D14.3 Report on the impact of OPTIDRILL on environmental footprint of geothermal power

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AoC	Areas of Concern
AoP	Areas of Protection
AWARE	Available WAter Remaining
DTH	Down-the-Hole
GTP	Global Temperature Potential
GWP	Global Warming Potential
IDDP	Iceland Deep Drilling Project
ILCD	International Reference Life Cycle Data System
ISO	International Organisation for Standardization
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
SOA	State-of-art

Executive Summary

Geothermal fields are found in a wide variety of geological settings and formations. To counteract the drilling environments with different lithology, geology and geochemistry in future geothermal project development, the OptiDrill project proposes to improve the well completion performances through utilising novel sensor and machine learning methods to predict ROP, lithology, and drilling problems to provide improved drilling performances. The environmental impacts of the test case for adopting OptiDrill drilling technology components have been evaluated and analysed in this study, alongside the environmental impacts of the test case using state-of-the-art (SOA) drilling technology components. A cradle-to-gate life cycle assessment (LCA) approach has been considered and a SimaPro 9.5.0.0 LCA software tool has been used following ISO LCA standards 14040 and 14044. For translating the life cycle inventory data of the products, the IMPACT World+ Midpoint version 1.03 Life Cycle Impact Assessment (LCIA) methodology has been applied for the evaluation of 18 midpoint impact categories such as climate change, human toxicity, ozone layer depletion, and water scarcity. The functional unit of this LCA study is 1 metre (m) of drilling activities. It has been reported that carbon footprint savings of about 16.2 % in the test case, could be achieved by adopting OptiDrill drilling technology components instead of SOA drilling technology components. It has been demonstrated that the carbon footprint savings of about 37.44 t CO_2 eq per MW installed capacity of the representative geothermal power plant in the test case in Hengil (Icelandic) area for the adoption of OptiDrill drilling technology components instead of using SOA drilling technology components.

Objectives met

To demonstrate the environmental benefit of the OPTIDRILL concept; LCA studies for the test case stated in task 14.2 have been performed.

1. Introduction

The geothermal drilling process is challenging and complex as it requires a robust drilling rig system comprising i) a hoisting system, ii) a rotating system, iii) a circulating system, iv) a blowout prevention system and v) a power system. Detailed knowledge and data about the geology and geochemistry of geothermal fields need to be explored beforehand to encounter potential drilling hazards. The overall objective for the OptiDrill project is to develop a drilling advisory system utilising novel sensor and machine learning methods to predict rate of penetration (ROP), lithology, and drilling problem prediction that will provide the drilling team with data in real-time. These developments will help to reduce downtime and non-productive time of drilling.

In this study, drill bits and drilling energy components have been considered to evaluate the environmental performances of OptiDrill and state-of-the-art (SOA) drilling technologies in the context of the Icelandic perspective. The functional unit of the life cycle assessment (LCA) studies is 1 m of drilling activities. The rate of penetration (ROP) of a drill bit in geothermal drilling depends on several factors such as the formation being drilled, drilling techniques, mud properties, bit type, and type of drilling equipment used. The properties of drill bits such as bit lifetime and ROP have been inventoried [1-6] and gathered for the adoption of SOA and OptiDrill drilling technologies in conductor, surface, intermediate and production casings and perforated liners depth regions' lithology in Icelandic perspective. The drilling energy consumption data have also been estimated based on drill rig size and drilling time spent from an Icelandic viewpoint [7]. Based on these inventoried data of drill bit, and drilling energy components for drilled depths of 5000 m, the mass and energy flows for 1 m drilling activities have been estimated and calculated considering an Icelandic perspective as a test case.

The main goal of this LCA study is to quantify the environmental footprints by adopting OptiDrill and SOA drilling technology components for 1 m of drilling activities from an Icelandic perspective. The scope of this LCA study is to consider the drill bits, drilling energy components and their properties in the context of Icelandic perspective. The cradle-to-gate system boundary for this LCA study of drilling activities does not include transportation due to unavailability of primary data source and is presented in Figure 1.1. The

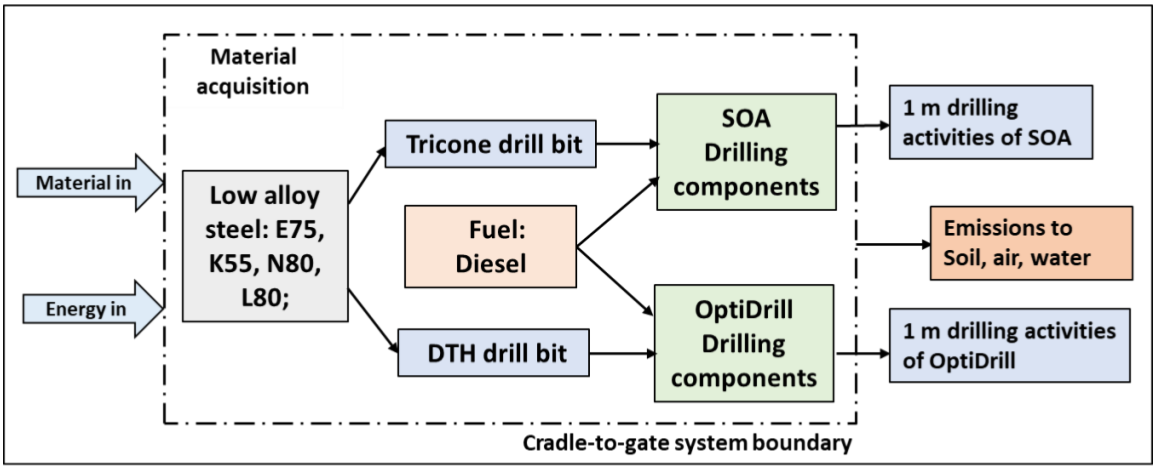

Figure 1.1 - The cradle-to-gate system boundary for LCA study of drilling activities.

The intended audiences for this study are listed below:

1. Geothermal Power plant industries

2. Drilling companies for geothermal applications

3. Investors

4. Policy and decision makers in the Geothermal sector

5. Environmental agencies

6. General public.

Section 2 describes the ISO standards LCA framework and impact assessment methodology used in this study. The detailed data inventories of drill bit and drilling energy components in the context of an Icelandic perspective are presented in section 3. In section 4, the environmental impact results of Icelandic perspective with the adoption of OptiDrill and SOA drilling technology components are presented and also comparative results of using SOA and OptiDrill drilling technology components are discussed in the context of the Icelandic perspective. Finally, a conclusion of the work is drawn, and recommendations are made and presented in section 5.

