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Towards Less Carbon Future: Integrated Strategy for Abating Carbon Emissions in Geothermal Drilling Project

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ABSTRACT

Indonesia has announced that it aims to reach net zero emissions target by 2060. Geothermal energy, as a clean and low-carbon sustainable energy source with abundant reserves is critical for decreasing greenhouse gas emissions and encouraging energy structure transformation. Geothermal energy campaign was usually as clean energy because this energy is less emissions compared to other conventional energy. But in fact, to exploit this clean and sustainable resources is also generate some of emissions by drilling operation.

This paper aims to analyze the root cause of the emissions, and propose several strategies that lead to emissions reduction since planning to post operation of drilling campaign. The methodology that used in this research is literature review supported with practitioner experiences in geothermal drilling project. As the result of this study, several strategies can be extracted like alternative energy utilization for power generation, drilling planning optimization. best practices on operation, rig system optimization, problem prevention, until the role of digitalization in reducing the emissions in drilling project that become main novelty of this research.

This paper is expected to raise awareness about how the drilling practitioners and all involved parties can exploit this clean resource with in cleaner way, also it can help developers in facing future carbon tax policy with proposed solutions. Briefly, this paper also can be a reference both for government and geothermal developers to develop comprehensive strategy in order to help world's joint mission to reach low carbon future.

1. INTRODUCTION

1.1 A Glimpse about GHG Emissions

The process of releasing carbon components into the atmosphere that have an impact on climate change as a result of global warming is referred to as carbon emission, which is also referred to as greenhouse gas (GHG). The term "global warming" refers to the gradual increase in the average temperature of the Earth's atmosphere and oceans that has been occurring since the late 19th century and is expected to continue for the foreseeable future. The carbon footprint itself represents the total / sum of all greenhouse gas emissions, expressed as CO2e, generated by an individual, event, organization, service, location, or product (Carbon Trust, 2009). Figure 1 shows the typical GHG emissions distribution and carbon emissions source

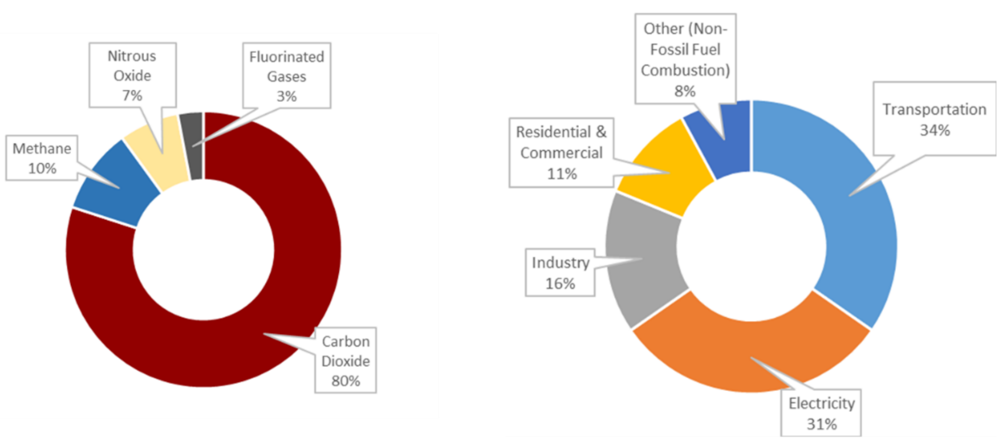

Figure 1: Typical distribution of GHG emissions (left), Carbon emissions by source (right) (EPA, 2020)

According to America's Climate Choices (2011), the average temperature of the earth's surface has risen by approximately 0.8 degrees Celsius since the beginning of the 20th century, with approximately two-thirds of the increase occurring since 1980. Additionally, there is an increase in sea level and acidity, both of which have an impact on the life in the environment (Zikra et al., 2015). These occurrences are brought on by greenhouse gases (GHG), which include CO2 (carbon dioxide), CH4 (methane), N2O (nitrous oxide), HFCs (hydrofluorocarbons), PFCs (perfluorocarbons), and SF6 (sulfur hexafluoride). These gases absorb infrared, which is re-emitted from solar radiation that travels through the atmosphere, which then heats the surface of the earth (Anderson et al., 2016). The typical unit to determine carbon emission is carbon dioxide equivalent (CO2e). The most significant of the gases that contribute to climate change is carbon dioxide (CO2) (Zhang and Da, 2015).

Figure 2 present the global greenhouse gas emissions and warming scenarios. It should be noted that each pathway comes with uncertainty, marked by the shading from low to high emissions under each scenario, and the warming refers to the expected global temperature rise by 2100.

