crude ore	Raw	fg	233948.7	0	0	161741.3	0	0	72207.4
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.22% in crude ore	Raw	fg	158096.6	0	0	115216.3	0	0	42880.37
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and	Raw	fg	302629.6	0	130588.6	109208.8	6137.512	0	56694.8

Cu 0.36% in crude ore									
Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore	Raw	fg	560566.9	0	302780.7	135081.8	70247.24	0	52457.08
Monocrotophos	Soil	5g	462.8107	0	0	18.34243	0	0	444.4683
Monoethanolamine	Air	fg	66493	0	5892.866	57057.69	2.694053	0	3539.758
Monoethanolamine	Water	5g	34.7642	0	0	1.951674	0	0	32.81253
Monosodium acid methanearsonate	Soil	5g	80.40287	0	0	3.371614	0	0	77.03126
n-Hexacosane	Water	fg	2184.456	1287.193	0.058142	0	0.000333	897.2052	0
Naphthalene	Air	fg	42388.12	40915.74	0.122283	0	0.000691	1472.257	0
Naphthalene	Water	fg	59532.62	35044.15	1.587095	0	0.009099	24486.88	0
Naphthalene, 2-methyl-	Water	fg	51829.55	30540.74	1.379502	0	0.007909	21287.42	0
Naphthalenes, alkylated, unspecified	Water	fg	1649.187	607.0692	0.07015	0	0.000402	1042.047	0
Napropamide	Soil	5g	56.64393	0	0.000775	22.72221	1.82E-06	0	33.92094
Neodymium	Raw	5g	514.1678	0	0	492.717	0	0	21.4508
Nickel	Air	m3/g	1.585405	1.261828	0.136041	0.043159	0.00786	0.090864	0.045653
Nickel	Water	oz	1.068249	0.013524	0.1347	0.101972	0.003887	0.012811	0.801355
Nickel	Soil	fg	10675.51	0	10496.69	61.5573	0.390371	0	116.8696
Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore	Raw	m3/g	1.00502	0	0.075218	0.593107	0.000381	0	0.336314
Nickel, 1.98% in silicates, 1.04% in crude ore	Raw	oz	9.315277	0	5.012179	2.85666	0.423782	0	1.022657
Nickel, Ni 2.3E+0%, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Cu 3.2E+0% in ore	Raw	fg	319624.8	0	0	218291.3	0	0	101333.5
Nickel, Ni 2.5E+0%, in mixed ore, in ground	Raw	fg	13616.87	0	0	8320.927	0	0	5295.94

Nickel, Ni 3.7E-2%, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Cu 5.2E-2% in ore	Raw	fg	10782.33	0	0	8791.123	0	0	1991.206
Nicosulfuron	Soil	5g	1.595328	0	0.060182	0.08711	0.000281	0	1.447755
Niobium-95	Air	eBq	52805917	0	0.036277	2304290	0.000118	0	50501627
Niobium-95	Water	eBq	255288	0	1618.265	2791.51	92.07051	0	250786.1
Nitrate	Air	fg	17626.91	0	4564.133	625.2727	31.34696	0	12406.16
Nitrate	Water	oz	11.50706	1.21E-08	0.956139	0.535463	0.014377	1.63E-10	10.00108
Nitrate	Soil	fg	1484.143	0	0	826.4053	0	0	657.7375
Nitrate compounds	Water	oz	6.550423	6.550418	5.35E-06	0	3.06E-08	6.56E-09	0
Nitric acid	Water	fg	31507.61	31090.38	0	0	0	417.23	0
Nitrite	Water	fg	23593.72	0	16994.18	3894.942	33.95629	0	2670.643
Nitrobenzene	Air	5g	31.38413	0	4.053002	1.230513	0.032685	0	26.06793
Nitrobenzene	Water	5g	125.7716	0	16.24237	4.931268	0.130986	0	104.467
Nitrogen	Raw	oz	12.73153	0	0	9.274401	0	0	3.457133
Nitrogen	Water	fg	656375.8	0	351379	51514.42	1110.039	0	252372.4
Nitrogen	Soil	5g	84.54265	0	0	27.95995	0	0	56.58271
Nitrogen dioxide	Air	5g	547.5065	0	544.3842	0	3.122318	0	0
Nitrogen fluoride	Air	5g	0.136189	0	0	0.123546	0	0	0.012643
Nitrogen oxides	Air	kgCOD	135.7762	110.004	4.185788	0.063349	0.001513	21.24847	0.273056
Nitrogen, atmospheric	Air	m3/g	2.661772	0	2.512547	0.100389	0.014409	0	0.034427
Nitrogen, organic bound	Water	m3/g	1.003494	0	0.714195	0.149259	0.019045	0	0.120995
Nitrogen, total	Water	fg	975902.4	962994	0	0	0	12908.38	0
NMVOC, non-methane volatile organic compounds, unspecified origin	Air	kgCOD	3.040509	0.453252	1.83737	0.007282	0.007033	0.70939	0.026182
Noble gases, radioactive, unspecified	Air	eBq	8.61E+12	0	2.88E+11	1.60E+11	1.17E+10	0	8.15E+12
o-Cresol	Water	fg	94132	55467.69	2.505423	0	0.014364	38661.79	0
o-Xylene	Air	5g	318.9447	0	0	178.8246	0	0	140.1201
o-Xylene	Water	fg	1598.558	0	696.845	17.56294	3.996757	0	880.1537

Occupation, arable	Raw	m2s	4154076	0	55131.12	176580.5	467.9059	0	3921897
Occupation, arable, greenhouse	Raw	m2s	28318.43	0	0	1134.561	0	0	27183.86
Occupation, arable, irrigated	Raw	m2s	96024.9	0	0	4364.621	0	0	91660.28
Occupation, arable, irrigated, intensive	Raw	m2s	355548.9	0	0	20072.74	0	0	335476.2
Occupation, arable, non-irrigated	Raw	m2s	3419797	0	3413040	916.8236	586.808	0	5253.58
Occupation, arable, non-irrigated, extensive	Raw	m2s	3780178	0	0	131949.5	0	0	3648228
Occupation, arable, non-irrigated, intensive	Raw	m2s	3724328	0	0	239950.7	0	0	3484377
Occupation, construction site	Raw	m2s	793707.4	0	566768.8	98623.73	2356.389	0	125958.5
Occupation, dump site	Raw	m2y	1.007889	0	0.296145	0.133283	0.004444	0	0.574017
Occupation, dump site, benthos	Raw	m2s	1011597	0	1011270	0	326.6973	0	0
Occupation, forest, extensive	Raw	m2s	15644127	0	0	4416151	0	0	11227976
Occupation, forest, intensive	Raw	m2y	4.61897	0	0.180468	0.717248	0.000554	0	3.7207
Occupation, forest, intensive, normal	Raw	m2y	1.606988	0	1.595399	0	0.011589	0	0
Occupation, forest, intensive, short-cycle	Raw	m2s	175012.7	0	174895.7	0	116.9442	0	0
Occupation, grassland, not used	Raw	m2s	2422693	0	0	126868.2	0	0	2295825
Occupation, industrial area	Raw	m2s	19203272	0	11807381	2728810	22934.77	0	4644146
Occupation, industrial area, benthos	Raw	m2s	9125.017	0	9121.36	0	3.656958	0	0

Occupation, industrial area, built up	Raw	m2s	2451495	0	2424385	0	27109.96	0	0
Occupation, industrial area, vegetation	Raw	m2s	2658706	0	2651393	0	7312.767	0	0
Occupation, inland waterbody, unspecified	Raw	m2s	4365.043	0	0	3487.141	0	0	877.9023
Occupation, mineral extraction site	Raw	m2s	18588700	0	8459106	1083802	18370.34	0	9027421
Occupation, pasture and meadow, extensive	Raw	m2s	2677.584	0	0	2167.211	0	0	510.3736
Occupation, pasture and meadow, intensive	Raw	m2s	550958.5	0	0	18931.49	0	0	532027
Occupation, permanent crop	Raw	m2s	59305.34	0	0	33269.58	0	0	26035.76
Occupation, permanent crop, fruit, intensive	Raw	m2s	255684.5	0	255612.9	0	71.56263	0	0
Occupation, permanent crops, irrigated, intensive	Raw	m2s	358072.6	0	0	42278.94	0	0	315793.7
Occupation, permanent crops, non-irrigated, intensive	Raw	m2s	376127.9	0	0	15104.3	0	0	361023.6
Occupation, seabed, drilling and mining	Raw	m2s	15160.53	0	0	6978.957	0	0	8181.57
Occupation, seabed, infrastructure	Raw	m2s	1374.175	0	0	93.032	0	0	1281.143
Occupation, shrub land, sclerophyllous	Raw	m2s	483478.2	0	392350	45029.03	1680.105	0	44419.12
Occupation, traffic area, rail network	Raw	m2s	2428812	0	1059146	157495.5	3465.486	0	1208704
Occupation, traffic area, rail/road embankment	Raw	m2s	3601018	0	957836.6	557565.3	3134.004	0	2082482

Occupation, traffic area, road embankment	Raw	m2s	22382474	0	22378127	0	4347.182	0	0
Occupation, traffic area, road network	Raw	m2y	3.634781	0	3.545655	0.050895	0.000589	0	0.037642
Occupation, unknown	Raw	m2y	3.277023	0	3.258337	0	0.018686	0	0
Occupation, urban, discontinuously built	Raw	m2s	34221.28	0	1484.095	8496.899	2.730293	0	24237.55
Occupation, urban/industrial fallow	Raw	m2s	2297.97	0	0	687.3189	0	0	1610.651
Occupation, water bodies, artificial	Raw	m2s	18497051	0	2944496	6759426	8623.618	0	8784506
Occupation, water courses, artificial	Raw	m2s	5716009	0	5686781	0	29227.76	0	0
Octadecane	Water	fg	48800.19	28755.7	1.298871	0	0.007447	20043.18	0
Oil, crude	Raw	kgCOD	639.5459	129.4263	147.0114	0.896461	0.047133	360.4128	1.751753
Oils, biogenic	Water	5g	239.8721	0	0	55.62683	0	0	184.2453
Oils, biogenic	Soil	fg	107689.4	0	36734.82	11668.4	185.6016	0	59100.61
Oils, unspecified	Water	EU	1.587425	0.619352	0.874308	0.009512	0.000287	0.068236	0.01573
Oils, unspecified	Soil	oz	14.30001	0	13.98301	0.102999	0.004584	0	0.209415
Olivine	Raw	fg	3024.339	0	2495.09	209.9667	177.477	0	141.8053
Orbencarb	Soil	5g	147.2451	0	13.58016	25.00202	0.12328	0	108.5396
Organic acids	Air	fg	6737.799	6648.678	0	0	0	89.12172	0
Organic carbon	Air	5g	44.03615	0	0	24.80896	0	0	19.22718
Organic carbon	Water	5g	143.2919	0	0	80.7275	0	0	62.56442
Organic carbon	Soil	5g	143.2919	0	0	80.7275	0	0	62.56442
Organic substances, unspecified	Air	m3/g	14.15809	14.1058	8.39E-06	0	4.80E-08	0.052283	0
Oryzalin	Soil	5g	103.0648	0	0	4.12923	0	0	98.93561
Other minerals, extracted for use	Raw	fg	683059.9	0	679173.6	0	3886.228	0	0
Oxamyl	Soil	5g	71.36267	0	20.0827	2.047184	0.182626	0	49.05015

Oxydemeton methyl	Soil	5g	0.311051	0	0	0.025908	0	0	0.285144
Oxygen	Raw	EU	1.023713	0	0	0.650681	0	0	0.373032
Ozone	Air	m3/g	2.304352	0	0.359336	0.100226	0.002322	0	1.842468
p-Cresol	Water	fg	101562.3	59846.65	2.703143	0	0.015497	41712.91	0
PAH, polycyclic aromatic hydrocarbons	Air	m3/g	1.238679	0.021277	0.054178	0.065508	0.001344	1.068602	0.02777
PAH, polycyclic aromatic hydrocarbons	Water	fg	47453.31	0	45037.18	1690.094	38.21066	0	687.8279
PAH, polycyclic aromatic hydrocarbons	Soil	5g	3.863674	0	0	2.151384	0	0	1.71229
Palladium, Pd 1.6E-6%, in mixed ore, in ground	Raw	5g	0.90993	0	0	0.556036	0	0	0.353895
Palladium, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore	Raw	5g	223.7171	0	202.6228	17.15341	0.055627	0	3.88528
Palladium, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore	Raw	5g	587.9348	0	486.9389	68.88493	0.133681	0	31.97722
Paraffins	Air	5g	267.8384	0	0	218.3093	0	0	49.52911
Paraffins	Water	5g	777.2934	0	0	633.555	0	0	143.7383
Paraquat	Air	5g	3.737037	0	0	0.16986	0	0	3.567177
Paraquat	Soil	5g	32.23691	0	1.470966	1.532408	0.012759	0	29.22078
Parathion	Soil	5g	19.98109	0	0.025857	2.398327	1.60E-05	0	17.55689
Parathion, methyl	Air	5g	0.717177	0	0	0.032598	0	0	0.684579
Parathion, methyl	Soil	5g	0.030741	0	0	0.001397	0	0	0.029344
Particulates, < 10 um	Air	fg	18021.56	0	17918.79	0	102.7733	0	0
Particulates, < 2.5 um	Air	EU	2.131199	0.006308	0.367227	0.07629	0.001229	0	1.680145
Particulates, > 10 um	Air	oz	13.42604	0	5.105087	1.467833	0.026583	0	6.826534

Particulates, > 2.5 um, and < 10um	Air	kgCOD	17.16688	16.3184	0.082047	0.015076	0.000642	0.65531	0.095402
Particulates, unspecified	Air	kgCOD	81.67844	81.56672	7.53E-05	0	4.31E-07	0.111639	0
Peat	Raw	oz	1.078354	0	0.081105	0.562821	0.000181	0	0.434247
Pendimethalin	Air	5g	40.12468	0	0	1.811927	0	0	38.31275
Pendimethalin	Water	5g	0.066404	0	0	0.001974	0	0	0.06443
Pendimethalin	Soil	fg	1328.854	0	436.7757	36.82796	0.306752	0	854.9438
Pentane	Air	m3/g	13.01774	0	11.31427	0.14571	0.004953	0	1.552806
Pentane, 3-methyl-	Air	5g	18.86338	0	0	9.876441	0	0	8.986936
Perlite	Raw	m3/g	2.019042	0	0	1.644532	0	0	0.374509
Permethrin	Air	5g	0.585044	0	0	0.026592	0	0	0.558452
Permethrin	Soil	5g	3.634647	0	0.856761	0.121601	0.007682	0	2.648603
Pesticides, unspecified	Soil	fg	9899.794	0	0	404.2344	0	0	9495.56
Phenanthrene	Air	fg	6267.007	6244.01	0.003739	0.085079	2.14E-05	22.72159	0.187183
Phenanthrene	Water	5g	692.9003	319.3376	0.024846	0	0.000142	373.5377	0
Phenanthrenes, alkylated, unspecified	Water	5g	683.8203	251.7156	0.029087	0	0.000167	432.0754	0
Phenmedipham	Soil	5g	941.7838	0	0	33.38728	0	0	908.3965
Phenol	Air	fg	39622.91	26958.87	9177.21	1153.873	183.4625	0.064887	2149.431
Phenol	Water	m3/g	1.564406	0.204969	0.756064	0.005217	0.000443	0.57075	0.026962
Phenol, 2,4-dichloro-	Air	5g	3.517142	0	0.287612	0.23918	0.001418	0	2.988933
Phenol, 2,4-dimethyl-	Water	fg	91655.56	54008.35	2.439517	0	0.013986	37644.76	0
Phenol, pentachloro-	Air	fg	1337.487	0	42.10148	841.4464	0.164709	0	453.7744
Phenol, pentachloro-	Soil	5g	1.584623	0	0	0.093481	0	0	1.491142
Phenols, unspecified	Air	fg	78883.22	74718.32	0.333497	0	0.001882	4164.563	0
Phenols, unspecified	Water	m3/g	1.486294	1.378031	6.02E-06	0	3.45E-08	0.108257	0
Phorate	Soil	5g	153.9612	0	43.32737	4.416691	0.394006	0	105.8231
Phosmet	Soil	5g	16.95342	0	4.770988	0.486343	0.043386	0	11.6527
Phosphate	Water	kgCOD	1.034955	0	0.103491	0.057137	0.004042	0	0.870286
Phosphine	Air	5g	318.0821	0	0.099425	288.4631	2.49E-05	0	29.51958
Phosphoric acid	Air	5g	0.246356	0	0	0.223486	0	0	0.02287
Phosphorus	Raw	m3/g	2.745861	0	0.841811	1.352237	0.005369	0	0.546443

Phosphorus	Air	fg	16723.06	0	2321.897	3082.22	40.56129	0	11278.38
Phosphorus	Water	fg	275096.5	173426	74442.84	5150.318	146.8207	0	21930.49
Phosphorus	Soil	fg	235221.5	0	163330.5	7316.019	74.83887	0	64500.15
Phosphorus trichloride	Air	fg	302793.2	0	0	302787.6	0	0	5.548412
Phosphorus, 18% in apatite, 4% in crude ore	Raw	m3/g	3.909331	0	1.50921	1.842838	0.011879	0	0.545405
Phthalate, dioctyl-	Air	fg	123000.2	122999.9	0.101094	0	0.000578	0.296045	0
Picloram	Soil	5g	0.008181	0	0	0.000256	0	0	0.007925
Picoxystrobin	Soil	5g	2.375091	0	0	0.078573	0	0	2.296519
Piperonyl butoxide	Soil	5g	17.35872	0	0.142158	0.689719	0.001293	0	16.52555
Pirimicarb	Soil	5g	414.1009	0	22.52017	15.77179	0.003545	0	375.8054
Platinum	Air	5g	0.000551	0	2.31E-05	0.0002	9.13E-08	0	0.000328
Platinum, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore	Raw	5g	37.99039	0	3.415254	23.61284	0.000937	0	10.96136
Platinum, Pt 4.7E-7%, in mixed ore, in ground	Raw	5g	0.263203	0	0	0.160837	0	0	0.102366
Platinum, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore	Raw	5g	61.75343	0	12.2434	40.36412	0.003358	0	9.14255
Plutonium-238	Air	5Bq	0.121941	0	0.003843	0.002275	0.000165	0	0.115658
Plutonium-alpha	Air	5Bq	0.279535	0	0.008808	0.005215	0.000379	0	0.265132
Polonium-210	Air	eBq	53897297	0	5734938	16054024	72369.74	0	32035965
Polonium-210	Water	eBq	26757350	0	12577263	1734611	79392.1	0	12366085
Polychlorinated biphenyls	Air	5g	248.7248	0	216.9754	23.48944	1.616926	0	6.643019
Polychlorinated biphenyls	Water	5g	0.004578	0	0	0.003365	0	0	0.001213
Potassium	Air	fg	983471	0	115559.7	110848	1044.916	0	756018.3
Potassium	Water	kgCOD	1.876242	0	0.257566	0.124842	0.010557	0	1.483276
Potassium	Soil	m3/g	1.566365	0	1.141212	0.042806	0.000514	0	0.381833

Potassium-40	Air	eBq	26330949	0	5178577	2967048	27554.36	0	18157770
Potassium-40	Water	eBq	23329365	0	7024534	1193657	38063.84	0	15073111
Potassium chloride	Raw	m3/g	8.77435	0	1.37329	2.377814	0.000948	0	5.022298
Praseodymium	Raw	5g	54.55521	0	0	52.2792	0	0	2.276014
Primisulfuron	Soil	5g	0.725165	0	0.027356	0.039596	0.000128	0	0.658085
Prochloraz	Soil	5g	1.055062	0	0	0.070462	0	0	0.984599
Procymidone	Soil	5g	0.726385	0	0	0.043975	0	0	0.68241
Profenofos	Soil	5g	125.1186	0	0	5.246722	0	0	119.8719
Prohexadione-calcium	Soil	5g	0.00493	0	0	0.000154	0	0	0.004776
Prometryn	Soil	5g	67.15359	0	0	2.816018	0	0	64.33757
Pronamide	Soil	5g	0.013103	0	0	0.011147	0	0	0.001956
Propachlor	Soil	fg	3931.923	0	0	157.5301	0	0	3774.393
Propamocarb HCl	Soil	5g	0.739242	0	0.208036	0.021207	0.001892	0	0.508108
Propanal	Air	fg	640398	640273.2	34.33361	17.6991	0.184377	1.541057	71.04167
Propanal	Water	5g	2.938166	0	0.258082	0.136033	0.001792	0	2.54226
Propane	Air	m3/g	10.08359	0	8.892667	0.148129	0.003632	0	1.039158
Propargite	Soil	5g	49.38245	0	13.89708	1.416636	0.126376	0	33.94235
Propene	Air	m3/g	17.25706	0.326751	0.47618	0.015143	0.000903	16.4108	0.027284
Propene	Water	fg	143355.2	0	130083.7	9271.759	1305.632	0	2694.107
Propiconazole	Air	5g	0.687154	0	0	0.031232	0	0	0.655922
Propiconazole	Water	5g	0.000245	0	0	8.12E-06	0	0	0.000237
Propiconazole	Soil	5g	9.978473	0	0	0.344051	0	0	9.634422
Propionic acid	Air	fg	23962.84	0	5615.873	652.4195	33.1692	0	17661.38
Propionic acid	Water	5g	13.75852	0	1.23098	0.663199	0.006386	0	11.85796
Propoxycarbazone-sodium (prop)	Soil	5g	0.02733	0	0	0.000855	0	0	0.026475
Propylamine	Air	5g	1.235348	0	0.04302	0.051282	0.000299	0	1.140748
Propylamine	Water	5g	2.964783	0	0.103249	0.123075	0.000717	0	2.737742
Propylene oxide	Air	fg	50248.56	0	48619.8	1132.362	306.1553	0	190.2507
Propylene oxide	Water	fg	120628.3	0	116987.3	2703.423	735.3824	0	202.225
Prosulfuron	Soil	5g	0.210984	0	0.004924	0.058921	2.30E-05	0	0.147116
Protactinium-234	Air	eBq	3623317	0	840871.8	129474.8	3375.766	0	2649595
Protactinium-234	Water	eBq	11036595	0	2008519	149280.3	10584.17	0	8868212

Prothioconazol	Air	5g	5.12E-07	0	0	1.60E-08	0	0	4.96E-07
Prothioconazol	Water	5g	5.34E-08	0	0	1.67E-09	0	0	5.17E-08
Prothioconazol	Soil	5g	0.575687	0	0	0.034848	0	0	0.540839
Pumice	Raw	m3/g	6.666069	0	0	5.429581	0	0	1.236489
Pymetrozine	Soil	5g	4.731239	0	1.331453	0.135725	0.012108	0	3.251953
Pyraclostrobin (prop)	Air	5g	1.618337	0	0	0.073558	0	0	1.54478
Pyraclostrobin (prop)	Water	5g	0.000542	0	0	1.59E-05	0	0	0.000526
Pyraclostrobin (prop)	Soil	5g	1.621753	0	0	0.053154	0	0	1.568599
Pyrene	Air	5g	765.9461	763.1544	0.000457	0.00444	2.61E-06	2.777052	0.009769
Pyrethrin	Soil	5g	18.72497	0	0	0.750204	0	0	17.97476
Pyrimethanil	Soil	5g	255.6363	0	0	10.24191	0	0	245.3944
Pyrithiobac sodium salt	Soil	5g	4.493739	0	0	0.18844	0	0	4.305298
Quinoxyfen	Soil	5g	0.239001	0	0	0.007475	0	0	0.231526
Quizalofop-P	Soil	5g	0.205993	0	0.101439	0.006326	6.27E-05	0	0.098165
Quizalofop-p-ethyl	Soil	5g	125.0441	0	0	5.009815	0	0	120.0343
Quizalofop ethyl ester	Air	5g	0.217172	0	0	0.009871	0	0	0.2073
Quizalofop ethyl ester	Soil	5g	0.102278	0	0	0.006052	0	0	0.096227
Radioactive species, alpha emitters	Water	eBq	36732.04	0	13239.78	15081.55	101.4749	0	8309.232
Radioactive species, Nuclides, unspecified	Water	eBq	5.79E+10	5.62E+10	1.17E+08	29827997	1501538	7.53E+08	8.27E+08
Radioactive species, other beta emitters	Air	eBq	2.38E+09	0	5.30E+08	1.48E+09	20371.13	0	3.75E+08
Radioactive species, unspecified	Air	eBq	3.60E+13	3.55E+13	76679.32	0	431.7323	4.77E+11	0
Radionuclides (Including Radon)	Air	oz	1.732163	1.709252	0	0	0	0.022912	0
Radium-224	Water	eBq	4.08E+08	0	4.01E+08	2144323	102582.5	0	4393426
Radium-226	Air	eBq	26475679	0	4986166	2609178	31365.79	0	18848969
Radium-226	Water	eBq	5.00E+09	0	1.94E+09	54936406	7042608	0	3.00E+09
Radium-226/kg	Water	5g	0.118283	0.069698	3.15E-06	0	1.80E-08	0.048582	0
Radium-228	Air	eBq	6784896	0	1119317	1891298	28731.98	0	3745550

Radium-228	Water	eBq	9.51E+08	0	8.61E+08	5771460	542605.5	0	83096972
Radium-228/kg	Water	5g	0.000605	0.000357	1.61E-08	0	9.23E-11	0.000249	0
Radon-220	Air	eBq	6.11E+08	0	1.07E+08	61901638	539722.7	0	4.41E+08
Radon-222	Air	eBq	5.63E+13	0	1.44E+13	6.93E+11	7.59E+10	0	4.12E+13
Rhenium	Raw	5g	5.531341	0	5.182894	0.131384	0.001134	0	0.215929
Rhodium, Rh 1.6E-7%, in mixed ore, in ground	Raw	5g	0.089301	0	0	0.05457	0	0	0.034731
Rhodium, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore	Raw	5g	5.517032	0	2.755266	1.88563	0.000805	0	0.875332
Rhodium, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore	Raw	5g	11.11094	0	8.629801	2.020886	0.002522	0	0.457735
Rimsulfuron	Soil	5g	2.992265	0	0.665357	0.104633	0.00593	0	2.216345
Rotenone	Soil	5g	10.48598	0	0	0.420115	0	0	10.06587
Rubidium	Water	fg	81568.54	0	80240.47	428.8646	20.5165	0	878.6851
Ruthenium-103	Air	5Bq	11.98133	0	0.00797	0.104256	2.58E-05	0	11.86908
Ruthenium-103	Water	eBq	16917.07	0	7.743809	200.5575	0.025096	0	16708.74
Samarium	Raw	5g	38.92985	0	0	37.30572	0	0	1.624132
Sand	Raw	tn.lg	1.254599	1.254596	1.45E-06	4.37E-07	1.28E-08	0	6.42E-07
Scandium	Air	fg	5202.059	0	1347.017	86.16193	7.540385	0	3761.34
Scandium	Water	fg	640364.7	0	118581.9	59504.73	6284.474	0	455993.7
Selenium	Air	m3/g	3.087587	3.020935	0.013452	0.004625	0.000439	0.011814	0.036322
Selenium	Water	m3/g	1.228053	0.143671	0.164308	0.127036	0.01287	0.015874	0.764295
Selenium	Soil	5g	19.74769	0	0	10.99597	0	0	8.751714
Sethoxydim	Air	5g	0.467444	0	0	0.021247	0	0	0.446197
Sethoxydim	Soil	5g	2.920128	0	1.012132	0.085984	0.005328	0	1.816685
Shale	Raw	tn.lg	1.61704	1.617035	1.34E-06	1.63E-06	7.82E-09	0	1.83E-06
Silicon	Air	m3/g	1.139117	0	0.373911	0.416448	0.009691	0	0.339067
Silicon	Water	kgCOD	3.915291	0	0.955183	0.392291	0.023567	0	2.544251
Silicon	Soil	fg	860695.5	0	364361.2	55177.69	280.0818	0	440876.5

Silicon dioxide	Water	5g	324.5871	0	0	313.416	0	0	11.17113
Silicon tetrachloride	Air	5g	38.24278	0	0	36.9266	0	0	1.31618
Silicon tetrafluoride	Air	5g	24.05026	0	11.21931	8.740811	0.089722	0	4.000421
Silthiofam	Soil	5g	0.367296	0	0	0.011487	0	0	0.355809
Silver	Air	5g	286.7765	0	117.4139	11.1313	0.537405	0	157.6939
Silver	Water	m3/g	7.049454	4.042621	0.081001	0.009825	0.001294	2.822855	0.091858
Silver	Soil	5g	0.098984	0	0	0.055117	0	0	0.043867
Silver-110	Air	5Bq	176.6892	0	0.078991	2.123414	0.000256	0	174.4865
Silver-110	Water	eBq	40067062	0	60980.72	366590.9	1768.815	0	39637722
Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In	Raw	fg	35486.11	0	9351.7	20631.79	26.79868	0	5475.822
Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore	Raw	fg	6695.705	0	6673.734	2.717244	19.22165	0	0.032076
Silver, Ag 1.5E-4%, Au 6.8E-4%, in ore	Raw	5g	3.010661	0	0	2.989826	0	0	0.020835
Silver, Ag 1.5E-5%, Au 5.4E-4%, in ore	Raw	5g	0.275587	0	0	0.27368	0	0	0.001907
Silver, Ag 1.8E-6%, in mixed ore, in ground	Raw	5g	1.015211	0	0	0.62037	0	0	0.394841
Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore	Raw	5g	749.003	0	615.8423	130.5595	1.773418	0	0.827817
Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore	Raw	fg	14158.81	0	1406.513	12649.82	4.050283	0	98.42328
Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore	Raw	fg	1595.741	0	1378.618	211.8144	3.969956	0	1.338222
Silver, Ag 5.4E-3%, in mixed ore	Raw	5g	208.1273	0	0	185.6932	0	0	22.43414
Silver, Ag 7.6E-5%, Au 9.7E-5%, in ore	Raw	5g	38.01995	0	0	37.75683	0	0	0.263116

Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore	Raw	fg	15472.07	0	909.6873	10016.14	2.619593	0	4543.617
Simazine	Soil	5g	14.64794	0	0.552578	0.799821	0.00258	0	13.29297
Slate	Raw	kgCOD	35.56653	35.5665	2.92E-05	0	1.67E-07	0	0
Sodium	Air	fg	286110.7	0	147511.9	27423.25	689.0967	0	110486.5
Sodium	Water	kgCOD	40.13993	19.6437	3.605342	0.251096	0.00881	13.68622	2.944761
Sodium	Soil	m3/g	11.86671	0	9.136247	2.075744	0.003972	0	0.65075
Sodium-24	Water	eBq	602172.7	0	277.674	7108.118	0.899888	0	594786
Sodium carbonate	Raw	fg	68423.13	0	68033.05	0	390.0799	0	0
Sodium chlorate	Air	5g	193.0881	0	125.7561	24.34979	0.950619	0	42.03159
Sodium chlorate	Water	5g	18.46653	0	0	0.774375	0	0	17.69215
Sodium chloride	Raw	kgCOD	1.89051	0	1.657004	0.19277	0.008164	0	0.032572
Sodium dichromate	Air	5g	429.749	0	192.1419	189.909	5.359912	0	42.33814
Sodium formate	Air	5g	25.60995	0	6.141012	14.66122	0.105597	0	4.702123
Sodium formate	Water	5g	61.52633	0	14.7534	35.22268	0.253689	0	11.29656
Sodium hydroxide	Air	fg	2782.126	0	1154.721	1247.538	371.121	0	8.746449
Sodium nitrate	Raw	5g	0.949525	0	0.772431	0.058609	0.02315	0	0.095335
Sodium sulfate	Raw	m3/g	3.155419	0	2.698142	0.221487	0.022576	0	0.213214
Sodium tetrahydroborate	Air	5g	90.41786	0	0	82.02391	0	0	8.393954
Solids, inorganic	Water	oz	13.37606	2.79E-06	0.284386	0.30865	0.003149	3.74E-08	12.77988
Spinosad	Soil	5g	0.098566	0	0.027738	0.002828	0.000252	0	0.067748
Spiroxamine	Soil	5g	3.807589	0	0	0.23356	0	0	3.574029
Spodumene	Raw	fg	162131.9	0	0	160836.3	0	0	1295.592
Stibnite	Raw	5g	154.0207	0	34.35644	95.44914	0.00132	0	24.21382
Strontium	Raw	fg	24162.18	0	0	19302.66	0	0	4859.525
Strontium	Air	fg	78870.57	0	3820.992	10866.36	96.80131	0	64086.42
Strontium	Water	oz	10.51707	3.70772	0.900896	0.173322	0.011356	2.584408	3.139369
Strontium	Soil	fg	36276.64	0	32740.57	293.0759	13.62072	0	3229.378
Strontium-89	Water	eBq	998817.5	0	1794.171	9372.526	74.43386	0	987576.4

Strontium-90	Water	eBq	50582083	0	2259861	20444222	28717.21	0	27849283
Styrene	Air	fg	44954	42123.24	822.0986	465.148	860.6368	0.101385	682.7797
Sulfate	Air	m3/g	3.113586	0	1.499788	0.27069	0.011001	0	1.332108
Sulfate	Water	kgCOD	45.2834	20.31411	2.449083	1.475673	0.114953	0.108242	20.82134
Sulfate	Soil	fg	2477.66	0	0	1379.619	0	0	1098.041
Sulfentrazone	Air	5g	4.469912	0	0	0.203171	0	0	4.266741
Sulfentrazone	Soil	5g	120.1659	0	84.74153	1.404548	0.013334	0	34.00646
Sulfide	Water	m3/g	2.186983	2.104271	0.011085	0.000697	1.10E-05	0.066226	0.004693
Sulfite	Water	fg	102444.6	0	21765.14	9877.438	216.5558	0	70585.49
Sulfosate	Soil	5g	494.0117	0	348.9357	5.747572	0.054905	0	139.2735
Sulfosulfuron	Soil	5g	0.098175	0	0	0.00307	0	0	0.095105
Sulfur	Raw	fg	865356.6	0	201980.7	449928.9	5401.051	0	208046
Sulfur	Water	m3/g	9.999681	5.108466	1.136465	0.026622	0.000815	3.560694	0.166618
Sulfur	Soil	m3/g	2.223382	0	1.956918	0.023703	0.00086	0	0.241901
Sulfur dioxide	Air	kgCOD	136.7589	134.7258	0.591651	0.119899	0.003838	0.593639	0.724064
Sulfur hexafluoride	Air	fg	69261.94	0	9822.56	4403.156	34.04662	0	55002.17
Sulfur monoxide	Air	kgCOD	2.213007	1.263978	7.94E-05	0	4.55E-07	0.948949	0
Sulfur oxides	Air	oz	8.076079	0	0	4.47E-05	0	8.076022	1.23E-05
Sulfur trioxide	Air	5g	246.2449	0	30.61139	22.55458	0.250431	0	192.8285
Sulfuric acid	Air	fg	7887.626	0	242.5523	6108.59	61.87119	0	1474.612
Sulfuric acid	Soil	fg	17374.15	0	4889.496	498.4134	44.46226	0	11941.78
Sulfuric acid, dimethyl ester	Air	fg	80876.87	80876.61	0.066473	0	0.00038	0.19466	0
Suspended solids, unspecified	Water	kgCOD	162.7758	95.97273	1.500118	0.045399	0.008329	63.43712	1.812111
t-Butyl methyl ether	Air	fg	59562.96	58972.53	406.4507	76.19771	0.202193	0.141939	107.4347
t-Butyl methyl ether	Water	fg	11988.25	0	11974.33	4.910735	3.921087	0	5.091662
t-Butylamine	Air	5g	3.068358	0	0.164884	0.221138	0.001213	0	2.681123
t-Butylamine	Water	5g	7.364132	0	0.395722	0.530738	0.002912	0	6.434761
Talc	Raw	fg	228034.5	0	82278.28	65858.91	6275.24	0	73622.09
Tantalum	Raw	fg	44590.92	0	7330.818	36838.2	2.582014	0	419.3161
Tar	Air	5g	55.49854	54.76362	0	0	0	0.734923	0
Tar	Water	5g	0.793894	0.783381	0	0	0	0.010513	0
Tebuconazole	Air	5g	1.36E-06	0	0	4.27E-08	0	0	1.32E-06

Tebuconazole	Water	5g	4.22E-07	0	0	1.32E-08	0	0	4.09E-07
Tebuconazole	Soil	5g	8.356283	0	0	0.534864	0	0	7.82142
Tebufenpyrad	Soil	5g	7.884589	0	0	0.324759	0	0	7.55983
Tebupirimphos	Soil	5g	6.091559	0	0.229797	0.332617	0.001073	0	5.528071
Tebutam	Soil	5g	218.0404	0	0.001836	94.99042	4.30E-06	0	123.0481
Technetium-99m	Water	eBq	1319514	0	843.3555	12010.1	2.732939	0	1306658
Teflubenzuron	Soil	5g	1.817818	0	0.167656	0.308662	0.001522	0	1.339978
Tefluthrin	Air	5g	0.034969	0	0	0.001039	0	0	0.03393
Tefluthrin	Water	5g	1.71E-07	0	0	5.09E-09	0	0	1.66E-07
Tefluthrin	Soil	5g	4.904996	0	0.180546	0.264884	0.000843	0	4.458723
Tellurium	Raw	fg	1004.372	0	1001.077	0.407591	2.883295	0	0.004811
Tellurium-123m	Water	eBq	91180.93	0	1205.221	1538.334	60.2692	0	88377.1
Tellurium-132	Water	eBq	4753.108	0	2.124942	57.12187	0.006887	0	4693.854
Terbacil	Soil	fg	1388.244	0	0	55.61916	0	0	1332.625
Terbufos	Soil	5g	17.43957	0	0.612755	1.696374	0.002861	0	15.12758
Terpenes	Air	5g	574.0623	0	179.3951	29.51429	0.119953	0	365.033
Tetradecane	Water	fg	79313.27	46735.59	2.111014	0	0.012103	32575.55	0
Tetramethyl ammonium hydroxide	Air	fg	3266.2	0	0	2962.984	0	0	303.2165
Thallium	Air	5g	161.9499	0	115.2552	31.08323	0.704979	0	14.90652
Thallium	Water	fg	73128.27	8919.967	13488.37	12435.05	1547.272	15274.61	21462.99
Thiamethoxam	Soil	5g	12.05174	0	1.220488	0.447926	0.011099	0	10.37223
Thiazole, 2-(thiocyanatemethylthio)benzo-	Soil	fg	1435.52	0	403.9804	41.18082	3.673674	0	986.685
Thidiazuron	Soil	5g	7.872319	0	0	0.330118	0	0	7.542201
Thifensulfuron	Air	5g	0.063707	0	0	0.002896	0	0	0.060812
Thifensulfuron-methyl	Soil	5g	0.075723	0	0	0.002757	0	0	0.072967
Thiodicarb	Air	5g	0.227039	0	0	0.01032	0	0	0.216719
Thiodicarb	Soil	5g	0.009733	0	0	0.000442	0	0	0.00929
Thiram	Soil	5g	2.790412	0	0.816736	1.106903	0.000546	0	0.866228
Thorium	Air	5g	79.18361	0	33.15391	34.38576	0.841894	0	10.80204
Thorium-228	Air	eBq	3088822	0	494781.2	496090.1	4411.596	0	2093539
Thorium-228	Water	eBq	1.63E+09	0	1.60E+09	8584013	410750.8	0	17576779

Thorium-230	Air	eBq	4649723	0	1156196	164334.8	5086.649	0	3324106
Thorium-230	Water	eBq	1.04E+09	0	2.74E+08	12638867	1444106	0	7.51E+08
Thorium-232	Air	eBq	3640906	0	487743	644762.6	3967.964	0	2504433
Thorium-232	Water	eBq	4221168	0	1199623	210616.3	6323.245	0	2804606
Thorium-234	Air	eBq	3623726	0	840957.7	129480.1	3376.138	0	2649912
Thorium-234	Water	eBq	11040964	0	2009436	149336.4	10588.15	0	8871603
Tin	Raw	fg	735903.4	0	369341.4	352834.1	1775.662	0	11952.15
Tin	Air	fg	10533.47	0	4470.01	3392.535	603.6328	0	2067.289
Tin	Water	m3/g	1.835443	0.265077	0.120116	1.011465	0.015259	0.294961	0.128564
Tin	Soil	5g	19.20015	0	17.4333	1.523262	0.152967	0	0.090622
TiO2, 54% in ilmenite, 18% in crude ore	Raw	fg	437894.4	0	0	42283.25	0	0	395611.2
TiO2, 54% in ilmenite, 2.6% in crude ore	Raw	oz	1.475032	0	1.260236	0.022134	0.002572	0	0.190089
TiO2, 95% in rutile, 0.40% in crude ore	Raw	fg	926701.2	0	495.8884	96964.32	7.49E-01	0	829240.2
Titanium	Air	fg	117348.7	0	37515.27	8563.35	306.7437	0	70963.36
Titanium	Water	oz	1.240559	0.022915	0.31995	0.678666	0.009389	0.039267	0.170371
Titanium	Soil	fg	8222.067	0	205.6283	1037.187	0.987314	0	6978.264
TOC, Total Organic Carbon	Water	EU	1.039653	0	0.963483	0.039364	0.001989	0	0.034817
Toluene	Air	m3/g	12.41308	0.456182	5.72628	0.060966	0.006833	2.601563	3.56126
Toluene	Water	m3/g	6.320534	3.055964	1.052702	0.006746	0.000542	2.130065	0.074516
Toluene, 2-chloro-	Air	5g	11.07366	0	1.407537	0.456187	0.01093	0	9.199009
Toluene, 2-chloro-	Water	5g	21.28199	0	2.711444	0.877583	0.021261	0	17.6717
Toluene, 2,4-dinitro-	Air	5g	471.7818	471.7802	0.000388	0	2.22E-06	0.001136	0
Tolylfluanid	Soil	5g	324.8562	0	0	13.01517	0	0	311.8411
Tralkoxydim	Soil	5g	15.86822	0	0	0.526888	0	0	15.34133
Transformation, from arable	Raw	sq.in	342.0805	0	3.066291	15.68619	0.033901	0	323.2941
Transformation, from arable, greenhouse	Raw	sq.in	3.021277	0	0	0.121046	0	0	2.900231
Transformation, from arable,	Raw	sq.in	54.31768	0	0	2.088096	0	0	52.22958

irrigated, intensive									
Transformation, from arable, non-irrigated	Raw	sq.in	180.0862	0	173.2478	3.724615	0.03215	0	3.081617
Transformation, from arable, non-irrigated, extensive	Raw	sq.in	340.8175	0	0	11.50795	0	0	329.3096
Transformation, from arable, non-irrigated, fallow	Raw	sq.in	0.051855	0	0.048718	0	0.003137	0	0
Transformation, from arable, non-irrigated, intensive	Raw	sq.in	124.7443	0	0	7.251021	0	0	117.4933
Transformation, from cropland fallow (non-use)	Raw	sq.in	0.380054	0	0	0.369341	0	0	0.010713
Transformation, from dump site, inert material landfill	Raw	sq.in	3.769659	0	3.311985	0.07452	0.002659	0	0.380495
Transformation, from dump site, residual material landfill	Raw	sq.in	0.843982	0	0.52644	0.259053	0.013724	0	0.044765
Transformation, from dump site, sanitary landfill	Raw	sq.in	0.014955	0	0.005837	0.004624	2.76E-05	0	0.004466
Transformation, from dump site, slag compartment	Raw	sq.in	0.121204	0	0.010527	0.10389	7.73E-05	0	0.00671
Transformation, from forest	Raw	sq.in	226.1588	0	208.5381	2.233909	0.062445	0	15.32434
Transformation, from forest, extensive	Raw	sq.in	27.73723	0	20.36397	2.547647	0.143167	0	4.682444
Transformation, from forest, intensive	Raw	sq.in	91.83086	0	0	13.68652	0	0	78.14434
Transformation, from forest, intensive, clear-cutting	Raw	sq.in	0.307118	0	0.306913	0	0.000205	0	0

Transformation, from forest, primary	Raw	sq.in	1.955282	0	0	0.120989	0	0	1.834293
Transformation, from grassland, not used	Raw	sq.in	0.00094	0	0	0.000527	0	0	0.000413
Transformation, from heterogeneous, agricultural	Raw	sq.in	0.000357	0	0	2.08E-05	0	0	0.000336
Transformation, from industrial area	Raw	sq.in	0.514567	0	0.143969	0.02366	0.000406	0	0.346532
Transformation, from industrial area, benthos	Raw	sq.in	4.44E-05	0	4.39E-05	0	5.04E-07	0	0
Transformation, from industrial area, built up	Raw	sq.in	0.000828	0	0.000821	0	6.57E-06	0	0
Transformation, from industrial area, vegetation	Raw	sq.in	0.001412	0	0.001401	0	1.12E-05	0	0
Transformation, from mineral extraction site	Raw	sq.in	12.24477	0	2.99814	2.927097	0.020578	0	6.298956
Transformation, from pasture and meadow	Raw	sq.in	9.976872	0	6.653252	0.946123	0.035023	0	2.342474
Transformation, from pasture and meadow, extensive	Raw	sq.in	0.002631	0	0	0.00213	0	0	0.000502
Transformation, from pasture and meadow, intensive	Raw	sq.in	29.14237	0	7.57E-06	1.212067	1.77E-08	0	27.9303
Transformation, from permanent crop	Raw	sq.in	0.071279	0	0	0.039987	0	0	0.031292
Transformation, from permanent crops, irrigated, intensive	Raw	sq.in	14.15621	0	0	0.56716	0	0	13.58905

Transformation, from permanent crops, non-irrigated, intensive	Raw	sq.in	18.48108	0	0	0.742151	0	0	17.73893
Transformation, from sea and ocean	Raw	sq.in	50.53169	0	49.73859	0.370788	0.016198	0	0.406117
Transformation, from seabed, infrastructure	Raw	sq.in	0.000242	0	0	2.39E-05	0	0	0.000218
Transformation, from shrub land, sclerophyllous	Raw	sq.in	7.648347	0	4.124181	0.658452	0.024478	0	2.841236
Transformation, from traffic area, rail/road embankment	Raw	sq.in	0.533054	0	0	0.107783	0	0	0.425272
Transformation, from traffic area, road network	Raw	sq.in	0.000887	0	0	0.000834	0	0	5.32E-05
Transformation, from tropical rain forest	Raw	sq.in	0.307118	0	0.306913	0	0.000205	0	0
Transformation, from unknown	Raw	sq.in	94.26911	0	61.34449	8.977282	0.141165	0	23.80618
Transformation, from unspecified, natural	Raw	sq.in	0.042386	0	0	0.000451	0	0	0.041935
Transformation, from wetland, inland (non-use)	Raw	sq.in	0.018315	0	0	0.017212	0	0	0.001103
Transformation, to arable	Raw	sq.in	172.5097	0	3.3998	8.243057	0.036599	0	160.8303
Transformation, to arable, fallow	Raw	sq.in	0.42414	0	0	0.400539	0	0	0.023601
Transformation, to arable, greenhouse	Raw	sq.in	3.021277	0	0	0.121046	0	0	2.900231
Transformation, to arable, irrigated, extensive	Raw	sq.in	2.237551	0	0	0.089646	0	0	2.147905
Transformation, to arable,	Raw	sq.in	52.96018	0	0	2.593861	0	0	50.36632

irrigated, intensive									
Transformation, to arable, non-irrigated	Raw	sq.in	174.1466	0	173.2554	0.12248	0.032185	0	0.736578
Transformation, to arable, non-irrigated, extensive	Raw	sq.in	341.3826	0	0	11.6476	0	0	329.735
Transformation, to arable, non-irrigated, fallow	Raw	sq.in	0.079451	0	0.076031	0	0.00342	0	0
Transformation, to arable, non-irrigated, intensive	Raw	sq.in	308.0364	0	0	18.0707	0	0	289.9657
Transformation, to dump site	Raw	sq.in	12.03603	0	3.298451	1.595347	0.05043	0	7.091802
Transformation, to dump site, benthos	Raw	sq.in	49.70492	0	49.68887	0	0.016052	0	0
Transformation, to dump site, inert material landfill	Raw	sq.in	3.769659	0	3.311985	0.07452	0.002659	0	0.380495
Transformation, to dump site, residual material landfill	Raw	sq.in	0.844222	0	0.526455	0.259215	0.013725	0	0.044827
Transformation, to dump site, sanitary landfill	Raw	sq.in	0.014955	0	0.005837	0.004624	2.76E-05	0	0.004466
Transformation, to dump site, slag compartment	Raw	sq.in	0.121204	0	0.010527	0.10389	7.73E-05	0	0.00671
Transformation, to forest	Raw	sq.in	7.225675	0	5.75955	0.881403	0.021256	0	0.563466
Transformation, to forest, extensive	Raw	sq.in	6.042598	0	0	1.774842	0	0	4.267757
Transformation, to forest, intensive	Raw	sq.in	94.51843	0	1.864372	14.12624	0.00572	0	78.52209
Transformation, to forest, intensive, clear-cutting	Raw	sq.in	0.307118	0	0.306913	0	0.000205	0	0
Transformation, to forest,	Raw	sq.in	18.20947	0	18.07594	0	0.133531	0	0

intensive, normal									
Transformation, to forest, intensive, short-cycle	Raw	sq.in	0.307118	0	0.306913	0	0.000205	0	0
Transformation, to forest, secondary (non-use)	Raw	sq.in	0.001045	0	0	0.000982	0	0	6.27E-05
Transformation, to grassland, natural (non-use)	Raw	sq.in	1.600094	0	0	0.095246	0	0	1.504848
Transformation, to heterogeneous, agricultural	Raw	sq.in	11.4817	0	10.51961	0.124383	0.003458	0	0.834254
Transformation, to industrial area	Raw	sq.in	12.80951	0	3.309359	3.21784	0.022669	0	6.259638
Transformation, to industrial area, benthos	Raw	sq.in	0.049864	0	0.049718	0	0.000146	0	0
Transformation, to industrial area, built up	Raw	sq.in	2.65216	0	2.623829	0	0.02833	0	0
Transformation, to industrial area, vegetation	Raw	sq.in	2.853516	0	2.845929	0	0.007587	0	0
Transformation, to inland waterbody, unspecified	Raw	sq.in	0.002145	0	0	0.001713	0	0	0.000431
Transformation, to mineral extraction site	Raw	sq.in	254.4893	0	226.1734	5.122733	0.097231	0	23.0959
Transformation, to pasture and meadow	Raw	sq.in	0.15963	0	0.009514	0.017134	7.02E-05	0	0.132913
Transformation, to pasture and meadow, extensive	Raw	sq.in	0.002631	0	0	0.00213	0	0	0.000502
Transformation, to pasture and meadow, intensive	Raw	sq.in	27.87912	0	0	0.860548	0	0	27.01857
Transformation, to permanent crop	Raw	sq.in	0.145699	0	0	0.081735	0	0	0.063963
Transformation, to	Raw	sq.in	0.176852	0	0.176803	0	4.95E-05	0	0

permanent crop, fruit, intensive									
Transformation, to permanent crops, irrigated, intensive	Raw	sq.in	14.18638	0	0	0.58769	0	0	13.59869
Transformation, to permanent crops, non-irrigated	Raw	sq.in	0.001045	0	0	0.000982	0	0	6.27E-05
Transformation, to permanent crops, non-irrigated, intensive	Raw	sq.in	18.48108	0	0	0.742151	0	0	17.73893
Transformation, to sea and ocean	Raw	sq.in	4.44E-05	0	4.39E-05	0	5.04E-07	0	0
Transformation, to seabed, drilling and mining	Raw	sq.in	0.744914	0	0	0.342912	0	0	0.402002
Transformation, to seabed, infrastructure	Raw	sq.in	0.031992	0	0	0.027877	0	0	0.004115
Transformation, to seabed, unspecified	Raw	sq.in	0.000242	0	0	2.39E-05	0	0	0.000218
Transformation, to shrub land, sclerophyllous	Raw	sq.in	4.7498	0	3.854789	0.442087	0.016488	0	0.436436
Transformation, to traffic area, rail network	Raw	sq.in	0.276039	0	0.120374	0.017901	0.000394	0	0.137371
Transformation, to traffic area, rail/road embankment	Raw	sq.in	0.865839	0	0.109513	0.165124	0.000358	0	0.590843
Transformation, to traffic area, road embankment	Raw	sq.in	2.863782	0	2.862311	0	0.001472	0	0
Transformation, to traffic area, road network	Raw	sq.in	14.14082	0	12.9121	0.572852	0.012075	0	0.643793
Transformation, to unknown	Raw	sq.in	2.119208	0	0.868526	0.857298	0.002242	0	0.391141

Transformation, to urban, discontinuously built	Raw	sq.in	0.035727	0	0.001453	0.009136	2.67E-06	0	0.025136
Transformation, to urban/industrial fallow	Raw	sq.in	0.001505	0	0	0.00045	0	0	0.001055
Transformation, to water bodies, artificial	Raw	sq.in	13.04002	0	5.979506	2.974949	0.003876	0	4.081689
Transformation, to water courses, artificial	Raw	sq.in	2.553788	0	2.536623	0	0.017164	0	0
Transformation, to wetland, inland (non-use)	Raw	sq.in	0.003309	0	0	0.003111	0	0	0.000198
Triadimenol	Soil	5g	0.217077	0	0	0.015173	0	0	0.201904
Triallate	Soil	5g	0.2209	0	0	0.006909	0	0	0.213991
Triasulfuron	Soil	5g	0.065452	0	0	0.002047	0	0	0.063405
Tribenuron	Soil	5g	0.016762	0	0	0.001396	0	0	0.015366
Tribenuron-methyl	Soil	5g	0.442691	0	0	0.014573	0	0	0.428118
Tribufos	Soil	5g	73.62459	0	0	3.087373	0	0	70.53722
Tributyltin compounds	Water	fg	8716.552	0	8144.143	414.6897	13.76272	0	143.9568
Trichlorfon	Soil	5g	0.073924	0	0.020804	0.002121	0.000189	0	0.050811
Triclopyr	Soil	5g	21.61435	0	0	6.269758	0	0	15.34459
Triethylene glycol	Water	5g	317.3529	0	25.62863	186.7374	0.059428	0	104.9274
Trifloxystrobin	Air	5g	0.040762	0	0	0.001853	0	0	0.03891
Trifloxystrobin	Water	5g	1.58E-08	0	0	4.95E-10	0	0	1.53E-08
Trifloxystrobin	Soil	5g	167.5603	0	0	6.704252	0	0	160.856
Trifluralin	Air	5g	64.38001	0	0	2.926265	0	0	61.45374
Trifluralin	Soil	fg	1343.498	0	497.0849	44.11256	0.106574	0	802.1943
Triforine	Soil	5g	31.10099	0	0	1.246042	0	0	29.85495
Trimethylamine	Air	5g	0.784574	0	0.089682	0.033785	0.000618	0	0.660488
Trimethylamine	Water	5g	1.920323	0	0.252409	0.081085	0.001658	0	1.585172
Trinexapac-ethyl	Soil	5g	14.57818	0	0	0.550887	0	0	14.02729
Tungsten	Air	5g	581.1243	0	148.9558	7.14135	0.784943	0	424.2423
Tungsten	Water	fg	448640.1	0	165779.1	173694.7	22441.54	0	86724.72

Ulexite	Raw	fg	110124	0	29025.54	24768.85	98.23651	0	56231.33
Unspecified input	Raw	kgCOD	830.9341	830.9341	0	0	0	0	0
Uranium	Raw	m3/g	2.59144	0	0.453937	0.035979	0.002412	0	2.099112
Uranium	Air	5g	88.00802	0	27.03626	45.692	1.031483	0	14.24827
Uranium-234	Air	eBq	11063583	0	2717444	324986.9	12308.59	0	8008843
Uranium-234	Water	eBq	12859828	0	2410222	172778	12701	0	10264127
Uranium-235	Air	eBq	248099.7	0	61460.67	3084.359	323.8755	0	183230.8
Uranium-235	Water	eBq	15643066	0	3976867	192781.4	20956.65	0	11452461
Uranium-238	Air	eBq	15133814	0	2831348	2136453	18481.67	0	10147530
Uranium-238	Water	eBq	38878925	0	11079130	1068754	62792.97	0	26668248
Uranium alpha	Air	eBq	27330631	0	5870205	354492.4	30988.87	0	21074945
Uranium alpha	Water	eBq	4.68E+08	0	1.16E+08	5828296	609530.2	0	3.46E+08
Uranium oxide, 332 GJ per kg, in ore	Raw	oz	1.218557	1.202439	0	0	0	0.016118	0
Urea	Water	5g	3.642441	0	0.410241	0.168983	0.002843	0	3.060374
Vanadium	Air	fg	200000.8	0	137187	17410.47	520.7623	0	44882.61
Vanadium	Water	m3/g	3.042212	0.052358	0.957061	0.864633	0.021443	0.036494	1.110223
Vanadium	Soil	5g	225.6231	0	5.885285	24.27624	0.028258	0	195.4333
Vermiculite	Raw	m3/g	2.252731	0	0.007621	1.828641	6.91E-05	0	0.4164
Vinclozolin	Soil	5g	0.242126	0	0	0.014658	0	0	0.227467
Vinyl acetate	Air	fg	12805.51	12805.46	0.010525	0	6.02E-05	0.030821	0
VOC, volatile organic compounds	Air	kgCOD	3.071793	2.512291	0.001592	0	9.13E-06	0.557901	0
VOC, volatile organic compounds, unspecified origin	Water	m3/g	2.879653	0	2.8134	0.015327	0.000744	0	0.050182
Volume occupied, final repository for low-active radioactive waste	Raw	ml	6.586731	0	0.655041	0.197203	0.003787	0	5.7307
Volume occupied, final repository for radioactive waste	Raw	ml	0.860463	0	0.137144	0.013938	0.000853	0	0.708528
Volume occupied, reservoir	Raw	cm*m2/d	2.524858	0	0.226274	0.493742	0.004007	0	1.800834

Volume occupied, underground deposit	Raw	ml	10.75276	0	4.94038	0.753695	0.364572	0	4.69411
Water	Air	m3/g	11.70043	0	11.39133	0	0.309101	0	0
Water, AT	Water	Nm3	1.890201	0	0	1.091815	0	0	0.798386
Water, AU	Water	CCF	1.15753	0	0	1.067314	0	0	0.090215
Water, BA	Water	GPU	1.271257	0	0	1.233806	0	0	0.037451
Water, BE	Water	cuft	1.191374	0	0	0.714645	0	0	0.476729
Water, BG	Water	Bales	1.963601	0	0	1.207831	0	0	0.755771
Water, BR	Water	CCF	2.229298	0	0	1.865484	0	0	0.363814
Water, CA	Water	MCF	2.040693	0	0	0.803306	0	0	1.237387
Water, CH	Water	Nm3	2.022104	0	0	0.598672	0	0	1.423431
Water, CL	Water	Bales	6.237301	0	0	3.315138	0	0	2.922163
Water, CN	Water	MCF	2.039848	0	0	1.621068	0	0	0.41878
Water, CO	Water	ml	0.342593	0	0	0.192189	0	0	0.150404
Water, cooling, unspecified natural origin, AT	Raw	dm3	1.569254	0	0	1.048265	0	0	0.520989
Water, cooling, unspecified natural origin, AU	Raw	bushel	1.077705	0	0	0.959485	0	0	0.11822
Water, cooling, unspecified natural origin, BA	Raw	ml	938.9824	0	0	750.5706	0	0	188.4118
Water, cooling, unspecified natural origin, BE	Raw	gal*	1.366537	0	0	0.856152	0	0	0.510384
Water, cooling, unspecified natural origin, BG	Raw	dm3	3.441813	0	0	2.17314	0	0	1.268673
Water, cooling, unspecified natural origin, BR	Raw	gal*	1.681733	0	0	1.217896	0	0	0.463837
Water, cooling, unspecified	Raw	Bales	4.030327	0	0	0.102429	0	0	3.927897

natural origin, CA									
Water, cooling, unspecified natural origin, CH	Raw	gal*	2.370188	0	0	0.742182	0	0	1.628005
Water, cooling, unspecified natural origin, CL	Raw	dm3	1.302456	0	0	0.692258	0	0	0.610198
Water, cooling, unspecified natural origin, CN	Raw	Bales	5.382592	0	0	4.636473	0	0	0.746118
Water, cooling, unspecified natural origin, CY	Raw	ml	164.5309	0	0	86.22285	0	0	78.30803
Water, cooling, unspecified natural origin, CZ	Raw	gal*	6.774167	0	0	4.234216	0	0	2.539951
Water, cooling, unspecified natural origin, DE	Raw	bushel	1.326124	0	0	0.872257	0	0	0.453867
Water, cooling, unspecified natural origin, DK	Raw	dm3	1.39793	0	0	0.993693	0	0	0.404238
Water, cooling, unspecified natural origin, EE	Raw	ml	792.3748	0	0	489.6824	0	0	302.6924
Water, cooling, unspecified natural origin, ES	Raw	gal*	4.956865	0	0	3.610593	0	0	1.346272
Water, cooling, unspecified natural origin, Europe without Switzerland	Raw	dm3	2.423187	0	0	1.546368	0	0	0.876819
Water, cooling,	Raw	dm3	2.838361	0	0	1.854977	0	0	0.983384

unspecified natural origin, FI									
Water, cooling, unspecified natural origin, FR	Raw	Bales	1.000714	0	0	0.363723	0	0	0.636991
Water, cooling, unspecified natural origin, GB	Raw	gal*	4.656833	0	0	2.970947	0	0	1.685886
Water, cooling, unspecified natural origin, GLO	Raw	gal*	1.762459	0	0	1.194421	0	0	0.568038
Water, cooling, unspecified natural origin, GR	Raw	gal*	2.642806	0	0	1.825541	0	0	0.817266
Water, cooling, unspecified natural origin, HR	Raw	ml	619.0602	0	0	432.4643	0	0	186.5959
Water, cooling, unspecified natural origin, HU	Raw	dm3	2.855327	0	0	1.829823	0	0	1.025504
Water, cooling, unspecified natural origin, ID	Raw	gal*	2.994612	0	0	2.181855	0	0	0.812757
Water, cooling, unspecified natural origin, IE	Raw	dm3	1.161601	0	0	0.739091	0	0	0.42251
Water, cooling, unspecified natural origin, IN	Raw	bushel	2.345583	0	0	1.834298	0	0	0.511285
Water, cooling, unspecified natural origin, IR	Raw	gal*	2.740523	0	0	1.487987	0	0	1.252536
Water, cooling, unspecified	Raw	ml	2.380766	0	0	2.231713	0	0	0.149054

natural origin, IS									
Water, cooling, unspecified natural origin, IT	Raw	gal*	3.750986	0	0	2.572282	0	0	1.178704
Water, cooling, unspecified natural origin, JP	Raw	gal*	6.167273	0	0	3.290404	0	0	2.876869
Water, cooling, unspecified natural origin, KR	Raw	gal*	4.428322	0	0	2.411998	0	0	2.016325
Water, cooling, unspecified natural origin, LT	Raw	ml	539.6161	0	0	408.1684	0	0	131.4477
Water, cooling, unspecified natural origin, LU	Raw	ml	221.6579	0	0	147.4278	0	0	74.23003
Water, cooling, unspecified natural origin, LV	Raw	ml	454.7671	0	0	356.6035	0	0	98.16358
Water, cooling, unspecified natural origin, MA	Raw	ml	15.39582	0	0	10.56146	0	0	4.834355
Water, cooling, unspecified natural origin, MK	Raw	ml	329.2377	0	0	208.2381	0	0	120.9996
Water, cooling, unspecified natural origin, MT	Raw	ml	179.888	0	0	110.4671	0	0	69.42088
Water, cooling, unspecified natural origin, MX	Raw	gal*	1.939884	0	0	1.024729	0	0	0.915155
Water, cooling, unspecified	Raw	dm3	2.955335	0	0	1.437002	0	0	1.518332

natural origin, MY									
Water, cooling, unspecified natural origin, NL	Raw	gal*	2.005232	0	0	1.422633	0	0	0.582599
Water, cooling, unspecified natural origin, NO	Raw	ml	500.3983	0	0	437.2532	0	0	63.14513
Water, cooling, unspecified natural origin, PE	Raw	ml	734.545	0	0	408.3726	0	0	326.1724
Water, cooling, unspecified natural origin, PH	Raw	ml	1.338113	0	0	0.90689	0	0	0.431223
Water, cooling, unspecified natural origin, PL	Raw	bushel	1.048469	0	0	0.642195	0	0	0.406274
Water, cooling, unspecified natural origin, PT	Raw	dm3	1.803661	0	0	1.216189	0	0	0.587471
Water, cooling, unspecified natural origin, RER	Raw	Bales	1.096215	0	0	0.82448	0	0	0.271735
Water, cooling, unspecified natural origin, RNA	Raw	ml	0.013797	0	0	0.010641	0	0	0.003156
Water, cooling, unspecified natural origin, RO	Raw	gal*	2.264043	0	0	1.835964	0	0	0.428079
Water, cooling, unspecified natural origin, RoW	Raw	Bales	5.19055	0	0	3.684423	0	0	1.506127
Water, cooling, unspecified	Raw	dm3	2.034421	0	0	1.274779	0	0	0.759642

natural origin, RS									
Water, cooling, unspecified natural origin, RU	Raw	Bales	1.907213	0	0	1.227914	0	0	0.679299
Water, cooling, unspecified natural origin, SA	Raw	gal*	3.311643	0	0	1.887079	0	0	1.424564
Water, cooling, unspecified natural origin, SE	Raw	gal*	1.872571	0	0	1.314452	0	0	0.558119
Water, cooling, unspecified natural origin, SI	Raw	gal*	1.688697	0	0	1.194694	0	0	0.494003
Water, cooling, unspecified natural origin, SK	Raw	gal*	2.736561	0	0	2.229755	0	0	0.506806
Water, cooling, unspecified natural origin, TH	Raw	gal*	1.08691	0	0	0.570758	0	0	0.516152
Water, cooling, unspecified natural origin, TR	Raw	gal*	1.689274	0	0	1.012348	0	0	0.676926
Water, cooling, unspecified natural origin, TW	Raw	gal*	1.757027	0	0	0.939578	0	0	0.817449
Water, cooling, unspecified natural origin, TZ	Raw	ml	244.1442	0	0	148.9949	0	0	95.14921
Water, cooling, unspecified natural origin, UA	Raw	gal*	3.783793	0	0	2.432847	0	0	1.350946
Water, cooling, unspecified	Raw	CCF	6.754543	0	0.712355	0.02445	0.003744	0	6.013994

natural origin, US									
Water, cooling, unspecified natural origin, WEU	Raw	ml	0.844057	0	0	0.561357	0	0	0.2827
Water, cooling, unspecified natural origin, ZA	Raw	gal*	6.238027	0	0	5.136024	0	0	1.102003
Water, cooling, unspecified natural origin/m3	Raw	bushel	2.330479	0	2.277931	0	0.052548	0	0
Water, CY	Water	ml	163.5171	0	0	85.69155	0	0	77.8255
Water, CZ	Water	Bales	1.573223	0	0	0.959415	0	0	0.613807
Water, DE	Water	Nm3	1.494915	0	0	1.009404	0	0	0.485511
Water, DK	Water	dm3	1.856267	0	0	1.268827	0	0	0.587441
Water, EE	Water	dm3	3.197461	0	0	1.966819	0	0	1.230642
Water, ES	Water	Nm3	1.164746	0	0	0.873739	0	0	0.291007
Water, Europe without Switzerland	Water	dm3	2.146104	0	0	1.899179	0	0	0.246925
Water, FI	Water	Bales	3.159717	0	0	1.932921	0	0	1.226796
Water, FR	Water	CCF	2.275577	0	0	0.812159	0	0	1.463418
Water, GB	Water	Bales	3.30582	0	0	2.091699	0	0	1.214121
Water, GLO	Water	bushel	1.041095	0	0	0.647316	0	0	0.393778
Water, GR	Water	Bales	5.409845	0	0	4.454437	0	0	0.955408
Water, HR	Water	gal*	3.280576	0	0	2.049593	0	0	1.230984
Water, HU	Water	gal*	3.65655	0	0	2.248142	0	0	1.408409
Water, IAI Area 1	Water	ml	274.4936	0	0	266.9209	0	0	7.572712
Water, IAI Area 2, without Quebec	Water	ml	377.1747	0	0	366.7764	0	0	10.39825
Water, IAI Area 3	Water	ml	343.6775	0	0	334.201	0	0	9.476462
Water, IAI Area 4&5 without China	Water	ml	507.9842	0	0	493.9795	0	0	14.0047
Water, IAI Area 8	Water	ml	612.9725	0	0	596.0715	0	0	16.90097

Water, IAI Area, EU27 & EFTA	Water	gal*	1.703534	0	0	1.656525	0	0	0.04701
Water, IAI Area, Europe outside EU & EFTA	Water	ml	953.2075	0	0	926.9188	0	0	26.28879
Water, ID	Water	Bales	1.165677	0	0	0.77926	0	0	0.386418
Water, IE	Water	bushel	1.026847	0	0	0.624214	0	0	0.402633
Water, IL	Water	ml	0.000395	0	0	0.000283	0	0	0.000112
Water, IN	Water	Bales	8.466781	0	0	5.633043	0	0	2.833738
Water, IR	Water	Bales	5.519777	0	0	3.601025	0	0	1.918752
Water, IS	Water	GPU	1.300691	0	0	1.247965	0	0	0.052726
Water, IT	Water	cu.yd	1.053906	0	0	0.699819	0	0	0.354087
Water, JP	Water	Nm3	1.663264	0	0	0.875783	0	0	0.787481
Water, KR	Water	Bales	1.230157	0	0	0.652542	0	0	0.577615
Water, lake	Raw	ml	1.883637	0	1.878465	0	0.005171	0	0
Water, lake, AT	Raw	ml	0.000506	0	0	0.000411	0	0	9.49E-05
Water, lake, BE	Raw	ml	0.001025	0	0	0.000832	0	0	0.000193
Water, lake, BG	Raw	ml	0.004161	0	0	0.002866	0	0	0.001295
Water, lake, CA	Raw	dm3	1.300148	0	0	0.05769	0	0	1.242458
Water, lake, CH	Raw	ml	55.66394	0	0	22.9533	0	0	32.71065
Water, lake, CN	Raw	ml	0.00355	0	0	0.002666	0	0	0.000884
Water, lake, CZ	Raw	ml	3.72E-05	0	0	2.78E-05	0	0	9.38E-06
Water, lake, DE	Raw	ml	0.033986	0	0	0.009804	0	0	0.024183
Water, lake, DK	Raw	ml	0.001147	0	0	0.000958	0	0	0.000188
Water, lake, ES	Raw	ml	0.000961	0	0	0.0008	0	0	0.000161
Water, lake, Europe without Switzerland	Raw	ml	804.6129	0	0	739.7367	0	0	64.87623
Water, lake, FI	Raw	ml	0.000317	0	0	0.000261	0	0	5.62E-05
Water, lake, FR	Raw	ml	0.002517	0	0	0.002018	0	0	0.000499
Water, lake, GB	Raw	ml	0.002045	0	0	0.001659	0	0	0.000386
Water, lake, GLO	Raw	ml	1.158211	0	0	0.754724	0	0	0.403487

Water, lake, HU	Raw	ml	0.000523	0	0	0.000378	0	0	0.000145
Water, lake, IT	Raw	ml	0.002251	0	0	0.001833	0	0	0.000418
Water, lake, JP	Raw	ml	0.003273	0	0	0.002852	0	0	0.00042
Water, lake, KR	Raw	ml	0.000129	0	0	0.000102	0	0	2.77E-05
Water, lake, LU	Raw	ml	3.85E-05	0	0	3.06E-05	0	0	7.87E-06
Water, lake, NL	Raw	ml	0.002068	0	0	0.001662	0	0	0.000406
Water, lake, NO	Raw	ml	0.000116	0	0	9.74E-05	0	0	1.83E-05
Water, lake, PL	Raw	ml	0.000125	0	0	0.000108	0	0	1.70E-05
Water, lake, PT	Raw	ml	0.000352	0	0	0.000293	0	0	5.93E-05
Water, lake, RER	Raw	ml	1.359632	0	0	1.065469	0	0	0.294163
Water, lake, RNA	Raw	ml	0.000852	0	0	0.000657	0	0	0.000195
Water, lake, RoW	Raw	dm3	1.984236	0	0	1.773978	0	0	0.210258
Water, lake, RU	Raw	ml	0.001156	0	0	0.000929	0	0	0.000227
Water, lake, SE	Raw	ml	0.006523	0	0	0.005251	0	0	0.001272
Water, lake, SK	Raw	ml	2.65E-05	0	0	2.16E-05	0	0	4.89E-06
Water, lake, TR	Raw	ml	3.92E-05	0	0	3.32E-05	0	0	5.92E-06
Water, lake, TW	Raw	ml	0.001281	0	0	0.001121	0	0	0.00016
Water, lake, US	Raw	gal*	2.112129	0	2.092911	1.59E-06	0.019216	0	3.46E-08
Water, LT	Water	gal*	5.308035	0	0	3.352212	0	0	1.955823
Water, LU	Water	gal*	4.27489	0	0	2.575167	0	0	1.699723
Water, LV	Water	Bales	1.768995	0	0	1.086324	0	0	0.682671
Water, MA	Water	ml	10.36601	0	0	7.079775	0	0	3.286235
Water, MK	Water	gal*	2.545774	0	0	1.569628	0	0	0.976146
Water, MT	Water	ml	179.2802	0	0	110.0939	0	0	69.18634
Water, MX	Water	cu.yd	1.128791	0	0	0.596276	0	0	0.532515
Water, MY	Water	Bales	1.072824	0	0	0.652646	0	0	0.420178
Water, NL	Water	gal*	3.719652	0	0	2.633257	0	0	1.086395
Water, NO	Water	Bales	6.600454	0	0	5.901733	0	0	0.698721
Water, NORDEL	Water	ml	1.240001	0	0	0.753318	0	0	0.486683
Water, PE	Water	gal*	2.884746	0	0	1.58178	0	0	1.302966

Water, PG	Water	ml	75.17551	0	0	74.7028	0	0	0.472712
Water, PH	Water	ml	99.32358	0	0	67.60648	0	0	31.7171
Water, PL	Water	Bales	1.587078	0	0	0.967498	0	0	0.61958
Water, process, unspecified natural origin/m3	Raw	GPU	1.363701	1.363701	0	0	0	0	0
Water, PT	Water	Bales	2.248161	0	0	1.370086	0	0	0.878075
Water, RAF	Water	ml	271.3051	0	0	88.93496	0	0	182.3702
Water, RAS	Water	dm3	1.253284	0	0	0.86646	0	0	0.386824
Water, RER	Water	bushel	2.087792	0	0	1.388131	0	0	0.699661
Water, river	Raw	gal*	1.657972	0	1.478308	0	0.179664	0	0
Water, river, AT	Raw	ml	1.421783	0	0	1.062262	0	0	0.359521
Water, river, AU	Raw	ml	191.2305	0	0	151.8536	0	0	39.37686
Water, river, BE	Raw	ml	2.514875	0	0	1.948551	0	0	0.566324
Water, river, BG	Raw	ml	8.503129	0	0	5.856476	0	0	2.646652
Water, river, BR	Raw	dm3	2.49776	0	0	0.523033	0	0	1.974728
Water, river, CA	Raw	bushel	1.233761	0	0	0.025062	0	0	1.2087
Water, river, CH	Raw	ml	733.5427	0	0	210.6437	0	0	522.8991
Water, river, CN	Raw	gal*	2.0031	0	0	0.103923	0	0	1.899177
Water, river, CZ	Raw	ml	1.006796	0	0	0.616602	0	0	0.390194
Water, river, DE	Raw	ml	191.8524	0	0	114.4427	0	0	77.40969
Water, river, DK	Raw	ml	2.568235	0	0	2.095833	0	0	0.472403
Water, river, EE	Raw	ml	0.009727	0	0	0.005922	0	0	0.003804
Water, river, ES	Raw	ml	166.4058	0	0	10.01985	0	0	156.386
Water, river, Europe without Switzerland	Raw	gal*	3.372904	0	0	3.069444	0	0	0.30346
Water, river, FI	Raw	ml	0.709728	0	0	0.570522	0	0	0.139205
Water, river, FR	Raw	ml	35.88187	0	0	5.900631	0	0	29.98124
Water, river, GB	Raw	ml	6.817881	0	0	4.966808	0	0	1.851073

Water, river, GLO	Raw	gal*	1.067974	0	0	0.922156	0	0	0.145819
Water, river, GR	Raw	ml	0.100565	0	0	0.062953	0	0	0.037612
Water, river, HR	Raw	ml	0.037617	0	0	0.023157	0	0	0.01446
Water, river, HU	Raw	ml	1.184412	0	0	0.841818	0	0	0.342594
Water, river, IE	Raw	ml	0.088836	0	0	0.053295	0	0	0.035541
Water, river, IN	Raw	dm3	2.648466	0	0	0.290435	0	0	2.358032
Water, river, IR	Raw	ml	0.005779	0	0	0.003005	0	0	0.002774
Water, river, IT	Raw	ml	8.211707	0	0	5.921359	0	0	2.290349
Water, river, JP	Raw	ml	7.576909	0	0	6.298661	0	0	1.278249
Water, river, KR	Raw	ml	197.9054	0	0	104.5254	0	0	93.38005
Water, river, LT	Raw	ml	0.019389	0	0	0.012043	0	0	0.007346
Water, river, LU	Raw	ml	0.112957	0	0	0.083034	0	0	0.029924
Water, river, LV	Raw	ml	0.095487	0	0	0.057882	0	0	0.037605
Water, river, MX	Raw	ml	0.026539	0	0	0.013806	0	0	0.012733
Water, river, MY	Raw	ml	85.50228	0	0	23.65675	0	0	61.84553
Water, river, NL	Raw	ml	4.816038	0	0	3.754685	0	0	1.061354
Water, river, NO	Raw	ml	0.245144	0	0	0.205269	0	0	0.039875
Water, river, PE	Raw	ml	0.784997	0	0	0.767904	0	0	0.017093
Water, river, PH	Raw	ml	533.5959	0	0	116.506	0	0	417.0899
Water, river, PL	Raw	ml	0.545083	0	0	0.395657	0	0	0.149426
Water, river, PT	Raw	ml	0.819735	0	0	0.658766	0	0	0.160968
Water, river, RAS	Raw	dm3	2.549641	0	0	1.760988	0	0	0.788653
Water, river, RER	Raw	Bales	3.047035	0	0	0.145629	0	0	2.901406
Water, river, RLA	Raw	ml	690.9159	0	0	495.7127	0	0	195.2032
Water, river, RNA	Raw	dm3	1.248348	0	0	0.908042	0	0	0.340306
Water, river, RO	Raw	ml	479.2595	0	0	394.3406	0	0	84.91892
Water, river, RoW	Raw	Bales	7.971552	0	0	0.545851	0	0	7.425701

Water, river, RS	Raw	ml	0.00329	0	0	0.002006	0	0	0.001284
Water, river, RU	Raw	ml	180.8365	0	0	111.5972	0	0	69.23928
Water, river, SE	Raw	ml	6.632218	0	0	5.266647	0	0	1.365571
Water, river, SI	Raw	ml	0.113585	0	0	0.072798	0	0	0.040786
Water, river, SK	Raw	ml	0.178983	0	0	0.121084	0	0	0.057899
Water, river, TH	Raw	ml	0.030813	0	0	0.015927	0	0	0.014886
Water, river, TN	Raw	ml	9.634882	0	0	0.4832	0	0	9.151682
Water, river, TR	Raw	ml	0.245527	0	0	0.153993	0	0	0.091534
Water, river, TW	Raw	ml	2.622238	0	0	2.29449	0	0	0.327748
Water, river, TZ	Raw	ml	11.62834	0	0	11.55593	0	0	0.072405
Water, river, US	Raw	Bales	2.720554	0	2.645951	0.003564	0.016688	0	0.054351
Water, river, WEU	Raw	ml	0.000121	0	0	9.29E-05	0	0	2.81E-05
Water, river, ZA	Raw	ml	9.072803	0	0	7.397288	0	0	1.675515
Water, RLA	Water	ml	370.272	0	0	266.5963	0	0	103.6757
Water, RME	Water	dm3	2.667834	0	0	0.874527	0	0	1.793307
Water, RNA	Water	cuft	1.032234	0	0	0.025654	0	0	1.006581
Water, RO	Water	Nm3	1.404376	0	0	1.171982	0	0	0.232395
Water, RoW	Water	MCF	1.476109	0	0	1.013836	0	0	0.462273
Water, RS	Water	Bales	4.632974	0	0	2.851968	0	0	1.781006
Water, RU	Water	MCF	1.808237	0	0	1.698771	0	0	0.109465
Water, SA	Water	gal*	3.331145	0	0	1.899836	0	0	1.431309
Water, salt, ocean	Raw	bushel	1.215019	0	0.785237	0.39331	0.001587	0	0.034885
Water, salt, sole	Raw	Bales	1.131783	0	1.112465	0.006092	0.000366	0	0.012861
Water, SE	Water	CCF	1.551624	0	0	1.090483	0	0	0.461141
Water, SI	Water	Bales	7.545881	0	0	6.373067	0	0	1.172814
Water, SK	Water	Bales	6.566571	0	0	5.603206	0	0	0.963366
Water, TH	Water	bushel	1.267685	0	0	0.665687	0	0	0.601998
Water, TR	Water	cu.yd	1.292237	0	0	0.712984	0	0	0.579253
Water, turbine use, unspecified natural origin	Raw	Bales	4.659016	0	4.64745	0	0.011566	0	0

Water, turbine use, unspecified natural origin, AT	Raw	Nm3	1.889128	0	0	1.091057	0	0	0.798071
Water, turbine use, unspecified natural origin, AU	Raw	CCF	1.143787	0	0	1.055108	0	0	0.088679
Water, turbine use, unspecified natural origin, BA	Raw	GPU	1.27123	0	0	1.23386	0	0	0.03737
Water, turbine use, unspecified natural origin, BE	Raw	cuft	1.008624	0	0	0.600165	0	0	0.408459
Water, turbine use, unspecified natural origin, BG	Raw	Bales	1.923594	0	0	1.182599	0	0	0.740994
Water, turbine use, unspecified natural origin, BR	Raw	CCF	2.234601	0	0	1.8705	0	0	0.364101
Water, turbine use, unspecified natural origin, CA	Raw	MCF	2.034257	0	0	0.803892	0	0	1.230365
Water, turbine use, unspecified natural origin, CH	Raw	Nm3	2.013426	0	0	0.595449	0	0	1.417977
Water, turbine use, unspecified natural origin, CL	Raw	Bales	6.221817	0	0	3.306908	0	0	2.914909
Water, turbine use, unspecified natural origin, CN	Raw	MCF	2.022872	0	0	1.606434	0	0	0.416437
Water, turbine use, unspecified natural origin, CZ	Raw	Bales	1.278705	0	0	0.775274	0	0	0.503431

Water, turbine use, unspecified natural origin, DE	Raw	Nm3	1.449573	0	0	0.979632	0	0	0.469941
Water, turbine use, unspecified natural origin, DK	Raw	ml	944.3115	0	0	580.4938	0	0	363.8177
Water, turbine use, unspecified natural origin, EE	Raw	dm3	2.397691	0	0	1.472541	0	0	0.92515
Water, turbine use, unspecified natural origin, ES	Raw	Nm3	1.146298	0	0	0.860306	0	0	0.285991
Water, turbine use, unspecified natural origin, FI	Raw	Bales	3.132584	0	0	1.91498	0	0	1.217605
Water, turbine use, unspecified natural origin, FR	Raw	CCF	2.245701	0	0	0.801363	0	0	1.444338
Water, turbine use, unspecified natural origin, GB	Raw	Bales	3.094321	0	0	1.956662	0	0	1.13766
Water, turbine use, unspecified natural origin, GLO	Raw	ml	3.312944	0	0	2.364584	0	0	0.94836
Water, turbine use, unspecified natural origin, GR	Raw	Bales	5.294105	0	0	4.374308	0	0	0.919797
Water, turbine use, unspecified natural origin, HR	Raw	gal*	3.168414	0	0	1.967161	0	0	1.201253
Water, turbine use, unspecified natural origin, HU	Raw	gal*	2.899475	0	0	1.76284	0	0	1.136635

Water, turbine use, unspecified natural origin, ID	Raw	Bales	1.030314	0	0	0.68045	0	0	0.349864
Water, turbine use, unspecified natural origin, IE	Raw	cuft	1.23496	0	0	0.749541	0	0	0.485419
Water, turbine use, unspecified natural origin, IN	Raw	Bales	7.518213	0	0	4.885926	0	0	2.632287
Water, turbine use, unspecified natural origin, IR	Raw	Bales	5.396495	0	0	3.534074	0	0	1.862421
Water, turbine use, unspecified natural origin, IS	Raw	GPU	1.305399	0	0	1.252483	0	0	0.052917
Water, turbine use, unspecified natural origin, IT	Raw	cu.yd	1.037512	0	0	0.688476	0	0	0.349037
Water, turbine use, unspecified natural origin, JP	Raw	Nm3	1.64002	0	0	0.863392	0	0	0.776627
Water, turbine use, unspecified natural origin, KR	Raw	Bales	1.038145	0	0	0.547946	0	0	0.490199
Water, turbine use, unspecified natural origin, LT	Raw	gal*	5.172543	0	0	3.248779	0	0	1.923764
Water, turbine use, unspecified natural origin, LU	Raw	gal*	4.215579	0	0	2.535732	0	0	1.679847
Water, turbine use, unspecified natural origin, LV	Raw	Bales	1.763563	0	0	1.082063	0	0	0.681499

Water, turbine use, unspecified natural origin, MK	Raw	gal*	2.464383	0	0	1.518034	0	0	0.946349
Water, turbine use, unspecified natural origin, MX	Raw	cu.yd	1.119086	0	0	0.591149	0	0	0.527937
Water, turbine use, unspecified natural origin, MY	Raw	Bales	1.040951	0	0	0.637599	0	0	0.403352
Water, turbine use, unspecified natural origin, NL	Raw	gal*	1.799305	0	0	1.260935	0	0	0.538369
Water, turbine use, unspecified natural origin, NO	Raw	Bales	6.815184	0	0	6.094603	0	0	0.720581
Water, turbine use, unspecified natural origin, PE	Raw	gal*	2.787747	0	0	1.526823	0	0	1.260924
Water, turbine use, unspecified natural origin, PL	Raw	Bales	1.2076	0	0	0.735153	0	0	0.472447
Water, turbine use, unspecified natural origin, PT	Raw	Bales	2.227942	0	0	1.35638	0	0	0.871562
Water, turbine use, unspecified natural origin, RER	Raw	ml	303.3552	0	0	163.2411	0	0	140.1141
Water, turbine use, unspecified natural origin, RNA	Raw	ml	1.132733	0	0	0.87359	0	0	0.259142
Water, turbine use, unspecified natural origin, RO	Raw	Nm3	1.39631	0	0	1.165434	0	0	0.230877

Water, turbine use, unspecified natural origin, RoW	Raw	MCF	1.451855	0	0	1.00524	0	0	0.446616
Water, turbine use, unspecified natural origin, RS	Raw	Bales	4.609662	0	0	2.837357	0	0	1.772305
Water, turbine use, unspecified natural origin, RU	Raw	MCF	1.8032	0	0	1.695631	0	0	0.107569
Water, turbine use, unspecified natural origin, SE	Raw	CCF	1.549387	0	0	1.088912	0	0	0.460475
Water, turbine use, unspecified natural origin, SI	Raw	Bales	7.471881	0	0	6.320636	0	0	1.151244
Water, turbine use, unspecified natural origin, SK	Raw	Bales	6.450668	0	0	5.508623	0	0	0.942045
Water, turbine use, unspecified natural origin, TH	Raw	bushel	1.152994	0	0	0.60546	0	0	0.547533
Water, turbine use, unspecified natural origin, TR	Raw	cu.yd	1.284468	0	0	0.708293	0	0	0.576174
Water, turbine use, unspecified natural origin, TW	Raw	Bales	1.766438	0	0	0.925771	0	0	0.840667
Water, turbine use, unspecified natural origin, TZ	Raw	gal*	3.158325	0	0	1.927445	0	0	1.23088
Water, turbine use, unspecified natural origin, UA	Raw	Bales	5.341806	0	0	3.264923	0	0	2.076884

Water, turbine use, unspecified natural origin, US	Raw	ML	1.359034	0	0.285906	0.010187	0.008301	0	1.05464
Water, turbine use, unspecified natural origin, ZA	Raw	bushel	1.496632	0	0	1.313215	0	0	0.183417
Water, TW	Water	Bales	1.844356	0	0	0.967376	0	0	0.87698
Water, TZ	Water	gal*	3.214619	0	0	1.962801	0	0	1.251818
Water, UA	Water	Bales	5.511377	0	0	3.374004	0	0	2.137372
Water, UCTE	Water	ml	0.136095	0	0	0.003183	0	0	0.132912
Water, UCTE without Germany	Water	ml	0.003322	0	0	0.002198	0	0	0.001124
Water, UN-OCEANIA	Water	ml	365.8736	0	0	355.7868	0	0	10.08688
Water, unspecified natural origin, AT	Raw	ml	4.421304	0	0	3.521916	0	0	0.899388
Water, unspecified natural origin, AU	Raw	ml	0.041496	0	0	0.02329	0	0	0.018207
Water, unspecified natural origin, BE	Raw	ml	8.683388	0	0	6.977068	0	0	1.706321
Water, unspecified natural origin, BG	Raw	ml	33.80663	0	0	23.2841	0	0	10.52252
Water, unspecified natural origin, BR	Raw	ml	0.388627	0	0	0.207744	0	0	0.180882
Water, unspecified natural origin, CA	Raw	ml	269.9592	0	0	233.5237	0	0	36.43543
Water, unspecified natural origin, CH	Raw	ml	591.0626	0	0	188.4721	0	0	402.5905
Water, unspecified natural origin, CL	Raw	ml	0.075774	0	0	0.075189	0	0	0.000585
Water, unspecified	Raw	dm3	2.791193	0	0	2.713886	0	0	0.077307

natural origin, CN									
Water, unspecified natural origin, CZ	Raw	ml	0.769918	0	0	0.512691	0	0	0.257227
Water, unspecified natural origin, DE	Raw	ml	53.12729	0	0	42.36674	0	0	10.76055
Water, unspecified natural origin, DK	Raw	ml	9.322934	0	0	7.792071	0	0	1.530863
Water, unspecified natural origin, EE	Raw	ml	0.090695	0	0	0.056223	0	0	0.034472
Water, unspecified natural origin, ES	Raw	ml	7.937503	0	0	6.580006	0	0	1.357497
Water, unspecified natural origin, Europe without Switzerland	Raw	ml	102.6098	0	0	27.81832	0	0	74.79146
Water, unspecified natural origin, FI	Raw	ml	2.642624	0	0	2.161278	0	0	0.481346
Water, unspecified natural origin, FR	Raw	ml	21.23562	0	0	16.65057	0	0	4.585044
Water, unspecified natural origin, GB	Raw	ml	16.73312	0	0	13.5548	0	0	3.178327
Water, unspecified natural origin, GLO	Raw	gal*	4.902092	0	0	4.293323	0	0	0.608769
Water, unspecified natural origin, HU	Raw	ml	4.262152	0	0	3.078025	0	0	1.184127
Water, unspecified natural origin, IAI Area 1	Raw	ml	206.6039	0	0	200.9042	0	0	5.699734
Water, unspecified natural origin, IAI Area 2,	Raw	ml	291.9723	0	0	283.923	0	0	8.049269

without Quebec									
Water, unspecified natural origin, IAI Area 3	Raw	ml	274.2704	0	0	266.7078	0	0	7.562607
Water, unspecified natural origin, IAI Area 4&5 without China	Raw	ml	383.6203	0	0	373.0443	0	0	10.57601
Water, unspecified natural origin, IAI Area 8	Raw	ml	461.3678	0	0	448.647	0	0	12.72081
Water, unspecified natural origin, IAI Area, EU27 & EFTA	Raw	dm3	2.240533	0	0	2.178705	0	0	0.061828
Water, unspecified natural origin, IAI Area, Europe outside EU & EFTA	Raw	ml	680.9575	0	0	662.1773	0	0	18.7802
Water, unspecified natural origin, IN	Raw	ml	0.562725	0	0	0.479694	0	0	0.083031
Water, unspecified natural origin, IT	Raw	ml	18.78326	0	0	15.20073	0	0	3.582536
Water, unspecified natural origin, JP	Raw	ml	29.03101	0	0	24.47888	0	0	4.552125
Water, unspecified natural origin, KR	Raw	ml	2.267944	0	0	1.474397	0	0	0.793547
Water, unspecified natural origin, LU	Raw	ml	0.313002	0	0	0.248983	0	0	0.06402
Water, unspecified natural origin, MX	Raw	ml	0.030551	0	0	0.016265	0	0	0.014285
Water, unspecified natural origin, NL	Raw	ml	17.29642	0	0	13.8094	0	0	3.487017

Water, unspecified natural origin, NO	Raw	ml	0.972105	0	0	0.814439	0	0	0.157666
Water, unspecified natural origin, PG	Raw	ml	9.17792	0	0	9.120209	0	0	0.057712
Water, unspecified natural origin, PH	Raw	ml	0.334528	0	0	0.226723	0	0	0.107806
Water, unspecified natural origin, PL	Raw	ml	1.1269	0	0	0.948846	0	0	0.178054
Water, unspecified natural origin, PT	Raw	ml	2.862381	0	0	2.380343	0	0	0.482038
Water, unspecified natural origin, RAF	Raw	ml	319.1825	0	0	104.6294	0	0	214.5531
Water, unspecified natural origin, RER	Raw	gal*	1.696389	0	0	1.040303	0	0	0.656087
Water, unspecified natural origin, RME	Raw	dm3	3.138628	0	0	1.028855	0	0	2.109773
Water, unspecified natural origin, RNA	Raw	dm3	1.140326	0	0	0.018876	0	0	1.12145
Water, unspecified natural origin, RoW	Raw	bushel	1.174496	0	0	0.474321	0	0	0.700175
Water, unspecified natural origin, RU	Raw	ml	456.2146	0	0	154.0527	0	0	302.1619
Water, unspecified natural origin, SE	Raw	ml	12.81734	0	0	10.47099	0	0	2.346346
Water, unspecified natural origin, SK	Raw	ml	0.275782	0	0	0.213445	0	0	0.062337
Water, unspecified natural origin, TH	Raw	ml	0.056364	0	0	0.029586	0	0	0.026778

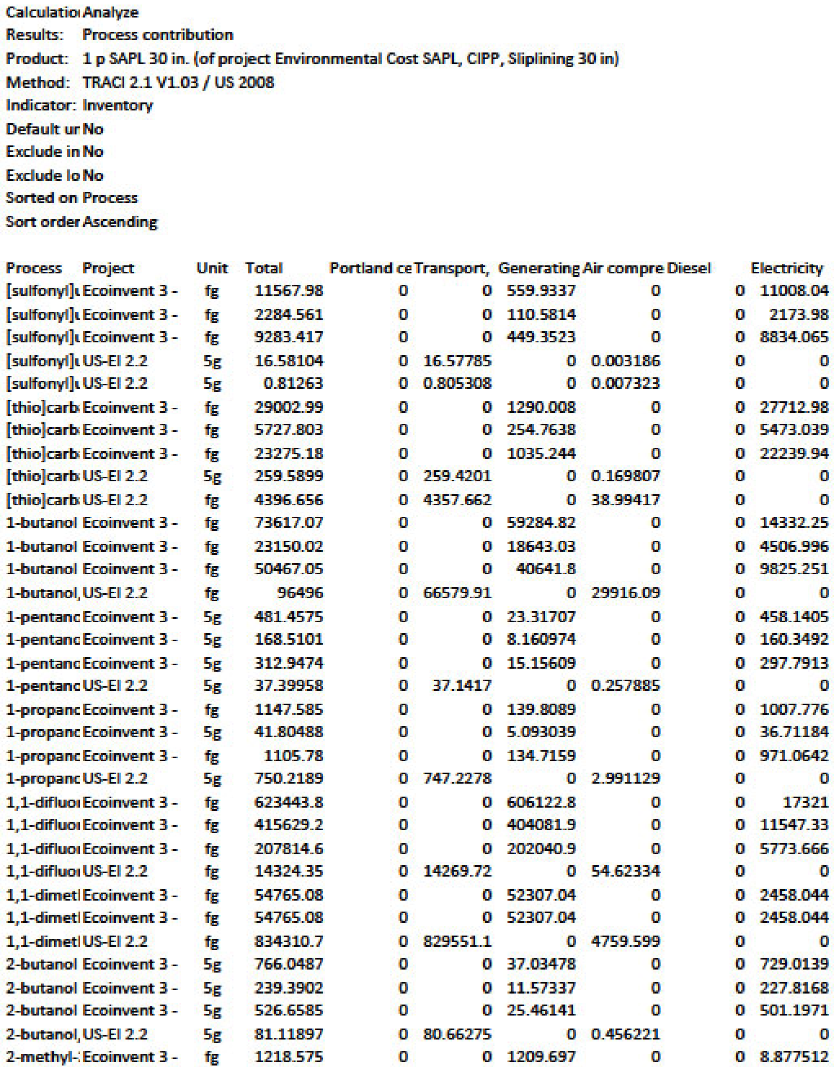
Water, unspecified natural origin, TR	Raw	ml	0.416368	0	0	0.322768	0	0	0.0936
Water, unspecified natural origin, TW	Raw	ml	10.61683	0	0	9.224396	0	0	1.392433
Water, unspecified natural origin, UA	Raw	ml	0.032554	0	0	0.020184	0	0	0.01237
Water, unspecified natural origin, UN-OCEANIA	Raw	ml	275.3832	0	0	267.7911	0	0	7.592066
Water, unspecified natural origin, US	Raw	Nm3	1.032771	0	1.029882	1.63E-05	0.002808	0	6.42E-05
Water, unspecified natural origin, WEU	Raw	ml	0.112388	0	0	0.081791	0	0	0.030597
Water, unspecified natural origin/m3	Raw	CCF	8.467897	8.358639	0.109232	0	2.61E-05	0	0
Water, US	Water	ML	1.081795	0	0	0.010255	0	0	1.07154
Water, well, in ground	Raw	gal*	3.661314	0	3.634482	0	0.026831	0	0
Water, well, in ground, AT	Raw	ml	0.153238	0	0	0.124093	0	0	0.029145
Water, well, in ground, AU	Raw	ml	411.7885	0	0	268.7593	0	0	143.0292
Water, well, in ground, BE	Raw	ml	0.308884	0	0	0.250404	0	0	0.05848
Water, well, in ground, BG	Raw	ml	1.245743	0	0	0.857997	0	0	0.387745
Water, well, in ground, BR	Raw	ml	576.4537	0	0	120.2996	0	0	456.1542
Water, well, in ground, CA	Raw	dm3	1.689812	0	0	0.182488	0	0	1.507324
Water, well, in ground, CH	Raw	ml	326.1128	0	0	122.9151	0	0	203.1977
Water, well, in ground, CN	Raw	gal*	4.346131	0	0	3.018738	0	0	1.327393
Water, well, in ground, CZ	Raw	ml	0.015107	0	0	0.010735	0	0	0.004372
Water, well, in ground, DE	Raw	ml	91.41031	0	0	12.32253	0	0	79.08778
Water, well, in ground, DK	Raw	ml	0.344505	0	0	0.287726	0	0	0.056779
Water, well, in ground, EE	Raw	ml	4.13E-05	0	0	2.53E-05	0	0	1.60E-05

Water, well, in ground, ES	Raw	ml	97.06678	0	0	5.033415	0	0	92.03337
Water, well, in ground, Europe without Switzerland	Raw	dm3	2.898956	0	0	2.665212	0	0	0.233744
Water, well, in ground, FI	Raw	ml	0.095294	0	0	0.078344	0	0	0.016949
Water, well, in ground, FR	Raw	ml	24.35824	0	0	1.696352	0	0	22.66189
Water, well, in ground, GB	Raw	ml	0.623966	0	0	0.503888	0	0	0.120078
Water, well, in ground, GLO	Raw	dm3	1.289338	0	0	0.741334	0	0	0.548004
Water, well, in ground, GR	Raw	ml	0.000425	0	0	0.000269	0	0	0.000157
Water, well, in ground, HR	Raw	ml	0.00016	0	0	9.91E-05	0	0	6.07E-05
Water, well, in ground, HU	Raw	ml	0.157024	0	0	0.113399	0	0	0.043625
Water, well, in ground, ID	Raw	ml	349.7479	0	0	244.0718	0	0	105.6762
Water, well, in ground, IE	Raw	ml	0.000375	0	0	0.000227	0	0	0.000148
Water, well, in ground, IN	Raw	gal*	1.061735	0	0	0.053681	0	0	1.008054
Water, well, in ground, IR	Raw	ml	2.41E-05	0	0	1.27E-05	0	0	1.14E-05
Water, well, in ground, IS	Raw	ml	0.019176	0	0	0.000203	0	0	0.018974
Water, well, in ground, IT	Raw	ml	0.710451	0	0	0.55881	0	0	0.151642
Water, well, in ground, JP	Raw	ml	0.990466	0	0	0.855037	0	0	0.135429
Water, well, in ground, KR	Raw	ml	0.039481	0	0	0.030875	0	0	0.008607
Water, well, in ground, LT	Raw	ml	8.20E-05	0	0	5.14E-05	0	0	3.06E-05
Water, well, in ground, LU	Raw	ml	0.01168	0	0	0.009262	0	0	0.002417
Water, well, in ground, LV	Raw	ml	0.000403	0	0	0.000247	0	0	0.000156
Water, well, in ground, MA	Raw	ml	1.418292	0	0	0.925576	0	0	0.492717
Water, well, in ground, MX	Raw	ml	0.021521	0	0	0.000285	0	0	0.021237
Water, well, in ground, MY	Raw	ml	7.434613	0	0	2.056933	0	0	5.377679
Water, well, in ground, NL	Raw	ml	0.621862	0	0	0.499456	0	0	0.122406
Water, well, in ground, NO	Raw	ml	0.034713	0	0	0.029219	0	0	0.005495

Water, well, in ground, NORDEL	Raw	ml	1.458824	0	0	0.886256	0	0	0.572568
Water, well, in ground, PE	Raw	ml	1.229543	0	0	1.22181	0	0	0.007733
Water, well, in ground, PG	Raw	ml	79.26386	0	0	78.76544	0	0	0.49842
Water, well, in ground, PH	Raw	ml	83.42063	0	0	18.21416	0	0	65.20647
Water, well, in ground, PL	Raw	ml	250.7208	0	0	167.5134	0	0	83.20744
Water, well, in ground, PT	Raw	ml	0.10644	0	0	0.087979	0	0	0.01846
Water, well, in ground, RER	Raw	dm3	2.427362	0	0	1.642961	0	0	0.784401
Water, well, in ground, RLA	Raw	ml	39.73629	0	0	28.51413	0	0	11.22215
Water, well, in ground, RNA	Raw	gal*	5.184109	0	0	0.049273	0	0	5.134836
Water, well, in ground, RO	Raw	ml	4.38E-05	0	0	2.71E-05	0	0	1.67E-05
Water, well, in ground, RoW	Raw	Bales	4.480572	0	0	0.176999	0	0	4.303573
Water, well, in ground, RS	Raw	ml	1.39E-05	0	0	8.57E-06	0	0	5.37E-06
Water, well, in ground, RU	Raw	ml	201.6842	0	0	142.7128	0	0	58.97143
Water, well, in ground, SE	Raw	ml	1.064916	0	0	0.84399	0	0	0.220926
Water, well, in ground, SI	Raw	ml	0.000484	0	0	0.000312	0	0	0.000172
Water, well, in ground, SK	Raw	ml	0.00848	0	0	0.006813	0	0	0.001667
Water, well, in ground, TH	Raw	ml	0.000132	0	0	6.74E-05	0	0	6.48E-05
Water, well, in ground, TN	Raw	ml	14.81913	0	0	0.743196	0	0	14.07594
Water, well, in ground, TR	Raw	ml	0.028735	0	0	0.024132	0	0	0.004603
Water, well, in ground, TW	Raw	ml	0.383863	0	0	0.336031	0	0	0.047832
Water, well, in ground, US	Raw	Bales	1.181902	0	1.10703	0.003224	0.003248	0	0.0684
Water, well, in ground, WEU	Raw	ml	209.7341	0	0	128.5985	0	0	81.13557
Water, well, in ground, ZA	Raw	ml	244.1335	0	0	220.2822	0	0	23.85131
Water, WEU	Water	ml	233.7137	0	0	143.3382	0	0	90.37551
Water, ZA	Water	bushel	2.178768	0	0	1.875011	0	0	0.303757
Water/m3	Air	Nm3	1.416089	0	0	0.269309	0	0	1.14678
Wood, hard, standing	Raw	dm3	2.080903	0	0.254674	0.32185	0.001527	0	1.502853

Wood, primary forest, standing	Raw	ml	2.051544	0	2.050173	0	0.001371	0	0
Wood, soft, standing	Raw	dm3	2.061816	0	0.464324	0.260221	0.003426	0	1.333846
Wood, unspecified, standing/m3	Raw	ml	0.062774	0	0.020721	0.026088	0.00088	0	0.015083
Xenon	Raw	5g	75.73149	0	0	61.91662	0	0	13.81488
Xenon-131m	Air	eBq	9.69E+08	0	669193.1	8853008	2140.939	0	9.60E+08
Xenon-133	Air	eBq	4.67E+10	0	24352190	5.32E+08	78135.78	0	4.62E+10
Xenon-133m	Air	eBq	33346512	0	27353.96	374150.6	82.79402	0	32944925
Xenon-135	Air	eBq	1.73E+10	0	9750597	1.85E+08	31270.4	0	1.71E+10
Xenon-135m	Air	eBq	8.97E+09	0	6130819	80020043	19686.88	0	8.89E+09
Xenon-137	Air	eBq	2.85E+08	0	190412.2	2489682	615.9017	0	2.82E+08
Xenon-138	Air	eBq	2.12E+09	0	1427066	18649163	4606.164	0	2.10E+09
Xylene	Air	m3/g	8.020796	0.098437	3.079866	0.115733	0.004389	1.812846	2.909526
Xylene	Water	m3/g	3.618973	1.599333	0.829555	0.004992	0.000354	1.143884	0.040856
Yttrium	Water	fg	22051.42	12993.72	0.586934	0	0.003365	9057.108	0
Zeta-cypermethrin	Soil	5g	0.0115	0	0	0.000523	0	0	0.010977
Zinc	Raw	oz	3.05265	0	1.908146	0.898234	0.007772	0	0.238498
Zinc	Air	fg	804531.2	2796.454	601735.9	128944.2	9358.601	41.79219	61654.17
Zinc	Water	oz	2.343277	0.117136	0.928977	0.281664	0.031292	0.094731	0.889477
Zinc	Soil	m3/g	2.302855	0	2.281423	0.005652	6.54E-05	0	0.015715
Zinc-65	Air	eBq	2293.835	0	1.525911	19.95985	0.004945	0	2272.344
Zinc-65	Water	eBq	9047266	0	3764.632	196967.6	12.20045	0	8846522
Zinc, Zn 0.63%, Au 9.7E-4%, Ag 9.7E-4%, Cu 0.38%, Pb 0.014%, in ore	Raw	m3/g	1.851193	0	0	1.273497	0	0	0.577696
Zinc, Zn 3.1%, in mixed ore	Raw	fg	118167.8	0	0	105430.5	0	0	12737.37
Zirconium	Raw	fg	908986.3	0	9825.996	93779.14	2.57E+00	0	805378.6
Zirconium	Air	5g	258.4174	0	256.1749	0.638538	1.340788	0	0.263181
Zirconium-95	Air	eBq	3312.175	0	1.49152	39.64137	0.004834	0	3271.037
Zirconium-95	Water	eBq	21623026	0	43.59549	940585.1	0.141285	0	20682397

Table B-5 Process Contribution Results for SAPL Renewal Method of 500-ft Length and Diameter of 30 in. Culvert[29]



Calculatio Analyze
Results: Process contribution
Product: 1 p SAPL 30 in. (of project Environmental Cost SAPL, CIPP, Sliplining 30 in)
Method: TRACI 2.1 V1.03 / US 2008
Indicator: Inventory
Default ur No
Exclude in No
Exclude lo No
Sorted on Process
Sort order Ascending

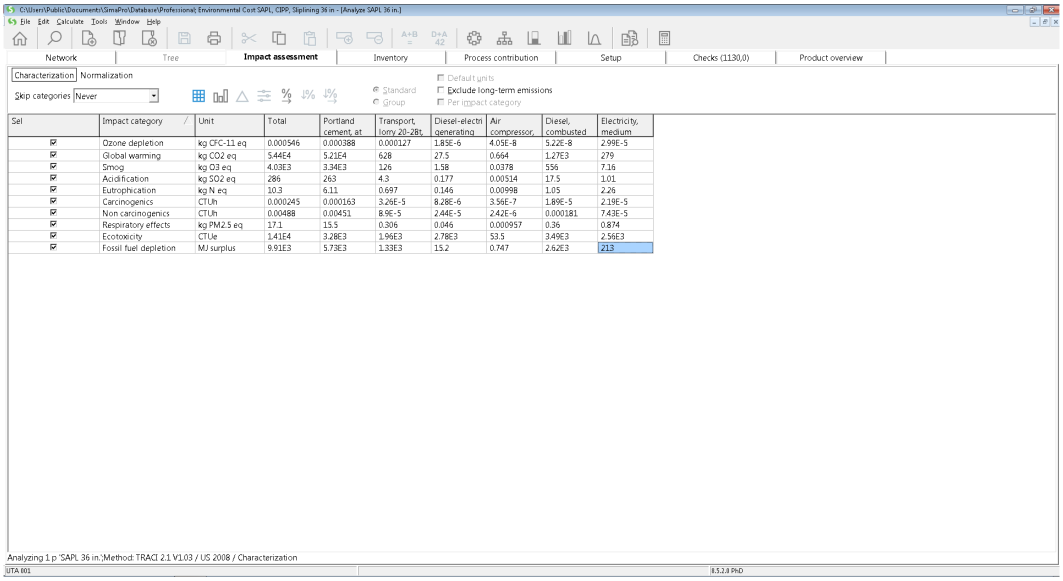
Process	Project	Unit	Total	Portland ce	Transport,	Generating	Air compre	Diesel	Electricity
[sulfonyl]	Ecoinvent 3 -	fg	11567.98	0	0	559.9337	0	0	11008.04
[sulfonyl]	Ecoinvent 3 -	fg	2284.561	0	0	110.5814	0	0	2173.98
[sulfonyl]	Ecoinvent 3 -	fg	9283.417	0	0	449.3523	0	0	8834.065
[sulfonyl]	US-EI 2.2	5g	16.58104	0	16.57785	0	0.003186	0	0
[sulfonyl]	US-EI 2.2	5g	0.81263	0	0.805308	0	0.007323	0	0
[thio]carb	Ecoinvent 3 -	fg	29002.99	0	0	1290.008	0	0	27712.98
[thio]carb	Ecoinvent 3 -	fg	5727.803	0	0	254.7638	0	0	5473.039
[thio]carb	Ecoinvent 3 -	fg	23275.18	0	0	1035.244	0	0	22239.94
[thio]carb	US-EI 2.2	5g	259.5899	0	259.4201	0	0.169807	0	0
[thio]carb	US-EI 2.2	fg	4396.656	0	4357.662	0	38.99417	0	0
1-butanol	Ecoinvent 3 -	fg	73617.07	0	0	59284.82	0	0	14332.25
1-butanol	Ecoinvent 3 -	fg	23150.02	0	0	18643.03	0	0	4506.996
1-butanol	Ecoinvent 3 -	fg	50467.05	0	0	40641.8	0	0	9825.251
1-butanol,	US-EI 2.2	fg	96496	0	66579.91	0	29916.09	0	0
1-pentanc	Ecoinvent 3 -	5g	481.4575	0	0	23.31707	0	0	458.1405
1-pentanc	Ecoinvent 3 -	5g	168.5101	0	0	8.160974	0	0	160.3492
1-pentanc	Ecoinvent 3 -	5g	312.9474	0	0	15.15609	0	0	297.7913
1-pentanc	US-EI 2.2	5g	37.39958	0	37.1417	0	0.257885	0	0
1-propanc	Ecoinvent 3 -	fg	1147.585	0	0	139.8089	0	0	1007.776
1-propanc	Ecoinvent 3 -	5g	41.80488	0	0	5.093039	0	0	36.71184
1-propanc	Ecoinvent 3 -	fg	1105.78	0	0	134.7159	0	0	971.0642
1-propanc	US-EI 2.2	5g	750.2189	0	747.2278	0	2.991129	0	0
1,1-difluo	Ecoinvent 3 -	fg	623443.8	0	0	606122.8	0	0	17321
1,1-difluo	Ecoinvent 3 -	fg	415629.2	0	0	404081.9	0	0	11547.33
1,1-difluo	Ecoinvent 3 -	fg	207814.6	0	0	202040.9	0	0	5773.666
1,1-difluo	US-EI 2.2	fg	14324.35	0	14269.72	0	54.62334	0	0
1,1-dimet	Ecoinvent 3 -	fg	54765.08	0	0	52307.04	0	0	2458.044
1,1-dimet	Ecoinvent 3 -	fg	54765.08	0	0	52307.04	0	0	2458.044
1,1-dimet	US-EI 2.2	fg	834310.7	0	829551.1	0	4759.599	0	0
2-butanol	Ecoinvent 3 -	5g	766.0487	0	0	37.03478	0	0	729.0139
2-butanol	Ecoinvent 3 -	5g	239.3902	0	0	11.57337	0	0	227.8168
2-butanol	Ecoinvent 3 -	5g	526.6585	0	0	25.46141	0	0	501.1971
2-butanol,	US-EI 2.2	5g	81.11897	0	80.66275	0	0.456221	0	0
2-methyl-	Ecoinvent 3 -	fg	1218.575	0	0	1209.697	0	0	8.877512

---

[29] Please contact the author for complete sets of process contribution for all SAPL, CIPP, and sliplining methods with various diameter at Ramtin.serajiantehrani@mavs.uta.edu

]

A.1.2 SAPL 36 in.