An independent LCA reviewer has reviewed the LCA work of this report, and it has been updated based on the recommendations.

2. LCA Modelling

2.1 LCA Framework and Tool

Life Cycle Assessment (LCA) is a methodology for assessing the environmental impacts of a product or service throughout its entire life cycle from extraction of raw materials through design and production, packaging and distribution, use and maintenance, and disposal or recycling. It provides a holistic approach to evaluating environmental performance by considering the potential environmental impacts from all stages of manufacture, product use and end-of-life stages. This LCA methodology was standardised in the 1990s by the International Organisation for Standardization (ISO), which comprises mainly two standards: ISO 14040 [8] and 14044 [9] and is still updated and extended regularly. It involves the compilation of relevant inputs and outputs in the context of the goal and scope of the study, subsequent evaluation of their associated environmental impacts using an appropriate impact assessment methodology and finally, interpretation of the results to the aims of the analysis.

The framework of LCA methodology comprises four stages, shown in Figure 2.1:

i) goal and scope definition,
ii) inventory analysis,
iii) impact assessment and
iv) interpretation

The first stage of an LCA is the goal and scope of the study, which must be defined before any collection of life cycle inventory data. The second stage of an LCA is the inventory analysis when the quality of the inventory data gathered is organised and assessed. In the third stage of an LCA study, an appropriate life cycle impact assessment (LCIA) method is considered for evaluating the potential environmental impacts such as global warming potential and other impacts from the list of the following LCIA methodologies: CML-IA baseline, IMPACT World+, IMPACT 2002+, ReCiPe 2016, ILCD 2011 and others. The interpretation is the last stage of an LCA, where the findings of the inventory analysis and the impact assessment results are analysed with the defined goal and scope of the study and finally drawn conclusions and recommendations.

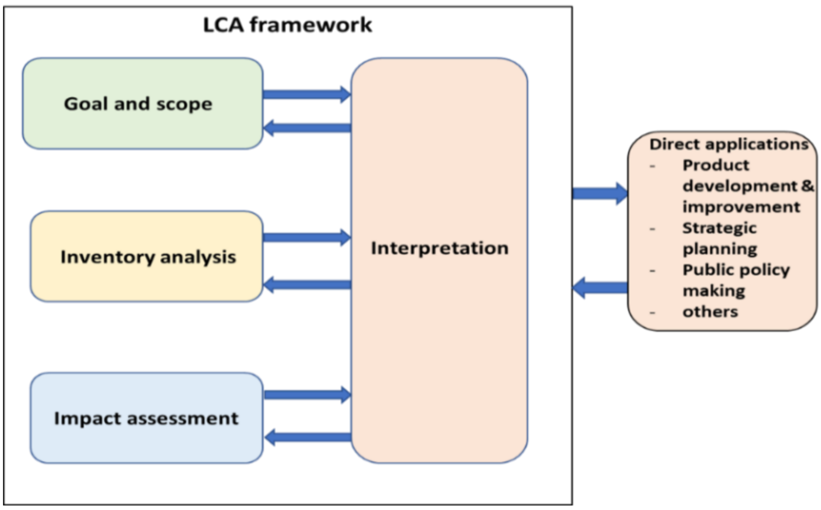

Figure 2.1 - An LCA framework

The LCA framework, shown in Figure 2.1, follows the methodology defined by the ISO standards that have been applied in this study. To perform LCA analysis of 1 m of drilling activities, SimaPro 9.5.0.0 LCA software tool [10], developed by PRé Sustainability, has been used in this study.

2.2 Life Cycle Impact Assessment Method

The application of Life Cycle Impact Assessment (LCIA) methods allows translating inventory data of a product into a number of environmental impact scores by the mean of characterisation factors, which indicate the environmental impact per unit of emission or resource use. Many LCIA methods have been developed and applied in life cycle assessment analysis. Some existing LCIA methods (Eco-indicator 99, CML, ReCiPe, IMPACT 2002+) partially address regionalisation with characterisation models being representative of the region where the elementary flow takes place, but they usually only cover a specific region of the world and do not depict the spatial variability within this specific region. There is a need to develop a globally regionalised LCIA method, to analyse the importance of spatial variability and to account for such variability in characterisation results in a parsimonious way [11]. In 2019, an LCIA methodology IMPACT World+ [12] has been developed as a joint major update to IMPACT 2002+ [13], EDIP [14] and LUCAS [15]; this method addresses the need to assess regional impacts of any geo-referenced elementary flow, integrating multiple state-of-the-art developments as well as damages on water and carbon areas of concern within a consistent LCIA framework. Most of the regional impact categories have been spatially resolved and all the long-term impact categories have been subdivided between shorter-term damages (over the 100 years after the emission) and long-term damages.

The IMPACT World+ Midpoint version 1.03 LCIA methodology was based on the following models:

- Global Warming Potential (GWP100) and Global Temperature Potentials (GTP100) are used for, respectively, climate change short- and long-term impacts. Those two indicators are needed because they express different impacts: GTP100 (climate change long-term) are impacts related to long-term cumulative warming (e.g. sea level rise), while GWP100 (climate change shorter-term) are impacts related to a rapid increase in temperature to which humans and species must adapt very quickly.
- Marine acidification impact is based on the same fate model as climate change, combined with the H+ concentration affecting 50% of the exposed species,
- For mineral resources depletion impact, the material competition scarcity index from de Bruille (2014) [16] is applied as a midpoint indicator,
- Terrestrial and freshwater acidification impact assessment is based on Roy et al. (Roy et al. 2014 [17]) and combines, at a resolution of 2°x 2.5° (latitude x longitude), global atmospheric source-deposition relationships with soil and water ecosystems sensitivity,
- Freshwater eutrophication impact is spatially assessed at a resolution grid of 0.5°x0.5°, based on a model from Helmes et al. (2012) [18],
- Ecotoxicity and human toxicity impact is based on the parameterized version of USEtox for continents. The developers considered indoor emissions and differentiated the impacts of metals and persistent organic pollutants for the first 100 years from longer-term impacts,
- Impacts on human health related to particulate matter formation are modelled using the USEtox regional archetypes to calculate intake fractions and epidemiologically derived exposure response factors,
- Photochemical oxidant formation, ionizing radiation and ozone layer depletion are based on ILCD (International Reference Life Cycle Data System) handbook recommendations. Model calculations were updated to account for the most up-to-date World Meteorological Organization (WMO) values of ozone depletion potential,
- Water consumption impacts are modelled using the consensus-based scarcity indicator AWARE (Available WAter REmaining),
- Impacts from land occupation and transformation on biodiversity are based on de Baan et al. (2013) [19].