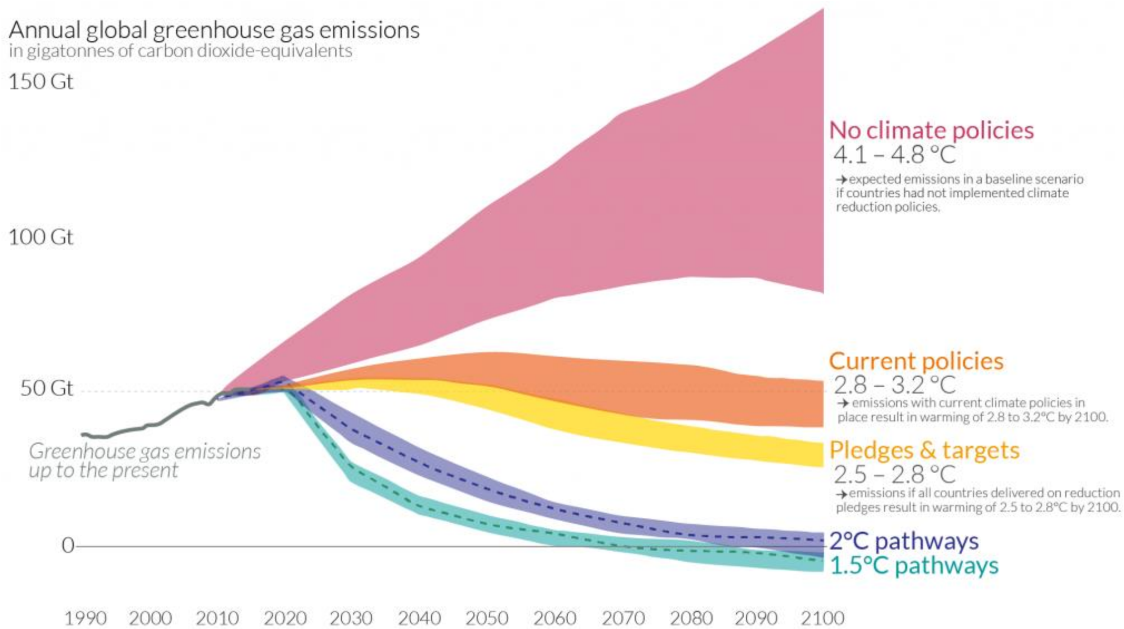

Figure 2: Global greenhouse gas emissions and warming scenarios (Ritchie, H., and Roser, M., 2019)

Figure 3 illustrates historical data obtained from the International Energy Agency (IEA) indicating the trendline of CO2 emissions in Indonesia generated solely from the combustion of fuel. These emissions were measured over a period of time. The energy balances provided by the IEA and the IPCC Guidelines from 2006 are used in the calculation of emissions. It has been demonstrated that the annual production of carbon dioxide has increased from 131 metric tons in 1990 to 543 metric tons in 2018. A significant contributor to the rise in emissions is the expansion of the human population. Along with dramatically rising population numbers comes a commensurate rise in the amount of energy being consumed.

The generation of electricity accounts for the vast majority of energy usage (Faizah and Husaeni, 2018). Many nations, especially Indonesia, continue to rely on fossil fuels such crude oil, natural gas, and coal as their primary source of energy because these fuels are the most stable compared to other energy options (Hasan et al., 2012; Suharyati et al., 2019). On the other hand, using fossil fuels as a source of energy results in significant emissions of greenhouse gases (GHG), which contributes to the acceleration of global warming.

The last COP meetings (COP26 Glasgow) develop the Climate Pact in November 2021 with world's joint mission to keep the rise of global temperature below to 1.5 deg C through worldwide initiatives that summarized as follows:

- Mitigation to reduce emissions to achieve net zero carbon, a shift away from coal power, stopping and reversing deforestation, reducing methane emissions, and accelerating the switch to electric vehicles. The international community has mobilized over $20 billion for a just and inclusive transition from coal to clean energy, with support from organizations such as The Asian Development Bank. Indonesia, as a top 10 methane emitter, has signed the Global Methane Pledge to reduce global methane emissions by 30% in 2030, and over 100 countries have committed to the initiative.
- Countries are taking proactive measures to increase their preparedness to the impacts of climate change. This is done through Adaptation Communications or National Adaptation Plans, with 80 countries now covered. 45 of these have been submitted in the last year. This helps to ensure that countries are better equipped to handle the consequences of a changing climate.
- Financial aspect plays a critical role in enabling countries to deliver their climate goals. In 2009, developed nations agreed to mobilize USD 100 Billion per year from 2020 to 2025 to help developing nations adapt to climate change and reduce emissions.

Currently, 34 countries and 5 public finance institutions will stop international support for the unabated fossil fuel energy sector in 2022.

- Collaboration between government, business, and civil society: Collaboration will help deliver on climate goals faster, with councils and dialogues in energy, electric vehicles, shipping, and commodities helping to meet commitments. The UK and Indonesia established the Forest, Agriculture, and Commodity Trade (FACT) Dialogue in 2021 to protect forests and promote development and trade. 28 countries, including Indonesia, launched the FACT Roadmap at COP26, committing to sustainable production and trade, incentivizing sustainability, supporting smallholder farmers, improving supply chain transparency, and driving innovation.

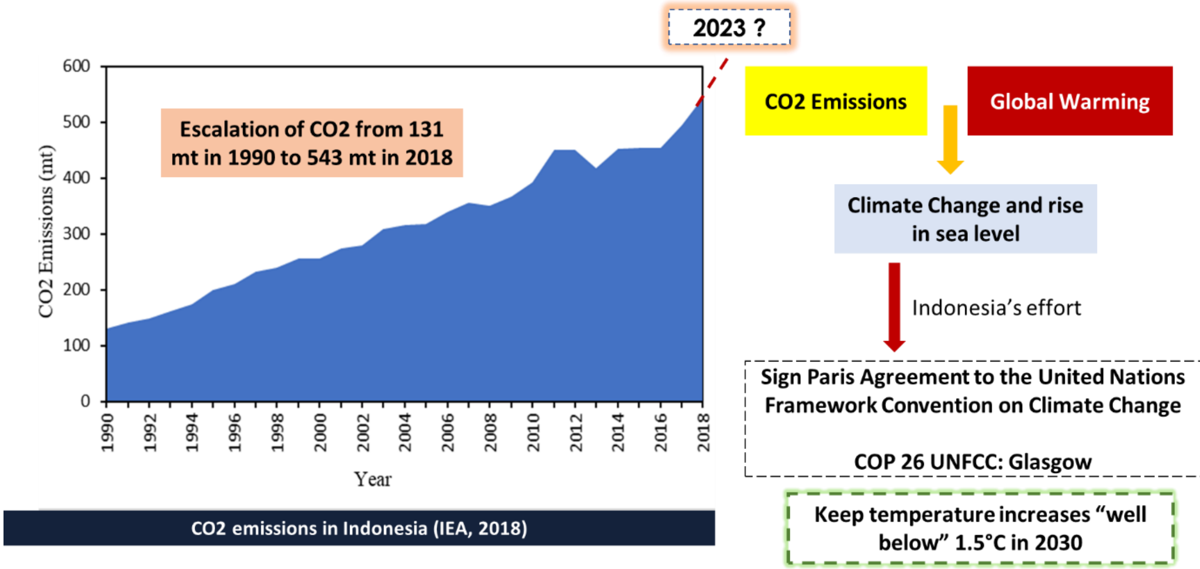

Figure 3: CO2 emissions in Indonesia and related efforts (Al Asy'ari, M. R and Tobing, J., 2022; IEA, 2018)

As illustrated in Figure 4, Greenhouse gas emissions that classified as Scope 1 are those that are directly produced by the Agency from sources it owns or manages, such as burning fossil fuels for energy or fuel used by the Agency's fleets. On the other hand, Scope 2 emissions are indirect emissions resulting from the Agency's use of electricity, heat, or steam purchased from a utility provider. These are not direct emissions from the Agency's own sources, but rather from sources it controls.