Skip categories: Never

☐ Exclude long-term emissions

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.000546	0.000388	0.000127	1.85E-6	4.05E-8	5.22E-8	2.99E-5
☑	Global warming	kg CO2 eq	5.44E4	5.21E4	628	27.5	0.664	1.27E3	279
☑	Smog	kg O3 eq	4.03E3	3.34E3	126	1.58	0.0378	556	7.16
☑	Acidification	kg SO2 eq	286	263	4.3	0.177	0.00514	17.5	1.01
☑	Eutrophication	kg N eq	10.3	6.11	0.697	0.146	0.00998	1.05	2.26
☑	Carcinogenics	CTUh	0.000245	0.000163	3.26E-5	8.28E-6	3.56E-7	1.89E-5	2.19E-5
☑	Non carcinogenics	CTUh	0.00488	0.00451	8.9E-5	2.44E-5	2.42E-6	0.000181	7.43E-5
☑	Respiratory effects	kg PM2.5 eq	17.1	15.5	0.306	0.046	0.000957	0.36	0.874
☑	Ecotoxicity	CTUe	1.41E4	3.28E3	1.96E3	2.78E3	53.5	3.49E3	2.56E3
☑	Fossil fuel depletion	MJ surplus	9.91E3	5.73E3	1.33E3	15.2	0.747	2.62E3	213

Analyzing 1 p 'SAPL 36 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-5 Screenshot of the Impact Assessment Table from SimaPro Software for 36 in. SAPL

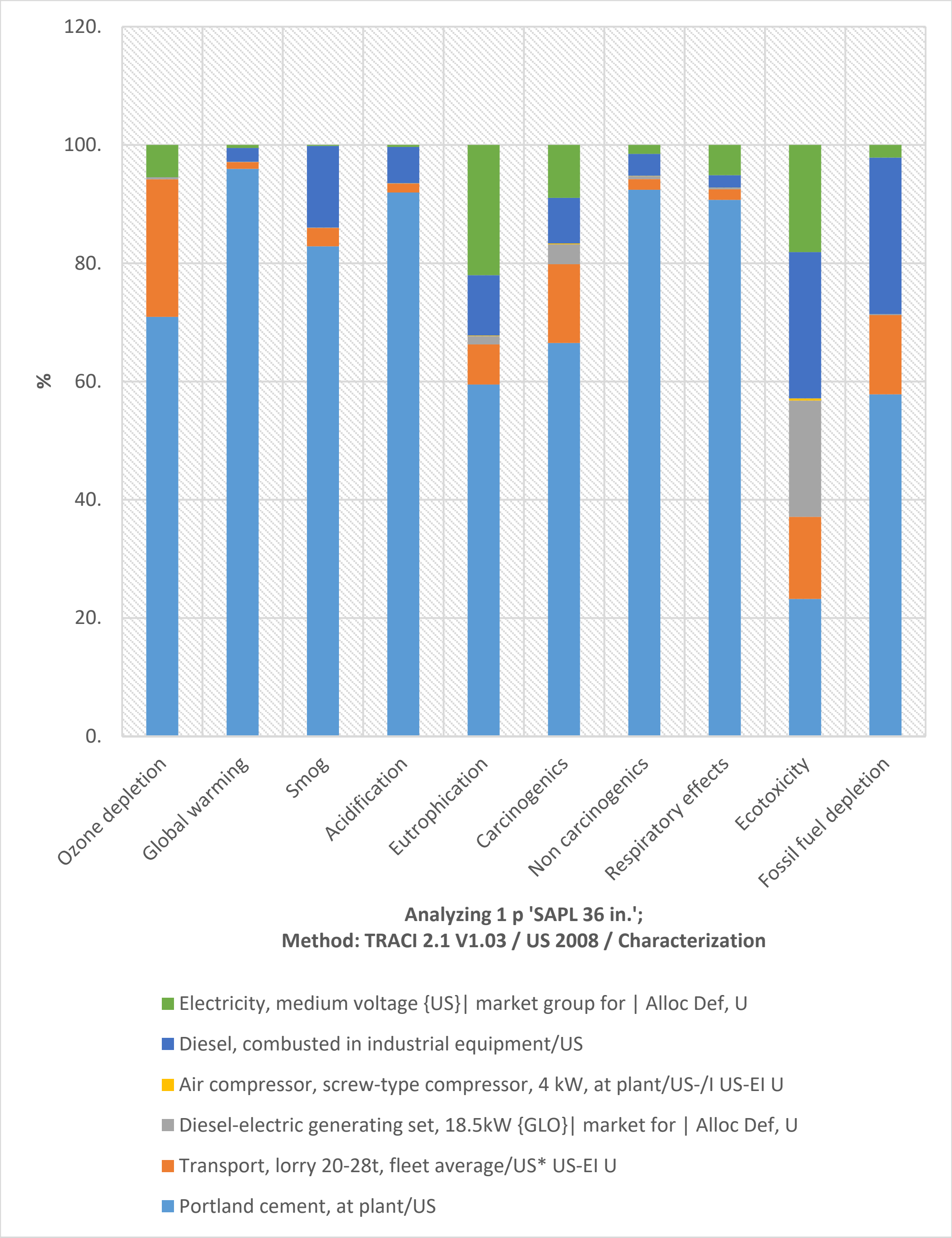


Figure B-6 Environmental Impact Assessment of 36 in. Diameter SAPL Renewal Method

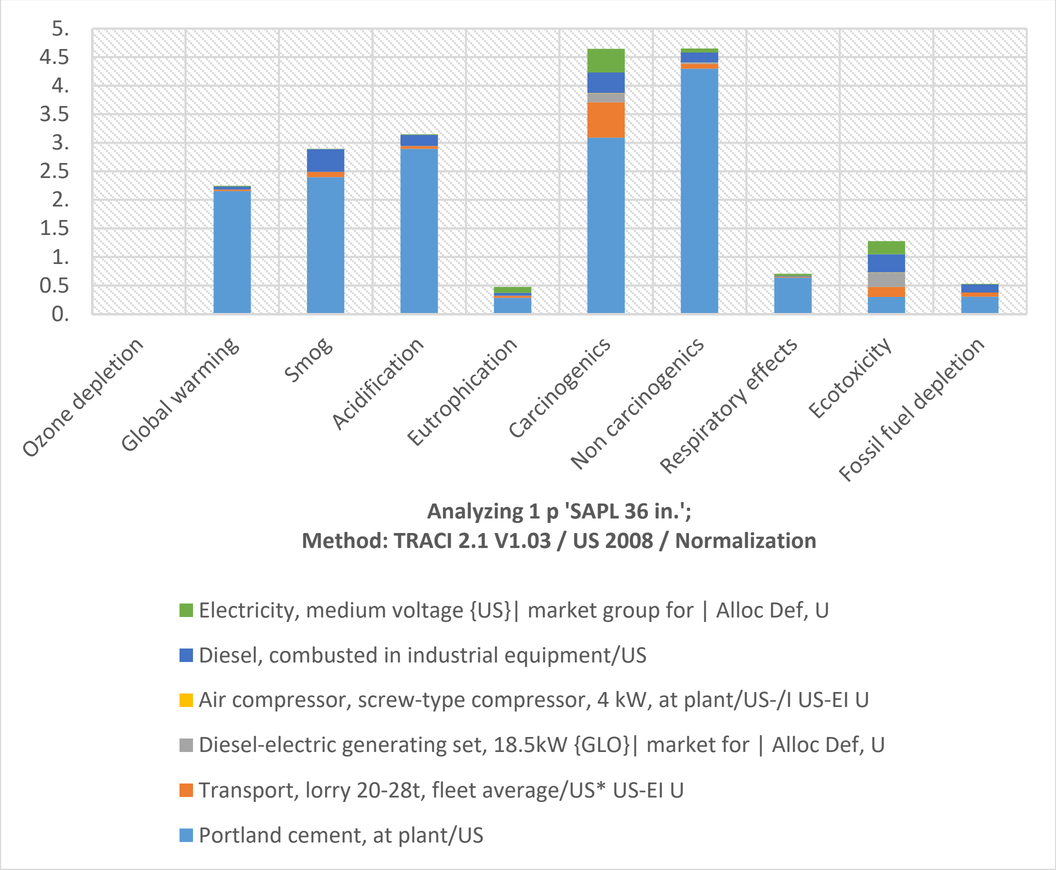


Figure B-7 Normalized Environmental Impact Assessment of 36 in. Diameter SAPL Renewal Method

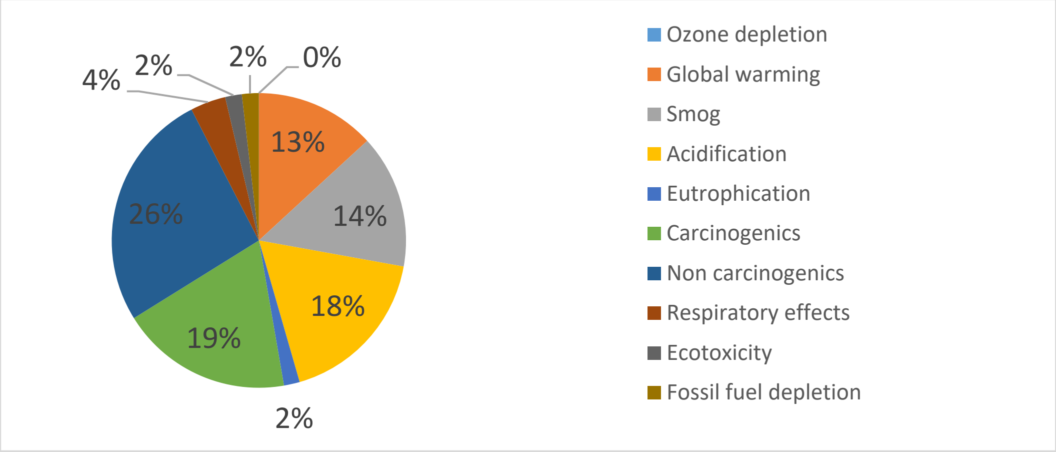


Figure B-8 Percentage of Normalized Environmental Impact Assessment of 36 in. Diameter SAPL Renewal Method

Table B-6 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 36 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.000546	0.000388	0.00	1.85E-06	4.05E-08	5.22E-08	2.99E-05
Global warming	kg CO2 eq	54356.88	52146.91	627.5904	27.46688	0.664274	1274.999	279.245
Smog	kg O3 eq	4026.23	3335.659	126.0075	1.576492	0.037764	555.7919	7.157954
Acidification	kg SO2 eq	285.7896	262.8031	4.295318	0.176797	0.005138	17.50412	1.005061
Eutrophication	kg N eq	10.272	6.108507	0.696758	0.146058	0.00998	1.047081	2.263621
Carcinogenics	CTUh	0.000245	0.000163	3.26E-05	8.28E-06	3.56E-07	1.89E-05	2.19E-05
Non carcinogenics	CTUh	0.004883	0.004512	8.90E-05	2.44E-05	2.42E-06	0.000181	7.43E-05
Respiratory effects	kg PM2.5 eq	17.05211	15.46495	0.306228	0.046028	0.000957	0.360251	0.873698
Ecotoxicity	CTUe	14127.25	3281.387	1960.748	2777.057	53.52642	3491.797	2562.738
Fossil fuel depletion	MJ surplus	9905.957	5727.597	1327.529	15.17393	0.746784	2621.826	213.085

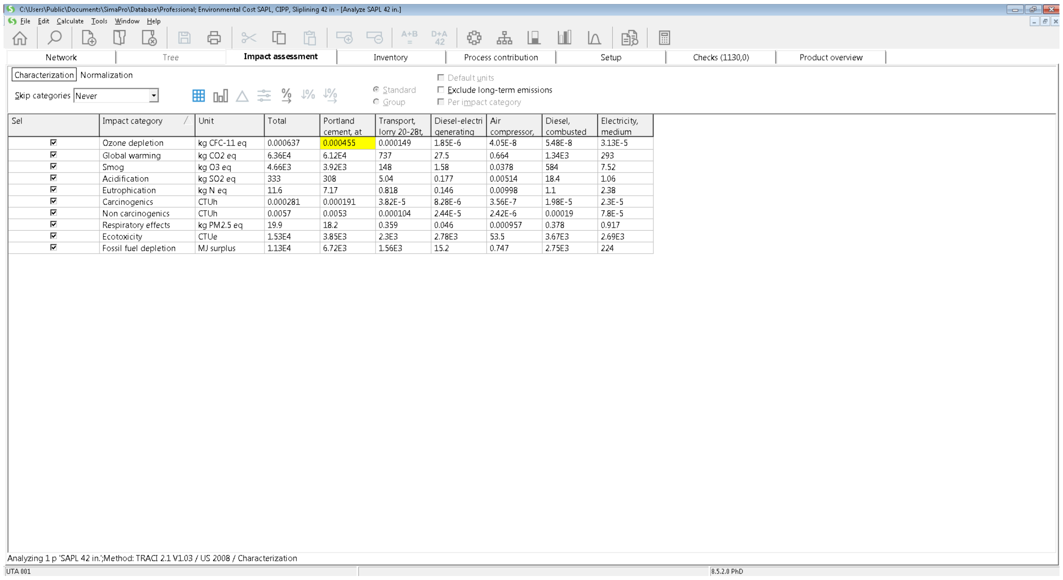
Table B-7 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 36 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.003389	0.002403	0.000788	1.14E-05	2.51E-07	3.24E-07	0.000185
Global warming	-	2.243955	2.152724	0.025908	0.001134	2.74E-05	0.052634	0.011528
Smog	-	2.892589	2.396457	0.090528	0.001133	2.71E-05	0.399301	0.005143
Acidification	-	3.146425	2.893354	0.04729	0.001946	5.66E-05	0.192713	0.011065
Eutrophication	-	0.475209	0.282595	0.032234	0.006757	0.000462	0.048441	0.104721
Carcinogenics	-	4.644017	3.088682	0.617971	0.157095	0.006752	0.357673	0.415844
Non carcinogenics	-	4.649113	4.295873	0.084726	0.023204	0.0023	0.172307	0.070705
Respiratory effects	-	0.703238	0.637783	0.012629	0.001898	3.95E-05	0.014857	0.036032
Ecotoxicity	-	1.27618	0.296423	0.177123	0.250864	0.004835	0.31543	0.231504
Fossil fuel depletion	-	0.526342	0.30433	0.070537	0.000806	3.97E-05	0.139308	0.011322

Table B-8 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 36 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.000546	0.02
Global warming	kg CO2 eq	54356.88	3,424.48
Smog	kg O3 eq	4026.23	8,857.71
Acidification	kg SO2 eq	285.7896	1,563.27
Eutrophication	kg N eq	10.272	21.06
Carcinogenic	CTUh	0.000245	0.00
Non carcinogenic	CTUh	0.004883	0.04
Respiratory effects	kg PM2.5 eq	17.05211	1,080.08
Ecotoxicity	CTUe	14127.25	579.22
Fossil fuel depletion	MJ surplus	9905.957	97.08
Total			15,622.95

A.1.3 SAPL 42 in.



Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.000637	0.000455	0.000149	1.85E-6	4.05E-8	5.48E-8	3.13E-5
☑	Global warming	kg CO2 eq	6.36E4	6.12E4	737	27.5	0.664	1.34E3	293
☑	Smog	kg O3 eq	4.66E3	3.92E3	148	1.58	0.0378	584	7.52
☑	Acidification	kg SO2 eq	333	308	5.04	0.177	0.00514	18.4	1.06
☑	Eutrophication	kg N eq	11.6	7.17	0.818	0.146	0.00998	1.1	2.38
☑	Carcinogenics	CTUh	0.000281	0.000191	3.82E-5	8.28E-6	3.56E-7	1.98E-5	2.3E-5
☑	Non carcinogenics	CTUh	0.0057	0.0053	0.000104	2.44E-5	2.42E-6	0.00019	7.8E-5
☑	Respiratory effects	kg PM2.5 eq	19.9	18.2	0.359	0.046	0.000957	0.378	0.917
☑	Ecotoxicity	CTUe	1.53E4	3.85E3	2.3E3	2.78E3	53.5	3.67E3	2.69E3
☑	Fossil fuel depletion	MJ surplus	1.13E4	6.72E3	1.56E3	15.2	0.747	2.75E3	224

Analyzing 1 p 'SAPL 42 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-9 Screenshot of the Impact Assessment Table from SimaPro Software for 42 in. SAPL

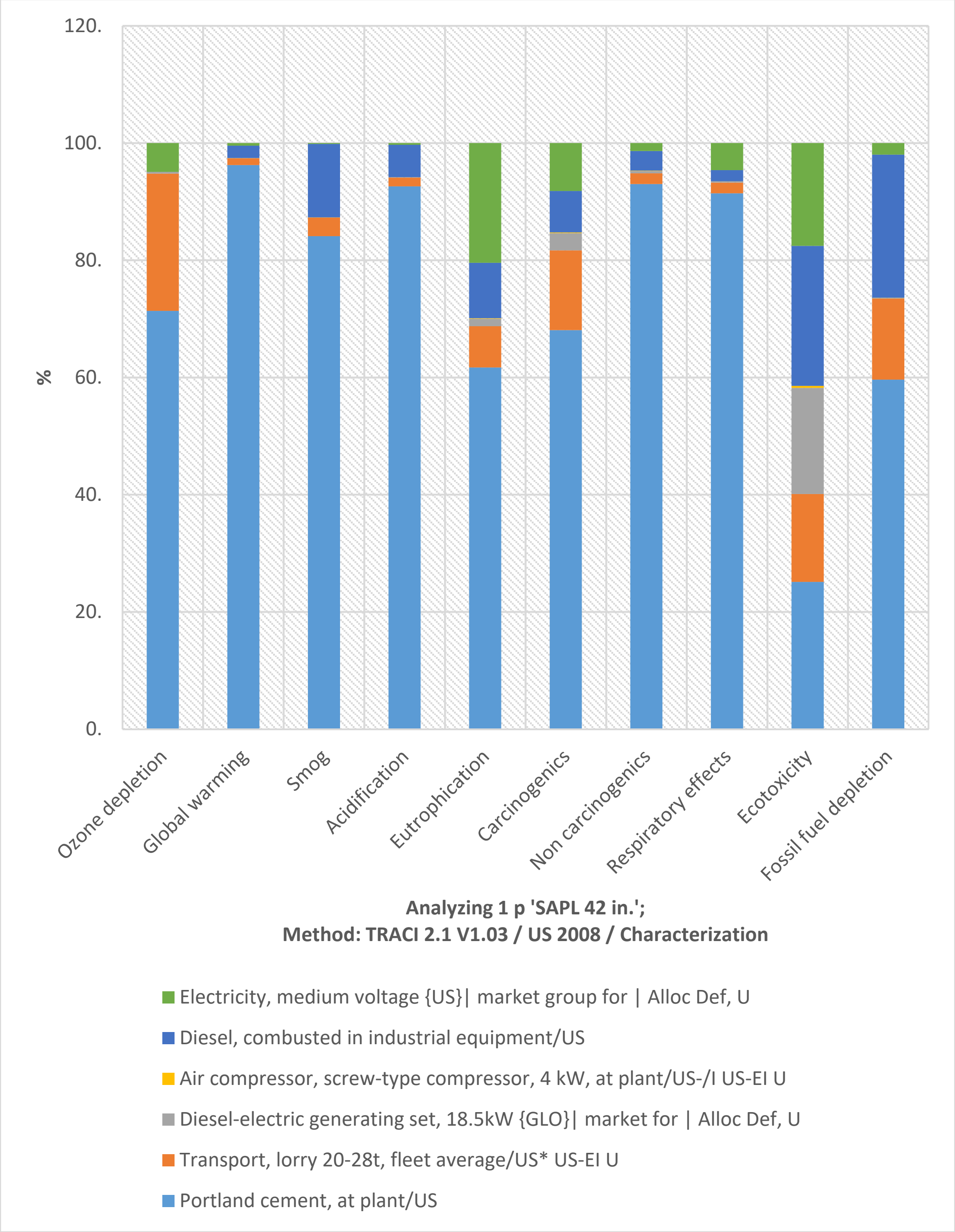


Figure B-10 Environmental Impact Assessment of 42 in. Diameter SAPL Renewal Method

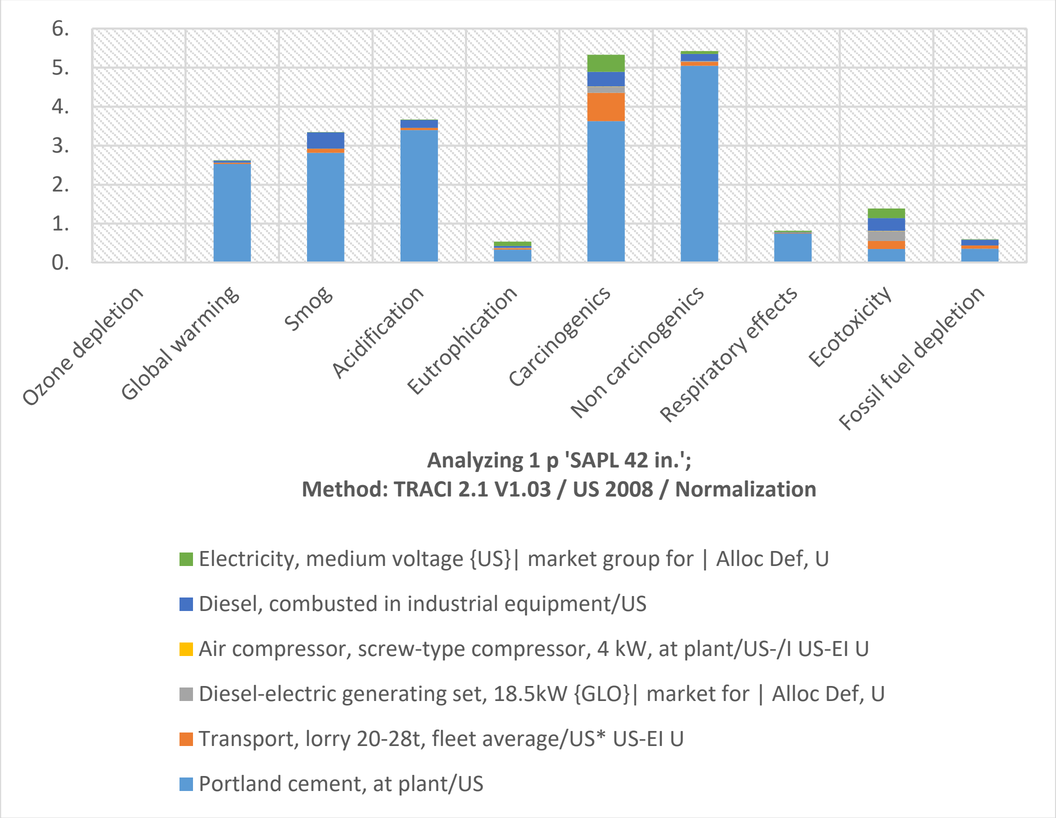


Figure B-11 Normalized Environmental Impact Assessment of 42 in. Diameter SAPL Renewal Method

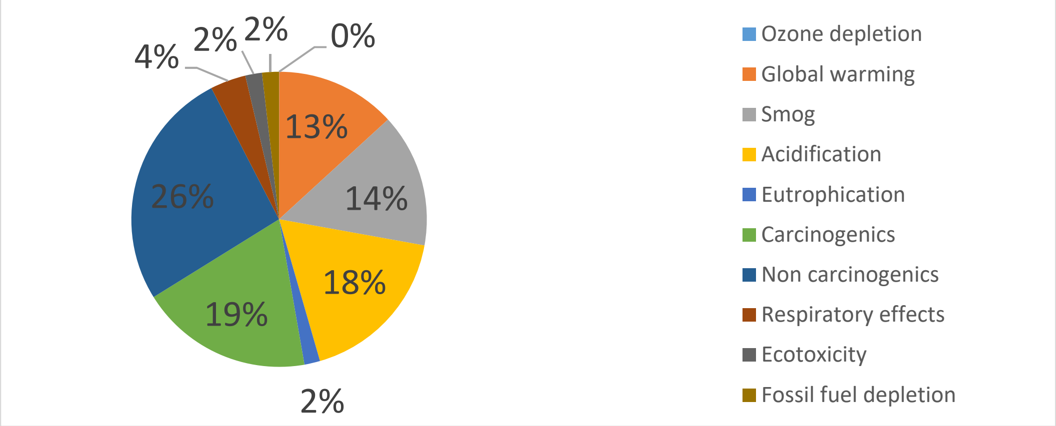


Figure B-12 Percentage of Normalized Environmental Impact Assessment of 42 in. Diameter SAPL Renewal Method

Table B-9 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 42 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.000637	0.000455	0.000149	1.85E-06	4.05E-08	5.48E-08	3.13E-05
Global warming	kg CO2 eq	63610.51	61213.65	736.7104	27.46688	0.664274	1338.815	293.2072
Smog	kg O3 eq	4656.284	3915.627	147.9166	1.576492	0.037764	583.6103	7.515852
Acidification	kg SO2 eq	333.1561	308.4965	5.042151	0.176797	0.005138	18.38023	1.055314
Eutrophication	kg N eq	11.62082	7.170587	0.817904	0.146058	0.00998	1.099489	2.376802
Carcinogenics	CTUh	0.000281	0.000191	3.82E-05	8.28E-06	3.56E-07	1.98E-05	2.30E-05
Non carcinogenics	CTUh	0.005696	0.005296	1.04E-04	2.44E-05	2.42E-06	0.00019	7.80E-05
Respiratory effects	kg PM2.5 eq	19.85594	18.15382	0.359472	0.046028	0.000957	0.378282	0.917383
Ecotoxicity	CTUe	15341.61	3851.919	2301.666	2777.057	53.52642	3666.567	2690.875
Fossil fuel depletion	MJ surplus	11274.51	6723.449	1558.349	15.17393	0.746784	2753.053	223.7393

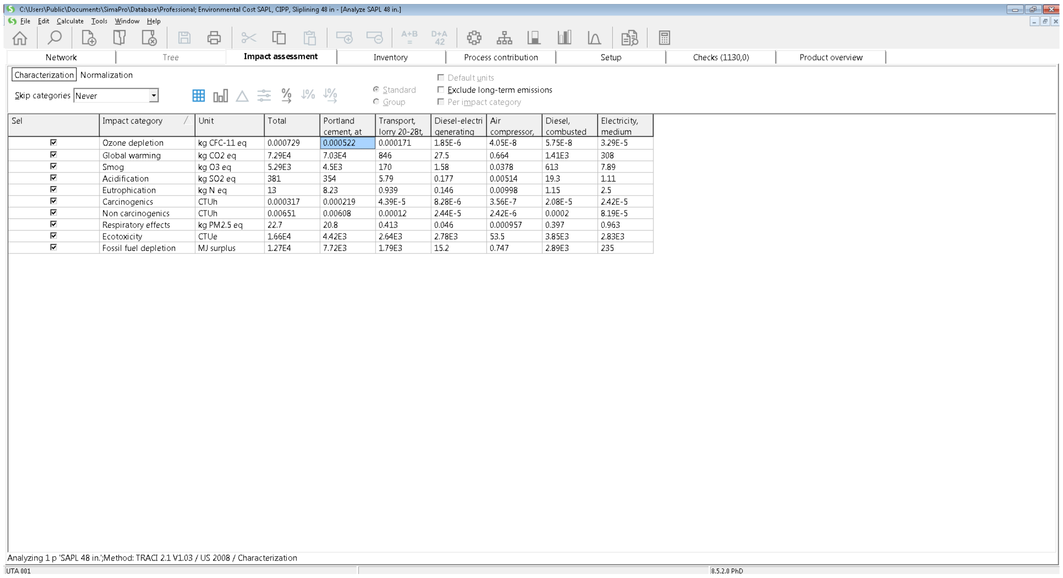
Table B-10 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 42 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.003953	0.002821	0.000926	1.14E-05	2.51E-07	3.40E-07	0.000194
Global warming	-	2.625963	2.527016	0.030413	0.001134	2.74E-05	0.055269	0.012104
Smog	-	3.345242	2.813127	0.106269	0.001133	2.71E-05	0.419287	0.0054
Acidification	-	3.667911	3.396418	0.055512	0.001946	5.66E-05	0.202359	0.011619
Eutrophication	-	0.537608	0.331729	0.037838	0.006757	0.000462	0.050865	0.109957
Carcinogenics	-	5.327185	3.625708	0.725418	0.157095	0.006752	0.375575	0.436637
Non carcinogenics	-	5.422924	5.042792	0.099457	0.023204	0.0023	0.180931	0.07424
Respiratory effects	-	0.81887	0.748674	0.014825	0.001898	3.95E-05	0.015601	0.037833
Ecotoxicity	-	1.385878	0.347962	0.20792	0.250864	0.004835	0.331218	0.243079
Fossil fuel depletion	-	0.599059	0.357243	0.082801	0.000806	3.97E-05	0.14628	0.011888

Table B-11 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 42 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.000637	0.02
Global warming	kg CO2 eq	63610.51	4,007.46
Smog	kg O3 eq	4656.284	10,243.82
Acidification	kg SO2 eq	333.1561	1,822.36
Eutrophication	kg N eq	11.62082	23.82
Carcinogenic	CTUh	0.000281	0.00
Non carcinogenic	CTUh	0.005696	0.05
Respiratory effects	kg PM2.5 eq	19.85594	1,257.68
Ecotoxicity	CTUe	15341.61	629.01
Fossil fuel depletion	MJ surplus	11274.51	110.49
Total			18,094.72

A.1.4 SAPL 48 in.



Skip categories: Never

● Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.000729	0.000522	0.000171	1.85E-6	4.05E-8	5.75E-8	3.29E-5
☑	Global warming	kg CO2 eq	7.29E4	7.03E4	846	27.5	0.664	1.41E3	308
☑	Smog	kg O3 eq	5.29E3	4.5E3	170	1.58	0.0378	613	7.89
☑	Acidification	kg SO2 eq	381	354	5.79	0.177	0.00514	19.3	1.11
☑	Eutrophication	kg N eq	13	8.23	0.939	0.146	0.00998	1.15	2.5
☑	Carcinogenics	CTUh	0.000317	0.000219	4.39E-5	8.28E-6	3.56E-7	2.08E-5	2.42E-5
☑	Non carcinogenics	CTUh	0.00651	0.00608	0.00012	2.44E-5	2.42E-6	0.0002	8.19E-5
☑	Respiratory effects	kg PM2.5 eq	22.7	20.8	0.413	0.046	0.000957	0.397	0.963
☑	Ecotoxicity	CTUe	1.66E4	4.42E3	2.64E3	2.78E3	53.5	3.85E3	2.83E3
☑	Fossil fuel depletion	MJ surplus	1.27E4	7.72E3	1.79E3	15.2	0.747	2.89E3	235

Analyzing 1 p 'SAPL 48 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-13 Screenshot of the Impact Assessment Table from SimaPro Software for 48 in. SAPL

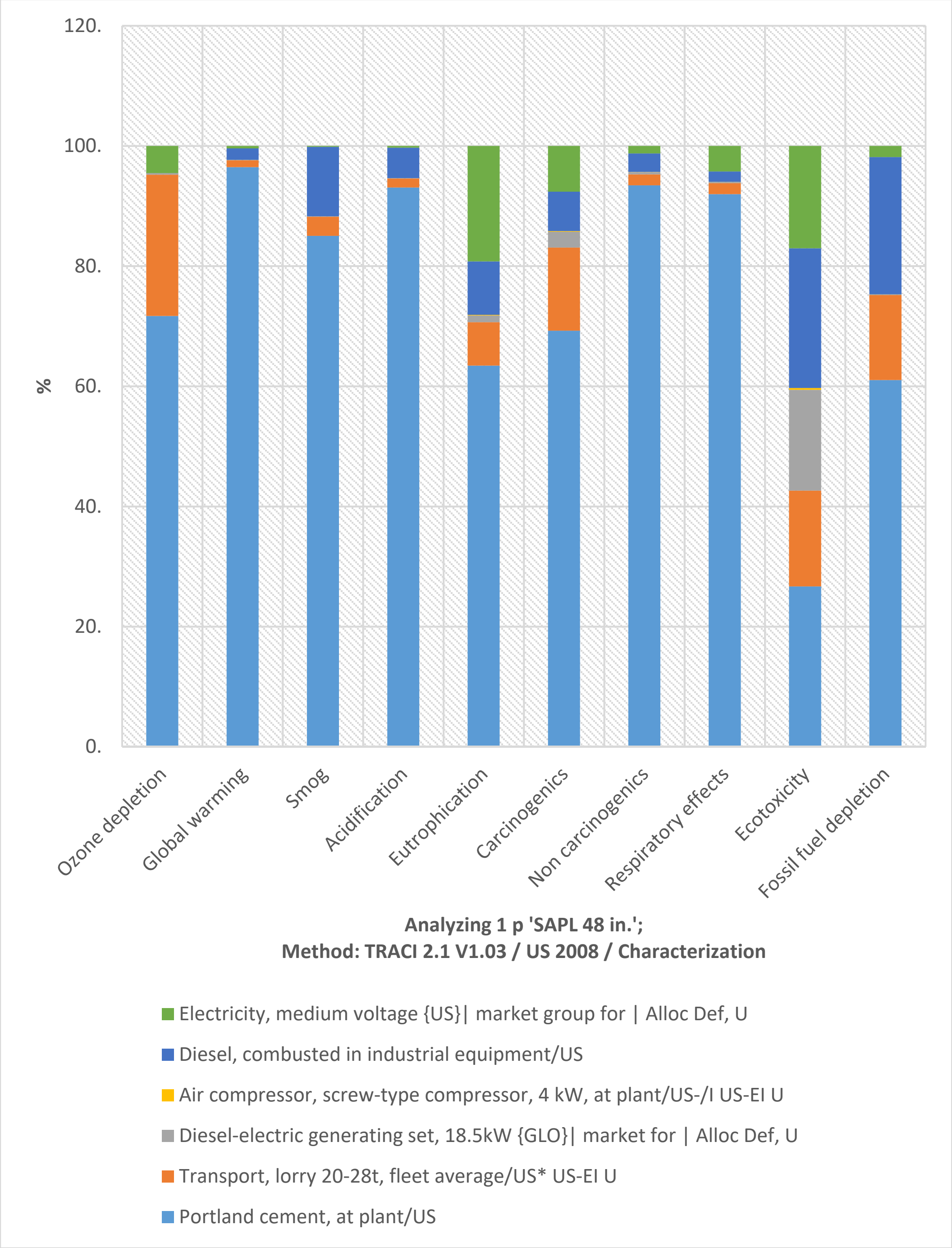


Figure B-14 Environmental Impact Assessment of 48 in. Diameter SAPL Renewal Method

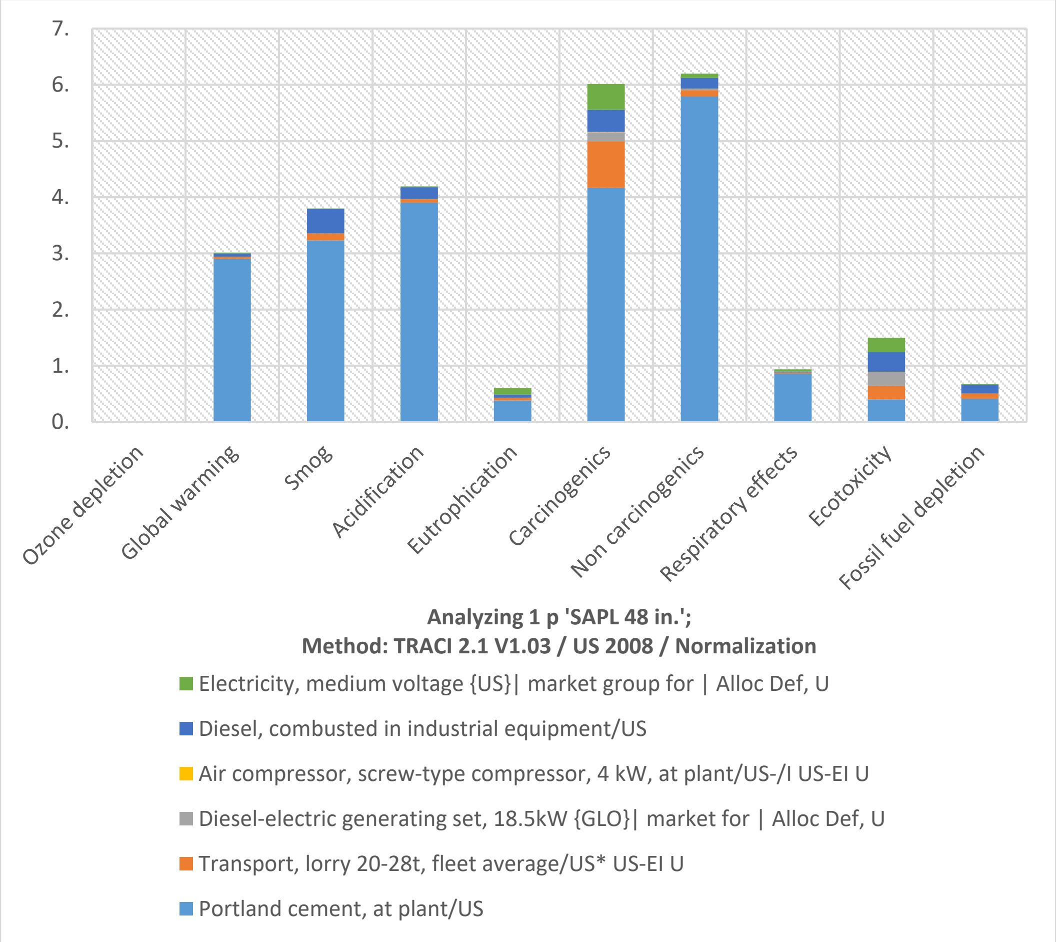


Figure B-15 Normalized Environmental Impact Assessment of 48 in. Diameter SAPL Renewal Method

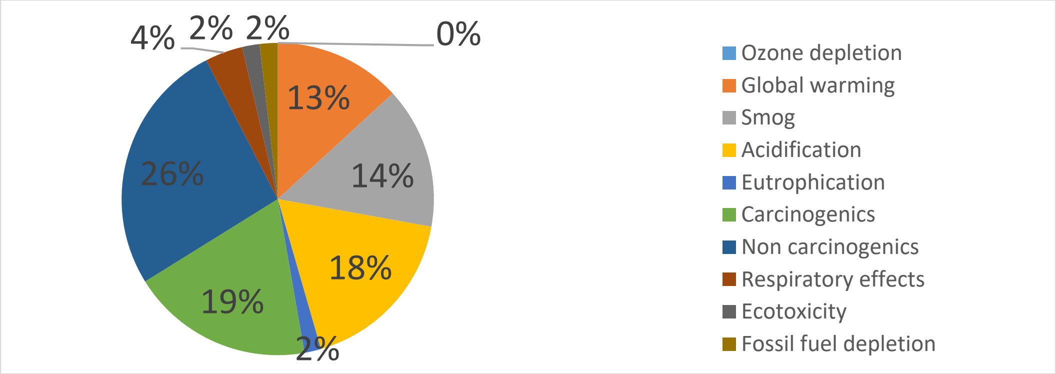


Figure B-16 Percentage of Normalized Environmental Impact Assessment of 48 in. Diameter SAPL Renewal Method

Table B-12 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 48 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.000729	0.000522	0.000171	1.85E-06	4.05E-08	5.75E-08	3.29E-05
Global warming	kg CO2 eq	72871.11	70283.49	845.8663	27.46688	0.664274	1405.756	307.867
Smog	kg O3 eq	5287.923	4495.793	169.833	1.576492	0.037764	612.7908	7.891628
Acidification	kg SO2 eq	380.5839	354.2055	5.789229	0.176797	0.005138	19.29924	1.108078
Eutrophication	kg N eq	12.97826	8.233031	0.93909	0.146058	0.00998	1.154463	2.495637
Carcinogenics	CTUh	0.000317	0.000219	4.39E-05	8.28E-06	3.56E-07	2.08E-05	2.42E-05
Non carcinogenics	CTUh	0.006509	0.006081	1.20E-04	2.44E-05	2.42E-06	0.0002	8.19E-05
Respiratory effects	kg PM2.5 eq	22.66378	20.84362	0.412734	0.046028	0.000957	0.397197	0.96325
Ecotoxicity	CTUe	16571.24	4422.646	2642.696	2777.057	53.52642	3849.896	2825.413
Fossil fuel depletion	MJ surplus	12650.44	7719.642	1789.244	15.17393	0.746784	2890.705	234.9257

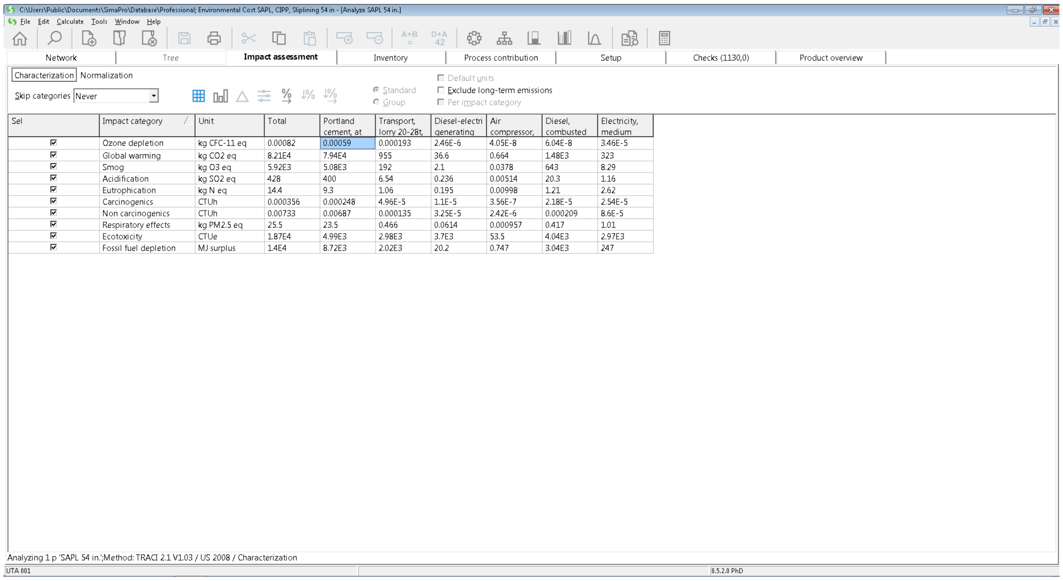
Table B-13 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 48 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.004518	0.003239	0.001063	1.14E-05	2.51E-07	3.57E-07	0.000204
Global warming	-	3.008258	2.901436	0.034919	0.001134	2.74E-05	0.058032	0.012709
Smog	-	3.799034	3.229939	0.122014	0.001133	2.71E-05	0.440251	0.00567
Acidification	-	4.190072	3.899655	0.063737	0.001946	5.66E-05	0.212477	0.012199
Eutrophication	-	0.600407	0.380881	0.043445	0.006757	0.000462	0.053408	0.115454
Carcinogenics	-	6.012487	4.162918	0.832901	0.157095	0.006752	0.394354	0.458467
Non carcinogenics	-	6.197593	5.789967	0.114193	0.023204	0.0023	0.189978	0.077952
Respiratory effects	-	0.934667	0.859602	0.017021	0.001898	3.95E-05	0.016381	0.039725
Ecotoxicity	-	1.496956	0.399518	0.238727	0.250864	0.004835	0.347779	0.255233
Fossil fuel depletion	-	0.672167	0.410175	0.095069	0.000806	3.97E-05	0.153594	0.012483

Table B-14 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 48 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.000729	0.02
Global warming	kg CO2 eq	72871.11	4,590.88
Smog	kg O3 eq	5287.923	11,633.43
Acidification	kg SO2 eq	380.5839	2,081.79
Eutrophication	kg N eq	12.97826	26.61
Carcinogenic	CTUh	0.000317	0.00
Non carcinogenic	CTUh	0.006509	0.06
Respiratory effects	kg PM2.5 eq	22.66378	1,435.52
Ecotoxicity	CTUe	16571.24	679.42
Fossil fuel depletion	MJ surplus	12650.44	123.97
Total			20,571.71

A.1.5 SAPL 54 in.



Skip categories: Never

● Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.00082	0.00059	0.000193	2.46E-6	4.05E-8	6.04E-8	3.46E-5
☑	Global warming	kg CO2 eq	8.21E4	7.94E4	955	36.6	0.664	1.48E3	323
☑	Smog	kg O3 eq	5.92E3	5.08E3	192	2.1	0.0378	643	8.29
☑	Acidification	kg SO2 eq	428	400	6.54	0.236	0.00514	20.3	1.16
☑	Eutrophication	kg N eq	14.4	9.3	1.06	0.195	0.00998	1.21	2.62
☑	Carcinogenics	CTUh	0.000356	0.000248	4.96E-5	1.1E-5	3.56E-7	2.18E-5	2.54E-5
☑	Non carcinogenics	CTUh	0.00733	0.00687	0.000135	3.25E-5	2.42E-6	0.000209	8.6E-5
☑	Respiratory effects	kg PM2.5 eq	25.5	23.5	0.466	0.0614	0.000957	0.417	1.01
☑	Ecotoxicity	CTUe	1.87E4	4.99E3	2.98E3	3.7E3	53.5	4.04E3	2.97E3
☑	Fossil fuel depletion	MJ surplus	1.4E4	8.72E3	2.02E3	20.2	0.747	3.04E3	247

Analyzing 1 p 'SAPL 54 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-17 Screenshot of the Impact Assessment Table from SimaPro Software for 54 in. SAPL

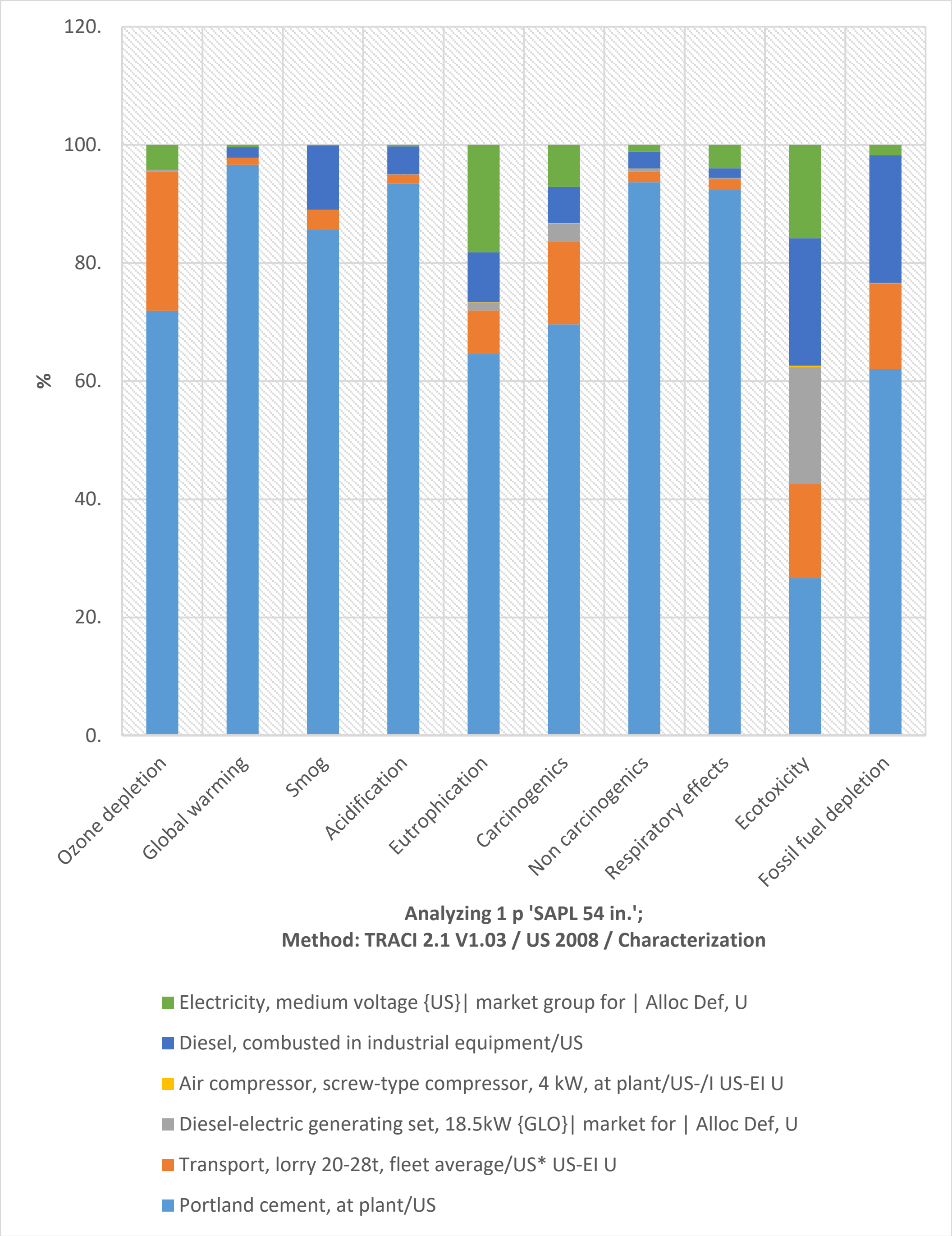


Figure B-18 Environmental Impact Assessment of 54 in. Diameter SAPL Renewal Method

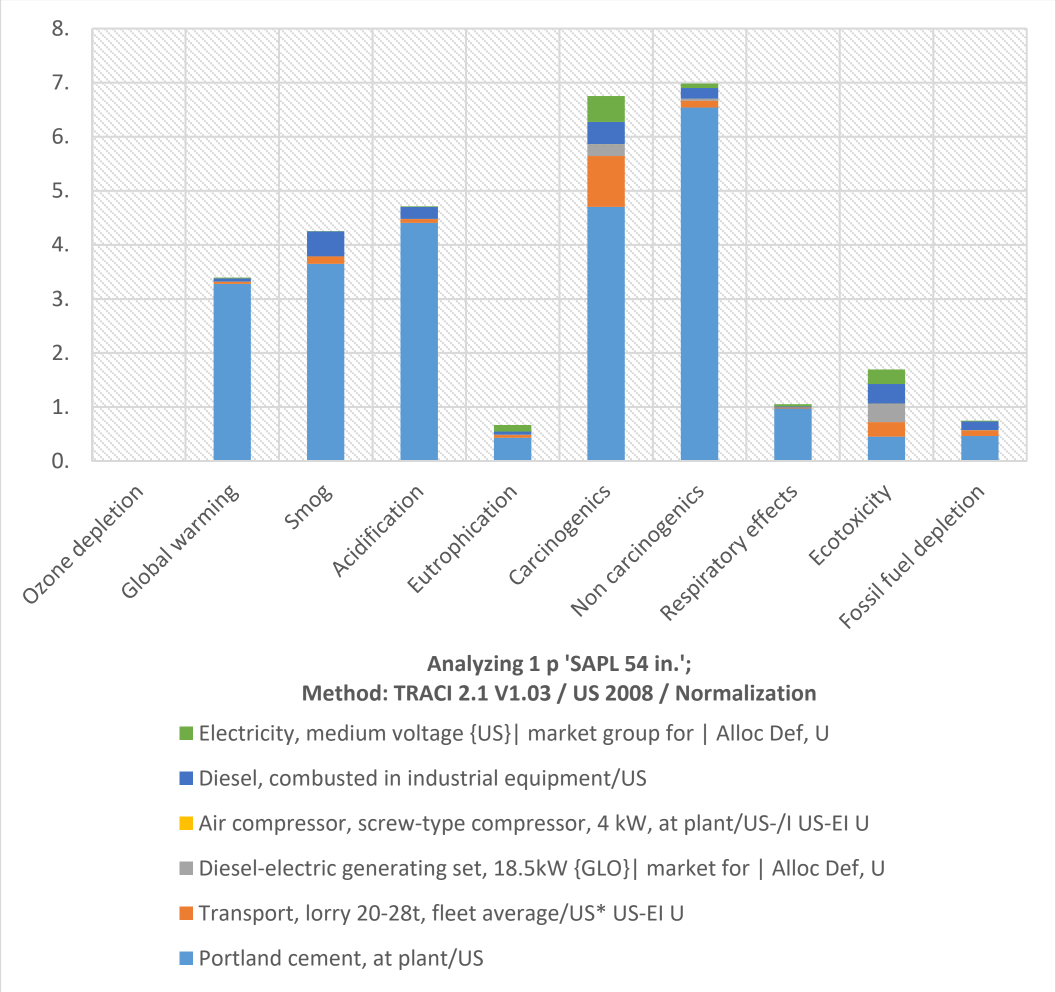


Figure B-19 Normalized Environmental Impact Assessment of 54 in. Diameter SAPL Renewal Method

Figure B-20 Percentage of Normalized Environmental Impact Assessment of 54 in. Diameter SAPL Renewal Method

Table B-15 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 54 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.00082	0.00059	0.000193	2.46E-06	4.05E-08	6.04E-08	3.46E-05
Global warming	kg CO2 eq	82144.84	79353.32	955.0222	36.6225	0.664274	1475.941	323.2632
Smog	kg O3 eq	5921.52	5075.959	191.7493	2.10199	0.037764	643.3858	8.286285
Acidification	kg SO2 eq	428.1179	399.9144	6.536307	0.235729	0.005138	20.2628	1.163492
Eutrophication	kg N eq	14.39302	9.295475	1.060276	0.194744	0.00998	1.212103	2.620442
Carcinogenics	CTUh	0.000356	0.000248	4.96E-05	1.10E-05	3.56E-07	2.18E-05	2.54E-05
Non carcinogenics	CTUh	0.007332	0.006866	1.35E-04	3.25E-05	2.42E-06	0.000209	8.60E-05
Respiratory effects	kg PM2.5 eq	25.49019	23.53341	0.465996	0.06137	0.000957	0.417027	1.011421
Ecotoxicity	CTUe	18742.19	4993.373	2983.726	3702.743	53.52642	4042.111	2966.711
Fossil fuel depletion	MJ surplus	14038.66	8715.834	2020.139	20.23191	0.746784	3035.031	246.6743

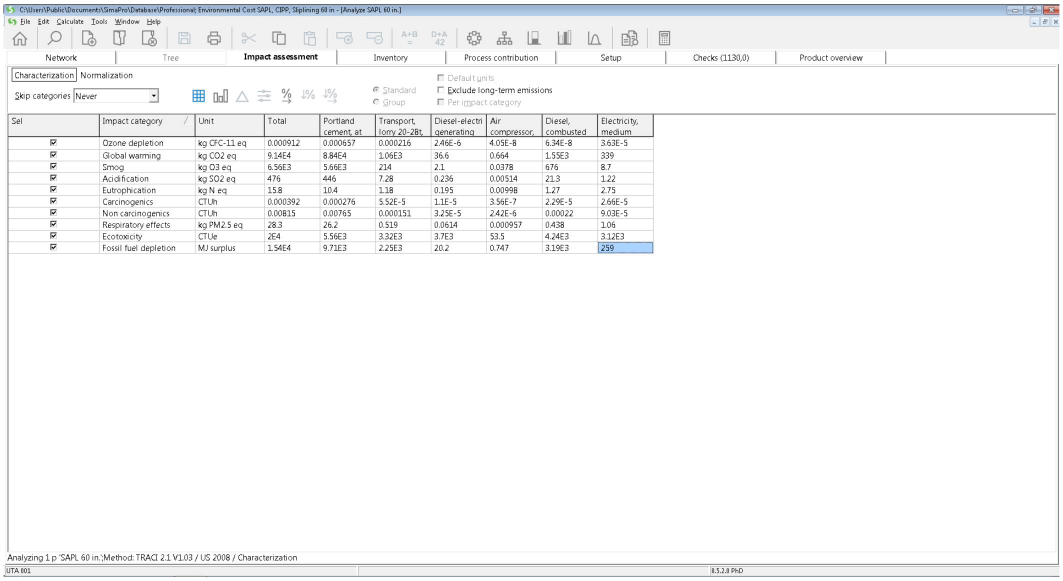
Table B-16 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 54 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.005087	0.003657	0.0012	1.53E-05	2.51E-07	3.75E-07	0.000214
Global warming	-	3.391095	3.275856	0.039425	0.001512	2.74E-05	0.06093	0.013345
Smog	-	4.254233	3.646752	0.13776	0.00151	2.71E-05	0.462232	0.005953
Acidification	-	4.713401	4.402892	0.071962	0.002595	5.66E-05	0.223085	0.01281
Eutrophication	-	0.665857	0.430032	0.049051	0.009009	0.000462	0.056075	0.121228
Carcinogenics	-	6.752161	4.700128	0.940383	0.209459	0.006752	0.414043	0.481395
Non carcinogenics	-	6.980622	6.537142	0.128929	0.030939	0.0023	0.199463	0.08185
Respiratory effects	-	1.051229	0.970531	0.019218	0.002531	3.95E-05	0.017198	0.041712
Ecotoxicity	-	1.693068	0.451074	0.269534	0.334486	0.004835	0.365142	0.267997
Fossil fuel depletion	-	0.745929	0.463106	0.107338	0.001075	3.97E-05	0.161263	0.013107

Table B-17 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 54 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.00082	0.03
Global warming	kg CO2 eq	82144.84	5,175.12
Smog	kg O3 eq	5921.52	13,027.34
Acidification	kg SO2 eq	428.1179	2,341.80
Eutrophication	kg N eq	14.39302	29.51
Carcinogenic	CTUh	0.000356	0.00
Non carcinogenic	CTUh	0.007332	0.07
Respiratory effects	kg PM2.5 eq	25.49019	1,614.55
Ecotoxicity	CTUe	18742.19	768.43
Fossil fuel depletion	MJ surplus	14038.66	137.58
Total			23,094.43

A.1.6 SAPL 60 in.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 60 in - [Analyze SAPL 60 in.]

Skip categories: Never

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.000912	0.000657	0.000216	2.46E-6	4.05E-8	6.34E-8	3.63E-5
☑	Global warming	kg CO2 eq	9.14E4	8.84E4	1.06E3	36.6	0.664	1.55E3	339
☑	Smog	kg O3 eq	6.56E3	5.66E3	214	2.1	0.0378	676	8.7
☑	Acidification	kg SO2 eq	476	446	7.28	0.236	0.00514	21.3	1.22
☑	Eutrophication	kg N eq	15.8	10.4	1.18	0.195	0.00998	1.27	2.75
☑	Carcinogenics	CTUh	0.000392	0.000276	5.52E-5	1.1E-5	3.56E-7	2.29E-5	2.66E-5
☑	Non carcinogenics	CTUh	0.00815	0.00765	0.000151	3.25E-5	2.42E-6	0.00022	9.03E-5
☑	Respiratory effects	kg PM2.5 eq	28.3	26.2	0.519	0.0614	0.000957	0.438	1.06
☑	Ecotoxicity	CTUe	2E4	5.56E3	3.32E3	3.7E3	53.5	4.24E3	3.12E3
☑	Fossil fuel depletion	MJ surplus	1.54E4	9.71E3	2.25E3	20.2	0.747	3.19E3	259

Analyzing 1 p 'SAPL 60 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-21 Screenshot of the Impact Assessment Table from SimaPro Software for 60 in. SAPL

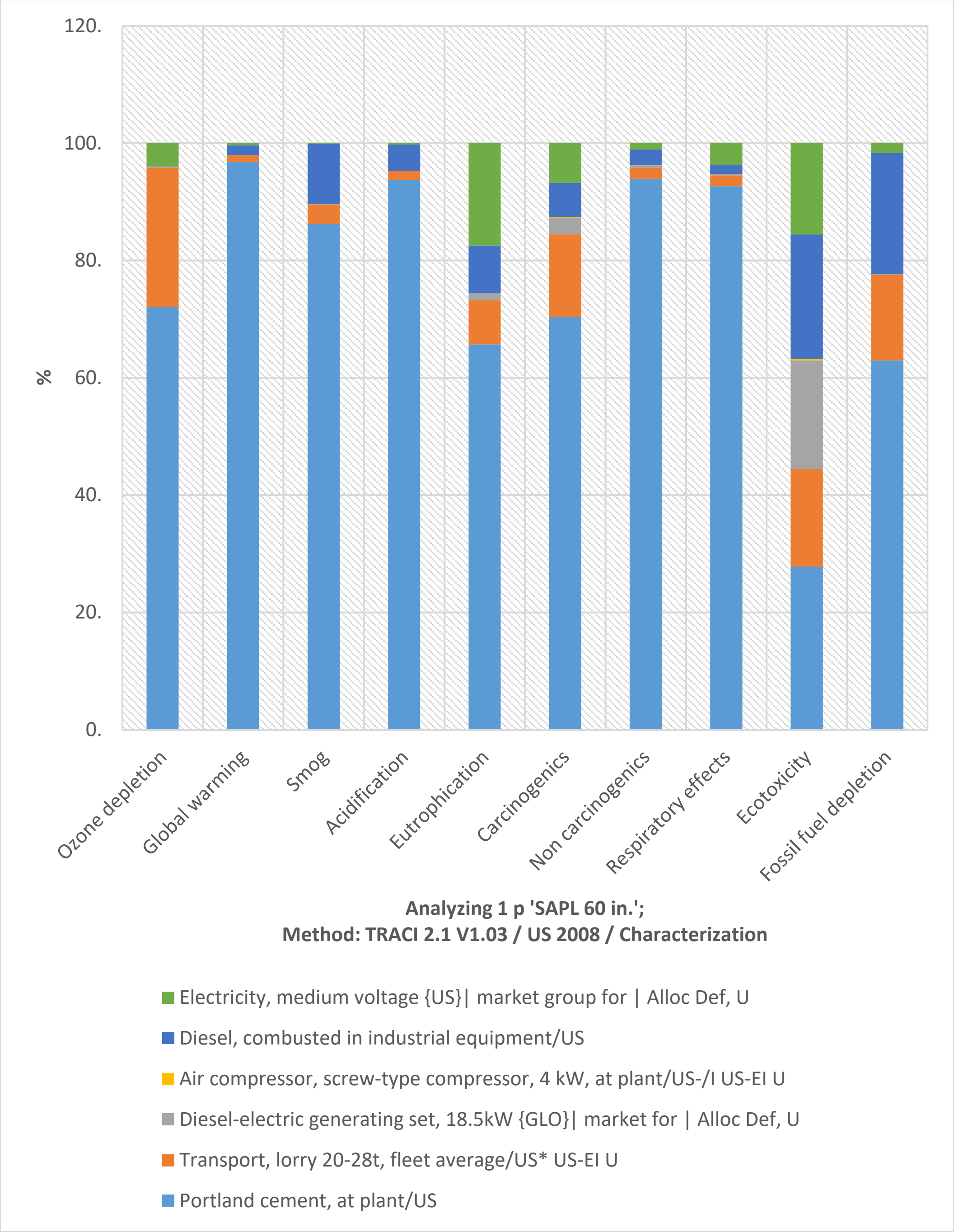


Figure B-22 Environmental Impact Assessment of 60 in. Diameter SAPL Renewal Method

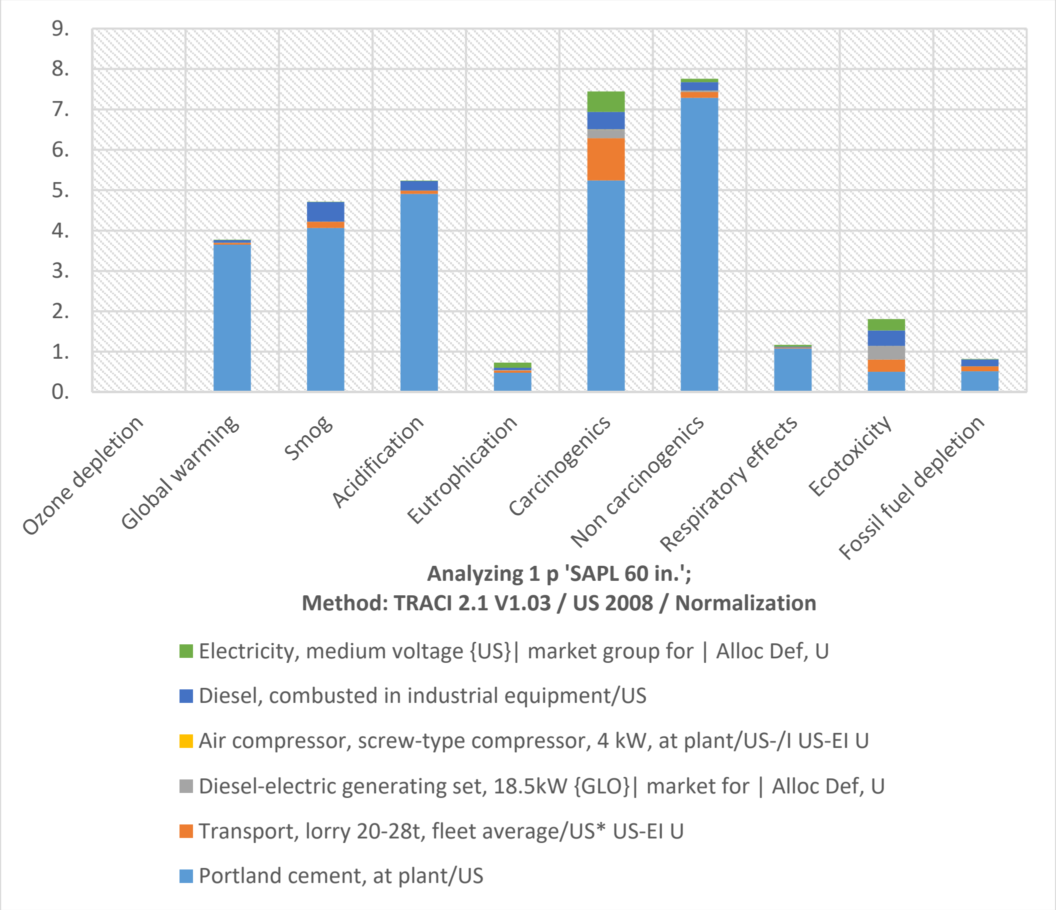


Figure B-23 Normalized Environmental Impact Assessment of 60 in. Diameter SAPL Renewal Method

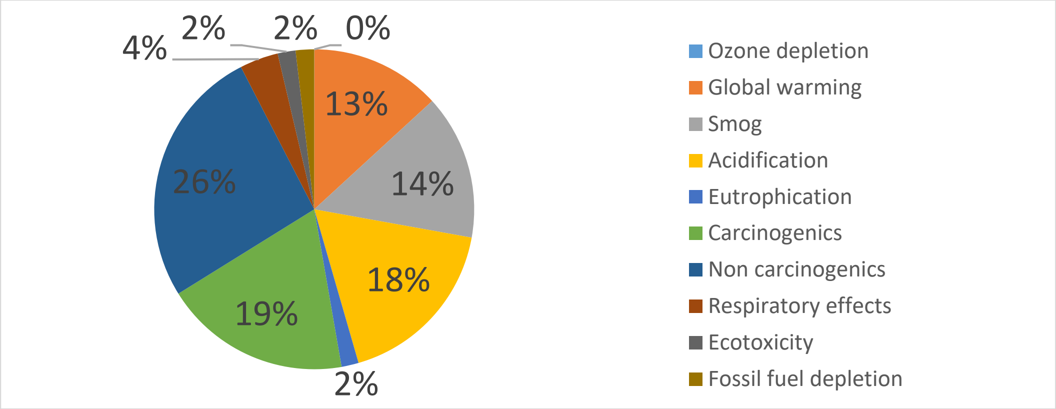


Figure B-24 Percentage of Normalized Environmental Impact Assessment of 60 in. Diameter SAPL Renewal Method

Table B-18 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 60 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.000912	0.000657	0.000216	2.46E-06	4.05E-08	6.34E-08	3.63E-05
Global warming	kg CO2 eq	91410.76	88420.06	1064.139	36.6225	0.664274	1549.853	339.4222
Smog	kg O3 eq	6556.03	5655.927	213.6578	2.10199	0.037764	675.6049	8.70049
Acidification	kg SO2 eq	475.6309	445.6078	7.28312	0.235729	0.005138	21.27751	1.221652
Eutrophication	kg N eq	15.76793	10.35756	1.181419	0.194744	0.00998	1.272802	2.75143
Carcinogenics	CTUh	0.000392	0.000276	5.52E-05	1.10E-05	3.56E-07	2.29E-05	2.66E-05
Non carcinogenics	CTUh	0.008147	0.00765	1.51E-04	3.25E-05	2.42E-06	0.00022	9.03E-05
Respiratory effects	kg PM2.5 eq	28.30375	26.22229	0.519239	0.06137	0.000957	0.437911	1.061979
Ecotoxicity	CTUe	20004.35	5563.905	3324.635	3702.743	53.52642	4244.529	3115.007
Fossil fuel depletion	MJ surplus	15429.64	9711.686	2250.952	20.23191	0.746784	3187.017	259.0047

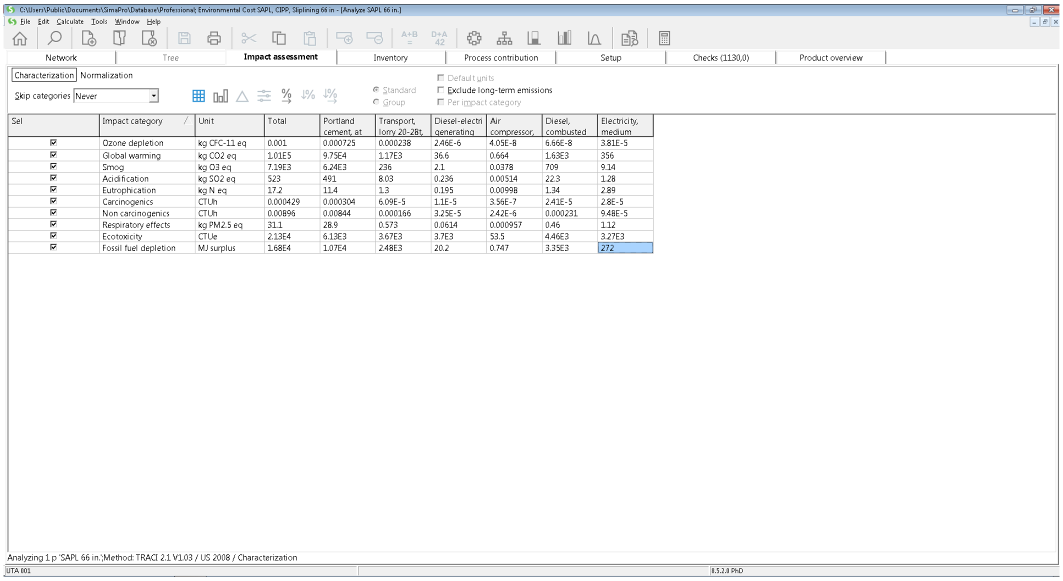
Table B-19 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 60 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.005653	0.004075	0.001337	1.53E-05	2.51E-07	3.93E-07	0.000225
Global warming	-	3.77361	3.650148	0.04393	0.001512	2.74E-05	0.063981	0.014012
Smog	-	4.710088	4.063422	0.153499	0.00151	2.71E-05	0.485379	0.006251
Acidification	-	5.236499	4.905957	0.080184	0.002595	5.66E-05	0.234257	0.01345
Eutrophication	-	0.729464	0.479166	0.054655	0.009009	0.000462	0.058883	0.127288
Carcinogenics	-	7.44143	5.237154	1.047828	0.209459	0.006752	0.434777	0.505459
Non carcinogenics	-	7.756353	7.284061	0.14366	0.030939	0.0023	0.209451	0.085942
Respiratory effects	-	1.167262	1.081422	0.021414	0.002531	3.95E-05	0.01806	0.043797
Ecotoxicity	-	1.807085	0.502613	0.30033	0.334486	0.004835	0.383428	0.281393
Fossil fuel depletion	-	0.819837	0.51602	0.119602	0.001075	3.97E-05	0.169339	0.013762

Table B-20 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 60 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.000912	0.03
Global warming	kg CO2 eq	91410.76	5,758.88
Smog	kg O3 eq	6556.03	14,423.27
Acidification	kg SO2 eq	475.6309	2,601.70
Eutrophication	kg N eq	15.76793	32.32
Carcinogenic	CTUh	0.000392	0.00
Non carcinogenic	CTUh	0.008147	0.07
Respiratory effects	kg PM2.5 eq	28.30375	1,792.76
Ecotoxicity	CTUe	20004.35	820.18
Fossil fuel depletion	MJ surplus	15429.64	151.21
Total			25,580.42

A.1.7 SAPL 66 in.



Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.001	0.000725	0.000238	2.46E-6	4.05E-8	6.66E-8	3.81E-5
☑	Global warming	kg CO2 eq	1.01E5	9.75E4	1.17E3	36.6	0.664	1.63E3	356
☑	Smog	kg O3 eq	7.19E3	6.24E3	236	2.1	0.0378	709	9.14
☑	Acidification	kg SO2 eq	523	491	8.03	0.236	0.00514	22.3	1.28
☑	Eutrophication	kg N eq	17.2	11.4	1.3	0.195	0.00998	1.34	2.89
☑	Carcinogenics	CTUh	0.000429	0.000304	6.09E-5	1.1E-5	3.56E-7	2.41E-5	2.8E-5
☑	Non carcinogenics	CTUh	0.00896	0.00844	0.000166	3.25E-5	2.42E-6	0.000231	9.48E-5
☑	Respiratory effects	kg PM2.5 eq	31.1	28.9	0.573	0.0614	0.000957	0.46	1.12
☑	Ecotoxicity	CTUe	2.13E4	6.13E3	3.67E3	3.7E3	53.5	4.46E3	3.27E3
☑	Fossil fuel depletion	MJ surplus	1.68E4	1.07E4	2.48E3	20.2	0.747	3.35E3	272

Analyzing 1 p 'SAPL 66 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-25 Screenshot of the Impact Assessment Table from SimaPro Software for 66 in. SAPL

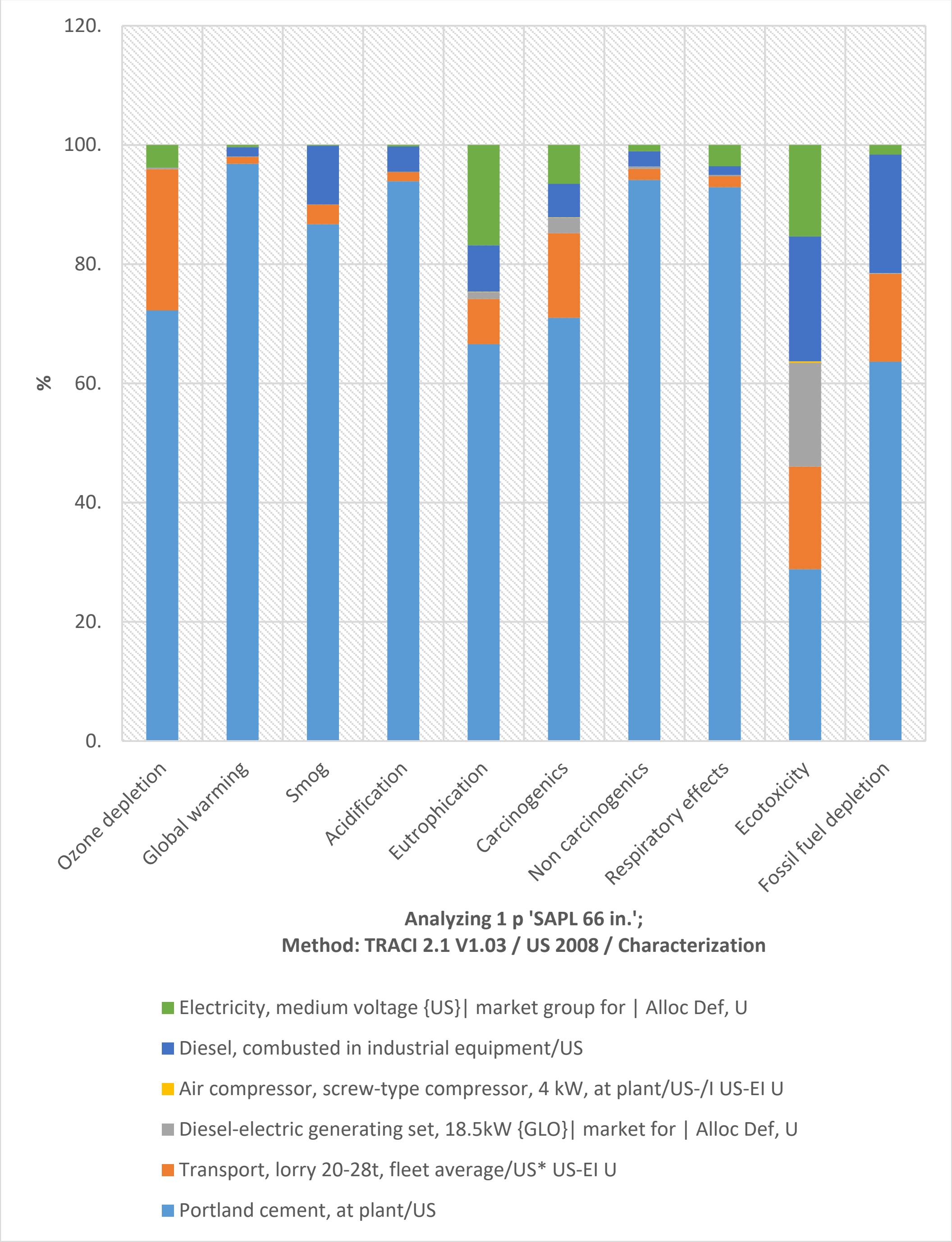


Figure B-26 Environmental Impact Assessment of 66 in. Diameter SAPL Renewal Method

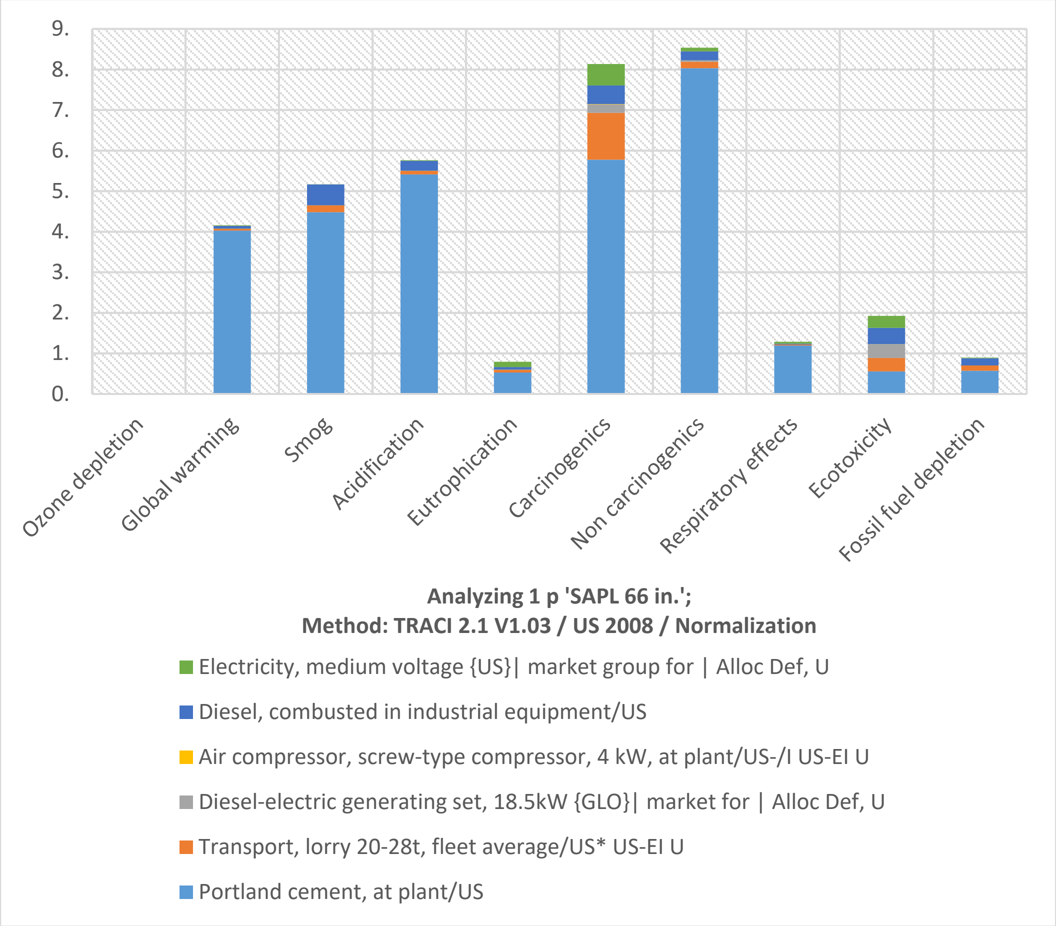


Figure B-27 Normalized Environmental Impact Assessment of 66 in. Diameter SAPL Renewal Method

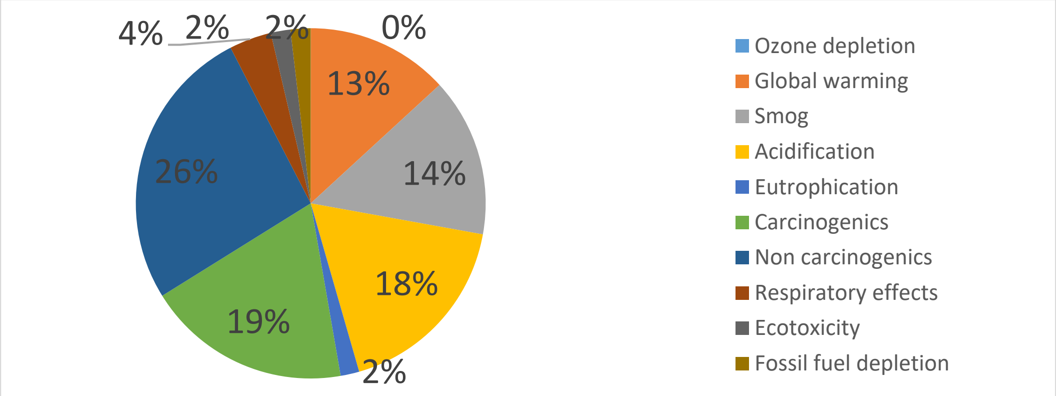


Figure B-28 Percentage of Normalized Environmental Impact Assessment of 66 in. Diameter SAPL Renewal Method

Table B-21 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 66 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.001003	0.000725	0.000238	2.46E-06	4.05E-08	6.66E-08	3.81E-05
Global warming	kg CO2 eq	100684.1	97489.9	1173.295	36.6225	0.664274	1627.249	356.3959
Smog	kg O3 eq	7192.286	6236.093	235.5741	2.10199	0.037764	709.3432	9.135582
Acidification	kg SO2 eq	523.2106	491.3167	8.030198	0.235729	0.005138	22.34006	1.282744
Eutrophication	kg N eq	17.15271	11.42	1.302605	0.194744	0.00998	1.336363	2.889023
Carcinogenics	CTUh	0.000429	0.000304	6.09E-05	1.10E-05	3.56E-07	2.41E-05	2.80E-05
Non carcinogenics	CTUh	0.008962	0.008435	1.66E-04	3.25E-05	2.42E-06	0.000231	9.48E-05
Respiratory effects	kg PM2.5 eq	31.12178	28.91209	0.5725	0.06137	0.000957	0.459779	1.115086
Ecotoxicity	CTUe	21283.84	6134.632	3665.665	3702.743	53.52642	4456.492	3270.782
Fossil fuel depletion	MJ surplus	16828.83	10707.88	2481.847	20.23191	0.746784	3346.17	271.957

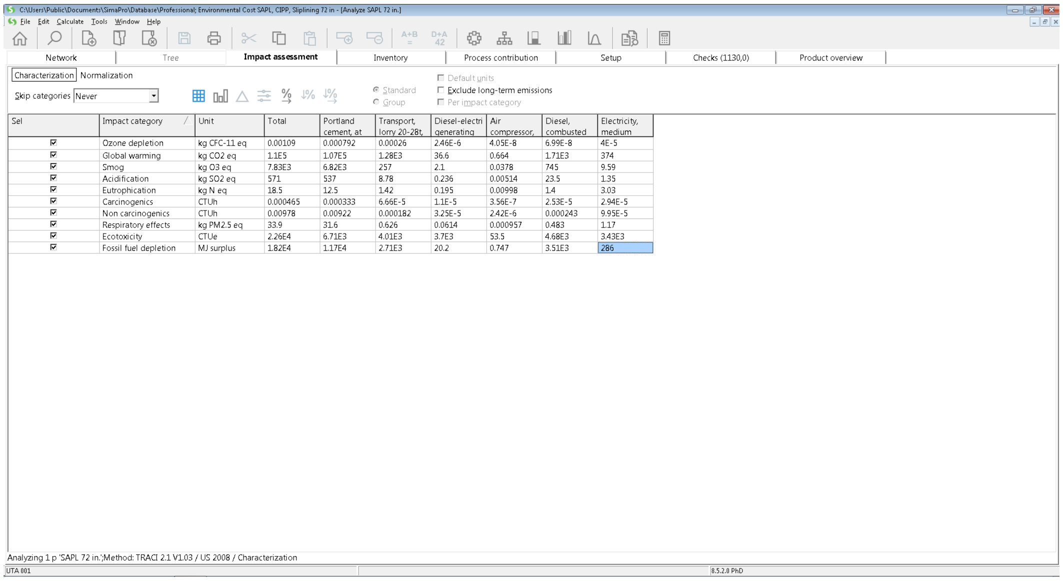
Table B-22 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 66 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.006219	0.004493	0.001474	1.53E-05	2.51E-07	4.13E-07	0.000236
Global warming	-	4.156432	4.024568	0.048436	0.001512	2.74E-05	0.067176	0.014713
Smog	-	5.167197	4.480234	0.169245	0.00151	2.71E-05	0.509618	0.006563
Acidification	-	5.760332	5.409194	0.088409	0.002595	5.66E-05	0.245955	0.014122
Eutrophication	-	0.793528	0.528318	0.060262	0.009009	0.000462	0.061823	0.133653
Carcinogenics	-	8.133111	5.774364	1.155311	0.209459	0.006752	0.456489	0.530735
Non carcinogenics	-	8.533021	8.031236	0.158396	0.030939	0.0023	0.219911	0.09024
Respiratory effects	-	1.283479	1.19235	0.02361	0.002531	3.95E-05	0.018962	0.045987
Ecotoxicity	-	1.922667	0.55417	0.331136	0.334486	0.004835	0.402575	0.295465
Fossil fuel depletion	-	0.894181	0.568951	0.13187	0.001075	3.97E-05	0.177795	0.01445

Table B-23 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 66 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001003	0.03
Global warming	kg CO2 eq	100684.1	6,343.10
Smog	kg O3 eq	7192.286	15,823.03
Acidification	kg SO2 eq	523.2106	2,861.96
Eutrophication	kg N eq	17.15271	35.16
Carcinogenic	CTUh	0.000429	0.00
Non carcinogenic	CTUh	0.008962	0.08
Respiratory effects	kg PM2.5 eq	31.12178	1,971.25
Ecotoxicity	CTUe	21283.84	872.64
Fossil fuel depletion	MJ surplus	16828.83	164.92
Total			28,072.18

A.1.8 SAPL 72 in.



Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.00109	0.000792	0.00026	2.46E-6	4.05E-8	6.99E-8	4E-5
☑	Global warming	kg CO2 eq	1.1E5	1.07E5	1.28E3	36.6	0.664	1.71E3	374
☑	Smog	kg O3 eq	7.83E3	6.82E3	257	2.1	0.0378	745	9.59
☑	Acidification	kg SO2 eq	571	537	8.78	0.236	0.00514	23.5	1.35
☑	Eutrophication	kg N eq	18.5	12.5	1.42	0.195	0.00998	1.4	3.03
☑	Carcinogenics	CTUh	0.000465	0.000333	6.66E-5	1.1E-5	3.56E-7	2.53E-5	2.94E-5
☑	Non carcinogenics	CTUh	0.00978	0.00922	0.000182	3.25E-5	2.42E-6	0.000243	9.95E-5
☑	Respiratory effects	kg PM2.5 eq	33.9	31.6	0.626	0.0614	0.000957	0.483	1.17
☑	Ecotoxicity	CTUe	2.26E4	6.71E3	4.01E3	3.7E3	53.5	4.68E3	3.43E3
☑	Fossil fuel depletion	MJ surplus	1.82E4	1.17E4	2.71E3	20.2	0.747	3.51E3	286

Analyzing 1 p 'SAPL 72 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-29 Screenshot of the Impact Assessment Table from SimaPro Software for 72 in. SAPL

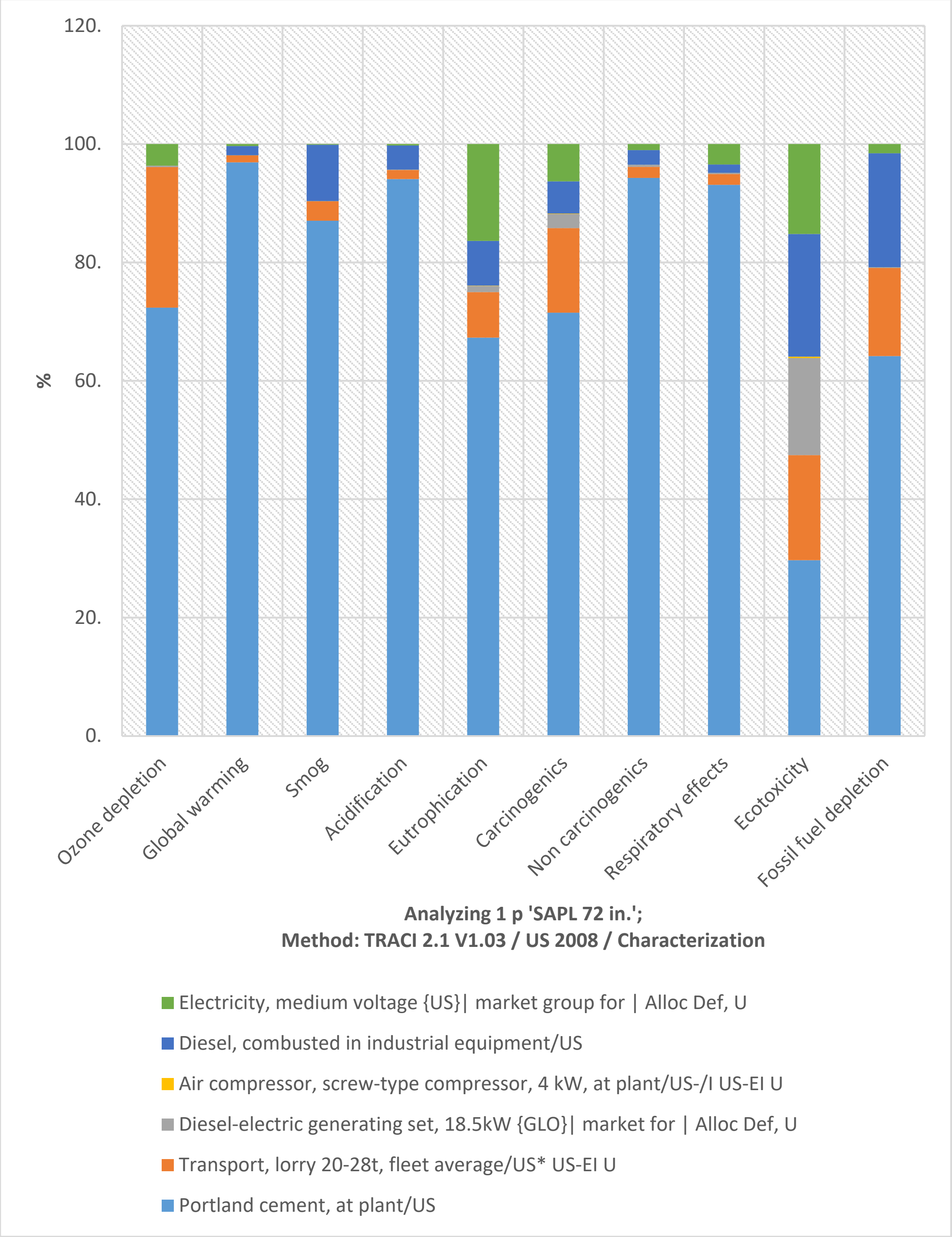


Figure B-30 Environmental Impact Assessment of 72 in. Diameter SAPL Renewal Method

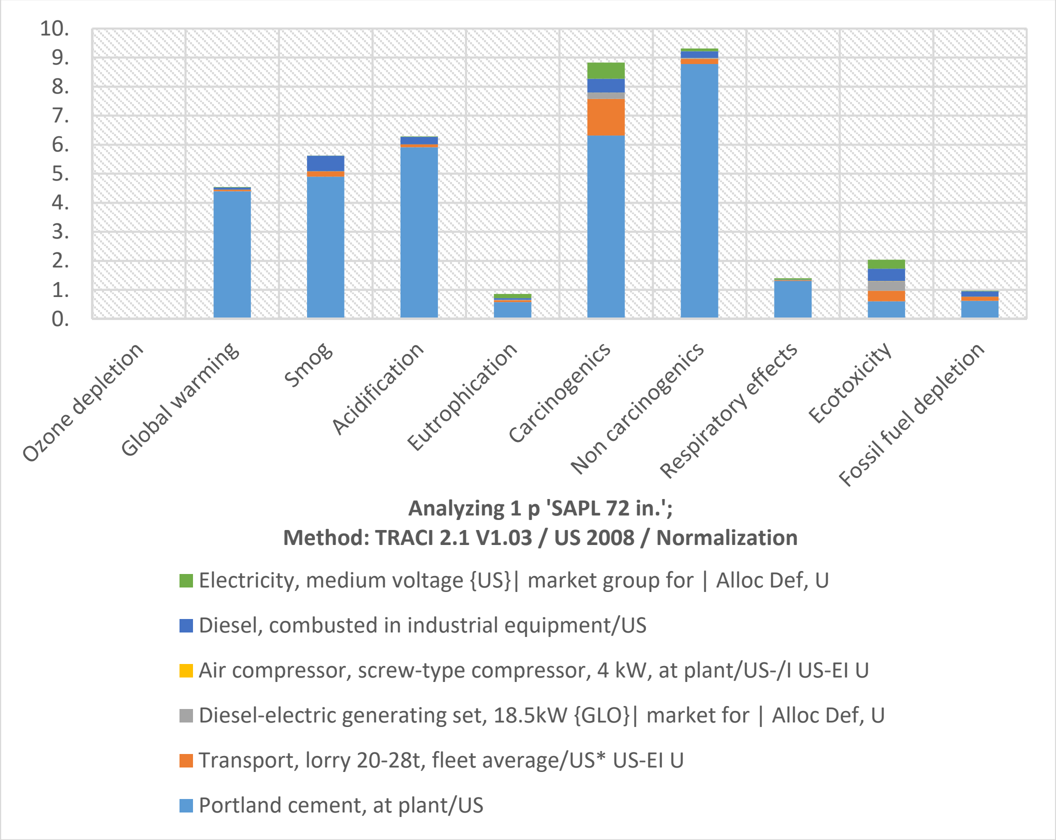


Figure B-31 Normalized Environmental Impact Assessment of 72 in. Diameter SAPL Renewal Method

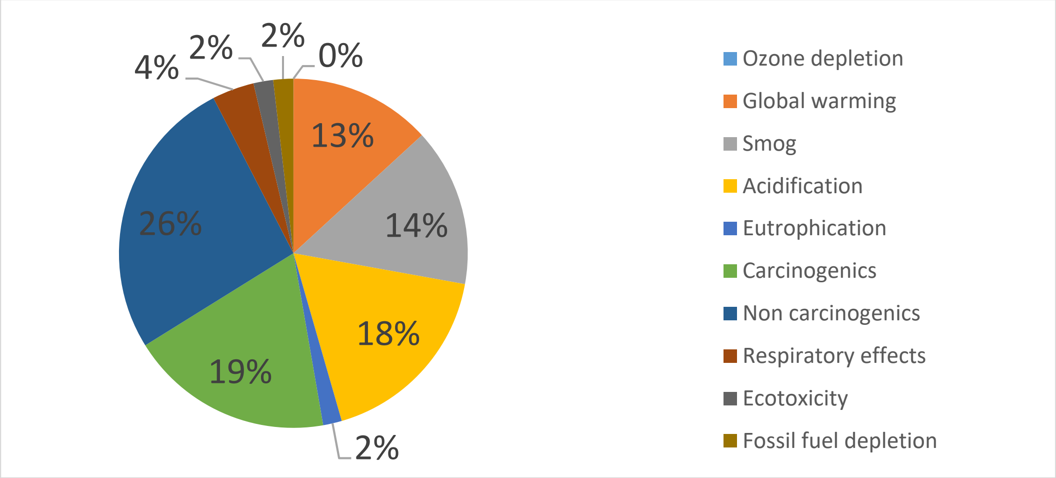


Figure B-32 Percentage of Normalized Environmental Impact Assessment of 72 in. Diameter SAPL Renewal Method

Table B-24 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 72 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.001094	0.000792	0.00026	2.46E-06	4.05E-08	6.99E-08	4.00E-05
Global warming	kg CO2 eq	109962.3	106559.7	1282.451	36.6225	0.664274	1708.611	374.217
Smog	kg O3 eq	7830.293	6816.26	257.4904	2.10199	0.037764	744.8104	9.592394
Acidification	kg SO2 eq	570.8478	537.0257	8.777277	0.235729	0.005138	23.45707	1.346885
Eutrophication	kg N eq	18.54762	12.48244	1.423791	0.194744	0.00998	1.403181	3.033484
Carcinogenics	CTUh	0.000465	0.000333	6.66E-05	1.10E-05	3.56E-07	2.53E-05	2.94E-05
Non carcinogenics	CTUh	0.009779	0.00922	1.82E-04	3.25E-05	2.42E-06	0.000243	9.95E-05
Respiratory effects	kg PM2.5 eq	33.94359	31.60188	0.625762	0.06137	0.000957	0.482768	1.170845
Ecotoxicity	CTUe	22581.97	6705.359	4006.695	3702.743	53.52642	4679.317	3434.333
Fossil fuel depletion	MJ surplus	18236.83	11704.07	2712.743	20.23191	0.746784	3513.479	285.5558

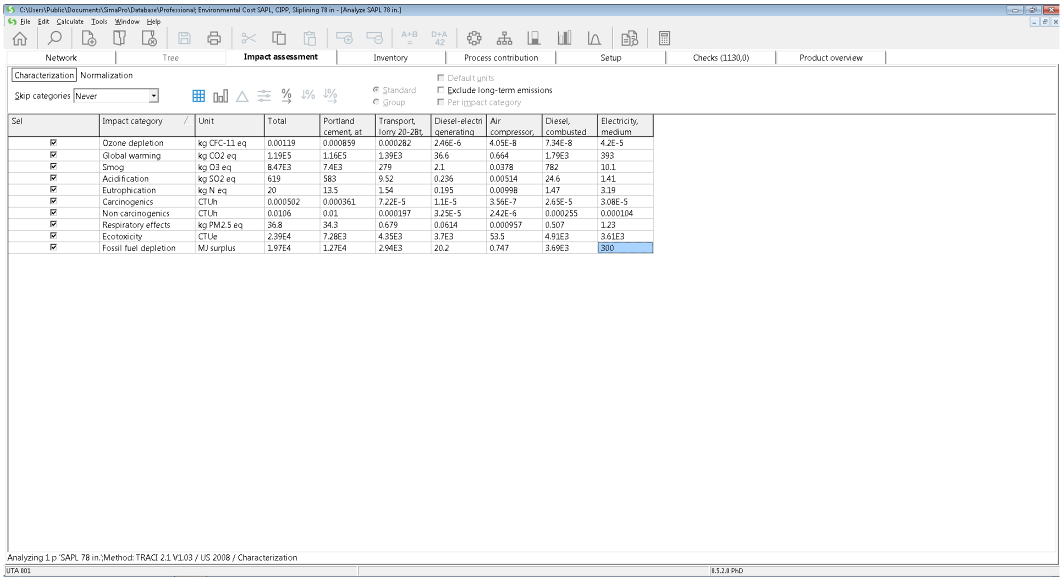
Table B-25 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 72 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.006786	0.004911	0.001611	1.53E-05	2.51E-07	4.34E-07	0.000248
Global warming	-	4.539453	4.398988	0.052942	0.001512	2.74E-05	0.070535	0.015448
Smog	-	5.625564	4.897046	0.18499	0.00151	2.71E-05	0.535099	0.006892
Acidification	-	6.284798	5.912431	0.096634	0.002595	5.66E-05	0.258253	0.014829
Eutrophication	-	0.85806	0.577469	0.065868	0.009009	0.000462	0.064915	0.140337
Carcinogenics	-	8.827167	6.311574	1.262793	0.209459	0.006752	0.479314	0.557274
Non carcinogenics	-	9.31044	8.778411	0.173133	0.030939	0.0023	0.230906	0.094752
Respiratory effects	-	1.399852	1.303279	0.025807	0.002531	3.95E-05	0.01991	0.048286
Ecotoxicity	-	2.039934	0.605726	0.361943	0.334486	0.004835	0.422704	0.310239
Fossil fuel depletion	-	0.968994	0.621883	0.144139	0.001075	3.97E-05	0.186685	0.015173

Table B-26 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 72 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001094	0.04
Global warming	kg CO2 eq	109962.3	6,927.62
Smog	kg O3 eq	7830.293	17,226.64
Acidification	kg SO2 eq	570.8478	3,122.54
Eutrophication	kg N eq	18.54762	38.02
Carcinogenic	CTUh	0.000465	0.00
Non carcinogenic	CTUh	0.009779	0.09
Respiratory effects	kg PM2.5 eq	33.94359	2,149.99
Ecotoxicity	CTUe	22581.97	925.86
Fossil fuel depletion	MJ surplus	18236.83	178.72
Total			30,569.52

A.1.9 SAPL 78 in.



Skip categories: Never

☐ Exclude long-term emissions

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.00119	0.000859	0.000282	2.46E-6	4.05E-8	7.34E-8	4.2E-5
☑	Global warming	kg CO2 eq	1.19E5	1.16E5	1.39E3	36.6	0.664	1.79E3	393
☑	Smog	kg O3 eq	8.47E3	7.4E3	279	2.1	0.0378	782	10.1
☑	Acidification	kg SO2 eq	619	583	9.52	0.236	0.00514	24.6	1.41
☑	Eutrophication	kg N eq	20	13.5	1.54	0.195	0.00998	1.47	3.19
☑	Carcinogenics	CTUh	0.000502	0.000361	7.22E-5	1.1E-5	3.56E-7	2.65E-5	3.08E-5
☑	Non carcinogenics	CTUh	0.0106	0.01	0.000197	3.25E-5	2.42E-6	0.000255	0.000104
☑	Respiratory effects	kg PM2.5 eq	36.8	34.3	0.679	0.0614	0.000957	0.507	1.23
☑	Ecotoxicity	CTUe	2.39E4	7.28E3	4.35E3	3.7E3	53.5	4.91E3	3.61E3
☑	Fossil fuel depletion	MJ surplus	1.97E4	1.27E4	2.94E3	20.2	0.747	3.69E3	300

Analyzing 1 p 'SAPL 78 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-33 Screenshot of the Impact Assessment Table from SimaPro Software for 78 in. SAPL

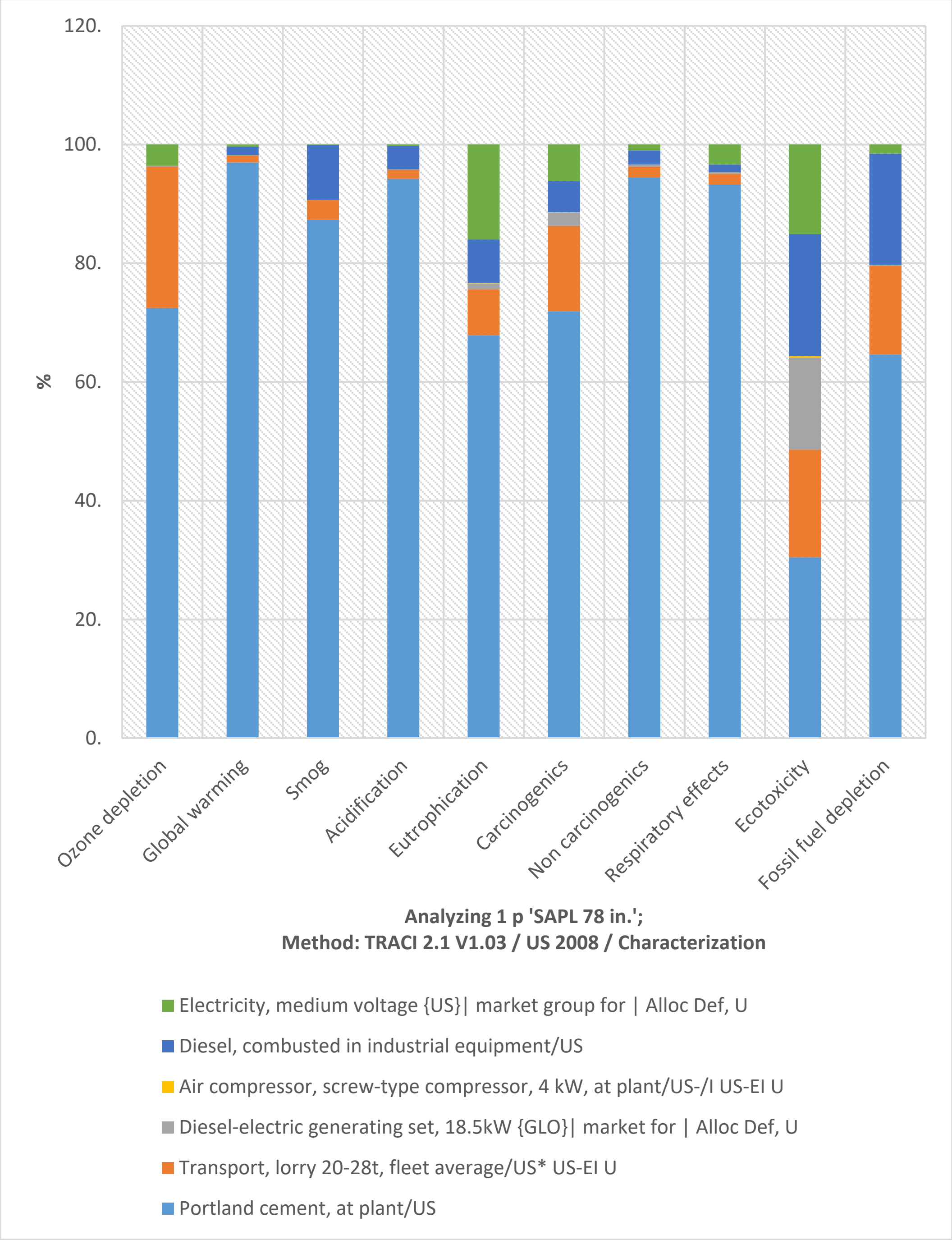


Figure B-34 Environmental Impact Assessment of 78 in. Diameter SAPL Renewal Method

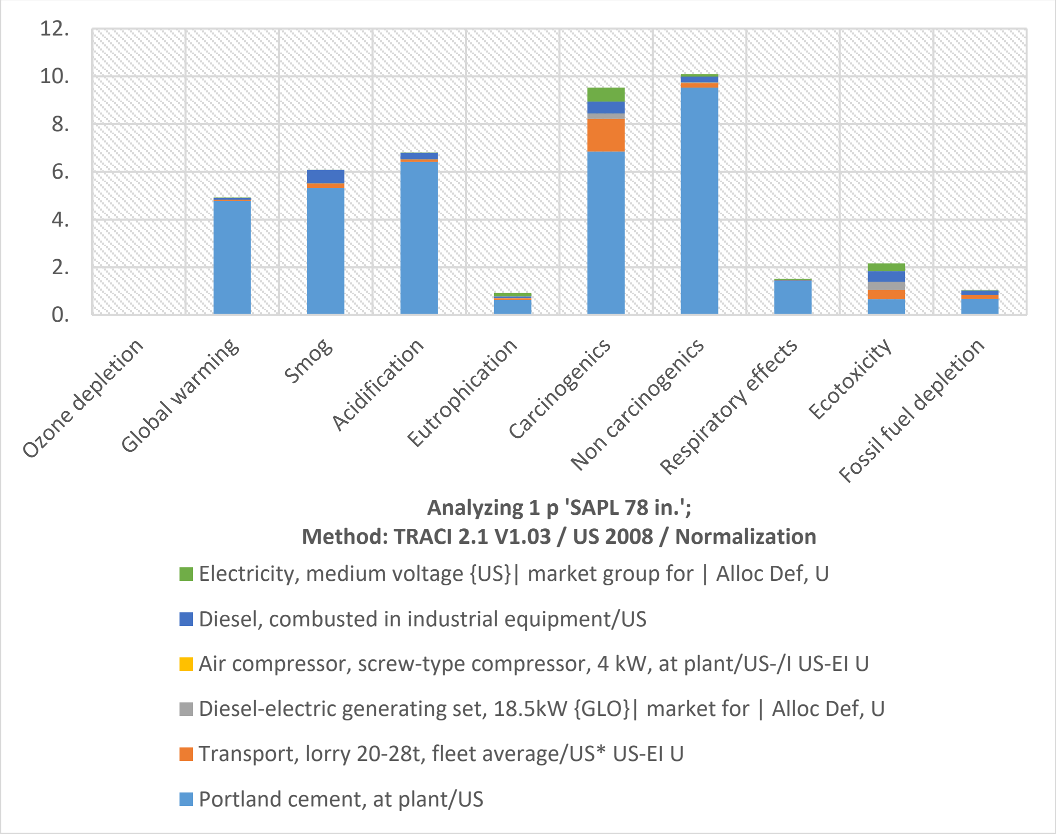


Figure B-35 Normalized Environmental Impact Assessment of 78 in. Diameter SAPL Renewal Method

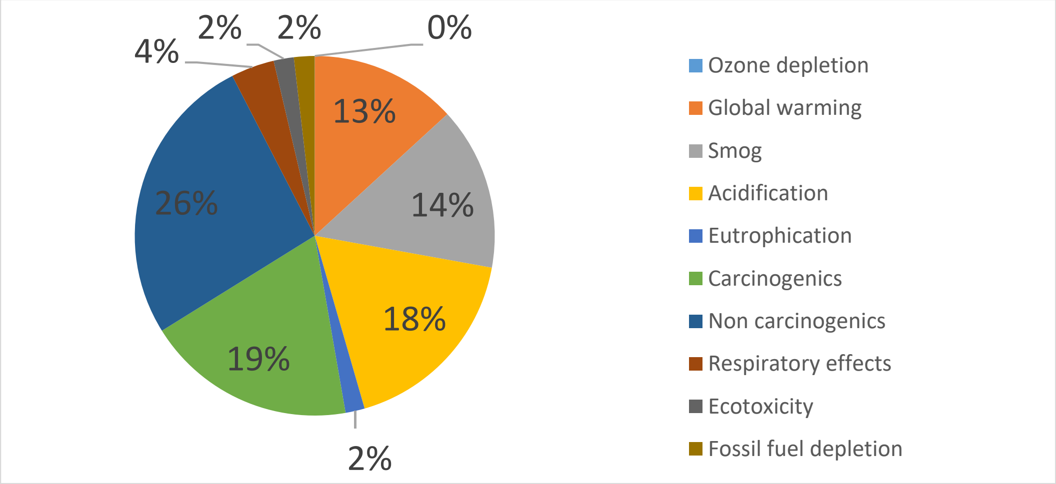


Figure B-36 Percentage of Normalized Environmental Impact Assessment of 78 in. Diameter SAPL Renewal Method

Table B-27 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 78 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.001186	0.000859	0.000282	2.46E-06	4.05E-08	7.34E-08	4.20E-05
Global warming	kg CO2 eq	119242.3	115626.5	1391.571	36.6225	0.664274	1794.06	392.9246
Smog	kg O3 eq	8469.897	7396.228	279.3995	2.10199	0.037764	782.0587	10.07193
Acidification	kg SO2 eq	618.5284	582.719	9.52411	0.235729	0.005138	24.63017	1.414218
Eutrophication	kg N eq	19.95267	13.54452	1.544937	0.194744	0.00998	1.473355	3.185132
Carcinogenics	CTUh	0.000502	0.000361	7.22E-05	1.10E-05	3.56E-07	2.65E-05	3.08E-05
Non carcinogenics	CTUh	0.010596	0.010005	1.97E-04	3.25E-05	2.42E-06	0.000255	1.04E-04
Respiratory effects	kg PM2.5 eq	36.76838	34.29076	0.679007	0.06137	0.000957	0.506912	1.229377
Ecotoxicity	CTUe	23899.12	7275.891	4347.613	3702.743	53.52642	4913.332	3606.019
Fossil fuel depletion	MJ surplus	19653.49	12699.92	2943.562	20.23191	0.746784	3689.19	299.8311

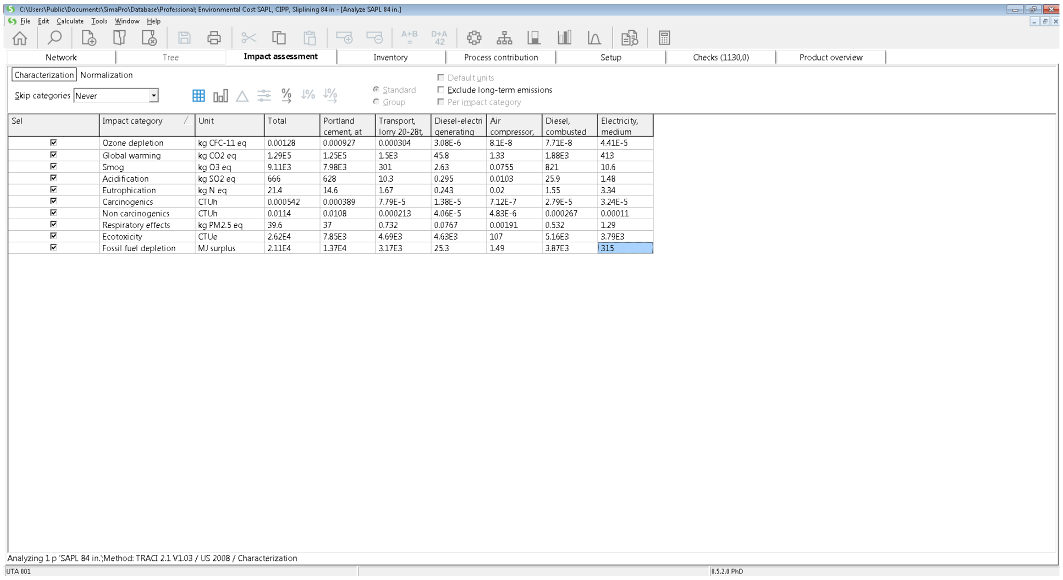
Table B-28 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 78 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.007353	0.005329	0.001748	1.53E-05	2.51E-07	4.55E-07	0.00026
Global warming	-	4.922549	4.77328	0.057447	0.001512	2.74E-05	0.074062	0.016221
Smog	-	6.085079	5.313716	0.200731	0.00151	2.71E-05	0.561859	0.007236
Acidification	-	6.809742	6.415495	0.104857	0.002595	5.66E-05	0.271168	0.01557
Eutrophication	-	0.923061	0.626604	0.071473	0.009009	0.000462	0.068161	0.147352
Carcinogenics	-	9.52347	6.8486	1.370241	0.209459	0.006752	0.503285	0.585133
Non carcinogenics	-	10.08838	9.52533	0.187864	0.030939	0.0023	0.242454	0.099489
Respiratory effects	-	1.516348	1.41417	0.028003	0.002531	3.95E-05	0.020905	0.0507
Ecotoxicity	-	2.158918	0.657265	0.39274	0.334486	0.004835	0.443844	0.325748
Fossil fuel depletion	-	1.044266	0.674796	0.156403	0.001075	3.97E-05	0.196021	0.015931

Table B-29 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 78 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001186	0.04
Global warming	kg CO2 eq	119242.3	7,512.27
Smog	kg O3 eq	8469.897	18,633.77
Acidification	kg SO2 eq	618.5284	3,383.35
Eutrophication	kg N eq	19.95267	40.90
Carcinogenic	CTUh	0.000502	0.00
Non carcinogenic	CTUh	0.010596	0.09
Respiratory effects	kg PM2.5 eq	36.76838	2,328.91
Ecotoxicity	CTUe	23899.12	979.86
Fossil fuel depletion	MJ surplus	19653.49	192.60
Total			33,071.80

A.1.10 SAPL 84 in.



Skip categories: Never

○ Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.00128	0.000927	0.000304	3.08E-6	8.1E-8	7.71E-8	4.41E-5
☑	Global warming	kg CO2 eq	1.29E5	1.25E5	1.5E3	45.8	1.33	1.88E3	413
☑	Smog	kg O3 eq	9.11E3	7.98E3	301	2.63	0.0755	821	10.6
☑	Acidification	kg SO2 eq	666	628	10.3	0.295	0.0103	25.9	1.48
☑	Eutrophication	kg N eq	21.4	14.6	1.67	0.243	0.02	1.55	3.34
☑	Carcinogenics	CTUh	0.000542	0.000389	7.79E-5	1.38E-5	7.12E-7	2.79E-5	3.24E-5
☑	Non carcinogenics	CTUh	0.0114	0.0108	0.000213	4.06E-5	4.83E-6	0.000267	0.00011
☑	Respiratory effects	kg PM2.5 eq	39.6	37	0.732	0.0767	0.00191	0.532	1.29
☑	Ecotoxicity	CTUe	2.62E4	7.85E3	4.69E3	4.63E3	107	5.16E3	3.79E3
☑	Fossil fuel depletion	MJ surplus	2.11E4	1.37E4	3.17E3	25.3	1.49	3.87E3	315

Analyzing 1 p 'SAPL 84 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-37 Screenshot of the Impact Assessment Table from SimaPro Software for 84 in. SAPL

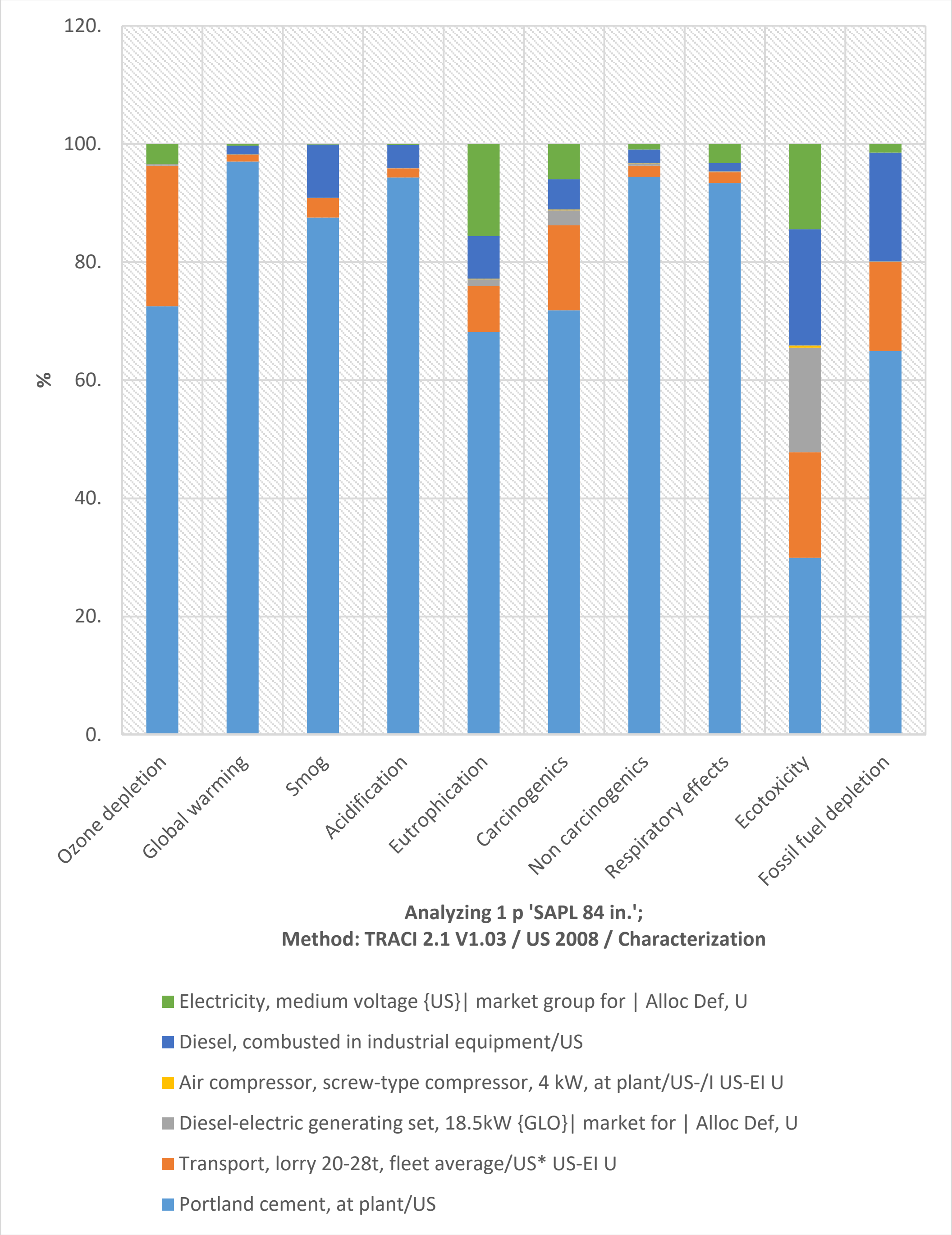


Figure B-38 Environmental Impact Assessment of 84 in. Diameter SAPL Renewal Method

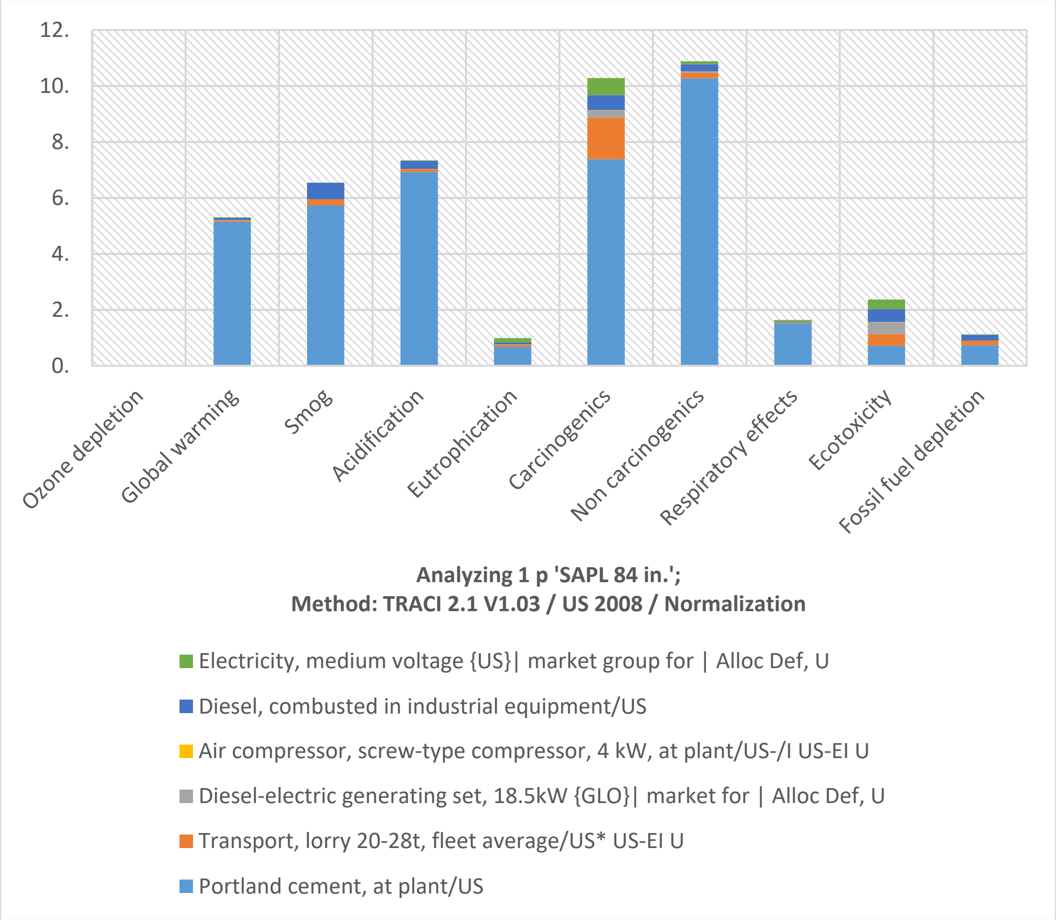


Figure B-39 Normalized Environmental Impact Assessment of 84 in. Diameter SAPL Renewal Method

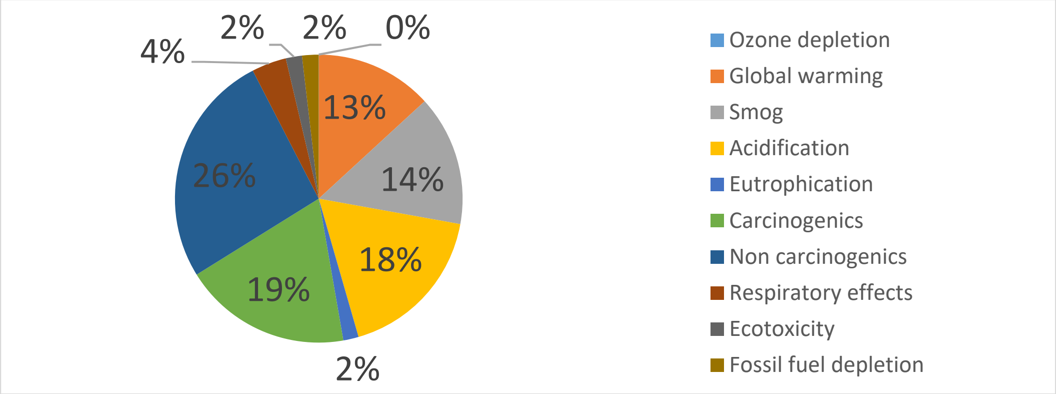


Figure B-40 Percentage of Normalized Environmental Impact Assessment of 84 in. Diameter SAPL Renewal Method

Table B-30 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 84 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.001278	0.000927	0.000304	3.08E-06	8.10E-08	7.71E-08	4.41E-05
Global warming	kg CO2 eq	128540.6	124696.3	1500.727	45.77813	1.328548	1883.835	412.5708
Smog	kg O3 eq	9112.181	7976.394	301.3158	2.627487	0.075528	821.1931	10.57553
Acidification	kg SO2 eq	666.3517	628.428	10.27119	0.294661	0.010277	25.86267	1.484929
Eutrophication	kg N eq	21.42795	14.60697	1.666123	0.24343	0.019961	1.547082	3.344389
Carcinogenics	CTUh	0.000542	0.000389	7.79E-05	1.38E-05	7.12E-07	2.79E-05	3.24E-05
Non carcinogenics	CTUh	0.011425	0.010789	2.13E-04	4.06E-05	4.83E-06	0.000267	1.10E-04
Respiratory effects	kg PM2.5 eq	39.61457	36.98055	0.732268	0.076713	0.001914	0.532278	1.290845
Ecotoxicity	CTUe	26216.26	7846.618	4688.643	4628.429	107.0529	5159.196	3786.32
Fossil fuel depletion	MJ surplus	21085.98	13696.12	3174.457	25.28988	1.493567	3873.797	314.8227

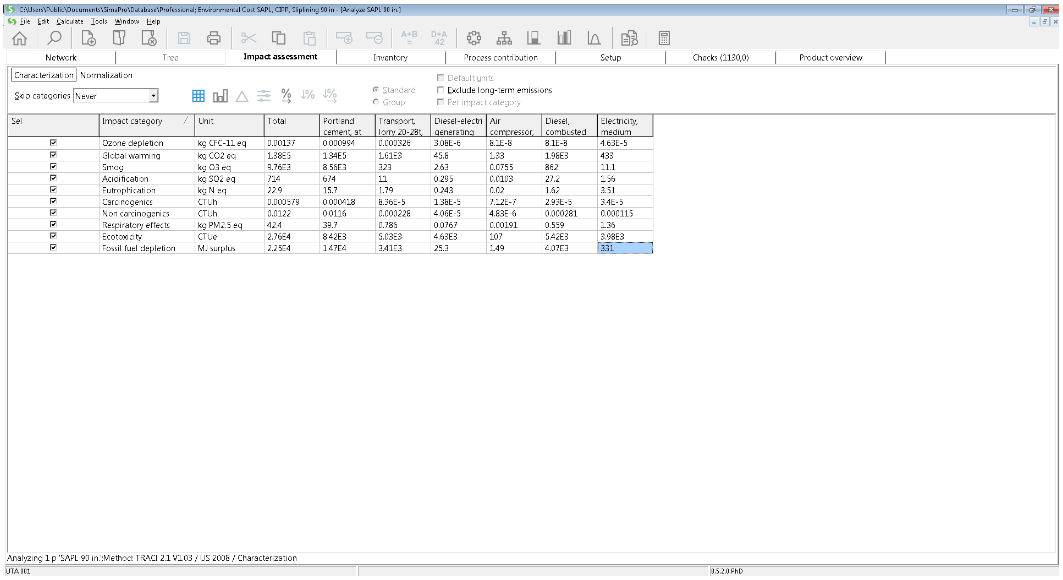
Table B-31 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 84 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.007926	0.005747	0.001885	1.91E-05	5.03E-07	4.78E-07	0.000273
Global warming	-	5.306398	5.1477	0.061953	0.00189	5.48E-05	0.077768	0.017032
Smog	-	6.546519	5.730529	0.216476	0.001888	5.43E-05	0.589975	0.007598
Acidification	-	7.336257	6.918732	0.113082	0.003244	1.13E-04	0.284737	0.016348
Eutrophication	-	0.991311	0.675755	0.077079	0.011262	0.000923	0.071572	0.15472
Carcinogenics	-	10.28172	7.38581	1.477724	0.261824	0.013504	0.528469	0.61439
Non carcinogenics	-	10.87743	10.27251	0.2026	0.038674	0.004599	0.254586	0.104463
Respiratory effects	-	1.633727	1.525099	0.030199	0.003164	7.89E-05	0.021951	0.053235
Ecotoxicity	-	2.368235	0.708821	0.423547	0.418107	0.009671	0.466054	0.342036
Fossil fuel depletion	-	1.12038	0.727728	0.168671	0.001344	7.94E-05	0.20583	0.016728

Table B-32 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 84 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001278	0.04
Global warming	kg CO2 eq	128540.6	8,098.05
Smog	kg O3 eq	9112.181	20,046.80
Acidification	kg SO2 eq	666.3517	3,644.94
Eutrophication	kg N eq	21.42795	43.93
Carcinogenic	CTUh	0.000542	0.00
Non carcinogenic	CTUh	0.011425	0.10
Respiratory effects	kg PM2.5 eq	39.61457	2,509.19
Ecotoxicity	CTUe	26216.26	1,074.87
Fossil fuel depletion	MJ surplus	21085.98	206.64
Total			35,624.56

A.1.11 SAPL 90 in.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 90 in - [Analyze SAPL 90 in.]

Skip categories: Never

☐ Exclude long-term emissions

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.00137	0.000994	0.000326	3.08E-6	8.1E-8	8.1E-8	4.63E-5
☑	Global warming	kg CO2 eq	1.38E5	1.34E5	1.61E3	45.8	1.33	1.98E3	433
☑	Smog	kg O3 eq	9.76E3	8.56E3	323	2.63	0.0755	862	11.1
☑	Acidification	kg SO2 eq	714	674	11	0.295	0.0103	27.2	1.56
☑	Eutrophication	kg N eq	22.9	15.7	1.79	0.243	0.02	1.62	3.51
☑	Carcinogenics	CTUh	0.000579	0.000418	8.36E-5	1.38E-5	7.12E-7	2.93E-5	3.4E-5
☑	Non carcinogenics	CTUh	0.0122	0.0116	0.000228	4.06E-5	4.83E-6	0.000281	0.000115
☑	Respiratory effects	kg PM2.5 eq	42.4	39.7	0.786	0.0767	0.00191	0.559	1.36
☑	Ecotoxicity	CTUe	2.76E4	8.42E3	5.03E3	4.63E3	107	5.42E3	3.98E3
☑	Fossil fuel depletion	MJ surplus	2.25E4	1.47E4	3.41E3	25.3	1.49	4.07E3	331

Analyzing 1 p 'SAPL 90 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-41 Screenshot of the Impact Assessment Table from SimaPro Software for 90 in. SAPL

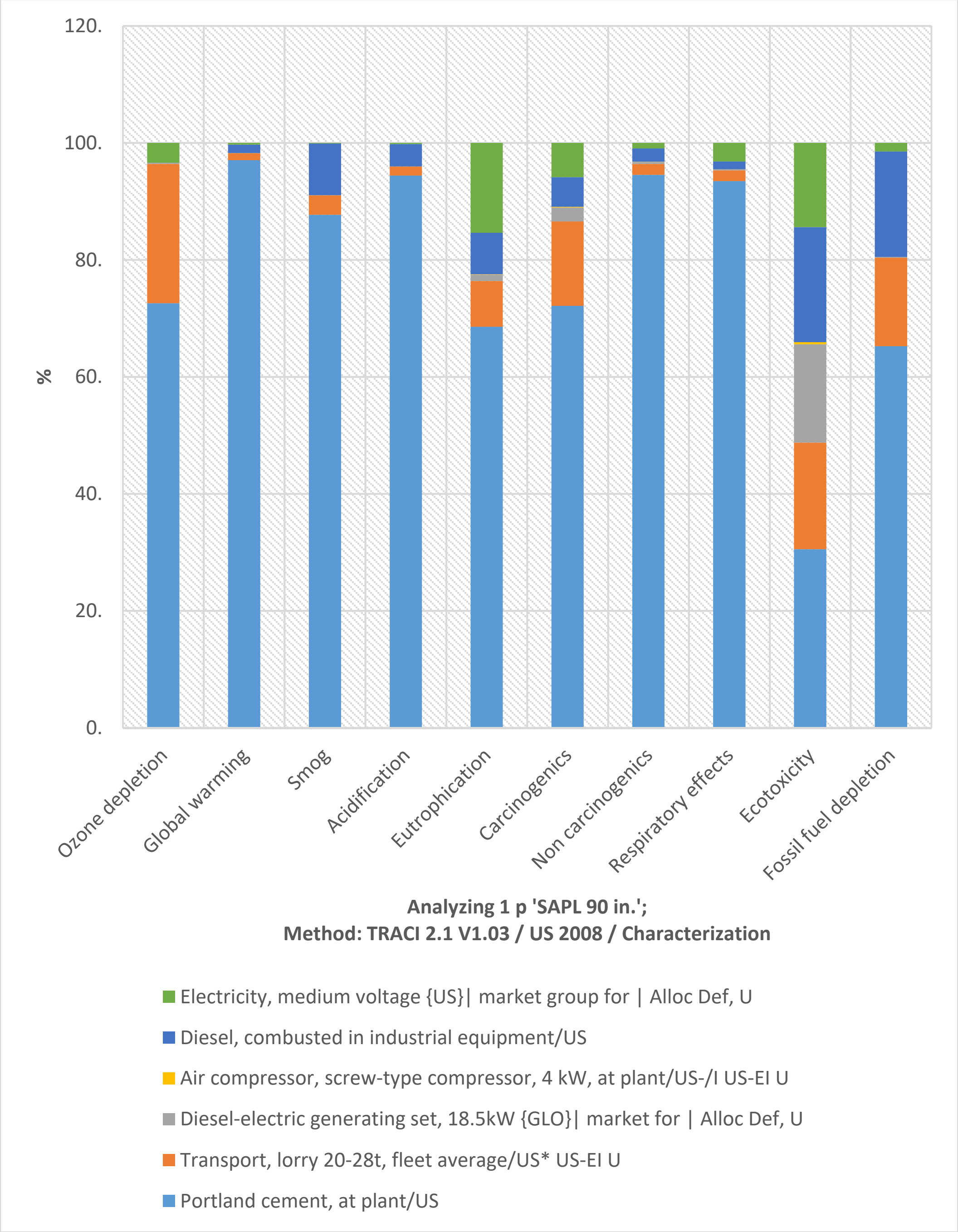


Figure B-42 Environmental Impact Assessment of 90 in. Diameter SAPL Renewal Method

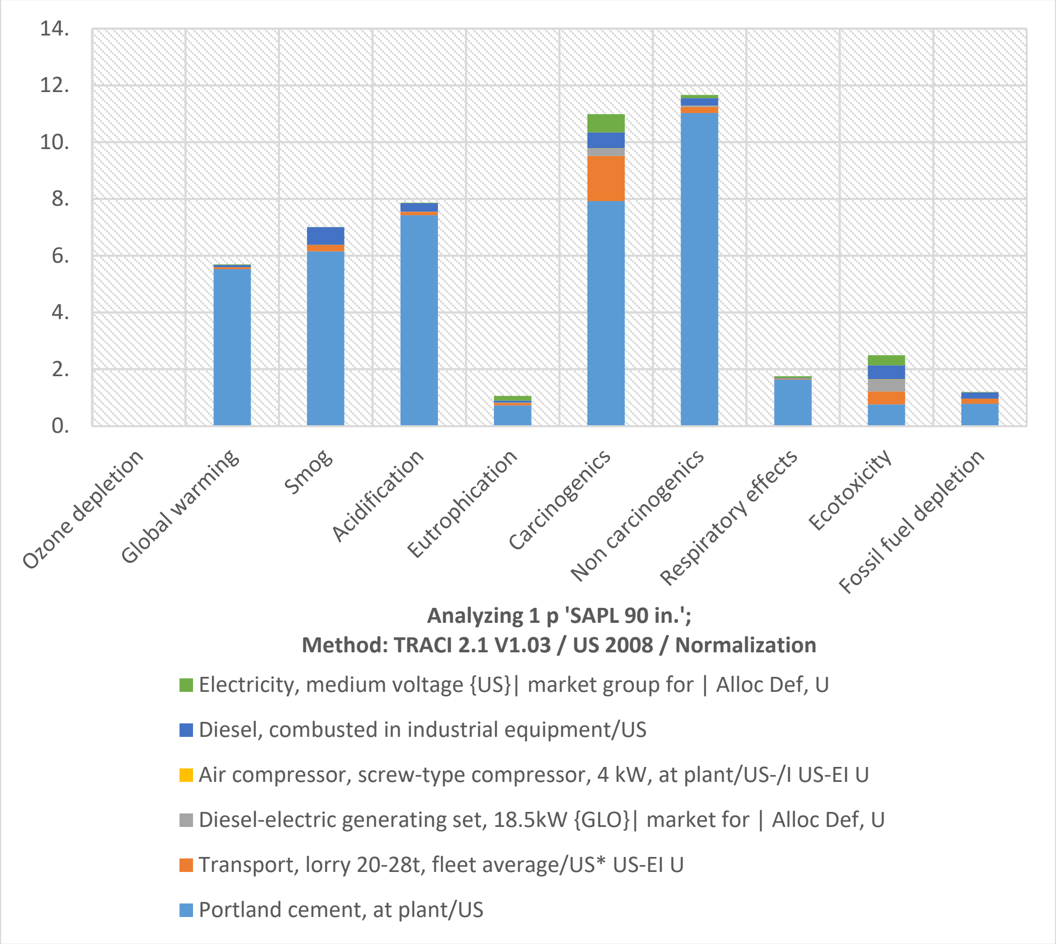


Figure B-43 Normalized Environmental Impact Assessment of 90 in. Diameter SAPL Renewal Method

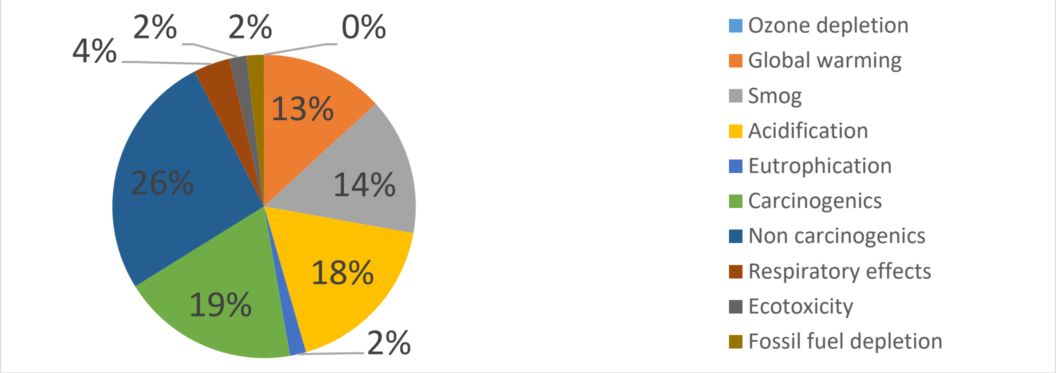


Figure B-44 Percentage of Normalized Environmental Impact Assessment of 90 in. Diameter SAPL Renewal Method

Table B-33 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 90 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.00137	0.000994	0.000326	3.08E-06	8.10E-08	8.10E-08	4.63E-05
Global warming	kg CO2 eq	137834.3	133766.1	1609.883	45.77813	1.328548	1977.937	433.2013
Smog	kg O3 eq	9755.813	8556.56	323.2321	2.627487	0.075528	862.2135	11.10435
Acidification	kg SO2 eq	714.1739	674.137	11.01827	0.294661	0.010277	27.15456	1.559182
Eutrophication	kg N eq	22.8561	15.66941	1.78731	0.24343	0.019961	1.624362	3.511624
Carcinogenics	CTUh	0.000579	0.000418	8.36E-05	1.38E-05	7.12E-07	2.93E-05	3.40E-05
Non carcinogenics	CTUh	0.012244	0.011574	2.28E-04	4.06E-05	4.83E-06	0.000281	1.15E-04
Respiratory effects	kg PM2.5 eq	42.44877	39.67035	0.78553	0.076713	0.001914	0.558866	1.355394
Ecotoxicity	CTUe	27575.06	8417.345	5029.673	4628.429	107.0529	5416.909	3975.654
Fossil fuel depletion	MJ surplus	22522.31	14692.31	3405.352	25.28988	1.493567	4067.302	330.5653

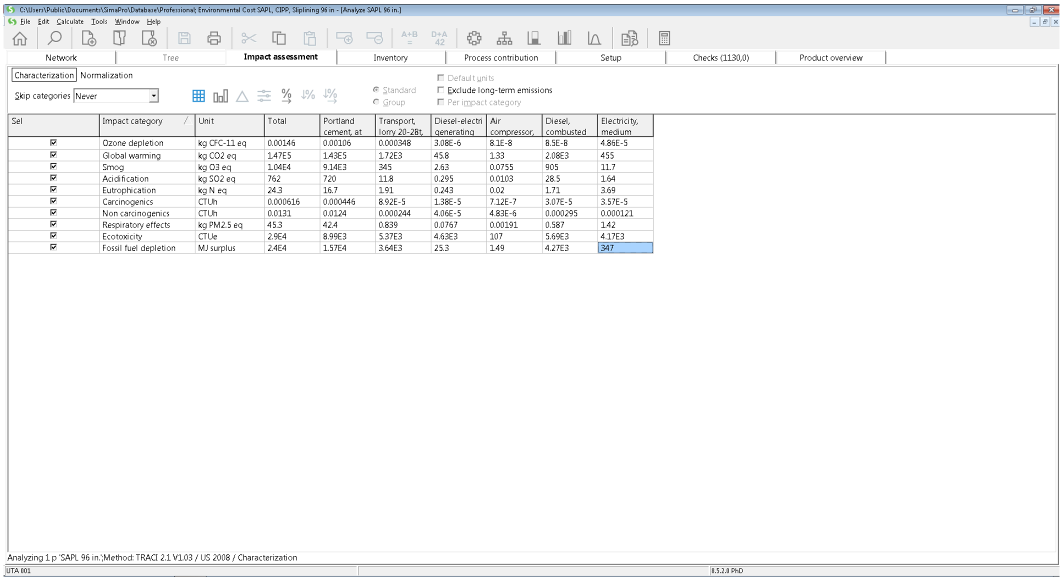
Table B-34 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 90 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.008494	0.006165	0.002022	1.91E-05	5.03E-07	5.02E-07	0.000287
Global warming	-	5.690061	5.522121	0.066459	0.00189	5.48E-05	0.081653	0.017883
Smog	-	7.008927	6.147341	0.232222	0.001888	5.43E-05	0.619445	0.007978
Acidification	-	7.862759	7.421969	0.121307	0.003244	1.13E-04	0.29896	0.017166
Eutrophication	-	1.05738	0.724906	0.082685	0.011262	0.000923	0.075147	0.162457
Carcinogenics	-	10.98353	7.92302	1.585206	0.261824	0.013504	0.554867	0.645112
Non carcinogenics	-	11.65728	11.01968	0.217336	0.038674	0.004599	0.267304	0.109687
Respiratory effects	-	1.750611	1.636027	0.032396	0.003164	7.89E-05	0.023048	0.055897
Ecotoxicity	-	2.490982	0.760377	0.454354	0.418107	0.009671	0.489334	0.359139
Fossil fuel depletion	-	1.196698	0.78066	0.18094	0.001344	7.94E-05	0.216112	0.017564

Table B-35 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 90 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.00137	0.05
Global warming	kg CO2 eq	137834.3	8,683.56
Smog	kg O3 eq	9755.813	21,462.79
Acidification	kg SO2 eq	714.1739	3,906.53
Eutrophication	kg N eq	22.8561	46.85
Carcinogenic	CTUh	0.000579	0.00
Non carcinogenic	CTUh	0.012244	0.11
Respiratory effects	kg PM2.5 eq	42.44877	2,688.70
Ecotoxicity	CTUe	27575.06	1,130.58
Fossil fuel depletion	MJ surplus	22522.31	220.72
Total			38,139.89

A.1.12 SAPL 96 in.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 96 in - [Analyze SAPL 96 in.]

Skip categories: Never

● Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.00146	0.00106	0.000348	3.08E-6	8.1E-8	8.5E-8	4.86E-5
☑	Global warming	kg CO2 eq	1.47E5	1.43E5	1.72E3	45.8	1.33	2.08E3	455
☑	Smog	kg O3 eq	1.04E4	9.14E3	345	2.63	0.0755	905	11.7
☑	Acidification	kg SO2 eq	762	720	11.8	0.295	0.0103	28.5	1.64
☑	Eutrophication	kg N eq	24.3	16.7	1.91	0.243	0.02	1.71	3.69
☑	Carcinogenics	CTUh	0.000616	0.000446	8.92E-5	1.38E-5	7.12E-7	3.07E-5	3.57E-5
☑	Non carcinogenics	CTUh	0.0131	0.0124	0.000244	4.06E-5	4.83E-6	0.000295	0.000121
☑	Respiratory effects	kg PM2.5 eq	45.3	42.4	0.839	0.0767	0.00191	0.587	1.42
☑	Ecotoxicity	CTUe	2.9E4	8.99E3	5.37E3	4.63E3	107	5.69E3	4.17E3
☑	Fossil fuel depletion	MJ surplus	2.4E4	1.57E4	3.64E3	25.3	1.49	4.27E3	347

Analyzing 1 p 'SAPL 96 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001 8.5.2.0 PhD

Figure B-45 Screenshot of the Impact Assessment Table from SimaPro Software for 96 in. SAPL

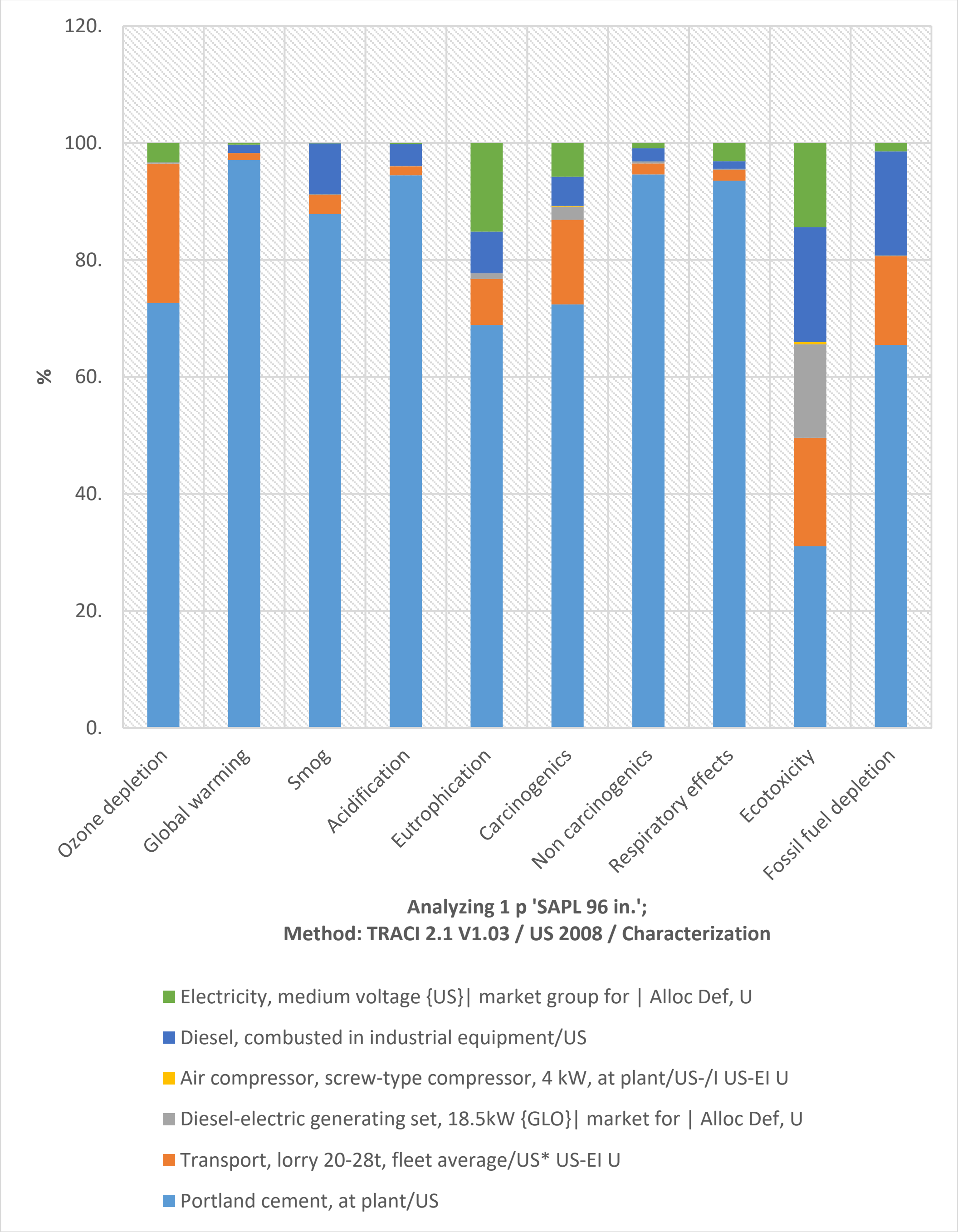


Figure B-46 Environmental Impact Assessment of 96 in. Diameter SAPL Renewal Method

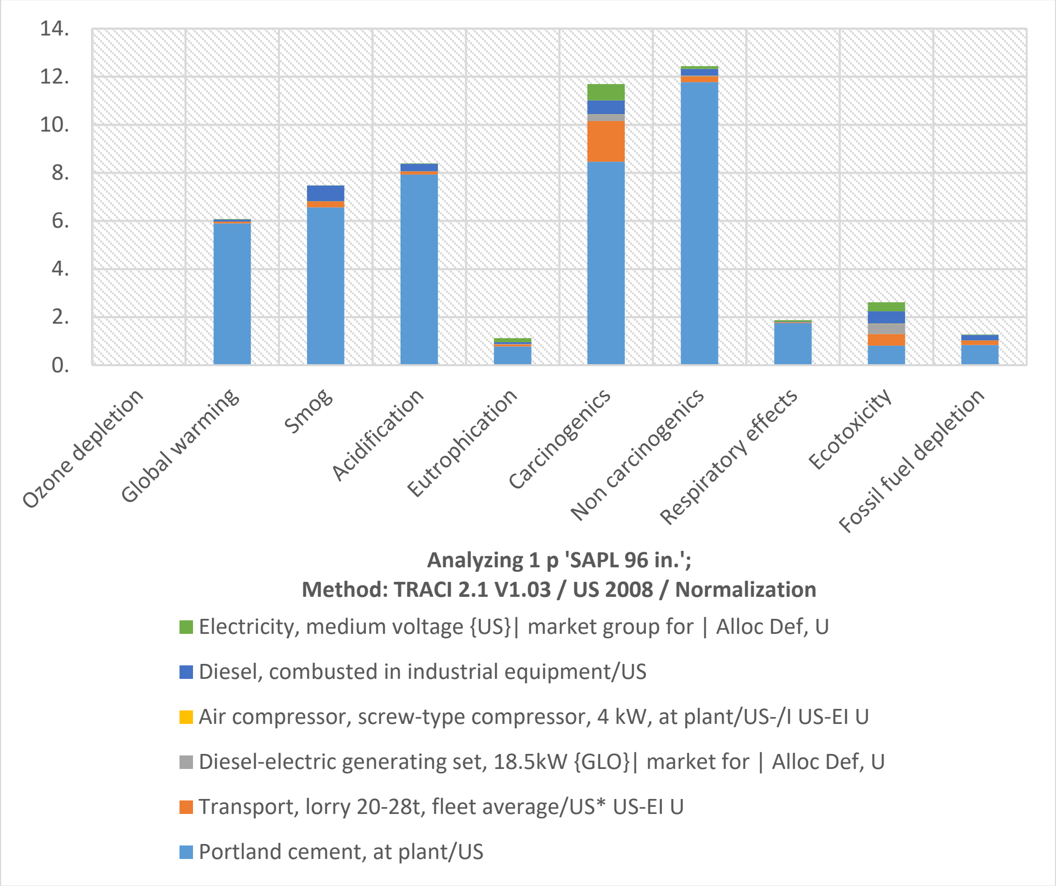


Figure B-47 Normalized Environmental Impact Assessment of 96 in. Diameter SAPL Renewal Method

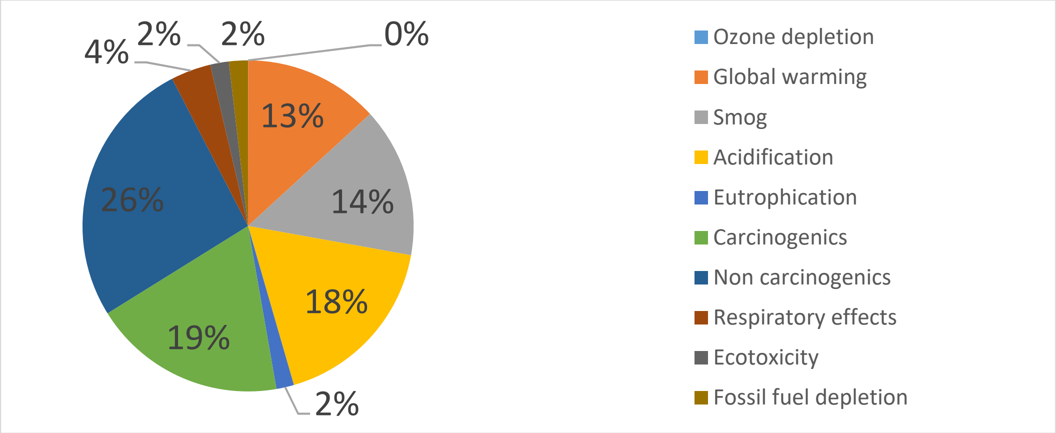


Figure B-48 Percentage of Normalized Environmental Impact Assessment of 96 in. Diameter SAPL Renewal Method

Table B-36 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 96 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.001462	0.001062	0.000348	3.08E-06	8.10E-08	8.50E-08	4.86E-05
Global warming	kg CO2 eq	147130.7	142832.9	1719	45.77813	1.328548	2076.846	454.8617
Smog	kg O3 eq	10401.36	9136.528	345.1406	2.627487	0.075528	905.3294	11.65958
Acidification	kg SO2 eq	762.0499	719.8303	11.76508	0.294661	0.010277	28.51246	1.637143
Eutrophication	kg N eq	24.29613	16.73149	1.908452	0.24343	0.019961	1.70559	3.687208
Carcinogenics	CTUh	0.000616	0.000446	8.92E-05	1.38E-05	7.12E-07	3.07E-05	3.57E-05
Non carcinogenics	CTUh	0.013063	0.012359	2.44E-04	4.06E-05	4.83E-06	0.000295	1.21E-04
Respiratory effects	kg PM2.5 eq	45.2866	42.35923	0.838773	0.076713	0.001914	0.586813	1.423165
Ecotoxicity	CTUe	28956.17	8987.876	5370.582	4628.429	107.0529	5687.787	4174.44
Fossil fuel depletion	MJ surplus	23968.9	15688.16	3636.166	25.28988	1.493567	4270.692	347.0938

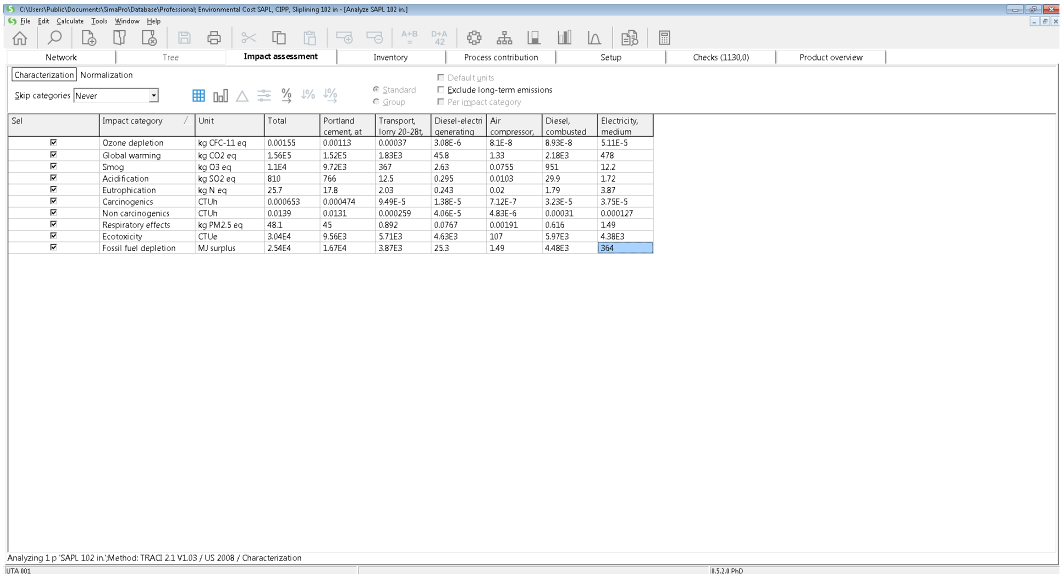
Table B-37 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 96 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.009064	0.006583	0.00216	1.91E-05	5.03E-07	5.27E-07	0.000302
Global warming	-	6.073835	5.896413	0.070964	0.00189	5.48E-05	0.085736	0.018778
Smog	-	7.472712	6.564011	0.247961	0.001888	5.43E-05	0.650421	0.008377
Acidification	-	8.389854	7.925034	0.129529	0.003244	1.13E-04	0.31391	0.018024
Eutrophication	-	1.124	0.774041	0.08829	0.011262	0.000923	0.078905	0.170579
Carcinogenics	-	11.68801	8.460047	1.692651	0.261824	0.013504	0.582614	0.677368
Non carcinogenics	-	12.43778	11.7666	0.232067	0.038674	0.004599	0.28067	0.115171
Respiratory effects	-	1.867645	1.746918	0.034591	0.003164	7.89E-05	0.0242	0.058692
Ecotoxicity	-	2.615744	0.811916	0.485149	0.418107	0.009671	0.513804	0.377096
Fossil fuel depletion	-	1.273561	0.833573	0.193204	0.001344	7.94E-05	0.226919	0.018442

Table B-38 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 96 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001462	0.05
Global warming	kg CO2 eq	147130.7	9,269.23
Smog	kg O3 eq	10401.36	22,882.99
Acidification	kg SO2 eq	762.0499	4,168.41
Eutrophication	kg N eq	24.29613	49.81
Carcinogenic	CTUh	0.000616	0.00
Non carcinogenic	CTUh	0.013063	0.12
Respiratory effects	kg PM2.5 eq	45.2866	2,868.45
Ecotoxicity	CTUe	28956.17	1,187.20
Fossil fuel depletion	MJ surplus	23968.9	234.90
Total			40,661.16

A.1.13 SAPL 102 in.



Skip categories: Never

● Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.00155	0.00113	0.00037	3.08E-6	8.1E-8	8.93E-8	5.11E-5
☑	Global warming	kg CO2 eq	1.56E5	1.52E5	1.83E3	45.8	1.33	2.18E3	478
☑	Smog	kg O3 eq	1.1E4	9.72E3	367	2.63	0.0755	951	12.2
☑	Acidification	kg SO2 eq	810	766	12.5	0.295	0.0103	29.9	1.72
☑	Eutrophication	kg N eq	25.7	17.8	2.03	0.243	0.02	1.79	3.87
☑	Carcinogenics	CTUh	0.000653	0.000474	9.49E-5	1.38E-5	7.12E-7	3.23E-5	3.75E-5
☑	Non carcinogenics	CTUh	0.0139	0.0131	0.000259	4.06E-5	4.83E-6	0.00031	0.000127
☑	Respiratory effects	kg PM2.5 eq	48.1	45	0.892	0.0767	0.00191	0.616	1.49
☑	Ecotoxicity	CTUe	3.04E4	9.56E3	5.71E3	4.63E3	107	5.97E3	4.38E3
☑	Fossil fuel depletion	MJ surplus	2.54E4	1.67E4	3.87E3	25.3	1.49	4.48E3	364

Analyzing 1 p 'SAPL 102 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-49 Screenshot of the Impact Assessment Table from SimaPro Software for 102 in. SAPL

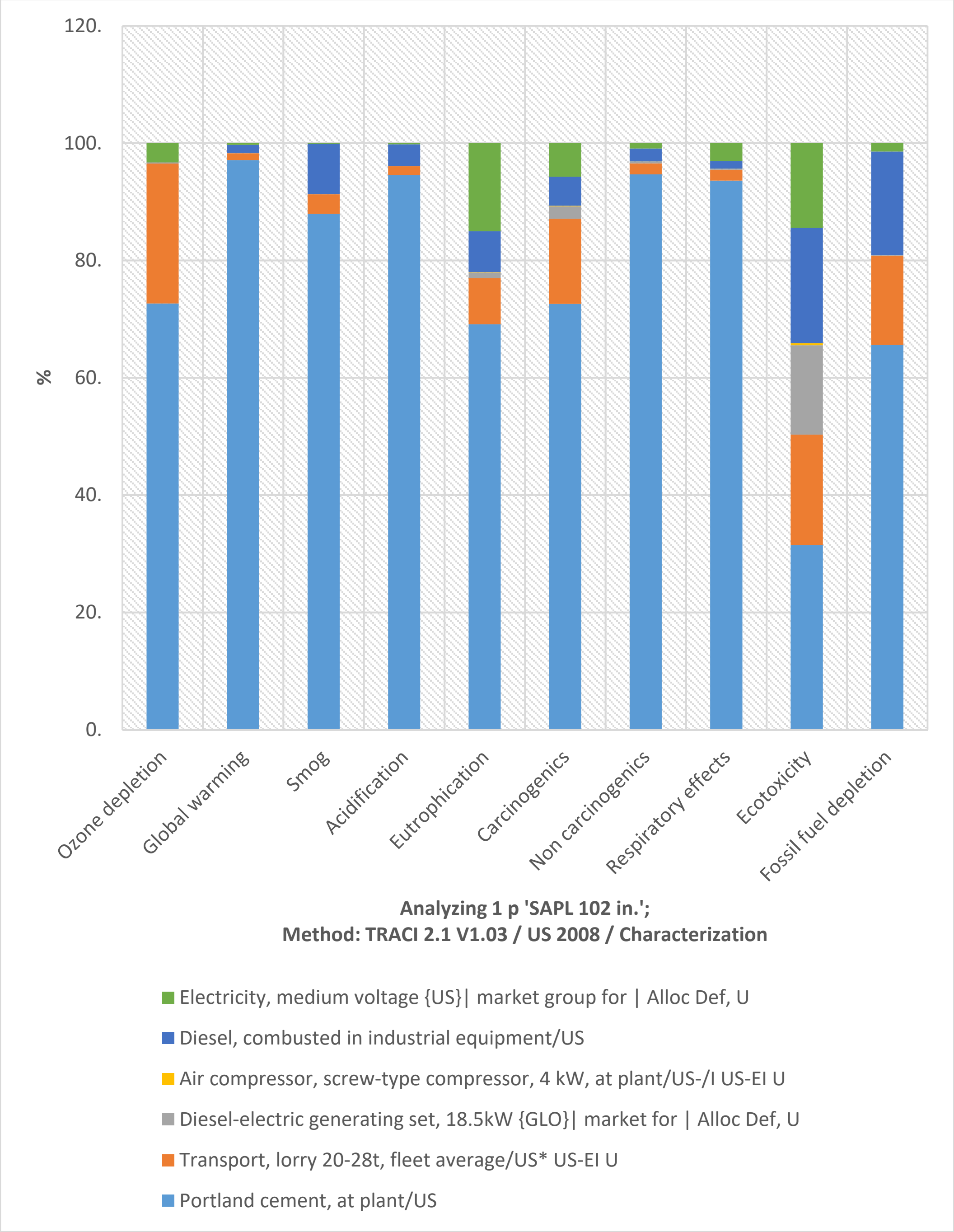


Figure B-50 Environmental Impact Assessment of 102 in. Diameter SAPL Renewal Method

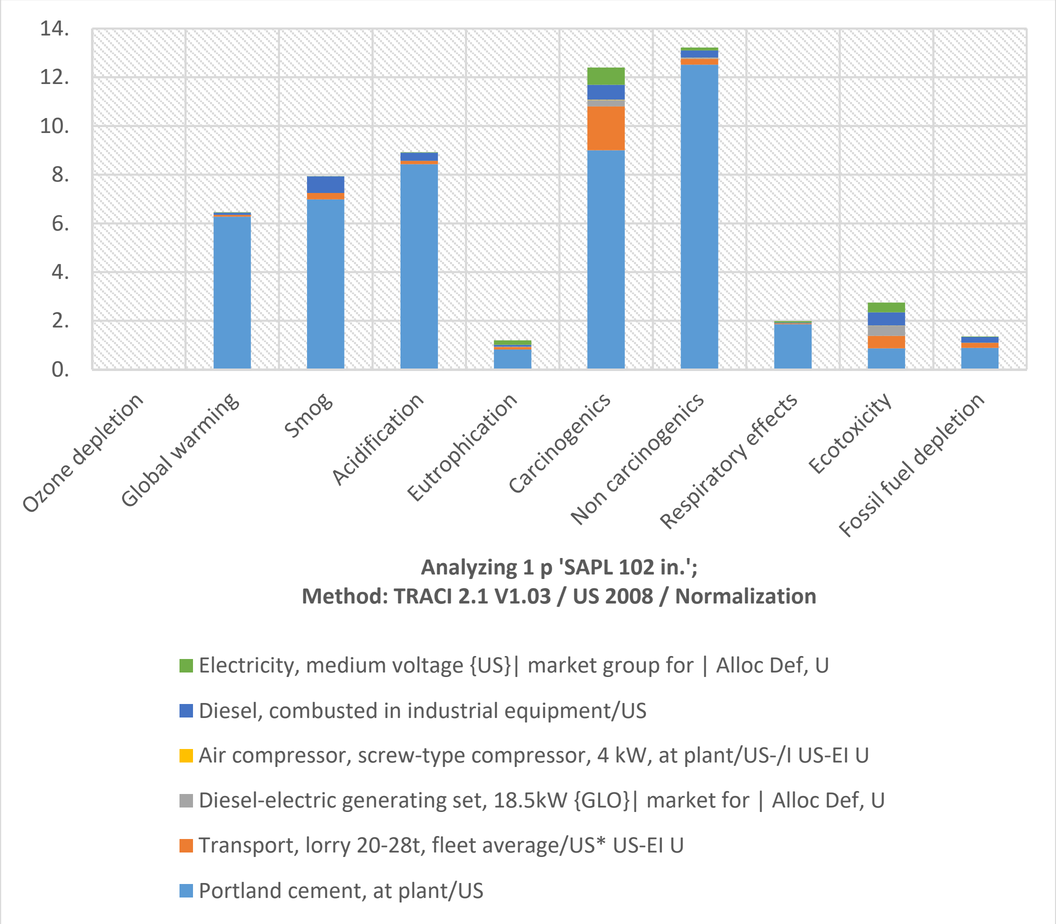


Figure B-51 Normalized Environmental Impact Assessment of 102 in. Diameter SAPL Renewal Method

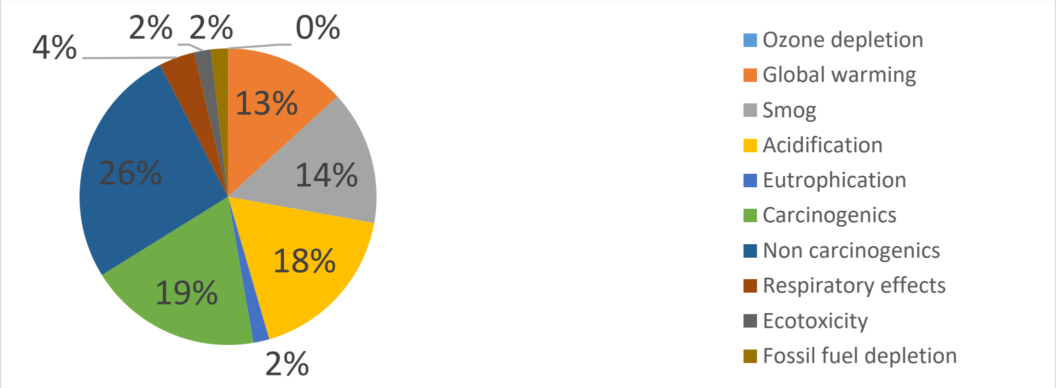


Figure B-52 Percentage of Normalized Environmental Impact Assessment of 102 in. Diameter SAPL Renewal Method

Table B-39 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 102 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.001554	0.001129	0.00037	3.08E-06	8.10E-08	8.93E-08	5.11E-05
Global warming	kg CO2 eq	156436.3	151902.7	1828.156	45.77813	1.328548	2180.682	477.6041
Smog	kg O3 eq	11049.29	9716.694	367.0569	2.627487	0.075528	950.5932	12.24254
Acidification	kg SO2 eq	810.0134	765.5393	12.51216	0.294661	0.010277	29.938	1.718997
Eutrophication	kg N eq	25.74939	17.79393	2.029638	0.24343	0.019961	1.790864	3.871563
Carcinogenics	CTUh	0.000653	0.000474	9.49E-05	1.38E-05	7.12E-07	3.23E-05	3.75E-05
Non carcinogenics	CTUh	0.013885	0.013143	2.59E-04	4.06E-05	4.83E-06	0.00031	1.27E-04
Respiratory effects	kg PM2.5 eq	48.13016	45.04902	0.892035	0.076713	0.001914	0.616152	1.494321
Ecotoxicity	CTUe	30361.01	9558.603	5711.612	4628.429	107.0529	5972.16	4383.156
Fossil fuel depletion	MJ surplus	25426.86	16684.35	3867.061	25.28988	1.493567	4484.214	364.448

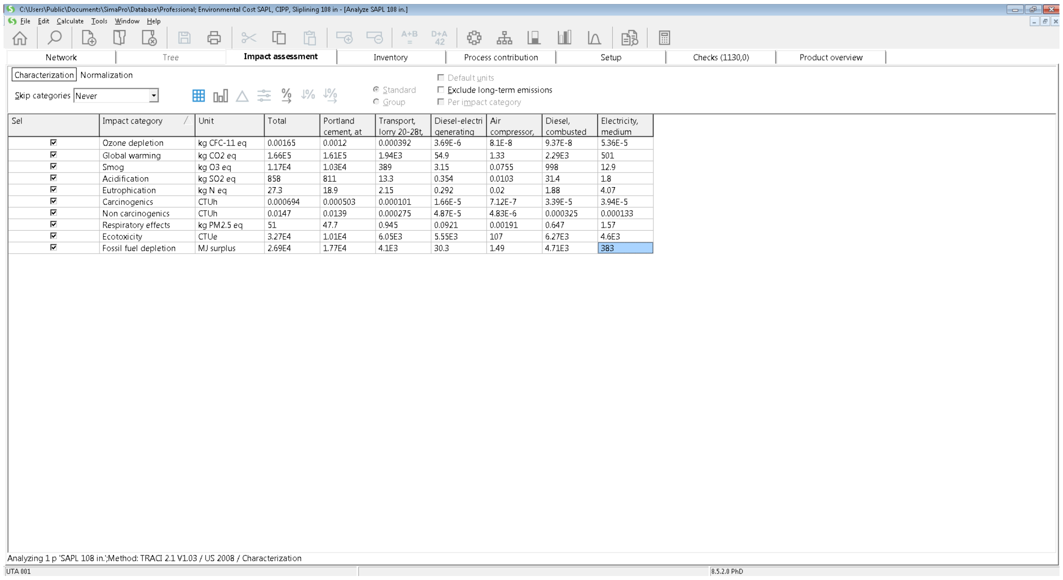
Table B-40 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 102 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.009634	0.007001	0.002297	1.91E-05	5.03E-07	5.54E-07	0.000317
Global warming	-	6.457986	6.270833	0.07547	0.00189	5.48E-05	0.090023	0.019716
Smog	-	7.938208	6.980823	0.263707	0.001888	5.43E-05	0.68294	0.008795
Acidification	-	8.917912	8.428271	0.137754	0.003244	1.13E-04	0.329605	0.018925
Eutrophication	-	1.191231	0.823192	0.093896	0.011262	0.000923	0.08285	0.179108
Carcinogenics	-	12.3957	8.997257	1.800134	0.261824	0.013504	0.611743	0.711235
Non carcinogenics	-	13.21948	12.51377	0.246803	0.038674	0.004599	0.294703	0.120929
Respiratory effects	-	1.984914	1.857847	0.036788	0.003164	7.89E-05	0.02541	0.061627
Ecotoxicity	-	2.74265	0.863473	0.515956	0.418107	0.009671	0.539493	0.395951
Fossil fuel depletion	-	1.351028	0.886505	0.205472	0.001344	7.94E-05	0.238264	0.019365

Table B-41 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 102 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001554	0.05
Global warming	kg CO2 eq	156436.3	9,855.48
Smog	kg O3 eq	11049.29	24,308.44
Acidification	kg SO2 eq	810.0134	4,430.77
Eutrophication	kg N eq	25.74939	52.79
Carcinogenic	CTUh	0.000653	0.00
Non carcinogenic	CTUh	0.013885	0.12
Respiratory effects	kg PM2.5 eq	48.13016	3,048.56
Ecotoxicity	CTUe	30361.01	1,244.80
Fossil fuel depletion	MJ surplus	25426.86	249.18
Total			43,190.21

A.1.14 SAPL 108 in.



Skip categories: Never

☐ Exclude long-term emissions

Sel	Impact category	Unit	Total	Portland cement, at	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Diesel, combusted	Electricity, medium
☑	Ozone depletion	kg CFC-11 eq	0.00165	0.0012	0.000392	3.69E-6	8.1E-8	9.37E-8	5.36E-5
☑	Global warming	kg CO2 eq	1.66E5	1.61E5	1.94E3	54.9	1.33	2.29E3	501
☑	Smog	kg O3 eq	1.17E4	1.03E4	389	3.15	0.0755	998	12.9
☑	Acidification	kg SO2 eq	858	811	13.3	0.354	0.0103	31.4	1.8
☑	Eutrophication	kg N eq	27.3	18.9	2.15	0.292	0.02	1.88	4.07
☑	Carcinogenics	CTUh	0.000694	0.000503	0.000101	1.66E-5	7.12E-7	3.39E-5	3.94E-5
☑	Non carcinogenics	CTUh	0.0147	0.0139	0.000275	4.87E-5	4.83E-6	0.000325	0.000133
☑	Respiratory effects	kg PM2.5 eq	51	47.7	0.945	0.0921	0.00191	0.647	1.57
☑	Ecotoxicity	CTUe	3.27E4	1.01E4	6.05E3	5.55E3	107	6.27E3	4.6E3
☑	Fossil fuel depletion	MJ surplus	2.69E4	1.77E4	4.1E3	30.3	1.49	4.71E3	383

Analyzing 1 p 'SAPL 108 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-53 Screenshot of the Impact Assessment Table from SimaPro Software for 108 in. SAPL

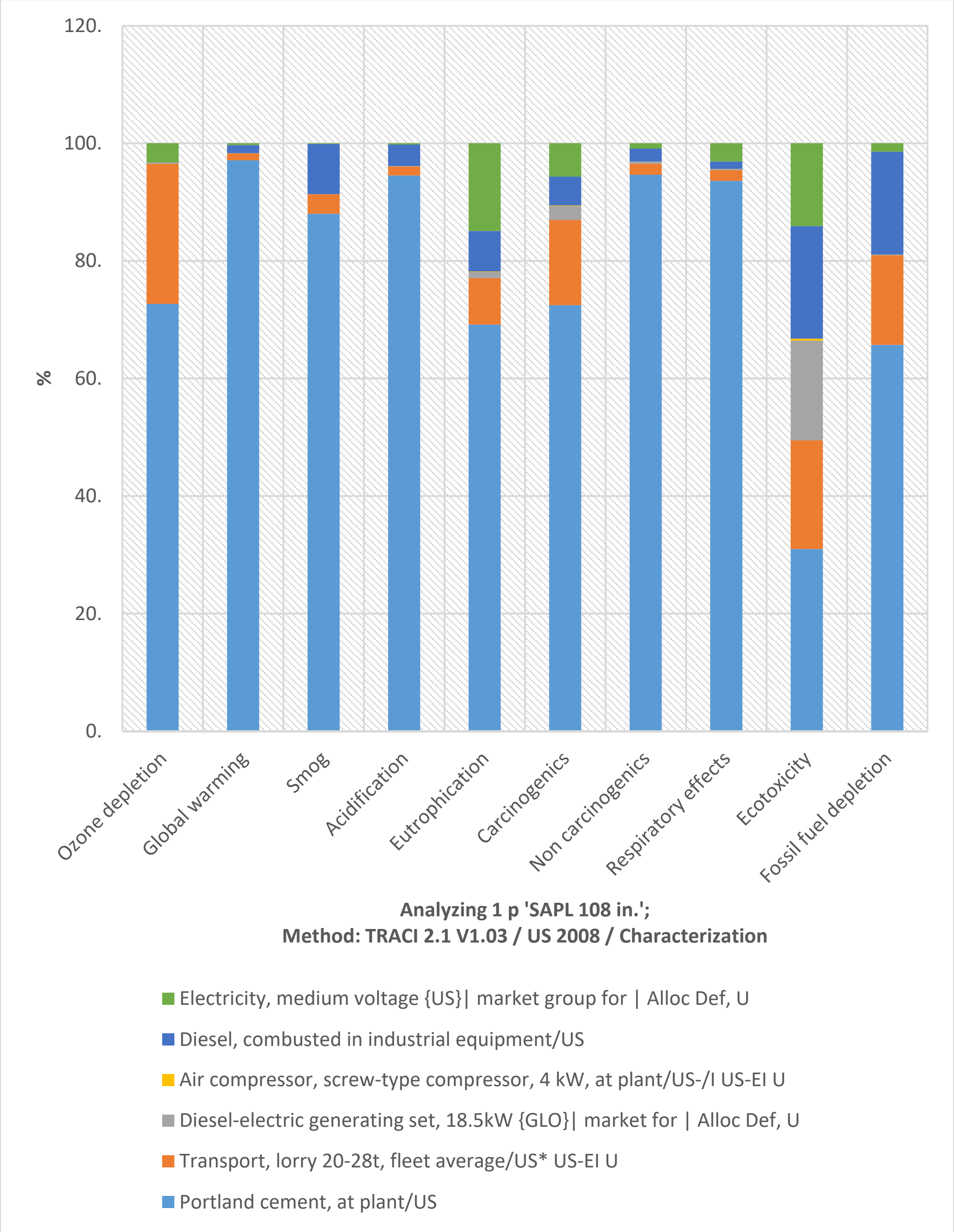


Figure B-54 Environmental Impact Assessment of 108 in. Diameter SAPL Renewal Method

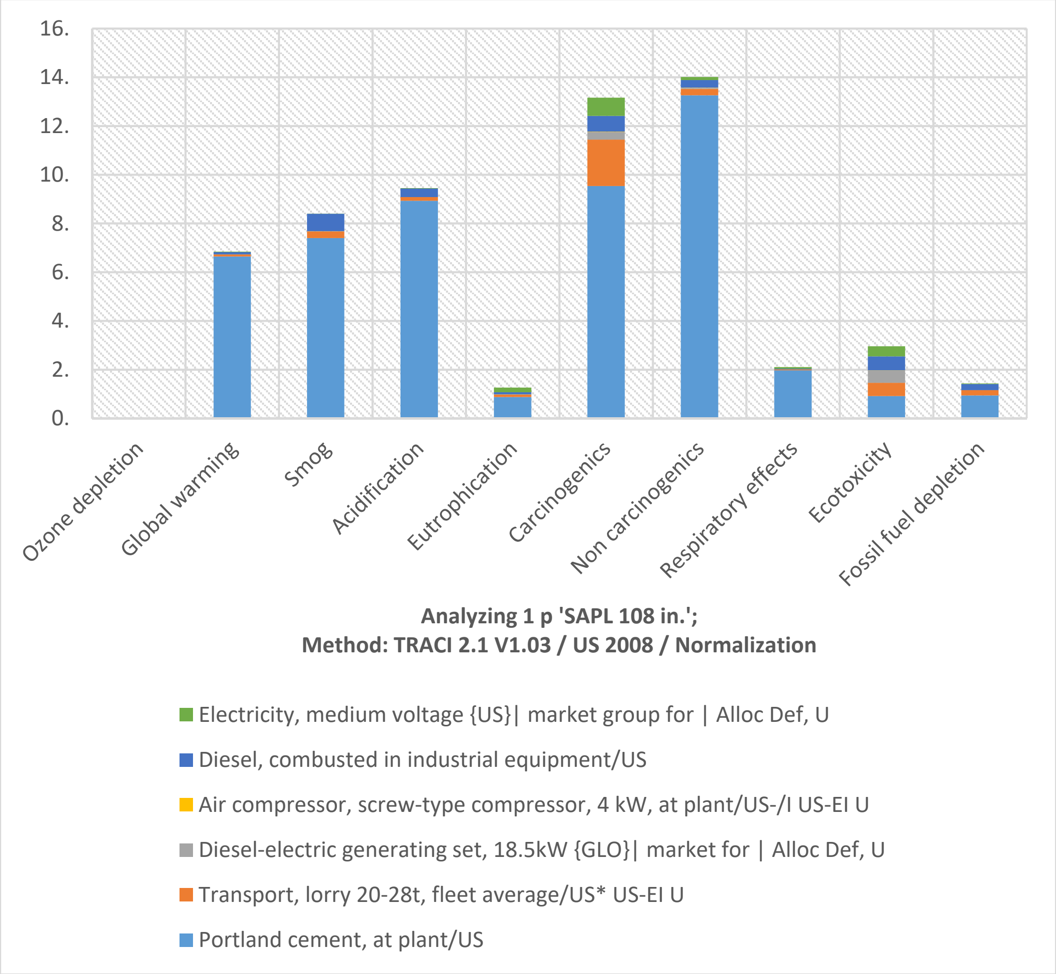


Figure B-55 Normalized Environmental Impact Assessment of 108 in. Diameter SAPL Renewal Method

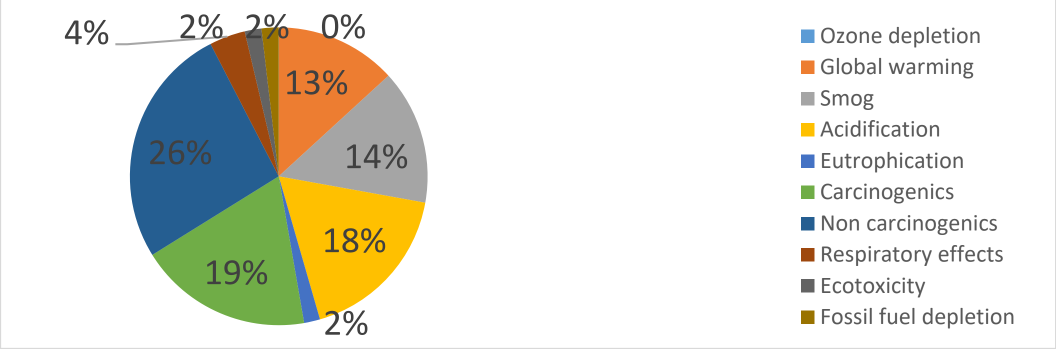


Figure B-56 Percentage of Normalized Environmental Impact Assessment of 108 in. Diameter SAPL Renewal Method

Table B-42 Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 108 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	kg CFC-11 eq	0.001646	0.001196	0.000392	3.69E-06	8.10E-08	9.37E-08	5.36E-05
Global warming	kg CO2 eq	165757.4	160972.6	1937.312	54.93375	1.328548	2289.806	501.4807
Smog	kg O3 eq	11700.08	10296.86	388.9732	3.152984	0.075528	998.1622	12.85458
Acidification	kg SO2 eq	858.1124	811.2483	13.25924	0.353594	0.010277	31.43613	1.804934
Eutrophication	kg N eq	27.26487	18.85638	2.150825	0.292116	0.019961	1.880482	4.065112
Carcinogenics	CTUh	0.000694	0.000503	1.01E-04	1.66E-05	7.12E-07	3.39E-05	3.94E-05
Non carcinogenics	CTUh	0.014715	0.013928	2.75E-04	4.87E-05	4.83E-06	0.000325	1.33E-04
Respiratory effects	kg PM2.5 eq	50.9941	47.73882	0.945296	0.092056	0.001914	0.646985	1.569026
Ecotoxicity	CTUe	32716.44	10129.33	6052.642	5554.115	107.0529	6271.015	4602.281
Fossil fuel depletion	MJ surplus	26901.62	17680.55	4097.956	30.34786	1.493567	4708.61	382.6677

Table B-43 Normalized Environmental Impact Assessment Results for SAPL Renewal Method of 500-ft Length and Diameter of 108 in. Culvert

Impact category	Unit	Total	Portland cement	Transport, lorry 20-28t	Generating set	Air compressor	Diesel	Electricity
Ozone depletion	-	0.010209	0.007419	0.002434	2.29E-05	5.03E-07	5.81E-07	0.000332
Global warming	-	6.842781	6.645253	0.079976	0.002268	5.48E-05	0.094528	0.020702
Smog	-	8.405758	7.397635	0.279452	0.002265	5.43E-05	0.717116	0.009235
Acidification	-	9.447463	8.931508	0.145979	0.003893	1.13E-04	0.346099	0.019872
Eutrophication	-	1.261341	0.872343	0.099503	0.013514	0.000923	0.086996	0.188062
Carcinogenics	-	13.15892	9.534467	1.907616	0.314189	0.013504	0.642355	0.746792
Non carcinogenics	-	14.00992	13.26095	0.26154	0.046408	0.004599	0.30945	0.126975
Respiratory effects	-	2.103025	1.968775	0.038985	0.003796	7.89E-05	0.026682	0.064707
Ecotoxicity	-	2.955426	0.915029	0.546763	0.501729	0.009671	0.56649	0.415745
Fossil fuel depletion	-	1.429388	0.939436	0.21774	0.001613	7.94E-05	0.250187	0.020333

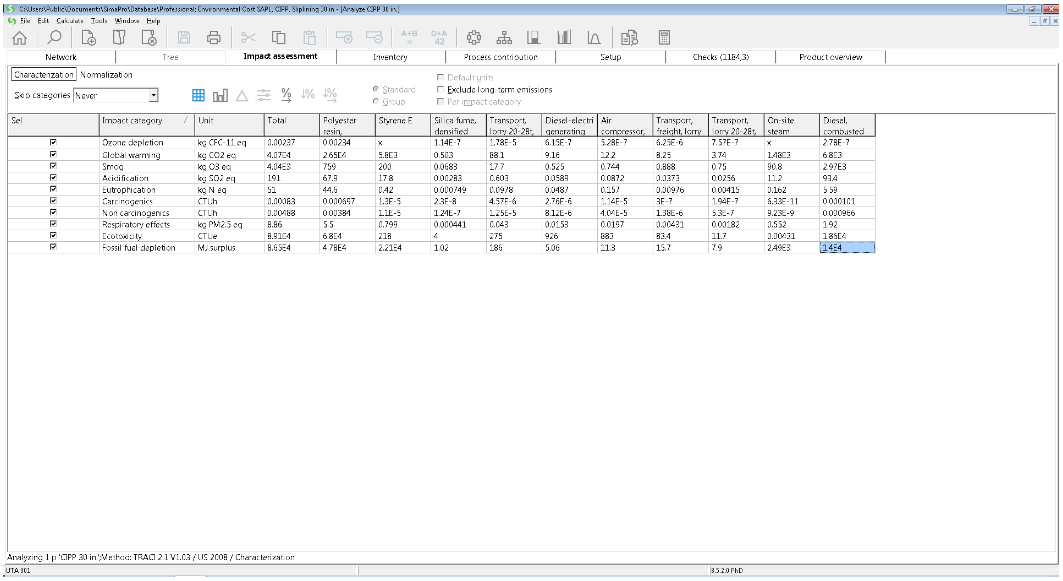
Table B-44 Environmental Impact Cost Results for SAPL Renewal Method of 500-ft Length and Diameter of 108 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001646	0.05
Global warming	kg CO2 eq	165757.4	10,442.72
Smog	kg O3 eq	11700.08	25,740.17
Acidification	kg SO2 eq	858.1124	4,693.88
Eutrophication	kg N eq	27.26487	55.89
Carcinogenic	CTUh	0.000694	0.00
Non carcinogenic	CTUh	0.014715	0.13
Respiratory effects	kg PM2.5 eq	50.9941	3,229.97
Ecotoxicity	CTUe	32716.44	1,341.37
Fossil fuel depletion	MJ surplus	26901.62	263.64
Total			45,767.82

A.2 CIPP Environmental Costs Results

In this Appendix, all the SimaPro analysis and results for CIPP method are presented.