IMPACT World+ relies on a midpoint-damage framework as shown in Figure 2.5 providing four consistent and complementary viewpoints to express a life cycle impact assessment profile:

1. A midpoint level viewpoint

2. A damage level viewpoint

3. An Area of Protection (AoP) viewpoint at damage level and

4. An Area of Concern (AoC) viewpoint at damage level.

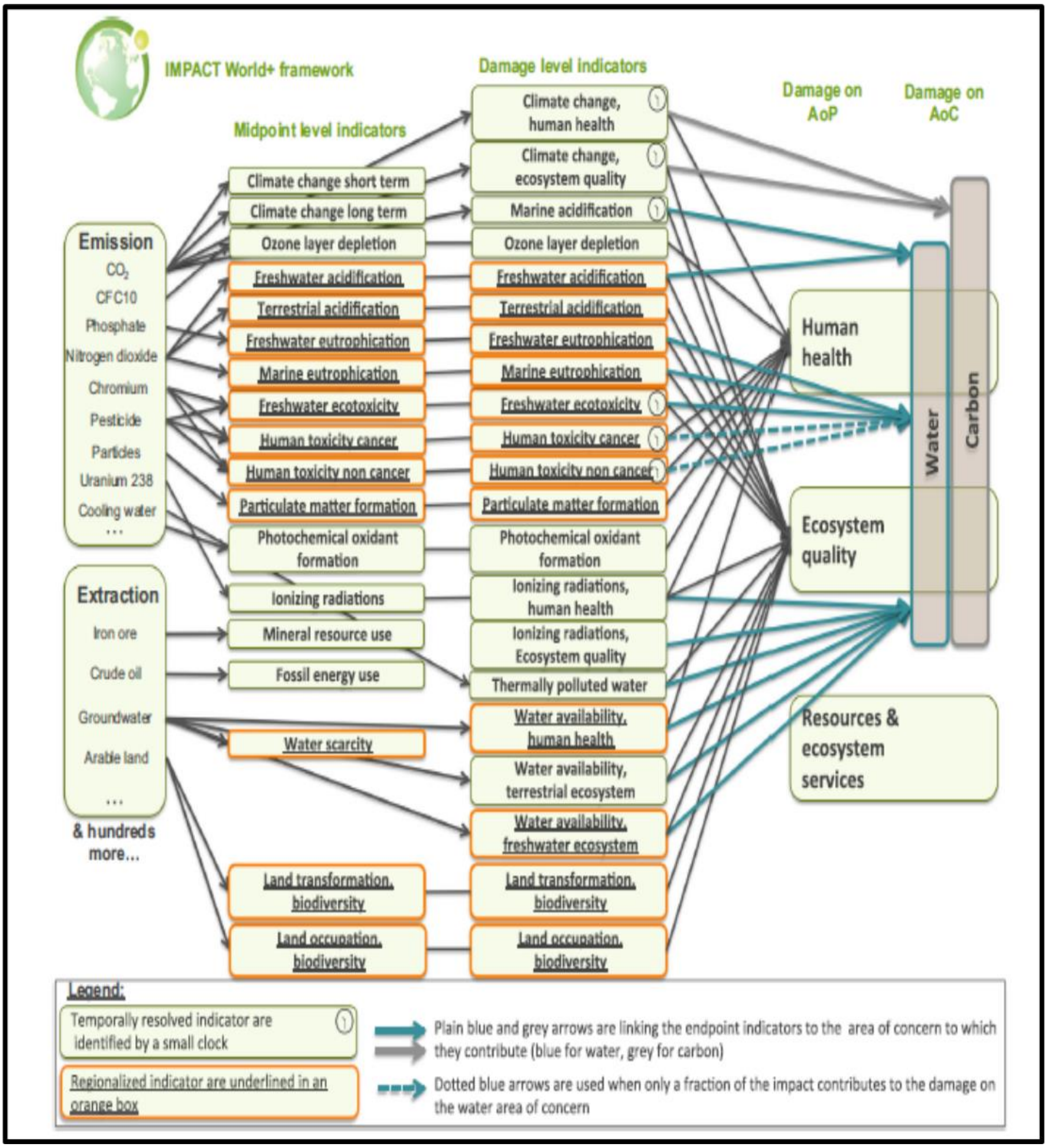

Figure 2.2 - IMPACT World+ LCIA framework (retrieved from http://www.impactworldplus.org/ [20]).

Table 2.1 lists the impact assessment categories in the IMPACT World+ Midpoint version 1.03.

Table 2.1 - An overview of the impact assessment categories in the IMPACT World+ Midpoint v1.03.