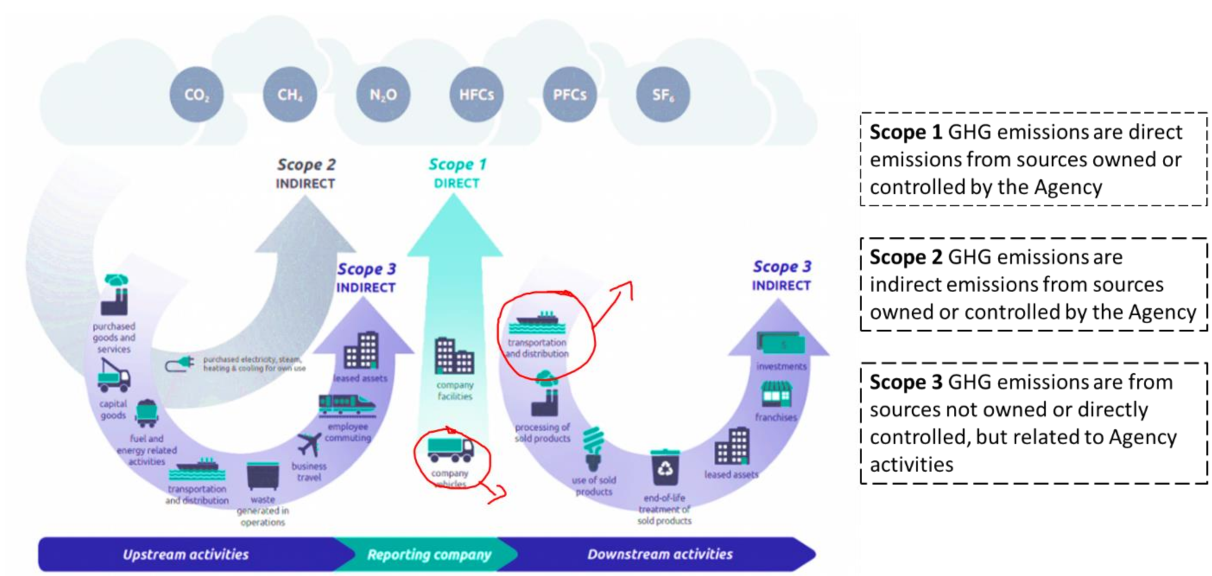

Figure 4: GHG protocol scopes and emissions (modified from GHG Protocol, 2011)

Scope 3 greenhouse gas emissions include contributions from various indirect sources, such as the carbon footprint created by employees during commuting and travel, waste treatment and disposal carried out by contracted parties, and losses incurred during transportation and distribution of purchased electricity. Scope 3 emissions come from sources that are neither owned nor directly controlled by the

Environmental Protection Agency (EPA) (EPA, 2011). This research has the potential to be very advantageous for the energy industry in realizing low-carbon future operations, which is in accordance with the goals of this campaign.

1.2 Research Background, Objective and Methodology

1.2.1. Research Background

Due to the fact that Indonesia is located on the Pacific Ocean ring of fire, the potential for the use of geothermal energy in this country is great, abundant, and widespread. This nation's installed capacity has reached 2,356 MW (Thinkgeoenergy, 2023), which has propelled it to the second position on the list of top geothermal producers worldwide based on installed capacity. In spite of the fact that it possessed huge resources, Indonesia was only able to utilize 8% of its total resources due to a number of difficulties stemming from both technical and non-technical elements. As shown in Figure 5, the Government of Indonesia (GoI) has established a new goal for the exploitation of geothermal energy, which is to reach 5,799 MW in the year 2030. (PLN, 2021).