A.2.1 CIPP 30 in.



Skip categories: Never

☐ Exclude long-term emissions

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00237	0.00234	x	1.14E-7	1.78E-5	6.15E-7	5.28E-7	6.25E-6	7.57E-7	x	2.78E-7
☑	Global warming	kg CO2 eq	4.07E4	2.65E4	5.8E3	0.503	88.1	9.16	12.2	8.25	3.74	1.48E3	6.8E3
☑	Smog	kg O3 eq	4.04E3	759	200	0.0683	17.7	0.525	0.744	0.888	0.75	90.8	2.97E3
☑	Acidification	kg SO2 eq	191	67.9	17.8	0.00283	0.603	0.0589	0.0872	0.0373	0.0256	11.2	93.4
☑	Eutrophication	kg N eq	51	44.6	0.42	0.000749	0.0978	0.0487	0.157	0.00976	0.00415	0.162	5.59
☑	Carcinogenics	CTUh	0.00083	0.000697	1.3E-5	2.3E-8	4.57E-6	2.76E-6	1.14E-5	3E-7	1.94E-7	6.33E-11	0.000101
☑	Non carcinogenics	CTUh	0.00488	0.00384	1.1E-5	1.24E-7	1.25E-5	8.12E-6	4.04E-5	1.38E-6	5.3E-7	9.23E-9	0.000966
☑	Respiratory effects	kg PM2.5 eq	8.86	5.5	0.799	0.000441	0.043	0.0153	0.0197	0.00431	0.00182	0.552	1.92
☑	Ecotoxicity	CTUe	8.91E4	6.8E4	218	4	275	926	883	83.4	11.7	0.00431	1.86E4
☑	Fossil fuel depletion	MJ surplus	8.65E4	4.78E4	2.21E4	1.02	186	5.06	11.3	15.7	7.9	2.49E3	1.4E4

Analyzing 1 p 'CIPP 30 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-57 Screenshot of the Impact Assessment Table from SimaPro Software for 30 in. CIPP

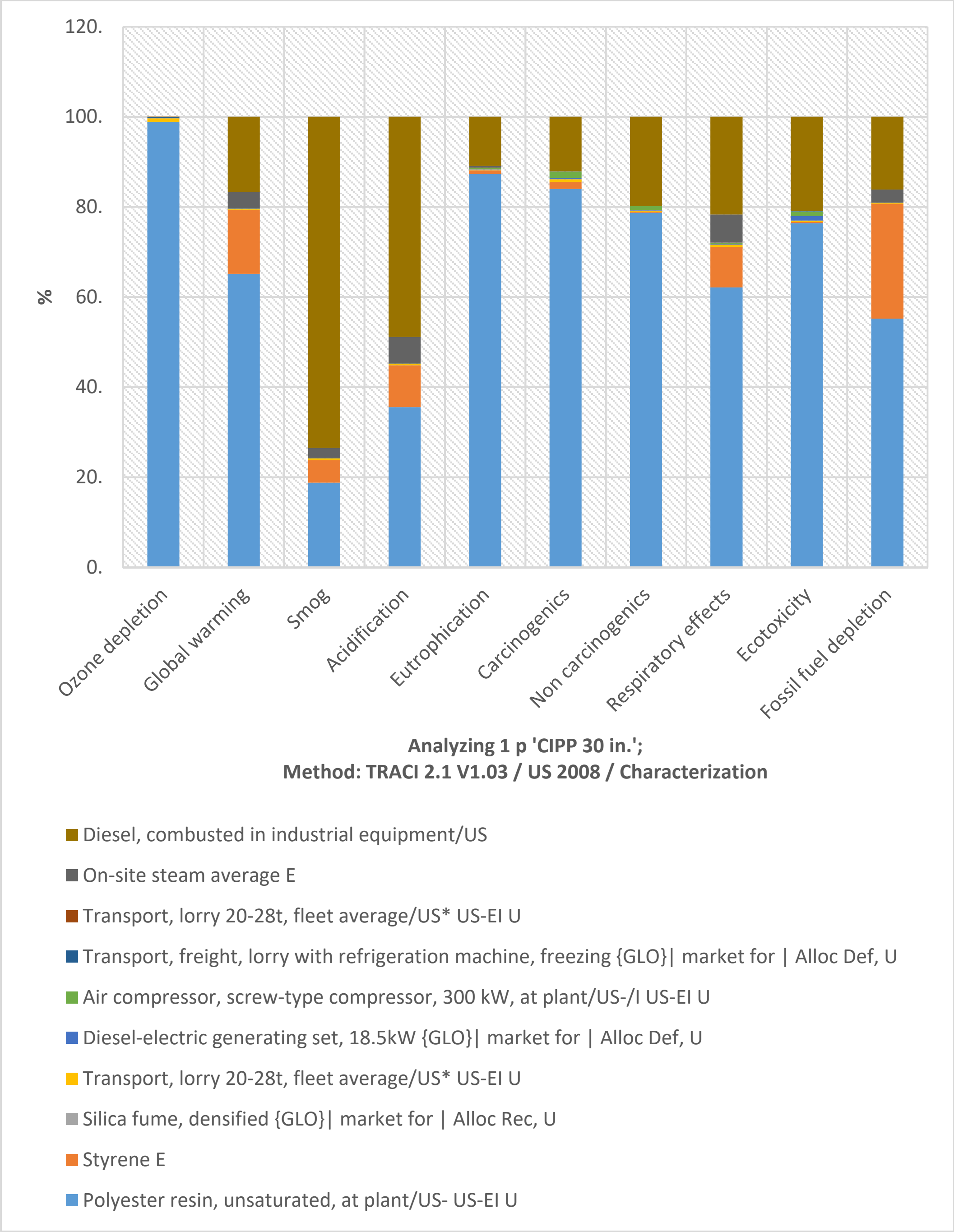


Figure B-58 Environmental Impact Assessment of 30 in. Diameter CIPP Renewal Method

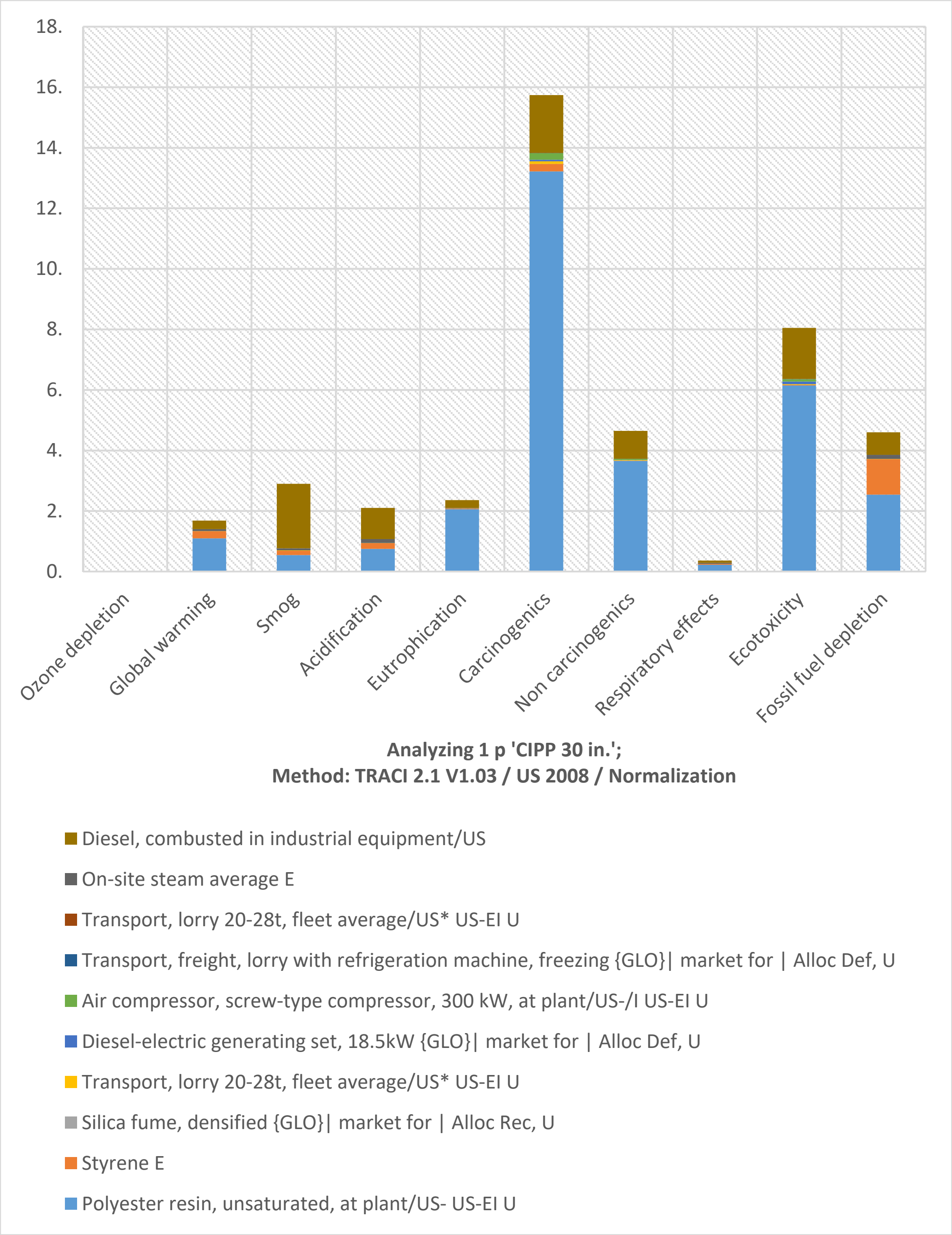


Figure B-59 Normalized Environmental Impact Assessment
of 30 in. Diameter CIPP Renewal Method

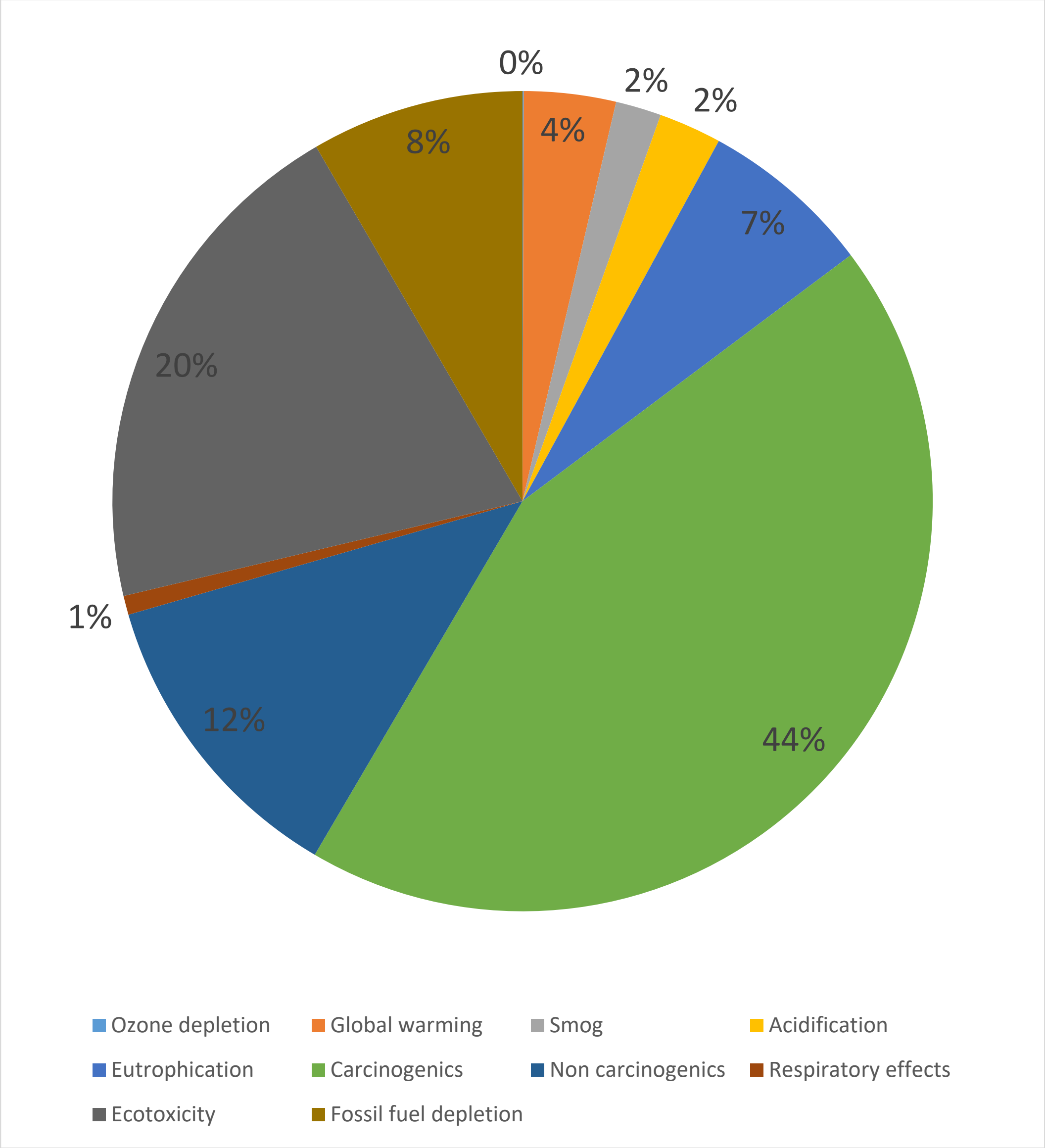


Figure B-60 Percentage of Normalized Environmental Impact Assessment of 30 in. Diameter CIPP Renewal Method

Table B-45 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.002368	0.002342	0	1.14E-07	1.78E-05	6.15E-07	5.28E-07	6.25E-06	7.57E-07	0	2.78E-07
Global warming	kg CO2 eq	40723.04	26522.55	5795.396	0.502756	88.07484	9.155625	12.19125	8.253799	3.735657	1479.977	6803.199
Smog	kg O3 eq	4035.44	758.5147	199.8396	0.068273	17.68366	0.525497	0.744435	0.888006	0.750045	90.80566	2965.62
Acidification	kg SO2 eq	191.0955	67.9045	17.76294	0.00283	0.602797	0.058932	0.087169	0.037294	0.025567	11.21423	93.39929
Eutrophication	kg N eq	51.04978	44.56274	0.41974	0.000749	0.097782	0.048686	0.156728	0.009765	0.004147	0.162383	5.587062
Carcinogenics	CTUh	0.00083	0.000697	1.30E-05	2.30E-08	4.57E-06	2.76E-06	1.14E-05	3.00E-07	1.94E-07	6.33E-11	0.000101
Non carcinogenics	CTUh	0.004878	0.003839	1.10E-05	1.24E-07	1.25E-05	8.12E-06	4.04E-05	1.38E-06	5.30E-07	9.23E-09	0.000966
Respiratory effects	kg PM2.5 eq	8.862105	5.504925	0.798746	0.000441	0.042975	0.015343	0.019726	0.004311	0.001823	0.55157	1.922245
Ecotoxicity	CTUe	89065.04	68032.24	217.7601	3.996024	275.1676	925.6858	883.4641	83.35973	11.67112	0.004306	18631.69
Fossil fuel depletion	MJ surplus	86541.85	47775.83	22058.38	1.018046	186.3029	5.057976	11.34395	15.68626	7.901959	2490.664	13989.66

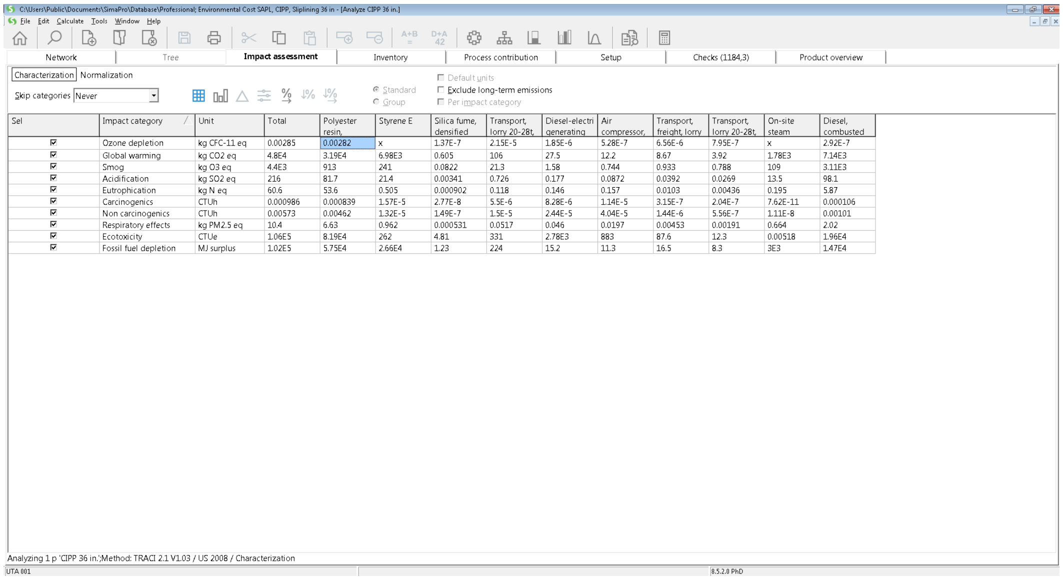
Table B-46 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.014686	0.014523	0	7.05E-07	1.11E-04	3.81E-06	3.28E-06	3.87E-05	4.69E-06	0	1.73E-06
Global warming	-	1.681125	1.094901	0.239245	2.08E-05	3.64E-03	0.000378	0.000503	0.000341	0.000154	0.061096	0.280849
Smog	-	2.899206	0.544944	0.143572	4.91E-05	1.27E-02	0.000378	0.000535	0.000638	0.000539	0.065238	2.130608
Acidification	-	2.103883	0.7476	0.195563	3.12E-05	6.64E-03	0.000649	0.00096	0.000411	0.000281	0.123464	1.028288
Eutrophication	-	2.361691	2.061584	0.019418	3.46E-05	0.004524	0.002252	0.007251	0.000452	0.000192	0.007512	0.258472
Carcinogenics	-	15.7368	13.21619	0.247249	0.000437	0.086725	0.052365	0.215978	0.005684	0.003678	1.20E-06	1.90849
Non carcinogenics	-	4.644769	3.654916	0.010426	0.000118	0.01189	0.007735	0.038459	0.00131	0.000504	8.78E-06	0.919402
Respiratory effects	-	0.365478	0.227026	0.032941	1.82E-05	1.77E-03	0.000633	0.000814	0.000178	7.52E-05	0.022747	0.079274
Ecotoxicity	-	8.045655	6.145665	0.019671	0.000361	0.024857	0.083621	0.079807	0.00753	0.001054	3.89E-07	1.683086
Fossil fuel depletion	-	4.598306	2.538516	1.172048	5.41E-05	9.90E-03	0.000269	0.000603	0.000833	0.00042	0.132339	0.743325

Table B-47 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.002368	0.08
Global warming	kg CO2 eq	40723.04	2,565.55
Smog	kg O3 eq	4035.44	8,877.97
Acidification	kg SO2 eq	191.0955	1,045.29
Eutrophication	kg N eq	51.04978	104.65
Carcinogenic	CTUh	0.00083	0.00
Non carcinogenic	CTUh	0.004878	0.04
Respiratory effects	kg PM2.5 eq	8.862105	561.33
Ecotoxicity	CTUe	89065.04	3,651.67
Fossil fuel depletion	MJ surplus	86541.85	848.11
Total			17,654.69

A.2.2 CIPP 36 in.



Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00285	0.00282	x	1.37E-7	2.15E-5	1.85E-6	5.28E-7	6.56E-6	7.95E-7	x	2.92E-7
☑	Global warming	kg CO2 eq	4.8E4	3.19E4	6.98E3	0.605	106	27.5	12.2	8.67	3.92	1.78E3	7.14E3
☑	Smog	kg O3 eq	4.4E3	913	241	0.0822	21.3	1.58	0.744	0.933	0.788	109	3.11E3
☑	Acidification	kg SO2 eq	216	81.7	21.4	0.00341	0.726	0.177	0.0872	0.0392	0.0269	13.5	98.1
☑	Eutrophication	kg N eq	60.6	53.6	0.505	0.000902	0.118	0.146	0.157	0.0103	0.00436	0.195	5.87
☑	Carcinogenics	CTUh	0.000986	0.000839	1.57E-5	2.77E-8	5.5E-6	8.28E-6	1.14E-5	3.15E-7	2.04E-7	7.62E-11	0.000106
☑	Non carcinogenics	CTUh	0.00573	0.00462	1.32E-5	1.49E-7	1.5E-5	2.44E-5	4.04E-5	1.44E-6	5.56E-7	1.11E-8	0.00101
☑	Respiratory effects	kg PM2.5 eq	10.4	6.63	0.962	0.000531	0.0517	0.046	0.0197	0.00453	0.00191	0.664	2.02
☑	Ecotoxicity	CTUe	1.06E5	8.19E4	262	4.81	331	2.78E3	883	87.6	12.3	0.00518	1.96E4
☑	Fossil fuel depletion	MJ surplus	1.02E5	5.75E4	2.66E4	1.23	224	15.2	11.3	16.5	8.3	3E3	1.47E4

Analyzing 1 p 'CIPP 36 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-61 Screenshot of the Impact Assessment Table from SimaPro Software for 36 in. CIPP

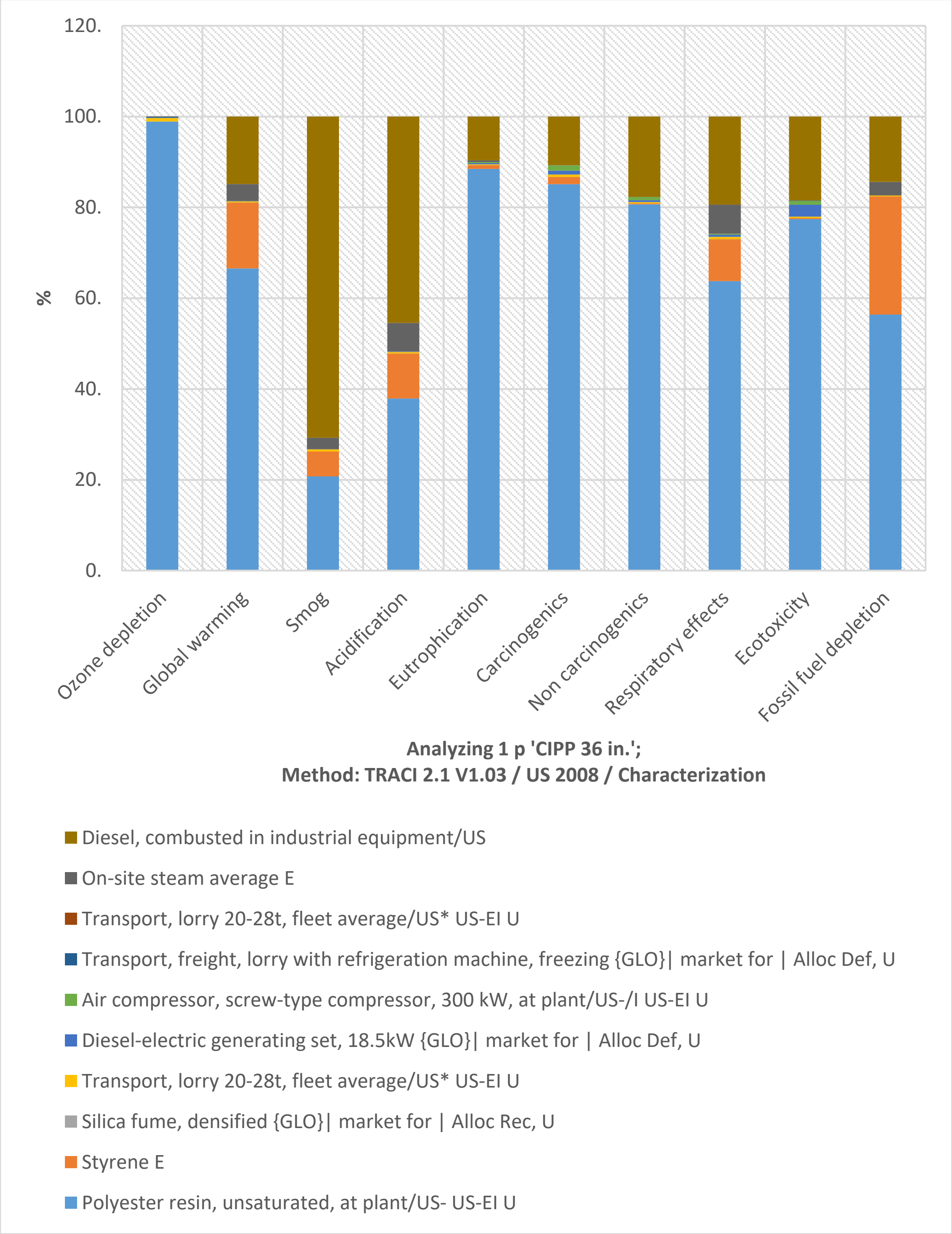


Figure B-62 Environmental Impact Assessment of 36 in. Diameter CIPP Renewal Method

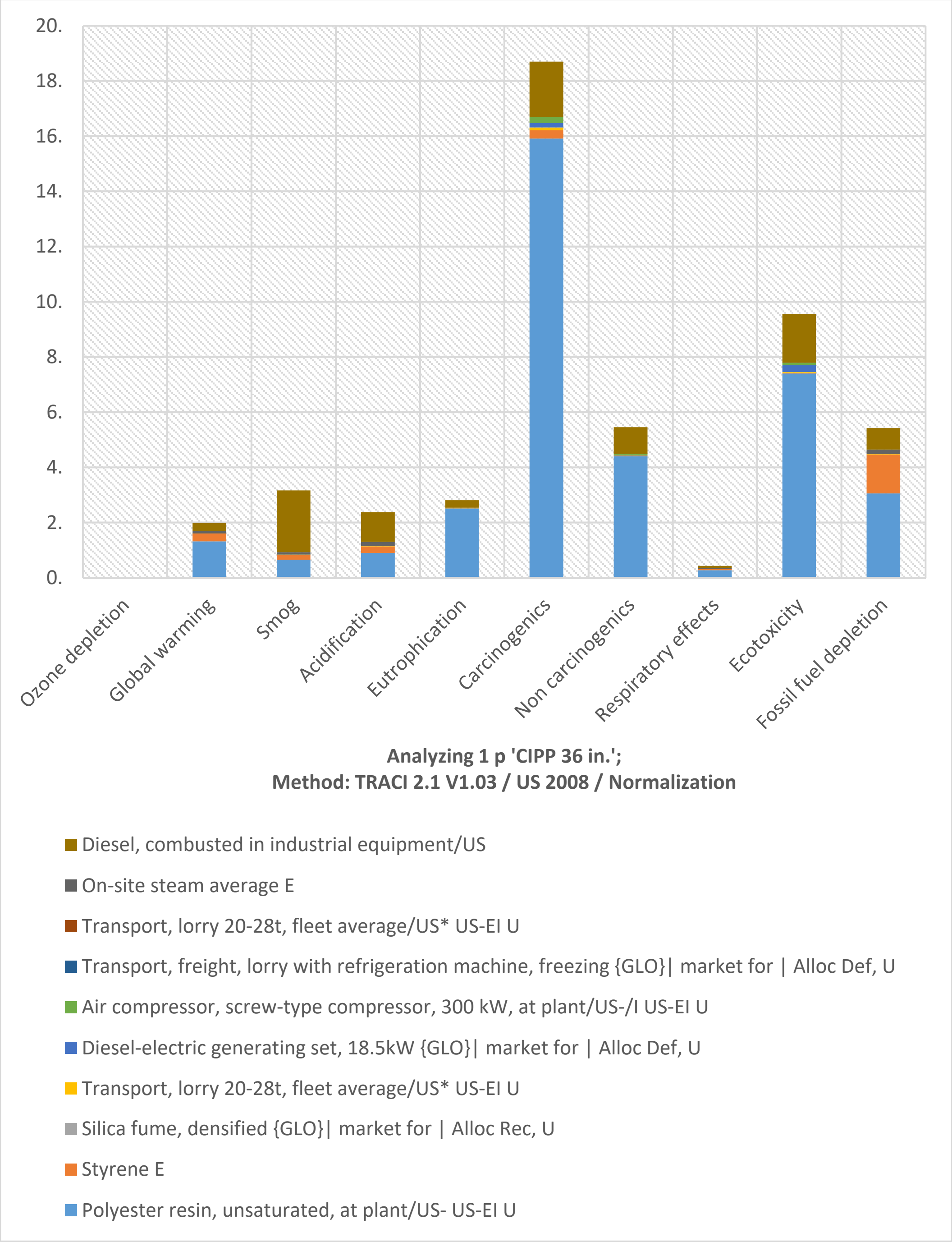


Figure B-63 Normalized Environmental Impact Assessment of 36 in. Diameter CIPP Renewal Method

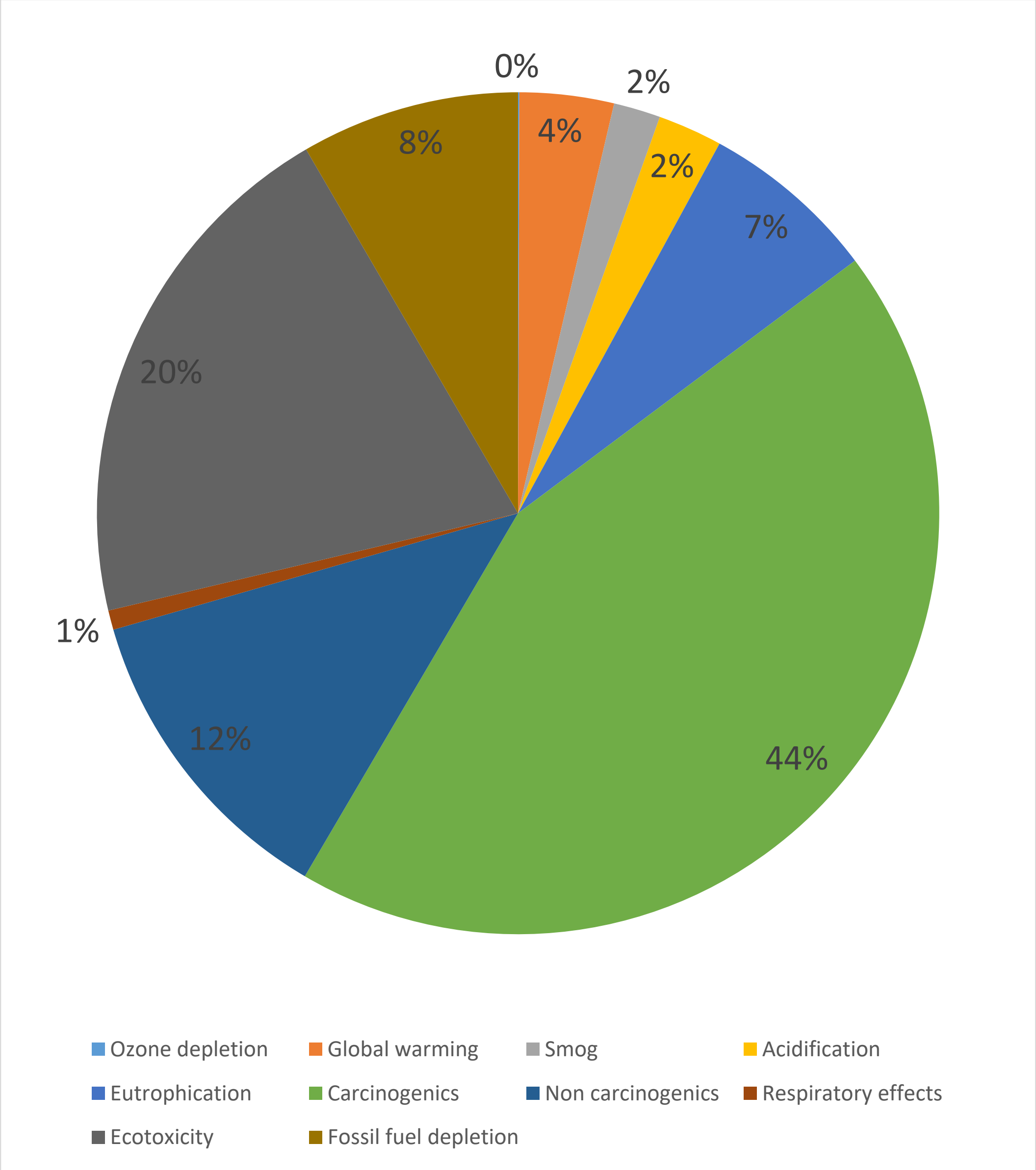


Figure B-64 Percentage of Normalized Environmental Impact Assessment of 36 in. Diameter CIPP Renewal Method

Table B-48 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 36 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.002851	0.002819	0	1.37E-07	2.15E-05	1.85E-06	5.28E-07	6.56E-06	7.95E-07	0	2.92E-07
Global warming	kg CO2 eq	47988.17	31927.92	6976.455	0.605286	106.0239	27.46688	12.19125	8.669791	3.923934	1781.601	7143.311
Smog	kg O3 eq	4402.271	913.1019	240.5654	0.082197	21.28747	1.576492	0.744435	0.932761	0.787847	109.3121	3113.88
Acidification	kg SO2 eq	215.7539	81.74361	21.38289	0.003407	0.725643	0.176797	0.087169	0.039174	0.026856	13.49972	98.06859
Eutrophication	kg N eq	60.64788	53.64474	0.50528	0.000902	0.117709	0.146058	0.156728	0.010257	0.004356	0.195478	5.866376
Carcinogenics	CTUh	0.000986	0.000839	1.57E-05	2.77E-08	5.50E-06	8.28E-06	1.14E-05	3.15E-07	2.04E-07	7.62E-11	0.000106
Non carcinogenics	CTUh	0.00573	0.004621	1.32E-05	1.49E-07	1.50E-05	2.44E-05	4.04E-05	1.44E-06	5.56E-07	1.11E-08	0.001014
Respiratory effects	kg PM2.5 eq	10.39515	6.626842	0.961524	0.000531	0.051734	0.046028	0.019726	0.004528	0.001915	0.663982	2.018344
Ecotoxicity	CTUe	105819.1	81897.38	262.138	4.810958	331.245	2777.057	883.4641	87.56106	12.25934	0.005184	19563.15
Fossil fuel depletion	MJ surplus	102030.5	57512.67	26553.72	1.225663	224.2702	15.17393	11.34395	16.47685	8.300218	2998.269	14689.04

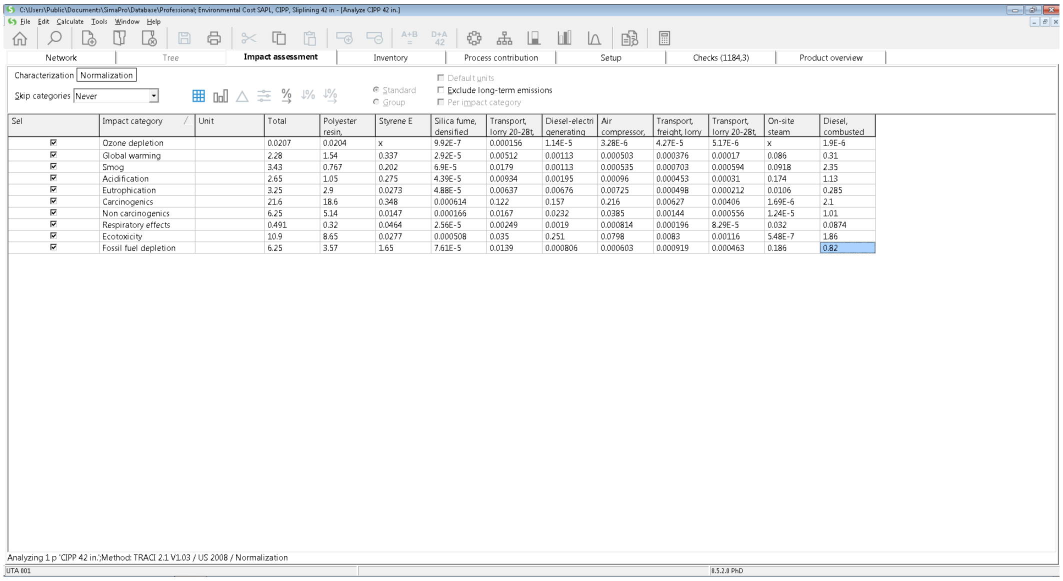
Table B-49 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 36 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.017678	0.017482	0	8.48E-07	1.33E-04	1.14E-05	3.28E-06	4.07E-05	4.93E-06	0	1.81E-06
Global warming	-	1.981043	1.318045	0.288001	2.50E-05	4.38E-03	0.001134	0.000503	0.000358	0.000162	0.073548	0.294889
Smog	-	3.16275	0.656005	0.172831	5.91E-05	1.53E-02	0.001133	0.000535	0.00067	0.000566	0.078534	2.237124
Acidification	-	2.375361	0.899963	0.235417	3.75E-05	7.99E-03	0.001946	0.00096	0.000431	0.000296	0.148626	1.079695
Eutrophication	-	2.805723	2.48174	0.023376	4.17E-05	0.005446	0.006757	0.007251	0.000475	0.000202	0.009043	0.271393
Carcinogenics	-	18.69905	15.90968	0.297637	0.000526	0.104399	0.157095	0.215978	0.00597	0.003864	1.45E-06	2.003901
Non carcinogenics	-	5.455749	4.399797	0.01255	0.000142	0.014313	0.023204	0.038459	0.001376	0.00053	1.06E-05	0.965366
Respiratory effects	-	0.428702	0.273295	0.039654	2.19E-05	2.13E-03	0.001898	0.000814	0.000187	7.90E-05	0.027383	0.083238
Ecotoxicity	-	9.559123	7.398167	0.02368	0.000435	0.029923	0.250864	0.079807	0.00791	0.001107	4.68E-07	1.767229
Fossil fuel depletion	-	5.421278	3.055872	1.410903	6.51E-05	1.19E-02	0.000806	0.000603	0.000875	0.000441	0.15931	0.780486

Table B-50 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 36 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.002851	0.09
Global warming	kg CO2 eq	47988.17	3,023.25
Smog	kg O3 eq	4402.271	9,685.00
Acidification	kg SO2 eq	215.7539	1,180.17
Eutrophication	kg N eq	60.64788	124.33
Carcinogenic	CTUh	0.000986	0.00
Non carcinogenic	CTUh	0.00573	0.05
Respiratory effects	kg PM2.5 eq	10.39515	658.43
Ecotoxicity	CTUe	105819.1	4,338.58
Fossil fuel depletion	MJ surplus	102030.5	999.90
Total			20,009.81

A.2.3 CIPP 42 in.



Skip categories: Never

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion		0.0207	0.0204	x	9.92E-7	0.000156	1.14E-5	3.28E-6	4.27E-5	5.17E-6	x	1.9E-6
☑	Global warming		2.28	1.54	0.337	2.92E-5	0.00512	0.00113	0.000503	0.000376	0.00017	0.086	0.31
☑	Smog		3.43	0.767	0.202	6.9E-5	0.0179	0.00113	0.000535	0.000703	0.000594	0.0918	2.35
☑	Acidification		2.65	1.05	0.275	4.39E-5	0.00934	0.00195	0.00096	0.000453	0.00031	0.174	1.13
☑	Eutrophication		3.25	2.9	0.0273	4.88E-5	0.00637	0.00676	0.00725	0.000498	0.000212	0.0106	0.285
☑	Carcinogenics		21.6	18.6	0.348	0.000614	0.122	0.157	0.216	0.00627	0.00406	1.69E-6	2.1
☑	Non carcinogenics		6.25	5.14	0.0147	0.000166	0.0167	0.0232	0.0385	0.00144	0.000556	1.24E-5	1.01
☑	Respiratory effects		0.491	0.32	0.0464	2.56E-5	0.00249	0.0019	0.000814	0.000196	8.29E-5	0.032	0.0874
☑	Ecotoxicity		10.9	8.65	0.0277	0.000508	0.035	0.251	0.0798	0.0083	0.00116	5.48E-7	1.86
☑	Fossil fuel depletion		6.25	3.57	1.65	7.61E-5	0.0139	0.000806	0.000603	0.000919	0.000463	0.186	0.82

Analyzing 1 p 'CIPP 42 in.';Method: TRACI 2.1 V1.03 / US 2008 / Normalization

Figure B-65 Screenshot of the Impact Assessment Table from SimaPro Software for 42 in. CIPP

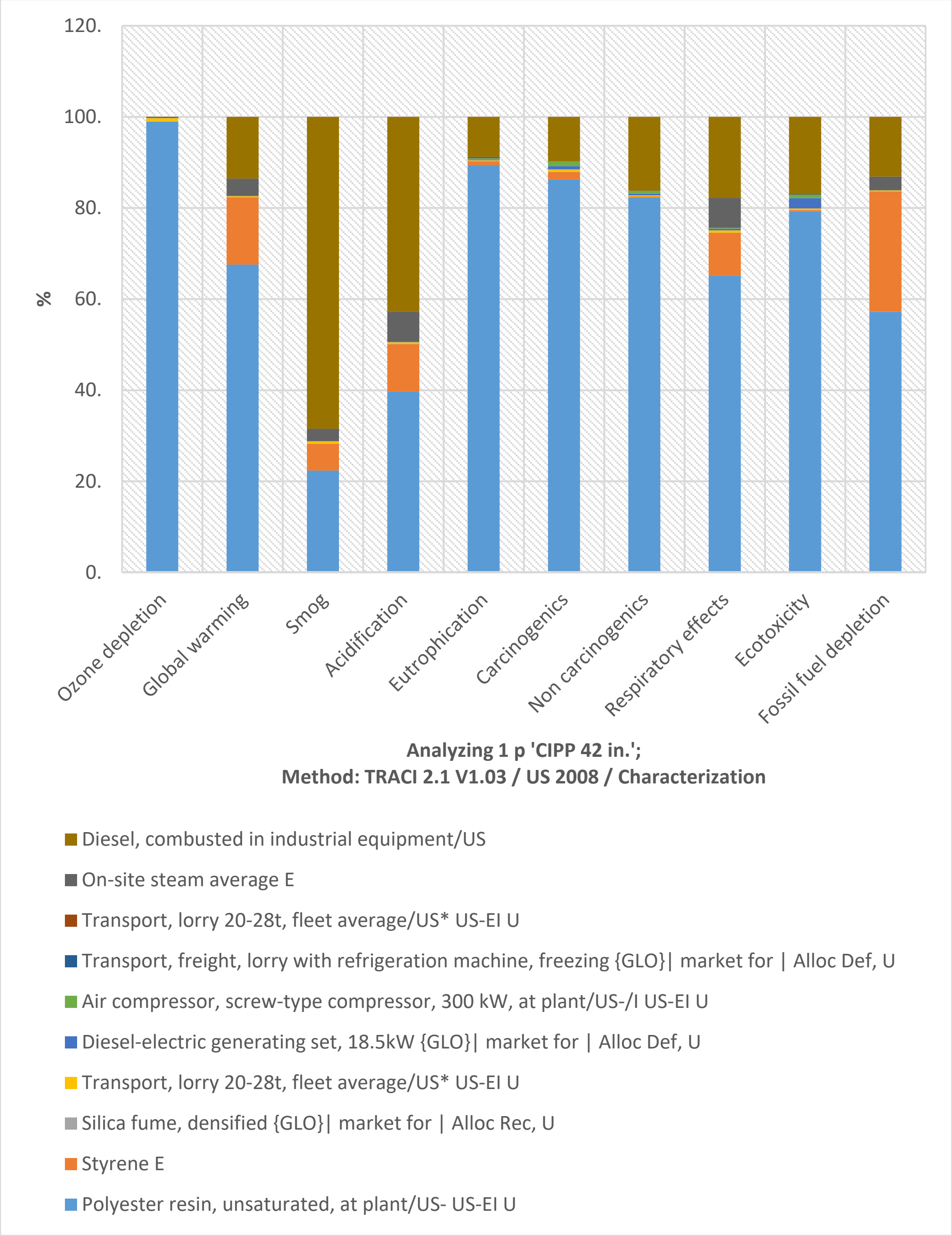


Figure B-66 Environmental Impact Assessment of 42 in. Diameter CIPP Renewal Method

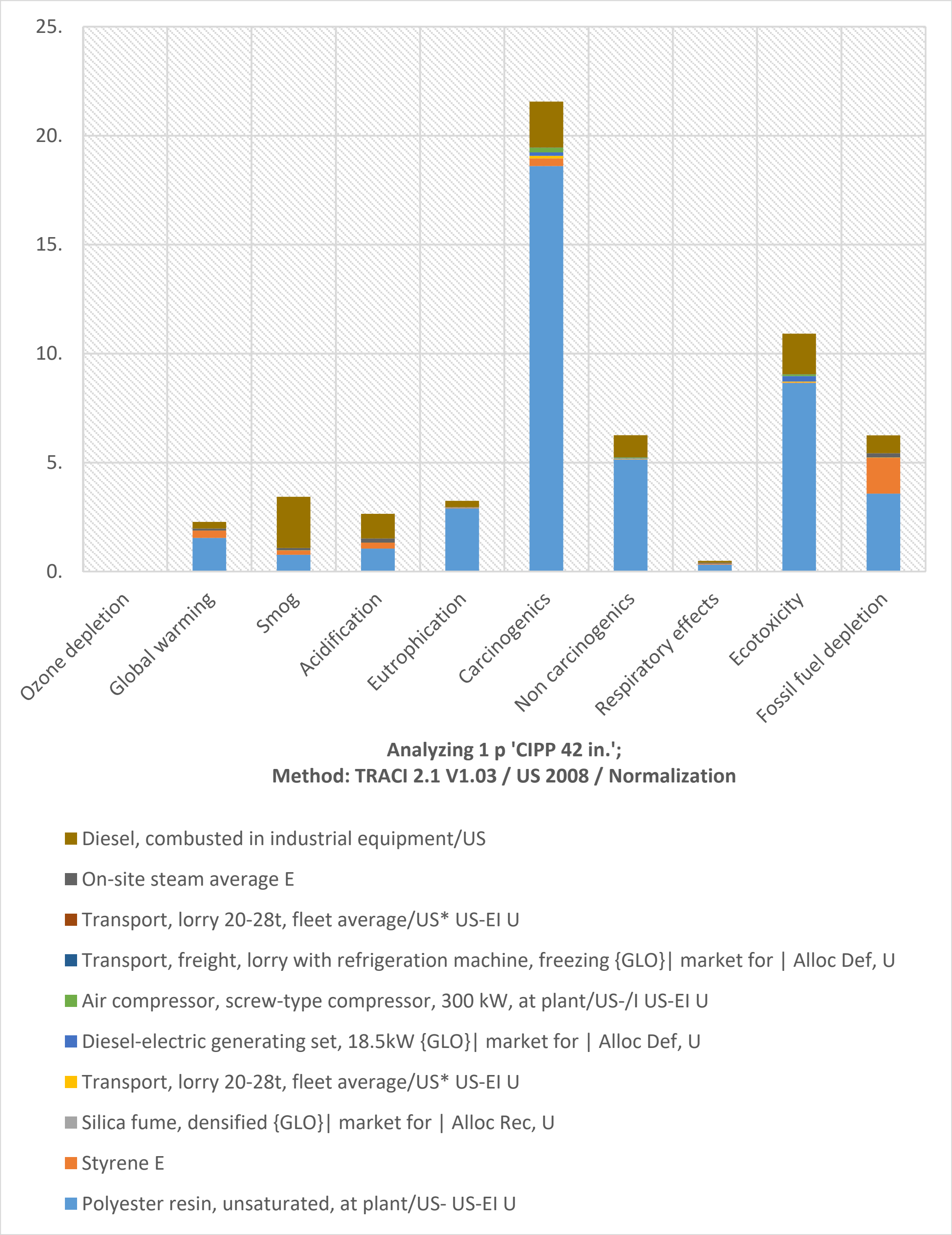


Figure B-67 Normalized Environmental Impact Assessment
of 42 in. Diameter CIPP Renewal Method

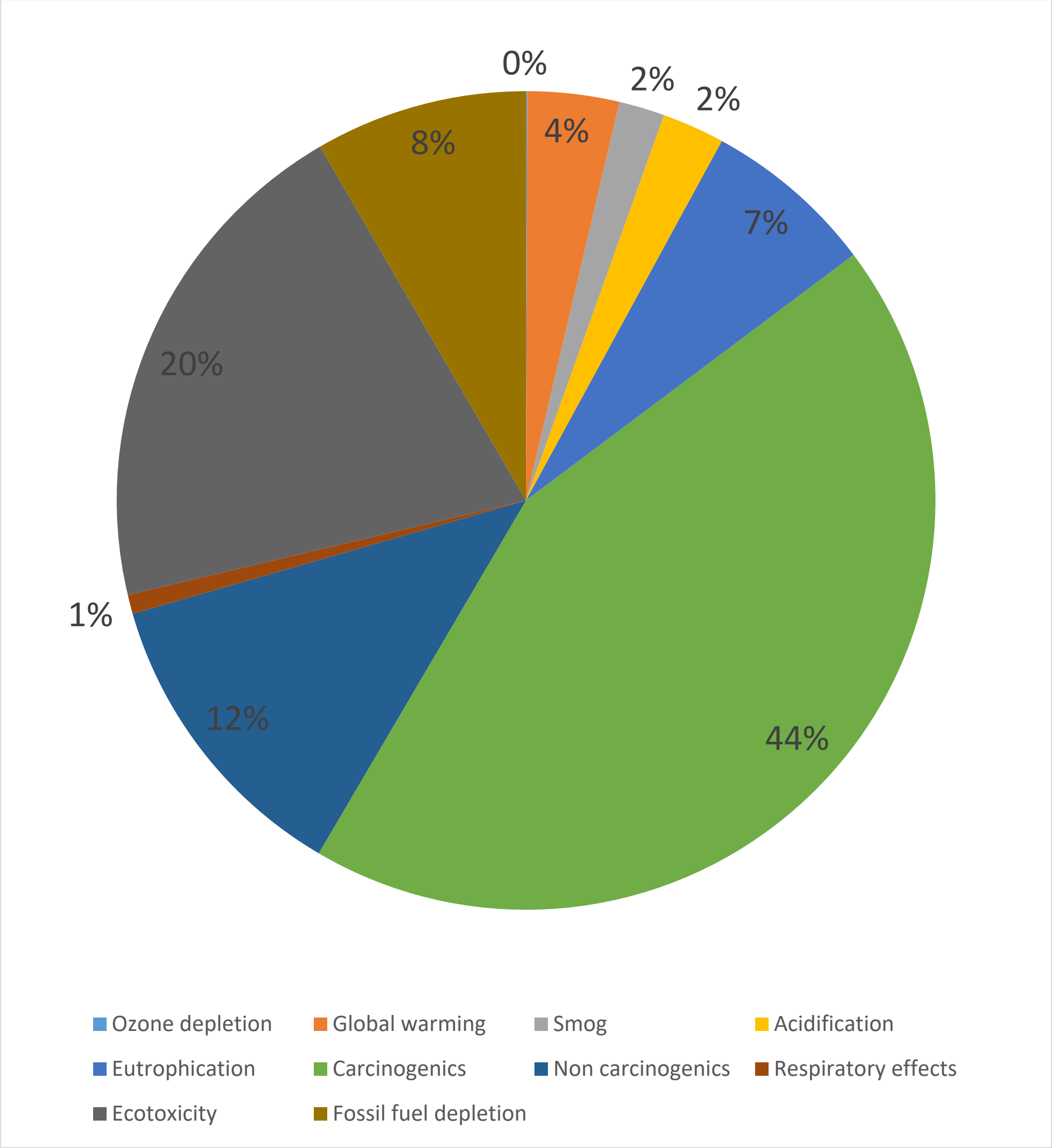


Figure B-68 Percentage of Normalized Environmental Impact Assessment of 42 in. Diameter CIPP Renewal Method

Table B-51 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 42 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.003332	0.003297	0	1.60E-07	2.51E-05	1.85E-06	5.28E-07	6.89E-06	8.34E-07	0	3.07E-07
Global warming	kg CO2 eq	55252.24	37333.28	8157.682	7.08E-01	123.976	27.46688	12.19125	9.098988	4.118188	2083.225	7500.488
Smog	kg O3 eq	4775.499	1067.689	281.2971	9.61E-02	24.89189	1.576492	0.744435	0.978938	0.826849	127.8186	3269.58
Acidification	kg SO2 eq	240.5292	95.58272	25.00336	3.98E-03	0.848509	0.176797	0.087169	0.041113	0.028185	15.78521	102.9722
Eutrophication	kg N eq	70.16266	62.72674	0.590832	1.05E-03	0.13764	0.146058	0.156728	0.010765	0.004572	0.228572	6.159704
Carcinogenics	CTUh	0.001137	0.000981	1.83E-05	3.24E-08	6.44E-06	8.28E-06	1.14E-05	3.30E-07	2.14E-07	8.91E-11	0.000111
Non carcinogenics	CTUh	0.006568	0.005403	1.54E-05	1.75E-07	1.76E-05	2.44E-05	4.04E-05	1.52E-06	5.84E-07	1.30E-08	0.001065
Respiratory effects	kg PM2.5 eq	11.90237	7.74876	1.124326	6.21E-04	0.060493	0.046028	0.019726	0.004752	2.01E-03	0.776393	2.119264
Ecotoxicity	CTUe	120768.6	95762.52	306.5222	5.624536	387.3317	2777.057	883.4641	91.89577	12.86624	6.06E-03	20541.34
Fossil fuel depletion	MJ surplus	117544.8	67249.5	31049.69	1.43E+00	262.2439	15.17393	11.34395	17.29253	8.71112	3505.873	15423.52

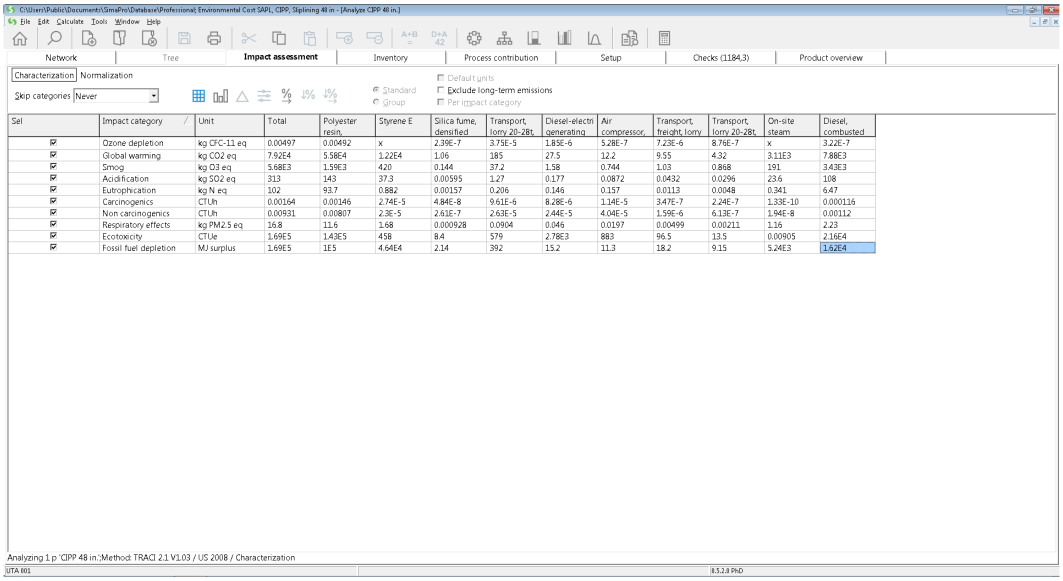
Table B-52 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 42 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.020663	0.020442	0	9.92E-07	1.56E-04	1.14E-05	3.28E-06	4.27E-05	5.17E-06	0	1.90E-06
Global warming	-	2.280917	1.541189	0.336765	2.92E-05	5.12E-03	0.001134	0.000503	0.000376	0.00017	0.085999	0.309634
Smog	-	3.430891	0.767066	0.202094	6.90E-05	1.79E-02	0.001133	0.000535	0.000703	0.000594	0.091829	2.348984
Acidification	-	2.648127	1.052326	0.275277	4.39E-05	9.34E-03	0.001946	0.00096	0.000453	0.00031	0.173789	1.133681
Eutrophication	-	3.245901	2.901896	0.027333	4.88E-05	0.006368	0.006757	0.007251	0.000498	0.000212	0.010574	0.284963
Carcinogenics	-	21.56139	18.60317	0.348031	0.000614	0.122076	0.157095	0.215978	0.006266	0.004055	1.69E-06	2.104099
Non carcinogenics	-	6.253568	5.144679	0.014675	0.000166	0.016737	0.023204	0.038459	0.001444	0.000556	1.24E-05	1.013636
Respiratory effects	-	0.49086	0.319563	0.046368	2.56E-05	2.49E-03	0.001898	0.000814	0.000196	8.29E-05	0.032019	0.0874
Ecotoxicity	-	10.90959	8.650669	0.02769	0.000508	0.034989	0.250864	0.079807	0.008301	0.001162	5.48E-07	1.855593
Fossil fuel depletion	-	6.245613	3.573228	1.649791	7.61E-05	1.39E-02	0.000806	0.000603	0.000919	0.000463	0.186281	0.819512

Table B-53 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 42 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.003332	0.11
Global warming	kg CO2 eq	55252.24	3,480.89
Smog	kg O3 eq	4775.499	10,506.10
Acidification	kg SO2 eq	240.5292	1,315.69
Eutrophication	kg N eq	70.16266	143.83
Carcinogenic	CTUh	0.001137	0.00
Non carcinogenic	CTUh	0.006568	0.06
Respiratory effects	kg PM2.5 eq	11.90237	753.90
Ecotoxicity	CTUe	120768.6	4,951.51
Fossil fuel depletion	MJ surplus	117544.8	1,151.94
Total			22,304.03

A.2.4 CIPP 48 in.



Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00497	0.00492	x	2.39E-7	3.75E-5	1.85E-6	5.28E-7	7.23E-6	8.76E-7	x	3.22E-7
☑	Global warming	kg CO2 eq	7.92E4	5.58E4	1.22E4	1.06	185	27.5	12.2	9.55	4.32	3.11E3	7.88E3
☑	Smog	kg O3 eq	5.68E3	1.59E3	420	0.144	37.2	1.58	0.744	1.03	0.868	191	3.43E3
☑	Acidification	kg SO2 eq	313	143	37.3	0.00595	1.27	0.177	0.0872	0.0432	0.0296	23.6	108
☑	Eutrophication	kg N eq	102	93.7	0.882	0.00157	0.206	0.146	0.157	0.0113	0.0048	0.341	6.47
☑	Carcinogenics	CTUh	0.00164	0.00146	2.74E-5	4.84E-8	9.61E-6	8.28E-6	1.14E-5	3.47E-7	2.24E-7	1.33E-10	0.000116
☑	Non carcinogenics	CTUh	0.00931	0.00807	2.3E-5	2.61E-7	2.63E-5	2.44E-5	4.04E-5	1.59E-6	6.13E-7	1.94E-8	0.00112
☑	Respiratory effects	kg PM2.5 eq	16.8	11.6	1.68	0.000928	0.0904	0.046	0.0197	0.00499	0.00211	1.16	2.23
☑	Ecotoxicity	CTUe	1.69E5	1.43E5	458	8.4	579	2.78E3	883	96.5	13.5	0.00905	2.16E4
☑	Fossil fuel depletion	MJ surplus	1.69E5	1E5	4.64E4	2.14	392	15.2	11.3	18.2	9.15	5.24E3	1.62E4

Analyzing 1 p 'CIPP 48 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-69 Screenshot of the Impact Assessment Table from SimaPro Software for 48 in. CIPP

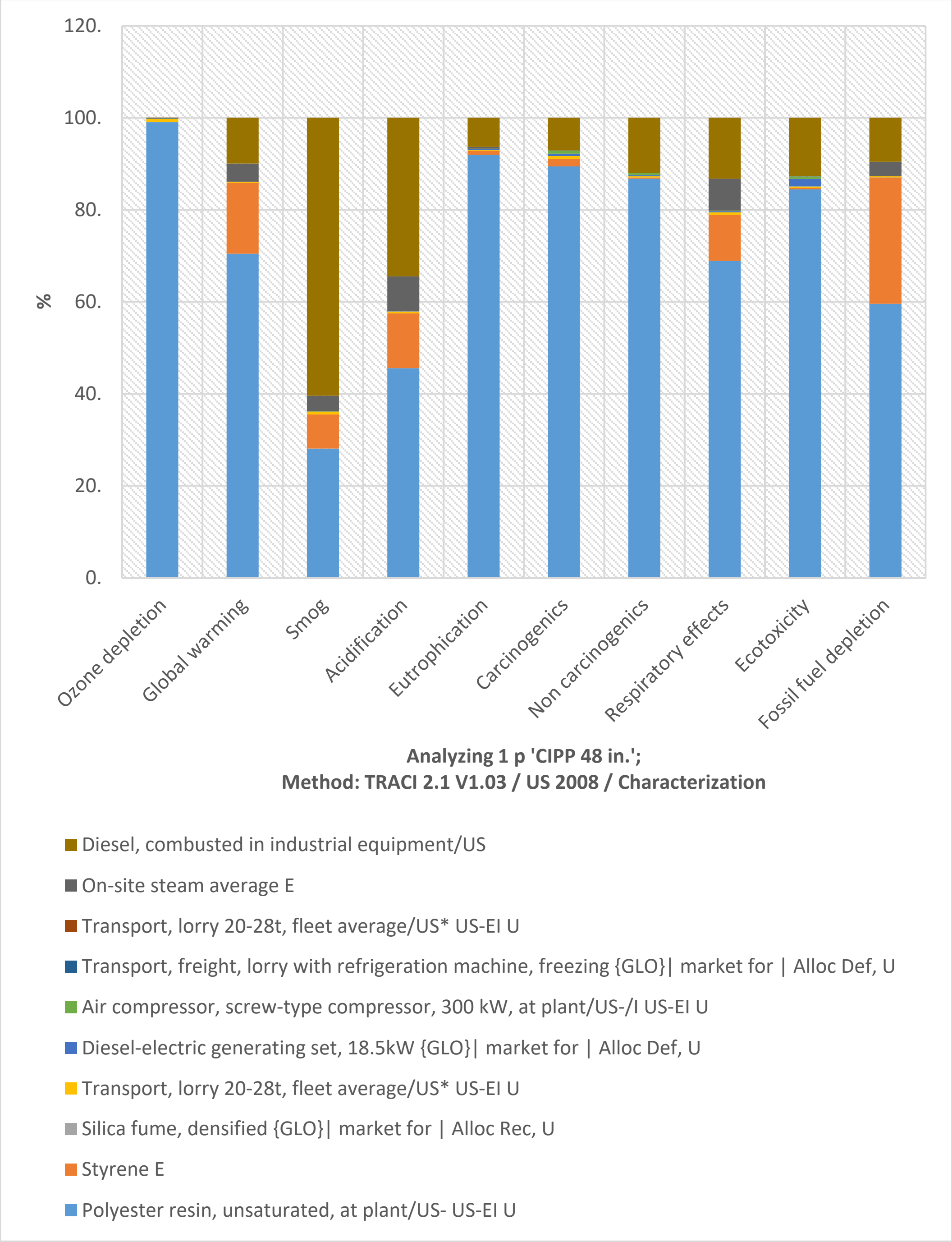


Figure B-70 Environmental Impact Assessment of 48 in. Diameter CIPP Renewal Method

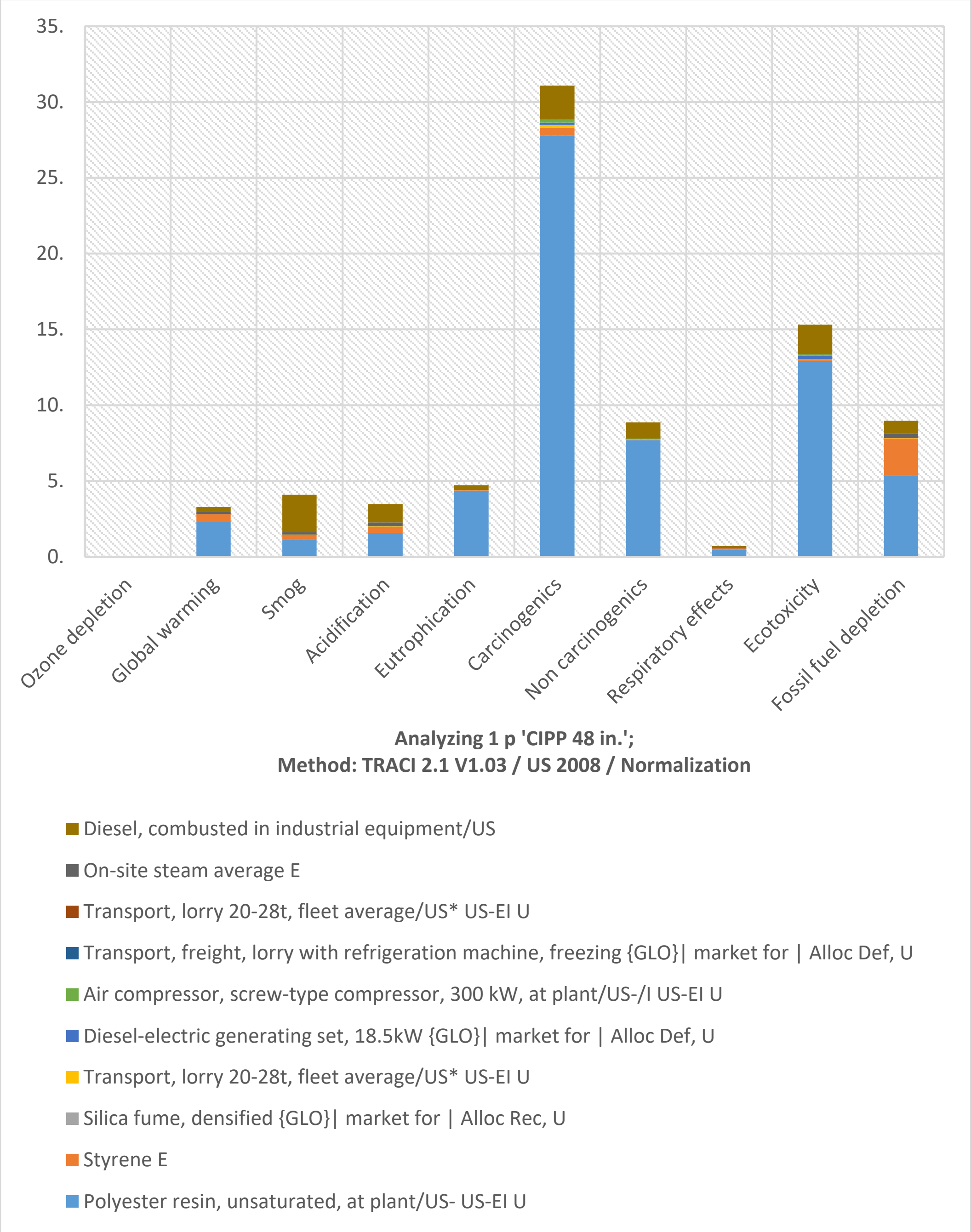


Figure B-71 Normalized Environmental Impact Assessment
of 48 in. Diameter CIPP Renewal Method

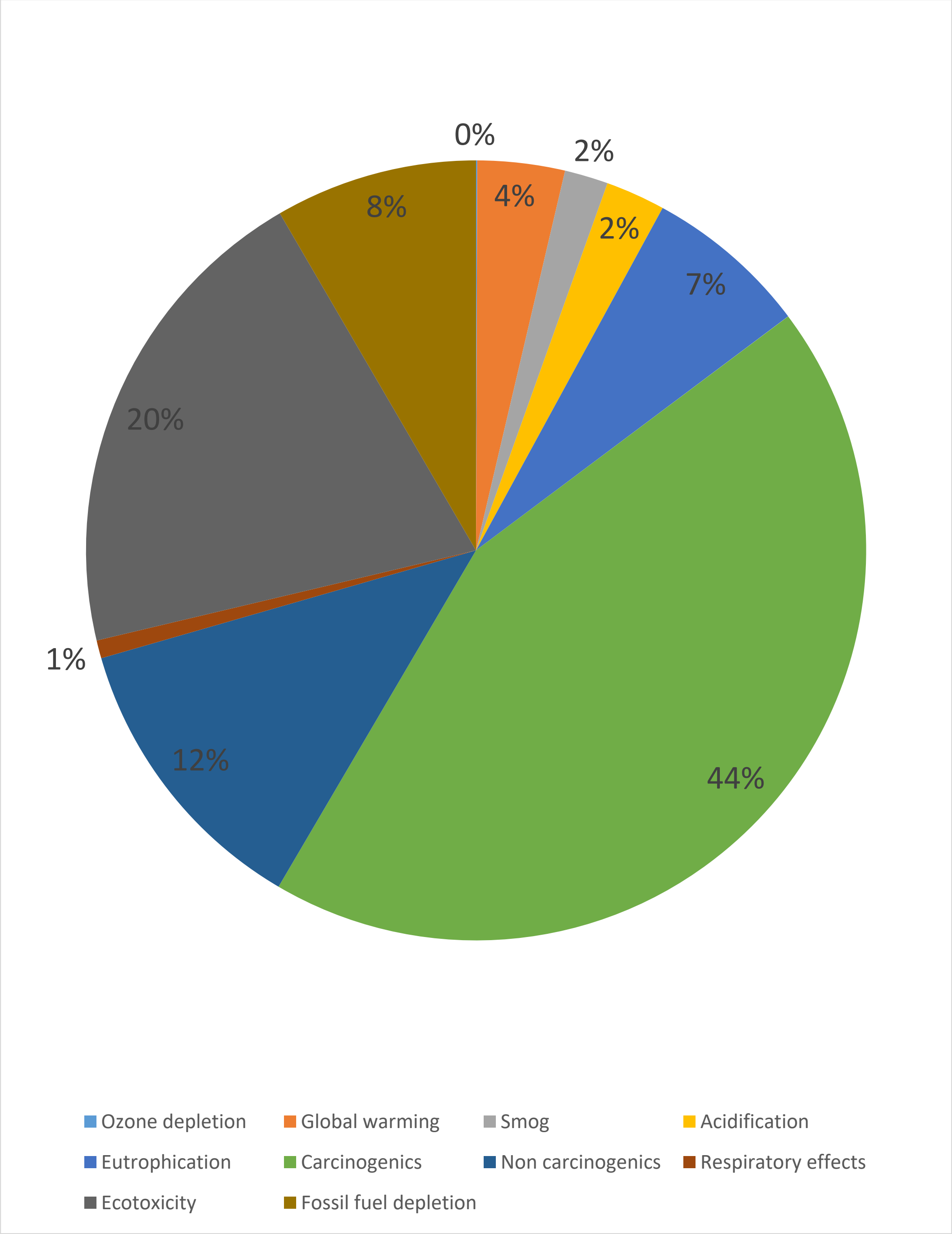


Figure B-72 Percentage of Normalized Environmental Impact Assessment of 48 in. Diameter CIPP Renewal Method

Table B-54 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 48 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.004972	0.004924	0	2.39E-07	3.75E-05	1.85E-06	5.28E-07	7.23E-06	8.76E-07	0	3.22E-07
Global warming	kg CO2 eq	79172.19	55761.07	12184.27	1.057033	185.1691	27.46688	12.19125	9.554598	4.324397	3111.512	7875.573
Smog	kg O3 eq	5680.381	1594.703	420.1438	0.143543	37.17822	1.576492	0.744435	1.027955	0.868252	190.9103	3433.085
Acidification	kg SO2 eq	313.4159	142.7626	37.34489	0.00595	1.267323	0.176797	0.087169	0.043172	0.029597	23.57685	108.1216
Eutrophication	kg N eq	101.9064	93.68879	0.882464	0.001575	0.205577	0.146058	0.156728	0.011304	0.004801	0.341396	6.467739
Carcinogenics	CTUh	0.001639	0.001465	2.74E-05	4.84E-08	9.61E-06	8.28E-06	1.14E-05	3.47E-07	2.24E-07	1.33E-10	0.000116
Non carcinogenics	CTUh	0.009305	0.008071	2.30E-05	2.61E-07	2.63E-05	2.44E-05	4.04E-05	1.59E-06	6.13E-07	1.94E-08	0.001118
Respiratory effects	kg PM2.5 eq	16.80186	11.57357	1.679288	0.000928	0.090352	0.046028	0.019726	0.00499	0.00211	1.159624	2.225244
Ecotoxicity	CTUe	169415	143031.1	457.8199	8.401549	578.514	2777.057	883.4641	96.49723	13.51049	0.009053	21568.57
Fossil fuel depletion	MJ surplus	168698.5	100444	46375.66	2.140419	391.6843	15.17393	11.34395	18.15842	9.147308	5236.385	16194.82

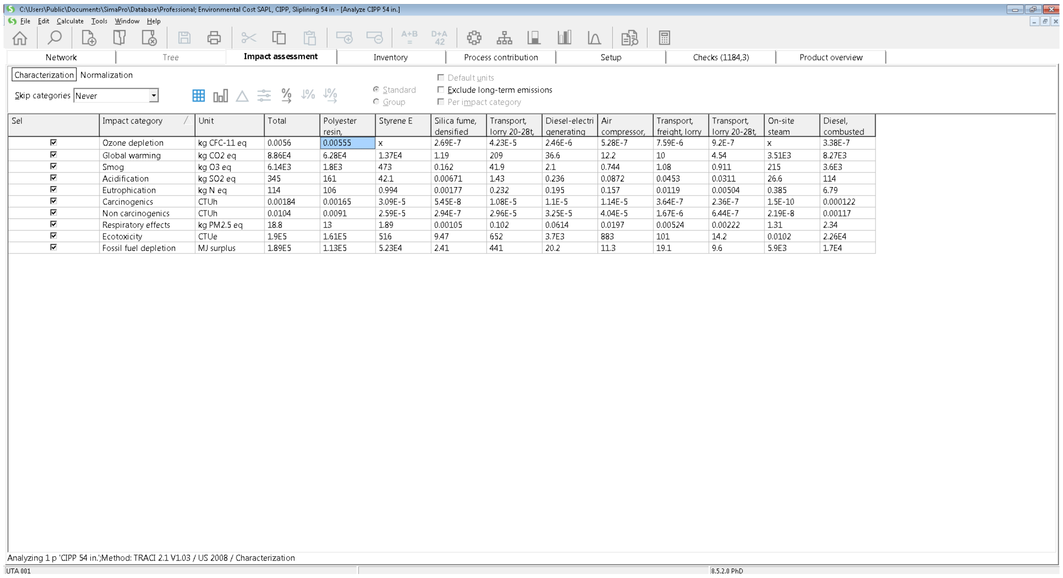
Table B-55 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 48 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.030833	0.030532	0	1.48E-06	2.33E-04	1.14E-05	3.28E-06	4.49E-05	5.43E-06	0	2.00E-06
Global warming	-	3.268379	2.301923	0.50299	4.36E-05	7.64E-03	0.001134	0.000503	0.000394	0.000179	0.128449	0.325119
Smog	-	4.08099	1.145692	0.301846	0.000103	2.67E-02	0.001133	0.000535	0.000739	0.000624	0.137157	2.466452
Acidification	-	3.45058	1.571757	0.411152	6.55E-05	1.40E-02	0.001946	0.00096	0.000475	0.000326	0.259571	1.190374
Eutrophication	-	4.714447	4.334279	0.040825	7.28E-05	0.00951	0.006757	0.007251	0.000523	0.000222	0.015794	0.299214
Carcinogenics	-	31.08204	27.78574	0.519818	0.000918	0.182331	0.157095	0.215978	0.006579	0.004258	2.52E-06	2.209321
Non carcinogenics	-	8.859376	7.684103	0.021919	0.000248	0.024998	0.023204	0.038459	0.001516	0.000584	1.85E-05	1.064326
Respiratory effects	-	0.692918	0.4773	0.069255	3.83E-05	3.73E-03	0.001898	0.000814	0.000206	8.70E-05	0.047824	0.09177
Ecotoxicity	-	15.30403	12.92066	0.041357	0.000759	0.05226	0.250864	0.079807	0.008717	0.00122	8.18E-07	1.948388
Fossil fuel depletion	-	8.96361	5.336982	2.46412	0.000114	2.08E-02	0.000806	0.000603	0.000965	0.000486	0.27823	0.860494

Table B-56 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 48 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.004972	0.16
Global warming	kg CO2 eq	79172.19	4,987.85
Smog	kg O3 eq	5680.381	12,496.84
Acidification	kg SO2 eq	313.4159	1,714.39
Eutrophication	kg N eq	101.9064	208.91
Carcinogenic	CTUh	0.001639	0.00
Non carcinogenic	CTUh	0.009305	0.08
Respiratory effects	kg PM2.5 eq	16.80186	1,064.23
Ecotoxicity	CTUe	169415	6,946.01
Fossil fuel depletion	MJ surplus	168698.5	1,653.25
Total			29,071.71

A.2.5 CIPP 54 in.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 54 in - [Analyze CIPP 54 in.]

Skip categories: Never

● Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.0056	0.00555	x	2.69E-7	4.23E-5	2.46E-6	5.28E-7	7.59E-6	9.2E-7	x	3.38E-7
☑	Global warming	kg CO2 eq	8.86E4	6.28E4	1.37E4	1.19	209	36.6	12.2	10	4.54	3.51E3	8.27E3
☑	Smog	kg O3 eq	6.14E3	1.8E3	473	0.162	41.9	2.1	0.744	1.08	0.911	215	3.6E3
☑	Acidification	kg SO2 eq	345	161	42.1	0.00671	1.43	0.236	0.0872	0.0453	0.0311	26.6	114
☑	Eutrophication	kg N eq	114	106	0.994	0.00177	0.232	0.195	0.157	0.0119	0.00504	0.385	6.79
☑	Carcinogenics	CTUh	0.00184	0.00165	3.09E-5	5.45E-8	1.08E-5	1.1E-5	1.14E-5	3.64E-7	2.36E-7	1.5E-10	0.000122
☑	Non carcinogenics	CTUh	0.0104	0.0091	2.59E-5	2.94E-7	2.96E-5	3.25E-5	4.04E-5	1.67E-6	6.44E-7	2.19E-8	0.00117
☑	Respiratory effects	kg PM2.5 eq	18.8	13	1.89	0.00105	0.102	0.0614	0.0197	0.00524	0.00222	1.31	2.34
☑	Ecotoxicity	CTUe	1.9E5	1.61E5	516	9.47	652	3.7E3	883	101	14.2	0.0102	2.26E4
☑	Fossil fuel depletion	MJ surplus	1.89E5	1.13E5	5.23E4	2.41	441	20.2	11.3	19.1	9.6	5.9E3	1.7E4

Analyzing 1 p 'CIPP 54 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-73 Screenshot of the Impact Assessment Table from SimaPro Software for 54 in. CIPP

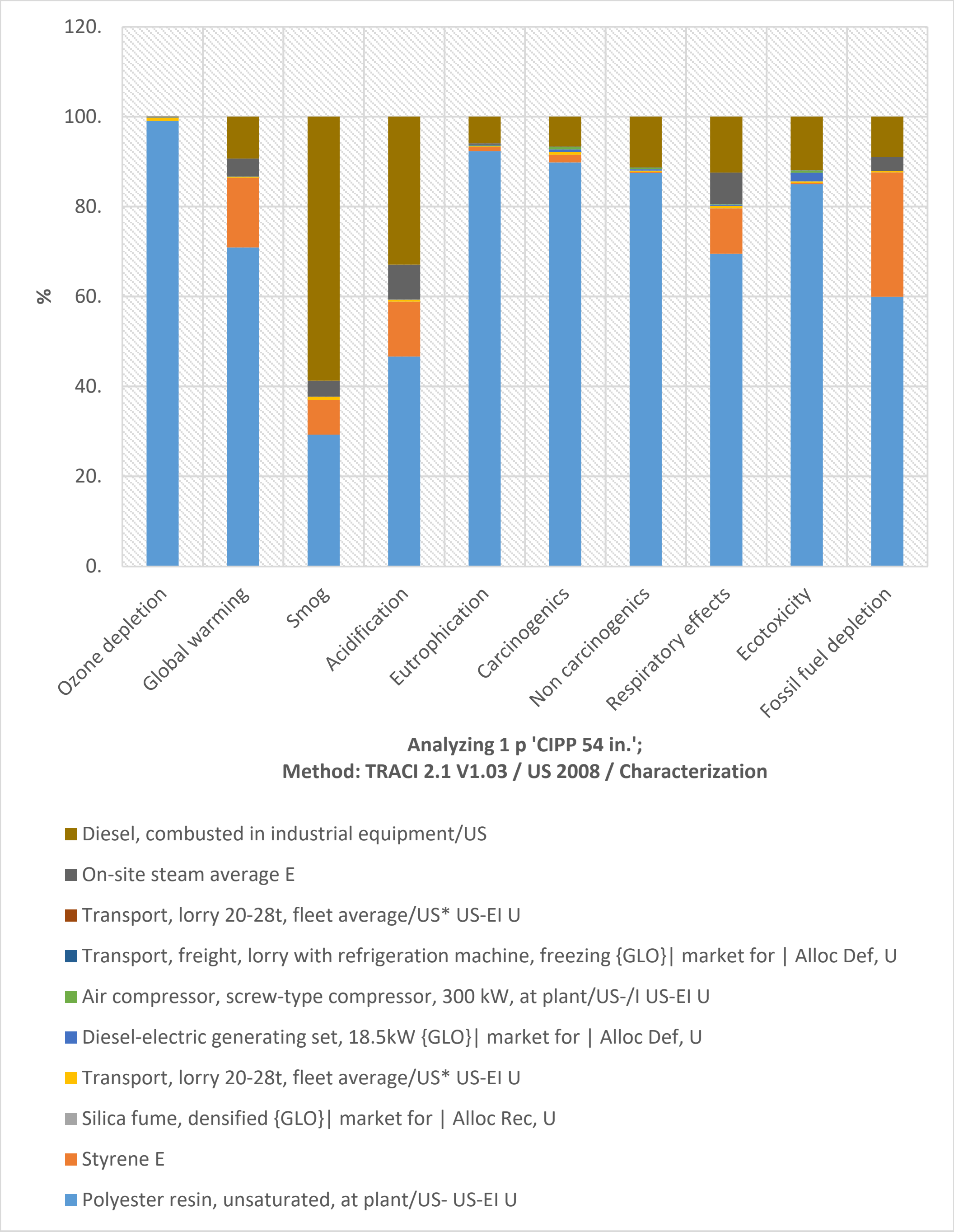


Figure B-74 Environmental Impact Assessment of 54 in. Diameter
CIPP Renewal Method

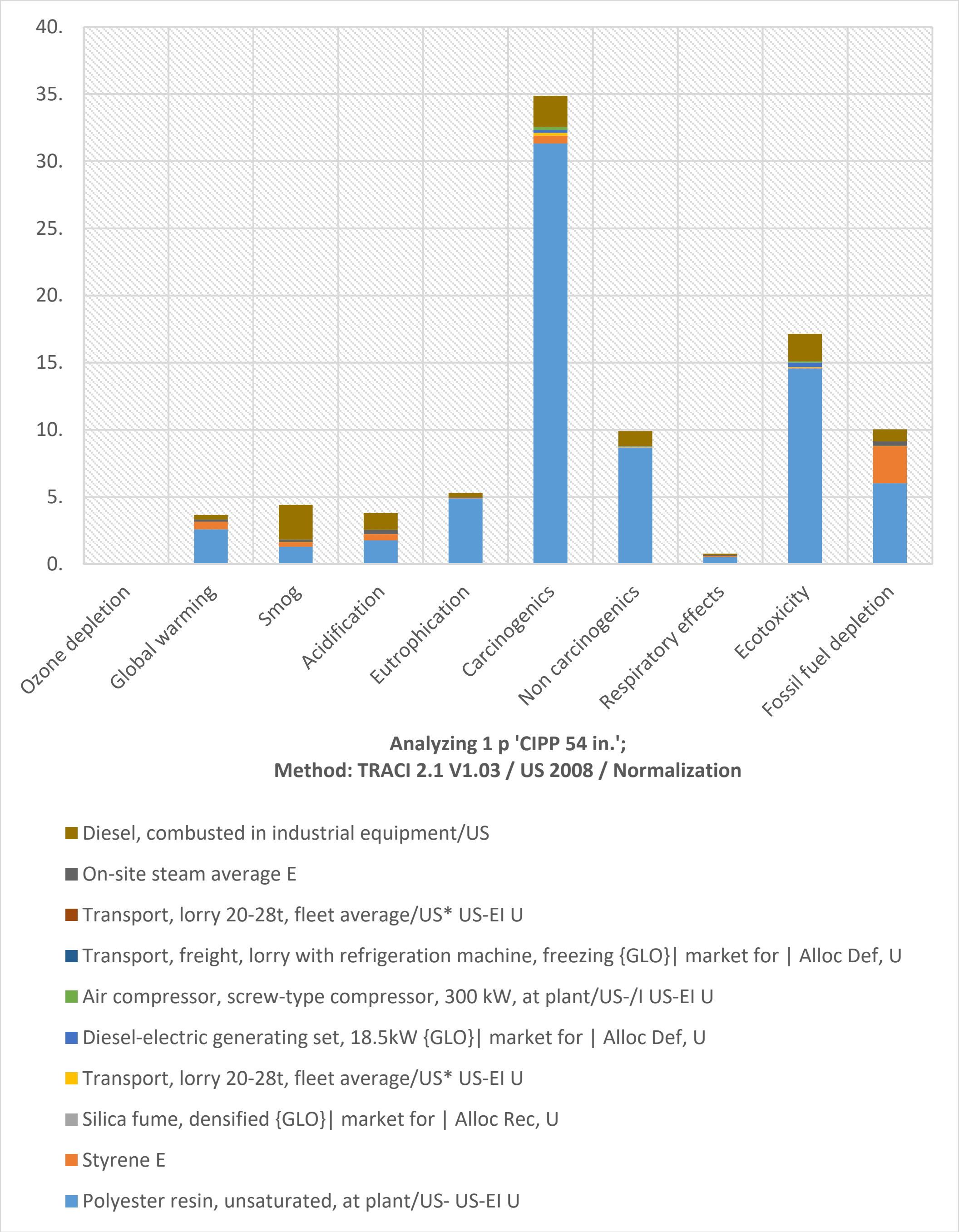


Figure B-75 Normalized Environmental Impact Assessment of 54 in. Diameter CIPP Renewal Method

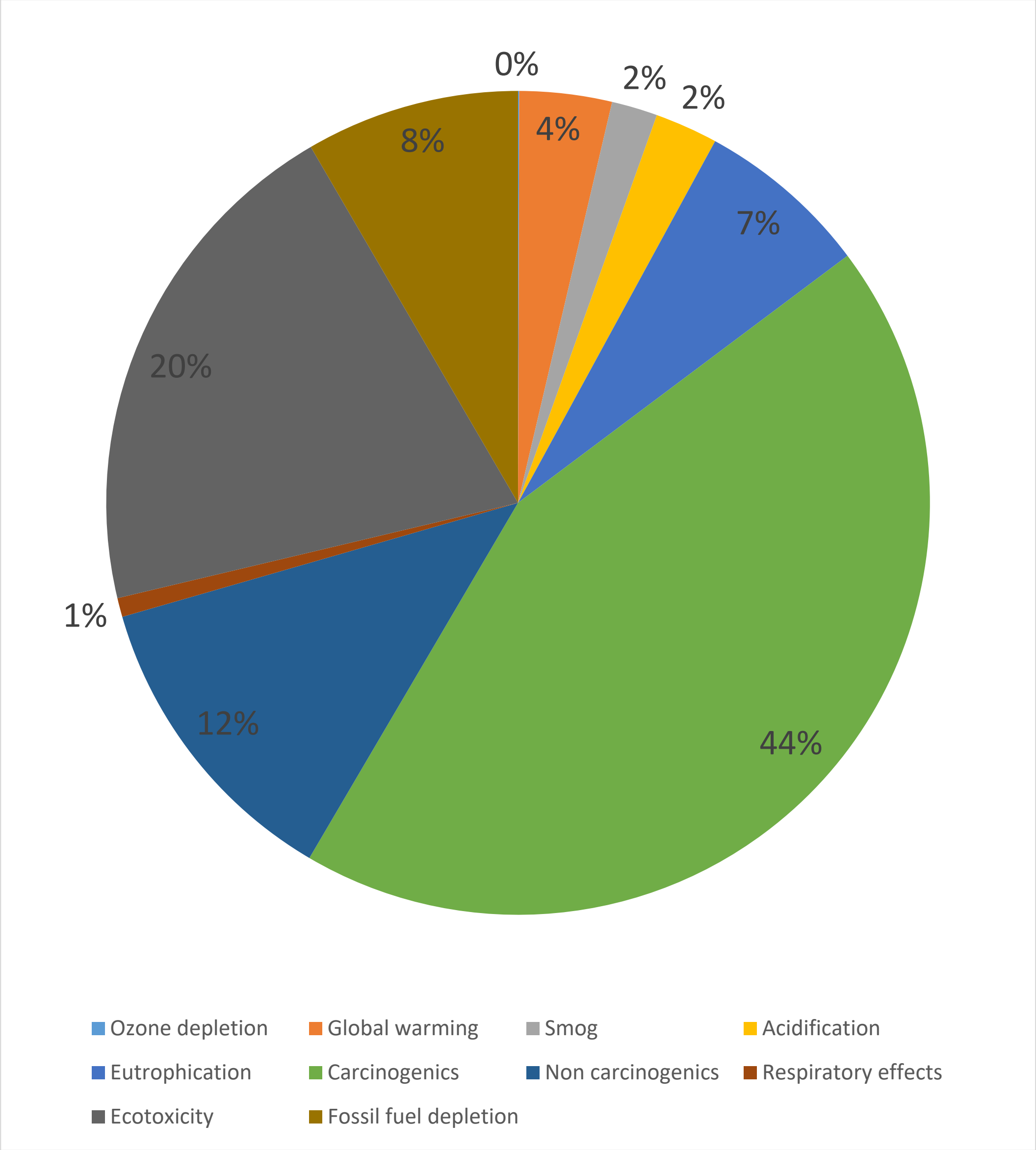


Figure B-76 Percentage of Normalized Environmental Impact Assessment of 54 in. Diameter CIPP Renewal Method

Table B-57 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 54 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.005603	0.005549	0	2.69E-07	4.23E-05	2.46E-06	5.28E-07	7.59E-06	9.20E-07	0	3.38E-07
Global warming	kg CO2 eq	88619.41	62839.47	13730.92	1.191295	208.6738	36.6225	12.19125	10.03002	4.53957	3506.481	8269.285
Smog	kg O3 eq	6137.364	1797.137	473.4762	0.161776	41.8975	2.10199	0.744435	1.079105	0.911454	215.1441	3604.71
Acidification	kg SO2 eq	344.9011	160.8851	42.08539	0.006706	1.428193	0.235729	0.087169	0.04532	0.031069	26.56965	113.5268
Eutrophication	kg N eq	114.3539	105.5818	0.994483	0.001775	0.231672	0.194744	0.156728	0.011866	0.00504	0.384732	6.791072
Carcinogenics	CTUh	0.001838	0.001651	3.09E-05	5.45E-08	1.08E-05	1.10E-05	1.14E-05	3.64E-07	2.36E-07	1.50E-10	0.000122
Non carcinogenics	CTUh	0.0104	0.009095	2.59E-05	2.94E-07	2.96E-05	3.25E-05	4.04E-05	1.67E-06	6.44E-07	2.19E-08	0.001174
Respiratory effects	kg PM2.5 eq	18.76992	13.04273	1.892454	0.001046	0.101821	0.06137	0.019726	0.005239	0.002215	1.306824	2.336488
Ecotoxicity	CTUe	189713.6	161187.7	515.9349	9.468692	651.9487	3702.743	883.4641	101.2988	14.18274	0.010203	22646.81
Fossil fuel depletion	MJ surplus	188866.6	113194.5	52262.51	2.412289	441.4034	20.23191	11.34395	19.06194	9.602461	5901.081	17004.43

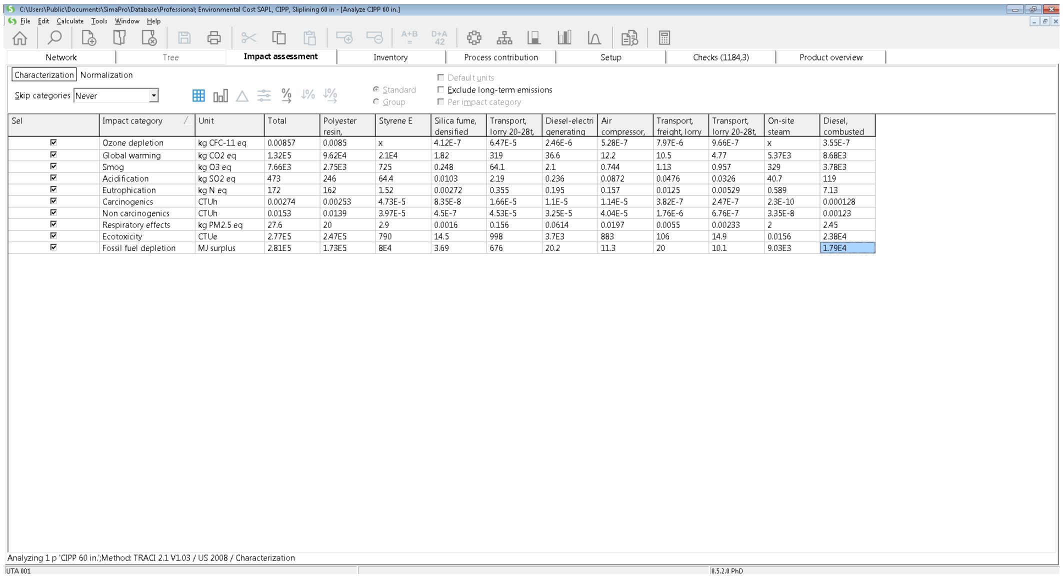
Table B-58 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 54 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.034745	0.034408	0	1.67E-06	2.62E-04	1.53E-05	3.28E-06	4.71E-05	5.70E-06	0	2.10E-06
Global warming	-	3.658378	2.594133	0.566839	4.92E-05	8.61E-03	0.001512	0.000503	0.000414	0.000187	0.144754	0.341372
Smog	-	4.409303	1.291128	0.340162	0.000116	3.01E-02	0.00151	0.000535	0.000775	0.000655	0.154567	2.589754
Acidification	-	3.797218	1.771278	0.463343	7.38E-05	1.57E-02	0.002595	0.00096	0.000499	0.000342	0.292521	1.249883
Eutrophication	-	5.290299	4.884479	0.046007	8.21E-05	0.010718	0.009009	0.007251	0.000549	0.000233	0.017799	0.314172
Carcinogenics	-	34.86181	31.31291	0.585803	0.001034	0.205475	0.209459	0.215978	0.006907	0.00447	2.84E-06	2.319769
Non carcinogenics	-	9.901845	8.659536	0.024702	0.00028	0.028171	0.030939	0.038459	0.001592	0.000613	2.08E-05	1.117533
Respiratory effects	-	0.774082	0.537889	0.078046	4.31E-05	4.20E-03	0.002531	0.000814	0.000216	9.13E-05	0.053894	0.096358
Ecotoxicity	-	17.1377	14.56083	0.046607	0.000855	0.058894	0.334486	0.079807	0.009151	0.001281	9.22E-07	2.045791
Fossil fuel depletion	-	10.03522	6.014467	2.776911	0.000128	2.35E-02	0.001075	0.000603	0.001013	0.00051	0.313547	0.903511

Table B-59 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 54 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.005603	0.19
Global warming	kg CO2 eq	88619.41	5,583.02
Smog	kg O3 eq	6137.364	13,502.20
Acidification	kg SO2 eq	344.9011	1,886.61
Eutrophication	kg N eq	114.3539	234.43
Carcinogenic	CTUh	0.001838	0.00
Non carcinogenic	CTUh	0.0104	0.09
Respiratory effects	kg PM2.5 eq	18.76992	1,188.89
Ecotoxicity	CTUe	189713.6	7,778.26
Fossil fuel depletion	MJ surplus	188866.6	1,850.89
Total			32,024.57

A.2.6 *CIPP 60 in.*



Skip categories: Never

☐ Exclude long-term emissions

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00857	0.0085	x	4.12E-7	6.47E-5	2.46E-6	5.28E-7	7.97E-6	9.66E-7	x	3.55E-7
☑	Global warming	kg CO2 eq	1.32E5	9.62E4	2.1E4	1.82	319	36.6	12.2	10.5	4.77	5.37E3	8.68E3
☑	Smog	kg O3 eq	7.66E3	2.75E3	725	0.248	64.1	2.1	0.744	1.13	0.957	329	3.78E3
☑	Acidification	kg SO2 eq	473	246	64.4	0.0103	2.19	0.236	0.0872	0.0476	0.0326	40.7	119
☑	Eutrophication	kg N eq	172	162	1.52	0.00272	0.355	0.195	0.157	0.0125	0.00529	0.589	7.13
☑	Carcinogenics	CTUh	0.00274	0.00253	4.73E-5	8.35E-8	1.66E-5	1.1E-5	1.14E-5	3.82E-7	2.47E-7	2.3E-10	0.000128
☑	Non carcinogenics	CTUh	0.0153	0.0139	3.97E-5	4.5E-7	4.53E-5	3.25E-5	4.04E-5	1.76E-6	6.76E-7	3.35E-8	0.00123
☑	Respiratory effects	kg PM2.5 eq	27.6	20	2.9	0.0016	0.156	0.0614	0.0197	0.0055	0.00233	2	2.45
☑	Ecotoxicity	CTUe	2.77E5	2.47E5	790	14.5	998	3.7E3	883	106	14.9	0.0156	2.38E4
☑	Fossil fuel depletion	MJ surplus	2.81E5	1.73E5	8E4	3.69	676	20.2	11.3	20	10.1	9.03E3	1.79E4

Analyzing 1 p 'CIPP 60 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-77 Screenshot of the Impact Assessment Table from SimaPro Software for 60 in. CIPP

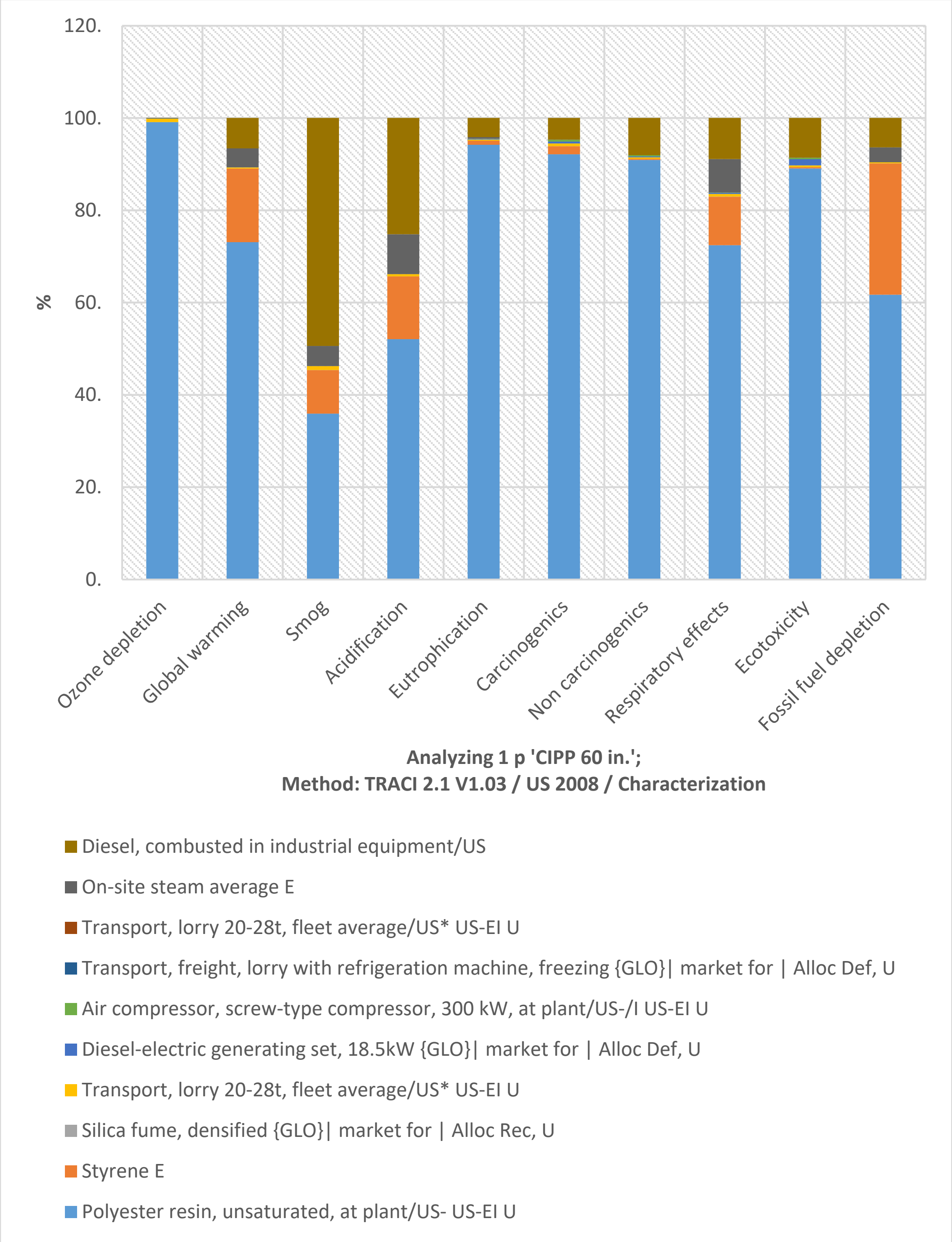


Figure B-78 Environmental Impact Assessment of 60 in. Diameter CIPP Renewal Method

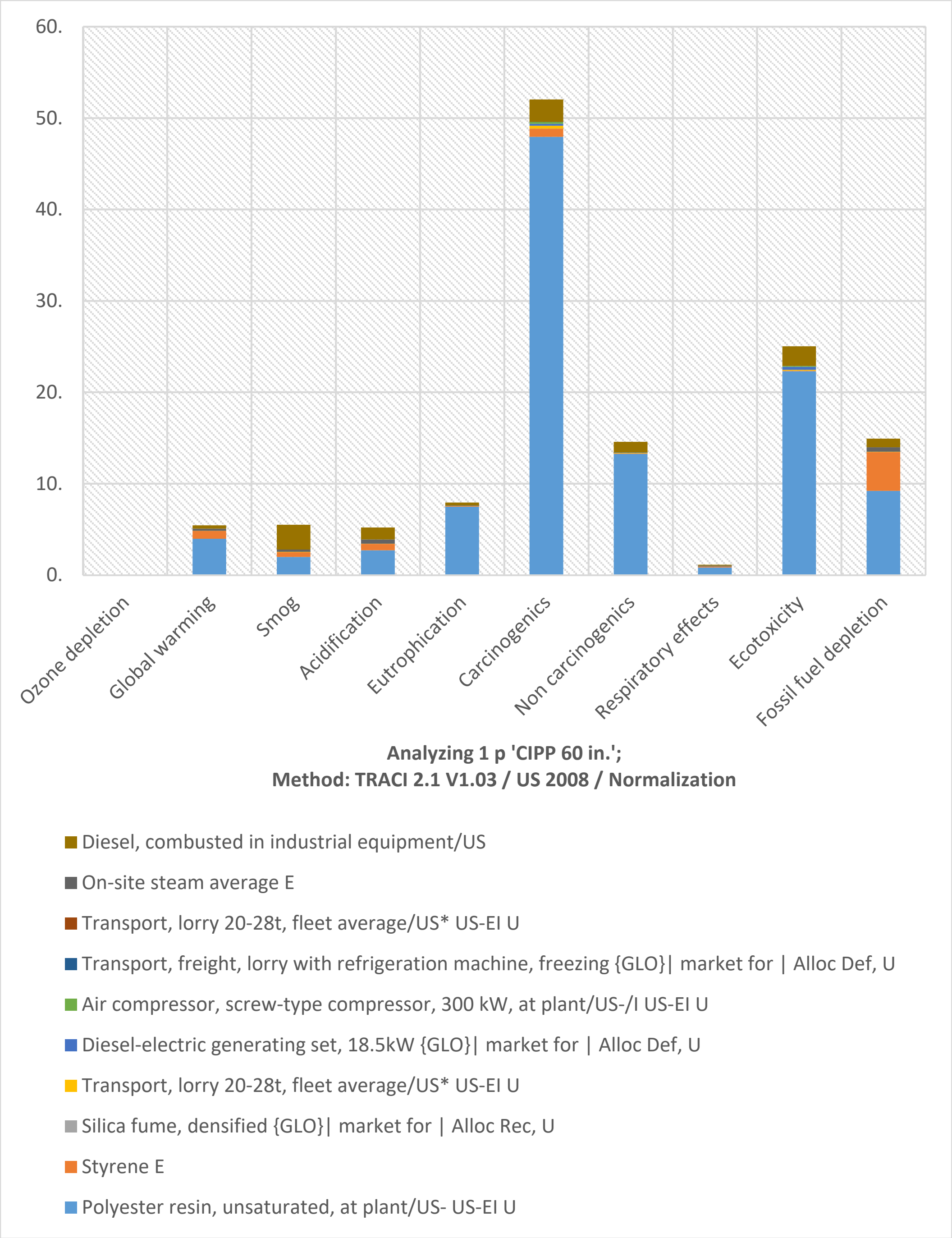


Figure B-79 Normalized Environmental Impact Assessment of 60 in. Diameter CIPP Renewal Method

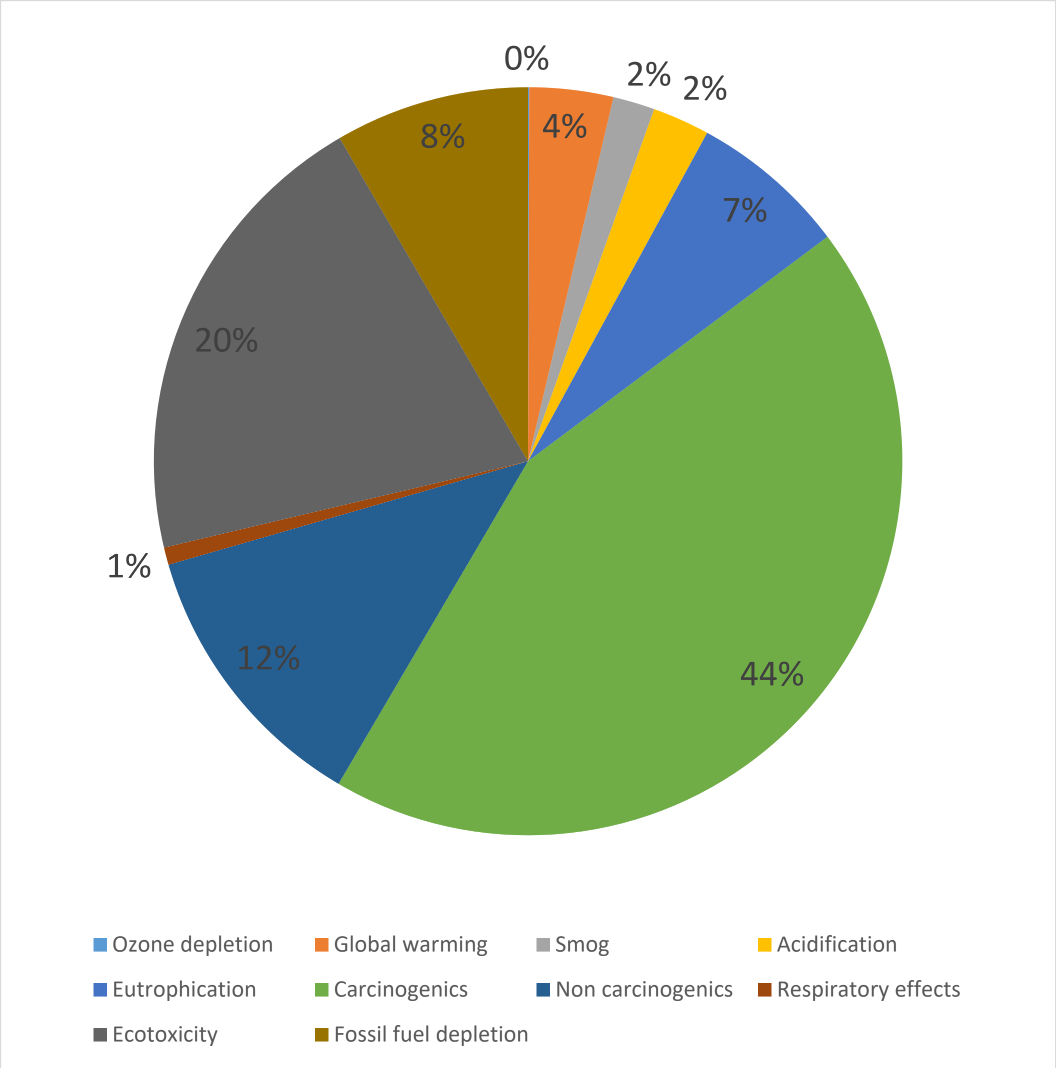


Figure B-80 Percentage of Normalized Environmental Impact Assessment of 60 in. Diameter CIPP Renewal Method

Table B-60 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 60 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.008573	0.008495	0	4.12E-07	6.47E-05	2.46E-06	5.28E-07	7.97E-06	9.66E-07	0	3.55E-07
Global warming	kg CO2 eq	131663.4	96205.28	21021.56	1.823706	319.4764	36.6225	12.19125	10.53185	4.766698	5368.32	8682.828
Smog	kg O3 eq	7659.924	2751.361	724.8755	0.247656	64.14443	2.10199	0.744435	1.133095	0.957057	329.3793	3784.98
Acidification	kg SO2 eq	473.2228	246.31	64.43126	0.010266	2.186542	0.235729	0.087169	0.047587	0.032624	40.67736	119.2042
Eutrophication	kg N eq	171.6113	161.6425	1.522519	0.002717	0.354686	0.194744	0.156728	0.01246	0.005292	0.589013	7.130689
Carcinogenics	CTUh	0.002743	0.002527	4.73E-05	8.35E-08	1.66E-05	1.10E-05	1.14E-05	3.82E-07	2.47E-07	2.30E-10	0.000128
Non carcinogenics	CTUh	0.015318	0.013924	3.97E-05	4.50E-07	4.53E-05	3.25E-05	4.04E-05	1.76E-06	6.76E-07	3.35E-08	0.001232
Respiratory effects	kg PM2.5 eq	27.56575	19.96802	2.897281	0.001601	0.155886	0.06137	0.019726	0.005501	0.002326	2.00071	2.453334
Ecotoxicity	CTUe	277062.7	246773.4	789.8782	14.49525	998.1234	3702.743	883.4641	106.367	14.89235	0.01562	23779.37
Fossil fuel depletion	MJ surplus	280939.7	173297.3	80012.08	3.692879	675.7819	20.23191	11.34395	20.01567	10.0829	9034.383	17854.81

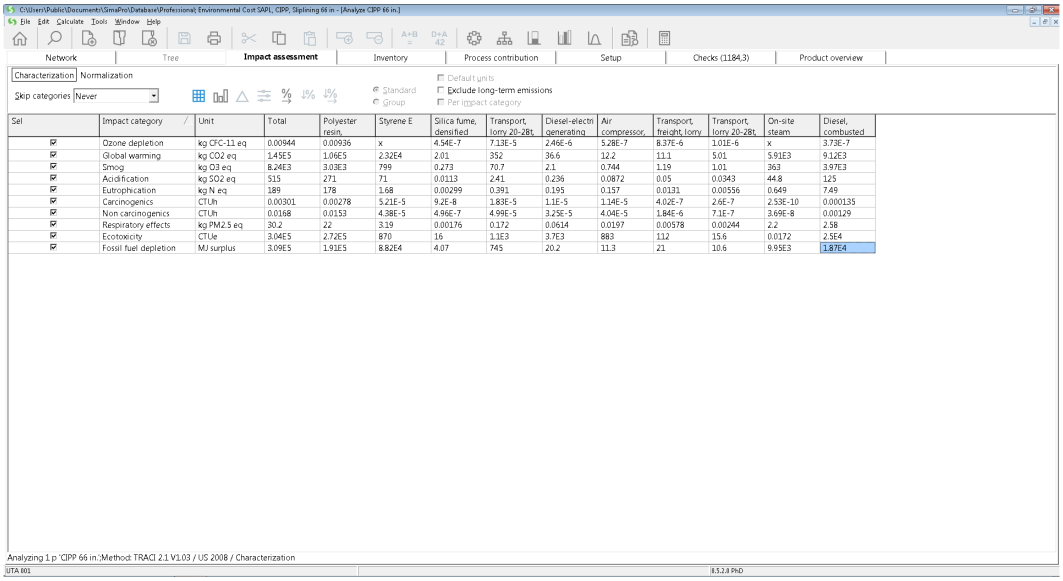
Table B-61 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 60 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.053158	0.052678	0	2.56E-06	4.01E-04	1.53E-05	3.28E-06	4.94E-05	5.99E-06	0	2.20E-06
Global warming	-	5.435315	3.971537	0.86781	7.53E-05	1.32E-02	0.001512	0.000503	0.000435	0.000197	0.221614	0.358444
Smog	-	5.503165	1.976677	0.520777	0.000178	4.61E-02	0.00151	0.000535	0.000814	0.000688	0.236638	2.719266
Acidification	-	5.209987	2.711772	0.709362	0.000113	2.41E-02	0.002595	0.00096	0.000524	0.000359	0.447841	1.312389
Eutrophication	-	7.939169	7.477985	0.070436	0.000126	0.016409	0.009009	0.007251	0.000576	0.000245	0.027249	0.329884
Carcinogenics	-	52.02526	47.93909	0.896843	0.001584	0.314579	0.209459	0.215978	0.007252	0.004694	4.36E-06	2.435779
Non carcinogenics	-	14.58402	13.25748	0.037817	0.000428	0.04313	0.030939	0.038459	0.001671	0.000644	3.19E-05	1.17342
Respiratory effects	-	1.136827	0.823492	0.119485	6.60E-05	6.43E-03	0.002531	0.000814	0.000227	9.59E-05	0.08251	0.101177
Ecotoxicity	-	25.02835	22.29217	0.071353	0.001309	0.090165	0.334486	0.079807	0.009609	0.001345	1.41E-06	2.1481
Fossil fuel depletion	-	14.92742	9.207962	4.251354	0.000196	3.59E-02	0.001075	0.000603	0.001064	0.000536	0.480032	0.948696

Table B-62 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 60 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.008573	0.28
Global warming	kg CO2 eq	131663.4	8,294.79
Smog	kg O3 eq	7659.924	16,851.83
Acidification	kg SO2 eq	473.2228	2,588.53
Eutrophication	kg N eq	171.6113	351.80
Carcinogenic	CTUh	0.002743	0.00
Non carcinogenic	CTUh	0.015318	0.14
Respiratory effects	kg PM2.5 eq	27.56575	1,746.01
Ecotoxicity	CTUe	277062.7	11,359.57
Fossil fuel depletion	MJ surplus	280939.7	2,753.21
Total			43,946.18

A.2.7 CIPP 66 in.