Impact categories	Impact score unit	Addresses
Climate change, short term	kg CO_2 eq	Global Warming Potential (GWP100) used for climate change short-term impact. This impact is related to a rapid increase in temperature to which humans and species must adapt very quickly. Emissions of greenhouse gasses to air expressed in kg CO2 eq.
Climate change, long term	kg CO_2 eq	Global Temperature Potential GTP100 used for climate change long-term. This impact is related to long-term cumulative warming (e.g. sea level rise. Emissions of greenhouse gasses to air expressed in kg CO2 eq.
Fossil and nuclear energy use	MJ deprived	-
Mineral resources use	kg deprived	-
Photochemical oxidant formation	kg NMVOC eq	Summer smog, or formation of reactive substances injurious to human health and ecosystems, expressed as kg NMVOC eq
Ozone layer depletion	kg CFC-11 eq	Ozone depletion potential of different gasses expressed in kg CFC-11 equivalents.
Freshwater ecotoxicity	CTUe	Effects of toxic substances on fresh water ecosystems, expressed as CTUe
Human toxicity cancer	CTUh	Effects of toxic substances on the human environment, expressed as CTUh
Human toxicity non-cancer	CTUh	Effects of toxic substances on the human environment, expressed as CTUh
Freshwater acidification	kg SO_2 eq	-
Terrestrial acidification	kg SO_2 eq	Acidifying substances emitted to air expressed in kg SO2 equivalents.
Freshwater eutrophication	kg PO_4 eq	Impacts due to excessive levels of macro-nutrients in the environment, expressed in kg PO4 equivalents
Marine eutrophication	kg N eq	-
Particulate matter formation	kg $PM_{2.5}$ eq	Particulate matter formation flows representing ground-level, low-stack and high-stack are not included, since they are not used in the inventories.
Ionising radiation	Bq C-14 eq	-
Land transformation, biodiversity	m2yr arable	Impacts from land occupation and transformation on biodiversity are based on de Baan et al. (2013): de Baan L, Alkemade R, Koellner T (2013) Land use impacts on biodiversity in LCA: a global approach. The International Journal of Life Cycle Assessment 18:1216–1230 26 doi:10.1007/s11367-012-0412-0.
Land occupation, biodiversity	m2yr arable	Land transformation and occupation: the original list of characterized flows was extended to cover all land use flows present in SimaPro. No new characterization factors were developed, but existing factors were reused to characterize similar flows.
Water scarcity	m3 world eq	Water consumption impacts are modelled using the consensus-based scarcity indicator AWARE

This LCIA methodology is based on the latest scientific knowledge and incorporating a wide range of environmental impact categories, including climate change, resource depletion, water use, land use, and human toxicity. In this LCA analysis, the IMPACT World+ Midpoint version 1.03 has been applied for evaluating the midpoint impact categories listed in Table 2.1.

3. Data Inventories

Iceland is located on the Mid-Atlantic ridge where the Eurasian and North American plates are diverging at a rate of around 2 cm per year. This explains the high tectonic activity and accessibility of the country to high temperature geothermal sources. The surface of the land is covered by Paleogene and Neogene basalts, which are volcanic rocks that were formed during different geological periods. These basalts have a total thickness of 10 km, which means that there are many layers of volcanic rock beneath the surface of Iceland. There are both high and low temperature zones around the country and there are 3 main geothermal sites; the Krafla area, the Reykjanes area and the Hengill area. The main rock types in the Hengill area are interglacial lava flows and glacial hyaloclastites that are younger than 0.7 million years. Volcanic rocks of basaltic composition (of tholeiitic or olivine-tholeiitic type) cover a large amount of the surface. The hyaloclastite ridges in the northeast, north, and west part of the area are composed of basaltic pillow lava, breccia and tuffs and formed during the last glacial periods. Flat lying Postglacial basaltic lavas cover the central parts of Hellisheidi, including postglacial lavas erupted 5000 and 2000 years ago. The character of geological evolution of the Hengill volcanic region is favourable for the generation of hydrothermal reservoirs. In this study, drill bits, and drilling energy components have been considered to evaluate the environmental performances of OptiDrill and state-of-art (SOA) drilling technologies in the context of Icelandic perspective. The functional unit of the life cycle assessment (LCA) studies is 1 m of drilling activities. The properties of drill bits such as bit lifetime and rate of penetration (ROP) have been inventoried from primary and secondary sources [1-6] and gathered for the adoption of SOA and OptiDrill drilling technologies in conductor, surface, intermediate and production casings and perforated liners depth regions' lithology in Icelandic perspective. The drilling energy consumption data have also been estimated based on drill rig size and drilling time spent in an Icelandic perspective. Based on these inventoried data of drill bit and drilling energy components for drilled depths of 5000 m, the mass and energy flows for 1 m drilling activities have been estimated and calculated for an Icelandic perspective. All these inventoried data for SOA and OptiDrill drilling systems in the context of the Icelandic perspective are given in subsections 3.1 and 3.2, respectively.

3.1 State-of-art (SOA) System

Table 3.1 lists the lithology types at different drilling depths in Icelandic perspective, along with drill bit types, material name and grade and their respective drill bit nomenclature in the context of the SOA system for the drilled depth of 5000 m.

Table 3.1 – Basic data inventories of Icelandic perspectives in the context of SOA for the drilled depth of 5000m.

Lithology types [1]	Drilling regions	Drilling depths (m)	Drill bit			
			Types	Material [2]	Grade	ID
Pillow Basalt	Conductor casing	100	Tricone	Low alloy steel	E75	SOA_IS_DB_CC_E75
Hyaloclastite tuff	Surface casing	500	Tricone	Low alloy steel	K55	SOA_IS_DB_SC_K55
Lava	Intermediate / Anchor casing	1200	Tricone	Low alloy steel	N80	SOA_IS_DB_IC_N80
Hyaloclastite tuff	Production casing	1400	Tricone	Low alloy steel	L80	SOA_IS_DB_PC_L80
Basalt Rock	Perforated Liner	1800	Tricone	Low alloy steel	E75	SOA_IS_DB_PL_E75

The names and weight percentages of different elemental composition of various drill bit material grades (E75, K55, N80, L80) are given in Table A1 of the Appendix A section. The mass, lifetime and average rate of penetration (ROP) of drill bits used in different drilling regions for SOA drilling system in Icelandic perspective have been gathered from the secondary source [3] and listed in Table 3.2.

Table 3.2 - SOA drill bit properties.

Drill bit ID	Diameter	Mass	Lifetime	Average ROP
	(mm)	(kg)	(h)	(m/h)
SOA_IS_DB_CC_E75	762	761.00	100	12.00
SOA_IS_DB_SC_K55	609.6	624.00	64	11.28
SOA_IS_DB_IC_N80	444.5	258.10	61	6.10
SOA_IS_DB_PC_L80	323.85	109.40	45	4.57
SOA_IS_DB_PL_E75	215.9	40.80	38	2.44

The functional mass flow and weighted functional mass flow of drill bits have been calculated using the respective masses, lifetimes, ROPs and drilling depths in the context of SOA drilling system and tabulated in Table 3.3. The weighted functional mass flow of the drill bit is the product of the drill bit functional mass flow and the weighted mass factor. The weighted mass factor is the ratio of the mass flow of the respective drill bit and the total mass of all the drill bits used for 5000 m drilled depth.