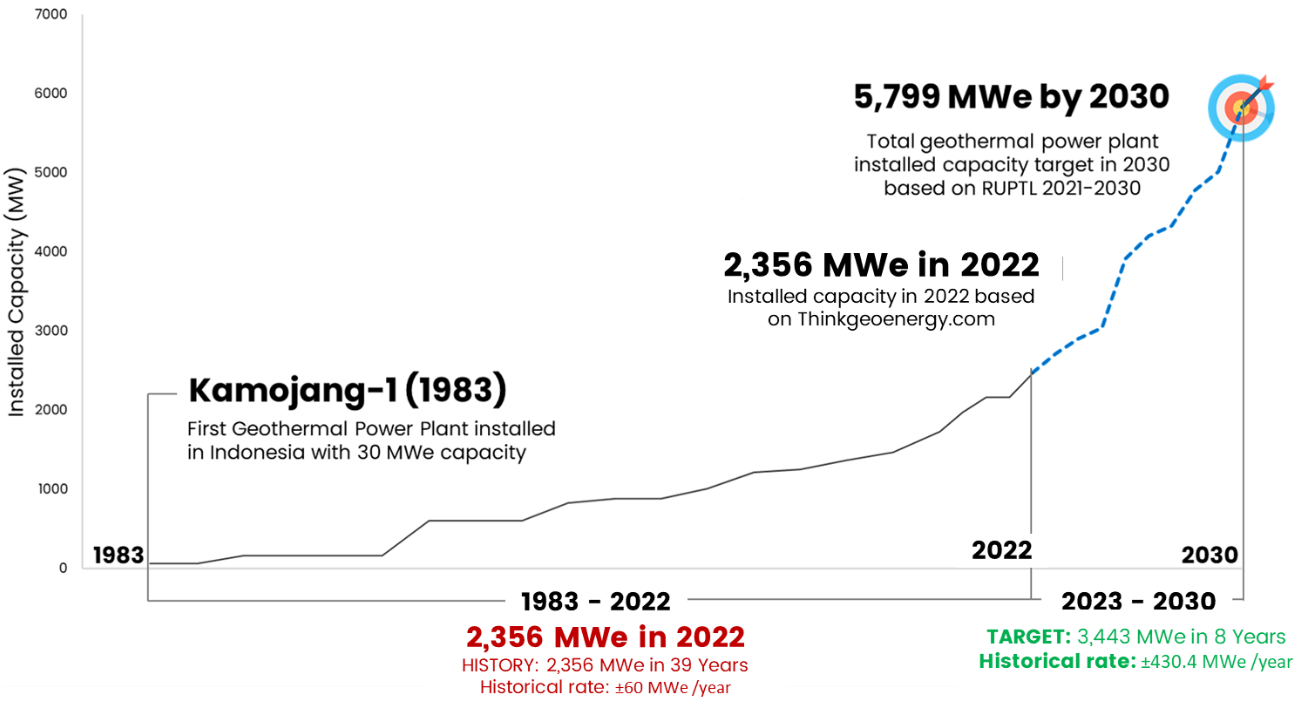

Figure 5: Current and target of Indonesia's installed capacity (updated data from Thinkgeoenergy, 2023; EBTKE, 2022; PLN 2021; Purba et al, 2020)

1.2.2. Research Objective and Method

This research aims to analyse the root cause of the emissions, and propose several strategies that lead to emissions reduction since planning to post operation of drilling campaign. The methodology that used in this research is literature review supported with practitioner experiences in geothermal drilling project. Figure 6 shows the thought process of this research.

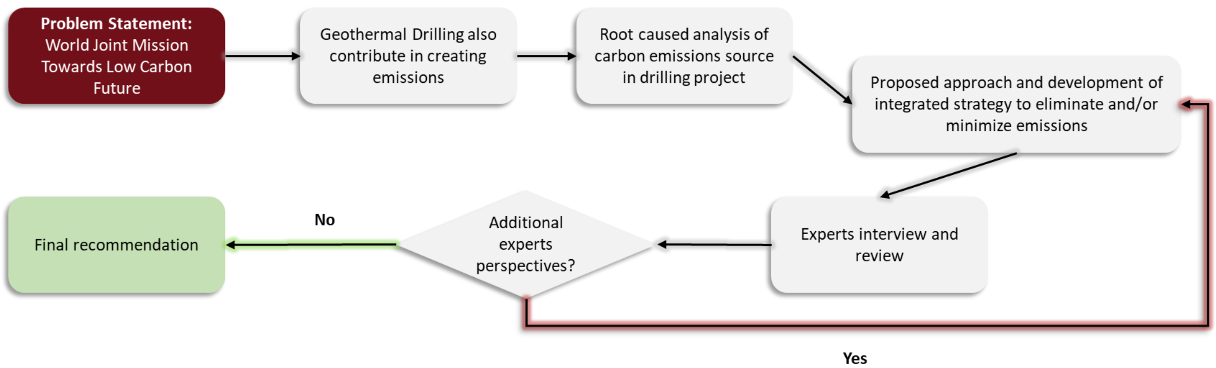

Figure 6: Thought process of the study

In order to gain complete understanding of this research, the authors started by offering several objectives that will be explained in the next section which the detail as follows:

- What are the carbon emissions of drilling activities and why it become concerns nowadays?
- When and where the carbon emissions were generated during the drilling project?
- What are the options / related strategy to reduce carbon emissions in the geothermal drilling project?

This paper is expected to raise awareness about how the drilling practitioners and all involved parties can exploit this clean resource with in cleaner way, also it can help developers in facing future carbon tax policy with proposed solutions. Sooner or later, energy company will be dealing with future carbon tax policy which means the approach in this study also have potential developers to reduce the carbon tax. Briefly, this paper also can be a reference both for government and geothermal developer to develop strategy in order to help world's joint mission to reach low carbon future by raise awareness about how developers can exploit this clean resource with in cleaner way.

2. CARBON EMISSIONS IN DRILLING PROJECT

2.1 Source of Carbon Emissions in Drilling Project

Geothermal energy campaign was usually as clean energy because this energy is less emissions compared to other conventional energy. But in fact, to exploit this clean and sustainable resources is also generate some of emissions by drilling operation. Some of drilling operation need to be conducted to achieve this target that mean that some of carbon emission will be generated.

The drilling operation that is carried out to obtain geothermal fluid is extremely comparable to the drilling operation that is carried out during the extraction of oil and gas (Allahvirdizadeh, 2020). This indicates that in order to extract geothermal fluid, a drilling rig that is comprised of a variety of tools and vehicles is required. The Environmental Protection Agency (EPA) compiles annual reports on greenhouse gas emissions from the 564 facilities that make up the onshore production segment in the United States. These facilities are responsible for the generation of about 103 MMT CO2e (EPA, 2015). The majority of the emissions came from combustion equipment, which resulted in 31.6 MMT CO2e being released into the atmosphere. According to these data, geothermal drilling projects in Indonesia that take place in onshore environments rely on combustible engines that are powered by fossil fuels.

The carbon emissions is begin since early preparation until post operation in drilling project which the detail is presented in Figure 7. The source of carbon emissions might be varied like in planning and post operation in company head and site office, preparation of services in company workshop, fuel from mobilization and shipping of drilling rig and their respective supporting equipment, on well pad during drilling operation, until waste end disposal.