Skip categories: Never

☐ Exclude long-term emissions

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00944	0.00936	x	4.54E-7	7.13E-5	2.46E-6	5.28E-7	8.37E-6	1.01E-6	x	3.73E-7
☑	Global warming	kg CO2 eq	1.45E5	1.06E5	2.32E4	2.01	352	36.6	12.2	11.1	5.01	5.91E3	9.12E3
☑	Smog	kg O3 eq	8.24E3	3.03E3	799	0.273	70.7	2.1	0.744	1.19	1.01	363	3.97E3
☑	Acidification	kg SO2 eq	515	271	71	0.0113	2.41	0.236	0.0872	0.05	0.0343	44.8	125
☑	Eutrophication	kg N eq	189	178	1.68	0.00299	0.391	0.195	0.157	0.0131	0.00556	0.649	7.49
☑	Carcinogenics	CTUh	0.00301	0.00278	5.21E-5	9.2E-8	1.83E-5	1.1E-5	1.14E-5	4.02E-7	2.6E-7	2.53E-10	0.000135
☑	Non carcinogenics	CTUh	0.0168	0.0153	4.38E-5	4.96E-7	4.99E-5	3.25E-5	4.04E-5	1.84E-6	7.1E-7	3.69E-8	0.00129
☑	Respiratory effects	kg PM2.5 eq	30.2	22	3.19	0.00176	0.172	0.0614	0.0197	0.00578	0.00244	2.2	2.58
☑	Ecotoxicity	CTUe	3.04E5	2.72E5	870	16	1.1E3	3.7E3	883	112	15.6	0.0172	2.5E4
☑	Fossil fuel depletion	MJ surplus	3.09E5	1.91E5	8.82E4	4.07	745	20.2	11.3	21	10.6	9.95E3	1.87E4

Analyzing 1 p 'CIPP 66 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-81 Screenshot of the Impact Assessment Table from SimaPro Software for 66 in. CIPP

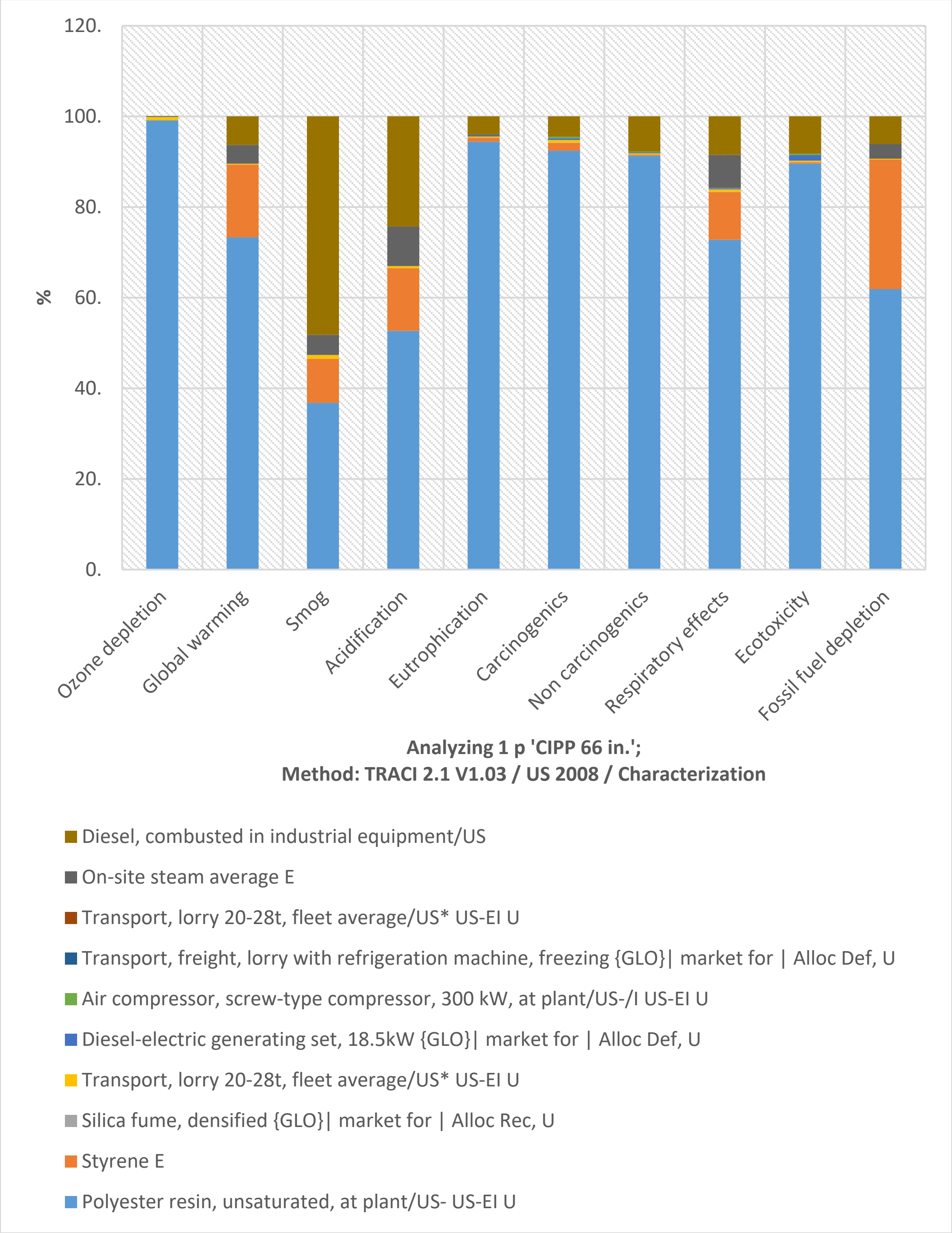


Figure B-82 Environmental Impact Assessment of 66 in. Diameter CIPP Renewal Method

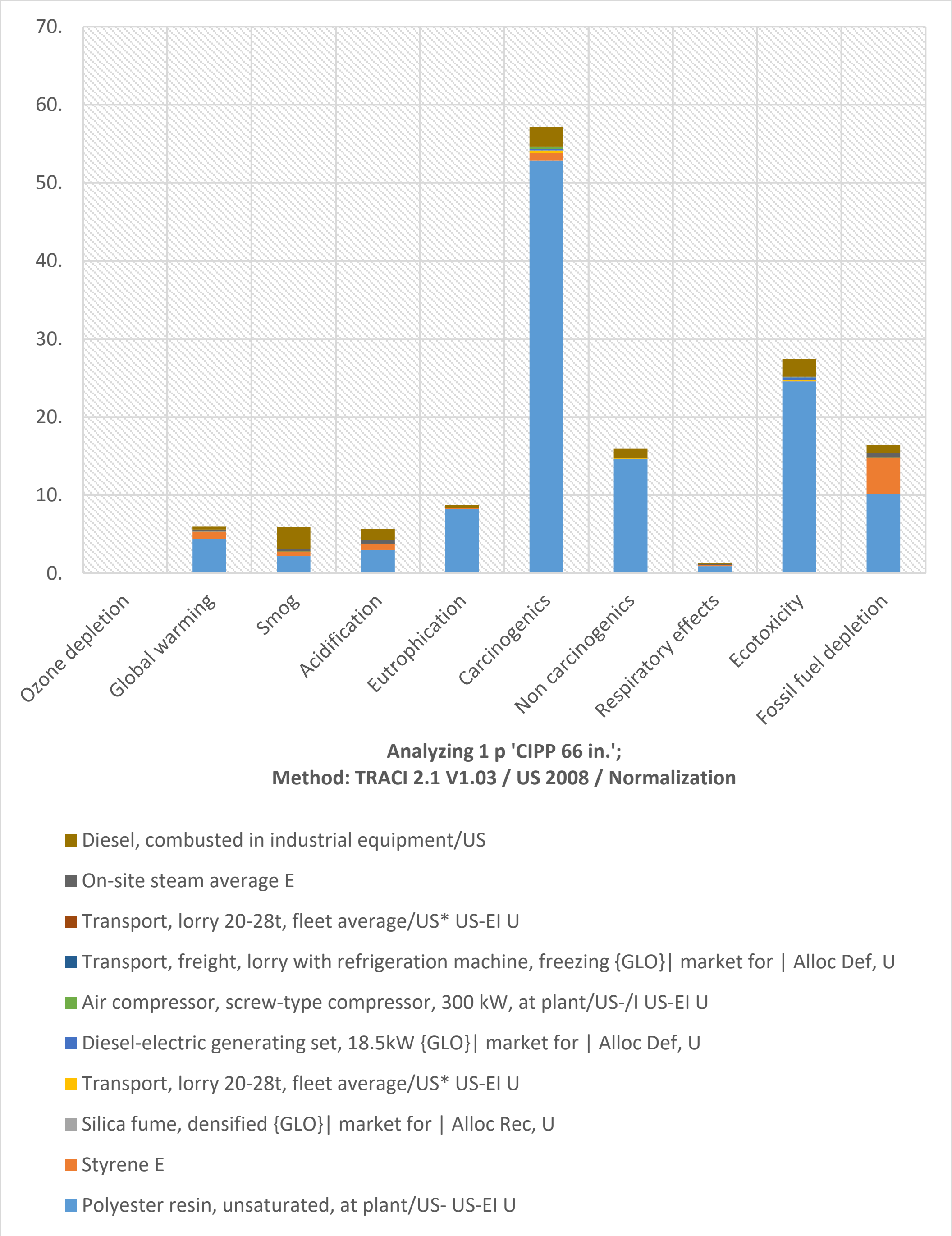


Figure B-83 Normalized Environmental Impact Assessment
of 66 in. Diameter CIPP Renewal Method

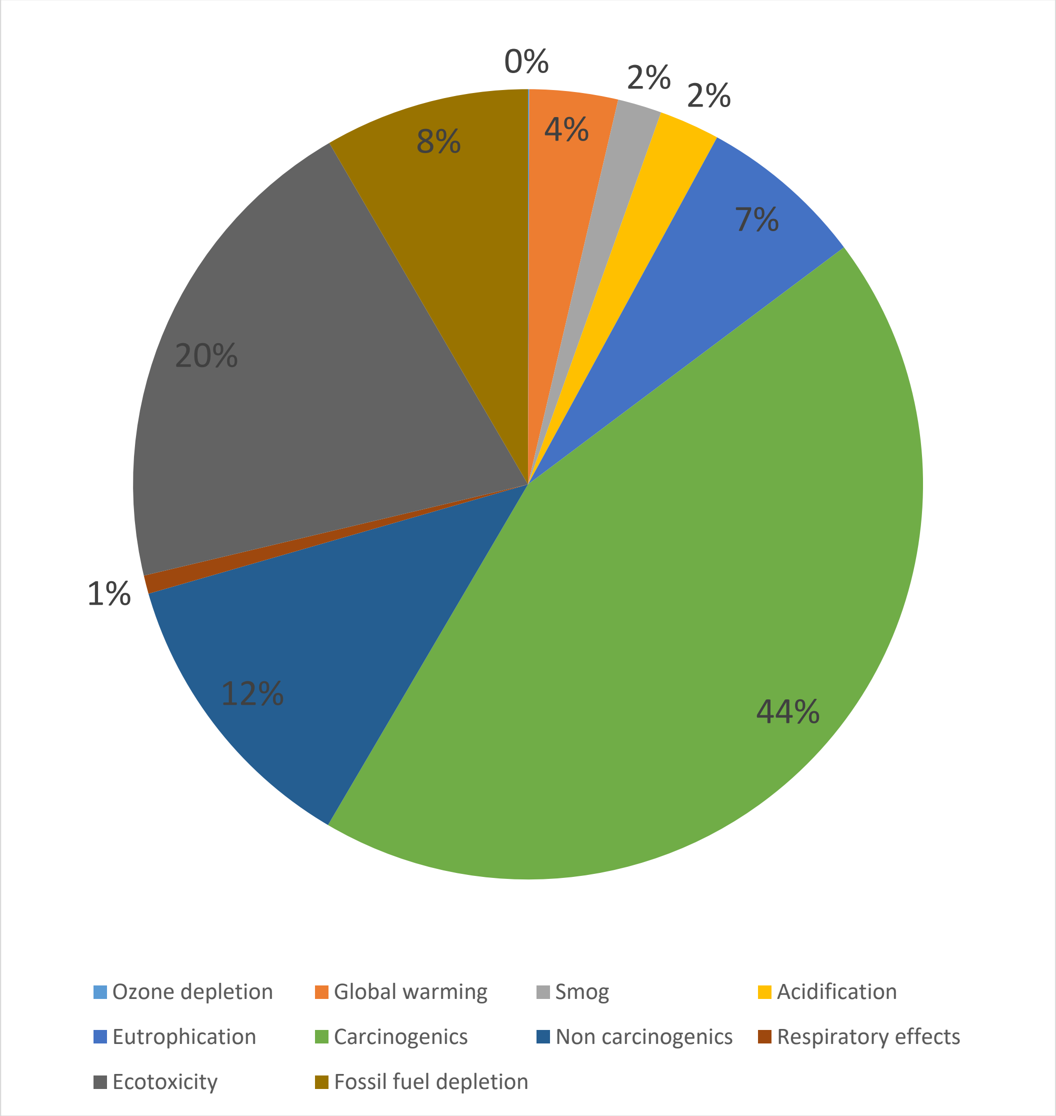


Figure B-84 Percentage of Normalized Environmental Impact Assessment of 66 in. Diameter CIPP Renewal Method

Table B-63 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 66 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.009444	0.009359	0	4.54E-07	7.13E-05	2.46E-06	5.28E-07	8.37E-06	1.01E-06	0	3.73E-07
Global warming	kg CO2 eq	144600.5	105990.5	23159.84	2.009148	351.9706	36.6225	12.19125	11.06009	5.00578	5914.349	9116.921
Smog	kg O3 eq	8242.888	3031.207	798.6086	0.272839	70.66862	2.10199	0.744435	1.189928	1.00506	362.8816	3974.208
Acidification	kg SO2 eq	515.1537	271.3627	70.9851	0.011311	2.408937	0.235729	0.087169	0.049974	0.03426	44.81478	125.1638
Eutrophication	kg N eq	188.6608	178.0834	1.677387	0.002993	0.390762	0.194744	0.156728	0.013085	0.005557	0.648924	7.487184
Carcinogenics	CTUh	0.003013	0.002784	5.21E-05	9.20E-08	1.83E-05	1.10E-05	1.14E-05	4.02E-07	2.60E-07	2.53E-10	0.000135
Non carcinogenics	CTUh	0.016804	0.015341	4.38E-05	4.96E-07	4.99E-05	3.25E-05	4.04E-05	1.84E-06	7.10E-07	3.69E-08	0.001294
Respiratory effects	kg PM2.5 eq	30.23401	21.999	3.191987	0.001763	0.171741	0.06137	0.019726	0.005777	0.002443	2.204209	2.575988
Ecotoxicity	CTUe	303540.8	271873.2	870.2233	15.96918	1099.643	3702.743	883.4641	111.702	15.6393	0.017209	24968.21
Fossil fuel depletion	MJ surplus	308587	190923.7	88150.77	4.068385	744.5163	20.23191	11.34395	21.01959	10.58863	9953.299	18747.45

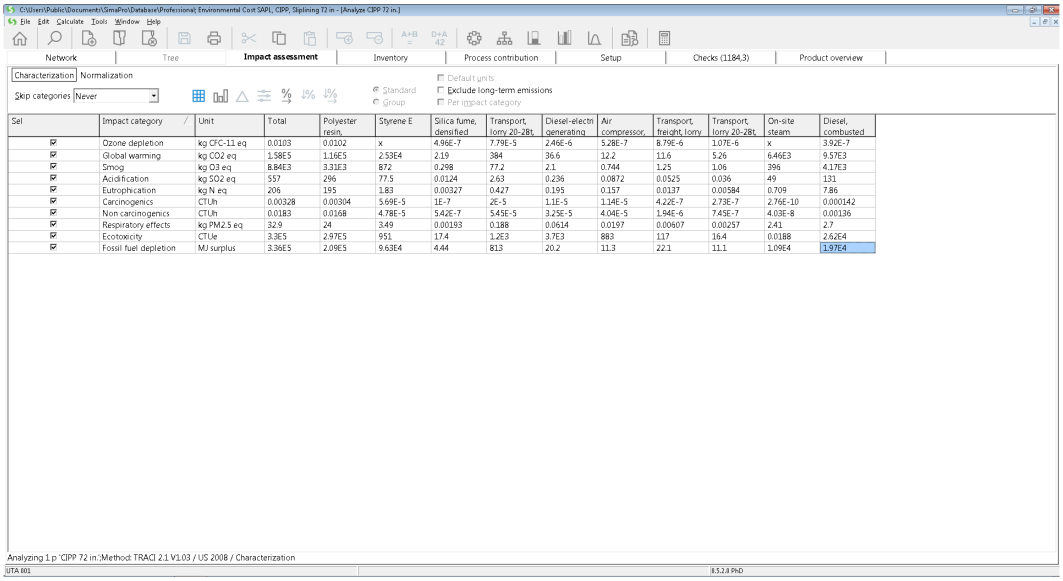
Table B-64 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 66 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.05856	0.058036	0	2.82E-06	4.42E-04	1.53E-05	3.28E-06	5.19E-05	6.29E-06	0	2.31E-06
Global warming	-	5.969382	4.375489	0.956082	8.29E-05	1.45E-02	0.001512	0.000503	0.000457	0.000207	0.244156	0.376364
Smog	-	5.921988	2.177728	0.573749	0.000196	5.08E-02	0.00151	0.000535	0.000855	0.000722	0.260707	2.855214
Acidification	-	5.671629	2.987591	0.781517	0.000125	2.65E-02	0.002595	0.00096	0.00055	0.000377	0.493392	1.378001
Eutrophication	-	8.72792	8.238585	0.0776	0.000138	0.018078	0.009009	0.007251	0.000605	0.000257	0.030021	0.346376
Carcinogenics	-	57.147	52.81507	0.988068	0.001745	0.346576	0.209459	0.215978	0.007616	0.004929	4.80E-06	2.557554
Non carcinogenics	-	15.99952	14.60592	0.041664	0.000472	0.047516	0.030939	0.038459	0.001755	0.000676	3.51E-05	1.232085
Respiratory effects	-	1.246867	0.907251	0.131639	7.27E-05	7.08E-03	0.002531	0.000814	0.000238	0.000101	0.090903	0.106235
Ecotoxicity	-	27.42023	24.55955	0.078611	0.001443	0.099336	0.334486	0.079807	0.010091	0.001413	1.55E-06	2.255493
Fossil fuel depletion	-	16.39643	10.14452	4.683794	0.000216	3.96E-02	0.001075	0.000603	0.001117	0.000563	0.528858	0.996125

Table B-65 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 66 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.009444	0.31
Global warming	kg CO2 eq	144600.5	9,109.83
Smog	kg O3 eq	8242.888	18,134.35
Acidification	kg SO2 eq	515.1537	2,817.89
Eutrophication	kg N eq	188.6608	386.75
Carcinogenic	CTUh	0.003013	0.00
Non carcinogenic	CTUh	0.016804	0.15
Respiratory effects	kg PM2.5 eq	30.23401	1,915.02
Ecotoxicity	CTUe	303540.8	12,445.17
Fossil fuel depletion	MJ surplus	308587	3,024.15
Total			47,833.64

A.2.8 CIPP 72 in.



Skip categories: Never

☐ Exclude long-term emissions

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.0103	0.0102	x	4.96E-7	7.79E-5	2.46E-6	5.28E-7	8.79E-6	1.07E-6	x	3.92E-7
☑	Global warming	kg CO2 eq	1.58E5	1.16E5	2.53E4	2.19	384	36.6	12.2	11.6	5.26	6.46E3	9.57E3
☑	Smog	kg O3 eq	8.84E3	3.31E3	872	0.298	77.2	2.1	0.744	1.25	1.06	396	4.17E3
☑	Acidification	kg SO2 eq	557	296	77.5	0.0124	2.63	0.236	0.0872	0.0525	0.036	49	131
☑	Eutrophication	kg N eq	206	195	1.83	0.00327	0.427	0.195	0.157	0.0137	0.00584	0.709	7.86
☑	Carcinogenics	CTUh	0.00328	0.00304	5.69E-5	1E-7	2E-5	1.1E-5	1.14E-5	4.22E-7	2.73E-7	2.76E-10	0.000142
☑	Non carcinogenics	CTUh	0.0183	0.0168	4.78E-5	5.42E-7	5.45E-5	3.25E-5	4.04E-5	1.94E-6	7.45E-7	4.03E-8	0.00136
☑	Respiratory effects	kg PM2.5 eq	32.9	24	3.49	0.00193	0.188	0.0614	0.0197	0.00607	0.00257	2.41	2.7
☑	Ecotoxicity	CTUe	3.3E5	2.97E5	951	17.4	1.2E3	3.7E3	883	117	16.4	0.0188	2.62E4
☑	Fossil fuel depletion	MJ surplus	3.36E5	2.09E5	9.63E4	4.44	813	20.2	11.3	22.1	11.1	1.09E4	1.97E4

Analyzing 1 p 'CIPP 72 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-85 Screenshot of the Impact Assessment Table from SimaPro Software for 72 in. CIPP

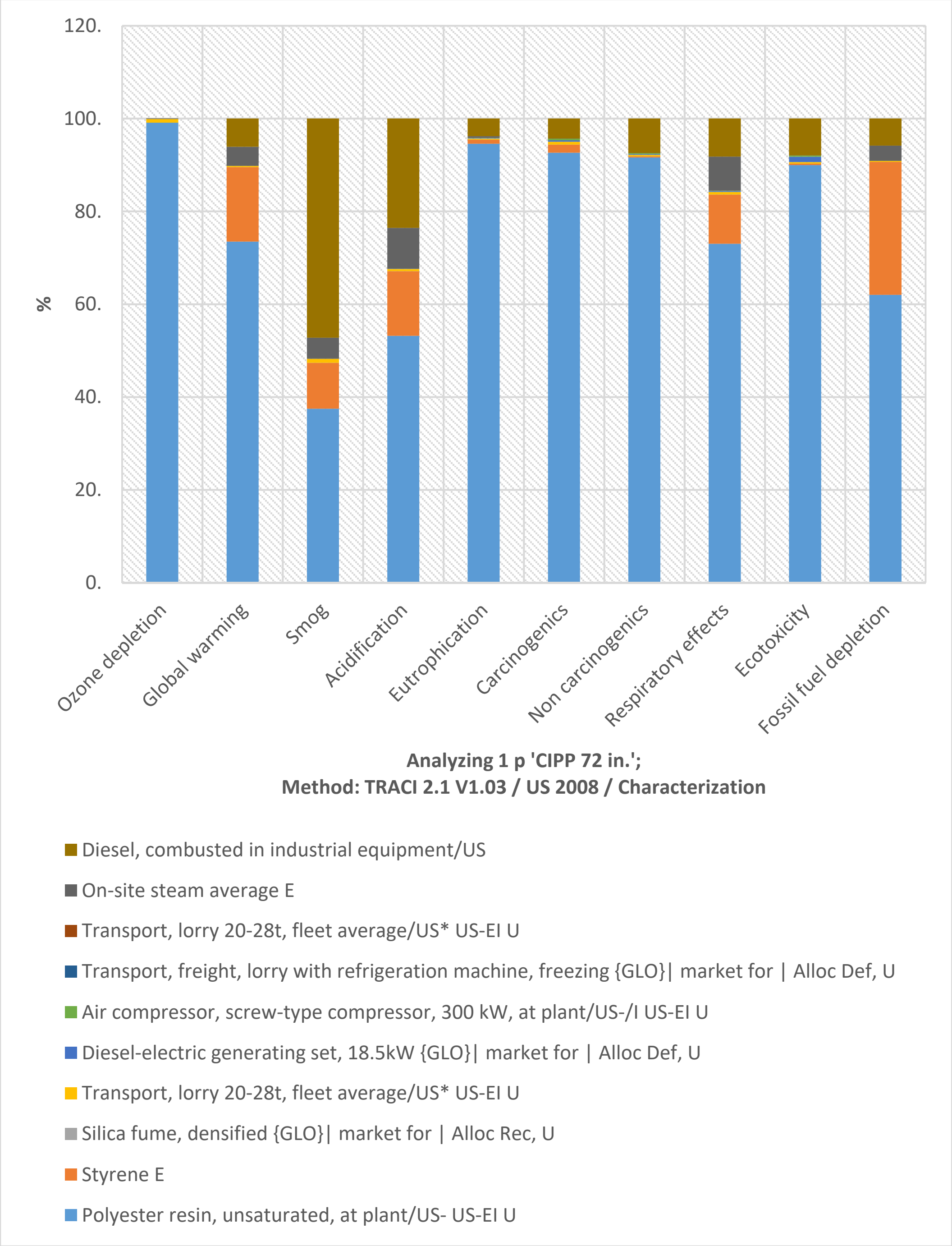


Figure B-86 Environmental Impact Assessment of 72 in. Diameter CIPP Renewal Method

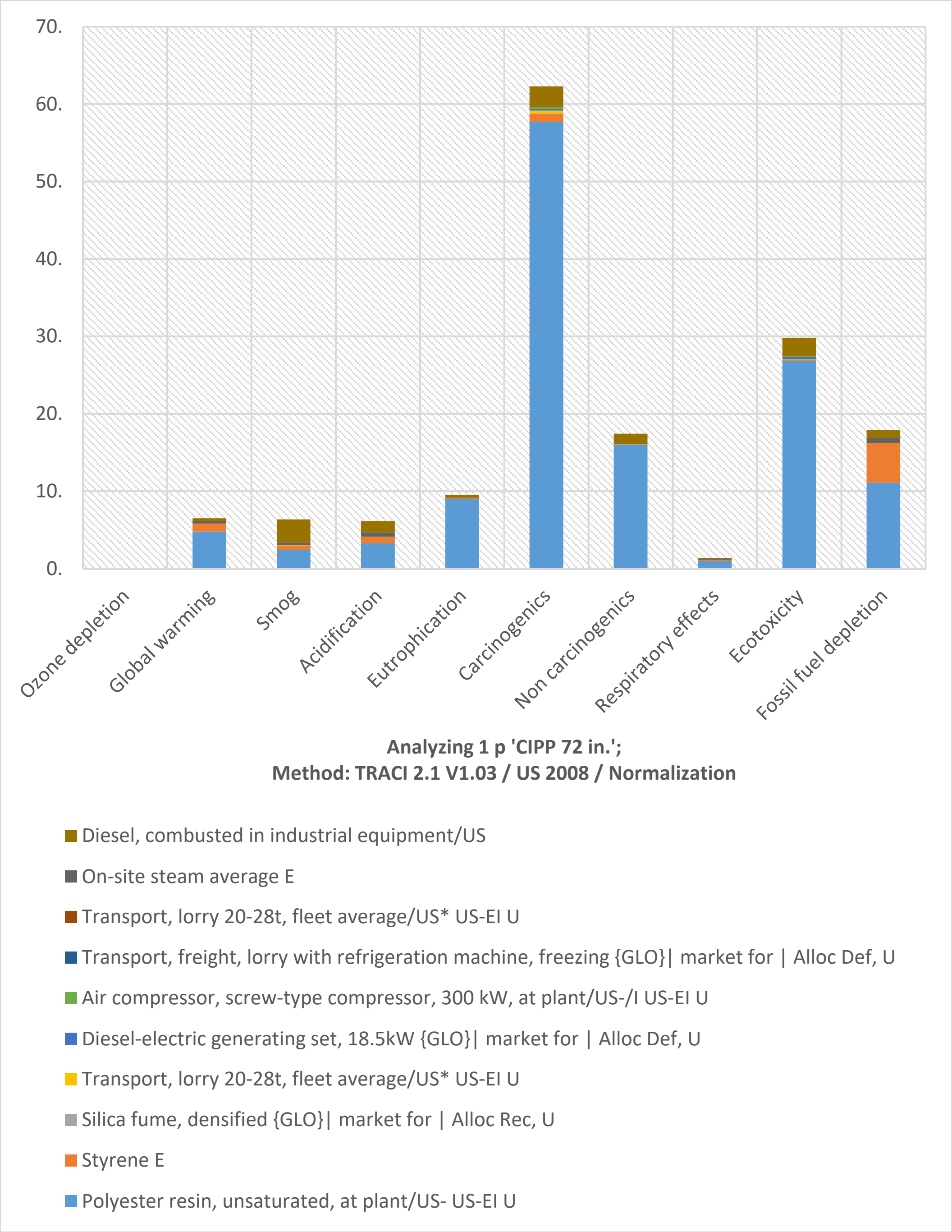


Figure B-87 Normalized Environmental Impact Assessment
of 72 in. Diameter CIPP Renewal Method

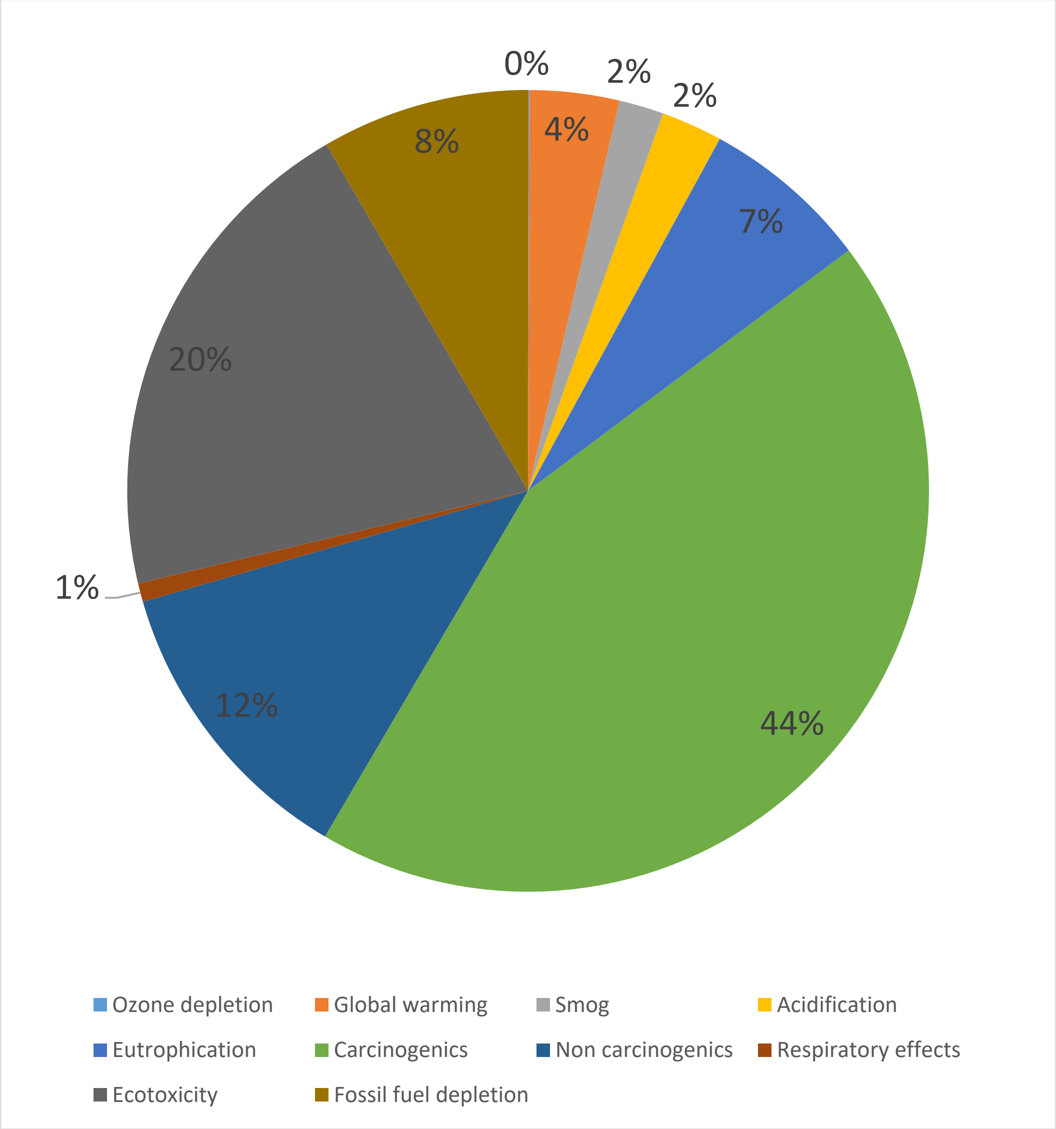


Figure B-88 Percentage of Normalized Environmental Impact Assessment of 72 in. Diameter CIPP Renewal Method

Table B-66 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 72 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.010315	0.010223	0	4.96E-07	7.79E-05	2.46E-06	5.28E-07	8.79E-06	1.07E-06	0	3.92E-07
Global warming	kg CO2 eq	157559.6	115776.2	25297.95	2.19476	384.4649	36.6225	12.19125	11.61475	5.256817	6460.394	9572.767
Smog	kg O3 eq	8835.347	3311.066	872.3359	0.298045	77.19281	2.10199	0.744435	1.249602	1.055463	396.3847	4172.918
Acidification	kg SO2 eq	557.3842	296.4165	77.53842	0.012355	2.631332	0.235729	0.087169	0.05248	0.035978	48.95233	131.4219
Eutrophication	kg N eq	205.7289	194.5251	1.832242	0.003269	0.426837	0.194744	0.156728	0.013741	0.005836	0.708836	7.861544
Carcinogenics	CTUh	0.003283	0.003041	5.69E-05	1.00E-07	2.00E-05	1.10E-05	1.14E-05	4.22E-07	2.73E-07	2.76E-10	0.000142
Non carcinogenics	CTUh	0.018294	0.016757	4.78E-05	5.42E-07	5.45E-05	3.25E-05	4.04E-05	1.94E-06	7.45E-07	4.03E-08	0.001359
Respiratory effects	kg PM2.5 eq	32.9085	24.03008	3.48667	0.001926	0.187597	0.06137	0.019726	0.006066	0.002565	2.407713	2.704787
Ecotoxicity	CTUe	330079.8	296974.1	950.562	17.44447	1201.164	3702.743	883.4641	117.3038	16.4236	0.018798	26216.62
Fossil fuel depletion	MJ surplus	336279.2	208550.9	96288.82	4.444236	813.2507	20.23191	11.34395	22.07371	11.11964	10872.24	19684.82

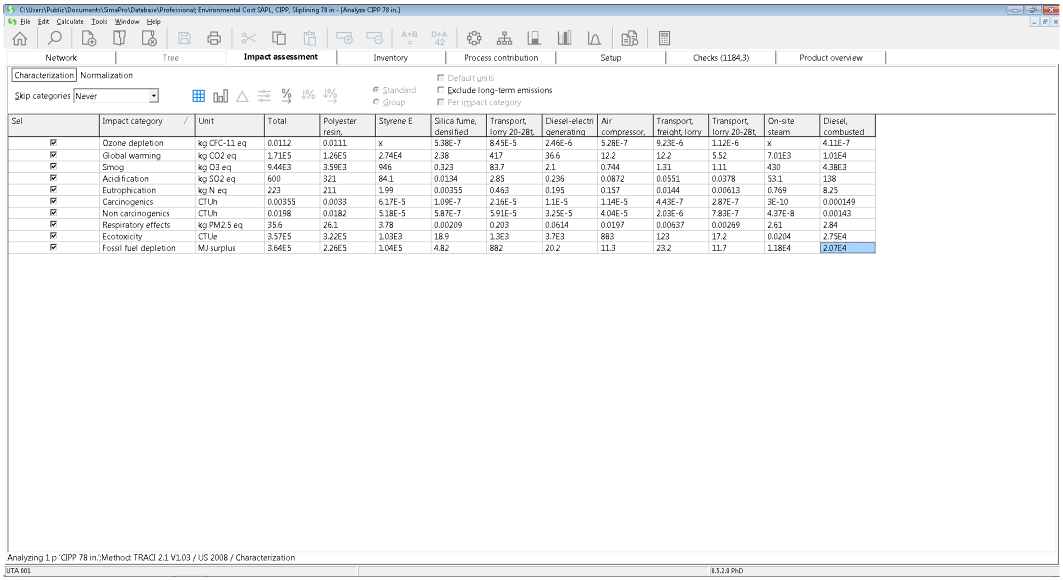
Table B-67 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 72 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.05856	0.063962	0.063394	0	3.08E-06	4.83E-04	1.53E-05	3.28E-06	5.45E-05	6.60E-06	0
Global warming	-	5.969382	6.50436	4.77946	1.044347	9.06E-05	1.59E-02	0.001512	0.000503	0.000479	0.000217	0.266697
Smog	-	5.921988	6.347631	2.378789	0.626718	0.000214	5.55E-02	0.00151	0.000535	0.000898	0.000758	0.284777
Acidification	-	5.671629	6.136569	3.263423	0.853666	0.000136	2.90E-02	0.002595	0.00096	0.000578	0.000396	0.538945
Eutrophication	-	8.72792	9.517534	8.999219	0.084764	0.000151	0.019747	0.009009	0.007251	0.000636	0.00027	0.032793
Carcinogenics	-	57.147	62.27507	57.69126	1.079287	0.001906	0.378572	0.209459	0.215978	0.007998	0.005176	5.24E-06
Non carcinogenics	-	15.99952	17.41803	15.95443	0.04551	0.000516	0.051903	0.030939	0.038459	0.001843	0.00071	3.83E-05
Respiratory effects	-	1.246867	1.357165	0.991014	0.143792	7.94E-05	7.74E-03	0.002531	0.000814	0.00025	0.000106	0.099295
Ecotoxicity	-	27.42023	29.81763	26.82703	0.085869	0.001576	0.108507	0.334486	0.079807	0.010597	0.001484	1.70E-06
Fossil fuel depletion	-	16.39643	17.86783	11.08112	5.116201	0.000236	4.32E-02	0.001075	0.000603	0.001173	0.000591	0.577685

Table B-68 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 72 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.010315	0.34
Global warming	kg CO2 eq	157559.6	9,926.26
Smog	kg O3 eq	8835.347	19,437.76
Acidification	kg SO2 eq	557.3842	3,048.89
Eutrophication	kg N eq	205.7289	421.74
Carcinogenic	CTUh	0.003283	0.00
Non carcinogenic	CTUh	0.018294	0.16
Respiratory effects	kg PM2.5 eq	32.9085	2,084.42
Ecotoxicity	CTUe	330079.8	13,533.27
Fossil fuel depletion	MJ surplus	336279.2	3,295.54
Total			51,748.39

A.2.9 CIPP 78 in.



Skip categories: Never

☐ Default units

☐ Exclude long-term emissions

☐ Per impact category

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.0112	0.0111	x	5.38E-7	8.45E-5	2.46E-6	5.28E-7	9.23E-6	1.12E-6	x	4.11E-7
☑	Global warming	kg CO2 eq	1.71E5	1.26E5	2.74E4	2.38	417	36.6	12.2	12.2	5.52	7.01E3	1.01E4
☑	Smog	kg O3 eq	9.44E3	3.59E3	946	0.323	83.7	2.1	0.744	1.31	1.11	430	4.38E3
☑	Acidification	kg SO2 eq	600	321	84.1	0.0134	2.85	0.236	0.0872	0.0551	0.0378	53.1	138
☑	Eutrophication	kg N eq	223	211	1.99	0.00355	0.463	0.195	0.157	0.0144	0.00613	0.769	8.25
☑	Carcinogenics	CTUh	0.00355	0.0033	6.17E-5	1.09E-7	2.16E-5	1.1E-5	1.14E-5	4.43E-7	2.87E-7	3E-10	0.000149
☑	Non carcinogenics	CTUh	0.0198	0.0182	5.18E-5	5.87E-7	5.91E-5	3.25E-5	4.04E-5	2.03E-6	7.83E-7	4.37E-8	0.00143
☑	Respiratory effects	kg PM2.5 eq	35.6	26.1	3.78	0.00209	0.203	0.0614	0.0197	0.00637	0.00269	2.61	2.84
☑	Ecotoxicity	CTUe	3.57E5	3.22E5	1.03E3	18.9	1.3E3	3.7E3	883	123	17.2	0.0204	2.75E4
☑	Fossil fuel depletion	MJ surplus	3.64E5	2.26E5	1.04E5	4.82	882	20.2	11.3	23.2	11.7	1.18E4	2.07E4

Analyzing 1 p 'CIPP 78 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-89 Screenshot of the Impact Assessment Table from SimaPro Software for 78 in. CIPP

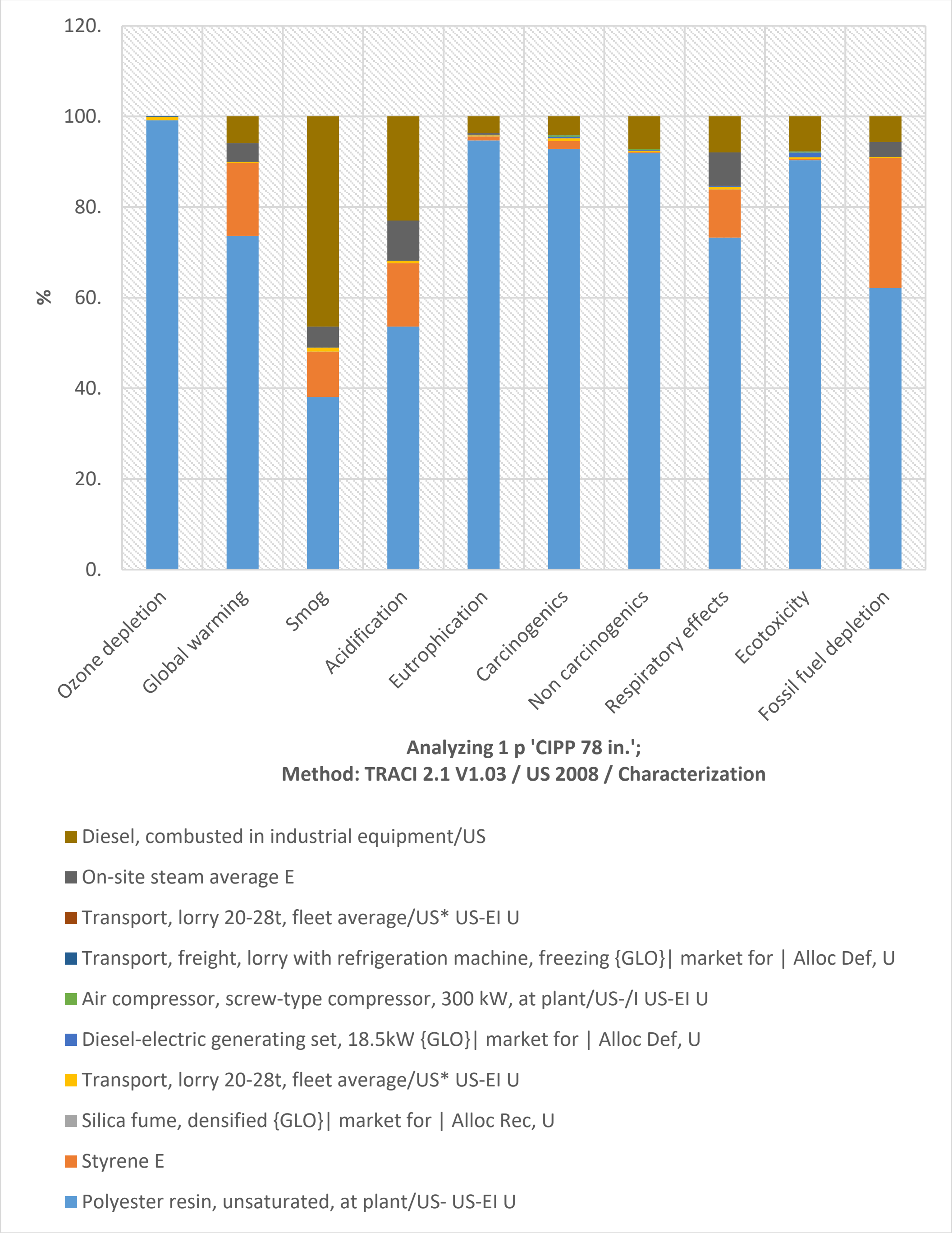


Figure B-90 Environmental Impact Assessment of 78 in. Diameter CIPP Renewal Method

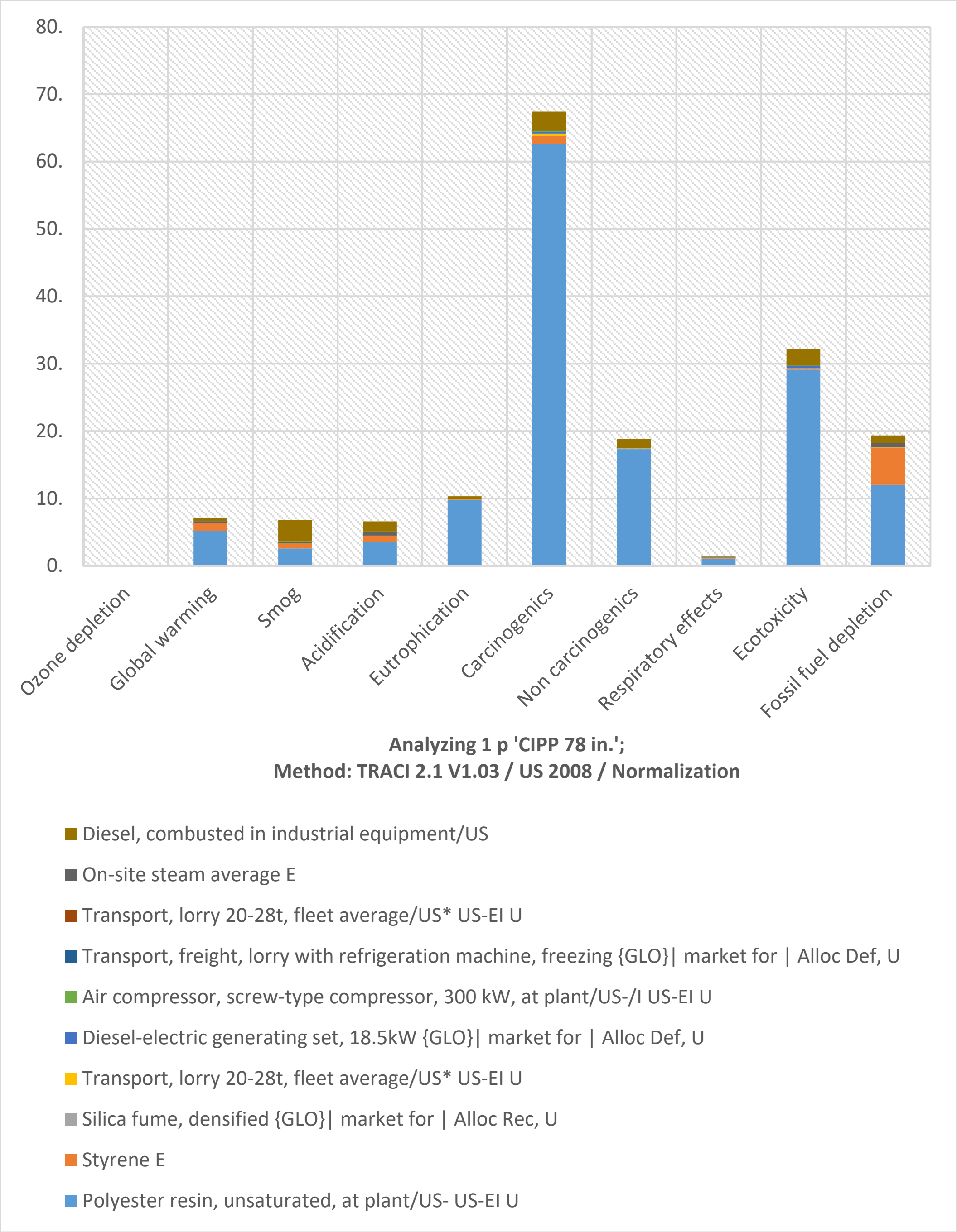


Figure B-91 Normalized Environmental Impact Assessment
of 78 in. Diameter CIPP Renewal Method

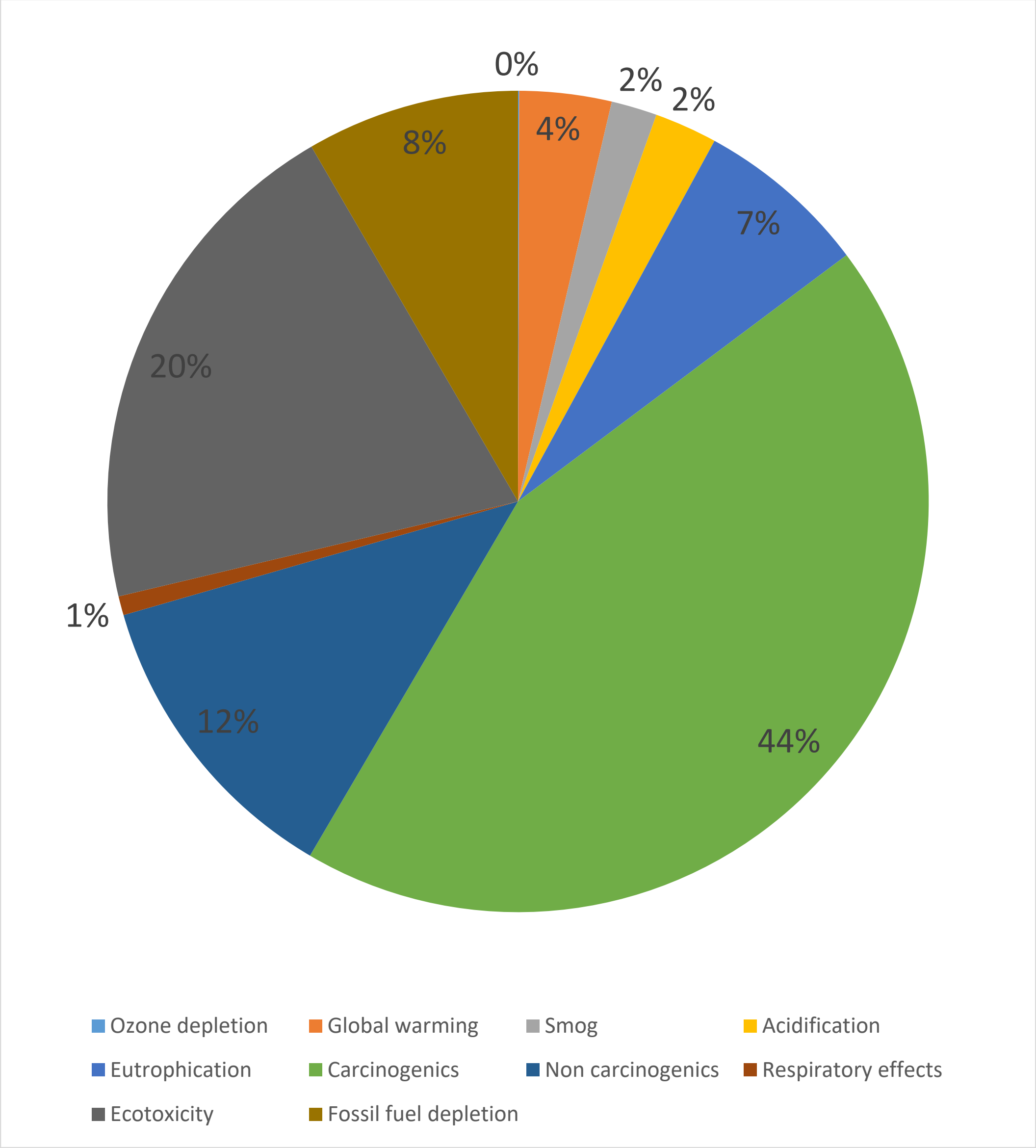


Figure B-92 Percentage of Normalized Environmental Impact Assessment of 78 in. Diameter CIPP Renewal Method

Table B-69 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 78 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.011186	0.011087	0	5.38E-07	8.45E-05	2.46E-06	5.28E-07	9.23E-06	1.12E-06	0	4.11E-07
Global warming	kg CO2 eq	170541.8	125561.8	27436.23	2.380201	416.9621	36.6225	12.19125	12.19581	5.519807	7006.438	10051.45
Smog	kg O3 eq	9437.771	3590.924	946.069	0.323227	83.7176	2.10199	0.744435	1.312117	1.108266	429.8879	4381.583
Acidification	kg SO2 eq	599.9289	321.4702	84.09226	0.013399	2.853748	0.235729	0.087169	0.055106	0.037778	53.08987	137.9936
Eutrophication	kg N eq	222.8158	210.9668	1.98711	0.003546	0.462916	0.194744	0.156728	0.014428	0.006128	0.768748	8.254655
Carcinogenics	CTUh	0.003554	0.003298	6.17E-05	1.09E-07	2.16E-05	1.10E-05	1.14E-05	4.43E-07	2.87E-07	3.00E-10	0.000149
Non carcinogenics	CTUh	0.019787	0.018173	5.18E-05	5.87E-07	5.91E-05	3.25E-05	4.04E-05	2.03E-06	7.83E-07	4.37E-08	0.001427
Respiratory effects	kg PM2.5 eq	35.58949	26.06115	3.781377	0.002089	0.203453	0.06137	0.019726	0.00637	0.002693	2.611217	2.840038
Ecotoxicity	CTUe	356681.7	322075	1030.907	18.9184	1302.693	3702.743	883.4641	123.1723	17.24524	0.020386	27527.56
Fossil fuel depletion	MJ surplus	364019.1	226178.1	104427.5	4.819742	881.9914	20.23191	11.34395	23.17802	11.67594	11791.18	20669.15

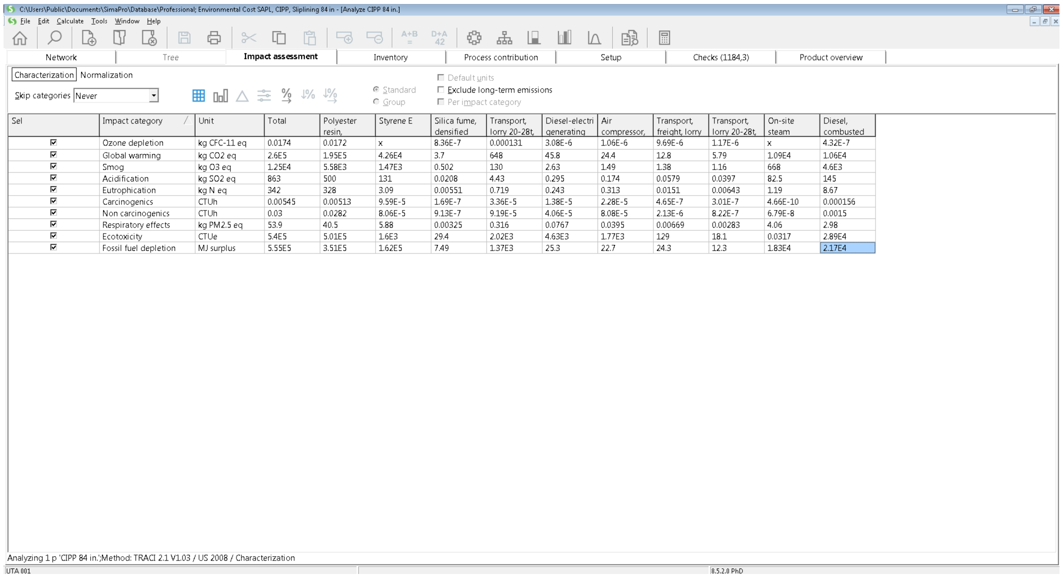
Table B-70 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 78 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.069364	0.068752	0	3.34E-06	5.24E-04	1.53E-05	3.28E-06	5.73E-05	6.93E-06	0	2.55E-06
Global warming	-	7.040289	5.18343	1.13262	9.83E-05	1.72E-02	0.001512	0.000503	0.000503	0.000228	0.289239	0.414943
Smog	-	6.780435	2.579849	0.67969	0.000232	6.01E-02	0.00151	0.000535	0.000943	0.000796	0.308847	3.147887
Acidification	-	6.604969	3.539254	0.925821	0.000148	3.14E-02	0.002595	0.00096	0.000607	0.000416	0.584497	1.519253
Eutrophication	-	10.30802	9.759853	0.091929	0.000164	0.021416	0.009009	0.007251	0.000667	0.000284	0.035564	0.381881
Carcinogenics	-	67.40959	62.56745	1.170512	0.002067	0.410571	0.209459	0.215978	0.008398	0.005435	5.68E-06	2.819715
Non carcinogenics	-	18.83964	17.30293	0.049357	0.000559	0.05629	0.030939	0.038459	0.001935	0.000745	4.16E-05	1.358379
Respiratory effects	-	1.46773	1.074776	0.155946	8.62E-05	8.39E-03	0.002531	0.000814	0.000263	0.000111	0.107688	0.117125
Ecotoxicity	-	32.2207	29.09451	0.093127	0.001709	0.117678	0.334486	0.079807	0.011127	0.001558	1.84E-06	2.486691
Fossil fuel depletion	-	19.34176	12.01772	5.548641	0.000256	4.69E-02	0.001075	0.000603	0.001232	0.00062	0.626512	1.098233

Table B-71 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 78 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.011186	0.37
Global warming	kg CO2 eq	170541.8	10,744.13
Smog	kg O3 eq	9437.771	20,763.10
Acidification	kg SO2 eq	599.9289	3,281.61
Eutrophication	kg N eq	222.8158	456.77
Carcinogenic	CTUh	0.003554	0.00
Non carcinogenic	CTUh	0.019787	0.18
Respiratory effects	kg PM2.5 eq	35.58949	2,254.24
Ecotoxicity	CTUe	356681.7	14,623.95
Fossil fuel depletion	MJ surplus	364019.1	3,567.39
Total			55,691.73

A.2.10 CIPP 84 in.



Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.0174	0.0172	x	8.36E-7	0.000131	3.08E-6	1.06E-6	9.69E-6	1.17E-6	x	4.32E-7
☑	Global warming	kg CO2 eq	2.6E5	1.95E5	4.26E4	3.7	648	45.8	24.4	12.8	5.79	1.09E4	1.06E4
☑	Smog	kg O3 eq	1.25E4	5.58E3	1.47E3	0.502	130	2.63	1.49	1.38	1.16	668	4.6E3
☑	Acidification	kg SO2 eq	863	500	131	0.0208	4.43	0.295	0.174	0.0579	0.0397	82.5	145
☑	Eutrophication	kg N eq	342	328	3.09	0.00551	0.719	0.243	0.313	0.0151	0.00643	1.19	8.67
☑	Carcinogenics	CTUh	0.00545	0.00513	9.59E-5	1.69E-7	3.36E-5	1.38E-5	2.28E-5	4.65E-7	3.01E-7	4.66E-10	0.000156
☑	Non carcinogenics	CTUh	0.03	0.0282	8.06E-5	9.13E-7	9.19E-5	4.06E-5	8.08E-5	2.13E-6	8.22E-7	6.79E-8	0.0015
☑	Respiratory effects	kg PM2.5 eq	53.9	40.5	5.88	0.00325	0.316	0.0767	0.0395	0.00669	0.00283	4.06	2.98
☑	Ecotoxicity	CTUe	5.4E5	5.01E5	1.6E3	29.4	2.02E3	4.63E3	1.77E3	129	18.1	0.0317	2.89E4
☑	Fossil fuel depletion	MJ surplus	5.55E5	3.51E5	1.62E5	7.49	1.37E3	25.3	22.7	24.3	12.3	1.83E4	2.17E4

Analyzing 1 p 'CIPP 84 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-93 Screenshot of the Impact Assessment Table from SimaPro Software for 84 in. CIPP

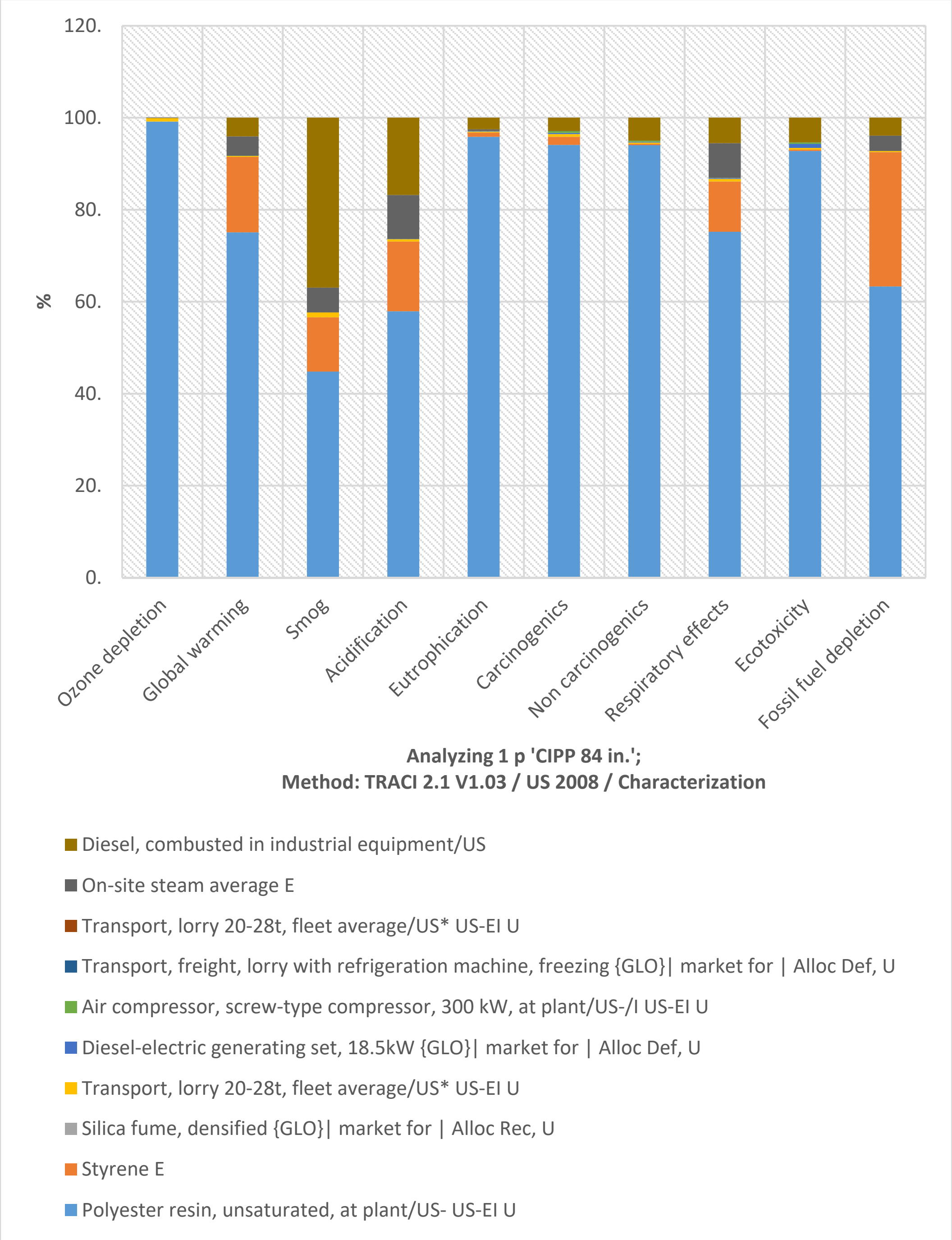


Figure B-94 Environmental Impact Assessment of 84 in. Diameter CIPP Renewal Method

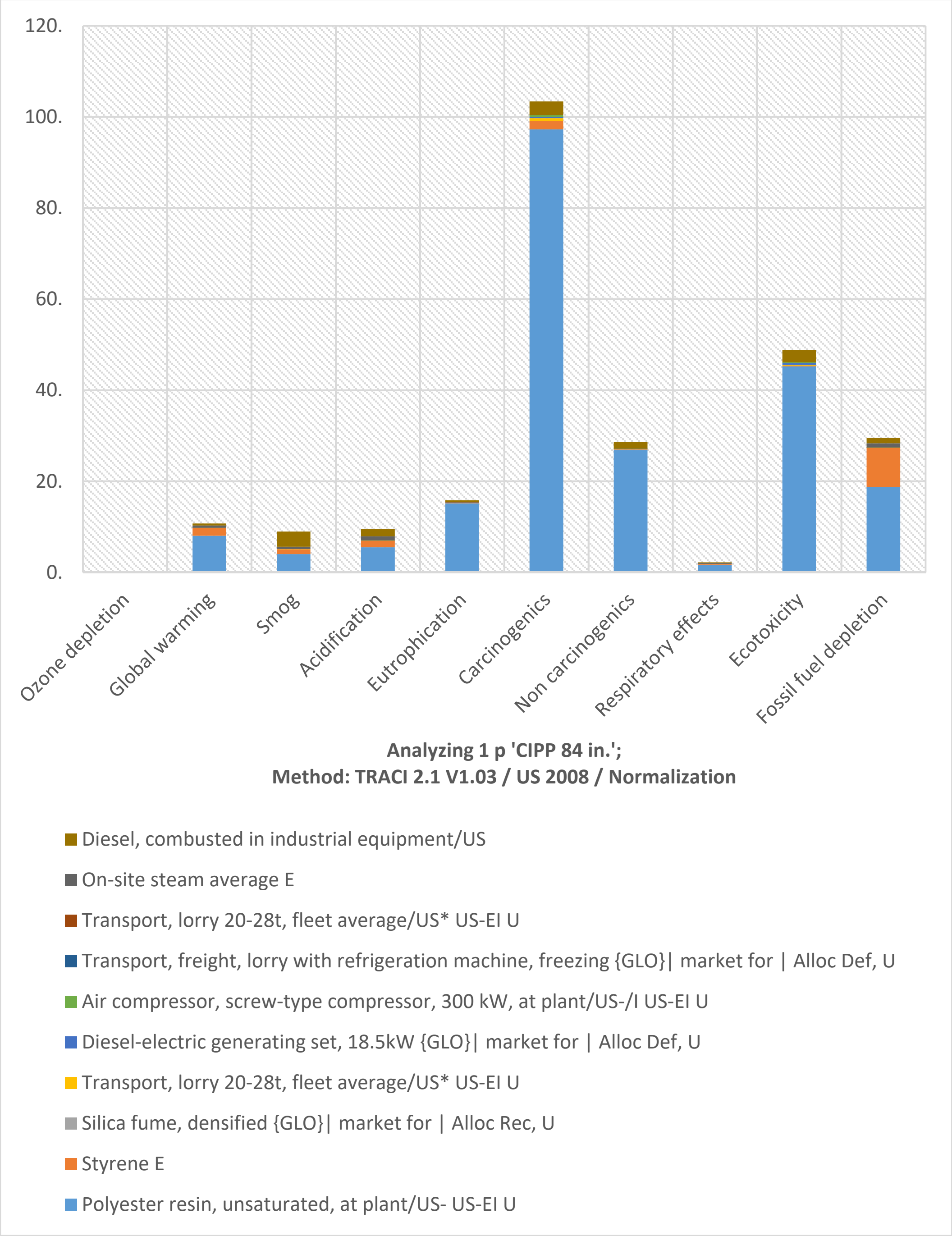


Figure B-95 Normalized Environmental Impact Assessment
of 84 in. Diameter CIPP Renewal Method

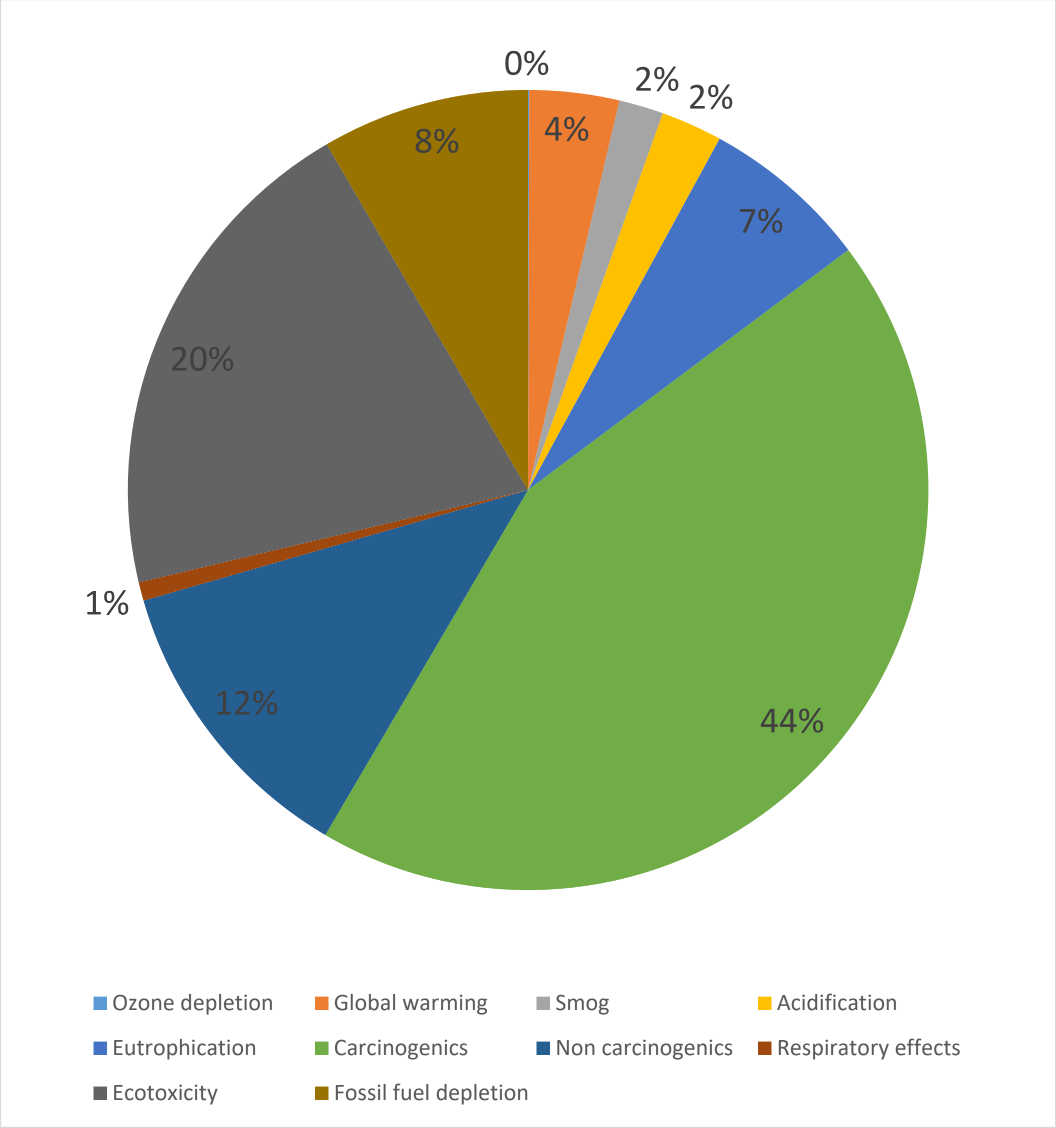


Figure B-96 Percentage of Normalized Environmental Impact Assessment of 84 in. Diameter CIPP Renewal Method

Table B-72 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 84 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.017378	0.01723	0	8.36E-07	1.31E-04	3.08E-06	1.06E-06	9.69E-06	1.17E-06	0	4.32E-07
Global warming	kg CO2 eq	259943.2	195124.3	42636.27	3.698933	647.9632	45.77813	24.3825	12.80329	5.794751	10888.08	10554.04
Smog	kg O3 eq	12456.52	5580.333	1470.204	0.502309	130.098	2.627487	1.488871	1.377475	1.16347	668.0502	4600.672
Acidification	kg SO2 eq	862.6665	499.5681	130.6805	0.020822	4.434752	0.294661	0.174338	0.057851	0.03966	82.5022	144.8936
Eutrophication	kg N eq	342.098	327.8446	3.087996	0.00551	0.719376	0.24343	0.313455	0.015147	0.006433	1.194642	8.667408
Carcinogenics	CTUh	0.005449	0.005126	9.59E-05	1.69E-07	3.36E-05	1.38E-05	2.28E-05	4.65E-07	3.01E-07	4.66E-10	0.000156
Non carcinogenics	CTUh	0.030037	0.028242	8.06E-05	9.13E-07	9.19E-05	4.06E-05	8.08E-05	2.13E-06	8.22E-07	6.79E-08	0.001498
Respiratory effects	kg PM2.5 eq	53.86061	40.4993	5.876311	0.003246	0.316169	0.076713	0.039453	0.006687	0.002828	4.057858	2.982047
Ecotoxicity	CTUe	539610.5	500507.8	1602.044	29.4	2024.397	4628.429	1766.928	129.3076	18.10424	0.031681	28904.01
Fossil fuel depletion	MJ surplus	555253.8	351483	162281.8	7.490084	1370.623	25.28988	22.6879	24.33253	12.25752	18323.62	21702.66

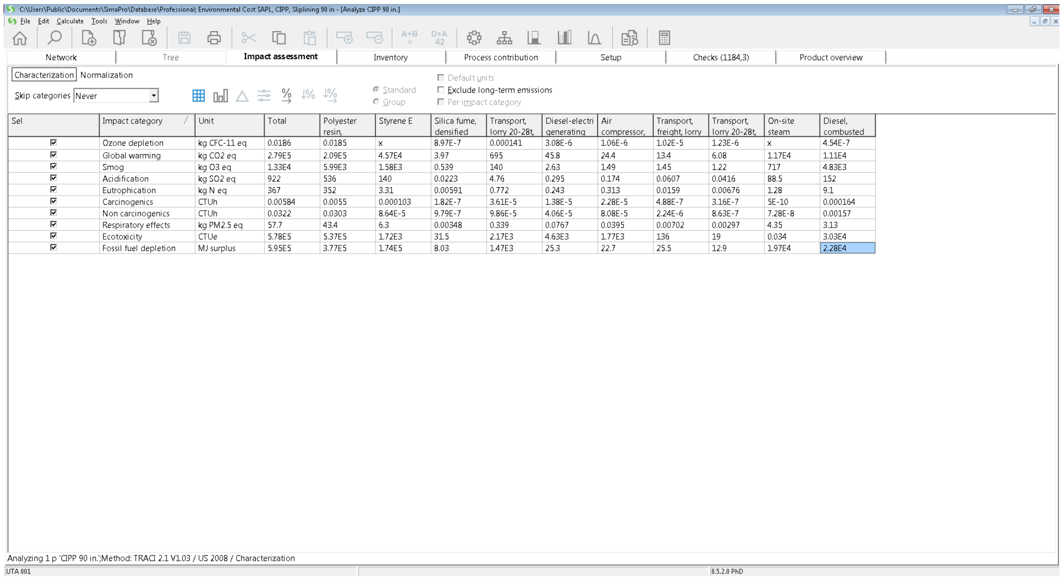
Table B-73 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 84 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.107756	0.106841	0	5.18E-06	8.14E-04	1.91E-05	6.55E-06	6.01E-05	7.28E-06	0	2.68E-06
Global warming	-	10.73095	8.055104	1.760106	0.000153	2.67E-02	0.00189	0.001007	0.000529	0.000239	0.449481	0.435691
Smog	-	8.94921	4.009112	1.056248	0.000361	9.35E-02	0.001888	0.00107	0.00099	0.000836	0.479951	3.305289
Acidification	-	9.497601	5.500038	1.438738	0.000229	4.88E-02	0.003244	0.001919	0.000637	0.000437	0.908315	1.595219
Eutrophication	-	15.82631	15.16691	0.142858	0.000255	0.03328	0.011262	0.014501	0.000701	0.000298	0.055267	0.400976
Carcinogenics	-	103.3597	97.23046	1.818992	0.003212	0.638031	0.261824	0.431957	0.008816	0.005706	8.83E-06	2.960708
Non carcinogenics	-	28.59875	26.88893	0.076702	0.000869	0.087476	0.038674	0.076919	0.002032	0.000782	6.46E-05	1.426301
Respiratory effects	-	2.221241	1.670213	0.242342	0.000134	1.30E-02	0.003164	0.001627	0.000276	0.000117	0.167348	0.122981
Ecotoxicity	-	48.74549	45.21317	0.14472	0.002656	0.182873	0.418107	0.159615	0.011681	0.001635	2.86E-06	2.611032
Fossil fuel depletion	-	29.5028	18.67567	8.622663	0.000398	7.28E-02	0.001344	0.001205	0.001293	0.000651	0.973605	1.153147

Table B-74 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 84 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.017378	0.57
Global warming	kg CO2 eq	259943.2	16,376.42
Smog	kg O3 eq	12456.52	27,404.34
Acidification	kg SO2 eq	862.6665	4,718.79
Eutrophication	kg N eq	342.098	701.30
Carcinogenic	CTUh	0.005449	0.00
Non carcinogenic	CTUh	0.030037	0.27
Respiratory effects	kg PM2.5 eq	53.86061	3,411.53
Ecotoxicity	CTUe	539610.5	22,124.03
Fossil fuel depletion	MJ surplus	555253.8	5,441.49
Total			80,178.73

A.2.11 CIPP 90 in.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 90 in - [Analyze CIPP 90 in.]

Skip categories: Never

● Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.0186	0.0185	x	8.97E-7	0.000141	3.08E-6	1.06E-6	1.02E-5	1.23E-6	x	4.54E-7
☑	Global warming	kg CO2 eq	2.79E5	2.09E5	4.57E4	3.97	695	45.8	24.4	13.4	6.08	1.17E4	1.11E4
☑	Smog	kg O3 eq	1.33E4	5.99E3	1.58E3	0.539	140	2.63	1.49	1.45	1.22	717	4.83E3
☑	Acidification	kg SO2 eq	922	536	140	0.0223	4.76	0.295	0.174	0.0607	0.0416	88.5	152
☑	Eutrophication	kg N eq	367	352	3.31	0.00591	0.772	0.243	0.313	0.0159	0.00676	1.28	9.1
☑	Carcinogenics	CTUh	0.00584	0.0055	0.000103	1.82E-7	3.61E-5	1.38E-5	2.28E-5	4.88E-7	3.16E-7	5E-10	0.000164
☑	Non carcinogenics	CTUh	0.0322	0.0303	8.64E-5	9.79E-7	9.86E-5	4.06E-5	8.08E-5	2.24E-6	8.63E-7	7.28E-8	0.00157
☑	Respiratory effects	kg PM2.5 eq	57.7	43.4	6.3	0.00348	0.339	0.0767	0.0395	0.00702	0.00297	4.35	3.13
☑	Ecotoxicity	CTUe	5.78E5	5.37E5	1.72E3	31.5	2.17E3	4.63E3	1.77E3	136	19	0.034	3.03E4
☑	Fossil fuel depletion	MJ surplus	5.95E5	3.77E5	1.74E5	8.03	1.47E3	25.3	22.7	25.5	12.9	1.97E4	2.28E4

Analyzing 1 p 'CIPP 90 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-97 Screenshot of the Impact Assessment Table from SimaPro Software for 90 in. CIPP

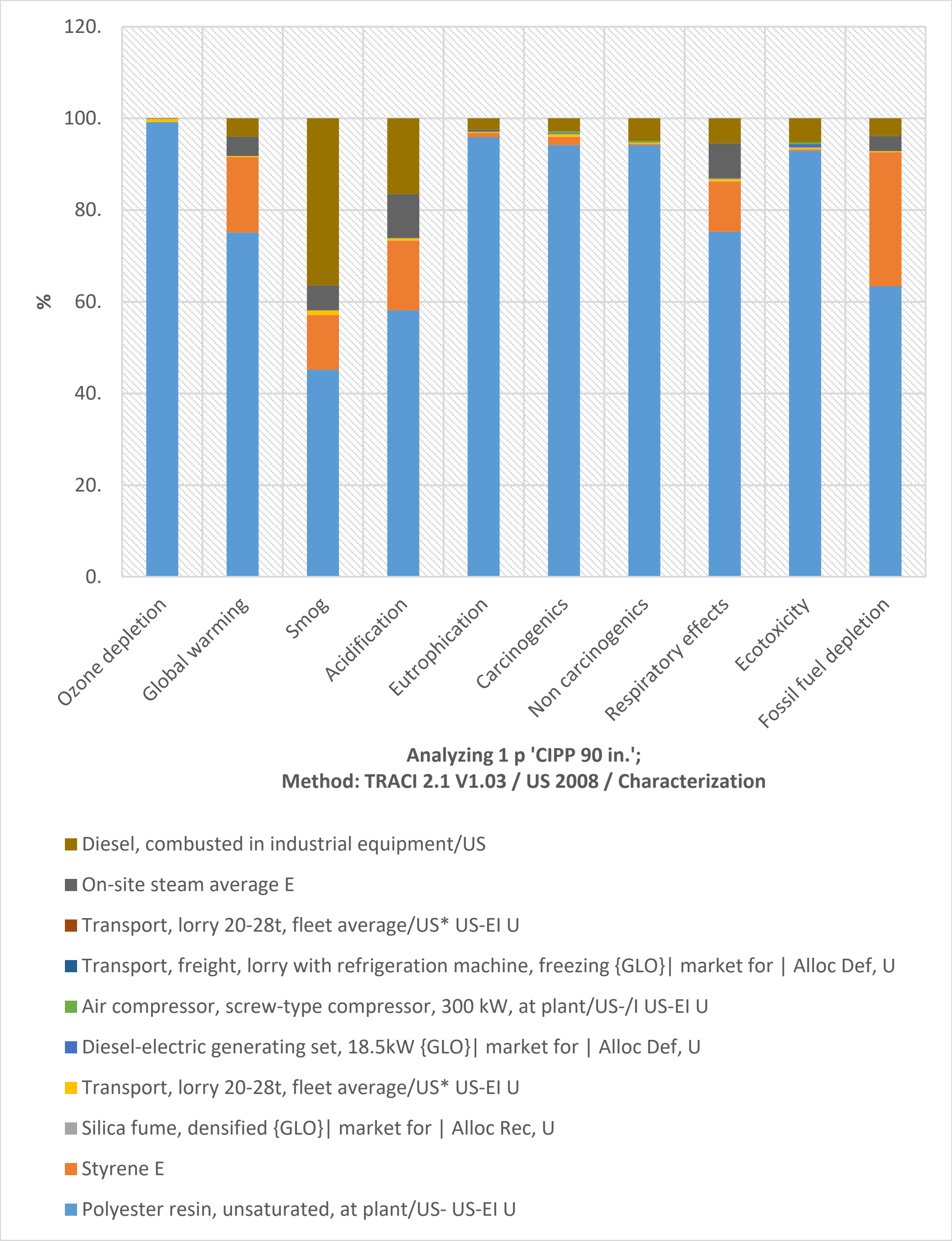


Figure B-98 Environmental Impact Assessment of 90 in. Diameter CIPP Renewal Method

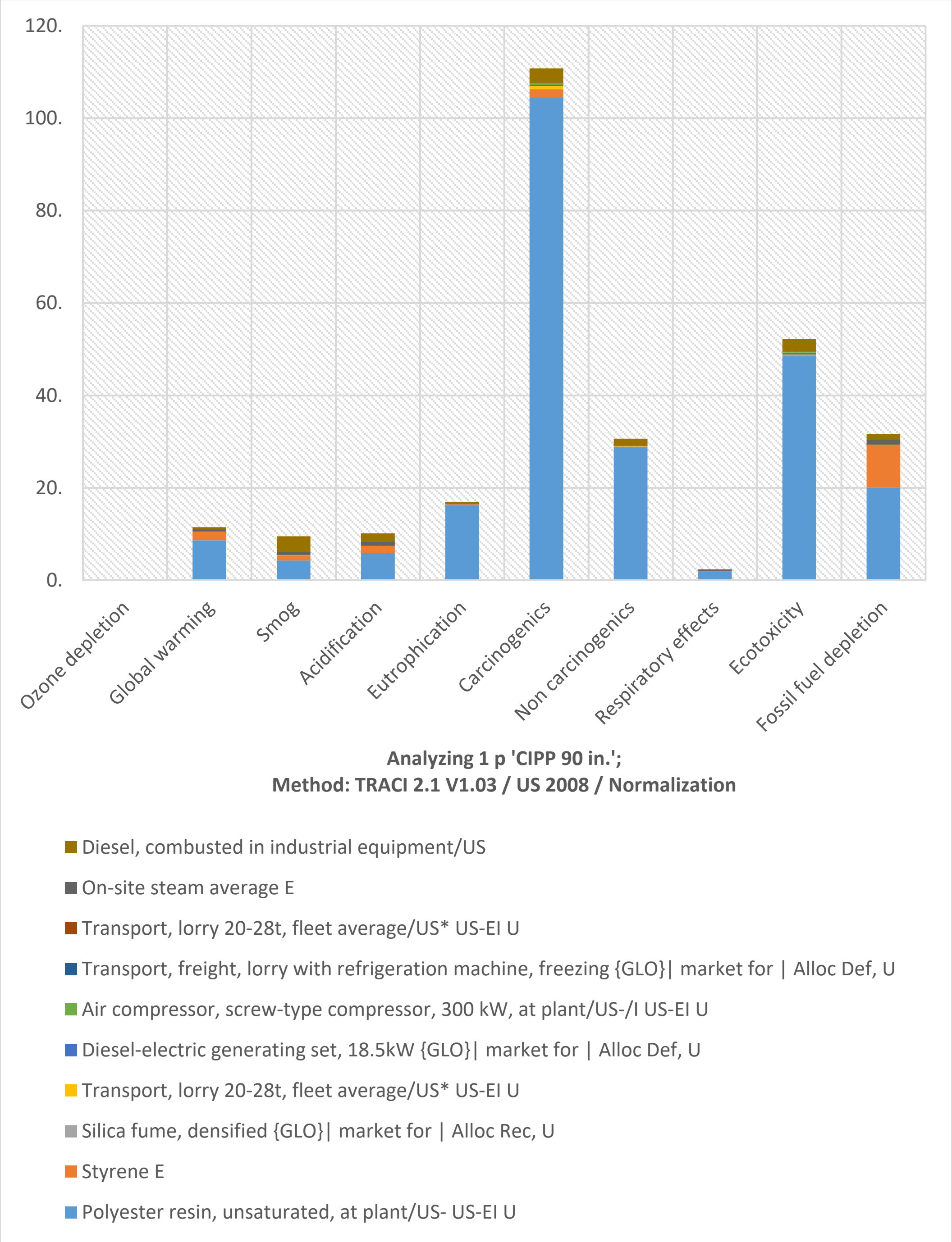


Figure B-99 Normalized Environmental Impact Assessment of 90 in. Diameter CIPP Renewal Method

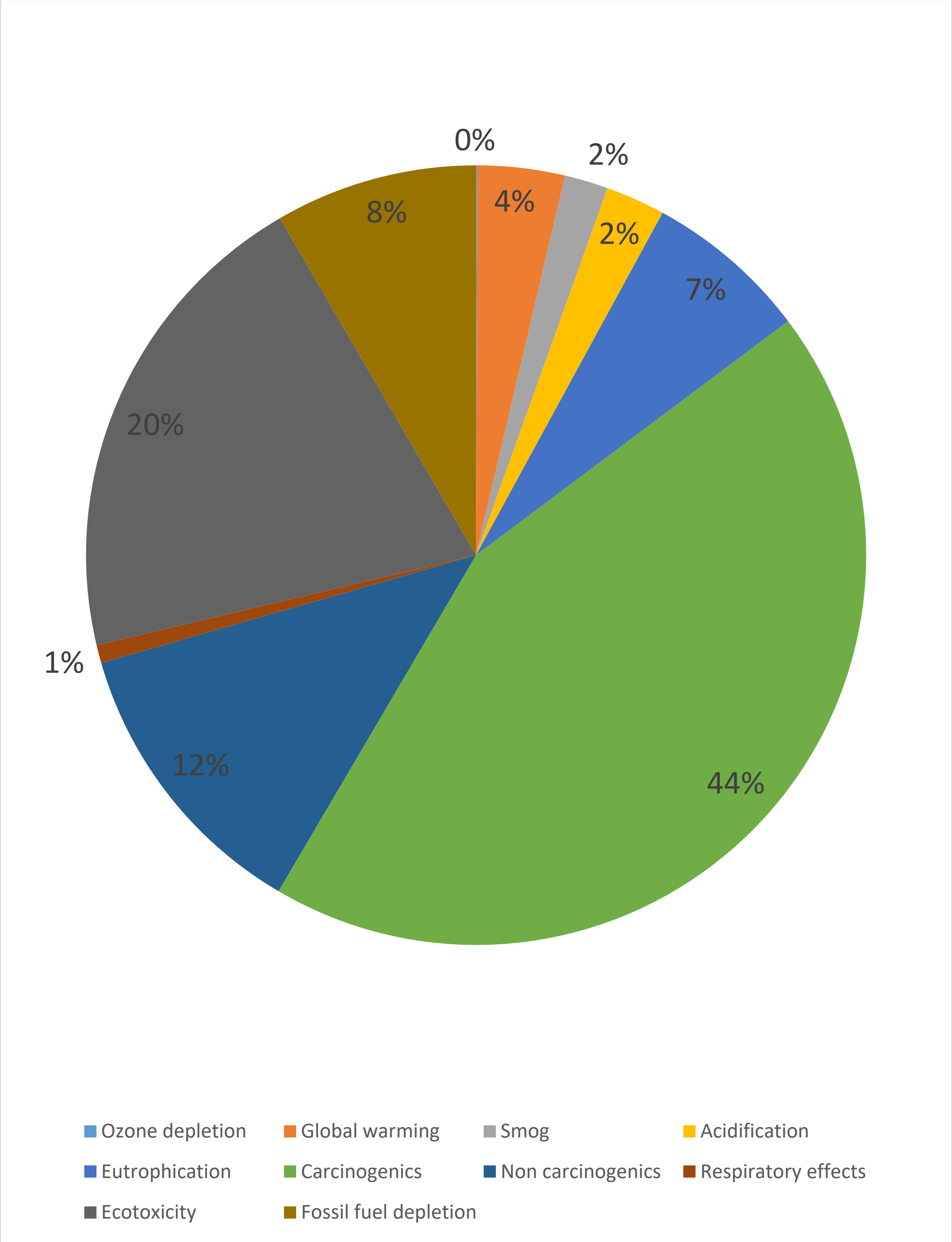


Figure B-100 Percentage of Normalized Environmental Impact Assessment of 90 in. Diameter CIPP Renewal Method

Table B-75 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 90 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.01864	0.018483	0	8.97E-07	1.41E-04	3.08E-06	1.06E-06	1.02E-05	1.23E-06	0	4.54E-07
Global warming	kg CO2 eq	278595.3	209309.5	45735.81	3.967798	695.0683	45.77813	24.3825	13.44379	6.084638	11679.63	11081.64
Smog	kg O3 eq	13257.25	5986.011	1577.084	0.53882	139.5557	2.627487	1.488871	1.446384	1.221673	716.6166	4830.659
Acidification	kg SO2 eq	922.0539	535.8856	140.1806	0.022336	4.757146	0.294661	0.174338	0.060745	0.041644	88.50001	152.1368
Eutrophication	kg N eq	366.7299	351.6781	3.312485	0.005911	0.771672	0.24343	0.313455	0.015905	0.006755	1.281491	9.100689
Carcinogenics	CTUh	0.005839	0.005499	1.03E-04	1.82E-07	3.61E-05	1.38E-05	2.28E-05	4.88E-07	3.16E-07	5.00E-10	0.000164
Non carcinogenics	CTUh	0.032178	0.030295	8.64E-05	9.79E-07	9.86E-05	4.06E-05	8.08E-05	2.24E-06	8.63E-07	7.28E-08	0.001573
Respiratory effects	kg PM2.5 eq	57.69978	43.44351	6.303503	0.003482	0.339153	0.076713	0.039453	0.007022	0.002969	4.35286	3.131119
Ecotoxicity	CTUe	577714.3	536893.6	1718.508	31.537	2171.566	4628.429	1766.928	135.7763	19.00992	0.033984	30348.91
Fossil fuel depletion	MJ surplus	595122.3	377035.1	174079.2	8.034516	1470.264	25.28988	22.6879	25.54978	12.87071	19655.72	22787.57

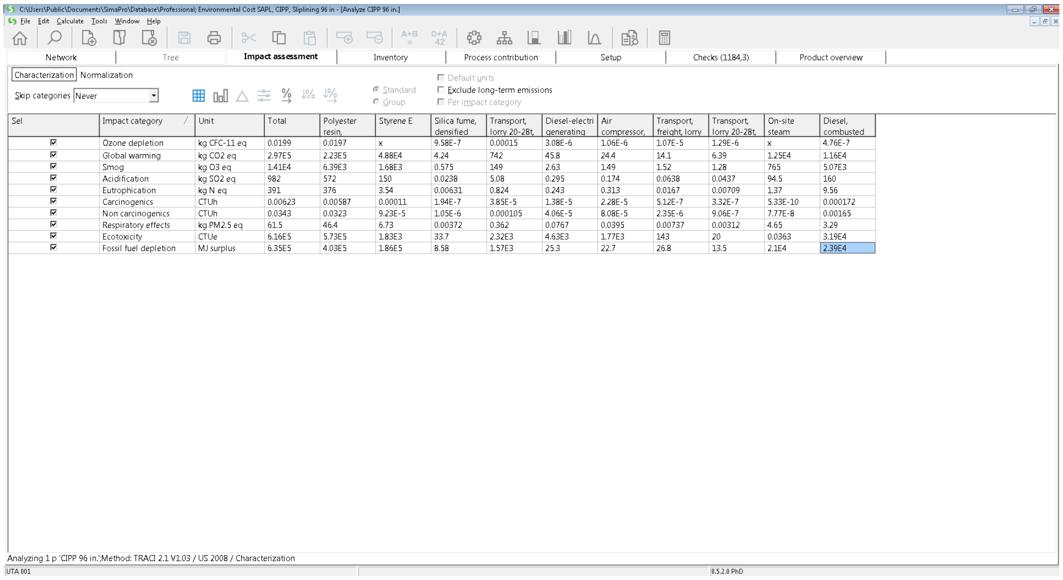
Table B-76 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 90 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.115586	0.114608	0	5.56E-06	8.73E-04	1.91E-05	6.55E-06	6.31E-05	7.64E-06	0	2.81E-06
Global warming	-	11.50094	8.640692	1.888061	0.000164	2.87E-02	0.00189	0.001007	0.000555	0.000251	0.482157	0.457471
Smog	-	9.524485	4.300566	1.133034	0.000387	1.00E-01	0.001888	0.00107	0.001039	0.000878	0.514843	3.470519
Acidification	-	10.15143	5.899878	1.543331	0.000246	5.24E-02	0.003244	0.001919	0.000669	0.000458	0.974348	1.674964
Eutrophication	-	16.96585	16.26951	0.153244	0.000273	0.035699	0.011262	0.014501	0.000736	0.000313	0.059285	0.421021
Carcinogenics	-	110.7557	104.2989	1.951227	0.003445	0.684414	0.261824	0.431957	0.009257	0.005991	9.48E-06	3.108713
Non carcinogenics	-	30.63696	28.8437	0.082278	0.000932	0.093835	0.038674	0.076919	0.002133	0.000821	6.93E-05	1.497602
Respiratory effects	-	2.379571	1.791634	0.25996	0.000144	1.40E-02	0.003164	0.001627	0.00029	0.000122	0.179514	0.129129
Ecotoxicity	-	52.18759	48.50007	0.155241	0.002849	0.196168	0.418107	0.159615	0.012265	0.001717	3.07E-06	2.741557
Fossil fuel depletion	-	31.62117	20.03334	9.249508	0.000427	7.81E-02	0.001344	0.001205	0.001358	0.000684	1.044385	1.210792

Table B-77 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 90 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.01864	0.62
Global warming	kg CO2 eq	278595.3	17,551.50
Smog	kg O3 eq	13257.25	29,165.95
Acidification	kg SO2 eq	922.0539	5,043.63
Eutrophication	kg N eq	366.7299	751.80
Carcinogenic	CTUh	0.005839	0.00
Non carcinogenic	CTUh	0.032178	0.29
Respiratory effects	kg PM2.5 eq	57.69978	3,654.70
Ecotoxicity	CTUe	577714.3	23,686.29
Fossil fuel depletion	MJ surplus	595122.3	5,832.20
Total			85,686.97

A.2.12 CIPP 96 in.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 96 in - [Analyze CIPP 96 in.]

Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.0199	0.0197	x	9.58E-7	0.00015	3.08E-6	1.06E-6	1.07E-5	1.29E-6	x	4.76E-7
☑	Global warming	kg CO2 eq	2.97E5	2.23E5	4.88E4	4.24	742	45.8	24.4	14.1	6.39	1.25E4	1.16E4
☑	Smog	kg O3 eq	1.41E4	6.39E3	1.68E3	0.575	149	2.63	1.49	1.52	1.28	765	5.07E3
☑	Acidification	kg SO2 eq	982	572	150	0.0238	5.08	0.295	0.174	0.0638	0.0437	94.5	160
☑	Eutrophication	kg N eq	391	376	3.54	0.00631	0.824	0.243	0.313	0.0167	0.00709	1.37	9.56
☑	Carcinogenics	CTUh	0.00623	0.00587	0.00011	1.94E-7	3.85E-5	1.38E-5	2.28E-5	5.12E-7	3.32E-7	5.33E-10	0.000172
☑	Non carcinogenics	CTUh	0.0343	0.0323	9.23E-5	1.05E-6	0.000105	4.06E-5	8.08E-5	2.35E-6	9.06E-7	7.77E-8	0.00165
☑	Respiratory effects	kg PM2.5 eq	61.5	46.4	6.73	0.00372	0.362	0.0767	0.0395	0.00737	0.00312	4.65	3.29
☑	Ecotoxicity	CTUe	6.16E5	5.73E5	1.83E3	33.7	2.32E3	4.63E3	1.77E3	143	20	0.0363	3.19E4
☑	Fossil fuel depletion	MJ surplus	6.35E5	4.03E5	1.86E5	8.58	1.57E3	25.3	22.7	26.8	13.5	2.1E4	2.39E4

Analyzing 1 p 'CIPP 96 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-101 Screenshot of the Impact Assessment Table from SimaPro Software for 96 in. CIPP

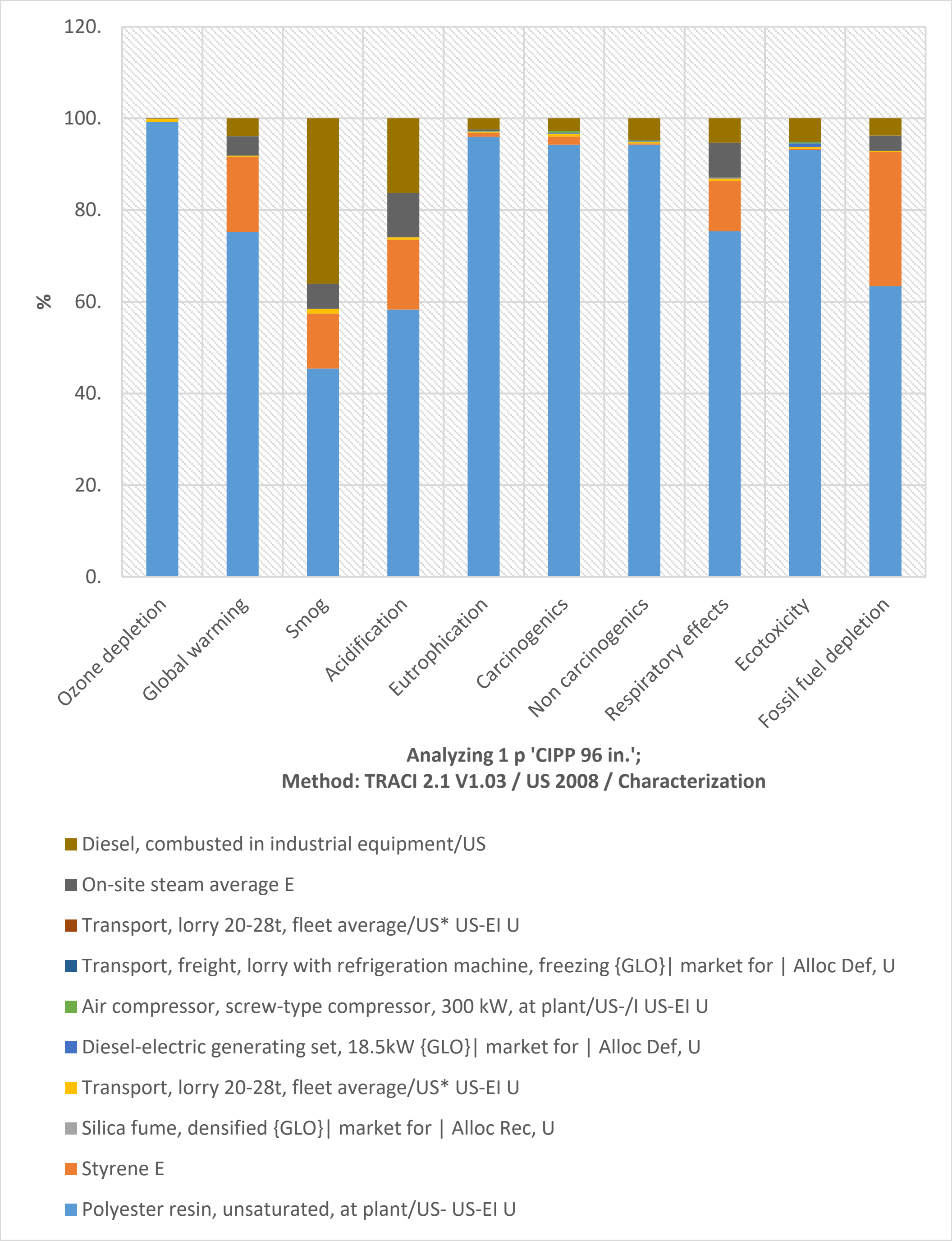


Figure B-102 Environmental Impact Assessment of 96 in. Diameter CIPP Renewal Method

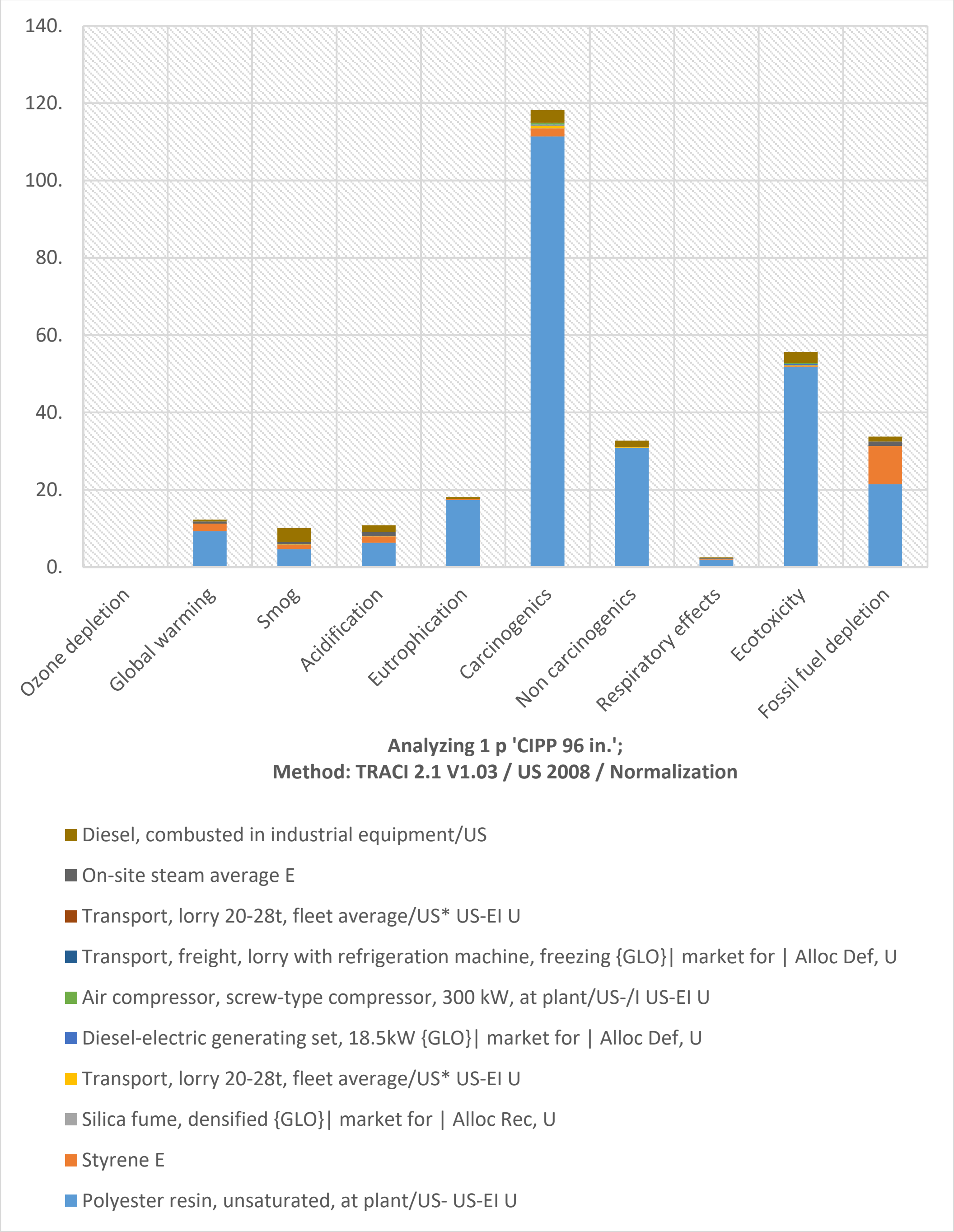


Figure B-103 Normalized Environmental Impact Assessment
of 96 in. Diameter CIPP Renewal Method

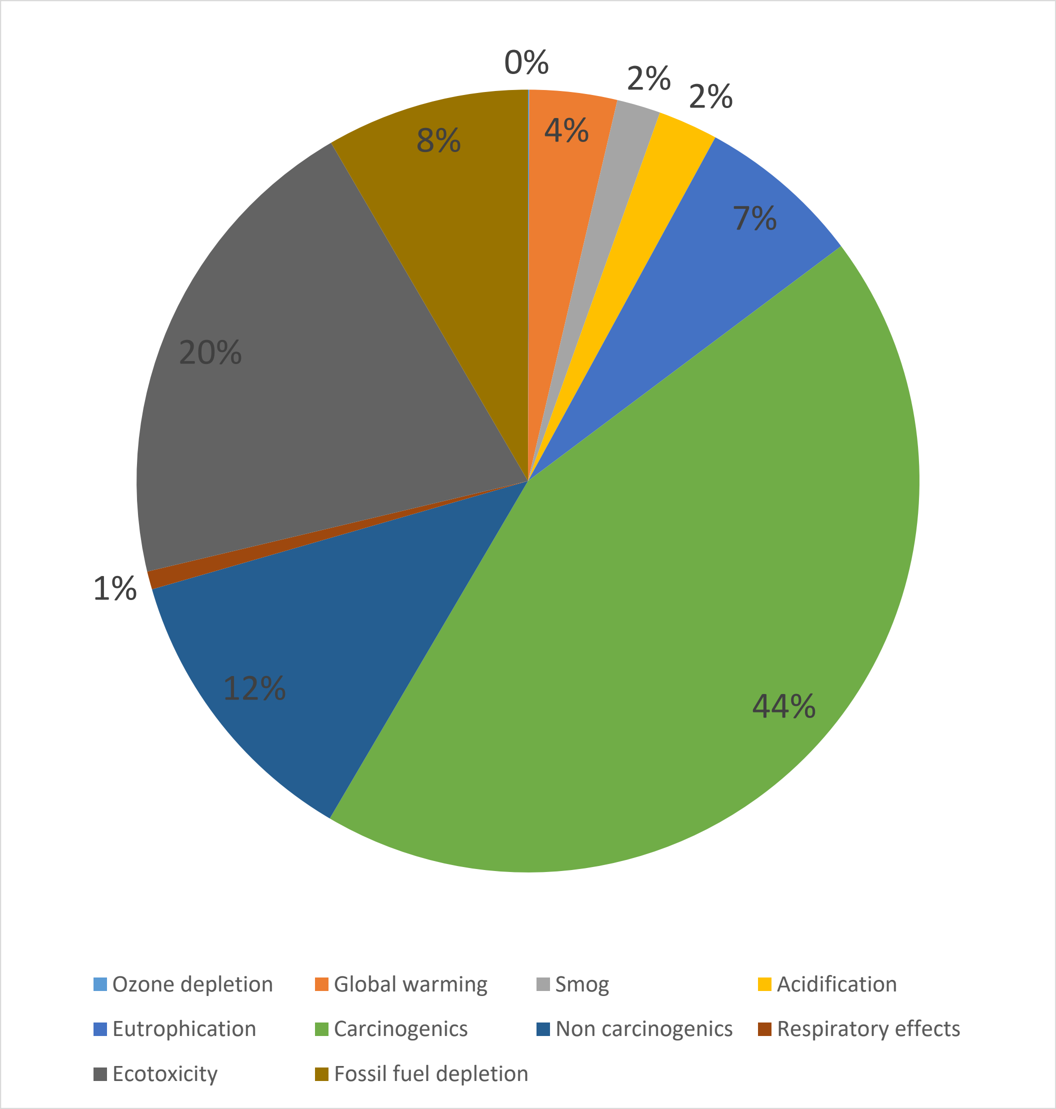


Figure B-104 Percentage of Normalized Environmental Impact Assessment of 96 in. Diameter CIPP Renewal Method

Table B-78 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 96 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.019903	0.019735	0	9.58E-07	1.50E-04	3.08E-06	1.06E-06	1.07E-05	1.29E-06	0	4.76E-07
Global warming	kg CO2 eq	297274	223494.6	48835.35	4.236662	742.1734	45.77813	24.3825	14.1173	6.389468	12471.18	11635.79
Smog	kg O3 eq	14069.57	6391.689	1683.964	0.575331	149.0135	2.627487	1.488871	1.518845	1.282877	765.1831	5072.223
Acidification	kg SO2 eq	981.8062	572.203	149.6808	0.023849	5.07954	0.294661	0.174338	0.063788	0.04373	94.49782	159.7447
Eutrophication	kg N eq	391.3838	375.5117	3.536974	0.006311	0.823969	0.24343	0.313455	0.016702	0.007094	1.36834	9.555783
Carcinogenics	CTUh	0.006229	0.005871	1.10E-04	1.94E-07	3.85E-05	1.38E-05	2.28E-05	5.12E-07	3.32E-07	5.33E-10	0.000172
Non carcinogenics	CTUh	0.034323	0.032348	9.23E-05	1.05E-06	1.05E-04	4.06E-05	8.08E-05	2.35E-06	9.06E-07	7.77E-08	0.001652
Respiratory effects	kg PM2.5 eq	61.54648	46.38771	6.730695	0.003718	0.362138	0.076713	0.039453	0.007373	0.003118	4.647861	3.287695
Ecotoxicity	CTUe	615891.3	573279.4	1834.972	33.67399	2318.734	4628.429	1766.928	142.5785	19.96228	0.036287	31866.55
Fossil fuel depletion	MJ surplus	635045.5	402587.1	185876.7	8.578948	1569.904	25.28988	22.6879	26.82978	13.51551	20987.83	23927.09

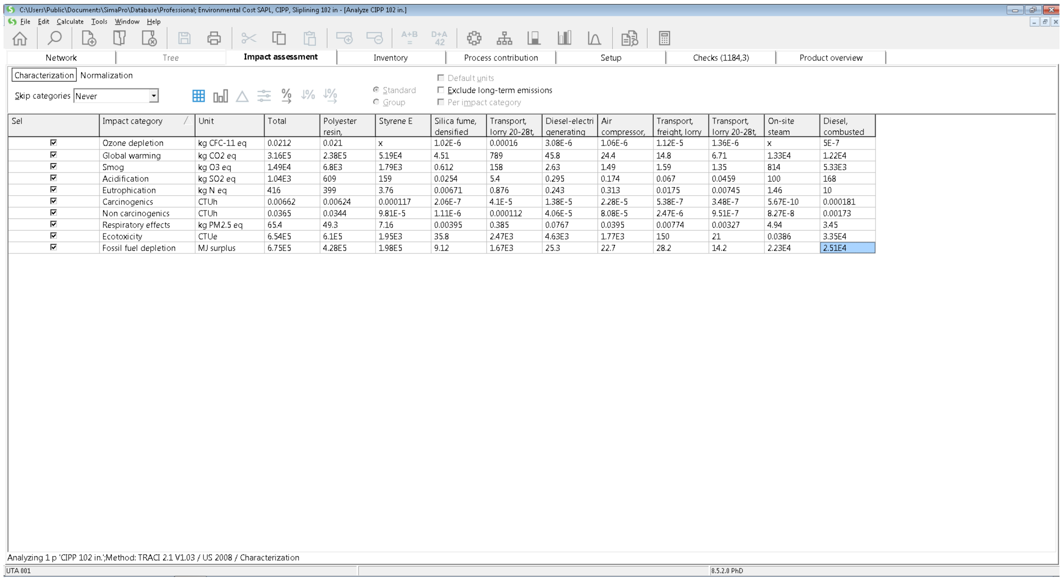
Table B-79 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 96 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.123417	0.122376	0	5.94E-06	9.32E-04	1.91E-05	6.55E-06	6.63E-05	8.03E-06	0	2.95E-06
Global warming	-	12.27203	9.22628	2.016016	0.000175	3.06E-02	0.00189	0.001007	0.000583	0.000264	0.514834	0.480348
Smog	-	10.10808	4.592019	1.20982	0.000413	1.07E-01	0.001888	0.00107	0.001091	0.000922	0.549735	3.644068
Acidification	-	10.80928	6.299719	1.647923	0.000263	5.59E-02	0.003244	0.001919	0.000702	0.000481	1.040382	1.758723
Eutrophication	-	18.10639	17.37211	0.163629	0.000292	0.038119	0.011262	0.014501	0.000773	0.000328	0.063303	0.442074
Carcinogenics	-	118.1593	111.3673	2.083463	0.003679	0.730797	0.261824	0.431957	0.009721	0.006292	1.01E-05	3.264169
Non carcinogenics	-	32.67877	30.79846	0.087854	0.000995	0.100194	0.038674	0.076919	0.00224	0.000863	7.40E-05	1.572491
Respiratory effects	-	2.538211	1.913055	0.277578	0.000153	1.49E-02	0.003164	0.001627	0.000304	0.000129	0.19168	0.135586
Ecotoxicity	-	55.63629	51.78697	0.165761	0.003042	0.209462	0.418107	0.159615	0.01288	0.001803	3.28E-06	2.878652
Fossil fuel depletion	-	33.74244	21.39102	9.876352	0.000456	8.34E-02	0.001344	0.001205	0.001426	0.000718	1.115165	1.27134

Table B-80 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 96 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.019903	0.66
Global warming	kg CO2 eq	297274	18,728.26
Smog	kg O3 eq	14069.57	30,953.04
Acidification	kg SO2 eq	981.8062	5,370.48
Eutrophication	kg N eq	391.3838	802.34
Carcinogenic	CTUh	0.006229	0.00
Non carcinogenic	CTUh	0.034323	0.31
Respiratory effects	kg PM2.5 eq	61.54648	3,898.35
Ecotoxicity	CTUe	615891.3	25,251.54
Fossil fuel depletion	MJ surplus	635045.5	6,223.45
Total			91,228.42

A.2.13 CIPP 102 in.



Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.0212	0.021	x	1.02E-6	0.00016	3.08E-6	1.06E-6	1.12E-5	1.36E-6	x	5E-7
☑	Global warming	kg CO2 eq	3.16E5	2.38E5	5.19E4	4.51	789	45.8	24.4	14.8	6.71	1.33E4	1.22E4
☑	Smog	kg O3 eq	1.49E4	6.8E3	1.79E3	0.612	158	2.63	1.49	1.59	1.35	814	5.33E3
☑	Acidification	kg SO2 eq	1.04E3	609	159	0.0254	5.4	0.295	0.174	0.067	0.0459	100	168
☑	Eutrophication	kg N eq	416	399	3.76	0.00671	0.876	0.243	0.313	0.0175	0.00745	1.46	10
☑	Carcinogenics	CTUh	0.00662	0.00624	0.000117	2.06E-7	4.1E-5	1.38E-5	2.28E-5	5.38E-7	3.48E-7	5.67E-10	0.000181
☑	Non carcinogenics	CTUh	0.0365	0.0344	9.81E-5	1.11E-6	0.000112	4.06E-5	8.08E-5	2.47E-6	9.51E-7	8.27E-8	0.00173
☑	Respiratory effects	kg PM2.5 eq	65.4	49.3	7.16	0.00395	0.385	0.0767	0.0395	0.00774	0.00327	4.94	3.45
☑	Ecotoxicity	CTUe	6.54E5	6.1E5	1.95E3	35.8	2.47E3	4.63E3	1.77E3	150	21	0.0386	3.35E4
☑	Fossil fuel depletion	MJ surplus	6.75E5	4.28E5	1.98E5	9.12	1.67E3	25.3	22.7	28.2	14.2	2.23E4	2.51E4

Analyzing 1 p 'CIPP 102 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-105 Screenshot of the Impact Assessment Table from SimaPro Software for 102 in. CIPP

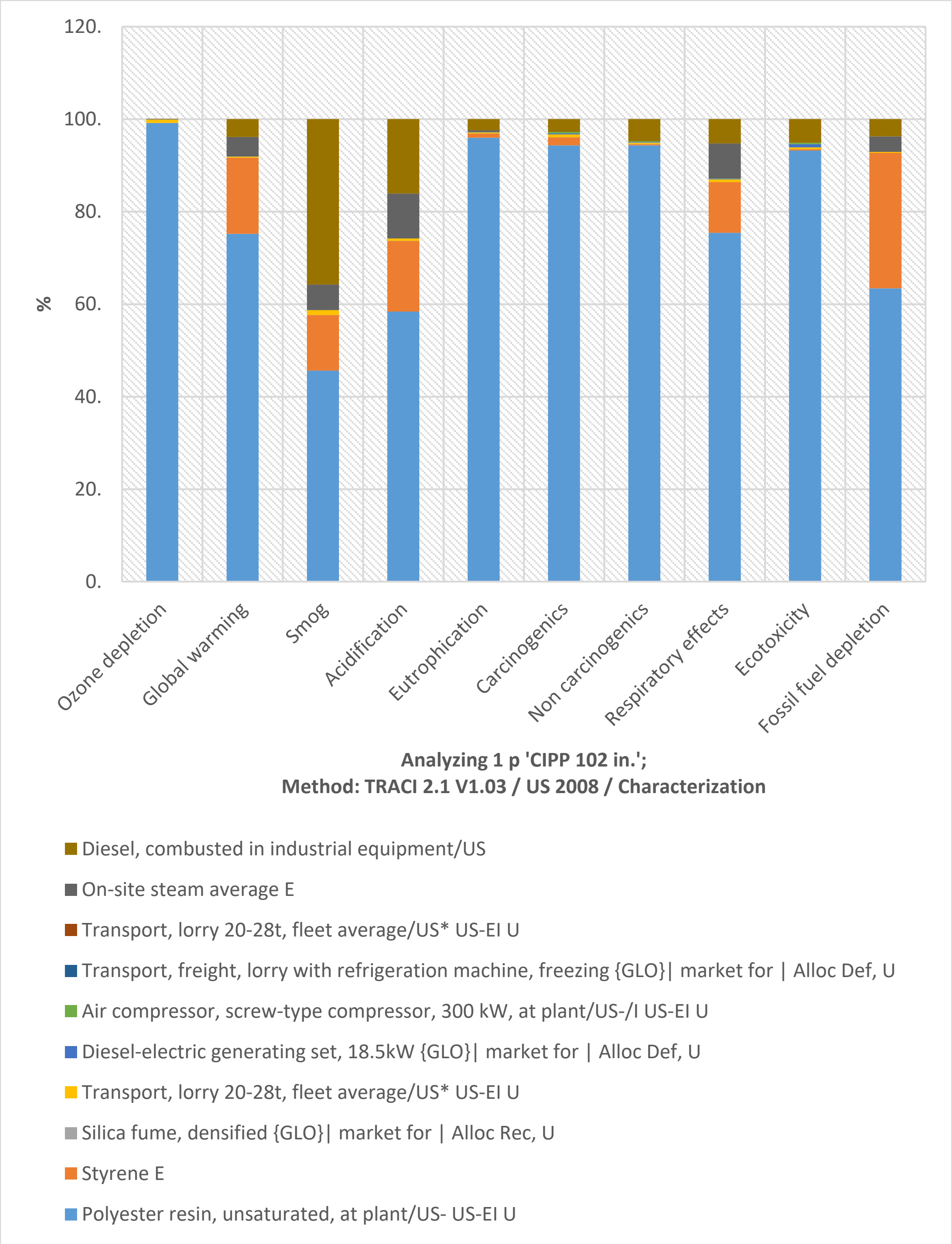


Figure B-106 Environmental Impact Assessment of 102 in. Diameter CIPP Renewal Method

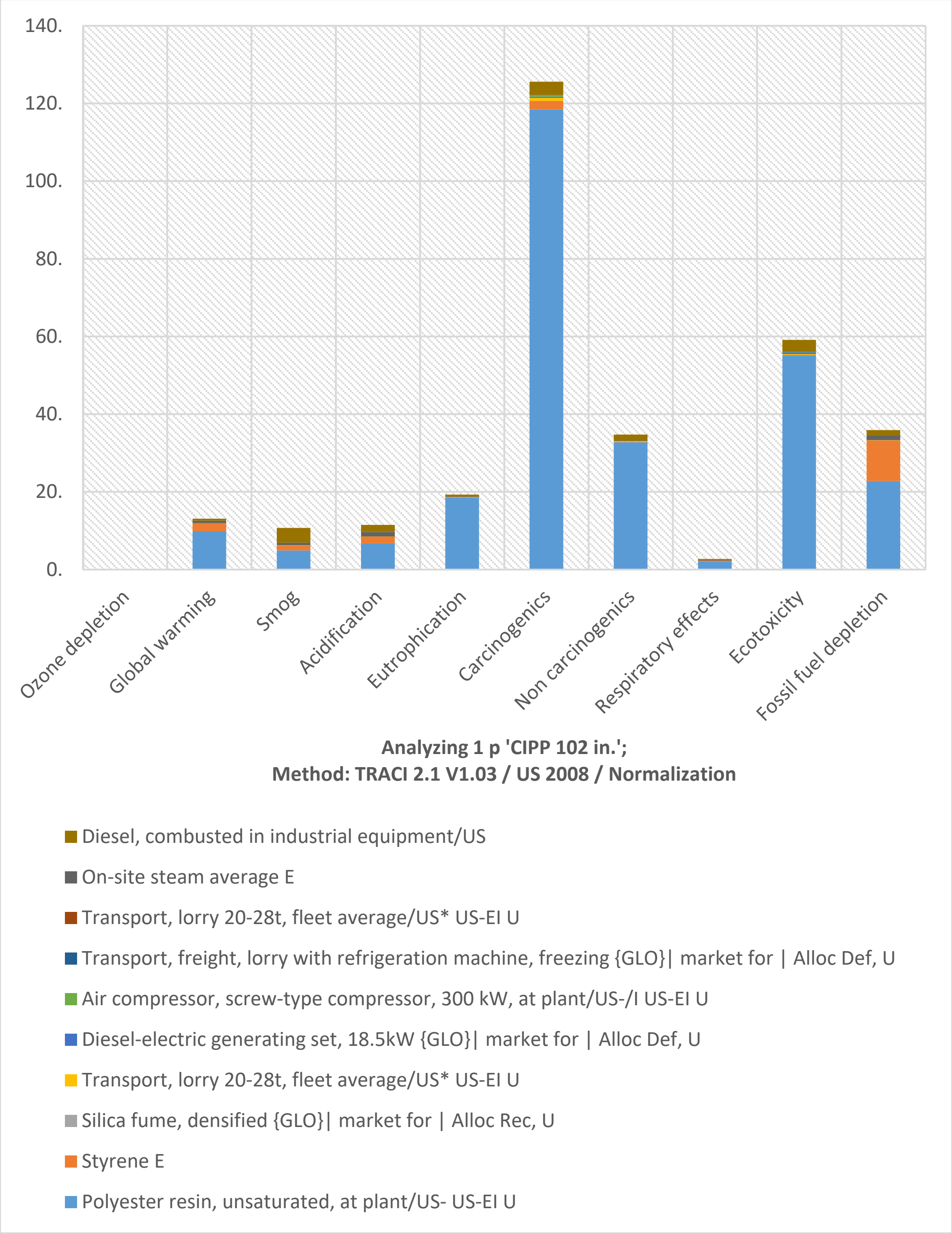


Figure B-107 Normalized Environmental Impact Assessment
of 102 in. Diameter CIPP Renewal Method

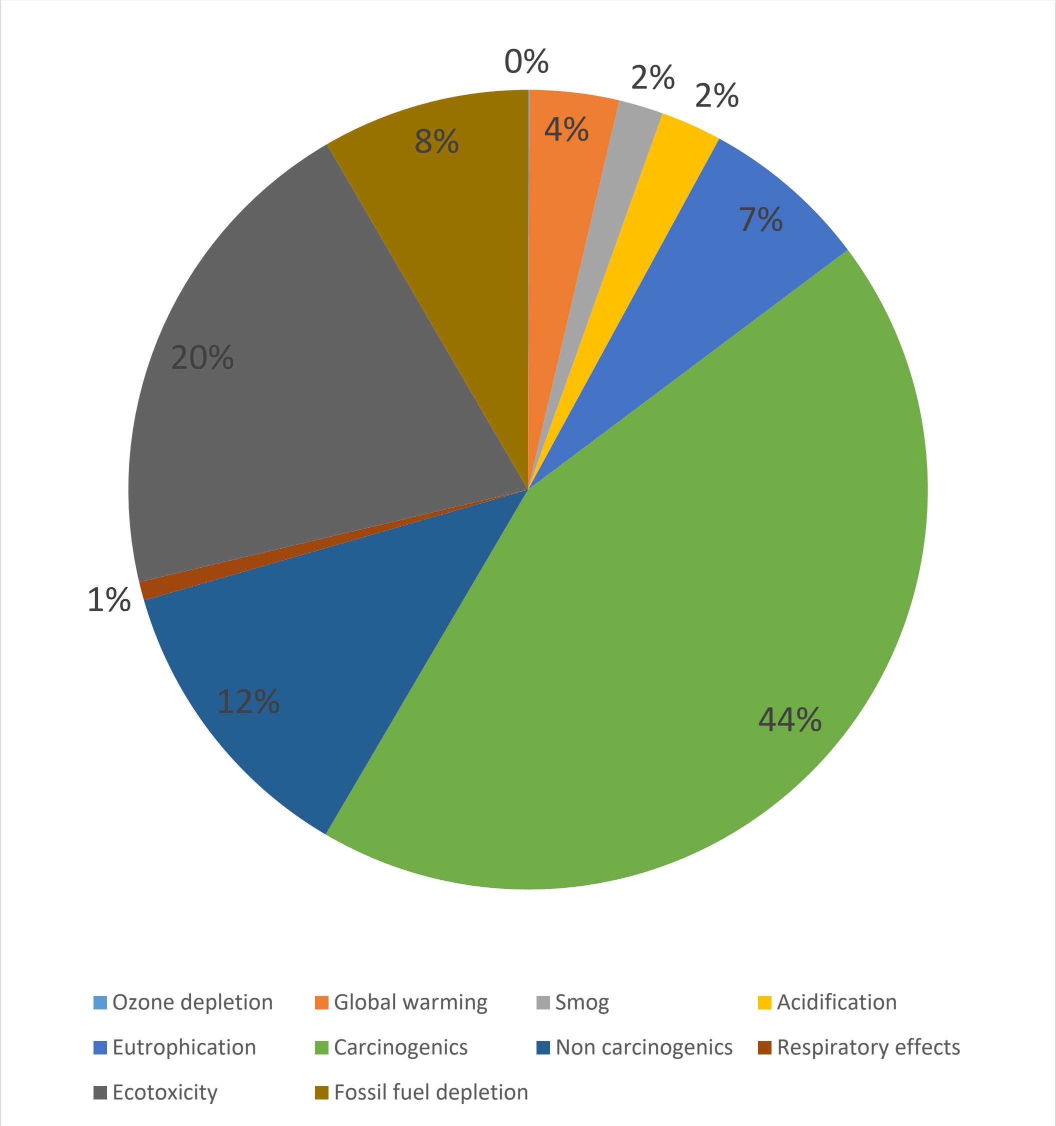


Figure B-108 Percentage of Normalized Environmental Impact Assessment of 102 in. Diameter CIPP Renewal Method

Table B-81 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 102 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.021166	0.020988	0	1.02E-06	1.60E-04	3.08E-06	1.06E-06	1.12E-05	1.36E-06	0	5.00E-07
Global warming	kg CO2 eq	315980.3	237679.7	51934.89	4.505527	789.2786	45.77813	24.3825	14.82382	6.70924	13262.71	12217.59
Smog	kg O3 eq	14893.94	6797.367	1790.844	0.611843	158.4713	2.627487	1.488871	1.594858	1.347081	813.7486	5325.837
Acidification	kg SO2 eq	1041.938	608.5205	159.1809	0.025363	5.401934	0.294661	0.174338	0.06698	0.045919	100.4955	167.732
Eutrophication	kg N eq	416.0603	399.3453	3.761463	0.006712	0.876266	0.24343	0.313455	0.017538	0.007449	1.455188	10.03358
Carcinogenics	CTUh	0.00662	0.006244	1.17E-04	2.06E-07	4.10E-05	1.38E-05	2.28E-05	5.38E-07	3.48E-07	5.67E-10	0.000181
Non carcinogenics	CTUh	0.036471	0.034401	9.81E-05	1.11E-06	1.12E-04	4.06E-05	8.08E-05	2.47E-06	9.51E-07	8.27E-08	0.001734
Respiratory effects	kg PM2.5 eq	65.40101	49.33192	7.157887	0.003954	0.385122	0.076713	0.039453	0.007742	0.003274	4.942857	3.452081
Ecotoxicity	CTUe	654144.3	609665.2	1951.436	35.81099	2465.902	4628.429	1766.928	149.7141	20.96133	0.03859	33459.9
Fossil fuel depletion	MJ surplus	675025.6	428139.1	197674.1	9.12338	1669.545	25.28988	22.6879	28.17252	14.19192	22319.91	25123.46

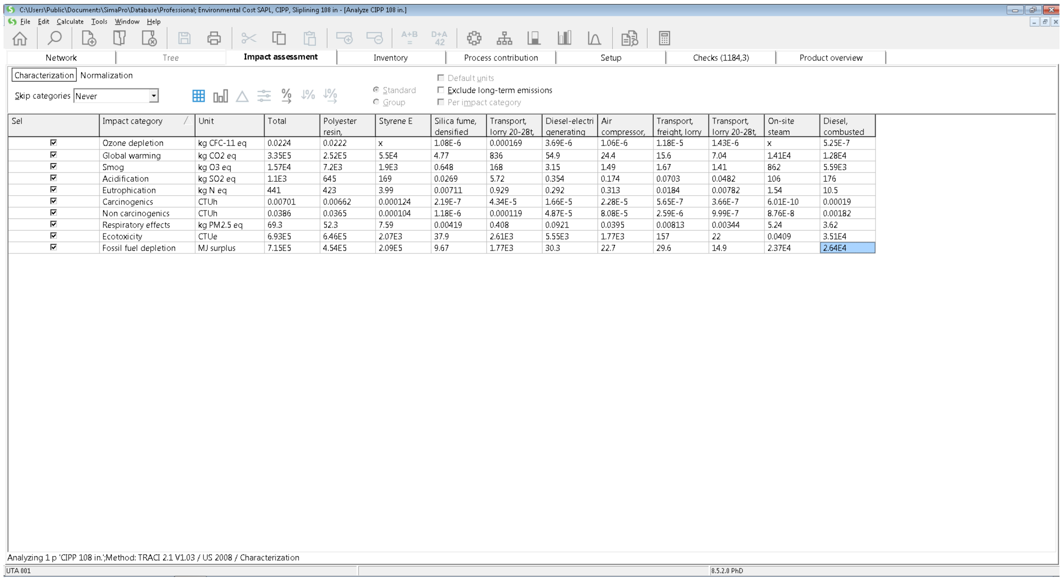
Table B-82 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 102 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.131247	0.130143	0	6.32E-06	9.92E-04	1.91E-05	6.55E-06	6.96E-05	8.43E-06	0	3.10E-06
Global warming	-	13.04427	9.811868	2.143971	0.000186	3.26E-02	0.00189	0.001007	0.000612	0.000277	0.54751	0.504365
Smog	-	10.70034	4.883473	1.286607	0.00044	1.14E-01	0.001888	0.00107	0.001146	0.000968	0.584626	3.826273
Acidification	-	11.47131	6.699559	1.752516	0.000279	5.95E-02	0.003244	0.001919	0.000737	0.000506	1.106414	1.84666
Eutrophication	-	19.248	18.47471	0.174015	0.00031	0.040538	0.011262	0.014501	0.000811	0.000345	0.067321	0.464178
Carcinogenics	-	125.5706	118.4358	2.215699	0.003912	0.77718	0.261824	0.431957	0.010208	0.006606	1.08E-05	3.427379
Non carcinogenics	-	34.72432	32.75323	0.09343	0.001058	0.106554	0.038674	0.076919	0.002352	0.000906	7.87E-05	1.651117
Respiratory effects	-	2.697174	2.034476	0.295195	0.000163	1.59E-02	0.003164	0.001627	0.000319	0.000135	0.203846	0.142366
Ecotoxicity	-	59.09187	55.07386	0.176282	0.003235	0.222756	0.418107	0.159615	0.013524	0.001894	3.49E-06	3.022586
Fossil fuel depletion	-	35.86674	22.7487	10.5032	0.000485	8.87E-02	0.001344	0.001205	0.001497	0.000754	1.185944	1.334907

Table B-83 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 102 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.021166	0.70
Global warming	kg CO2 eq	315980.3	19,906.76
Smog	kg O3 eq	14893.94	32,766.66
Acidification	kg SO2 eq	1041.938	5,699.40
Eutrophication	kg N eq	416.0603	852.92
Carcinogenic	CTUh	0.00662	0.00
Non carcinogenic	CTUh	0.036471	0.32
Respiratory effects	kg PM2.5 eq	65.40101	4,142.50
Ecotoxicity	CTUe	654144.3	26,819.92
Fossil fuel depletion	MJ surplus	675025.6	6,615.25
Total			96,804.44

A.2.14 CIPP 108 in.



Skip categories: Never

Sel	Impact category	Unit	Total	Polyester resin,	Styrene E	Silica fume, densified	Transport, lorry 20-28t,	Diesel-electri generating	Air compressor,	Transport, freight, lorry	Transport, lorry 20-28t,	On-site steam	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.0224	0.0222	x	1.08E-6	0.000169	3.69E-6	1.06E-6	1.18E-5	1.43E-6	x	5.25E-7
☑	Global warming	kg CO2 eq	3.35E5	2.52E5	5.5E4	4.77	836	54.9	24.4	15.6	7.04	1.41E4	1.28E4
☑	Smog	kg O3 eq	1.57E4	7.2E3	1.9E3	0.648	168	3.15	1.49	1.67	1.41	862	5.59E3
☑	Acidification	kg SO2 eq	1.1E3	645	169	0.0269	5.72	0.354	0.174	0.0703	0.0482	106	176
☑	Eutrophication	kg N eq	441	423	3.99	0.00711	0.929	0.292	0.313	0.0184	0.00782	1.54	10.5
☑	Carcinogenics	CTUh	0.00701	0.00662	0.000124	2.19E-7	4.34E-5	1.66E-5	2.28E-5	5.65E-7	3.66E-7	6.01E-10	0.00019
☑	Non carcinogenics	CTUh	0.0386	0.0365	0.000104	1.18E-6	0.000119	4.87E-5	8.08E-5	2.59E-6	9.99E-7	8.76E-8	0.00182
☑	Respiratory effects	kg PM2.5 eq	69.3	52.3	7.59	0.00419	0.408	0.0921	0.0395	0.00813	0.00344	5.24	3.62
☑	Ecotoxicity	CTUe	6.93E5	6.46E5	2.07E3	37.9	2.61E3	5.55E3	1.77E3	157	22	0.0409	3.51E4
☑	Fossil fuel depletion	MJ surplus	7.15E5	4.54E5	2.09E5	9.67	1.77E3	30.3	22.7	29.6	14.9	2.37E4	2.64E4

Analyzing 1 p 'CIPP 108 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-109 Screenshot of the Impact Assessment Table from SimaPro Software for 108 in. CIPP

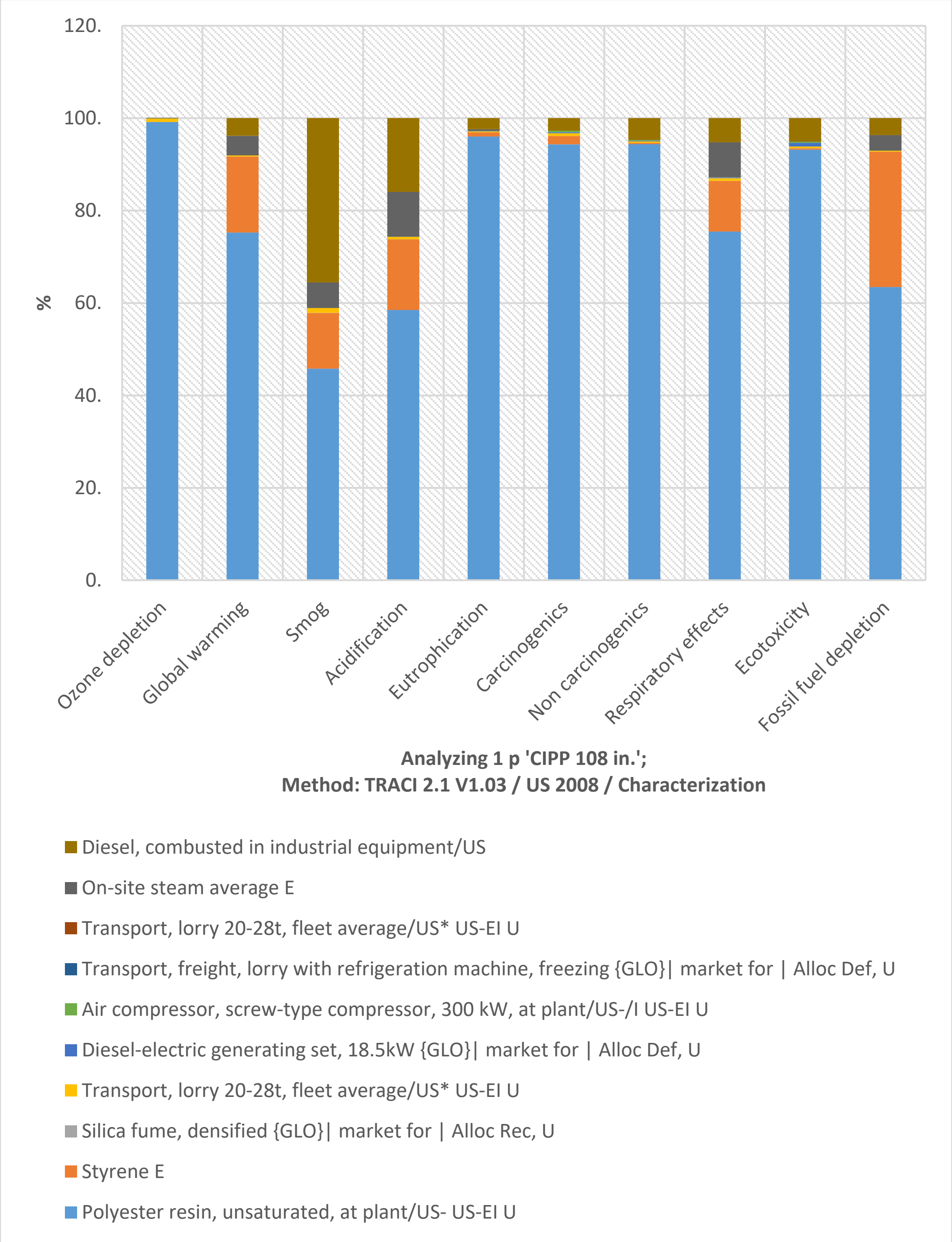


Figure B-110 Environmental Impact Assessment of 108 in. Diameter CIPP Renewal Method

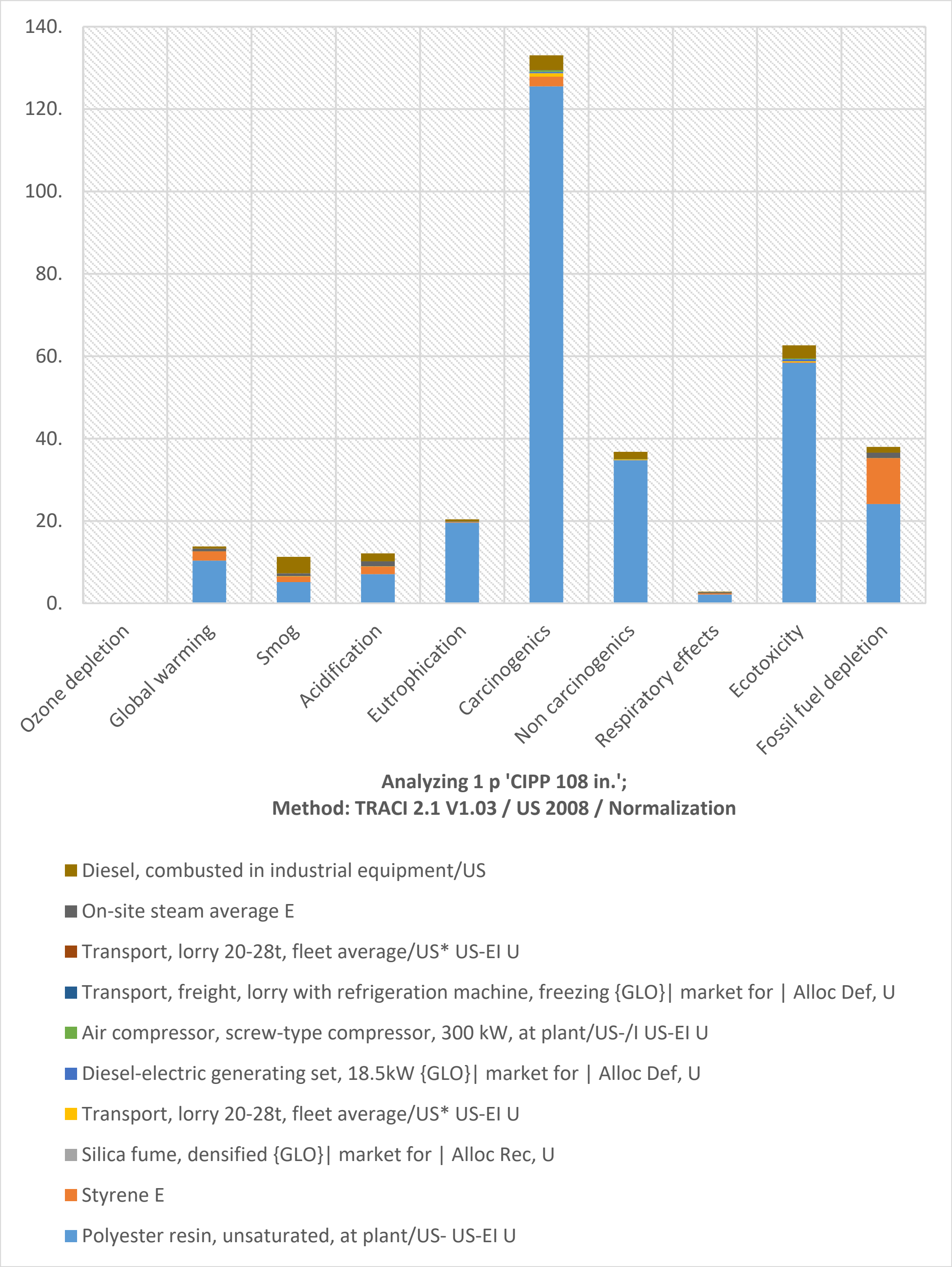


Figure B-111 Normalized Environmental Impact Assessment
of 108 in. Diameter CIPP Renewal Method

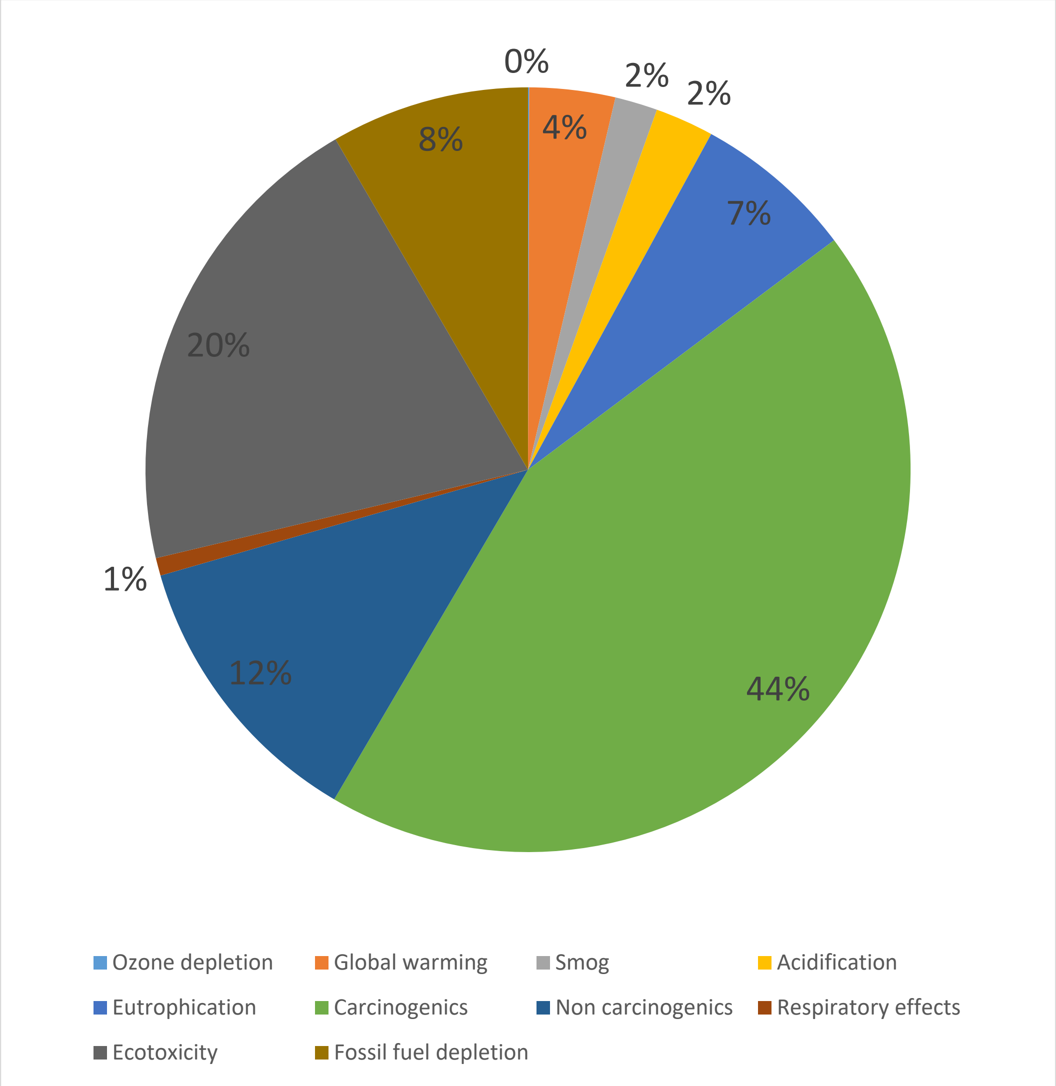


Figure B-112 Percentage of Normalized Environmental Impact Assessment of 108 in. Diameter CIPP Renewal Method

Table B-84 Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 108 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	kg CFC-11 eq	0.022429	0.02224	0	1.08E-06	1.69E-04	3.69E-06	1.06E-06	1.18E-05	1.43E-06	0	5.25E-07
Global warming	kg CO2 eq	334725.6	251865.2	55034.6	4.774562	836.3867	54.93375	24.3825	15.56336	7.043955	14054.26	12828.47
Smog	kg O3 eq	15731.54	7203.057	1897.729	0.648377	167.9296	3.152984	1.488871	1.674424	1.414285	862.315	5592.129
Acidification	kg SO2 eq	1102.53	644.8391	168.6815	0.026877	5.724349	0.353594	0.174338	0.070322	0.04821	106.4933	176.1186
Eutrophication	kg N eq	440.8103	423.1796	3.985965	0.007112	0.928566	0.292116	0.313455	0.018413	0.00782	1.542037	10.53526
Carcinogenics	CTUh	0.007014	0.006616	1.24E-04	2.19E-07	4.34E-05	1.66E-05	2.28E-05	5.65E-07	3.66E-07	6.01E-10	0.00019
Non carcinogenics	CTUh	0.038632	0.036454	1.04E-04	1.18E-06	1.19E-04	4.87E-05	8.08E-05	2.59E-06	9.99E-07	8.76E-08	0.001821
Respiratory effects	kg PM2.5 eq	69.27924	52.27622	7.585102	0.00419	0.408109	0.092056	0.039453	0.008129	0.003437	5.237858	3.624686
Ecotoxicity	CTUe	693404.2	646052.1	2067.907	37.94935	2613.079	5554.115	1766.928	157.1831	22.00706	0.040893	35132.89
Fossil fuel depletion	MJ surplus	715072.2	453692	209472.2	9.668157	1769.192	30.34786	22.6879	29.57801	14.89993	23652.01	26379.63

Table B-85 Normalized Environmental Impact Assessment Results for CIPP Renewal Method of 500-ft Length and Diameter of 108 in. Culvert

Impact category	Unit	Total	Polyes resin	Styrene E	Silica fume	Transp, lorry 20-28t	Gen set	Air comp	Refrig machine	Transp lorry	On-site steam E	Diesel
Ozone depletion	-	0.139082	0.13791	0	6.69E-06	1.05E-03	2.29E-05	6.55E-06	7.31E-05	8.85E-06	0	3.26E-06
Global warming	-	13.81811	10.39747	2.271933	0.000197	3.45E-02	0.002268	0.001007	0.000642	0.000291	0.580187	0.529583
Smog	-	11.3021	5.174935	1.363397	0.000466	1.21E-01	0.002265	0.00107	0.001203	0.001016	0.619518	4.017587
Acidification	-	12.1384	7.099412	1.857114	0.000296	6.30E-02	0.003893	0.001919	0.000774	0.000531	1.172447	1.938993
Eutrophication	-	20.39299	19.57735	0.184401	0.000329	0.042958	0.013514	0.014501	0.000852	0.000362	0.071338	0.487387
Carcinogenics	-	133.0426	125.5044	2.347942	0.004146	0.823566	0.314189	0.431957	0.010717	0.006936	1.14E-05	3.598748
Non carcinogenics	-	36.7816	34.70805	0.099006	0.001122	0.112913	0.046408	0.076919	0.00247	0.000951	8.34E-05	1.733673
Respiratory effects	-	2.857114	2.1559	0.312814	0.000173	1.68E-02	0.003796	0.001627	0.000335	0.000142	0.216012	0.149484
Ecotoxicity	-	62.63839	58.36086	0.186804	0.003428	0.236051	0.501729	0.159615	0.014199	0.001988	3.69E-06	3.173716
Fossil fuel depletion	-	37.99457	24.10642	11.13008	0.000514	9.40E-02	0.001613	0.001205	0.001572	0.000792	1.256724	1.401653

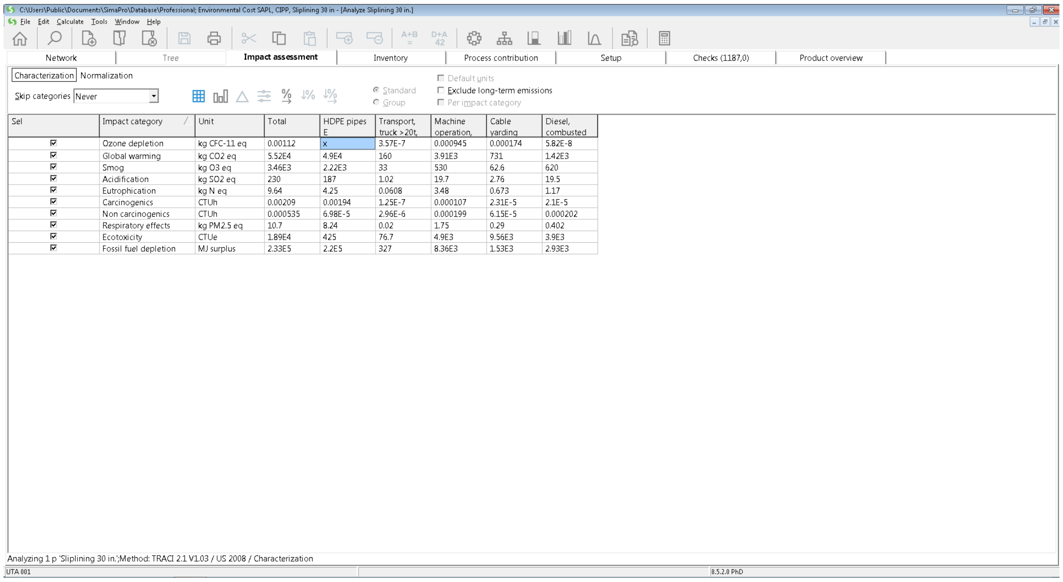
Table B-86 Environmental Impact Cost Results for CIPP Renewal Method of 500-ft Length and Diameter of 108 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.022429	0.74
Global warming	kg CO2 eq	334725.6	21,087.71
Smog	kg O3 eq	15731.54	34,609.38
Acidification	kg SO2 eq	1102.53	6,030.84
Eutrophication	kg N eq	440.8103	903.66
Carcinogenic	CTUh	0.007014	0.00
Non carcinogenic	CTUh	0.038632	0.34
Respiratory effects	kg PM2.5 eq	69.27924	4,388.15
Ecotoxicity	CTUe	693404.2	28,429.57
Fossil fuel depletion	MJ surplus	715072.2	7,007.71
Total			102,458.11

A.3 Sliplining Environmental Costs Results

In this Appendix, all the SimaPro analysis and results for sliplining method are presented.

A.3.1 Sliplining 30 in.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 30 in - [Analyze Sliplining 30 in.]

Characterization Normalization

Skip categories: Never

◉ Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00112	x	3.57E-7	0.000945	0.000174	5.82E-8
☑	Global warming	kg CO2 eq	5.52E4	4.9E4	160	3.91E3	731	1.42E3
☑	Smog	kg O3 eq	3.46E3	2.22E3	33	530	62.6	620
☑	Acidification	kg SO2 eq	230	187	1.02	19.7	2.76	19.5
☑	Eutrophication	kg N eq	9.64	4.25	0.0608	3.48	0.673	1.17
☑	Carcinogenics	CTUh	0.00209	0.00194	1.25E-7	0.000107	2.31E-5	2.1E-5
☑	Non carcinogenics	CTUh	0.000535	6.98E-5	2.96E-6	0.000199	6.15E-5	0.000202
☑	Respiratory effects	kg PM2.5 eq	10.7	8.24	0.02	1.75	0.29	0.402
☑	Ecotoxicity	CTUe	1.89E4	425	76.7	4.9E3	9.56E3	3.9E3
☑	Fossil fuel depletion	MJ surplus	2.33E5	2.2E5	327	8.36E3	1.53E3	2.93E3

Analyzing 1 p 'Sliplining 30 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-113 Screenshot of the Impact Assessment Table from SimaPro Software for 30 in. Sliplining

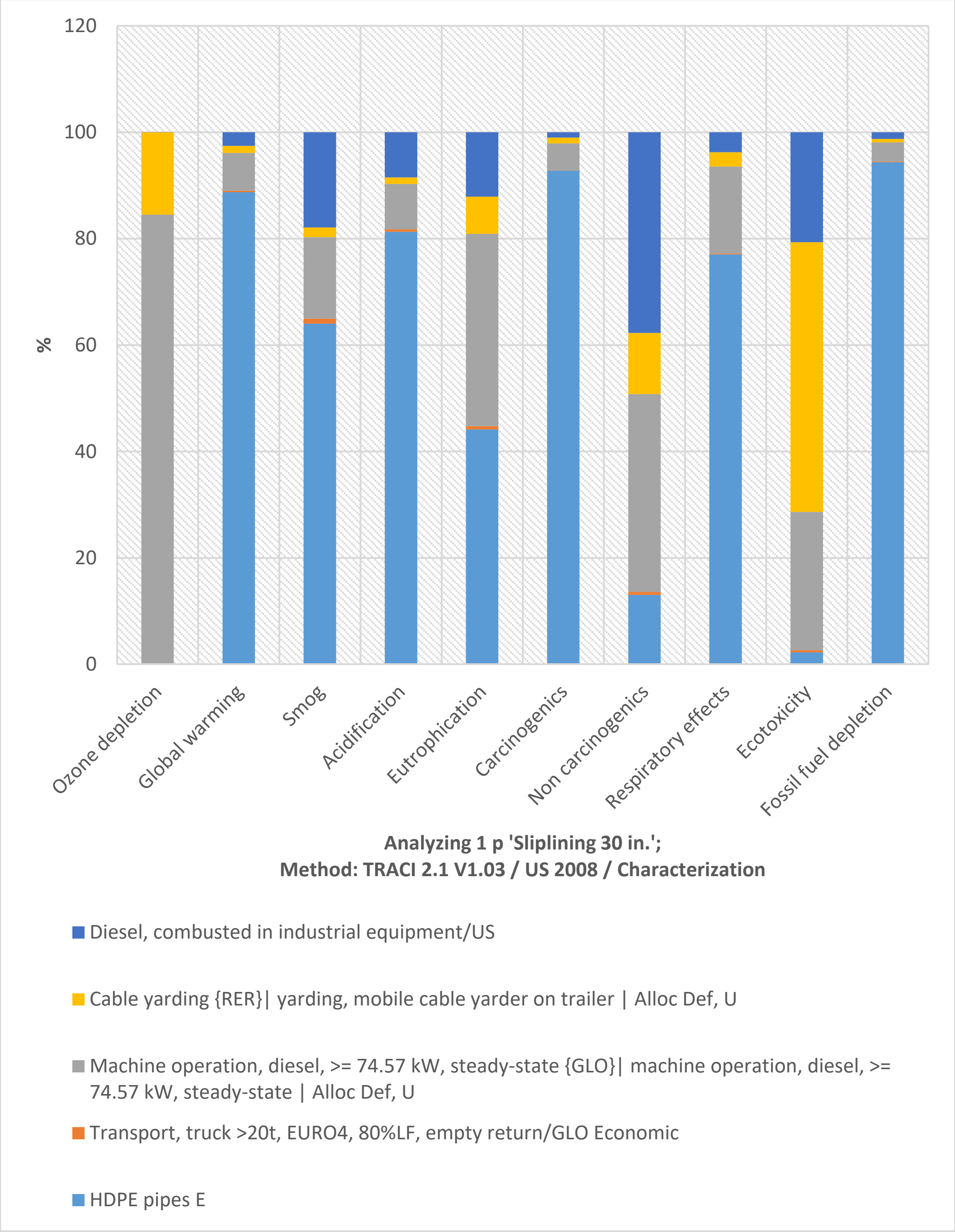


Figure B-114 Environmental Impact Assessment of 30 in. Diameter Sliplining Renewal Method

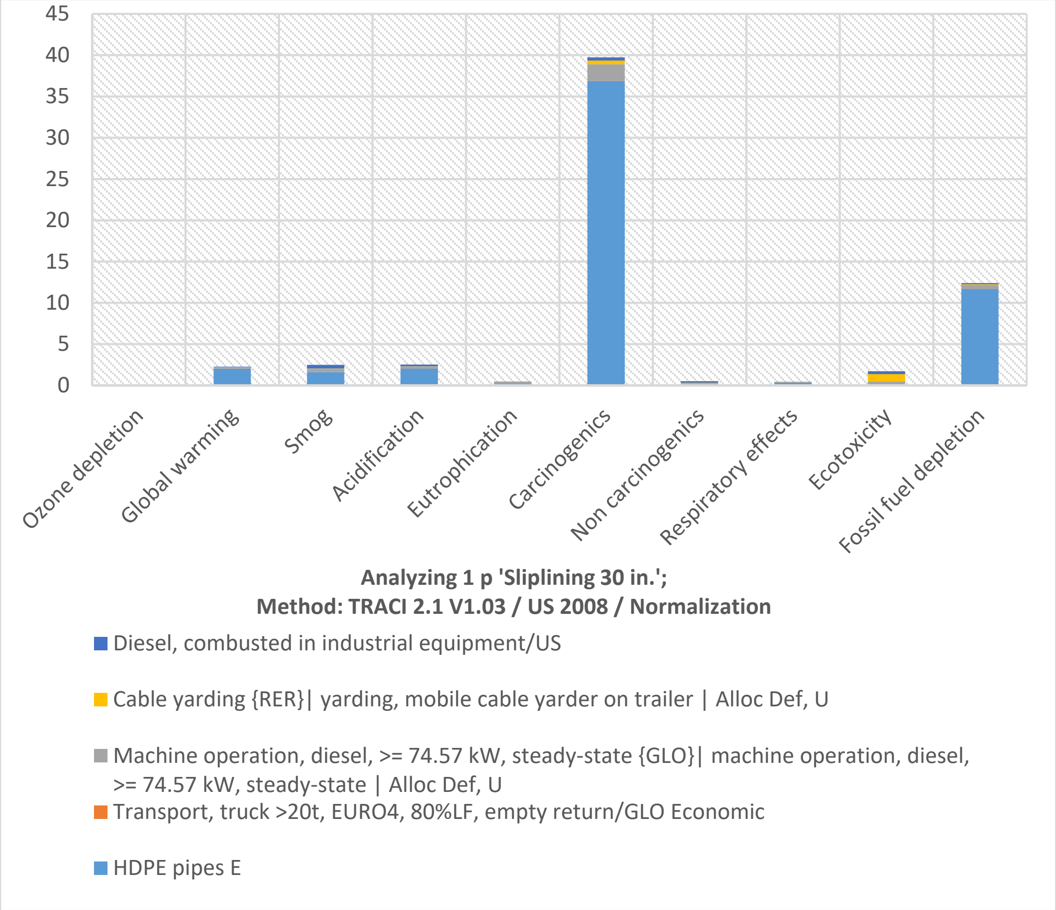


Figure B-115 Normalized Environmental Impact Assessment of 30 in. Diameter Sliplining Renewal Method

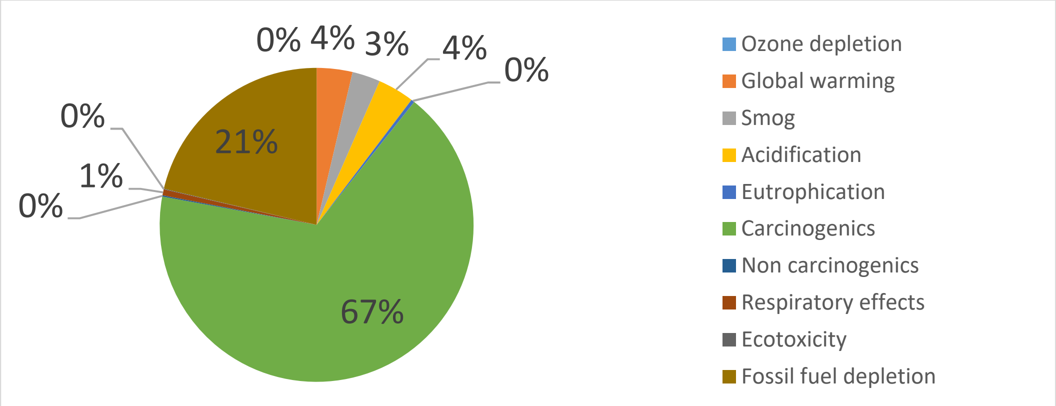


Figure B-116 Percentage of Normalized Environmental Impact Assessment of 30 in. Diameter Sliplining Renewal Method

Table B-87 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001119	0	3.57E-07	9.45E-04	1.74E-04	5.82E-08
Global warming	kg CO2 eq	55187.9	48964.18	159.7198	3910.769	730.7669	1422.461
Smog	kg O3 eq	3463.482	2217.59	33.03698	530.1696	62.61305	620.0728
Acidification	kg SO2 eq	229.6712	186.7103	1.02049	19.65103	2.760766	19.52858
Eutrophication	kg N eq	9.637307	4.254371	0.060775	3.481051	0.672927	1.168182
Carcinogenics	CTUh	0.002095	0.001944	1.25E-07	1.07E-04	2.31E-05	2.10E-05
Non carcinogenics	CTUh	0.000535	6.98E-05	2.96E-06	1.99E-04	6.15E-05	0.000202
Respiratory effects	kg PM2.5 eq	10.69869	8.241542	0.019983	1.74525	0.290003	0.401917
Ecotoxicity	CTUe	18853.25	424.937	76.71582	4898.033	9557.922	3895.646
Fossil fuel depletion	MJ surplus	233051.6	219917.9	326.6466	8355.063	1526.904	2925.057

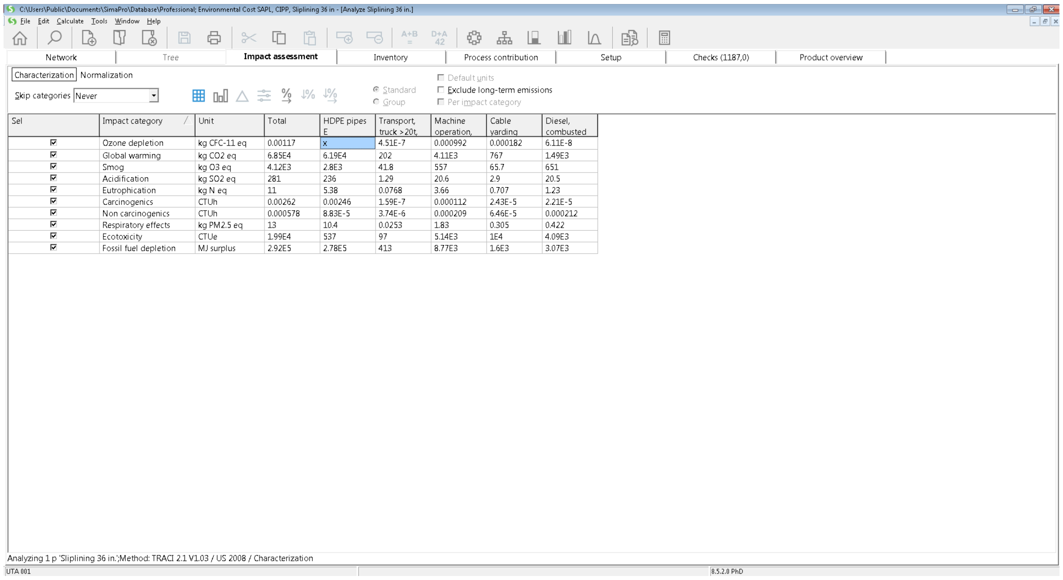
Table B-88 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.006938	0	2.21E-06	5.86E-03	1.08E-03	3.61E-07
Global warming	-	2.278261	2.021334	0.006594	0.161444	3.02E-02	0.058722
Smog	-	2.48829	1.593196	0.023735	0.380893	4.50E-02	0.445483
Acidification	-	2.528585	2.055603	0.011235	0.21635	3.04E-02	0.215002
Eutrophication	-	0.445846	0.196818	0.002812	0.161042	0.031131	0.054043
Carcinogenics	-	39.73481	36.86808	0.002379	2.026471	0.438836	0.399041
Non carcinogenics	-	0.509541	0.066497	0.00282	0.189448	0.058541	0.192235
Respiratory effects	-	0.44122	0.339886	0.000824	0.071975	1.20E-02	0.016575
Ecotoxicity	-	1.703101	0.038387	0.00693	0.442462	0.863411	0.351912
Fossil fuel depletion	-	12.38294	11.6851	0.017356	0.443937	8.11E-02	0.15542

Table B-89 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 30 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001119	0.04
Global warming	kg CO2 eq	55187.9	3,476.84
Smog	kg O3 eq	3463.482	7,619.66
Acidification	kg SO2 eq	229.6712	1,256.30
Eutrophication	kg N eq	9.637307	19.76
Carcinogenic	CTUh	0.002095	0.00
Non carcinogenic	CTUh	0.000535	0.00
Respiratory effects	kg PM2.5 eq	10.69869	677.66
Ecotoxicity	CTUe	18853.25	772.98
Fossil fuel depletion	MJ surplus	233051.6	2,283.91
Total			16,107.14

A.3.2 Sliplining 36 in.



Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00117	x	4.51E-7	0.000992	0.000182	6.11E-8
☑	Global warming	kg CO2 eq	6.85E4	6.19E4	202	4.11E3	767	1.49E3
☑	Smog	kg O3 eq	4.12E3	2.8E3	41.8	557	65.7	651
☑	Acidification	kg SO2 eq	281	236	1.29	20.6	2.9	20.5
☑	Eutrophication	kg N eq	11	5.38	0.0768	3.66	0.707	1.23
☑	Carcinogenics	CTUh	0.00262	0.00246	1.59E-7	0.000112	2.43E-5	2.21E-5
☑	Non carcinogenics	CTUh	0.000578	8.83E-5	3.74E-6	0.000209	6.46E-5	0.000212
☑	Respiratory effects	kg PM2.5 eq	13	10.4	0.0253	1.83	0.305	0.422
☑	Ecotoxicity	CTUe	1.99E4	537	97	5.14E3	1E4	4.09E3
☑	Fossil fuel depletion	MJ surplus	2.92E5	2.78E5	413	8.77E3	1.6E3	3.07E3

Analyzing 1 p 'Sliplining 36 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-117 Screenshot of the Impact Assessment Table from SimaPro Software for 36 in. Sliplining

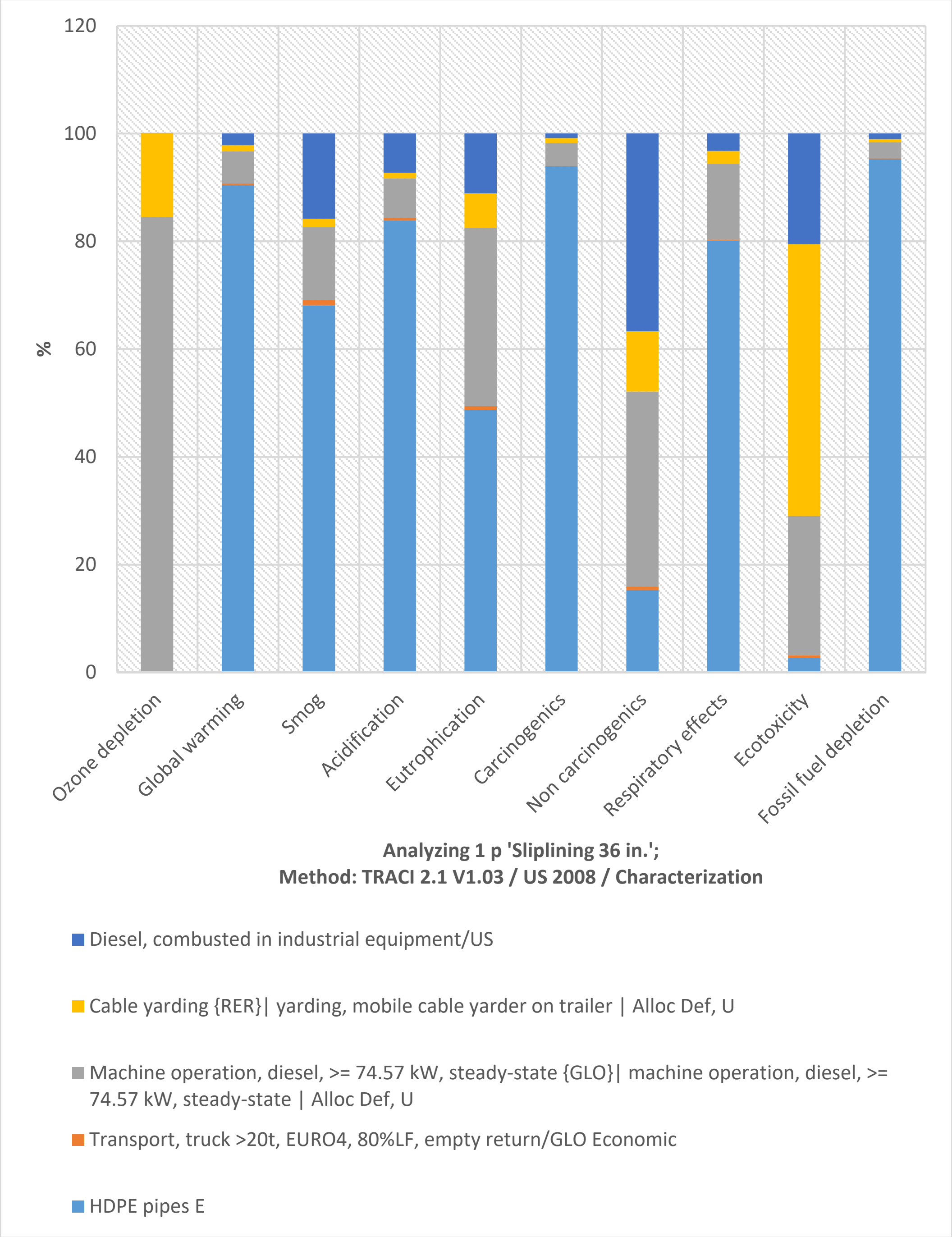


Figure B-118 Environmental Impact Assessment of 36 in. Diameter Sliplining Renewal Method

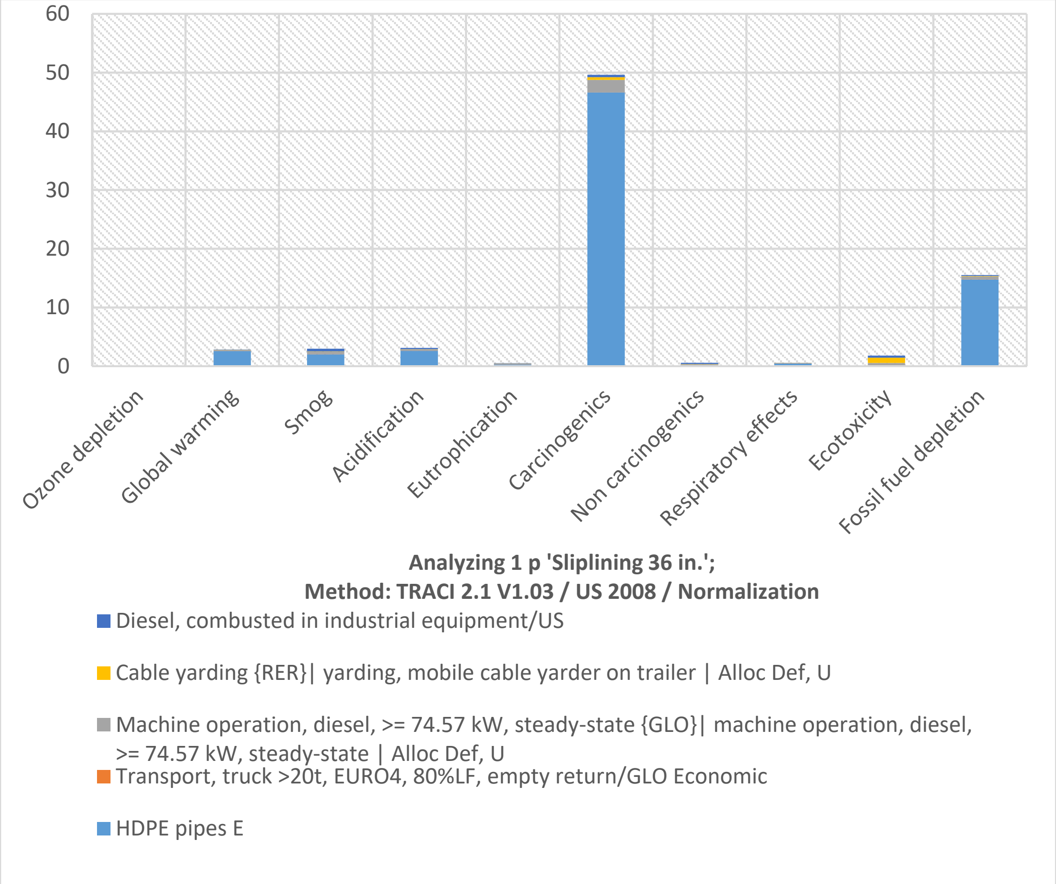


Figure B-119 Normalized Environmental Impact Assessment of 36 in. Diameter Sliplining Renewal Method

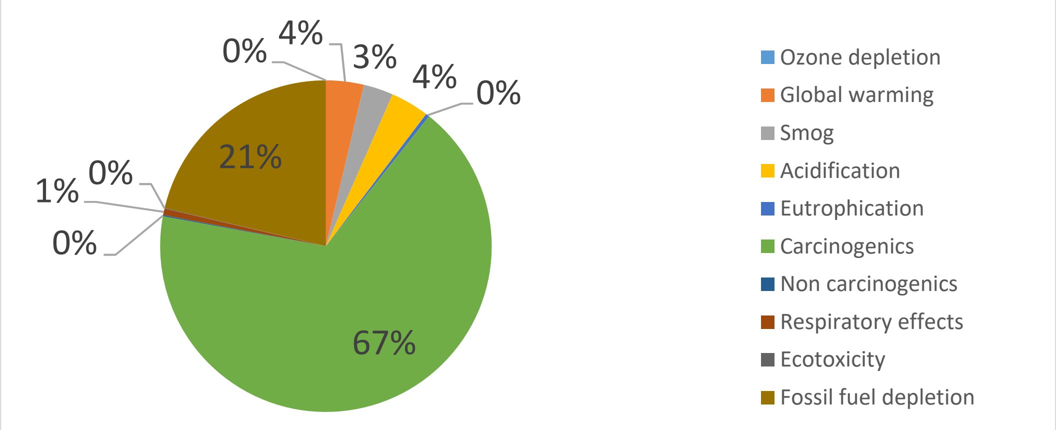


Figure B-120 Percentage of Normalized Environmental Impact Assessment of 36 in. Diameter Sliplining Renewal Method

Table B-90 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 36 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001175	0	4.51E-07	9.92E-04	1.82E-04	6.11E-08
Global warming	kg CO2 eq	68477.9	61908.74	201.9446	4106.307	767.3053	1493.608
Smog	kg O3 eq	4119.129	2803.849	41.7709	556.6781	65.7437	651.087
Acidification	kg SO2 eq	281.3985	236.0705	1.290274	20.63358	2.898804	20.50534
Eutrophication	kg N eq	11.04422	5.37909	0.076842	3.655103	0.706573	1.226611
Carcinogenics	CTUh	0.002616	0.002457	1.59E-07	1.12E-04	2.43E-05	2.21E-05
Non carcinogenics	CTUh	0.000578	8.83E-05	3.74E-06	2.09E-04	6.46E-05	0.000212
Respiratory effects	kg PM2.5 eq	13.00464	10.42034	0.025266	1.832512	0.304503	0.422019
Ecotoxicity	CTUe	19903.52	537.2767	96.99701	5142.935	10035.82	4090.494
Fossil fuel depletion	MJ surplus	291917.6	278057.2	413.0014	8772.816	1603.249	3071.359

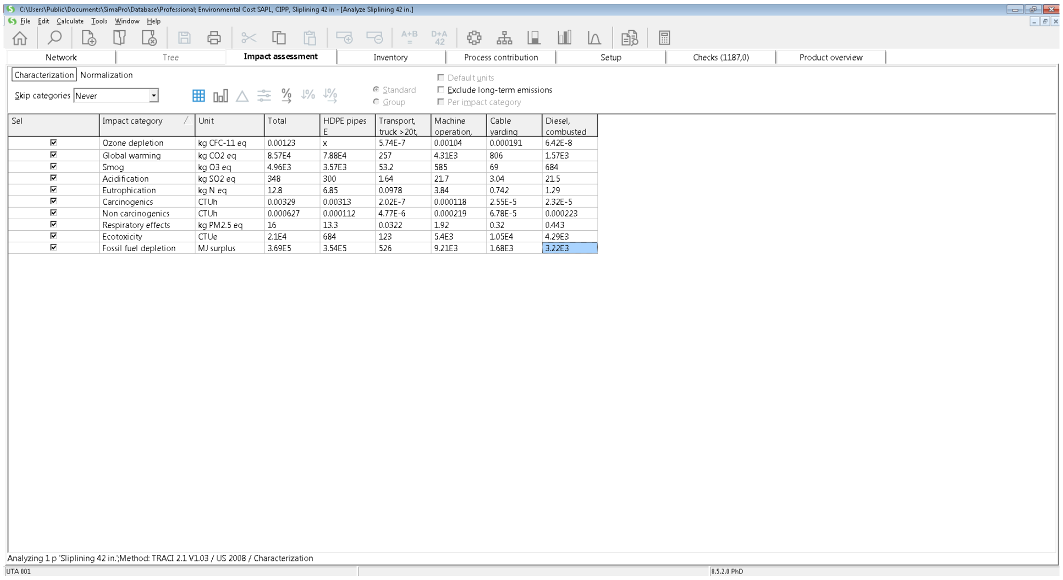
Table B-91 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 36 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.007286	0	2.80E-06	6.15E-03	1.13E-03	3.79E-07
Global warming	-	2.826898	2.55571	0.008337	0.169516	3.17E-02	0.061659
Smog	-	2.95933	2.014386	0.03001	0.399938	4.72E-02	0.467764
Acidification	-	3.098081	2.599039	0.014205	0.227167	3.19E-02	0.225755
Eutrophication	-	0.510933	0.24885	0.003555	0.169094	0.032688	0.056746
Carcinogenics	-	49.6254	46.61482	0.003009	2.127794	0.460777	0.418999
Non carcinogenics	-	0.549881	0.084077	0.003565	0.19892	0.061468	0.20185
Respiratory effects	-	0.536319	0.429741	0.001042	0.075574	1.26E-02	0.017404
Ecotoxicity	-	1.797977	0.048535	0.008762	0.464585	0.906582	0.369513
Fossil fuel depletion	-	15.51072	14.77426	0.021944	0.466134	8.52E-02	0.163193

Table B-92 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 36 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001175	0.04
Global warming	kg CO2 eq	68477.9	4,314.11
Smog	kg O3 eq	4119.129	9,062.08
Acidification	kg SO2 eq	281.3985	1,539.25
Eutrophication	kg N eq	11.04422	22.64
Carcinogenic	CTUh	0.002616	0.00
Non carcinogenic	CTUh	0.000578	0.01
Respiratory effects	kg PM2.5 eq	13.00464	823.71
Ecotoxicity	CTUe	19903.52	816.04
Fossil fuel depletion	MJ surplus	291917.6	2,860.79
Total			19,438.68

A.3.3 Sliplining 42 in.