Table 3.3 – SOA drill bit mass flows at different drilled regions in Icelandic perspective.

Drill bit ID	Mass flow	Functional mass flow	Weighted mass factor	Weighted functional mass flow
	(kg)	(kg/m)	-	(kg/m)
SOA_IS_DB_CC_E75	63.42	0.63	0.42	0.2691
SOA_IS_DB_SC_K55	432.27	0.86	0.35	0.3008
SOA_IS_DB_IC_N80	832.90	0.69	0.14	0.0999
SOA_IS_DB_PC_L80	744.43	0.53	0.06	0.0324
SOA_IS_DB_PL_E75	792.58	0.44	0.02	0.0100

For all drilling section depths, drill rig size of 3000 hp and diesel consumption rate of 1.25 gal hp^{-1} d^{-1} have been considered for estimating the daily diesel consumption in Icelandic perspective [7]. The drilling times have been calculated using the respective ROP and drilling section depths. Then the total diesel mass flow, diesel energy and functional diesel energy flow have been calculated using the respective drilling time, daily diesel consumption, conversion factor of diesel mass to energy and drilling depths. Table 3.4 lists the drilling time, diesel mass and energy flow, functional diesel energy flow and weighted functional diesel energy flow for the SOA drilling system. The weighted functional diesel energy flow of the diesel consumption is the product of the functional diesel energy flow and the weighted diesel mass factor.

Table 3.4 - Drilling energy data inventories for SOA drilling system in Icelandic perspective.

Drilling Energy ID	Drilling time	Diesel mass	Diesel energy	Functional Diesel energy Flow	Weighted functional Diesel Energy Flow
	(h)	(kg)	(MJ)	(MJ/m)	(MJ/m)
SOA_IS_EnergyD_CC_E75	8.33	4.19E+03	1.82E+05	1.82E+03	157.21

SOA_IS_ EnergyD _SC_K55	44.33	2.23E+04	9.68E+05	1.94E+03	177.91
SOA_IS_ EnergyD _IC_N80	196.72	9.90E+04	4.30E+06	3.58E+03	608.37
SOA_IS_ EnergyD _PC_L80	306.35	1.54E+05	6.69E+06	4.78E+03	1083.92
SOA_IS_ EnergyD _PL_E75	737.70	3.71E+05	1.61E+07	8.95E+03	3802.33
SOA_IS_EnergyDiesel_Average	1293.43	6.51E+05	2.82E+07	5.65E+03	-

3.2 OptiDrill System

Table 3.5 lists the lithology types at different drilling depths in Icelandic perspective, along with drill bit types, material name and grade and their respective drill bit nomenclature in the context of the OptiDrill drilling system for the drilled depth of 5000 m.

Table 3.5 – Basic data inventories of Icelandic perspectives in the context of OptiDrill for the drilled depth of 5000m.

Lithology types [1]	Drilling regions	Drilling depths (m)	Drill bit			
			Types	Material [2]	Grade	ID
Pillow Basalt	Conductor casing	100	DTH	Low alloy steel	E75	OptiDrill_IS_DB_CC_E75_FU
Hyaloclastite tuff	Surface casing	500	DTH	Low alloy steel	K55	OptiDrill_IS_DB_SC_K55_FU
Lava	Intermediate / Anchor casing	1200	DTH	Low alloy steel	N80	OptiDrill _IS_DB_IC_N80_FU
Hyaloclastite tuff	Production casing	1400	DTH	Low alloy steel	L80	OptiDrill _IS_DB_PC_L80_FU
Basalt Rock	Perforated Liner	1800	DTH	Low alloy steel	E75	OptiDrill _IS_DB_PL_E75_FU

The mass, lifetime and average rate of penetration (ROP) of drill bits used in different drilling regions for OptiDrill drilling system in Icelandic perspective have been gathered from primary and secondary sources and listed in Table 3.6. Fraunhofer IEG evaluated the impacts on ROP and bit lifetime due to OptiDrill technology drilling components and obtained the positive impacts on ROP and bit lifetime [21, 22].

Table 3.6 - OptiDrill drill bit properties.

Drill bit ID	Diameter	Mass [3]	Lifetime [21]	Average ROP [22]
	(mm)	(kg)	(h)	(m/h)
OptiDrill_IS_DB_CC_E75	762	154.58	127.00	14.28
OptiDrill _IS_DB_SC_K55	609.6	126.51	81.28	13.42
OptiDrill _IS_DB_IC_N80	444.5	96.09	77.47	7.25
OptiDrill _IS_DB_PC_L80	323.85	73.87	57.15	5.44
OptiDrill _IS_DB_PL_E75	215.9	54.00	48.26	2.90

The functional mass flow and weighted functional mass flow of drill bits have been calculated using the respective masses, lifetimes, ROPs and drilling depths in context of OptiDrill drilling system and tabulated in Table 3.7.

Table 3.7 – OptiDrill drill bit mass flows at different drilled regions in Icelandic perspective.

Drill bit ID	Mass flow	Functional mass flow	Weighted mass factor	Weighted functional mass flow
	(kg)	(kg/m)	-	(kg/m)
OptiDrill_IS_DB_CC_E75	8.52	0.09	0.31	0.0261
OptiDrill _IS_DB_SC_K55	57.99	0.12	0.25	0.0291
OptiDrill _IS_DB_IC_N80	205.18	0.17	0.19	0.0325
OptiDrill _IS_DB_PC_L80	332.60	0.24	0.15	0.0348
OptiDrill _IS_DB_PL_E75	694.11	0.39	0.11	0.0412

The total diesel mass flow, diesel energy and functional diesel energy flow have been calculated using the respective drilling time, daily diesel consumption, conversion factor of diesel mass to energy and drilling depths. Table 3.8 lists the drilling time, diesel mass and energy flow, and functional diesel energy flow for OptiDrill drilling system.

Table 3.8 - Drilling energy data inventories for OptiDrill drilling system in Icelandic perspective.