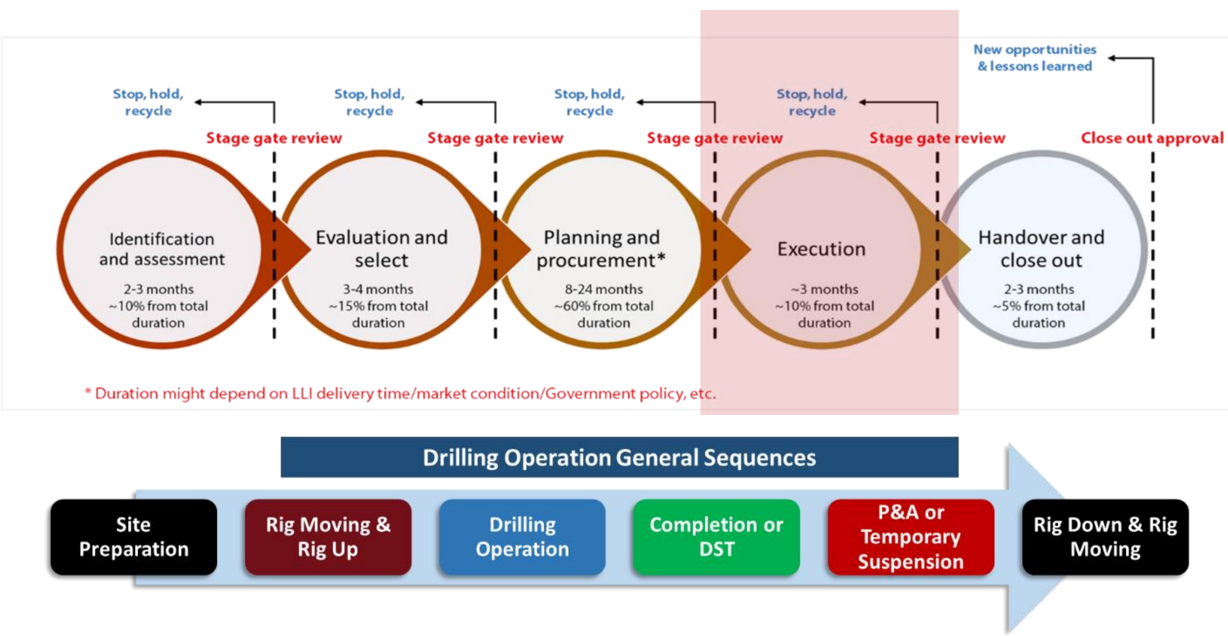

Figure 7: Typical drilling project stage (modified from Al Asy'ari, M. R and Tobing, J., 2022; Firnanto et al., 2020)

2.2 Proactive Strategy for Reducing Emissions in Geothermal Drilling Project

There are various strategies that already summarized as presented in Figure 8, starting from tracking, alternative power generation, best practices in operational management, until adapting digitalization and machine learning that have potential to become reference both for government and geothermal developer to develop drilling strategy with lower emissions and cost-effective approach.

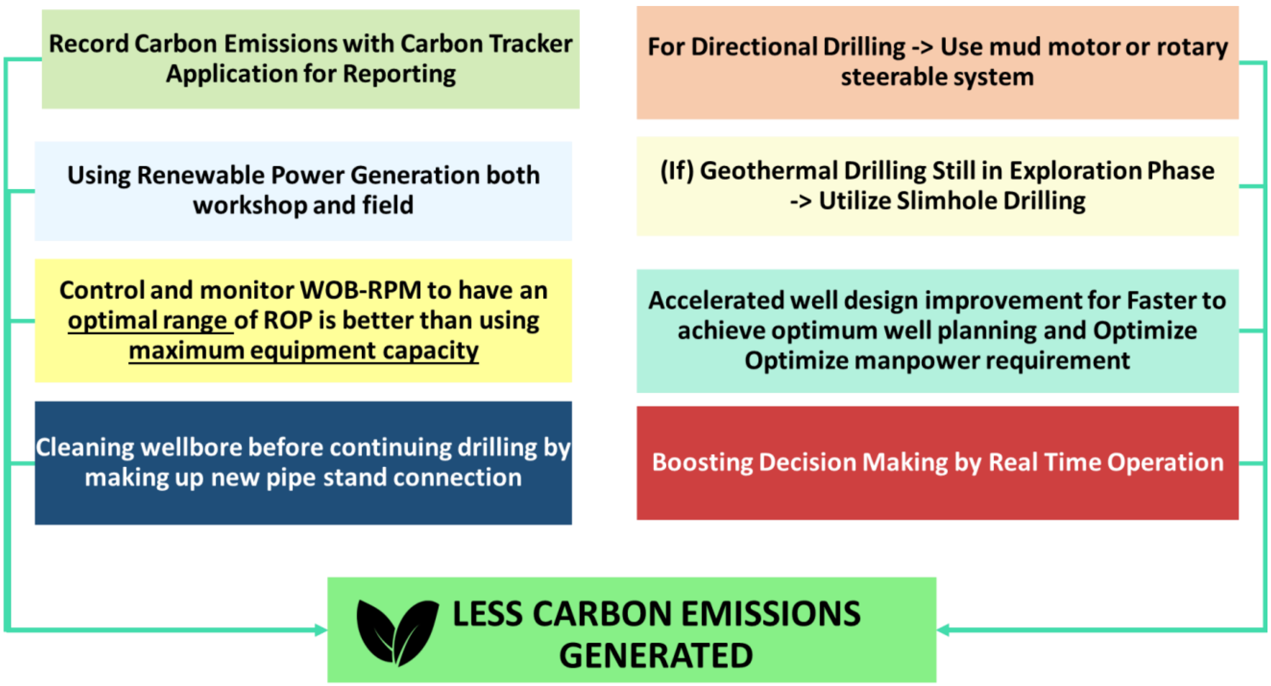

Figure 8: Integrated approach to make drilling project with less emissions generated

2.2.1 Starting with Record Carbon Emissions with Carbon Tracker Application for Reporting

According to (API Compendium, 2009), there are several approaches in shape of numerical calculation for determining carbon emissions which can be implemented for geothermal drilling project. In general, as presented in Figure 9.