Skip categories: Never

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00123	x	5.74E-7	0.00104	0.000191	6.42E-8
☑	Global warming	kg CO2 eq	8.57E4	7.88E4	257	4.31E3	806	1.57E3
☑	Smog	kg O3 eq	4.96E3	3.57E3	53.2	585	69	684
☑	Acidification	kg SO2 eq	348	300	1.64	21.7	3.04	21.5
☑	Eutrophication	kg N eq	12.8	6.85	0.0978	3.84	0.742	1.29
☑	Carcinogenics	CTUh	0.00329	0.00313	2.02E-7	0.000118	2.55E-5	2.32E-5
☑	Non carcinogenics	CTUh	0.000627	0.000112	4.77E-6	0.000219	6.78E-5	0.000223
☑	Respiratory effects	kg PM2.5 eq	16	13.3	0.0322	1.92	0.32	0.443
☑	Ecotoxicity	CTUe	2.1E4	684	123	5.4E3	1.05E4	4.29E3
☑	Fossil fuel depletion	MJ surplus	3.69E5	3.54E5	526	9.21E3	1.68E3	3.22E3

Analyzing 1 p 'Sliplining 42 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-121 Screenshot of the Impact Assessment Table from SimaPro Software for 42 in. Sliplining

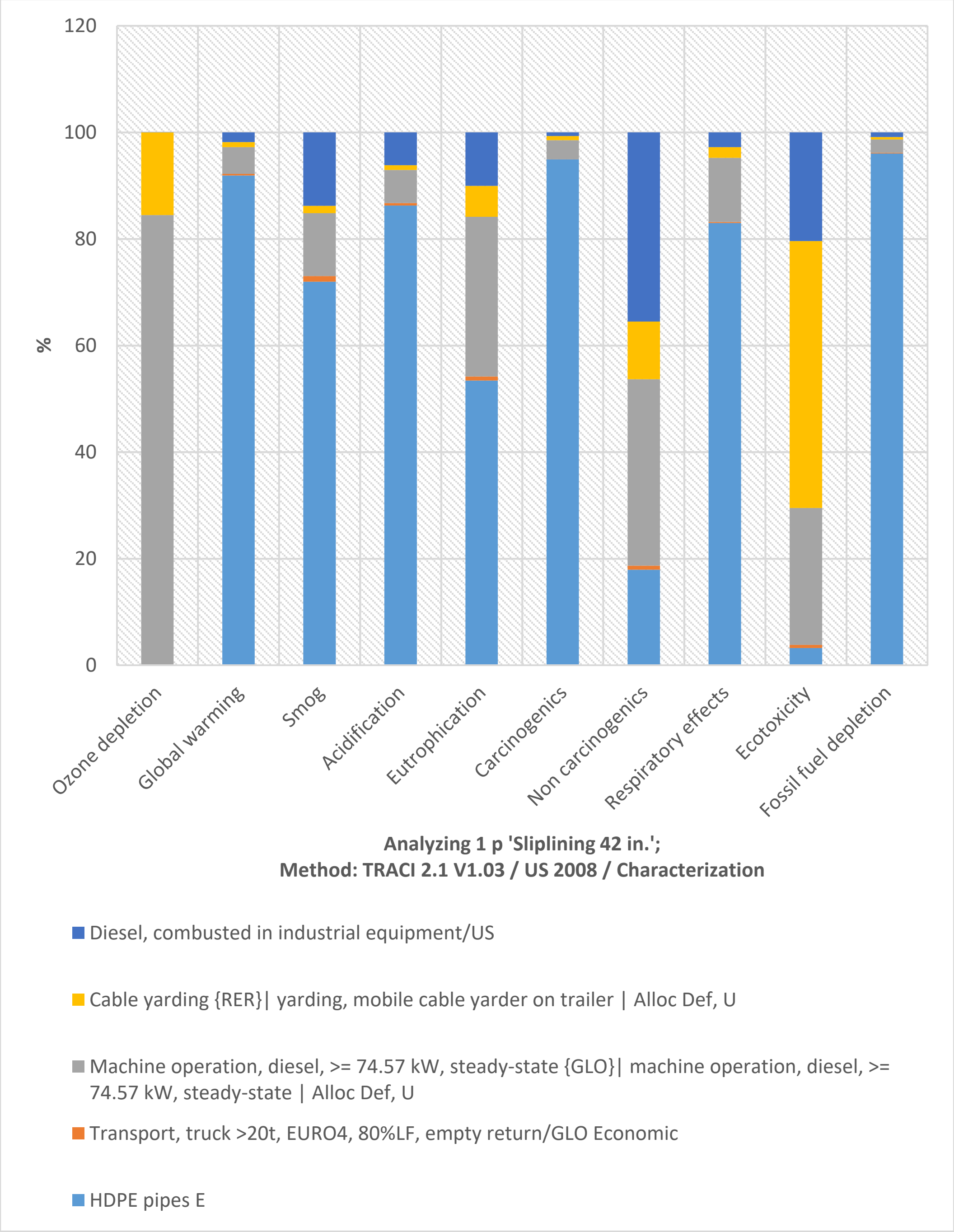


Figure B-122 Environmental Impact Assessment of 42 in. Diameter Sliplining Renewal Method

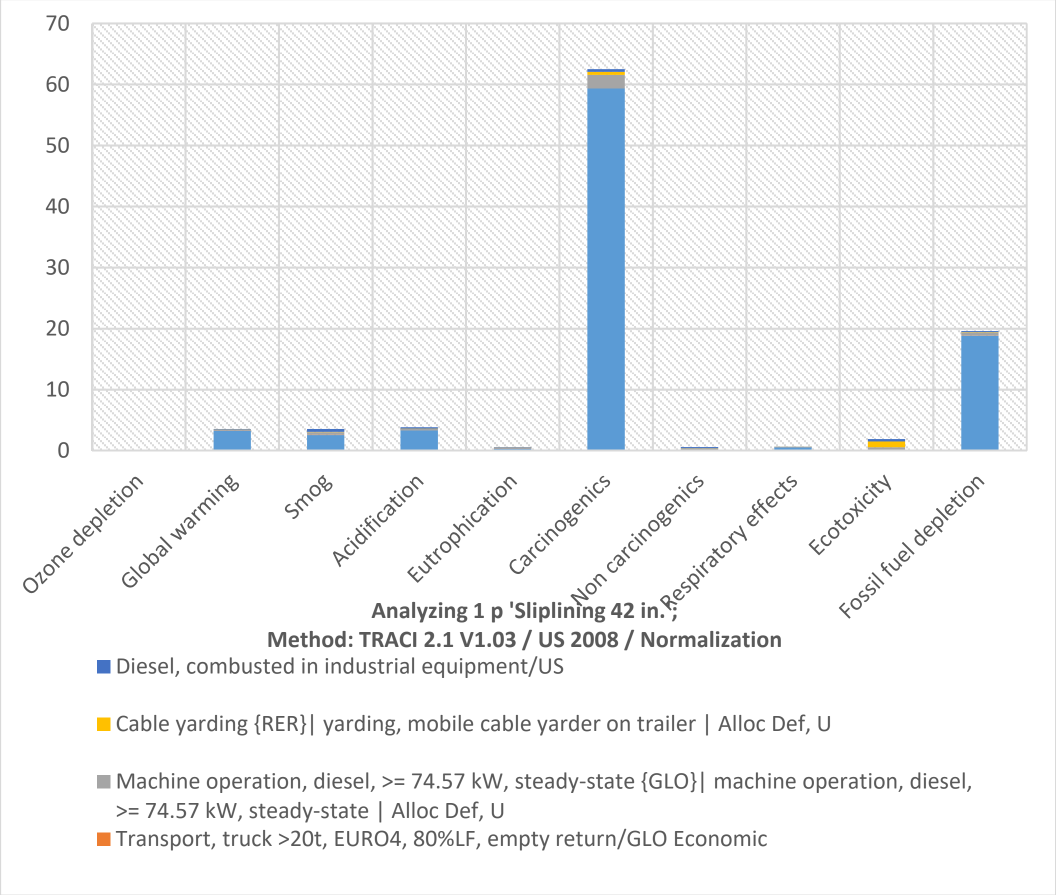


Figure B-123 Normalized Environmental Impact Assessment of 42 in. Diameter Sliplining Renewal Method

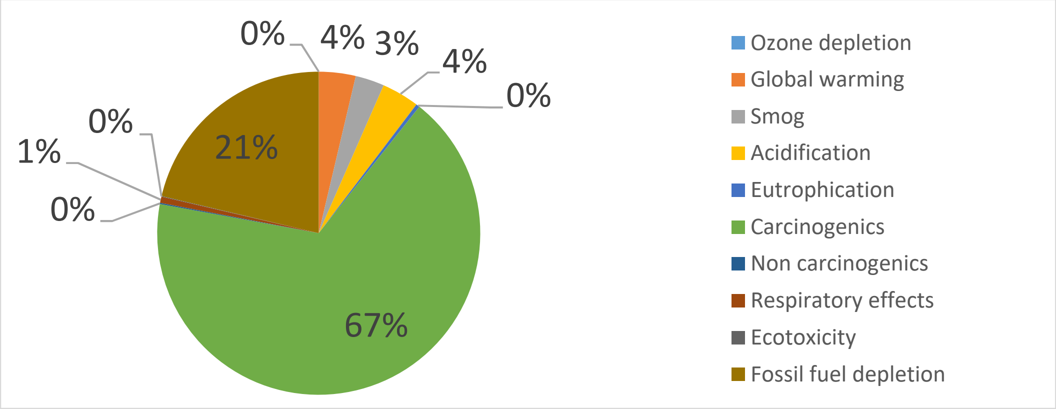


Figure B-124 Percentage of Normalized Environmental Impact Assessment of 42 in. Diameter Sliplining Renewal Method

Table B-93 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 42 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001234	0	5.74E-07	1.04E-03	1.91E-04	6.42E-08
Global warming	kg CO2 eq	85735.49	78792.94	257.0204	4311.623	805.6705	1568.24
Smog	kg O3 eq	4958.861	3568.535	53.16296	584.512	69.03088	683.6203
Acidification	kg SO2 eq	348.3345	300.4534	1.642167	21.66526	3.043744	21.52995
Eutrophication	kg N eq	12.81158	6.846115	0.097799	3.837859	0.741902	1.287902
Carcinogenics	CTUh	0.003294	0.003128	2.02E-07	1.18E-04	2.55E-05	2.32E-05
Non carcinogenics	CTUh	0.000627	0.000112	4.77E-06	2.19E-04	6.78E-05	0.000223
Respiratory effects	kg PM2.5 eq	15.98138	13.26225	0.032157	1.924138	0.319728	0.443107
Ecotoxicity	CTUe	21039.83	683.8067	123.4507	5400.082	10537.61	4294.887
Fossil fuel depletion	MJ surplus	368536.3	353890.9	525.6381	9211.457	1683.412	3224.828

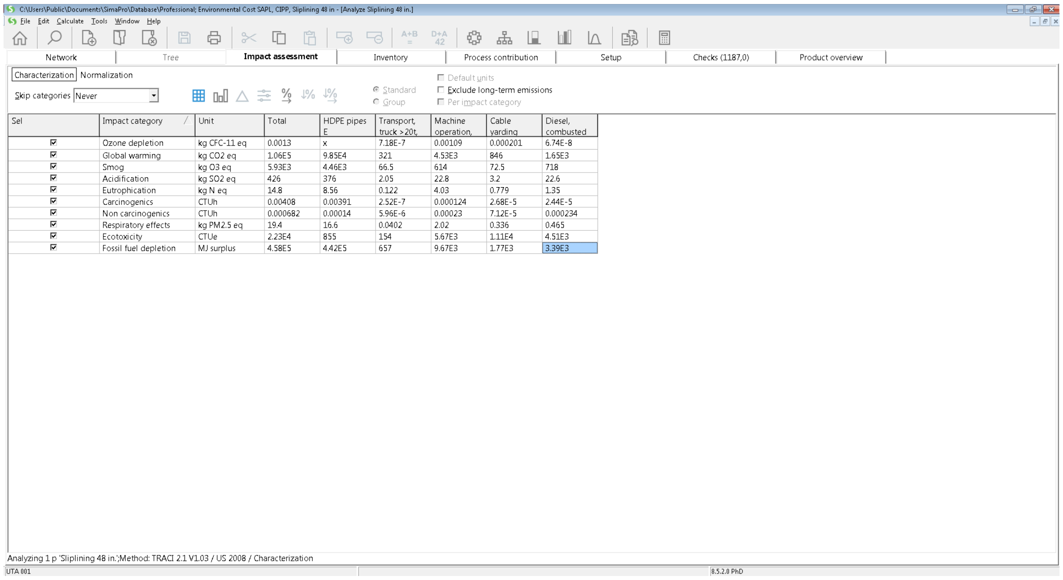
Table B-94 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 42 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.007651	0	3.56E-06	6.46E-03	1.19E-03	3.98E-07
Global warming	-	3.539324	3.252722	0.01061	0.177992	3.33E-02	0.06474
Smog	-	3.562624	2.563764	0.038194	0.419934	4.96E-02	0.491137
Acidification	-	3.835019	3.307868	0.01808	0.238526	3.35E-02	0.237036
Eutrophication	-	0.592696	0.316718	0.004524	0.177549	0.034322	0.059582
Carcinogenics	-	62.48972	59.32795	0.003829	2.234184	0.483816	0.439936
Non carcinogenics	-	0.596888	0.107007	0.004538	0.208866	0.064542	0.211936
Respiratory effects	-	0.659081	0.546943	0.001326	0.079352	1.32E-02	0.018274
Ecotoxicity	-	1.900625	0.061771	0.011152	0.487814	0.951911	0.387977
Fossil fuel depletion	-	19.58177	18.80361	0.027929	0.489441	8.94E-02	0.171348

Table B-95 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 42 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.000637	0.04
Global warming	kg CO2 eq	63610.51	5,401.34
Smog	kg O3 eq	4656.284	10,909.49
Acidification	kg SO2 eq	333.1561	1,905.39
Eutrophication	kg N eq	11.62082	26.26
Carcinogenic	CTUh	0.000281	0.00
Non carcinogenic	CTUh	0.005696	0.01
Respiratory effects	kg PM2.5 eq	19.85594	1,012.26
Ecotoxicity	CTUe	15341.61	862.63
Fossil fuel depletion	MJ surplus	11274.51	3,611.66
Total			23,729.08

A.3.4 Sliplining 48 in.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 48 in - [Analyze Sliplining 48 in.]

Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.0013	x	7.18E-7	0.00109	0.000201	6.74E-8
☑	Global warming	kg CO2 eq	1.06E5	9.85E4	321	4.53E3	846	1.65E3
☑	Smog	kg O3 eq	5.93E3	4.46E3	66.5	614	72.5	718
☑	Acidification	kg SO2 eq	426	376	2.05	22.8	3.2	22.6
☑	Eutrophication	kg N eq	14.8	8.56	0.122	4.03	0.779	1.35
☑	Carcinogenics	CTUh	0.00408	0.00391	2.52E-7	0.000124	2.68E-5	2.44E-5
☑	Non carcinogenics	CTUh	0.000682	0.00014	5.96E-6	0.00023	7.12E-5	0.000234
☑	Respiratory effects	kg PM2.5 eq	19.4	16.6	0.0402	2.02	0.336	0.465
☑	Ecotoxicity	CTUe	2.23E4	855	154	5.67E3	1.11E4	4.51E3
☑	Fossil fuel depletion	MJ surplus	4.58E5	4.42E5	657	9.67E3	1.77E3	3.39E3

Analyzing 1 p 'Sliplining 48 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-125 Screenshot of the Impact Assessment Table from SimaPro Software for 48 in. Sliplining

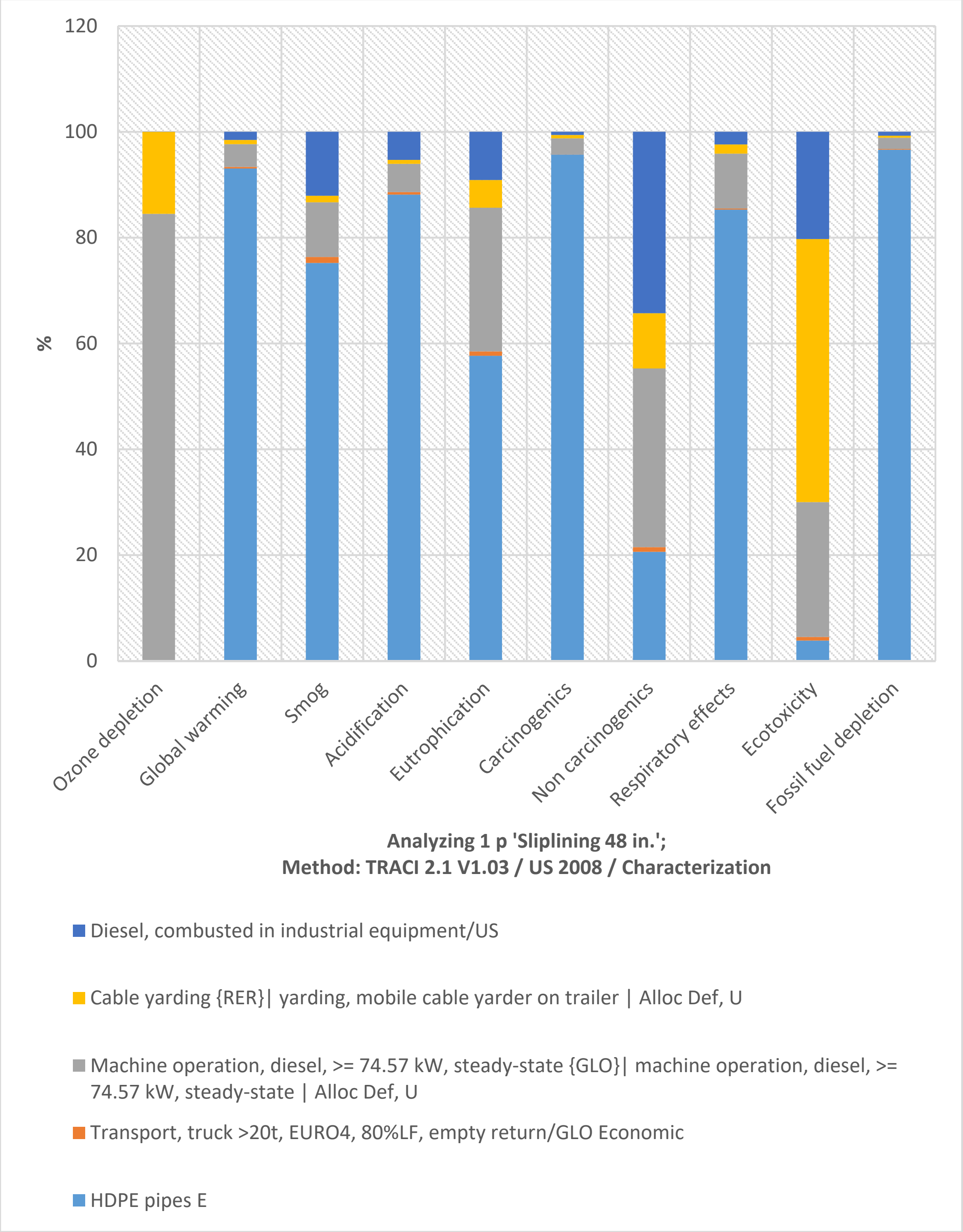


Figure B-126 Environmental Impact Assessment of 48 in. Diameter Sliplining Renewal Method

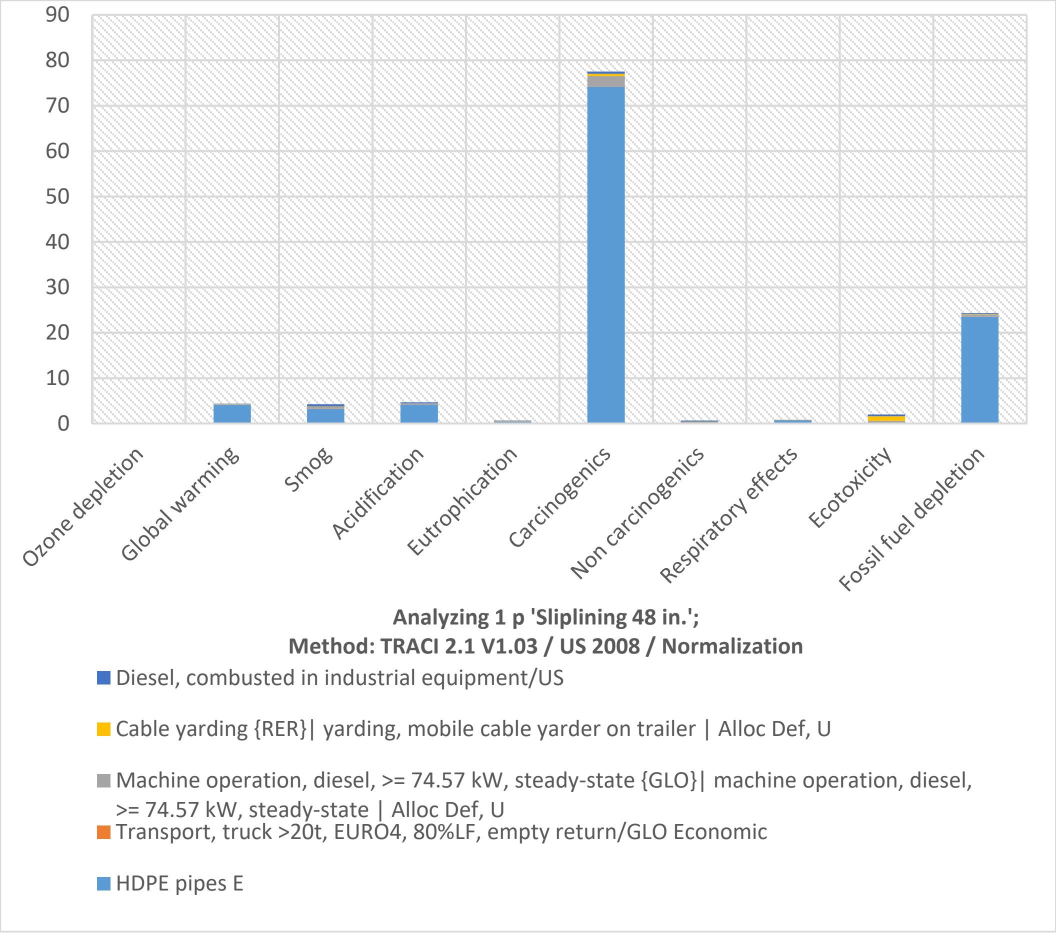


Figure B-127 Normalized Environmental Impact Assessment
of 48 in. Diameter Sliplining Renewal Method

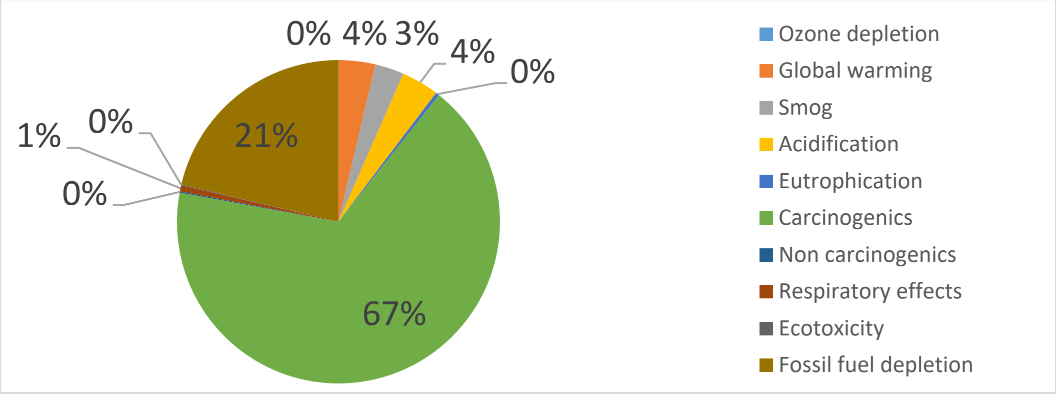


Figure B-128 Percentage of Normalized Environmental Impact Assessment of
48 in. Diameter Sliplining Renewal Method

Table B-96 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 48 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001296	0	7.18E-07	1.09E-03	2.01E-04	6.74E-08
Global warming	kg CO2 eq	105832.6	98491.17	321.2754	4527.53	845.8627	1646.718
Smog	kg O3 eq	5931.209	4460.669	66.4537	613.7818	72.4746	717.8302
Acidification	kg SO2 eq	426.1726	375.5668	2.052709	22.75016	3.195587	22.60735
Eutrophication	kg N eq	14.8412	8.557644	0.122249	4.030042	0.778913	1.352352
Carcinogenics	CTUh	0.004085	0.00391	2.52E-07	1.24E-04	2.68E-05	2.44E-05
Non carcinogenics	CTUh	0.000682	0.00014	5.96E-06	2.30E-04	7.12E-05	0.000234
Respiratory effects	kg PM2.5 eq	19.43946	16.57782	0.040196	2.02049	0.335678	0.465281
Ecotoxicity	CTUe	22252.67	854.7583	154.3134	5670.494	11063.29	4509.812
Fossil fuel depletion	MJ surplus	457847	442363.7	657.0477	9672.726	1767.391	3386.206

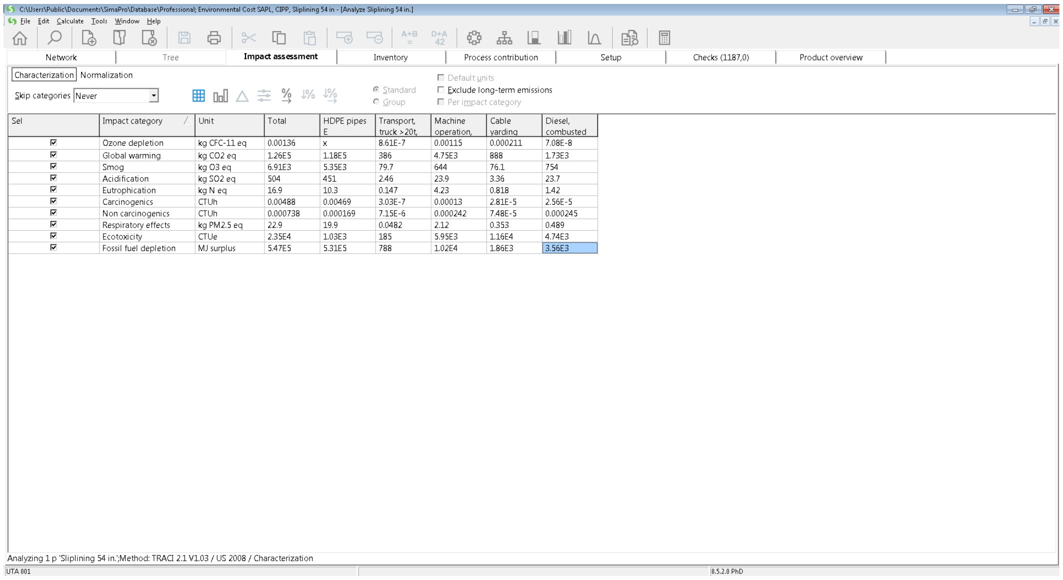
Table B-97 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 48 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.008034	0	4.45E-06	6.78E-03	1.25E-03	4.18E-07
Global warming	-	4.368969	4.065903	0.013263	0.186905	3.49E-02	0.06798
Smog	-	4.261194	3.204705	0.047743	0.440963	5.21E-02	0.515715
Acidification	-	4.691983	4.134834	0.022599	0.25047	3.52E-02	0.248898
Eutrophication	-	0.686591	0.395898	0.005656	0.18644	0.036034	0.062563
Carcinogenics	-	77.48069	74.15994	0.004786	2.346062	0.507952	0.461951
Non carcinogenics	-	0.649059	0.133758	0.005672	0.219325	0.067761	0.222542
Respiratory effects	-	0.801694	0.683678	0.001658	0.083326	1.38E-02	0.019188
Ecotoxicity	-	2.010186	0.077214	0.01394	0.512242	0.999398	0.407392
Fossil fuel depletion	-	24.3272	23.50451	0.034912	0.51395	9.39E-02	0.179922

Table B-98 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 48 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001296	0.04
Global warming	kg CO2 eq	105832.6	6,667.45
Smog	kg O3 eq	5931.209	13,048.66
Acidification	kg SO2 eq	426.1726	2,331.16
Eutrophication	kg N eq	14.8412	30.42
Carcinogenic	CTUh	0.004085	0.00
Non carcinogenic	CTUh	0.000682	0.01
Respiratory effects	kg PM2.5 eq	19.43946	1,231.30
Ecotoxicity	CTUe	22252.67	912.36
Fossil fuel depletion	MJ surplus	457847	4,486.90
Total			28,708.30

A.3.5 Sliplining 54 in.



Skip categories: Never

○ Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00136	x	8.61E-7	0.00115	0.000211	7.08E-8
☑	Global warming	kg CO2 eq	1.26E5	1.18E5	386	4.75E3	888	1.73E3
☑	Smog	kg O3 eq	6.91E3	5.35E3	79.7	644	76.1	754
☑	Acidification	kg SO2 eq	504	451	2.46	23.9	3.36	23.7
☑	Eutrophication	kg N eq	16.9	10.3	0.147	4.23	0.818	1.42
☑	Carcinogenics	CTUh	0.00488	0.00469	3.03E-7	0.00013	2.81E-5	2.56E-5
☑	Non carcinogenics	CTUh	0.000738	0.000169	7.15E-6	0.000242	7.48E-5	0.000245
☑	Respiratory effects	kg PM2.5 eq	22.9	19.9	0.0482	2.12	0.353	0.489
☑	Ecotoxicity	CTUe	2.35E4	1.03E3	185	5.95E3	1.16E4	4.74E3
☑	Fossil fuel depletion	MJ surplus	5.47E5	5.31E5	788	1.02E4	1.86E3	3.56E3

Analyzing 1 p 'Sliplining 54 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-129 Screenshot of the Impact Assessment Table from SimaPro Software for 54 in. Sliplining

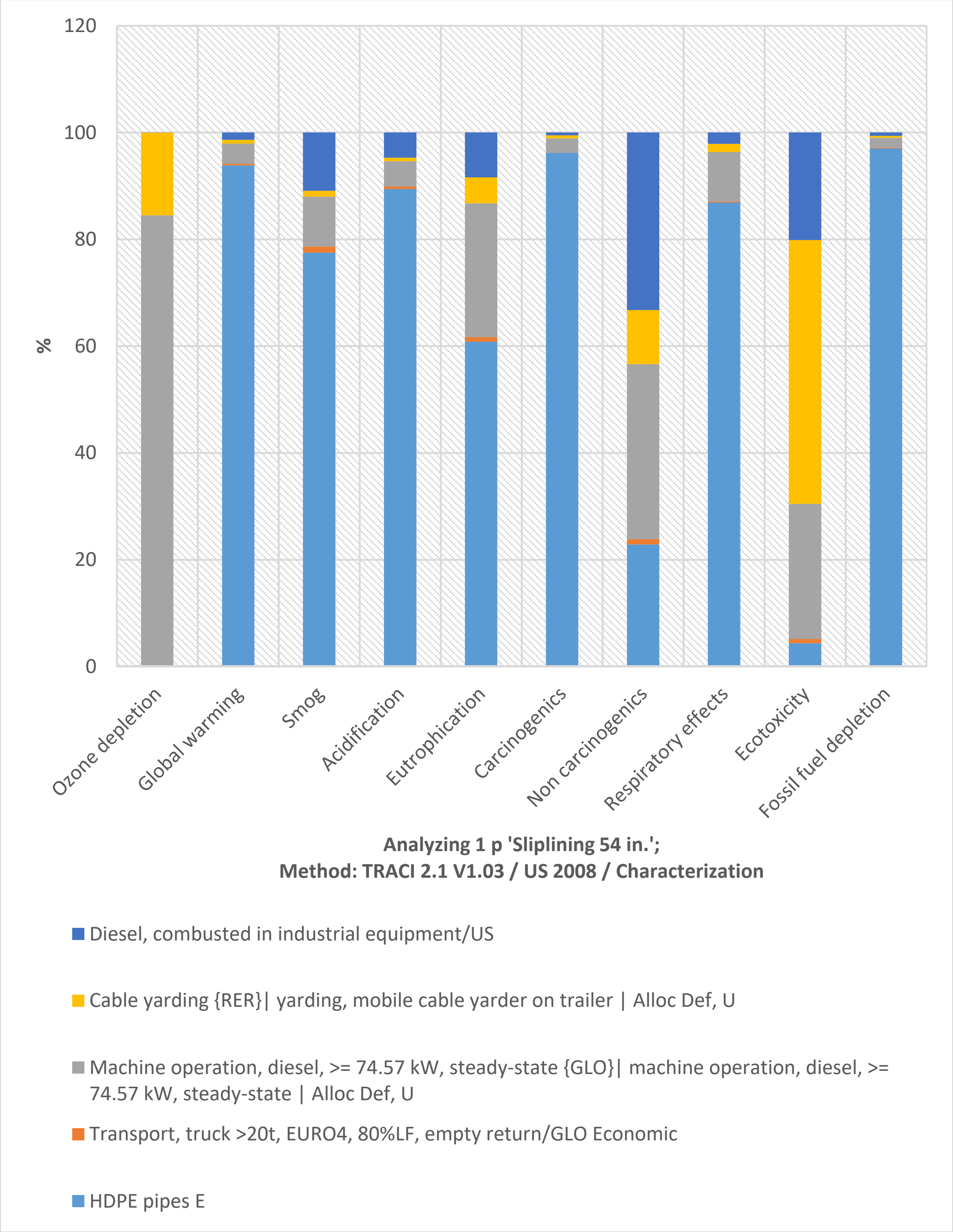


Figure B-130 Environmental Impact Assessment of 54 in. Diameter Sliplining Renewal Method

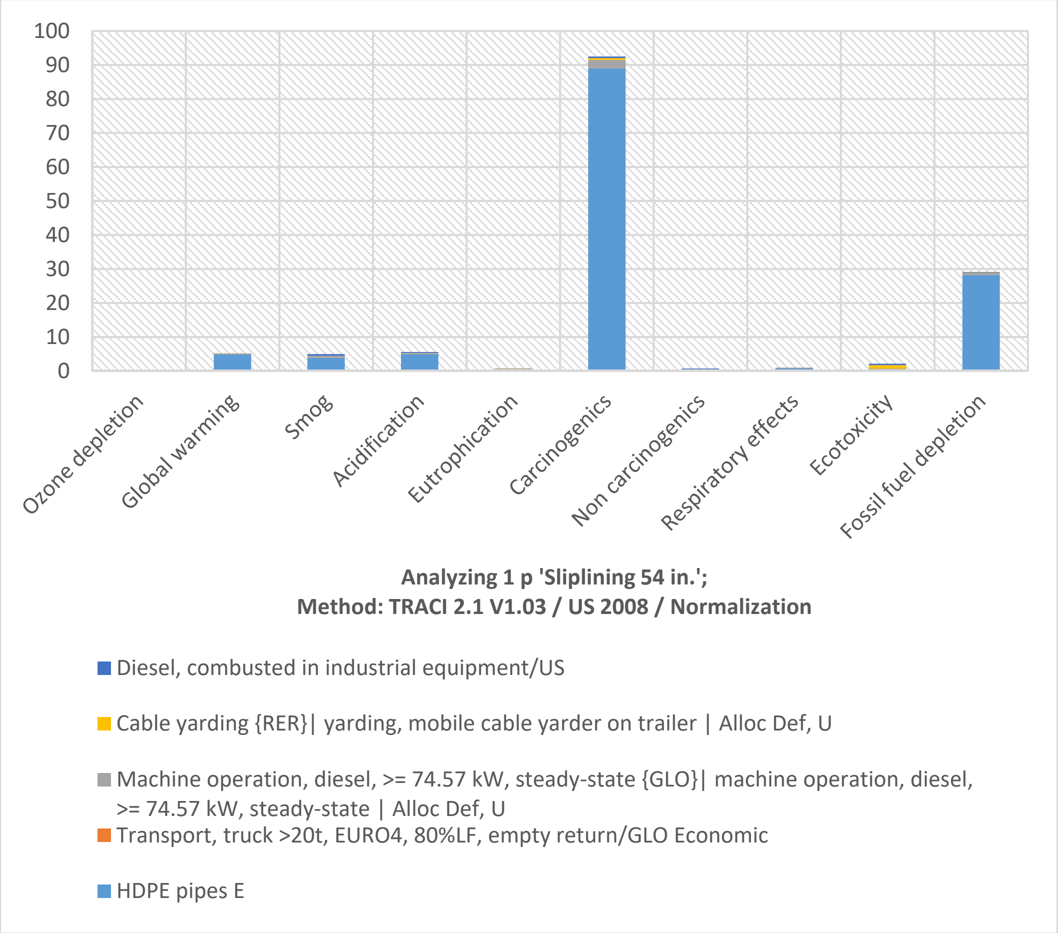


Figure B-131 Normalized Environmental Impact Assessment of 54 in. Diameter Sliplining Renewal Method

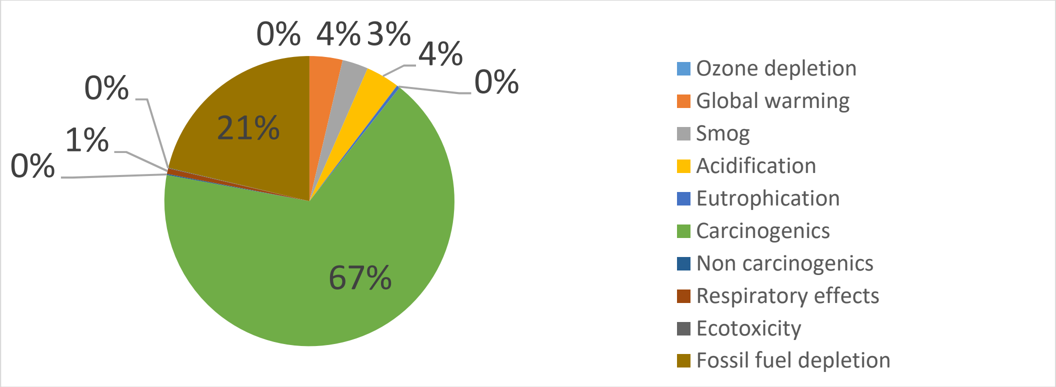


Figure B-132 Percentage of Normalized Environmental Impact Assessment of 54 in. Diameter Sliplining Renewal Method

Table B-99 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 54 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.00136	0	8.61E-07	1.15E-03	2.11E-04	7.08E-08
Global warming	kg CO2 eq	125945.7	118189.4	385.5305	4753.214	888.4908	1729.042
Smog	kg O3 eq	6906.767	5352.802	79.74444	644.377	76.12703	753.7164
Acidification	kg SO2 eq	504.1217	450.6801	2.463251	23.88419	3.356631	23.73756
Eutrophication	kg N eq	16.88493	10.26917	0.146699	4.230927	0.818167	1.419959
Carcinogenics	CTUh	0.004875	0.004692	3.03E-07	1.30E-04	2.81E-05	2.56E-05
Non carcinogenics	CTUh	0.000738	0.000169	7.15E-06	2.42E-04	7.48E-05	0.000245
Respiratory effects	kg PM2.5 eq	22.90395	19.89338	0.048235	2.121205	0.352595	0.488541
Ecotoxicity	CTUe	23520.15	1025.71	185.1761	5953.151	11620.84	4735.27
Fossil fuel depletion	MJ surplus	547191.7	530836.4	788.4572	10154.88	1856.461	3555.491

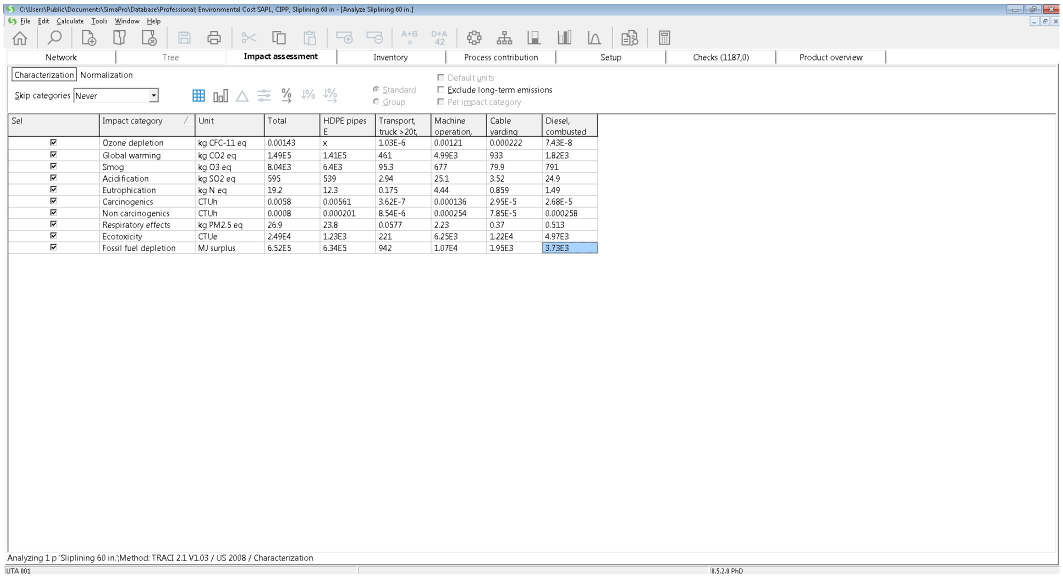
Table B-100 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 54 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.008436	0	5.34E-06	7.12E-03	1.31E-03	4.39E-07
Global warming	-	5.199277	4.879083	0.015915	0.196222	3.67E-02	0.071378
Smog	-	4.96207	3.845646	0.057291	0.462944	5.47E-02	0.541497
Acidification	-	5.550171	4.961801	0.027119	0.262955	3.70E-02	0.261341
Eutrophication	-	0.781139	0.475078	0.006787	0.195733	0.03785	0.065691
Carcinogenics	-	92.47927	88.99193	0.005744	2.463006	0.533551	0.485045
Non carcinogenics	-	0.702418	0.16051	0.006807	0.230258	0.071176	0.233667
Respiratory effects	-	0.944572	0.820414	0.001989	0.08748	1.45E-02	0.020148
Ecotoxicity	-	2.124683	0.092657	0.016728	0.537776	1.049764	0.427759
Fossil fuel depletion	-	29.07443	28.20541	0.041894	0.539569	9.86E-02	0.188917

Table B-101 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 54 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.00136	0.04
Global warming	kg CO2 eq	125945.7	7,934.58
Smog	kg O3 eq	6906.767	15,194.89
Acidification	kg SO2 eq	504.1217	2,757.55
Eutrophication	kg N eq	16.88493	34.61
Carcinogenic	CTUh	0.004875	0.00
Non carcinogenic	CTUh	0.000738	0.01
Respiratory effects	kg PM2.5 eq	22.90395	1,450.74
Ecotoxicity	CTUe	23520.15	964.33
Fossil fuel depletion	MJ surplus	547191.7	5,362.48
Total			33,699.22

A.3.6 Sliplining 60 in.



Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00143	x	1.03E-6	0.00121	0.000222	7.43E-8
☑	Global warming	kg CO2 eq	1.49E5	1.41E5	461	4.99E3	933	1.82E3
☑	Smog	kg O3 eq	8.04E3	6.4E3	95.3	677	79.9	791
☑	Acidification	kg SO2 eq	595	539	2.94	25.1	3.52	24.9
☑	Eutrophication	kg N eq	19.2	12.3	0.175	4.44	0.859	1.49
☑	Carcinogenics	CTUh	0.0058	0.00561	3.62E-7	0.000136	2.95E-5	2.68E-5
☑	Non carcinogenics	CTUh	0.0008	0.000201	8.54E-6	0.000254	7.85E-5	0.000258
☑	Respiratory effects	kg PM2.5 eq	26.9	23.8	0.0577	2.23	0.37	0.513
☑	Ecotoxicity	CTUe	2.49E4	1.23E3	221	6.25E3	1.22E4	4.97E3
☑	Fossil fuel depletion	MJ surplus	6.52E5	6.34E5	942	1.07E4	1.95E3	3.73E3

Analyzing 1 p 'Sliplining 60 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-133 Screenshot of the Impact Assessment Table from SimaPro Software for 60 in. Sliplining

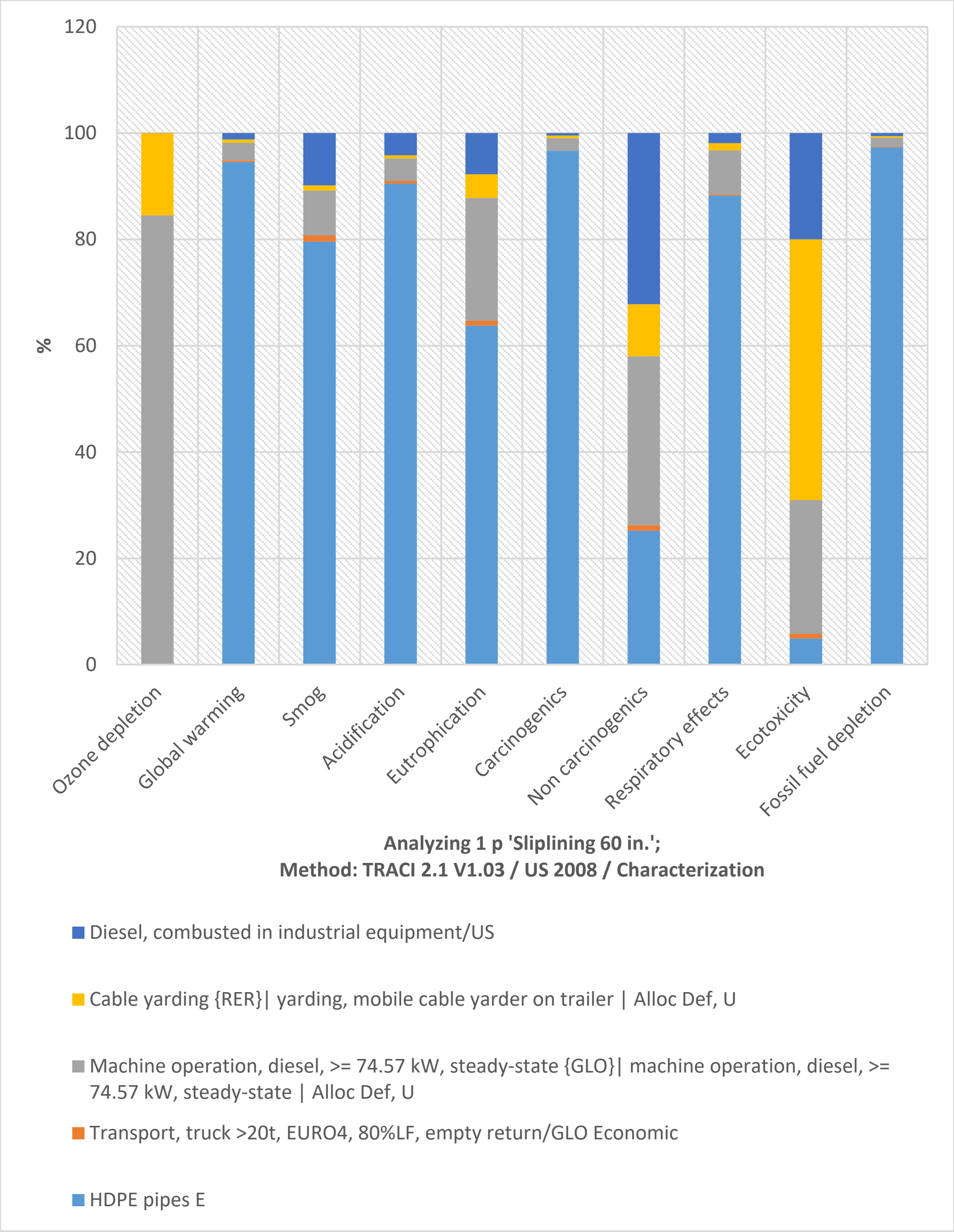


Figure B-134 Environmental Impact Assessment of 60 in. Diameter Sliplining Renewal Method

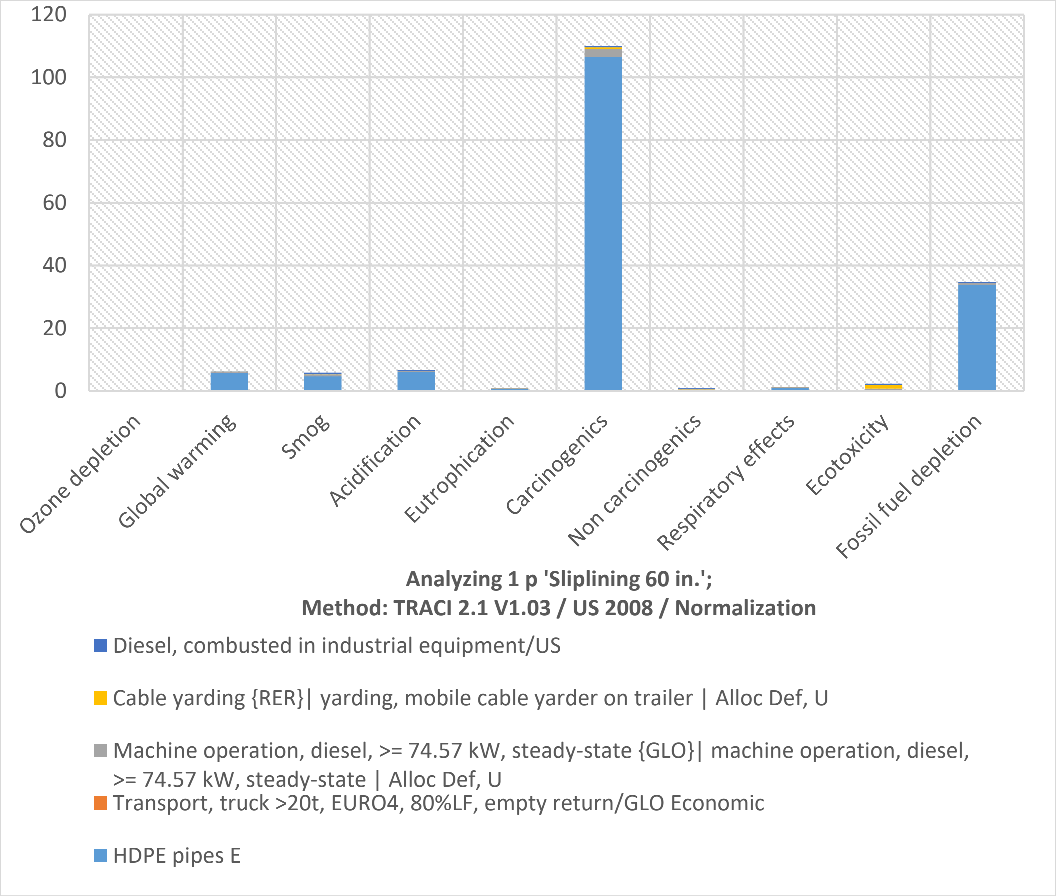


Figure B-135 Normalized Environmental Impact Assessment of 60 in. Diameter Sliplining Renewal Method

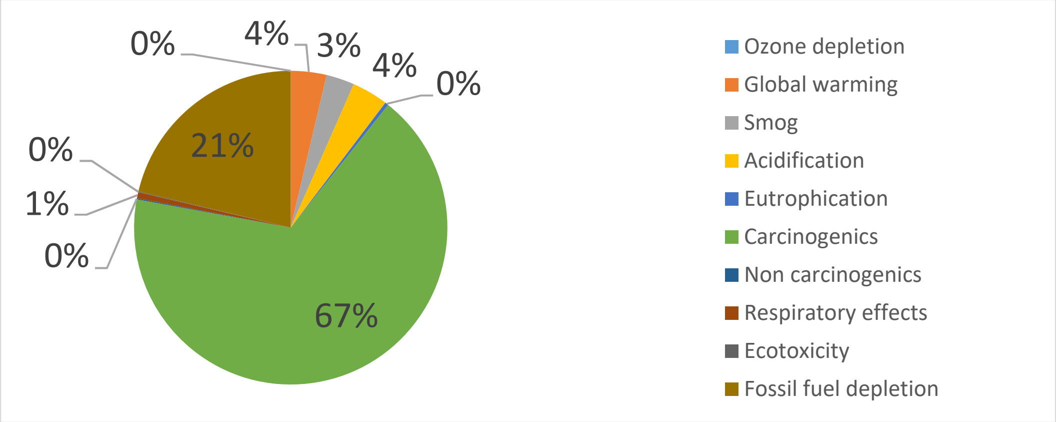


Figure B-136 Percentage of Normalized Environmental Impact Assessment of 60 in. Diameter Sliplining Renewal Method

Table B-102 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 60 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001429	0	1.03E-06	1.21E-03	2.22E-04	7.43E-08
Global warming	kg CO2 eq	149464.8	141264.5	460.8008	4991.119	932.9458	1815.452
Smog	kg O3 eq	8041.136	6397.873	95.31359	676.629	79.93599	791.3839
Acidification	kg SO2 eq	595.1423	538.67	2.944171	25.07962	3.524578	24.92386
Eutrophication	kg N eq	19.24216	12.27411	0.17534	4.442691	0.859103	1.490923
Carcinogenics	CTUh	0.005801	0.005608	3.62E-07	1.36E-04	2.95E-05	2.68E-05
Non carcinogenics	CTUh	0.0008	0.000201	8.54E-06	2.54E-04	7.85E-05	0.000258
Respiratory effects	kg PM2.5 eq	26.94554	23.77732	0.057653	2.227375	0.370237	0.512956
Ecotoxicity	CTUe	24872.61	1225.968	221.3295	6251.115	12202.28	4971.918
Fossil fuel depletion	MJ surplus	651763.9	634475.9	942.3941	10663.15	1949.347	3733.179

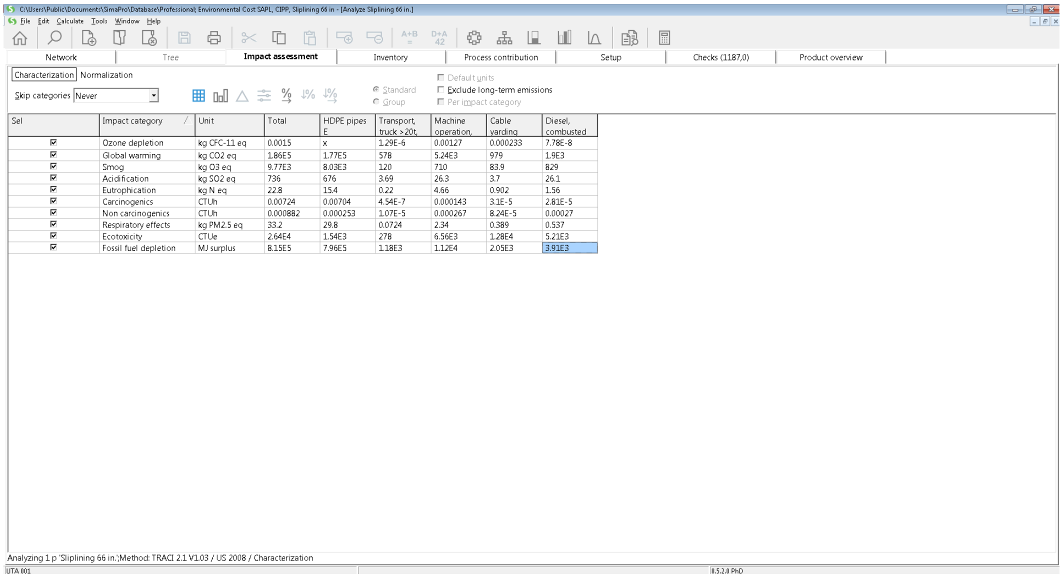
Table B-103 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 60 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.008859	0	6.38E-06	7.48E-03	1.37E-03	4.61E-07
Global warming	-	6.170191	5.831666	0.019023	0.206043	3.85E-02	0.074945
Smog	-	5.777041	4.596463	0.068477	0.486115	5.74E-02	0.568559
Acidification	-	6.55227	5.930534	0.032414	0.276116	3.88E-02	0.274401
Eutrophication	-	0.890191	0.567831	0.008112	0.20553	0.039744	0.068974
Carcinogenics	-	110.0292	106.3665	0.006865	2.586283	0.560247	0.509286
Non carcinogenics	-	0.761849	0.191848	0.008136	0.241783	0.074737	0.245345
Respiratory effects	-	1.111249	0.98059	0.002378	0.091858	1.53E-02	0.021155
Ecotoxicity	-	2.246857	0.110747	0.019994	0.564692	1.102288	0.449136
Fossil fuel depletion	-	34.63076	33.71218	0.050073	0.566575	1.04E-01	0.198358

Table B-104 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 60 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001429	0.05
Global warming	kg CO2 eq	149464.8	9,416.28
Smog	kg O3 eq	8041.136	17,690.50
Acidification	kg SO2 eq	595.1423	3,255.43
Eutrophication	kg N eq	19.24216	39.45
Carcinogenic	CTUh	0.005801	0.00
Non carcinogenic	CTUh	0.0008	0.01
Respiratory effects	kg PM2.5 eq	26.94554	1,706.73
Ecotoxicity	CTUe	24872.61	1,019.78
Fossil fuel depletion	MJ surplus	651763.9	6,387.29
Total			39,515.50

A.3.7 Sliplining 66 in.



Skip categories: Never

○ Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.0015	x	1.29E-6	0.00127	0.000233	7.78E-8
☑	Global warming	kg CO2 eq	1.86E5	1.77E5	578	5.24E3	979	1.9E3
☑	Smog	kg O3 eq	9.77E3	8.03E3	120	710	83.9	829
☑	Acidification	kg SO2 eq	736	676	3.69	26.3	3.7	26.1
☑	Eutrophication	kg N eq	22.8	15.4	0.22	4.66	0.902	1.56
☑	Carcinogenics	CTUh	0.00724	0.00704	4.54E-7	0.000143	3.1E-5	2.81E-5
☑	Non carcinogenics	CTUh	0.000882	0.000253	1.07E-5	0.000267	8.24E-5	0.00027
☑	Respiratory effects	kg PM2.5 eq	33.2	29.8	0.0724	2.34	0.389	0.537
☑	Ecotoxicity	CTUe	2.64E4	1.54E3	278	6.56E3	1.28E4	5.21E3
☑	Fossil fuel depletion	MJ surplus	8.15E5	7.96E5	1.18E3	1.12E4	2.05E3	3.91E3

Analyzing 1 p 'Sliplining 66 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-137 Screenshot of the Impact Assessment Table from SimaPro Software for 66 in. Sliplining

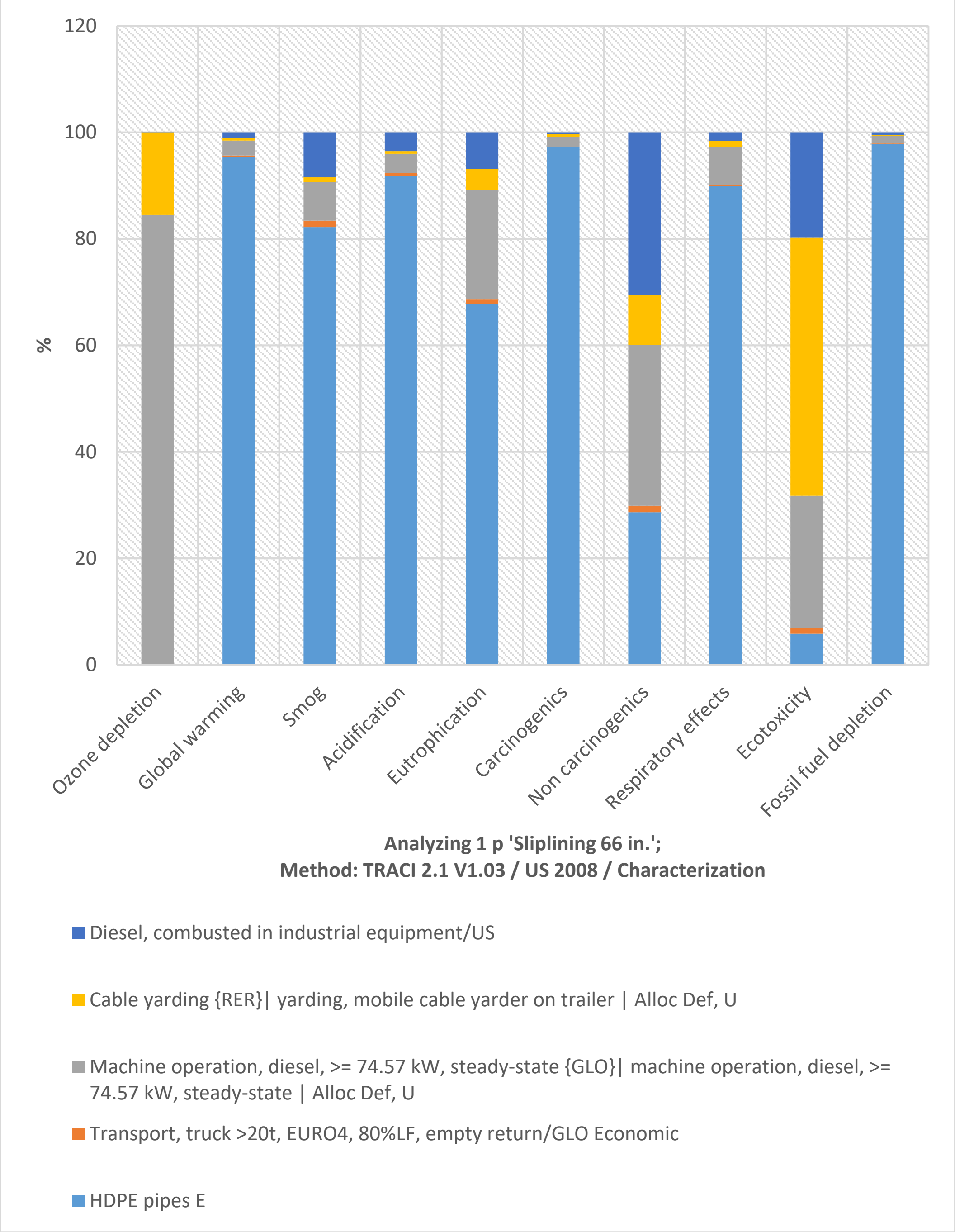


Figure B-138 Environmental Impact Assessment of 66 in. Diameter Sliplining Renewal Method

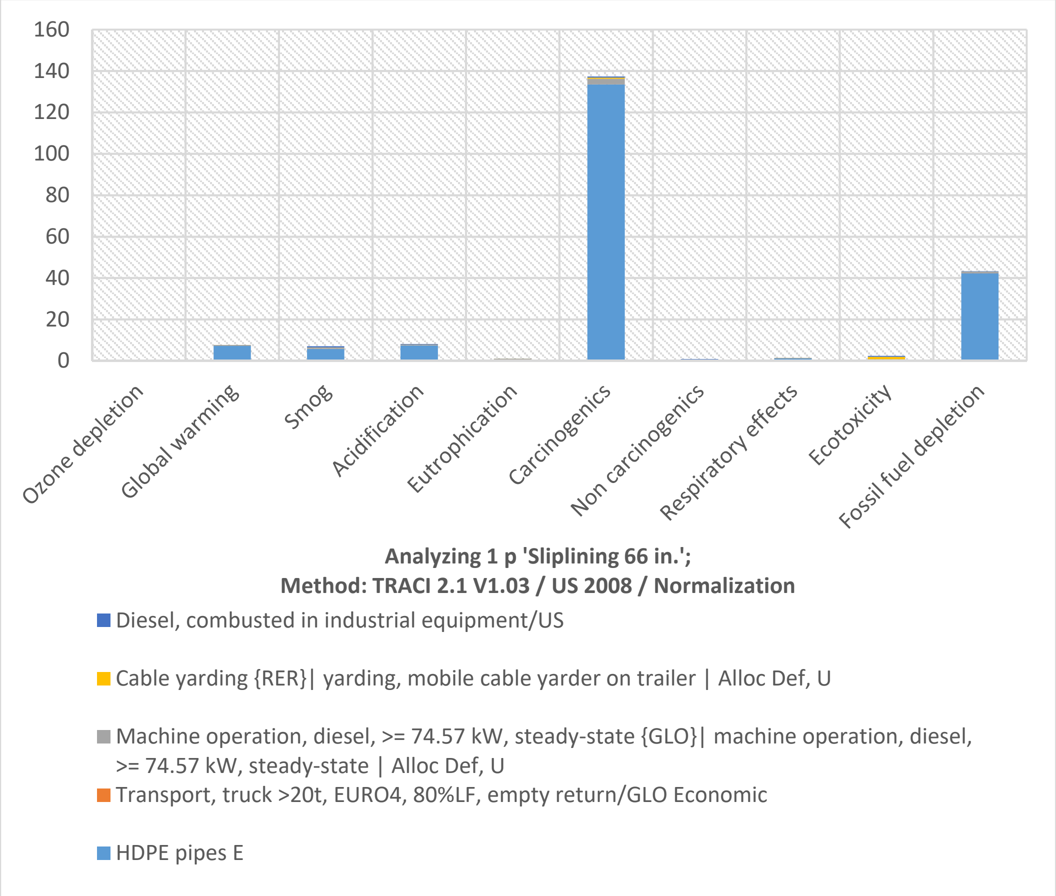


Figure B-139 Normalized Environmental Impact Assessment of 66 in. Diameter Sliplining Renewal Method

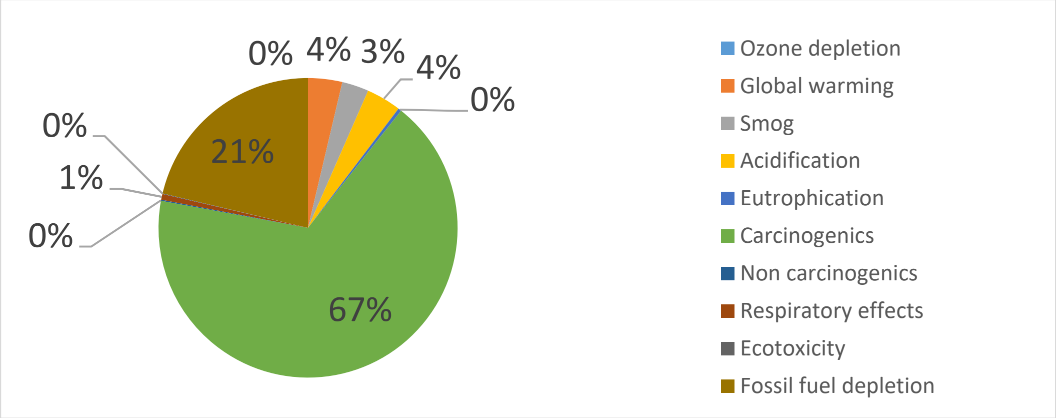


Figure B-140 Percentage of Normalized Environmental Impact Assessment of 66 in. Diameter Sliplining Renewal Method

Table B-105 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 66 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.0015	0	1.29E-06	1.27E-03	2.33E-04	7.78E-08
Global warming	kg CO2 eq	185982.8	177284.1	578.2958	5240.431	979.2277	1900.781
Smog	kg O3 eq	9771.729	8029.204	119.6167	710.4273	83.90148	828.5799
Acidification	kg SO2 eq	735.8421	676.0201	3.694876	26.33238	3.699426	26.09531
Eutrophication	kg N eq	22.75114	15.40376	0.220048	4.664608	0.901722	1.560998
Carcinogenics	CTUh	0.00724	0.007037	4.54E-07	1.43E-04	3.10E-05	2.81E-05
Non carcinogenics	CTUh	0.000882	0.000253	1.07E-05	2.67E-04	8.24E-05	0.00027
Respiratory effects	kg PM2.5 eq	33.17672	29.84007	0.072353	2.338634	0.388603	0.537066
Ecotoxicity	CTUe	26392.91	1538.565	277.7642	6563.364	12807.62	5205.604
Fossil fuel depletion	MJ surplus	814587.7	796254.6	1182.686	11195.78	2046.051	3908.643

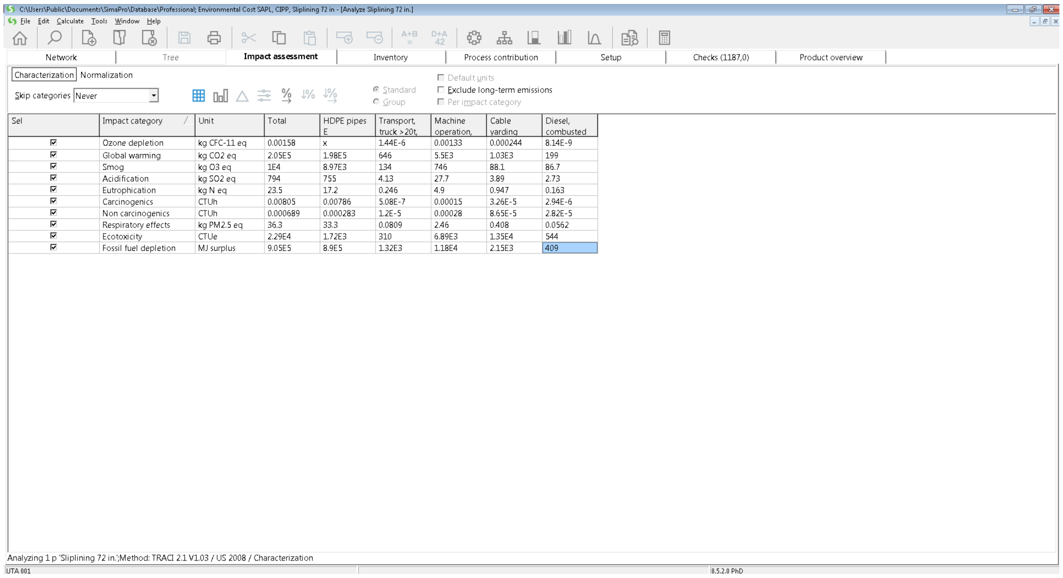
Table B-106 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 66 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.009302	0	8.01E-06	7.85E-03	1.44E-03	4.82E-07
Global warming	-	7.677725	7.318625	0.023873	0.216335	4.04E-02	0.078468
Smog	-	7.020362	5.768469	0.085937	0.510397	6.03E-02	0.595282
Acidification	-	8.101317	7.442702	0.040679	0.289909	4.07E-02	0.287299
Eutrophication	-	1.052525	0.712617	0.01018	0.215796	0.041716	0.072216
Carcinogenics	-	137.3332	133.4879	0.008615	2.71547	0.58804	0.533223
Non carcinogenics	-	0.840157	0.240765	0.01021	0.25386	0.078445	0.256876
Respiratory effects	-	1.368226	1.230621	0.002984	0.096447	1.60E-02	0.022149
Ecotoxicity	-	2.384193	0.138986	0.025092	0.592899	1.156971	0.470246
Fossil fuel depletion	-	43.28222	42.30811	0.062841	0.594876	1.09E-01	0.207681

Table B-107 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 66 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.0015	0.05
Global warming	kg CO2 eq	185982.8	11,716.92
Smog	kg O3 eq	9771.729	21,497.80
Acidification	kg SO2 eq	735.8421	4,025.06
Eutrophication	kg N eq	22.75114	46.64
Carcinogenic	CTUh	0.00724	0.00
Non carcinogenic	CTUh	0.000882	0.01
Respiratory effects	kg PM2.5 eq	33.17672	2,101.41
Ecotoxicity	CTUe	26392.91	1,082.11
Fossil fuel depletion	MJ surplus	814587.7	7,982.96
Total			48,452.96

A.3.8 Sliplining 72 in.



Skip categories: Never

○ Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00158	x	1.44E-6	0.00133	0.000244	8.14E-9
☑	Global warming	kg CO2 eq	2.05E5	1.98E5	646	5.5E3	1.03E3	199
☑	Smog	kg O3 eq	1E4	8.97E3	134	746	88.1	86.7
☑	Acidification	kg SO2 eq	794	755	4.13	27.7	3.89	2.73
☑	Eutrophication	kg N eq	23.5	17.2	0.246	4.9	0.947	0.163
☑	Carcinogenics	CTUh	0.00805	0.00786	5.08E-7	0.00015	3.26E-5	2.94E-6
☑	Non carcinogenics	CTUh	0.000689	0.000283	1.2E-5	0.00028	8.65E-5	2.82E-5
☑	Respiratory effects	kg PM2.5 eq	36.3	33.3	0.0809	2.46	0.408	0.0562
☑	Ecotoxicity	CTUe	2.29E4	1.72E3	310	6.89E3	1.35E4	544
☑	Fossil fuel depletion	MJ surplus	9.05E5	8.9E5	1.32E3	1.18E4	2.15E3	409

Analyzing 1 p 'Sliplining 72 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-141 Screenshot of the Impact Assessment Table from SimaPro Software for 72 in. Sliplining

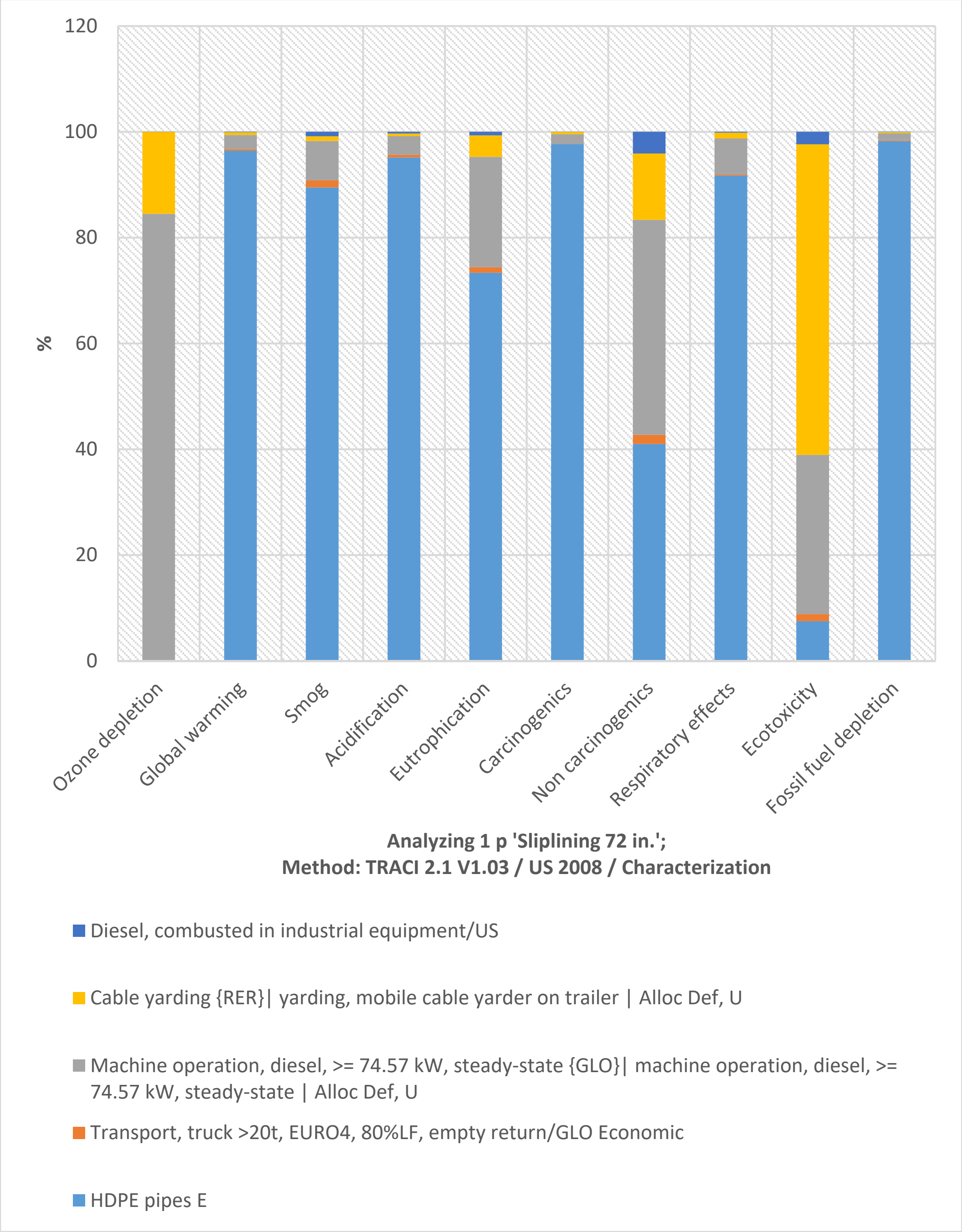


Figure B-142 Environmental Impact Assessment of 72 in. Diameter
Sliplining Renewal Method

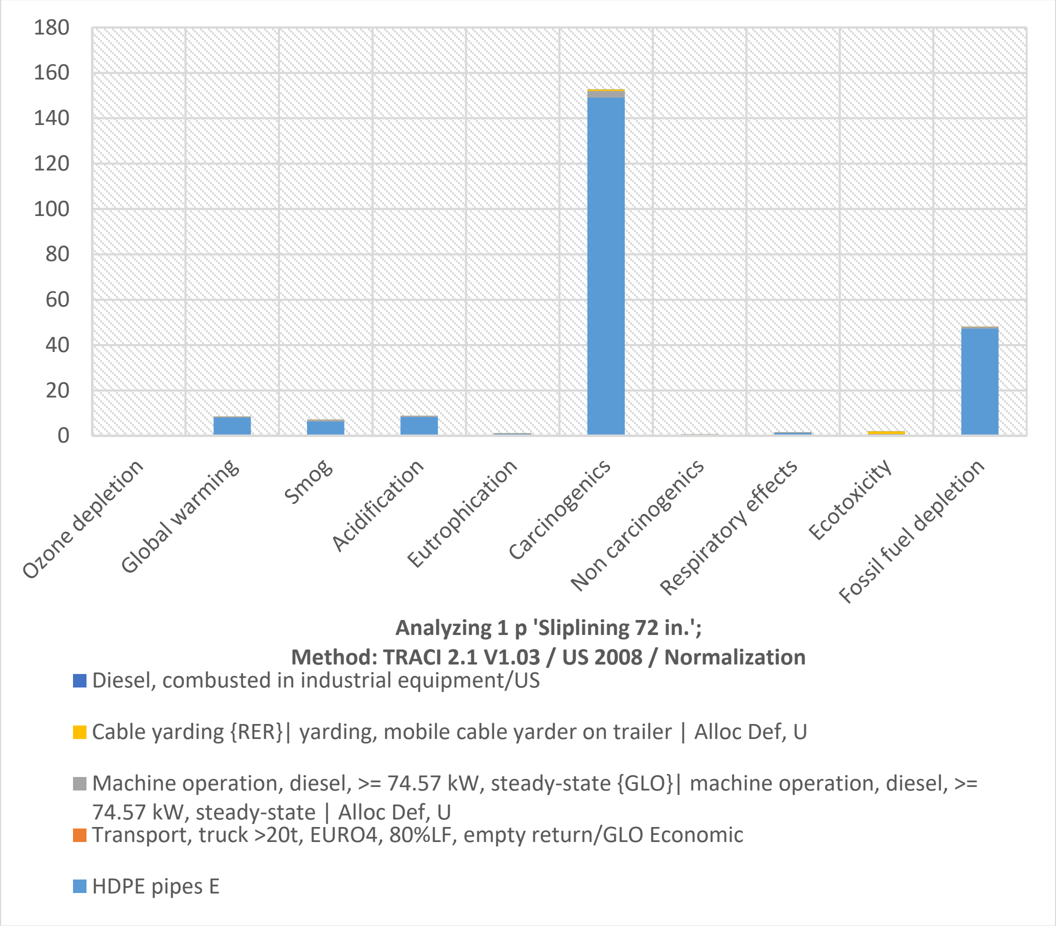


Figure B-143 Normalized Environmental Impact Assessment of 72 in. Diameter Sliplining Renewal Method

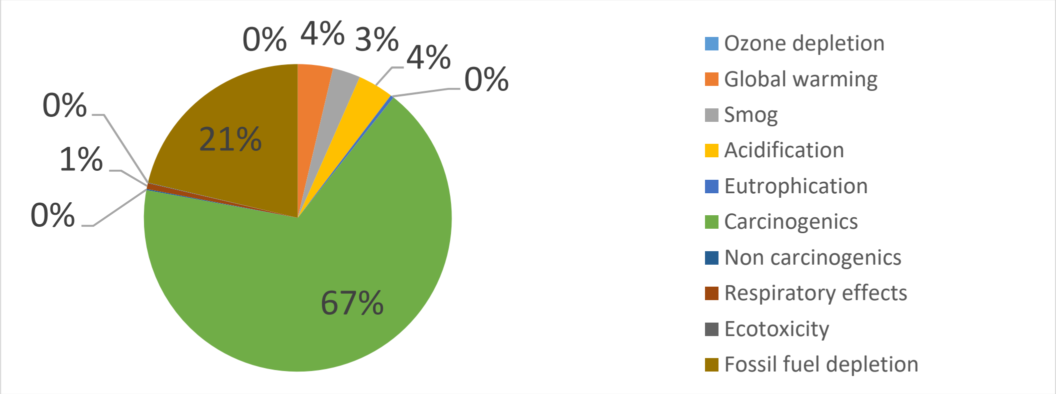


Figure B-144 Percentage of Normalized Environmental Impact Assessment of 72 in. Diameter Sliplining Renewal Method

Table B-108 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 72 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001575	0	1.44E-06	1.33E-03	2.44E-04	8.14E-09
Global warming	kg CO2 eq	205484.3	198108	646.2226	5502.778	1028.554	198.7792
Smog	kg O3 eq	10026.76	8972.316	133.6669	745.9929	88.12786	86.65093
Acidification	kg SO2 eq	793.82	755.4257	4.128877	27.65063	3.885778	2.728986
Eutrophication	kg N eq	23.4675	17.21309	0.245895	4.898129	0.947144	0.163245
Carcinogenics	CTUh	0.00805	0.007864	5.08E-07	1.50E-04	3.26E-05	2.94E-06
Non carcinogenics	CTUh	0.000689	0.000283	1.20E-05	2.80E-04	8.65E-05	2.82E-05
Respiratory effects	kg PM2.5 eq	36.346	33.34509	0.080852	2.455712	0.408179	0.056165
Ecotoxicity	CTUe	22918.78	1719.285	310.3904	6891.941	13452.78	544.3898
Fossil fuel depletion	MJ surplus	905418.6	889782.9	1321.604	11756.27	2149.117	408.7567

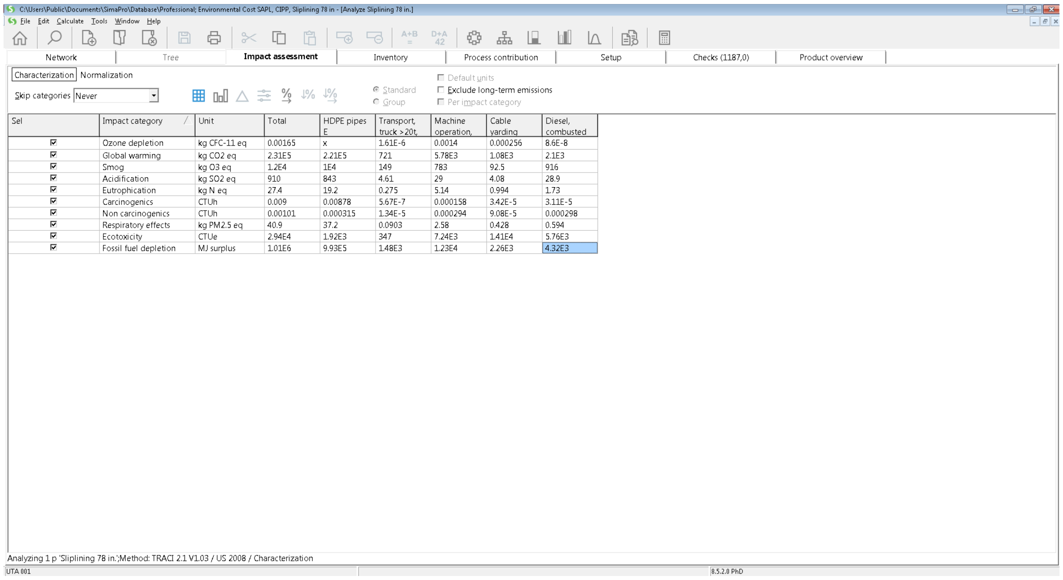
Table B-109 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 72 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.009768	0	8.95E-06	8.25E-03	1.51E-03	5.05E-08
Global warming	-	8.482782	8.178273	0.026677	0.227165	4.25E-02	0.008206
Smog	-	7.203582	6.446035	0.096031	0.535948	6.33E-02	0.062253
Acidification	-	8.739629	8.316924	0.045457	0.304422	4.28E-02	0.030045
Eutrophication	-	1.085666	0.796321	0.011376	0.2266	0.043817	0.007552
Carcinogenics	-	152.7019	149.1674	0.009627	2.851413	0.617661	0.055763
Non carcinogenics	-	0.656284	0.269046	0.011409	0.266569	0.082397	0.026864
Respiratory effects	-	1.498929	1.37517	0.003334	0.101275	1.68E-02	0.002316
Ecotoxicity	-	2.070359	0.155311	0.028039	0.622581	1.215251	0.049177
Fossil fuel depletion	-	48.10842	47.27764	0.070222	0.624656	1.14E-01	0.021719

Table B-110 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 72 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001575	0.05
Global warming	kg CO2 eq	205484.3	12,945.51
Smog	kg O3 eq	10026.76	22,058.86
Acidification	kg SO2 eq	793.82	4,342.20
Eutrophication	kg N eq	23.4675	48.11
Carcinogenic	CTUh	0.00805	0.00
Non carcinogenic	CTUh	0.000689	0.01
Respiratory effects	kg PM2.5 eq	36.346	2,302.16
Ecotoxicity	CTUe	22918.78	939.67
Fossil fuel depletion	MJ surplus	905418.6	8,873.10
Total			51,509.66

A.3.9 Sliplining 78 in.



Skip categories: Never

○ Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00165	x	1.61E-6	0.0014	0.000256	8.6E-8
☑	Global warming	kg CO2 eq	2.31E5	2.21E5	721	5.78E3	1.08E3	2.1E3
☑	Smog	kg O3 eq	1.2E4	1E4	149	783	92.5	916
☑	Acidification	kg SO2 eq	910	843	4.61	29	4.08	28.9
☑	Eutrophication	kg N eq	27.4	19.2	0.275	5.14	0.994	1.73
☑	Carcinogenics	CTUh	0.009	0.00878	5.67E-7	0.000158	3.42E-5	3.11E-5
☑	Non carcinogenics	CTUh	0.00101	0.000315	1.34E-5	0.000294	9.08E-5	0.000298
☑	Respiratory effects	kg PM2.5 eq	40.9	37.2	0.0903	2.58	0.428	0.594
☑	Ecotoxicity	CTUe	2.94E4	1.92E3	347	7.24E3	1.41E4	5.76E3
☑	Fossil fuel depletion	MJ surplus	1.01E6	9.93E5	1.48E3	1.23E4	2.26E3	4.32E3

Analyzing 1 p 'Sliplining 78 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

UTA 001

8.5.2.0 PhD

Figure B-145 Screenshot of the Impact Assessment Table from SimaPro Software for 78 in. Sliplining

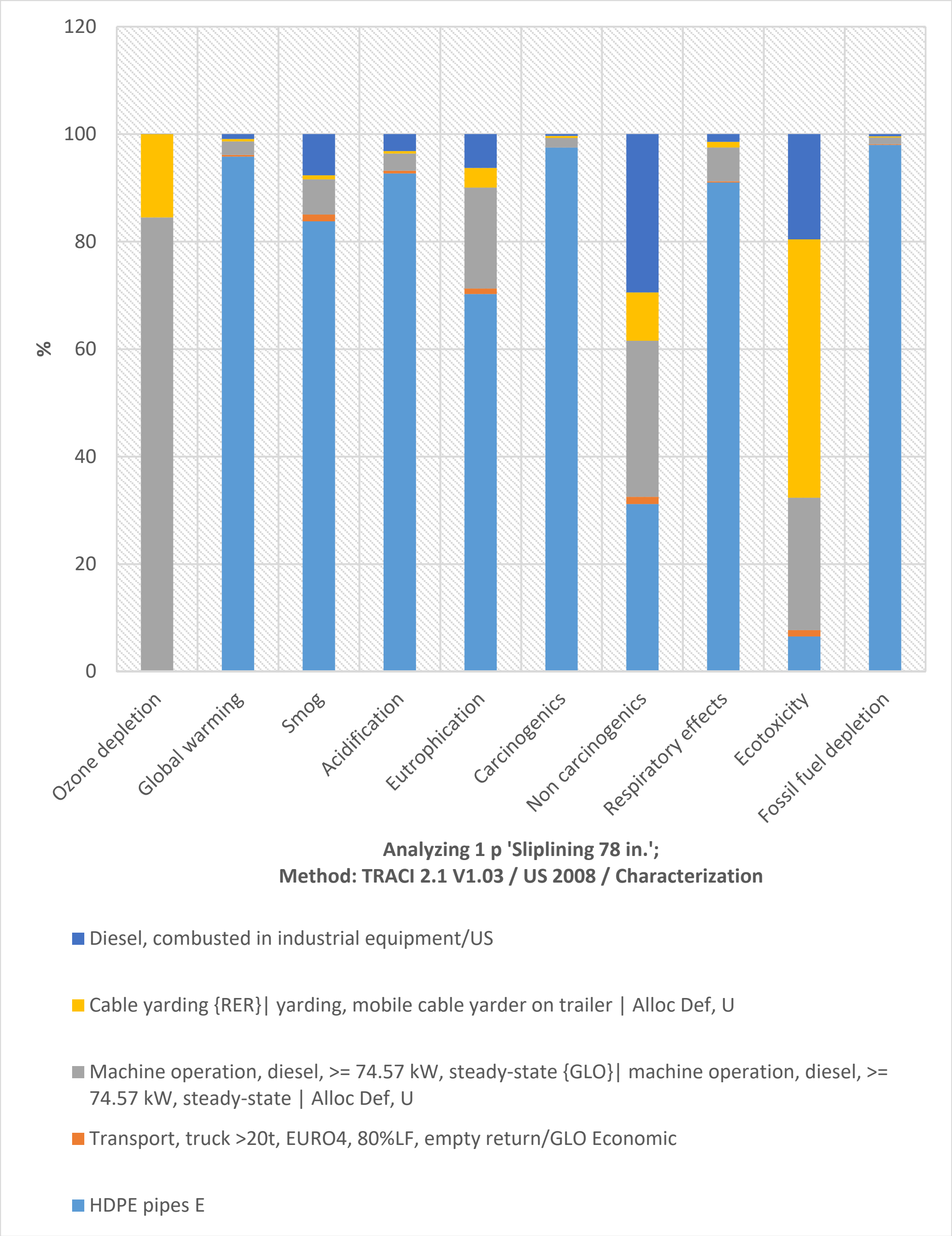


Figure B-146 Environmental Impact Assessment of 78 in. Diameter Sliplining Renewal Method

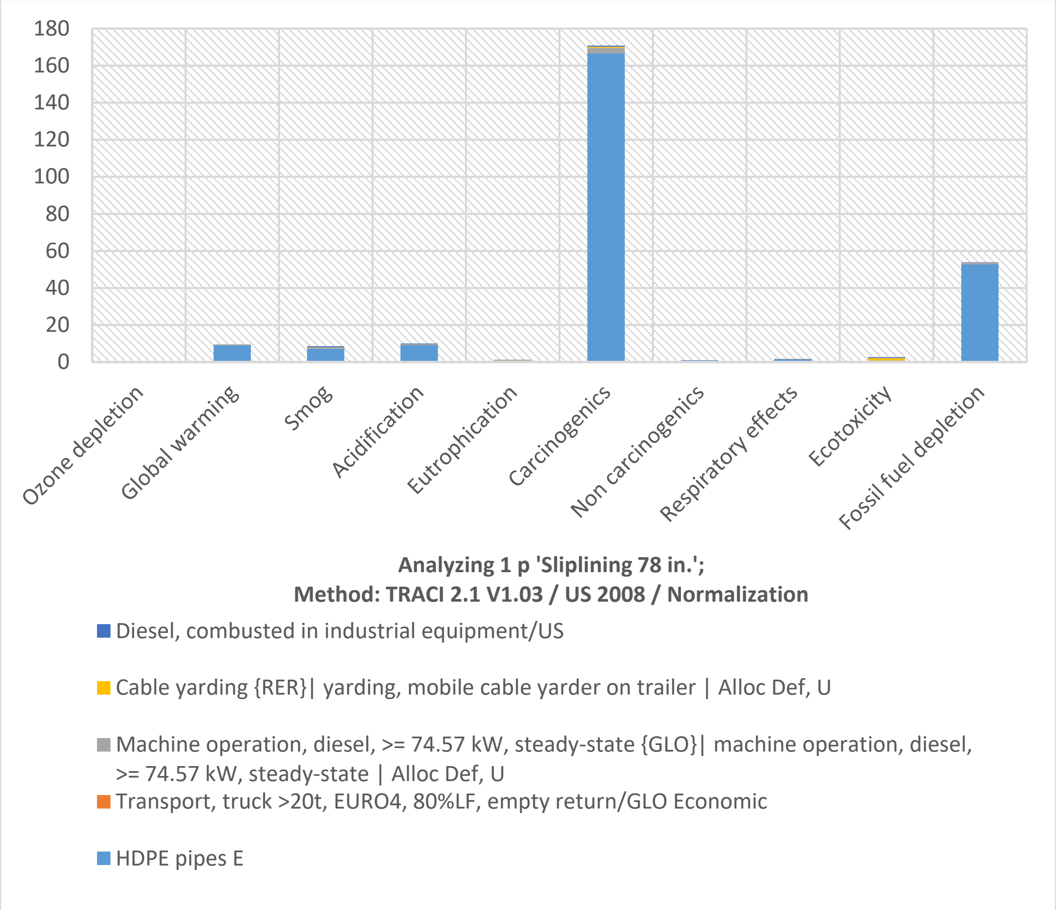


Figure B-147 Normalized Environmental Impact Assessment of 78 in. Diameter Sliplining Renewal Method

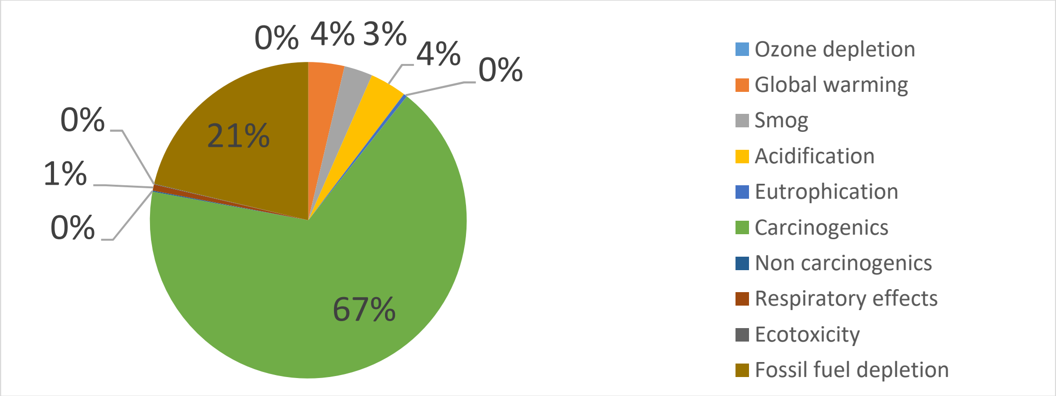


Figure B-148 Percentage of Normalized Environmental Impact Assessment of 78 in. Diameter Sliplining Renewal Method

Table B-111 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 78 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001654	0	1.61E-06	1.40E-03	2.56E-04	8.60E-08
Global warming	kg CO2 eq	230864	221183	721.4929	5778.161	1079.708	2101.603
Smog	kg O3 eq	11958.58	10017.39	149.236	783.3256	92.51077	916.1215
Acidification	kg SO2 eq	909.9912	843.4156	4.609798	29.03439	4.079032	28.85234
Eutrophication	kg N eq	27.35598	19.21802	0.274537	5.143253	0.994249	1.725921
Carcinogenics	CTUh	0.009004	0.00878	5.67E-07	1.58E-04	3.42E-05	3.11E-05
Non carcinogenics	CTUh	0.001012	0.000315	1.34E-05	2.94E-04	9.08E-05	0.000298
Respiratory effects	kg PM2.5 eq	40.9202	37.22904	0.090269	2.578606	0.428479	0.593808
Ecotoxicity	CTUe	29380.35	1919.543	346.5439	7236.844	14121.83	5755.589
Fossil fuel depletion	MJ surplus	1013820	993422.4	1475.541	12344.61	2256	4321.601

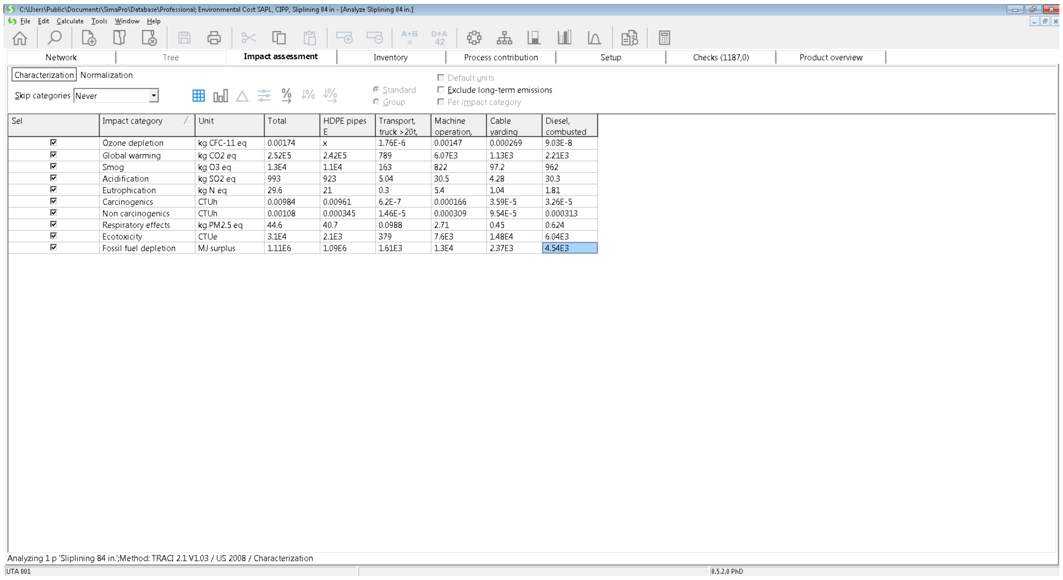
Table B-112 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 78 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.010258	0	9.99E-06	8.66E-03	1.59E-03	5.33E-07
Global warming	-	9.530504	9.130856	0.029785	0.238533	4.46E-02	0.086758
Smog	-	8.591475	7.196852	0.107217	0.562769	6.65E-02	0.658175
Acidification	-	10.01863	9.285657	0.050752	0.319657	4.49E-02	0.317652
Eutrophication	-	1.265556	0.889074	0.012701	0.23794	0.045996	0.079845
Carcinogenics	-	170.7848	166.542	0.010749	2.99411	0.64838	0.589559
Non carcinogenics	-	0.963541	0.300383	0.012738	0.279909	0.086494	0.284016
Respiratory effects	-	1.687572	1.535346	0.003723	0.106343	1.77E-02	0.024489
Ecotoxicity	-	2.654062	0.173401	0.031305	0.653737	1.27569	0.519929
Fossil fuel depletion	-	53.86822	52.78441	0.078401	0.655917	1.20E-01	0.229624

Table B-113 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 78 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001654	0.05
Global warming	kg CO2 eq	230864	14,544.43
Smog	kg O3 eq	11958.58	26,308.88
Acidification	kg SO2 eq	909.9912	4,977.65
Eutrophication	kg N eq	27.35598	56.08
Carcinogenic	CTUh	0.009004	0.00
Non carcinogenic	CTUh	0.001012	0.01
Respiratory effects	kg PM2.5 eq	40.9202	2,591.89
Ecotoxicity	CTUe	29380.35	1,204.59
Fossil fuel depletion	MJ surplus	1013820	9,935.44
Total			59,619.02

A.3.10 Sliplining 84 in.