Drilling Energy ID	Drilling time	Diesel mass	Diesel energy	Functional Diesel energy	Weighted Functional Diesel energy
	(h)	(kg)	(MJ)	(MJ/m)	(MJ/m)
OptiDrill_IS_ EnergyD _CC_E75_FU	7.00	3.52E+03	1.53E+05	1.53E+03	132.01
OptiDrill _IS_ EnergyD _SC_K55_FU	37.26	1.87E+04	8.14E+05	1.63E+03	149.48
OptiDrill _IS_ EnergyD _IC_N80_FU	165.52	8.33E+04	3.61E+06	3.01E+03	512.15
OptiDrill _IS_ EnergyD _PC_L80_FU	257.35	1.29E+05	5.62E+06	4.01E+03	909.66
OptiDrill _IS_ EnergyD _PL_E75_FU	620.69	3.12E+05	1.36E+07	7.53E+03	3200.97
OptiDrill_IS_EnergyDiesel_Average	1087.82	5.47E+05	2.38E+07	4.75E+03	-

Due to the unavailability of drill rig, diesel consumption rate and other relevant data, secondary data sources [7] have been used for the inventory of drilling energy.

In Table A2 of the Appendix A section, Ecoinvent dataset names of various materials involved in drill bits and diesel energy consumed for drilling have been inventoried from Ecoinvent database version 3.9.1 are listed.

4. Results and Discussions

Using the inventoried data in Tables 3.1-3.8, the environmental impacts (LCIA results) for 1 m of drilling activities of OptiDrill and SOA drilling technologies in Icelandic perspective have been evaluated and calculated using SimaPro 9.5.0.0 LCA tool considering the impact assessment methodology IMPACT World+ Midpoint version 1.03.

The long-term climate change (carbon footprint) networks for adopting OptiDrill and SOA drilling technology components in Icelandic perspective for 1 m drilling activities are presented in Figures 4.1a and 4.1b, respectively.

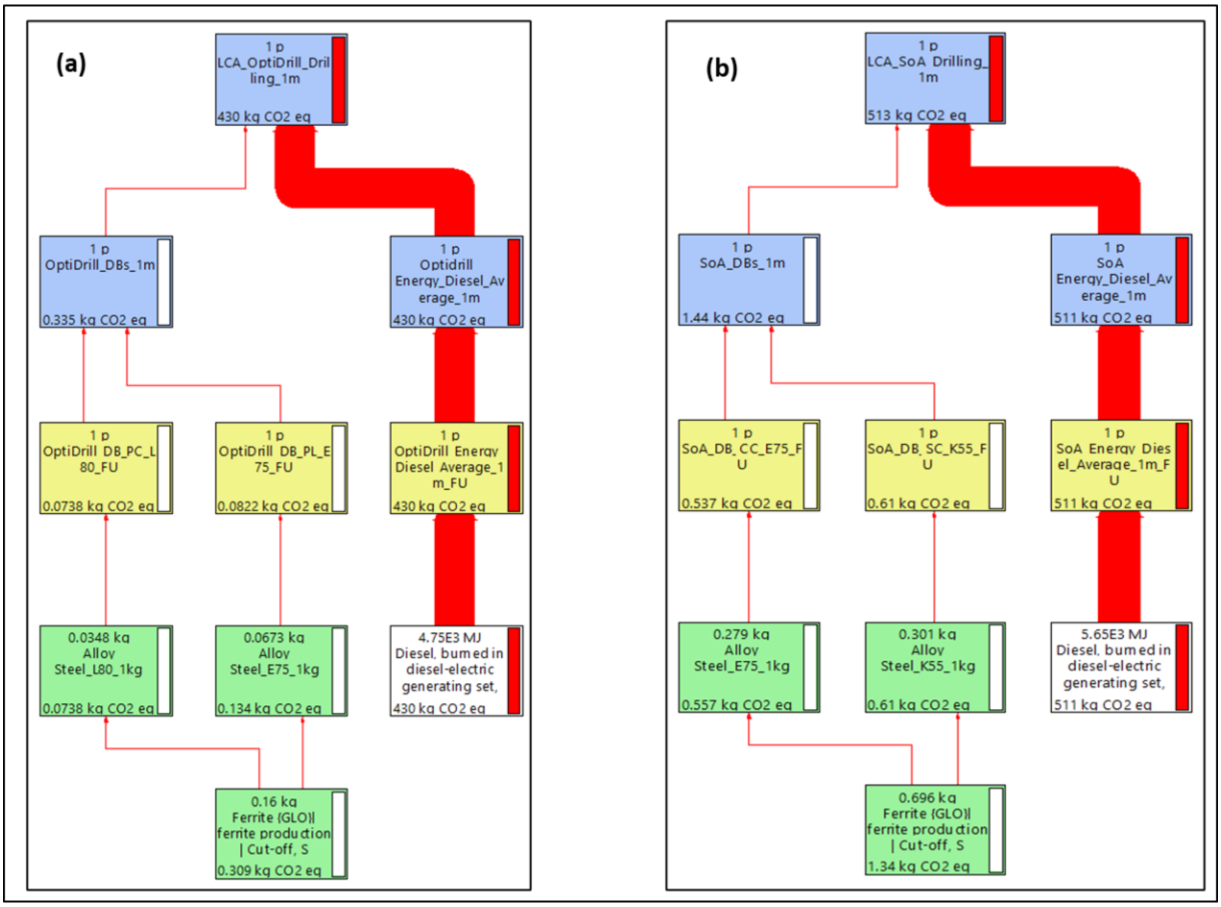

Figure 4.1 – A part of the long-term climate change network models for 1 m drilling activities of (a) OptiDrill and (b) SoA drilling technology components in Icelandic perspective.

Figure 4.1 shows that the long-term climate change for 1 m of drilling activities of OptiDrill and SOA drilling technologies in Icelandic perspective are 430 kg CO2 eq and 513 kg CO2 eq, respectively. It is calculated that the percentage savings of long-term climate change of drilling activities of about 16.2 % for using OptiDrill drilling technology components instead of using SoA drilling technology components in Icelandic perspective.

The LCA tool calculated 18 mid-point impact categories for 1 m of drilling activities of drill bit and drilling energy using OptiDrill and SOA drilling technology components in Icelandic perspective. The quantification of the LCIA results for mid-point impact categories of OptiDrill and SoA drilling technology components with respective units are given in Tables 4.1 and 4.2, respectively.