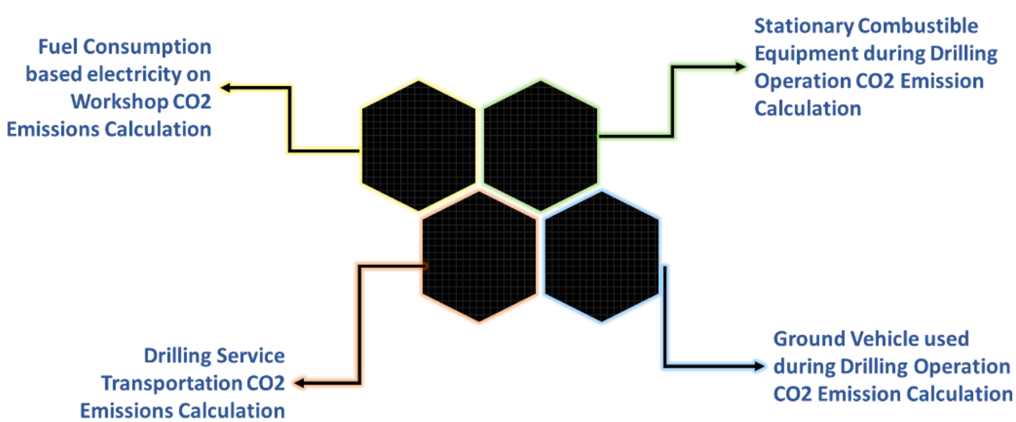

Figure 9: Several aspects that can be calculated with API standard for geothermal drilling (modified from Al Asy'ari et al., 2022)

Figure 10 shows the results of study of preliminary calculation from (Al Asy'ari et al, 2022) using case study of geothermal well in Indonesia, the results shows that drilling one geothermal well can produce more than 100+ tons of CO_2 emissions.

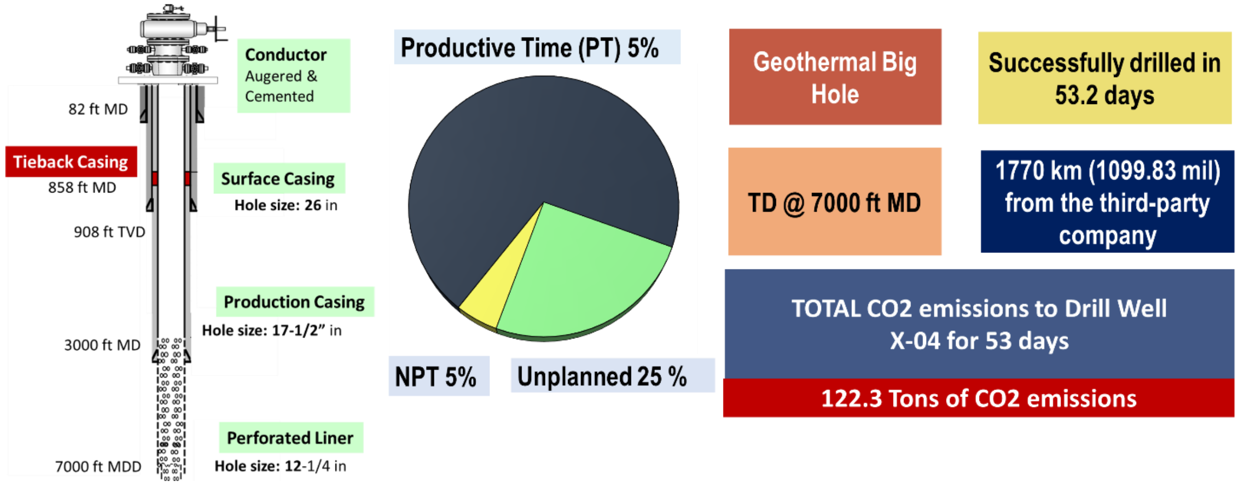

Figure 10: Well Schematic and Operation Drilling Breakdown of Well X-04 (modified from Al Asy'ari et al., 2022)

The concept and idea of this research is current calculation might be integrated in one application that can be assessed by all related parties that involved in drilling project which the example of visualization is illustrated in Figure 11. By implementing this idea, its expected for geothermal developers, service companies, and all related parties can store the data for reporting and evaluation that resulting improvement day by day for enhancing carbon emissions reduction approach.

Several basic features for the application that might be included in this application might be form as follows:

- PC Based and Android Based
- Calculation Progress saving (Internal Memory)
- Calculation Progress saving (cloud database system)
- GHG Scope 1, 2, and 3 input
- Optimization strategy catalog that contains best practices (can be updated overtime)

Expected Output

- Overall Project Carbon Emissions calculation
- Emissions source breakdown
- Emissions scope breakdown
- Carbon Tax Summary (depends on rate)