Skip categories: Never

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00174	x	1.76E-6	0.00147	0.000269	9.03E-8
☑	Global warming	kg CO2 eq	2.52E5	2.42E5	789	6.07E3	1.13E3	2.21E3
☑	Smog	kg O3 eq	1.3E4	1.1E4	163	822	97.2	962
☑	Acidification	kg SO2 eq	993	923	5.04	30.5	4.28	30.3
☑	Eutrophication	kg N eq	29.6	21	0.3	5.4	1.04	1.81
☑	Carcinogenics	CTUh	0.00984	0.00961	6.2E-7	0.000166	3.59E-5	3.26E-5
☑	Non carcinogenics	CTUh	0.00108	0.000345	1.46E-5	0.000309	9.54E-5	0.000313
☑	Respiratory effects	kg PM2.5 eq	44.6	40.7	0.0988	2.71	0.45	0.624
☑	Ecotoxicity	CTUe	3.1E4	2.1E3	379	7.6E3	1.48E4	6.04E3
☑	Fossil fuel depletion	MJ surplus	1.11E6	1.09E6	1.61E3	1.3E4	2.37E3	4.54E3

Analyzing 1 p 'Sliplining 84 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-149 Screenshot of the Impact Assessment Table from SimaPro Software for 84 in. Sliplining

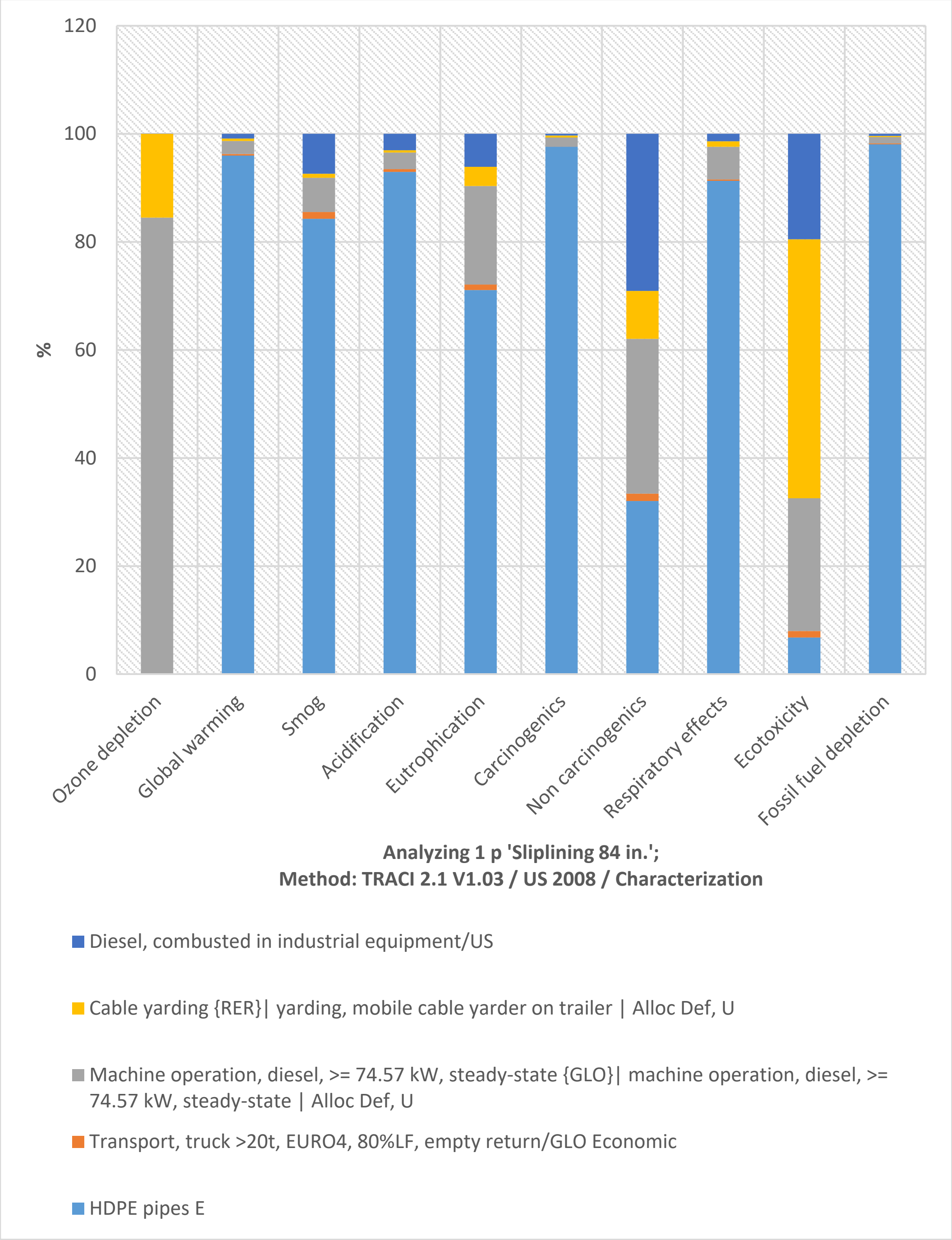


Figure B-150 Environmental Impact Assessment of 84 in. Diameter Sliplining Renewal Method

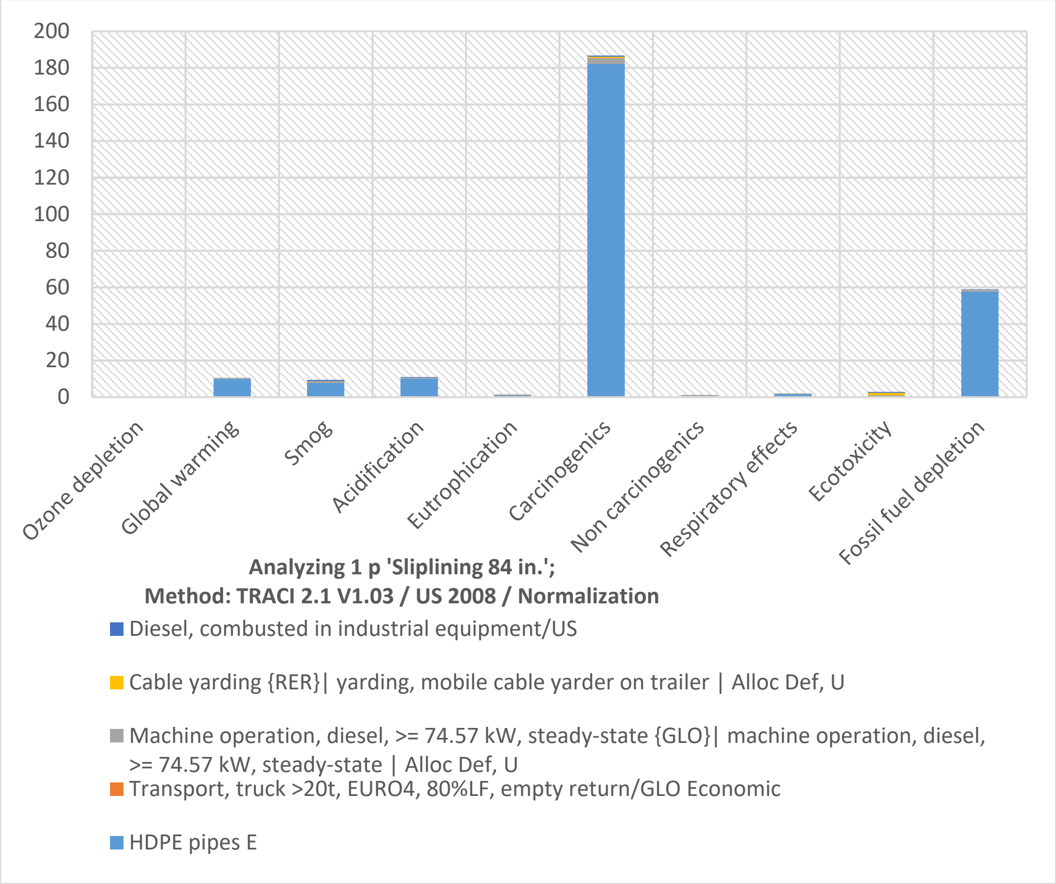


Figure B-151 Normalized Environmental Impact Assessment of 84 in. Diameter Sliplining Renewal Method

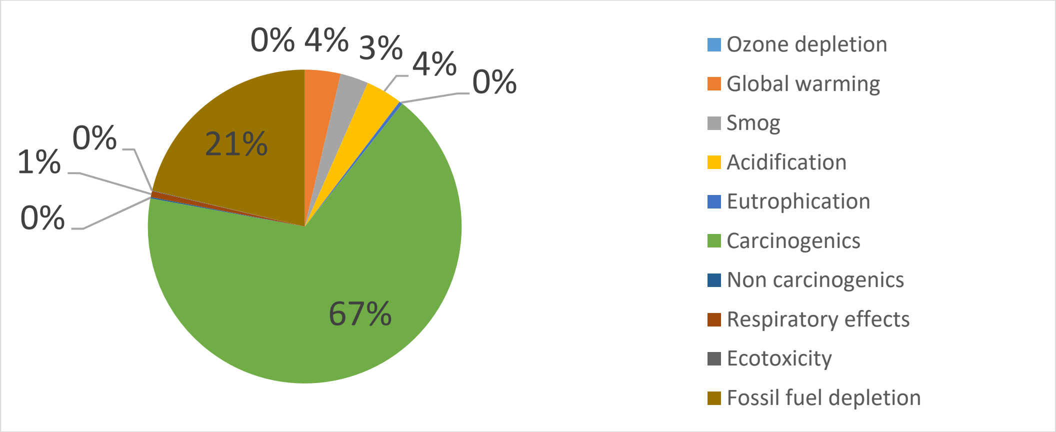


Figure B-152 Percentage of Normalized Environmental Impact Assessment of 84 in. Diameter Sliplining Renewal Method

Table B-114 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 84 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001737	0	1.76E-06	1.47E-03	2.69E-04	9.03E-08
Global warming	kg CO2 eq	252203.5	242006.9	789.4197	6066.58	1133.907	2206.761
Smog	kg O3 eq	13005.33	10960.5	163.2862	822.4257	97.15458	961.9616
Acidification	kg SO2 eq	992.9284	922.8212	5.043799	30.48366	4.283789	30.29603
Eutrophication	kg N eq	29.58416	21.02735	0.300384	5.39998	1.044158	1.812282
Carcinogenics	CTUh	0.009841	0.009607	6.20E-07	1.66E-04	3.59E-05	3.26E-05
Non carcinogenics	CTUh	0.001077	0.000345	1.46E-05	3.09E-04	9.54E-05	0.000313
Respiratory effects	kg PM2.5 eq	44.61365	40.73406	0.098768	2.707318	0.449987	0.623521
Ecotoxicity	CTUe	30951.8	2100.263	379.1701	7598.074	14830.71	6043.583
Fossil fuel depletion	MJ surplus	1108433	1086951	1614.46	12960.79	2369.246	4537.842

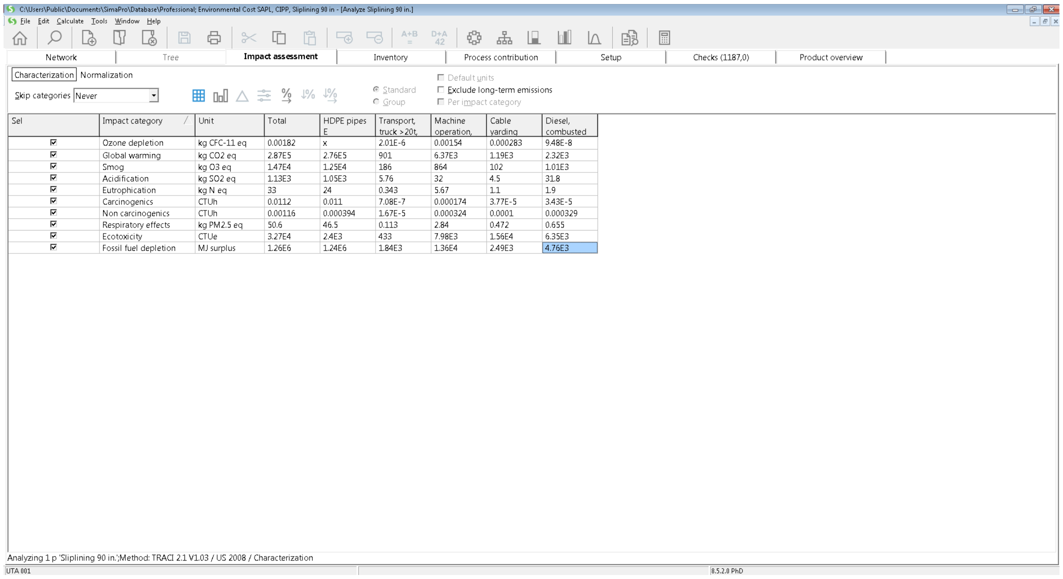
Table B-115 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 84 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.010771	0	1.09E-05	9.09E-03	1.67E-03	5.60E-07
Global warming	-	10.41144	9.990504	0.032589	0.25044	4.68E-02	0.091099
Smog	-	9.343496	7.874418	0.117311	0.59086	6.98E-02	0.691108
Acidification	-	10.93173	10.15988	0.05553	0.335612	4.72E-02	0.333547
Eutrophication	-	1.368637	0.972778	0.013897	0.249817	0.048305	0.083841
Carcinogenics	-	186.6769	182.2216	0.011761	3.143562	0.680927	0.619059
Non carcinogenics	-	1.025546	0.328664	0.013938	0.293881	0.090836	0.298227
Respiratory effects	-	1.839892	1.679895	0.004073	0.111651	1.86E-02	0.025714
Ecotoxicity	-	2.796018	0.189726	0.034252	0.686369	1.339726	0.545945
Fossil fuel depletion	-	58.89537	57.75393	0.085783	0.688657	1.26E-01	0.241113

Table B-116 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 84 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001737	0.06
Global warming	kg CO2 eq	252203.5	15,888.82
Smog	kg O3 eq	13005.33	28,611.72
Acidification	kg SO2 eq	992.9284	5,431.32
Eutrophication	kg N eq	29.58416	60.65
Carcinogenic	CTUh	0.009841	0.00
Non carcinogenic	CTUh	0.001077	0.01
Respiratory effects	kg PM2.5 eq	44.61365	2,825.83
Ecotoxicity	CTUe	30951.8	1,269.02
Fossil fuel depletion	MJ surplus	1108433	10,862.64
Total			64,950.08

A.3.11 Sliplining 90 in.



Skip categories Never

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00182	x	2.01E-6	0.00154	0.000283	9.48E-8
☑	Global warming	kg CO2 eq	2.87E5	2.76E5	901	6.37E3	1.19E3	2.32E3
☑	Smog	kg O3 eq	1.47E4	1.25E4	186	864	102	1.01E3
☑	Acidification	kg SO2 eq	1.13E3	1.05E3	5.76	32	4.5	31.8
☑	Eutrophication	kg N eq	33	24	0.343	5.67	1.1	1.9
☑	Carcinogenics	CTUh	0.0112	0.011	7.08E-7	0.000174	3.77E-5	3.43E-5
☑	Non carcinogenics	CTUh	0.00116	0.000394	1.67E-5	0.000324	0.0001	0.000329
☑	Respiratory effects	kg PM2.5 eq	50.6	46.5	0.113	2.84	0.472	0.655
☑	Ecotoxicity	CTUe	3.27E4	2.4E3	433	7.98E3	1.56E4	6.35E3
☑	Fossil fuel depletion	MJ surplus	1.26E6	1.24E6	1.84E3	1.36E4	2.49E3	4.76E3

Analyzing 1 p 'Sliplining 90 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-153 Screenshot of the Impact Assessment Table from SimaPro Software for 90 in. Sliplining

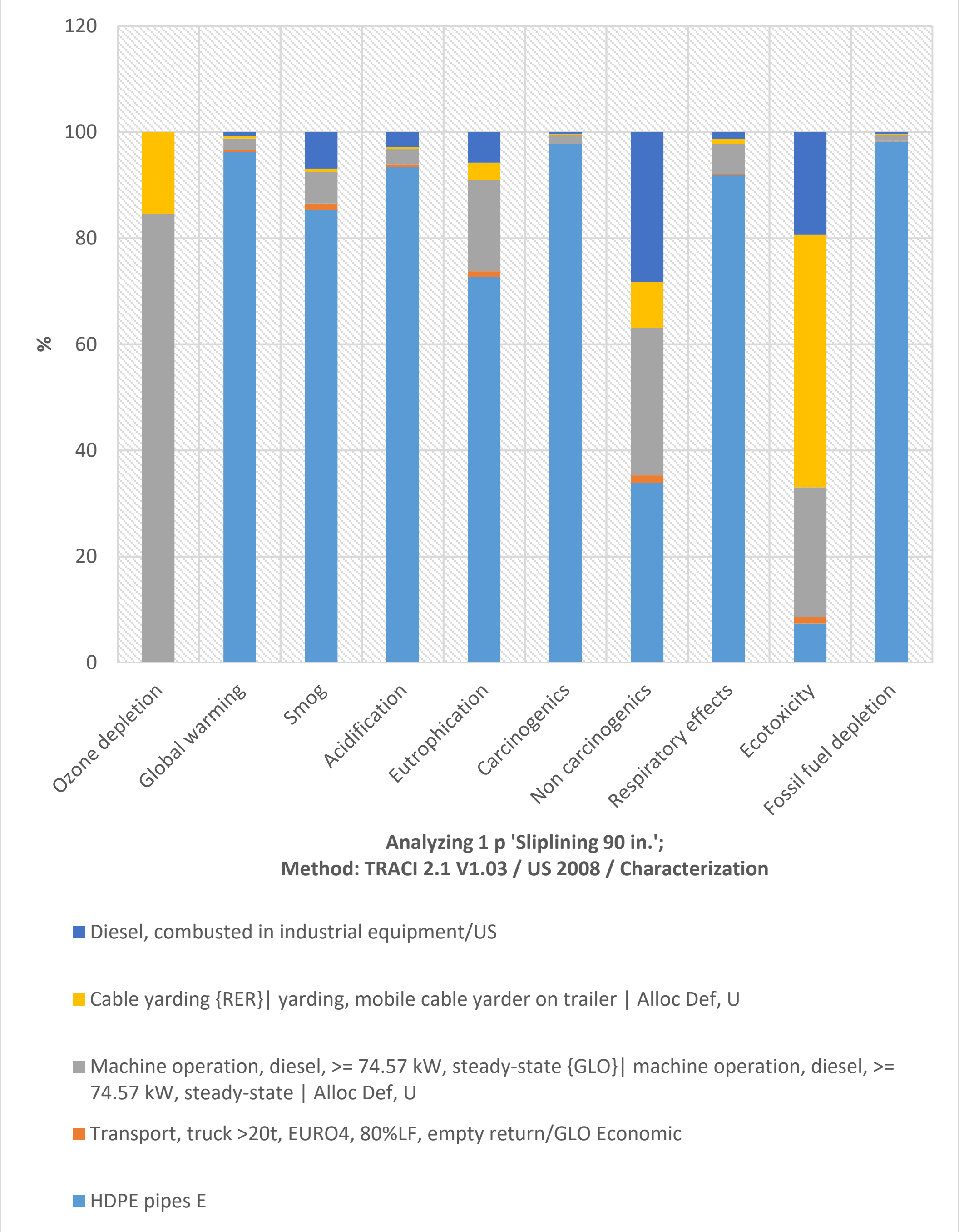


Figure B-154 Environmental Impact Assessment of 90 in. Diameter Sliplining Renewal Method

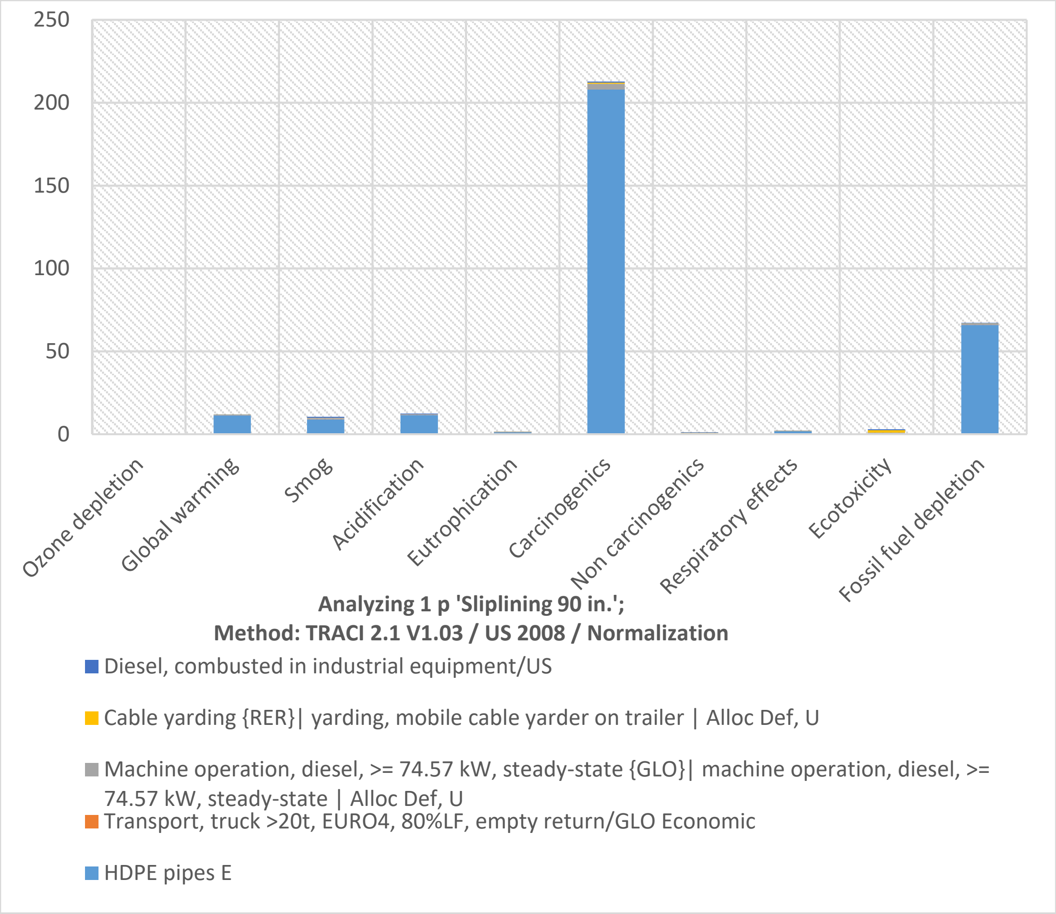


Figure B-155 Normalized Environmental Impact Assessment of 90 in. Diameter Sliplining Renewal Method

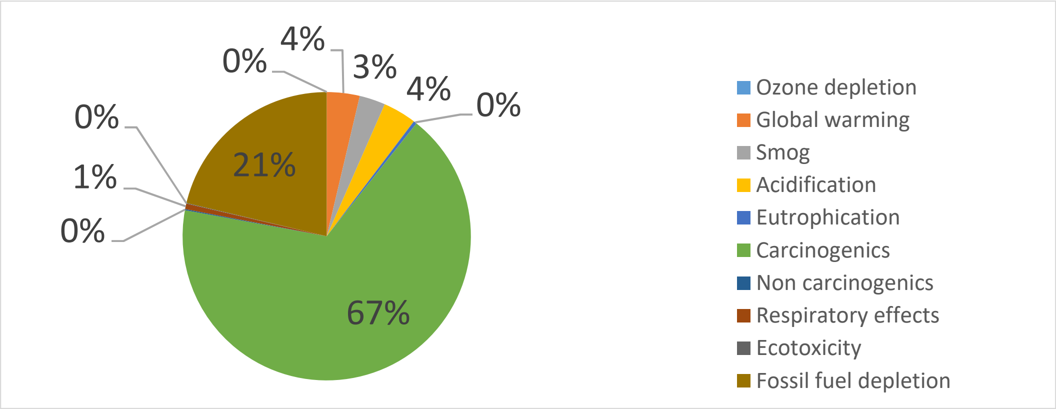


Figure B-156 Percentage of Normalized Environmental Impact Assessment of 90 in. Diameter Sliplining Renewal Method

Table B-117 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 90 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001824	0	2.01E-06	1.54E-03	2.83E-04	9.48E-08
Global warming	kg CO2 eq	287117.6	276338.1	901.4071	6370.48	1190.541	2317.087
Smog	kg O3 eq	14677.5	12515.36	186.4501	863.6242	102.0071	1010.054
Acidification	kg SO2 eq	1127.811	1053.733	5.759315	32.01071	4.497748	31.81067
Eutrophication	kg N eq	33.02298	24.0103	0.342996	5.670487	1.09631	1.902886
Carcinogenics	CTUh	0.011216	0.010969	7.08E-07	1.74E-04	3.77E-05	3.43E-05
Non carcinogenics	CTUh	0.001164	0.000394	1.67E-05	3.24E-04	1.00E-04	0.000329
Respiratory effects	kg PM2.5 eq	50.59549	46.51261	0.112779	2.842939	0.472462	0.654693
Ecotoxicity	CTUe	32727.04	2398.208	432.9594	7978.692	15571.45	6345.729
Fossil fuel depletion	MJ surplus	1263852	1241146	1843.488	13610.05	2487.581	4764.709

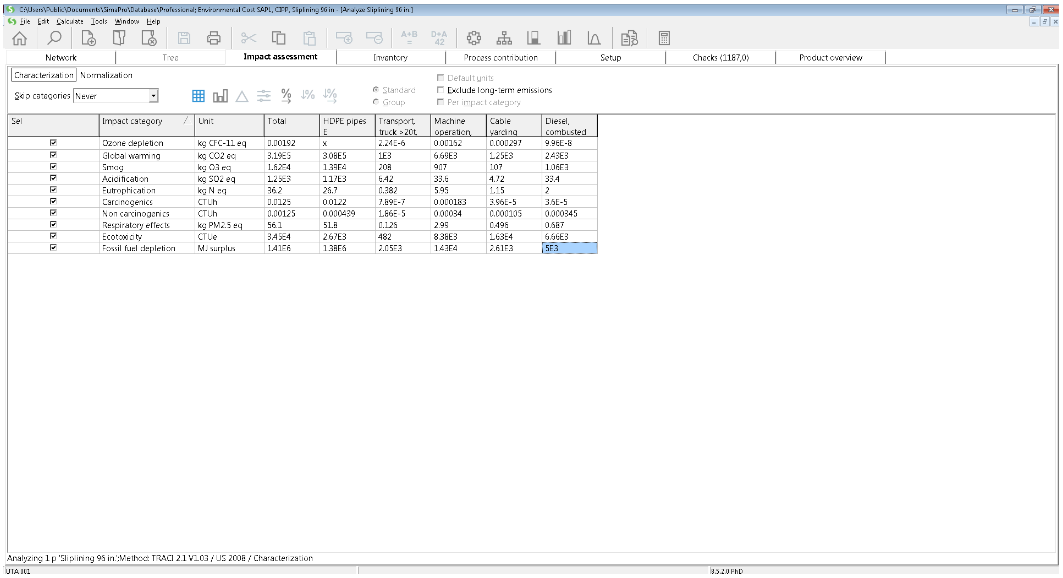
Table B-118 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 90 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.011311	0	1.25E-05	9.55E-03	1.75E-03	5.88E-07
Global warming	-	11.85276	11.40776	0.037212	0.262986	4.91E-02	0.095654
Smog	-	10.54484	8.991486	0.133952	0.620459	7.33E-02	0.725659
Acidification	-	12.41674	11.60116	0.063408	0.352425	4.95E-02	0.350222
Eutrophication	-	1.527726	1.110777	0.015868	0.262331	0.050718	0.088032
Carcinogenics	-	212.751	208.0716	0.013429	3.301036	0.714937	0.650009
Non carcinogenics	-	1.108316	0.375288	0.015915	0.308603	0.095373	0.313137
Respiratory effects	-	2.086586	1.918206	0.004651	0.117244	1.95E-02	0.027
Ecotoxicity	-	2.956384	0.216641	0.039111	0.720752	1.406641	0.573239
Fossil fuel depletion	-	67.15338	65.94693	0.097952	0.723155	1.32E-01	0.253168

Table B-119 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 90 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001824	0.06
Global warming	kg CO2 eq	287117.6	18,088.41
Smog	kg O3 eq	14677.5	32,290.50
Acidification	kg SO2 eq	1127.811	6,169.13
Eutrophication	kg N eq	33.02298	67.70
Carcinogenic	CTUh	0.011216	0.00
Non carcinogenic	CTUh	0.001164	0.01
Respiratory effects	kg PM2.5 eq	50.59549	3,204.72
Ecotoxicity	CTUe	32727.04	1,341.81
Fossil fuel depletion	MJ surplus	1263852	12,385.75
Total			73,548.08

A.3.12 Sliplining 96 in.



C:\Users\Public\Documents\SimaPro\Database\Professional; Environmental Cost SAPL, CIPP, Sliplining 96 in - [Analyze Sliplining 96 in.]

Skip categories: Never

● Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00192	x	2.24E-6	0.00162	0.000297	9.96E-8
☑	Global warming	kg CO2 eq	3.19E5	3.08E5	1E3	6.69E3	1.25E3	2.43E3
☑	Smog	kg O3 eq	1.62E4	1.39E4	208	907	107	1.06E3
☑	Acidification	kg SO2 eq	1.25E3	1.17E3	6.42	33.6	4.72	33.4
☑	Eutrophication	kg N eq	36.2	26.7	0.382	5.95	1.15	2
☑	Carcinogenics	CTUh	0.0125	0.0122	7.89E-7	0.000183	3.96E-5	3.6E-5
☑	Non carcinogenics	CTUh	0.00125	0.000439	1.86E-5	0.00034	0.000105	0.000345
☑	Respiratory effects	kg PM2.5 eq	56.1	51.8	0.126	2.99	0.496	0.687
☑	Ecotoxicity	CTUe	3.45E4	2.67E3	482	8.38E3	1.63E4	6.66E3
☑	Fossil fuel depletion	MJ surplus	1.41E6	1.38E6	2.05E3	1.43E4	2.61E3	5E3

Analyzing 1 p 'Sliplining 96 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-157 Screenshot of the Impact Assessment Table from SimaPro Software for 96 in. Sliplining

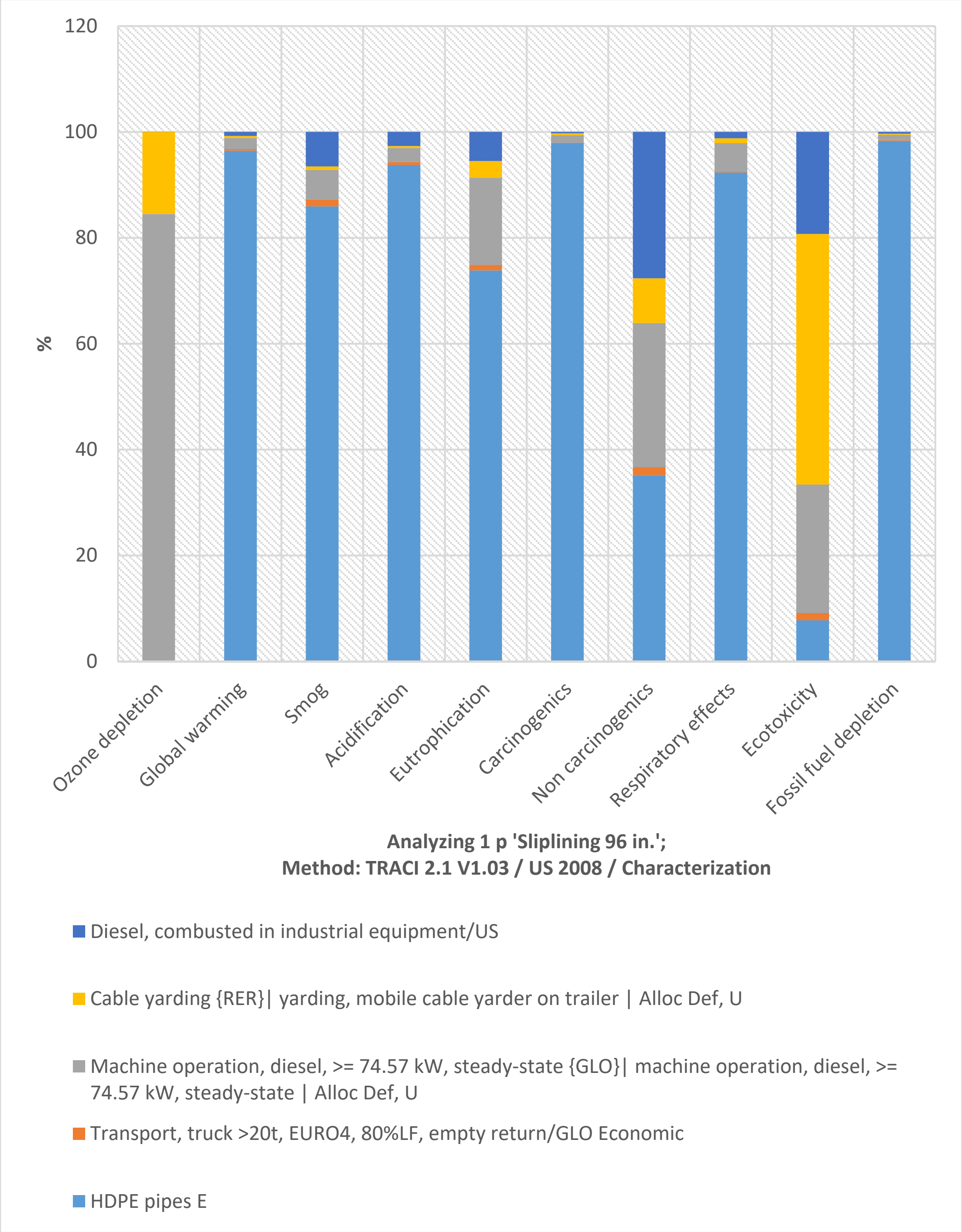


Figure B-158 Environmental Impact Assessment of 96 in. Diameter Sliplining Renewal Method

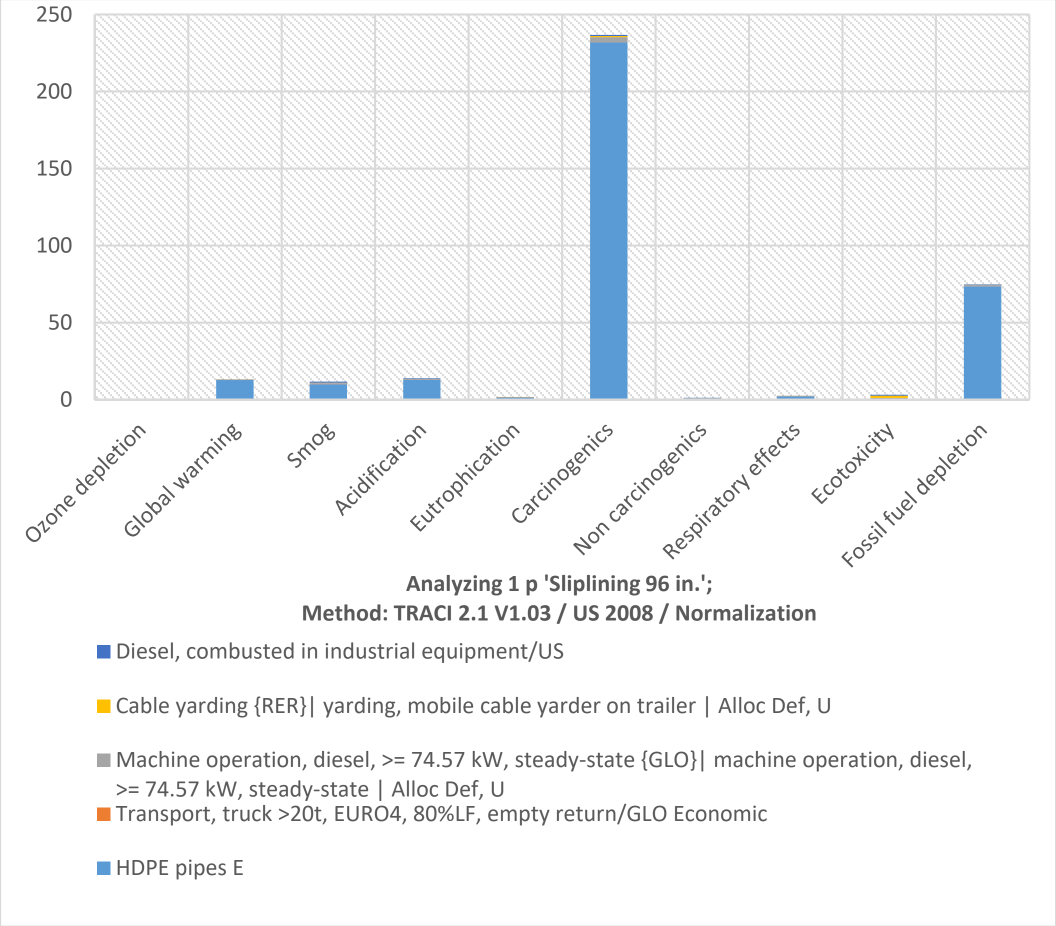


Figure B-159 Normalized Environmental Impact Assessment of 96 in. Diameter Sliplining Renewal Method

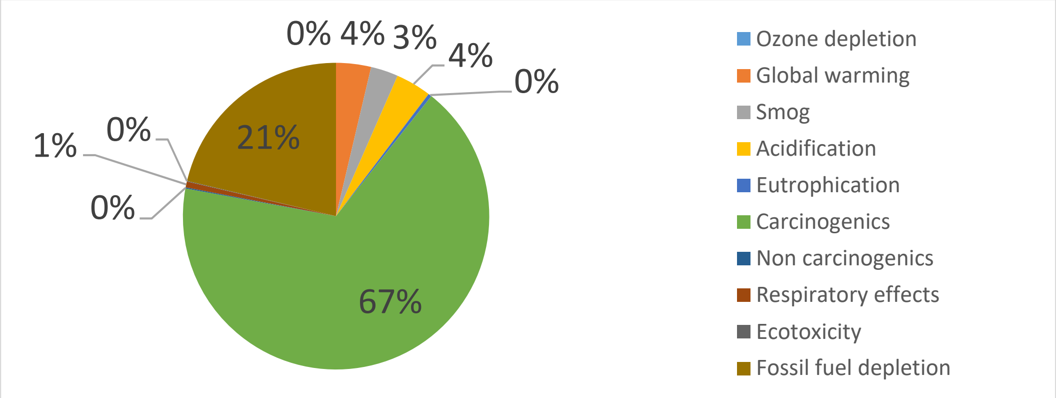


Figure B-160 Percentage of Normalized Environmental Impact Assessment of 96 in. Diameter Sliplining Renewal Method

Table B-120 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 96 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.001915	0	2.24E-06	1.62E-03	2.97E-04	9.96E-08
Global warming	kg CO2 eq	319231.1	307855.3	1004.215	6689.045	1249.611	2432.942
Smog	kg O3 eq	16224.93	13942.78	207.7153	906.811	107.0683	1060.557
Acidification	kg SO2 eq	1252.064	1173.914	6.416182	33.61145	4.72091	33.4012
Eutrophication	kg N eq	36.23365	26.74875	0.382116	5.954047	1.150705	1.99803
Carcinogenics	CTUh	0.012479	0.01222	7.89E-07	1.83E-04	3.96E-05	3.60E-05
Non carcinogenics	CTUh	0.001249	0.000439	1.86E-05	3.40E-04	1.05E-04	0.000345
Respiratory effects	kg PM2.5 eq	56.11159	51.81751	0.125642	2.985104	0.495904	0.687428
Ecotoxicity	CTUe	34538.81	2671.73	482.3397	8377.678	16344.05	6663.015
Fossil fuel depletion	MJ surplus	1406661	1382702	2053.743	14290.64	2611.006	5002.944

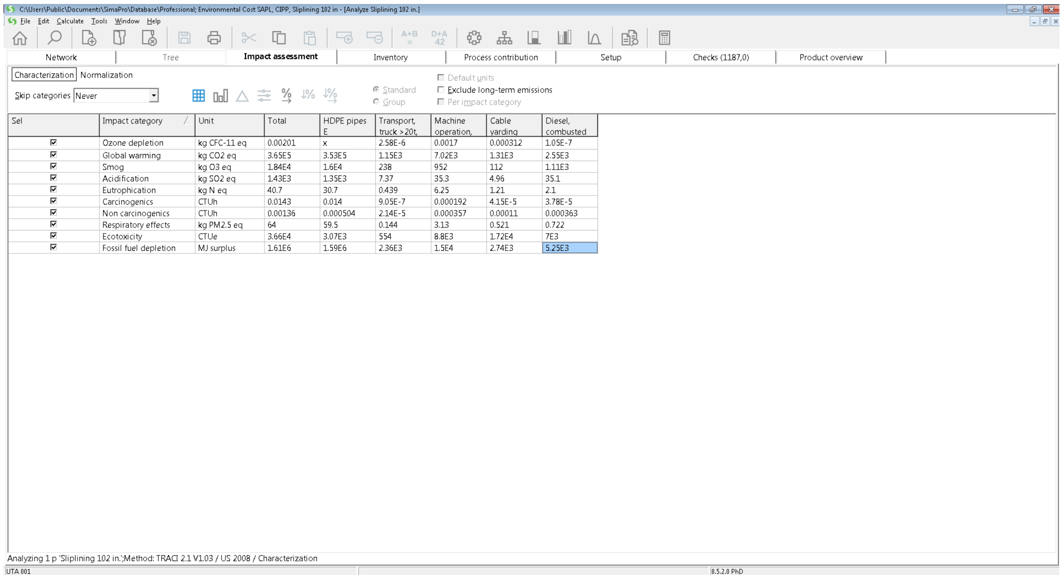
Table B-121 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 96 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.011877	0	1.39E-05	1.00E-02	1.84E-03	6.18E-07
Global warming	-	13.17847	12.70885	0.041456	0.276136	5.16E-02	0.100436
Smog	-	11.65657	10.01699	0.14923	0.651486	7.69E-02	0.761942
Acidification	-	13.78471	12.92431	0.07064	0.370048	5.20E-02	0.367733
Eutrophication	-	1.676259	1.237464	0.017678	0.275449	0.053234	0.092434
Carcinogenics	-	236.7168	231.8028	0.014961	3.466109	0.750409	0.682509
Non carcinogenics	-	1.188755	0.418091	0.01773	0.324035	0.100105	0.328794
Respiratory effects	-	2.314073	2.136983	0.005182	0.123107	2.05E-02	0.02835
Ecotoxicity	-	3.12005	0.24135	0.043572	0.756794	1.476433	0.601901
Fossil fuel depletion	-	74.74137	73.46837	0.109123	0.759317	1.39E-01	0.265826

Table B-122 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 96 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.001462	0.06
Global warming	kg CO2 eq	147130.7	20,111.56
Smog	kg O3 eq	10401.36	35,694.84
Acidification	kg SO2 eq	762.0499	6,848.79
Eutrophication	kg N eq	24.29613	74.28
Carcinogenic	CTUh	0.000616	0.00
Non carcinogenic	CTUh	0.013063	0.01
Respiratory effects	kg PM2.5 eq	45.2866	3,554.11
Ecotoxicity	CTUe	28956.17	1,416.09
Fossil fuel depletion	MJ surplus	23968.9	13,785.27
Total			81,485.02

A.3.13 Sliplining 102 in.



Skip categories: Never

☐ Exclude long-term emissions

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00201	x	2.58E-6	0.0017	0.000312	1.05E-7
☑	Global warming	kg CO2 eq	3.65E5	3.53E5	1.15E3	7.02E3	1.31E3	2.55E3
☑	Smog	kg O3 eq	1.84E4	1.6E4	238	952	112	1.11E3
☑	Acidification	kg SO2 eq	1.43E3	1.35E3	7.37	35.3	4.96	35.1
☑	Eutrophication	kg N eq	40.7	30.7	0.439	6.25	1.21	2.1
☑	Carcinogenics	CTUh	0.0143	0.014	9.05E-7	0.000192	4.15E-5	3.78E-5
☑	Non carcinogenics	CTUh	0.00136	0.000504	2.14E-5	0.000357	0.00011	0.000363
☑	Respiratory effects	kg PM2.5 eq	64	59.5	0.144	3.13	0.521	0.722
☑	Ecotoxicity	CTUe	3.66E4	3.07E3	554	8.8E3	1.72E4	7E3
☑	Fossil fuel depletion	MJ surplus	1.61E6	1.59E6	2.36E3	1.5E4	2.74E3	5.25E3

Analyzing 1 p 'Sliplining 102 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-161 Screenshot of the Impact Assessment Table from SimaPro Software for 102 in. Sliplining

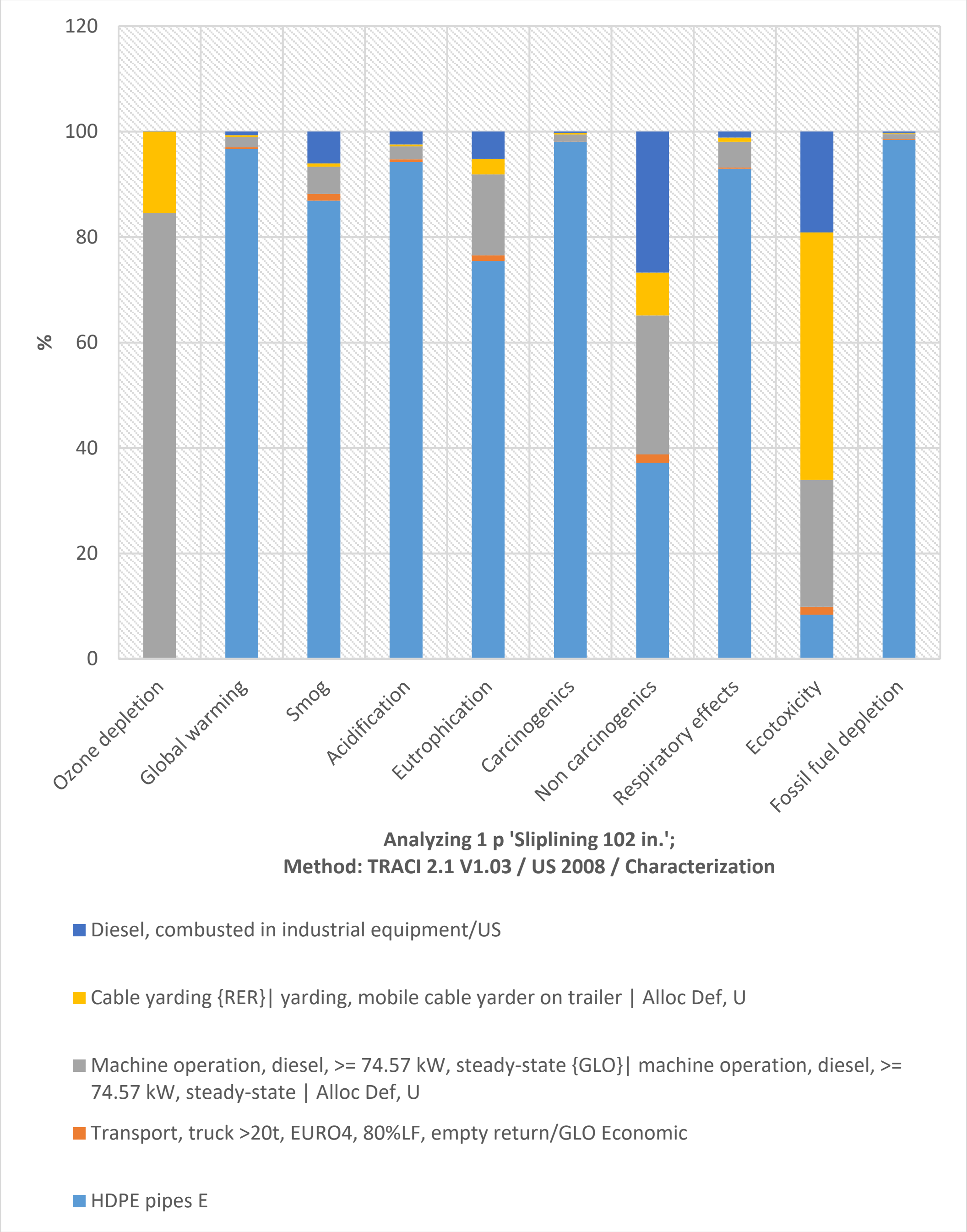


Figure B-162 Environmental Impact Assessment of 102 in. Diameter Sliplining Renewal Method

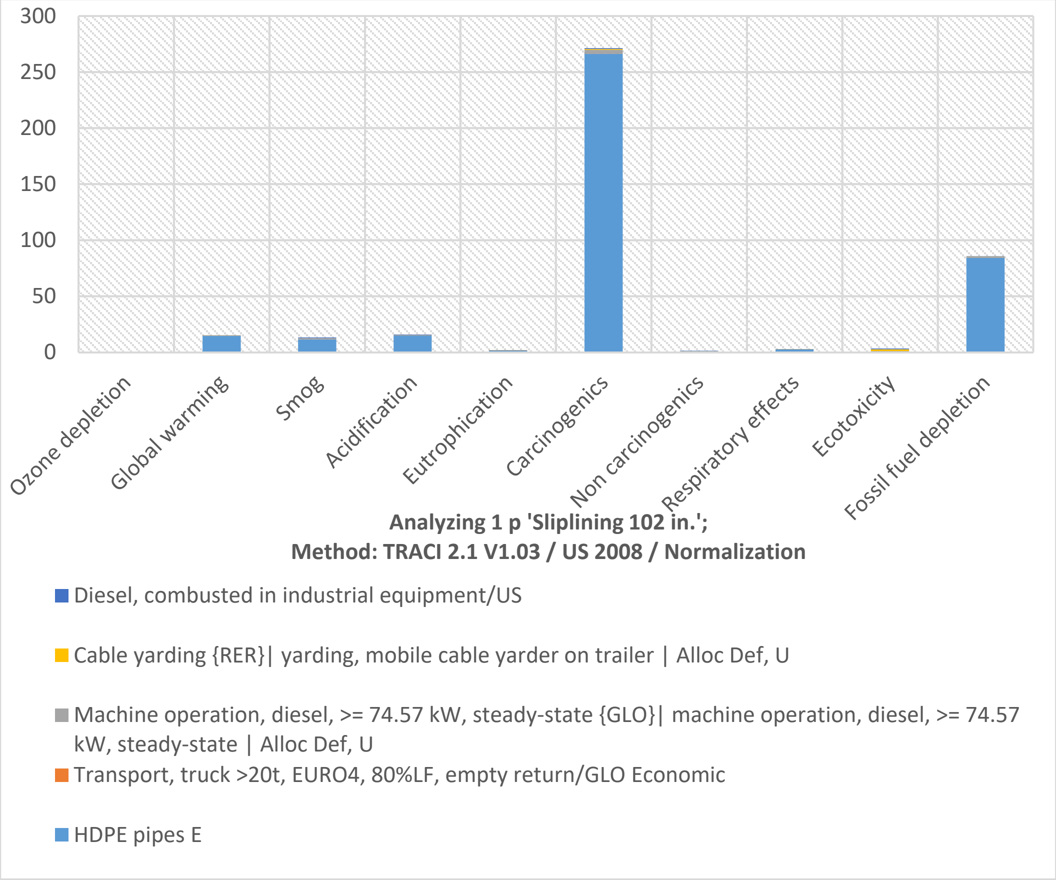


Figure B-163 Normalized Environmental Impact Assessment of 102 in. Diameter Sliplining Renewal Method

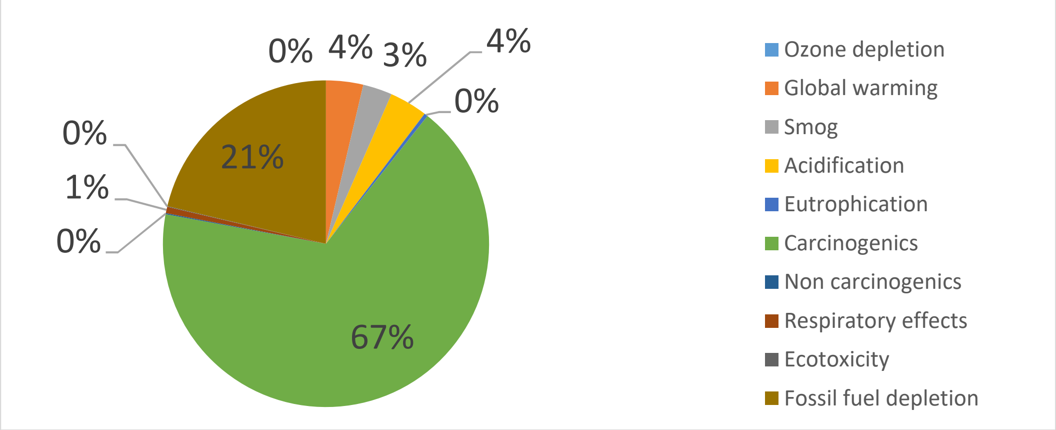


Figure B-164 Percentage of Normalized Environmental Impact Assessment of 102 in. Diameter Sliplining Renewal Method

Table B-123 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 102 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.002011	0	2.58E-06	1.70E-03	3.12E-04	1.05E-07
Global warming	kg CO2 eq	365485.5	353442.6	1152.92	7023.089	1312.336	2554.565
Smog	kg O3 eq	18424.02	16007.43	238.4739	952.0963	112.4426	1113.575
Acidification	kg SO2 eq	1430.433	1347.748	7.366293	35.28997	4.957876	35.07093
Eutrophication	kg N eq	40.70618	30.70972	0.4387	6.251387	1.208464	2.097912
Carcinogenics	CTUh	0.014302	0.01403	9.05E-07	1.92E-04	4.15E-05	3.78E-05
Non carcinogenics	CTUh	0.001356	0.000504	2.14E-05	3.57E-04	1.10E-04	0.000363
Respiratory effects	kg PM2.5 eq	64.01169	59.49067	0.144247	3.134177	0.520796	0.721793
Ecotoxicity	CTUe	36577.71	3067.361	553.7647	8796.051	17164.43	6996.1
Fossil fuel depletion	MJ surplus	1612811	1587454	2357.862	15004.3	2742.065	5253.042

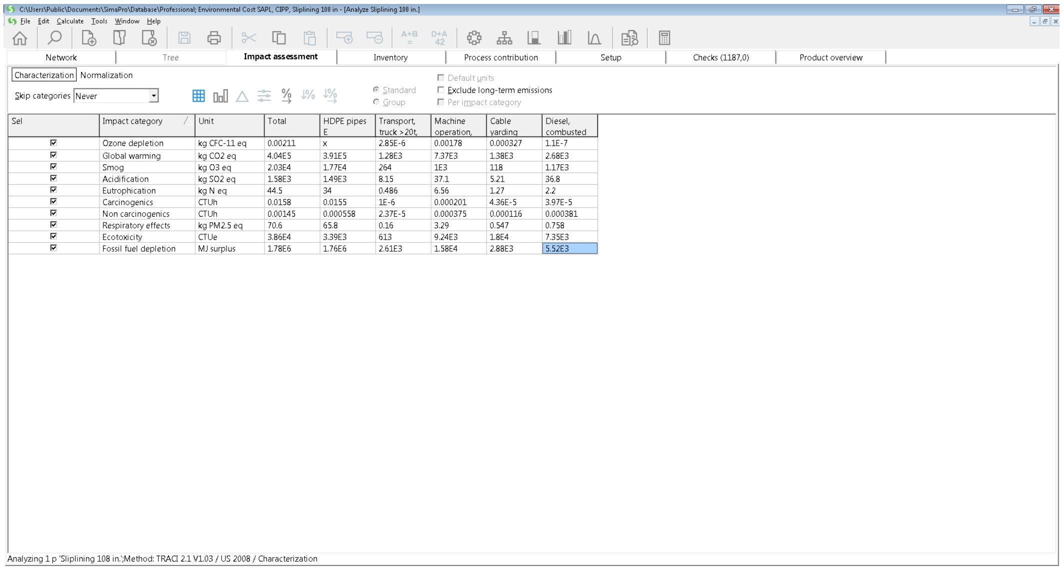
Table B-124 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 102 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.012472	0	1.60E-05	1.05E-02	1.93E-03	6.48E-07
Global warming	-	15.08794	14.59078	0.047595	0.289926	5.42E-02	0.105457
Smog	-	13.23648	11.50031	0.171328	0.68402	8.08E-02	0.800032
Acidification	-	15.74848	14.83815	0.0811	0.388528	5.46E-02	0.386116
Eutrophication	-	1.88317	1.420709	0.020295	0.289205	0.055907	0.097055
Carcinogenics	-	271.2893	266.1282	0.017176	3.639203	0.788076	0.716628
Non carcinogenics	-	1.290934	0.480002	0.020355	0.340217	0.10513	0.345231
Respiratory effects	-	2.639877	2.453428	0.005949	0.129255	2.15E-02	0.029767
Ecotoxicity	-	3.304233	0.277089	0.050024	0.794588	1.550542	0.63199
Fossil fuel depletion	-	85.69493	84.3476	0.125282	0.797237	1.46E-01	0.279115

Table B-125 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 102 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.002011	0.07
Global warming	kg CO2 eq	365485.5	23,025.59
Smog	kg O3 eq	18424.02	40,532.83
Acidification	kg SO2 eq	1430.433	7,824.47
Eutrophication	kg N eq	40.70618	83.45
Carcinogenic	CTUh	0.014302	0.00
Non carcinogenic	CTUh	0.001356	0.01
Respiratory effects	kg PM2.5 eq	64.01169	4,054.50
Ecotoxicity	CTUe	36577.71	1,499.69
Fossil fuel depletion	MJ surplus	1612811	15,805.55
Total			92,826.15

A.3.14 Sliplining 108 in.



Skip categories Never

● Standard
○ Group

☐ Default units
☐ Exclude long-term emissions
☐ Per impact category

Sel	Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t,	Machine operation,	Cable yarding	Diesel, combusted
☑	Ozone depletion	kg CFC-11 eq	0.00211	x	2.85E-6	0.00178	0.000327	1.1E-7
☑	Global warming	kg CO2 eq	4.04E5	3.91E5	1.28E3	7.37E3	1.38E3	2.68E3
☑	Smog	kg O3 eq	2.03E4	1.77E4	264	1E3	118	1.17E3
☑	Acidification	kg SO2 eq	1.58E3	1.49E3	8.15	37.1	5.21	36.8
☑	Eutrophication	kg N eq	44.5	34	0.486	6.56	1.27	2.2
☑	Carcinogenics	CTUh	0.0158	0.0155	1E-6	0.000201	4.36E-5	3.97E-5
☑	Non carcinogenics	CTUh	0.00145	0.000558	2.37E-5	0.000375	0.000116	0.000381
☑	Respiratory effects	kg PM2.5 eq	70.6	65.8	0.16	3.29	0.547	0.758
☑	Ecotoxicity	CTUe	3.86E4	3.39E3	613	9.24E3	1.8E4	7.35E3
☑	Fossil fuel depletion	MJ surplus	1.78E6	1.76E6	2.61E3	1.58E4	2.88E3	5.52E3

Analyzing 1 p 'Sliplining 108 in.';Method: TRACI 2.1 V1.03 / US 2008 / Characterization

Figure B-165 Screenshot of the Impact Assessment Table from SimaPro Software for 108 in. Sliplining

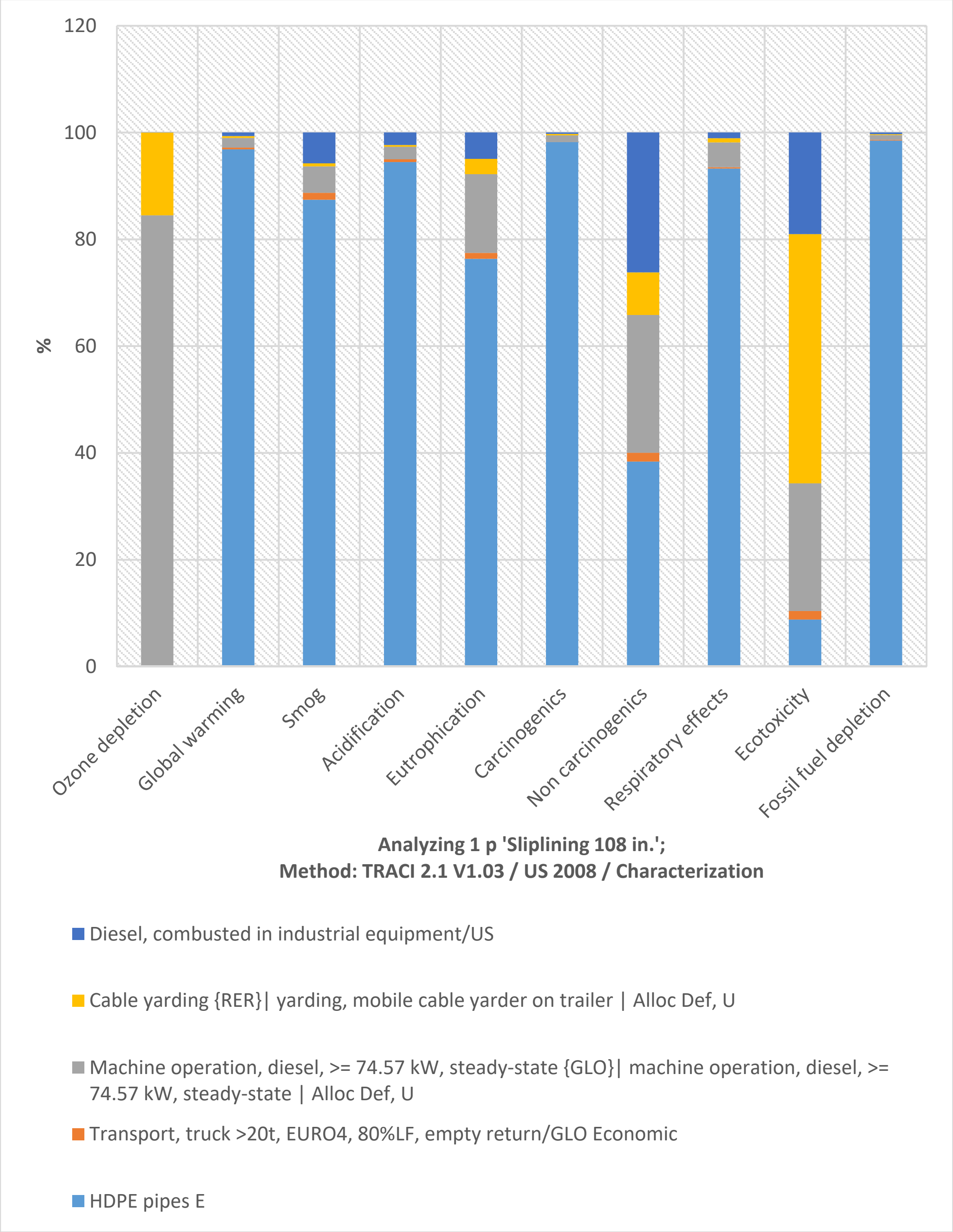


Figure B-166 Environmental Impact Assessment of 108 in. Diameter Sliplining Renewal Method

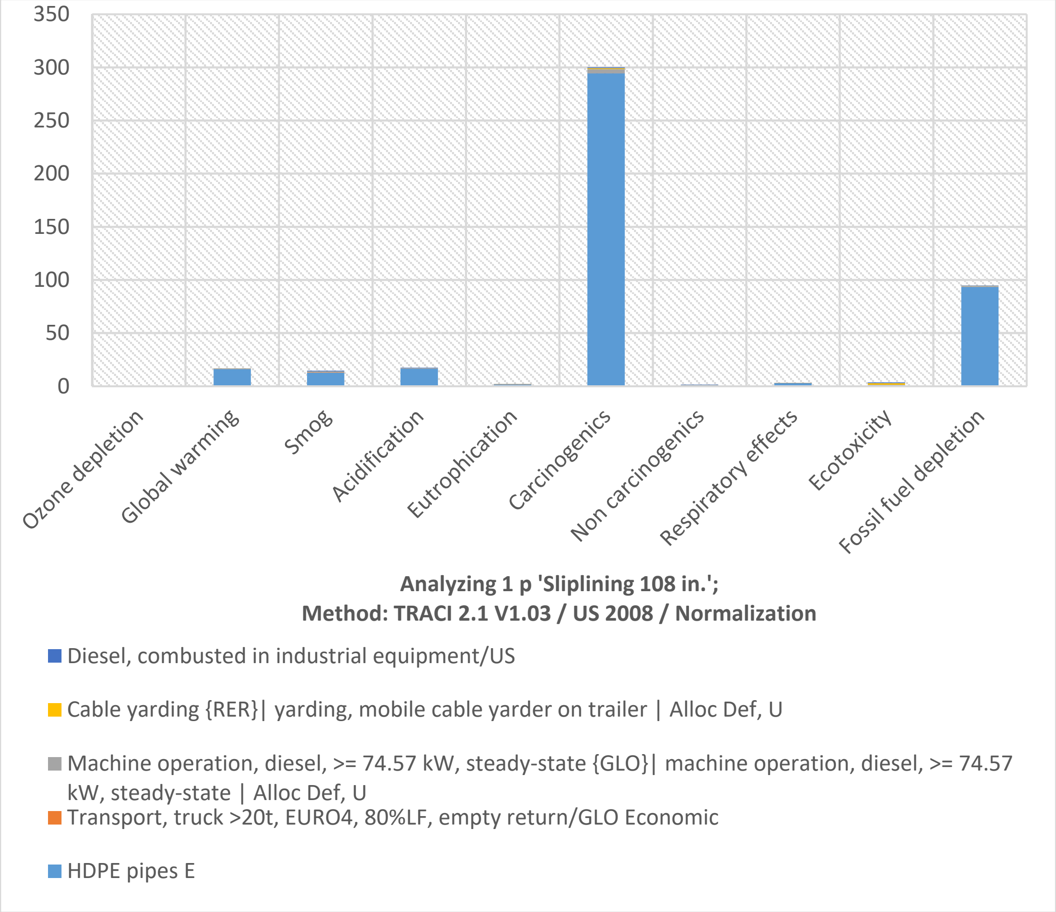


Figure B-167 Normalized Environmental Impact Assessment of 108 in. Diameter Sliplining Renewal Method

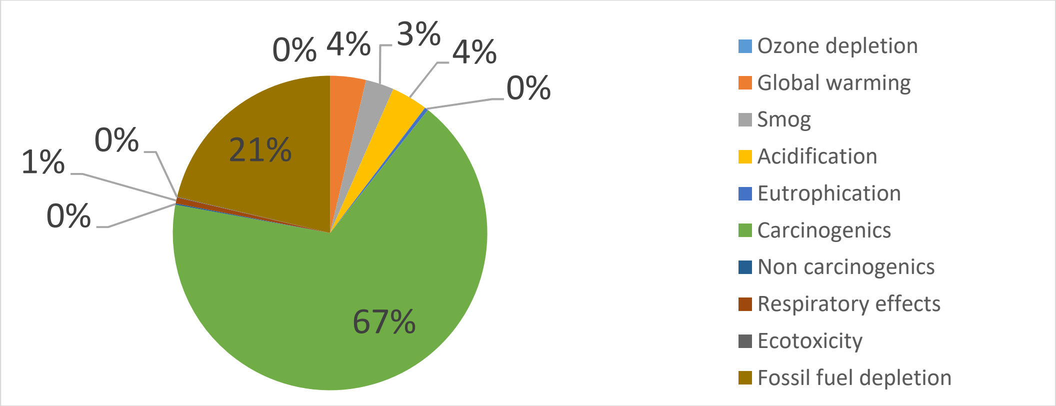


Figure B-168 Percentage of Normalized Environmental Impact Assessment of 108 in. Diameter Sliplining Renewal Method

Table B-126 Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 108 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	kg CFC-11 eq	0.002112	0	2.85E-06	1.78E-03	3.27E-04	1.10E-07
Global warming	kg CO2 eq	403861.2	391150.6	1275.923	7374.244	1378.105	2682.317
Smog	kg O3 eq	20266.19	17715.23	263.9161	999.7011	118.0778	1169.264
Acidification	kg SO2 eq	1578.774	1491.537	8.152187	37.05447	5.206344	36.82481
Eutrophication	kg N eq	44.50739	33.98607	0.485504	6.563956	1.269028	2.202827
Carcinogenics	CTUh	0.015813	0.015527	1.00E-06	2.01E-04	4.36E-05	3.97E-05
Non carcinogenics	CTUh	0.001453	0.000558	2.37E-05	3.75E-04	1.16E-04	0.000381
Respiratory effects	kg PM2.5 eq	70.59292	65.83761	0.159636	3.290886	0.546896	0.757889
Ecotoxicity	CTUe	38613.93	3394.612	612.8447	9235.854	18024.65	7345.971
Fossil fuel depletion	MJ surplus	1783575	1756816	2609.418	15754.52	2879.486	5515.744

Table B-127 Normalized Environmental Impact Assessment Results for Sliplining Renewal Method of 500-ft Length and Diameter of 108 in. Culvert

Impact category	Unit	Total	HDPE pipes E	Transport, truck >20t	Machine operation	Cable yarding	Diesel
Ozone depletion	-	0.013097	0	1.77E-05	1.10E-02	2.03E-03	6.81E-07
Global warming	-	16.67216	16.14744	0.052673	0.304423	5.69E-02	0.110731
Smog	-	14.55996	12.72726	0.189607	0.718221	8.48E-02	0.840041
Acidification	-	17.38165	16.4212	0.089752	0.407954	5.73E-02	0.405426
Eutrophication	-	2.059023	1.572281	0.022461	0.303665	0.058708	0.101908
Carcinogenics	-	299.9411	294.5209	0.019008	3.821163	0.827571	0.752466
Non carcinogenics	-	1.383861	0.531212	0.022527	0.357227	0.110399	0.362495
Respiratory effects	-	2.911291	2.715179	0.006583	0.135718	2.26E-02	0.031256
Ecotoxicity	-	3.488174	0.306651	0.055361	0.834317	1.628249	0.663595
Fossil fuel depletion	-	94.76829	93.34647	0.138649	0.837099	1.53E-01	0.293073

Table B-128 Environmental Impact Cost Results for Sliplining Renewal Method of 500-ft Length and Diameter of 108 in. Culvert

Impact category	Unit	Total	Cost ($)
Ozone depletion	kg CFC-11 eq	0.002112	0.07
Global warming	kg CO2 eq	403861.2	25,443.26
Smog	kg O3 eq	20266.19	44,585.61
Acidification	kg SO2 eq	1578.774	8,635.90
Eutrophication	kg N eq	44.50739	91.24
Carcinogenic	CTUh	0.015813	0.00
Non carcinogenic	CTUh	0.001453	0.01
Respiratory effects	kg PM2.5 eq	70.59292	4,471.36
Ecotoxicity	CTUe	38613.93	1,583.17
Fossil fuel depletion	MJ surplus	1783575	17,479.03
Total			102,289.65

Appendix B PYTHON CODES

This Appendix is provided to show the sample of the codes which are used in Python to analyze and develop a machine learning-based model in this dissertation. For more information about the complete set of the codes please contact author at Ramtin.serajiantehrani@mavs.uta.edu. The sample of codes are as follows:

```
# Importing the libraries
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import pickle
************************************
dfadj = pd.read_csv('hiring.csv')
dfadj = dfadj.fillna(method='ffill')
************************************
data = dfadj
X = data[['Location','Trenchless_Method','Pipe_Diameter','Pipe_Length','Rehab_Thickness','Letting_Year']]
Y = data.Unit_Cost_19
X = pd.get_dummies(data=X)
************************************
#Splitting Training and Test Set
from sklearn.model_selection import train_test_split
X_train, X_test, Y_train, Y_test = train_test_split(X, Y, test_size = .20, random_state = 42)
```

```
#Since we have a very small dataset, we will train our model with all availabe
data.
************************************
from sklearn.linear_model import LinearRegression
regr = LinearRegression()
************************************
#Fitting model with trainig data
regr.fit(X_train, Y_train)
predicted = regr.predict(X_test)
************************************
# Start Finalize Modeling
# user_input = [30, 500, 1.5, 2017,'NY', 'CIPP']
user_input =
{'Pipe_Diameter':30,'Pipe_Length':500,'Rehab_Thickness':1.5,'Letting_Year':2020,
'Location':'NY','Trenchless_Method':'CIPP'}
def input_to_one_hot(data):
    # initialize the target vector with zero values
    enc_input = np.zeros(14)
    # set the numerical input as they are
    enc_input[0] = data['Pipe_Diameter']
    enc_input[1] = data['Pipe_Length']
    enc_input[2] = data['Rehab_Thickness']
    enc_input[3] = data['Letting_Year']
    ##################### Location ####################
```

```
          # get the array of fuel type
          Location = dfadj.Location.unique()
          # redefine the the user inout to match the column name
          redefinded_user_input = 'Location_'+data['Location']
          # search for the index in columns name list
          Location_column_index = X.columns.tolist().index(redefinded_user_input)
          # fullfill the found index with 1
          enc_input[Location_column_index] = 1
          ################## Trenchless_Method #################
          # get the array of marks categories
          Trenchless_Method = dfadj.Trenchless_Method.unique()
          # redefine the the user inout to match the column name
          redefinded_user_input = 'Trenchless_Method_'+data['Trenchless_Method']
          # search for the index in columns name list
          Trenchless_Method_column_index =
X.columns.tolist().index(redefinded_user_input)
          #print(Trenchless_Method_column_index)
          # fullfill the found index with 1
          enc_input[Trenchless_Method_column_index] = 1
         *************************************
          return enc_input
        *************************************
        a = input_to_one_hot(user_input)
```

```
# Saving model to disk
from sklearn.externals import joblib
*************************************
joblib.dump(regr, 'model.pkl')
*************************************
# Loading model to compare the results
regr = joblib.load('model.pkl')
print ("The Predicted Unit Cost For this Trenchless Method is",
regr.predict([a])[0])
```

Appendix C DATASET[30]

---

[30]

No	Latitude	Longitude	Location	Letting_Year	Trenchless_Method	Pipe_Diameter	Pipe_Length	Rehab_Thickness	Unit_Cost_19
1	41.2033	-77.1945	PA	2015	SAPL	54	60	1	741.49
2	41.2033	-77.1945	PA	2015	SAPL	48	55	1	674.08
3	41.2033	-77.1945	PA	2015	SAPL	66	50	1	950.64
4	41.2033	-77.1945	PA	2015	SAPL	48	30	1	891.67
5	41.2033	-77.1945	PA	2018	SAPL	48	440	1.75	888.83
6	41.2033	-77.1945	PA	2018	SAPL	60	450	2.25	1027.09
7	41.2033	-77.1945	PA	2016	CIPP	36	62		444.88
8	41.2033	-77.1945	PA	2016	CIPP	30	125		220.67
9	41.2033	-77.1945	PA	2016	CIPP	36	70		394.04
10	41.2033	-77.1945	PA	2014	CIPP	36	145		468.9
11	41.2033	-77.1945	PA	2014	CIPP	48	110		618.1
12	41.2033	-77.1945	PA	2014	CIPP	30	320		212.47
13	41.2033	-77.1945	PA	2010	CIPP	36	445		142.68
14	41.2033	-77.1945	PA	2010	CIPP	30	116		170.57
15	41.2033	-77.1945	PA	2012	CIPP	48	216		335.61
16	41.2033	-77.1945	PA	2010	CIPP	60	75		294.43
17	35.7596	-80.7935	NC	2016	SAPL	30	188	1.5	328.49
18	35.7596	-80.7935	NC	2014	SAPL	30	208	1.5	387.99
19	35.7596	-80.7935	NC	2014	SAPL	42	68	1.5	831.41
20	35.7596	-80.7935	NC	2014	SAPL	54	64	1.5	942.26
21	35.7596	-80.7935	NC	2017	SAPL	78	405	1.5	890.38
22	35.7596	-80.7935	NC	2016	SAPL	48	160	1.5	497.55
23	35.7596	-80.7935	NC	2014	SAPL	72	253	1.5	1413.39

24	35.7596	-80.7935	NC	2017	SAPL	54	56	1.5	523.75
25	35.7596	-80.7935	NC	2014	CIPP	30	143		207.3
26	35.7596	-80.7935	NC	2016	CIPP	30	105		431.21
27	35.7596	-80.7935	NC	2014	CIPP	36	131		271.59
28	35.7596	-80.7935	NC	2015	CIPP	60	269		850.16
29	35.7596	-80.7935	NC	2017	CIPP	30	580		167.51
30	35.7596	-80.7935	NC	2019	CIPP	30	264		140
31	35.7596	-80.7935	NC	2019	Sliplining	30	211		250
32	35.7596	-80.7935	NC	2019	Sliplining	42	195		240
33	35.7596	-80.7935	NC	2019	Sliplining	54	578		260
34	35.7596	-80.7935	NC	2011	Sliplining	30	452		492.96
35	35.7596	-80.7935	NC	2010	Sliplining	36	135		359.2
36	35.7596	-80.7935	NC	2010	Sliplining	54	64		573.54
37	35.7596	-80.7935	NC	2010	Sliplining	66	110		617.11
38	35.7596	-80.7935	NC	2011	Sliplining	30	150		273.87
39	35.7596	-80.7935	NC	2015	Sliplining	42	19		727.78
40	35.7596	-80.7935	NC	2012	Sliplining	54	408		519.08
41	35.7596	-80.7935	NC	2014	Sliplining	54	244		909
42	35.7596	-80.7935	NC	2012	Sliplining	60	168		548.16
43	35.7596	-80.7935	NC	2011	Sliplining	60	358		513.5
44	35.7596	-80.7935	NC	2011	Sliplining	66	185		673.25
45	35.7596	-80.7935	NC	2011	Sliplining	72	345		568.27
46	40.4173	-82.9071	OH	2018	CIPP	36	246		183.66
47	40.4173	-82.9071	OH	2018	CIPP	36	262		230.22

48	40.4173	-82.9071	OH	2018	CIPP	42	286		255.8
49	40.4173	-82.9071	OH	2017	CIPP	36	265		246.16
50	40.4173	-82.9071	OH	2017	CIPP	36	210		235.69
51	40.4173	-82.9071	OH	2017	CIPP	42	218		288.06
52	40.4173	-82.9071	OH	2017	CIPP	30	173		219.98
53	40.4173	-82.9071	OH	2017	CIPP	36	265		246.16
54	40.4173	-82.9071	OH	2017	CIPP	36	210		235.69
55	40.4173	-82.9071	OH	2017	CIPP	42	218		288.06
56	40.4173	-82.9071	OH	2018	CIPP	36	264		133.01
57	40.4173	-82.9071	OH	2018	SAPL	36	496	1.5	306.96
58	40.4173	-82.9071	OH	2018	SAPL	42	298	1.5	342.77
59	40.4173	-82.9071	OH	2018	SAPL	48	476	1.5	368.35
60	40.4173	-82.9071	OH	2018	SAPL	54	1064	2	562.76
61	40.4173	-82.9071	OH	2017	SAPL	36	154	1	696.59
62	40.4173	-82.9071	OH	2017	SAPL	42	145	1	628.5
63	40.4173	-82.9071	OH	2018	SAPL	60	125	2	537.18
64	40.4173	-82.9071	OH	2017	SAPL	48	94	1.5	552.03
65	40.4173	-82.9071	OH	2017	SAPL	54	158	1.5	489.18
66	40.4173	-82.9071	OH	2017	SAPL	72	154	2	696.59
67	40.4173	-82.9071	OH	2017	SAPL	42	145	1.5	628.5
68	40.4173	-82.9071	OH	2017	SAPL	66	88	2	1089.4
69	40.4173	-82.9071	OH	2017	SAPL	60	489	2	505.94
70	40.4173	-82.9071	OH	2017	SAPL	48	332	2	501.75
71	40.4173	-82.9071	OH	2017	SAPL	60	279	2	518.51

72	40.4173	-82.9071	OH	2018	SAPL	36	496	1.5	306.96
73	40.4173	-82.9071	OH	2018	SAPL	42	298	1.5	342.77
74	40.4173	-82.9071	OH	2018	SAPL	48	476	1.5	368.35
75	40.4173	-82.9071	OH	2018	SAPL	60	1064	2	460.44
76	40.4173	-82.9071	OH	2018	SAPL	30	61	1.5	230.73
77	40.4173	-82.9071	OH	2018	SAPL	72	51	2	1137.29
78	40.4173	-82.9071	OH	2018	Sliplining	36	16		229.2
79	40.4173	-82.9071	OH	2018	Sliplining	36	42		713.86
80	40.4173	-82.9071	OH	2018	Sliplining	36	38		185.08
81	40.4173	-82.9071	OH	2018	Sliplining	42	36		190.18
82	40.4173	-82.9071	OH	2018	Sliplining	48	35		339.91
83	40.4173	-82.9071	OH	2018	Sliplining	48	52		266.14
84	40.4173	-82.9071	OH	2018	Sliplining	60	44		493.5
85	40.4173	-82.9071	OH	2018	Sliplining	60	386		617.06
86	40.4173	-82.9071	OH	2017	Sliplining	30	18		319.49
87	40.4173	-82.9071	OH	2017	Sliplining	36	40		204.26
88	40.4173	-82.9071	OH	2018	Sliplining	36	5		339.7
89	40.4173	-82.9071	OH	2017	Sliplining	30	18		319.49
90	40.4173	-82.9071	OH	2017	Sliplining	48	14		494.42
91	40.4173	-82.9071	OH	2017	Sliplining	54	32		230.45
92	40.4173	-82.9071	OH	2017	Sliplining	36	40		204.26
93	40.4173	-82.9071	OH	2017	Sliplining	60	105		618.03
94	40.4173	-82.9071	OH	2017	Sliplining	72	68		293.3
95	40.4173	-82.9071	OH	2017	Sliplining	72	84		246.16

96	40.4173	-82.9071	OH	2017	Sliplining	30	203		298.54
97	40.4173	-82.9071	OH	2017	Sliplining	36	110		356.15
98	40.4173	-82.9071	OH	2018	Sliplining	36	16		126.88
99	40.4173	-82.9071	OH	2018	Sliplining	60	94		874.84
100	40.4173	-82.9071	OH	2018	Sliplining	60	256		273.19
101	40.4173	-82.9071	OH	2018	Sliplining	48	154		445.09
102	40.4173	-82.9071	OH	2018	Sliplining	90	120		597.94
103	40.4173	-82.9071	OH	2018	Sliplining	60	53		508.53
104	40.4173	-82.9071	OH	2018	Sliplining	60	96		341.75
105	40.4173	-82.9071	OH	2018	Sliplining	72	85		383.7
106	40.4173	-82.9071	OH	2018	Sliplining	84	81		326.4
107	40.4173	-82.9071	OH	2018	Sliplining	42	82		710.1
108	40.4173	-82.9071	OH	2018	Sliplining	48	163		474.76
109	40.4173	-82.9071	OH	2018	Sliplining	60	317		564.81
110	40.4173	-82.9071	OH	2018	Sliplining	60	125		537.18
111	40.4173	-82.9071	OH	2018	Sliplining	102	452		716.24
112	40.4173	-82.9071	OH	2017	Sliplining	30	64		148.75
113	40.4173	-82.9071	OH	2017	Sliplining	36	76		168.65
114	40.4173	-82.9071	OH	2017	Sliplining	72	68		384.43
115	40.4173	-82.9071	OH	2017	Sliplining	30	204		329.96
116	40.4173	-82.9071	OH	2017	Sliplining	48	226		511.18
117	40.4173	-82.9071	OH	2017	Sliplining	48	226		273.4
118	40.4173	-82.9071	OH	2017	Sliplining	36	8		379.44
119	40.4173	-82.9071	OH	2017	Sliplining	60	77		575.26

120	40.4173	-82.9071	OH	2017	Sliplining	60	97			930.75
121	40.4173	-82.9071	OH	2017	Sliplining	36	128			477.02
122	40.4173	-82.9071	OH	2017	Sliplining	42	120			501.84
123	40.73061	-73.9352	NY	2012	CIPP	30	606			201.37
124	40.73061	-73.9352	NY	2012	CIPP	30	666			393.78
125	40.73061	-73.9352	NY	2012	CIPP	30	1291			283.89
126	40.73061	-73.9352	NY	2012	CIPP	30	60			313.24
127	40.73061	-73.9352	NY	2012	CIPP	30	100			313.24
128	40.73061	-73.9352	NY	2013	CIPP	30	820			440.89
129	40.73061	-73.9352	NY	2013	CIPP	30	190			304.21
130	40.73061	-73.9352	NY	2013	CIPP	30	248			281.26
131	40.73061	-73.9352	NY	2013	CIPP	30	132			369.24
132	40.73061	-73.9352	NY	2013	CIPP	30	50			308.62
133	40.73061	-73.9352	NY	2013	CIPP	30	100			445.16
134	40.73061	-73.9352	NY	2014	CIPP	30	140			443.42
135	40.73061	-73.9352	NY	2014	CIPP	30	325			308.26
136	40.73061	-73.9352	NY	2014	CIPP	30	270			210.62
137	40.73061	-73.9352	NY	2014	CIPP	30	100			310.39
138	40.73061	-73.9352	NY	2015	CIPP	30	880			202.52
139	40.73061	-73.9352	NY	2015	CIPP	30	2025			218.77
140	40.73061	-73.9352	NY	2015	CIPP	30	50			368.22
141	40.73061	-73.9352	NY	2016	CIPP	30	424			309.23
142	40.73061	-73.9352	NY	2016	CIPP	30	610			240.75
143	40.73061	-73.9352	NY	2016	CIPP	30	100			299.6

144	40.73061	-73.9352	NY	2016	CIPP	30	50		337.05
145	40.73061	-73.9352	NY	2017	CIPP	30	500		240.93
146	40.73061	-73.9352	NY	2018	CIPP	30	1094		214.87
147	40.73061	-73.9352	NY	2018	CIPP	30	100		332.54
148	40.73061	-73.9352	NY	2012	CIPP	36	912		246.11
149	40.73061	-73.9352	NY	2012	CIPP	36	270		307.64
150	40.73061	-73.9352	NY	2012	CIPP	36	122		520.2
151	40.73061	-73.9352	NY	2012	CIPP	36	1587		368.31
152	40.73061	-73.9352	NY	2012	CIPP	36	60		408.33
153	40.73061	-73.9352	NY	2012	CIPP	36	100		408.33
154	40.73061	-73.9352	NY	2013	CIPP	36	840		440.89
155	40.73061	-73.9352	NY	2013	CIPP	36	122		347.2
156	40.73061	-73.9352	NY	2015	CIPP	36	500		250.17
157	40.73061	-73.9352	NY	2013	CIPP	36	64		484.98
158	40.73061	-73.9352	NY	2013	CIPP	36	50		402.31
159	40.73061	-73.9352	NY	2013	CIPP	36	100		506.8
160	40.73061	-73.9352	NY	2014	CIPP	36	880		465.59
161	40.73061	-73.9352	NY	2014	CIPP	36	606		319.98
162	40.73061	-73.9352	NY	2014	CIPP	36	1120		232.79
163	40.73061	-73.9352	NY	2014	CIPP	36	100		404.62
164	40.73061	-73.9352	NY	2015	CIPP	36	810		218.77
165	40.73061	-73.9352	NY	2015	CIPP	36	3997		238.26
166	40.73061	-73.9352	NY	2015	CIPP	36	50		433.2
167	40.73061	-73.9352	NY	2016	CIPP	36	704		408.74

168	40.73061	-73.9352	NY	2016	CIPP	36	300		256.8
169	40.73061	-73.9352	NY	2016	CIPP	36	130		288.9
170	40.73061	-73.9352	NY	2016	CIPP	36	184		363.8
171	40.73061	-73.9352	NY	2016	CIPP	36	100		358.45
172	40.73061	-73.9352	NY	2016	CIPP	36	50		406.6
173	40.73061	-73.9352	NY	2017	CIPP	36	1500		261.88
174	40.73061	-73.9352	NY	2018	CIPP	36	426		250.68
175	40.73061	-73.9352	NY	2018	CIPP	42	100		414.4
176	40.73061	-73.9352	NY	2017	CIPP	42	850		314.25
177	40.73061	-73.9352	NY	2016	CIPP	42	50		433.35
178	40.73061	-73.9352	NY	2016	CIPP	42	100		433.35
179	40.73061	-73.9352	NY	2016	CIPP	42	188		659.12
180	40.73061	-73.9352	NY	2015	CIPP	42	50		525.26
181	40.73061	-73.9352	NY	2015	CIPP	42	363		314.07
182	40.73061	-73.9352	NY	2014	CIPP	42	100		471.13
183	40.73061	-73.9352	NY	2014	CIPP	42	575		288.22
184	40.73061	-73.9352	NY	2013	CIPP	42	50		468.44
185	40.73061	-73.9352	NY	2012	CIPP	42	100		475.45
186	40.73061	-73.9352	NY	2012	CIPP	42	60		475.45
187	40.73061	-73.9352	NY	2012	CIPP	42	433		422.94
188	40.73061	-73.9352	NY	2012	CIPP	42	1158		335.61
189	40.73061	-73.9352	NY	2012	CIPP	48	2008		413.92
190	40.73061	-73.9352	NY	2012	CIPP	48	60		503.42
191	40.73061	-73.9352	NY	2012	CIPP	48	100		531.38

192	40.73061	-73.9352	NY	2013	CIPP	48	50		551.11
193	40.73061	-73.9352	NY	2014	CIPP	48	100		526.56
194	40.73061	-73.9352	NY	2015	CIPP	48	356		357.39
195	40.73061	-73.9352	NY	2015	CIPP	48	50		579.41
196	40.73061	-73.9352	NY	2016	CIPP	48	200		353.1
197	40.73061	-73.9352	NY	2016	CIPP	48	180		535
198	40.73061	-73.9352	NY	2016	CIPP	48	100		502.9
199	40.73061	-73.9352	NY	2016	CIPP	48	50		508.25
200	40.73061	-73.9352	NY	2017	CIPP	48	450		366.63
201	40.73061	-73.9352	NY	2017	CIPP	48	188		471.38
202	40.73061	-73.9352	NY	2018	CIPP	48	100		486.02
203	40.73061	-73.9352	NY	2018	CIPP	48	180		486.21
204	40.73061	-73.9352	NY	2012	SAPL	36	890	1.5	335.61
205	40.73061	-73.9352	NY	2013	SAPL	36	46950	1.5	319.64
206	40.73061	-73.9352	NY	2015	SAPL	36	724	1.5	703.95
207	40.73061	-73.9352	NY	2014	SAPL	36	790	1.5	642.95
208	40.73061	-73.9352	NY	2016	SAPL	36	30768	1.5	396.6
209	40.73061	-73.9352	NY	2017	SAPL	36	15510	1.5	387.58
210	40.73061	-73.9352	NY	2018	SAPL	36	800	1.5	409.28
211	40.73061	-73.9352	NY	2019	Sliplining	30	266		170
212	40.73061	-73.9352	NY	2019	Sliplining	36	438		180
213	40.73061	-73.9352	NY	2010	Sliplining	48	50		353.31
214	40.73061	-73.9352	NY	2011	Sliplining	48	30		410.8
215	40.73061	-73.9352	NY	2011	Sliplining	48	50		410.8

216	40.73061	-73.9352	NY	2011	Sliplining	48	117		542.03
217	40.73061	-73.9352	NY	2012	Sliplining	48	124		374.76
218	40.73061	-73.9352	NY	2012	Sliplining	48	356		196.89
219	40.73061	-73.9352	NY	2013	Sliplining	48	520		413.33
220	40.73061	-73.9352	NY	2014	Sliplining	48	30		443.42
221	40.73061	-73.9352	NY	2015	Sliplining	48	295		303.24
222	40.73061	-73.9352	NY	2017	Sliplining	48	350		445.19
223	40.73061	-73.9352	NY	2018	Sliplining	48	251		417.47
224	40.73061	-73.9352	NY	2019	Sliplining	48	85		240
225	40.73061	-73.9352	NY	2011	Sliplining	60	400		473.56
226	40.73061	-73.9352	NY	2016	Sliplining	60	678		363.8
227	40.73061	-73.9352	NY	2019	Sliplining	60	96		700
228	40.73061	-73.9352	NY	2019	Sliplining	60	95		350
229	40.73061	-73.9352	NY	2012	Sliplining	84	165		894.96
230	40.73061	-73.9352	NY	2014	Sliplining	84	268		831.41
231	40.73061	-73.9352	NY	2019	Sliplining	84	150		606
232	40.73061	-73.9352	NY	2012	Sliplining	42	66		469.85
233	40.73061	-73.9352	NY	2012	Sliplining	42	60		357.98
234	40.73061	-73.9352	NY	2015	Sliplining	42	262		291.33
235	40.73061	-73.9352	NY	2013	Sliplining	42	50		413.33
236	40.73061	-73.9352	NY	2014	Sliplining	42	1738		294.87
237	40.73061	-73.9352	NY	2014	Sliplining	42	64		332.56
238	40.73061	-73.9352	NY	2015	Sliplining	42	50		406.13
239	40.73061	-73.9352	NY	2016	Sliplining	42	734		211.86

240	40.73061	-73.9352	NY	2017	Sliplining	42	412		319.49
241	40.73061	-73.9352	NY	2016	Sliplining	42	50		401.25
242	40.73061	-73.9352	NY	2018	Sliplining	42	100		383.7
243	40.73061	-73.9352	NY	2012	Sliplining	48	60		447.48
244	40.73061	-73.9352	NY	2015	Sliplining	48	324		292.41
245	40.73061	-73.9352	NY	2013	Sliplining	48	50		496
246	40.73061	-73.9352	NY	2013	Sliplining	48	700		305.28
247	40.73061	-73.9352	NY	2014	Sliplining	48	854		365.82
248	40.73061	-73.9352	NY	2015	Sliplining	48	50		487.35
249	40.73061	-73.9352	NY	2016	Sliplining	48	380		278.2
250	40.73061	-73.9352	NY	2016	Sliplining	48	50		481.5
251	40.73061	-73.9352	NY	2018	Sliplining	48	164		296.73
252	40.73061	-73.9352	NY	2018	Sliplining	48	100		460.44
253	40.73061	-73.9352	NY	2012	Sliplining	54	244		615.29
254	40.73061	-73.9352	NY	2012	Sliplining	54	60		531.38
255	40.73061	-73.9352	NY	2013	Sliplining	54	472		341.69
256	40.73061	-73.9352	NY	2013	Sliplining	54	123		396.8
257	40.73061	-73.9352	NY	2013	Sliplining	54	50		578.67
258	40.73061	-73.9352	NY	2014	Sliplining	54	250		287.11
259	40.73061	-73.9352	NY	2014	Sliplining	54	166		387.99
260	40.73061	-73.9352	NY	2015	Sliplining	54	50		568.58
261	40.73061	-73.9352	NY	2017	Sliplining	54	22		764.68
262	40.73061	-73.9352	NY	2016	Sliplining	54	50		561.75
263	40.73061	-73.9352	NY	2017	Sliplining	54	123		628.5

264	40.73061	-73.9352	NY	2017	Sliplining	54	676		392.81
265	40.73061	-73.9352	NY	2018	Sliplining	54	448		353
266	40.73061	-73.9352	NY	2018	Sliplining	54	100		537.18
267	40.73061	-73.9352	NY	2014	Sliplining	66	65		554.27
268	40.73061	-73.9352	NY	2016	Sliplining	66	594		535
269	40.73061	-73.9352	NY	2017	Sliplining	66	336		502.8
270	40.73061	-73.9352	NY	2018	Sliplining	66	398		450.21
271	40.73061	-73.9352	NY	2014	Sliplining	42	122		321.48
272	40.73061	-73.9352	NY	2018	Sliplining	42	160		681.45
273	40.73061	-73.9352	NY	2013	Sliplining	48	462		314.13
274	40.73061	-73.9352	NY	2015	Sliplining	48	140		354.25
275	40.73061	-73.9352	NY	2016	Sliplining	48	145		321
276	40.73061	-73.9352	NY	2017	Sliplining	48	110		356.15
277	40.73061	-73.9352	NY	2017	Sliplining	48	368		256.64
278	40.73061	-73.9352	NY	2012	Sliplining	54	90		866.99
279	40.73061	-73.9352	NY	2013	Sliplining	54	699		275.56
280	40.73061	-73.9352	NY	2014	Sliplining	54	765		279.35
281	40.73061	-73.9352	NY	2014	Sliplining	54	162		387.99
282	40.73061	-73.9352	NY	2014	Sliplining	54	538		387.99
283	40.73061	-73.9352	NY	2015	Sliplining	54	250		389.98
284	40.73061	-73.9352	NY	2016	Sliplining	54	90		310.3
285	40.73061	-73.9352	NY	2017	Sliplining	54	247		477.66
286	40.73061	-73.9352	NY	2017	Sliplining	54	440		340.44
287	40.73061	-73.9352	NY	2018	Sliplining	54	145		523.37

288	40.73061	-73.9352	NY	2012	Sliplining	60	60		604.1
289	40.73061	-73.9352	NY	2013	Sliplining	60	1726		380.27
290	40.73061	-73.9352	NY	2013	Sliplining	60	162		391.29
291	40.73061	-73.9352	NY	2013	Sliplining	60	50		661.33
292	40.73061	-73.9352	NY	2014	Sliplining	60	466		321.48
293	40.73061	-73.9352	NY	2014	Sliplining	60	69		554.27
294	40.73061	-73.9352	NY	2014	Sliplining	60	498		432.33
295	40.73061	-73.9352	NY	2015	Sliplining	60	50		649.8
296	40.73061	-73.9352	NY	2016	Sliplining	60	195		304.95
297	40.73061	-73.9352	NY	2016	Sliplining	60	50		642
298	40.73061	-73.9352	NY	2017	Sliplining	60	596		387.58
299	40.73061	-73.9352	NY	2017	Sliplining	60	410		419
300	40.73061	-73.9352	NY	2018	Sliplining	60	100		665.08
301	40.73061	-73.9352	NY	2018	Sliplining	60	15		289.05
302	40.73061	-73.9352	NY	2019	Sliplining	60	452		860
303	40.73061	-73.9352	NY	2012	Sliplining	66	275		671.22
304	40.73061	-73.9352	NY	2013	Sliplining	66	780		456.25
305	40.73061	-73.9352	NY	2016	Sliplining	66	169		642
306	40.73061	-73.9352	NY	2017	Sliplining	66	717		526.89
307	40.73061	-73.9352	NY	2018	Sliplining	66	85		953.11
308	40.73061	-73.9352	NY	2019	Sliplining	72	235		660
309	40.73061	-73.9352	NY	2013	Sliplining	78	245		578.67
310	40.73061	-73.9352	NY	2013	Sliplining	78	258		892.8
311	40.73061	-73.9352	NY	2014	Sliplining	78	340		458.94

312	40.73061	-73.9352	NY	2014	Sliplining	78	173		565.36
313	40.73061	-73.9352	NY	2017	Sliplining	78	12		1047.5
314	40.73061	-73.9352	NY	2013	Sliplining	84	245		578.67
315	40.73061	-73.9352	NY	2013	Sliplining	84	258		892.8
316	40.73061	-73.9352	NY	2014	Sliplining	84	340		458.94
317	40.73061	-73.9352	NY	2014	Sliplining	84	173		565.36
318	40.73061	-73.9352	NY	2017	Sliplining	84	12		1047.5
319	40.73061	-73.9352	NY	2014	Sliplining	90	675		515.47
320	40.73061	-73.9352	NY	2016	Sliplining	90	53		535
321	40.73061	-73.9352	NY	2015	Sliplining	96	1625		649.8
322	40.73061	-73.9352	NY	2017	Sliplining	96	85		885.14
323	40.73061	-73.9352	NY	2018	Sliplining	96	35		1028.32
324	46.7296	-94.6859	MN	2018	CIPP	30	3204		209.45
325	46.7296	-94.6859	MN	2018	CIPP	36	5878		252.51
326	46.7296	-94.6859	MN	2018	CIPP	42	547		307.43
327	46.7296	-94.6859	MN	2018	CIPP	48	1181		472.07
328	46.7296	-94.6859	MN	2018	CIPP	60	314		671.56
329	46.7296	-94.6859	MN	2018	CIPP	108	352		1100
330	46.7296	-94.6859	MN	2018	CIPP	36	346		209.76
331	46.7296	-94.6859	MN	2018	CIPP	48	227		562.76
332	46.7296	-94.6859	MN	2018	CIPP	54	215		332.54
333	46.7296	-94.6859	MN	2018	CIPP	60	243		419.51
334	46.7296	-94.6859	MN	2018	CIPP	66	190		491.14
335	46.7296	-94.6859	MN	2018	CIPP	72	359		547.41

336	46.7296	-94.6859	MN	2018	CIPP	72	93		767.4
337	46.7296	-94.6859	MN	2016	CIPP	84	580		1006.87
338	46.7296	-94.6859	MN	2018	CIPP	30	178		271.15
339	46.7296	-94.6859	MN	2018	CIPP	36	676		199.52
340	46.7296	-94.6859	MN	2019	CIPP	30	169		298
341	46.7296	-94.6859	MN	2019	CIPP	36	234		365
342	46.7296	-94.6859	MN	2019	CIPP	54	187		436
343	46.7296	-94.6859	MN	2019	CIPP	60	340		406
344	46.7296	-94.6859	MN	2010	CIPP	36	84		223.76
345	46.7296	-94.6859	MN	2019	CIPP	30	281		220
346	46.7296	-94.6859	MN	2019	CIPP	36	615		250
347	46.7296	-94.6859	MN	2019	CIPP	42	97		380
348	46.7296	-94.6859	MN	2019	CIPP	48	216		400
349	46.7296	-94.6859	MN	2019	CIPP	54	94		575
350	46.7296	-94.6859	MN	2019	CIPP	60	100		640
351	46.7296	-94.6859	MN	2016	CIPP	30	357		321
352	46.7296	-94.6859	MN	2016	CIPP	36	192		428
353	46.7296	-94.6859	MN	2016	CIPP	48	69		556.4
354	46.7296	-94.6859	MN	2018	SAPL	30	75	1.5	341.17
355	46.7296	-94.6859	MN	2018	SAPL	36	118	1.5	404.43
356	46.7296	-94.6859	MN	2018	SAPL	60	98	2	909.36
357	46.7296	-94.6859	MN	2016	SAPL	84	580	2	1177
358	46.7296	-94.6859	MN	2010	SAPL	36	84	1	294.43
359	46.7296	-94.6859	MN	2018	Sliplining	36	174		202.59

360	46.7296	-94.6859	MN	2018	Sliplining	42	116		427.7
361	46.7296	-94.6859	MN	2015	Sliplining	36	115		162.45
362	46.7296	-94.6859	MN	2015	Sliplining	30	731		238.26
363	46.7296	-94.6859	MN	2015	Sliplining	36	382		303.24
364	46.7296	-94.6859	MN	2015	Sliplining	42	138		422.37
365	46.7296	-94.6859	MN	2015	Sliplining	48	165		471.11
366	46.7296	-94.6859	MN	2015	Sliplining	60	106		785.18
367	46.7296	-94.6859	MN	2015	Sliplining	30	1429		135.38
368	46.7296	-94.6859	MN	2015	Sliplining	36	677		157.04
369	46.7296	-94.6859	MN	2015	Sliplining	42	364		222.02
370	46.7296	-94.6859	MN	2015	Sliplining	48	161		362.81
371	46.7296	-94.6859	MN	2015	Sliplining	54	1291		346.56
372	46.7296	-94.6859	MN	2015	Sliplining	60	1029		384.47
373	46.7296	-94.6859	MN	2015	Sliplining	72	1048		460.28
374	46.7296	-94.6859	MN	2010	Sliplining	36	84		123.66
375	38.9108	-75.5277	DE	2018	SAPL	36	400	1.5	419.51
376	38.9108	-75.5277	DE	2018	SAPL	42	400	1.5	419.51
377	38.9108	-75.5277	DE	2018	SAPL	48	400	1.5	419.51
378	38.9108	-75.5277	DE	2018	SAPL	54	200	2	532.06
379	38.9108	-75.5277	DE	2018	SAPL	60	200	2	532.06
380	27.6648	-81.5158	FL	2017	Sliplining	54	812		942.75
381	27.6648	-81.5158	FL	2017	Sliplining	60	812		942.75
382	27.6648	-81.5158	FL	2019	CIPP	54	1066		296.25
383	27.6648	-81.5158	FL	2019	CIPP	60	186		439.25

384	27.6648	-81.5158	FL	2019	CIPP	42	626		203
385	27.6648	-81.5158	FL	2019	CIPP	36	499		205.85
386	27.6648	-81.5158	FL	2018	CIPP	36	8263		108.25
387	27.6648	-81.5158	FL	2018	CIPP	48	2947		165.68
388	27.6648	-81.5158	FL	2018	CIPP	48	275		184.18
389	27.6648	-81.5158	FL	2018	CIPP	60	24		409.28
390	27.6648	-81.5158	FL	2018	CIPP	72	24		665.08
391	27.6648	-81.5158	FL	2019	CIPP	36	1633		105
392	27.6648	-81.5158	FL	2018	CIPP	36	300		158.6
393	27.6648	-81.5158	FL	2018	CIPP	48	100		230.22
394	27.6648	-81.5158	FL	2018	CIPP	60	100		250.68
395	27.6648	-81.5158	FL	2018	CIPP	72	50		613.92
396	27.6648	-81.5158	FL	2018	CIPP	36	640		118.08
397	27.6648	-81.5158	FL	2019	Sliplining	36	100		180
398	27.6648	-81.5158	FL	2019	Sliplining	48	100		250
399	27.6648	-81.5158	FL	2019	Sliplining	60	50		400
400	27.6648	-81.5158	FL	2019	Sliplining	72	50		750
401	27.6648	-81.5158	FL	2019	SAPL	48	526	1.5	350

BIOGRAPHICAL INFORMATION

Ramtin Serajiantehrani was born on June 01, 1988, in Tehran, Iran. He obtained his Bachelor's degree in Architectural Engineering from the Department of Art and Architecture in IAUCTB, Tehran, Iran in 2011. Right after his graduation from Bachelor's degree, he joined the Iran University of Science and Technology (IUST) in August 2011 due to successfully got ranked 27th among 100,000 participations in the highly competitive university entrance exam to pursue his Master's degree in Architectural Engineering. He successfully defended his Master's Thesis entitled "Development of a Residential Complex based on the Neighboorhood Unit" in June 2014 and graduated from Master's degree in July 2014.

Ramtin applied for his Doctoral studies in late 2013 and he got admission from the University of Texas at Arlington (UT Arlington) in early 2014 to pursue his Doctoal degree in Urban Planning and Public Policy. After a year of attending UT Arlington in Urban Planning studies, he was fortunate enough to have got accepted for his Doctoral studies in Civil Engineering by Dr. Mohammad Najafi and joined the Center for Underground Infrastructure Research and Education (CUIRE) research group at UT Arlington.

While working at CUIRE, Ramtin was a teaching assistant for various graduate courses such as Construction Management, Construction Planning and Scheduling, Field Operation and Equipment, Construction Sustainability, and Construction Project Administration. Ramtin also had an opportunity to work on several high-profile research assignments and projects for companies and organizations (both governments and industry associations) under the supervision of Dr. Mohammad Najafi at CUIRE. He attended and presented at a number of conferences in different states of the USA and also in other countries such as China, Cyprus, and Greece and published several journal and conference papers during this time. He was a recipient of the American Society of Civil Engineers (ASCE) Graduate Student Scholarship in 2019 and the North Texas Chapter of Construction Management Association of America (CMAA) Student Scholarships in 2019. Ramtin's great enthusiasm in the field of construction management, pipeline and utility, trenchless technology, and rehab led him to complete his dissertation on development of machine learning-based prediction model for environmental and construction costs analysis of trenchless spray-applied pipe linings (SAPL) cured-in-place pipe (CIPP) and sliplining renewal methods in large diameter culverts.