Table 4.1 – Quantification of 18 midpoint impact categories of OptiDrill drill bit and drilling energy components for 1 m drilling activities.

Midpoint impact categories	Unit	OptiDrill_DBs_1m	OptiDrill_ EnergyD_1m
Climate change, short term	kg CO2 eq	3.59E-01	4.56E+02
Climate change, long term	kg CO2 eq	3.35E-01	4.30E+02
Fossil and nuclear energy use	MJ deprived	4.10E+00	6.19E+03
Mineral resources use	kg deprived	2.08E-01	1.85E+00
Photochemical oxidant formation	kg NMVOC eq	1.90E-03	1.42E+00
Ozone layer depletion	kg CFC-11 eq	2.58E-09	7.34E-06
Freshwater ecotoxicity	CTUe	1.61E+02	2.68E+04
Human toxicity cancer	CTUh	1.54E-06	1.35E-06
Human toxicity non-cancer	CTUh	4.92E-08	9.79E-06
Freshwater acidification	kg SO2 eq	5.36E-09	9.82E-07
Terrestrial acidification	kg SO2 eq	4.36E-06	7.92E-04
Freshwater eutrophication	kg PO4 eq	7.25E-07	6.55E-04
Marine eutrophication	kg N eq	3.34E-05	1.81E-02
Particulate matter formation	kg PM2.5 eq	3.09E-04	1.64E-01
Ionizing radiation	Bq C-14 eq	1.04E+00	7.67E+01
Land transformation, biodiversity	m2yr arable	7.41E-05	2.29E-02
Land occupation, biodiversity	m2yr arable	9.56E-03	9.11E-01
Water scarcity	m3 world eq	5.50E-02	9.36E+00

Table 4.2 – Quantification of 18 midpoint impact categories of SoA drill bit and drilling energy components for 1 m drilling activities.

Midpoint impact categories	Unit	SoA_DBs_1m	SoA_ EnergyD_1m
Climate change, short term	kg CO2 eq	1.55E+00	5.42E+02
Climate change, long term	kg CO2 eq	1.44E+00	5.11E+02
Fossil and nuclear energy use	MJ deprived	1.77E+01	7.36E+03
Mineral resources use	kg deprived	8.97E-01	2.20E+00
Photochemical oxidant formation	kg NMVOC eq	8.12E-03	1.69E+00
Ozone layer depletion	kg CFC-11 eq	1.09E-08	8.73E-06
Freshwater ecotoxicity	CTUe	6.73E+02	3.19E+04
Human toxicity cancer	CTUh	6.68E-06	1.60E-06
Human toxicity non-cancer	CTUh	1.96E-07	1.17E-05
Freshwater acidification	kg SO2 eq	2.18E-08	1.17E-06
Terrestrial acidification	kg SO2 eq	1.78E-05	9.42E-04
Freshwater eutrophication	kg PO4 eq	2.66E-06	7.79E-04
Marine eutrophication	kg N eq	1.42E-04	2.16E-02
Particulate matter formation	kg PM2.5 eq	1.31E-03	1.95E-01
Ionizing radiation	Bq C-14 eq	4.43E+00	9.13E+01
Land transformation, biodiversity	m2yr arable	3.18E-04	2.72E-02

Land occupation, biodiversity	m2yr arable	4.10E-02	1.08E+00
Water scarcity	m3 world eq	2.18E-01	1.11E+01

The relative contribution of environmental footprints of OptiDrill and SOA technology components (drill bit and drilling energy) for 18 midpoint impact categories have been evaluated with reference to the worst environmental footprint contributions considered as 1 and presented in Figure 4.2.

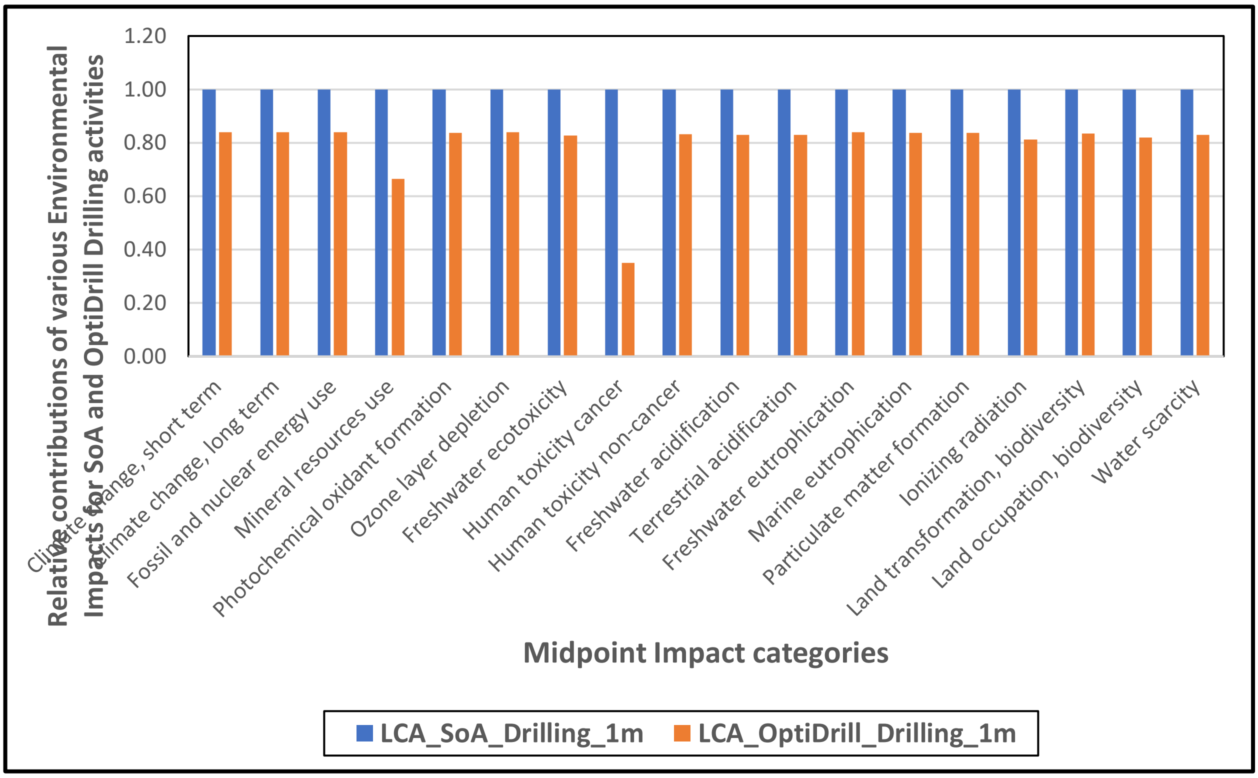

Figure 4.2 - Comparisons of environmental impacts in 18 midpoint damage categories for 1 m drilling activities of OptiDrill and SOA technology components.