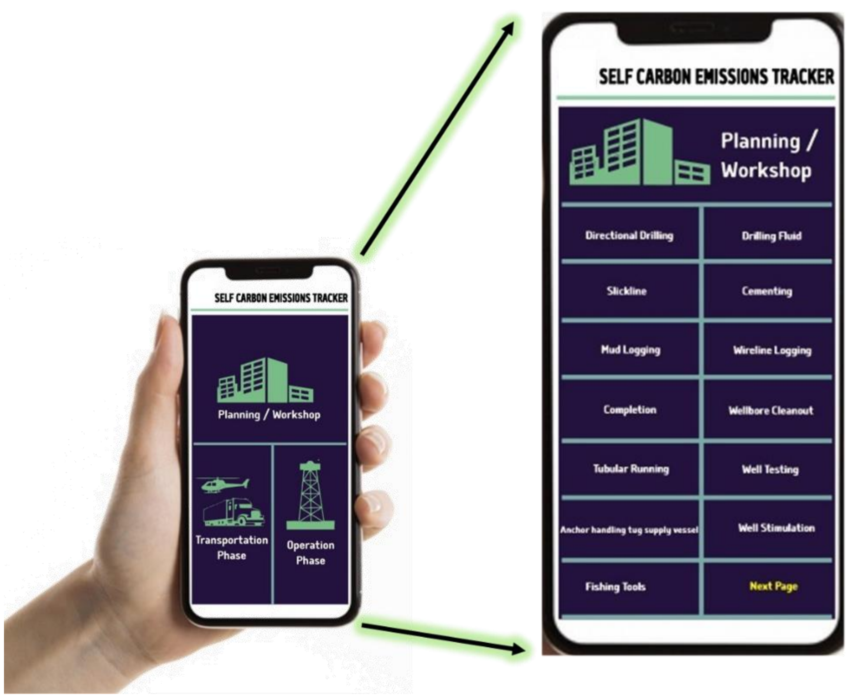

Figure 11: Example of Self-Assessment Carbon Tracker Visualization

2.2.2 Alternative Energy Utilization for Heavy Vehicle Fuels

Biodiesel is made by combining liquid biomass such as vegetable oil, plant oil, animal fat, and waste cooking oil with other fuels. Biodiesel emits fewer carbon emissions than petroleum-based diesel (DOE, 2001) (Du, Huque, & Kommalapati, 2018). Government Regulation No. 1/2006 on the purchase and use of biofuels was enacted in Indonesia to promote the procurement of biofuels and minimize the consumption of fossil fuels, hence initiating biodiesel use. Then, in 2007, law No. 30 specified the prioritization of biofuel use. (GAPKI, 2017). In 2008, the government began introducing biodiesel in a 2.5 percent fuel blend. This percentage shall rise in accordance with the government's improvement, intensity, and target outlined in Regulation No. 12 of 2015 issued by the Minister of Energy and Mineral Resources until the target of incorporating 30 percent of biofuels into the gasoline mixture by 2020 is met. The usage of biodiesel in Indonesia has saved 6.39 trillion IDR and reduced greenhouse gas emissions by 14.25 billion tons CO2 equivalent to 60.31 billion barrels of B30 per year (ESDM, 2019). Increasing trends indicate that Indonesia's biodiesel manufacturing capacity has a promising future. This element expands the potential applications of biodiesel to include drilling activities. Figure 12 depicts the production and average emissions associated with biodiesel use in Indonesia.

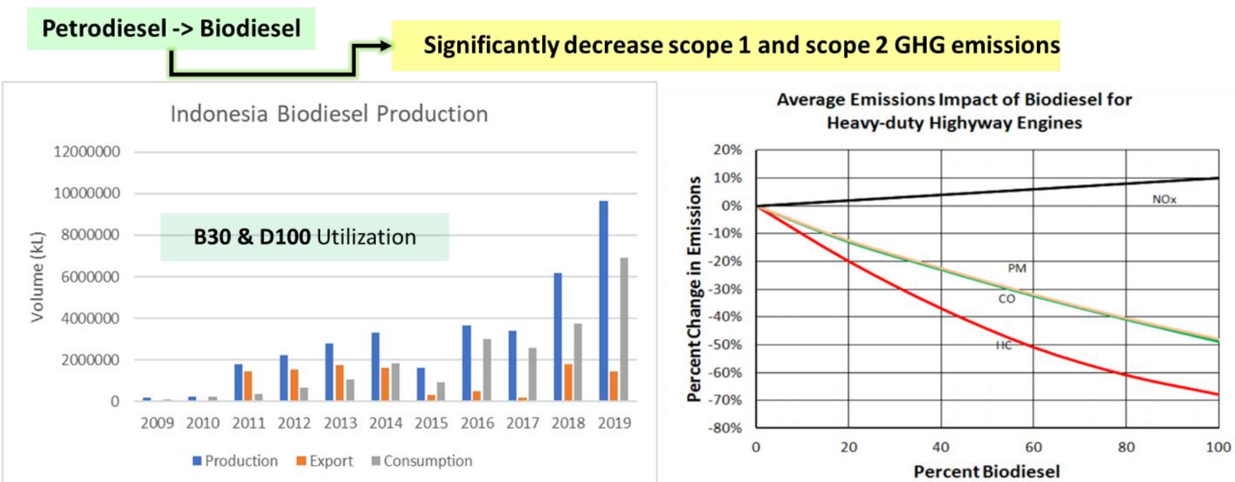

Figure 12: Indonesia biodiesel production (left) (ESDM, 2019; APROBI, 2019), generated GHG by utilizing biodiesel (Curto, 2021)

Details about biodiesel's use in drilling operations are yet infrequently published. However, a number of studies have been conducted on biodiesel for truck, trailer, and generator fuel, which is also utilized in drilling operations. According to Du et al. (2018) and Curto (2021), the application of biodiesel in long-haul heavy-duty diesel trucks (HDDTs) results in a significant reduction in emissions. Biodiesel produces 41 percent less sulfur, carbon monoxide, and other greenhouse gases than petroleum-based fuel. Biodiesel reduces Scope 1 and 2 emissions since it produces fewer emissions than petroleum-based fuel.

Utilization of biodiesel on a nationwide scale exhibited promising efficiency potential in relation to carbon and cost savings. The simple calculation of petro-diesel and biodiesel (B30) demonstrates that utilizing B30 will cut fuel costs by IDR 800/litre (8%) and CO2 emissions by 1.48 Kg per litre. These savings could improve the Indonesian government's chances of implementing a carbon price (GoI). Figure 13 shows an overview of Indonesia's biodiesel use based on ESDM (2019) and compares the price-carbon reduction of diesel and biodiesel.

Aspect	Biodiesel percentages	
	B20@2019	B30@2020
Utilized Volume	6.62 KL	9.57 KL
Budget efficiency	IDR 43.81 trillion	IDR 63.39 trillion
Carbon reduction (Ton CO_2)	9.91 million	14.25 million

Summary of budget and emission reduction of biodiesel (ESDM, 2019)

Showed promising efficiency potential related to economical and carbon reduction

Dealing with future carbon tax implementation by the Government of Indonesia (GoI)

Comparison Aspect	Diesel	Biodiesel (B30)
Industrial price / litre @2020	IDR 9,378	IDR 8,500
Carbon reduction / litre	0 kg CO_2 (as initial condition)	-1.48 kg CO_2

Comparison of diesel and biodiesel price and carbon reduction (ESDM, 2019)

Figure 13: Summary of budget and emission reduction of biodiesel and their respective comparison with conventional diesel (Al Asy'ari et al ., 2022; ESDM, 2019)

2.2.3 Alternative Energy Utilization for Power Generation and Rig Power System Optimization

In general, using renewable power generation that integrated with energy storage system will greatly decrease emissions by decrease scope 1 and 2 of GHG emissions compared to using PLN grids that most likely has higher portion of fossil fuel in energy mix. Figure 14 shows the concept of using intelligent power management that proposed by Schlumberger (2021) that might be applied massively future. Intelligent power management basically is a system that predicts and optimizes energy usage to reduce emissions, fuel consumption, and engine operation time on rigs. It does this by utilizing automated software with an energy storage system. (Schlumberger, 2021).