It is seen from Figure 4.2 that the environmental footprints of OptiDrill drilling technology components (drill bit and drilling energy) are lower than those of SOA drilling technology components for all impact categories. It is evident from Figure 4.2 that the overall environmental footprint savings of about 20% for using OptiDrill drilling technology components instead of using SOA drilling technology components, respectively.

5. Conclusions

The environmental performances of OptiDrill and SOA drilling technology components have been studied for 1 m of drilling activities in Icelandic perspective. The environmental impacts of OptiDrill on geothermal power plant in Icelandic perspective have been demonstrated. The main results of this LCA study in Icelandic perspective are as follows:

- About 16.2 % of carbon footprint (long-term climate change impact) savings for the adoption of OptiDrill drilling technology components as compared with SOA drilling technology components.
- For 1 m of drilling activities, the carbon footprint savings would be about 83 kg CO2 eq for using OptiDrill drilling technology components instead of using SOA drilling technology components.
- About 20 % of the overall environmental footprint savings for the adoption of OptiDrill drilling technology components as compared with SOA drilling technology components.

Recommendations

The accuracy of the geothermal drilling LCA studies largely depends on the accuracy levels of the basic LCI data generated from primary and secondary sources. To make LCA study more reliable and to ensure the acceptability and credibility of LCIA results, the following recommendations are made:

- Standardise geo-drilling data collection protocols for consistent and comparable data.
- Equip drill rig systems with advanced sensors to capture various real-time drilling parameters.
- Promote open data initiatives for knowledge sharing and collaboration in geothermal drilling activities.

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Appendix A: Inventory Data and Ecoinvent Datasets

Table A1 - Elemental composition of different drill bit materials used in geothermal drilling

Material name	Grade of the material	Elemental composition in weight percentage									
		Cr		Mn	C	Si	S	P	Ni	Cu	Fe
Low alloy steel	E75	0		1.8	0.405	0	0.01	0.02	-	-	97.765
	K55	0.05		1.5	0.365	0.25	0.01	0.02	0.05	0.02	97.735
	N80	0.15		1.575	0.36	0.25	0.01	0.02	0.25	0.20	97.185
	L80	-		1.90	0.43	0.50	0.03	0.03	0.25	0.35	98.46

Table A2 – ecoinvent dataset names of various processes

Process name	Unit	Dataset names
Diesel Energy	MJ	Diesel, burned in diesel-electric generating set, 10MW, for oil and gas extraction {GLO}| market for diesel, burned in diesel-electric generating set, 10MW, for oil and gas extraction | Cut-off, S
Chromium	kg	Chromium {RER}| chromium production | Cut-off, S
Manganese	kg	Manganese {RER}| manganese production | Cut-off, S
Carbon	kg	Carbon black {GLO}| carbon black production | Cut-off, S
Silicon	kg	Silicon, metallurgical grade {RoW}| silicon production, metallurgical grade | Cut-off, S
Sulfur	kg	Sulfur {GLO}| market for sulfur | Cut-off, S
Phosphorus	kg	Phosphorus, white, liquid {RER}| phosphorus production, white, liquid | Cut-off, S
Nickel	kg	Nickel, class 1 {GLO}| market for nickel, class 1 | Cut-off, S
Copper	kg	Copper {RER}| copper production, primary | Cut-off, S
Iron	kg	Ferrite {GLO}| market for ferrite | Cut-off, S

Appendix B: Critical Review Statement

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December 11, 2024

Critical Review Statement:
Impact of OPTIDRILL on environmental footprint on geothermal power

Carried out as part of Project OptiDrill: D14.3 Report on the impact of OPTIDRILL on environmental footprint on geothermal power

LCA Practitioners: M A H Chowdhury, M Ashadul Hoque

An independent critical review has been carried out on the LCA study (by Technovative Solutions Ltd., UK) that compared the environmental impacts of adopting OptiDrill drilling technology components with the state-of-the-art (SOA) drilling technology components.

The goal and scope of the study are clearly defined in the report. It specifies the purpose of the study, intended audiences, and applications of the LCA results. The functional unit is 1 m drilling activities, which is consistent with the study's objectives. The system boundary is appropriate and comprehensive. The exclusion of transportation from the system boundary is mentioned in the report but it is not explained explicitly. Also, the reason for exclusion of the drill bit-making processes is not mentioned clearly.

The study uses data from both primary and secondary sources. The data sources are credible; however, care should be taken during referencing to follow a standard format. The materials and energy flows for the OptiDrill and SOA drilling technology components have been mentioned in the report. However, there should be an explanation of how 'Weighted Functional Diesel Energy Flow' is calculated.

The selected impact assessment methodology 'IMPACT World+ Midpoint version 1.03' is suitable for the study context, technically robust, and fully aligned with international standards. The report outlines the rationale behind the selection of this LCIA methodology. The impact categories are relevant to the goal and scope of the study.

The results are clearly presented, interpreted, and supported by evidence. One of the recommendations made in the report is to standardize geo-drilling data collection protocols for consistent and comparable data. Additionally, a sensitivity or uncertainty analysis can evaluate the impact of key assumptions and data variability on the results. Nonetheless, the comparisons between OptiDrill and SOA are fair, consistent, and based on equivalent functional units.

The report is well-articulated and aligns with ISO 14040 and ISO 14044 guidelines. The methodologies, assumptions, and data sources are clearly documented. The results are valid, reliable, and well-communicated. However, the technical terms in the report could be explained more elaborately for its intended audience. The reviewer agrees with the report's findings and conclusions as presented within the scope of this review. There are no contradictions or inconsistencies in the analysis. The conclusions are balanced, logical, and aligned with the study's objectives.

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