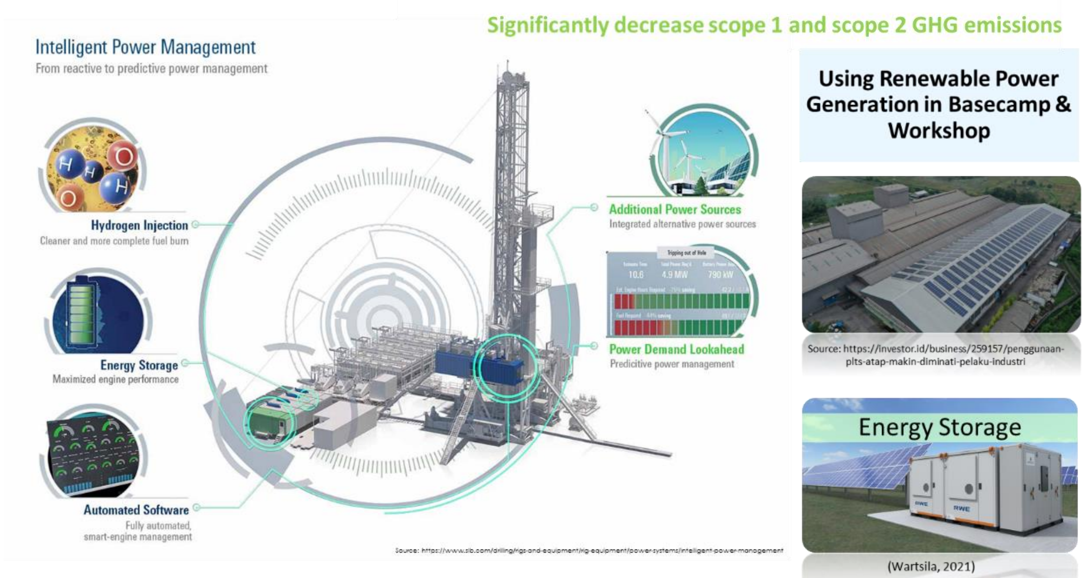

Figure 14: Alternative power generation concept for basecamp, workshops, office, and drilling site (modified from Al Asy'ari et al., 2022; Schlumberger, 2021)

2.2.4 Operational Management and Integrated Problem Prevention

The mobilization of equipment and resources is one of the drilling operations that consumes fossil fuel and produces emissions. Transport, waiting, and defects are examples of project waste (Thangarajoo, 2015). This aspect's efficiency must be applied to reduce drilling projects' fuel consumption and carbon footprint. This can be accomplished by improving drilling planning to reduce unprofitable fuel usage. This includes reducing non-profitable downtime caused by drilling issues, while the diesel-genset must continue producing electricity for site electrification. Poor planning and preparation for drilling can also necessitate extra mobilization for equipment changes (Al Asy'ari et al, 2022).

Since general drilling projects aim to reach total depth (TD) as faster as possible, this scenario places less emphasis on fuel consumption and emissions produced (Ahmed et al., 2009). There are numerous ways to reduce fuel consumption, such as:

- Controlling and monitoring WOB-RPM for optimal ROP range is preferable and very recommended for utilizing maximum equipment capacity. Higher WOB-RPM-ROP will result in increased fuel consumption. This method prevents excessive cutting, which necessitates additional hole cleaning and wiper trip. In addition, the additional operation might be requiring additional time and increases fuel consumption and emissions (Al Asy'ari et al, 2022). Figure 15 shows the illustration of this concept.

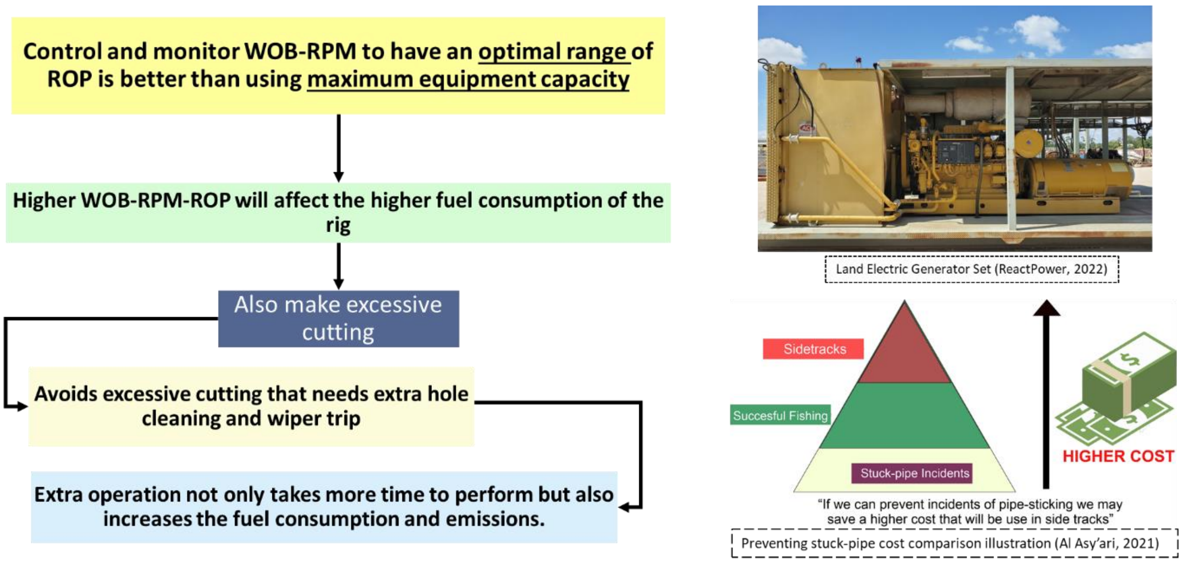

Figure 15: Control and monitor WOB-RPM concept and implication (modified from Al Asy'ari et al., 2022; ReactPower, 2022)

- As illustrated in Figure 16, It was recommended before continuing drilling by assembling a new pipe stand connection, ensure that the wellbore is already free of cuttings in order to reduce stuck pipe, which causes non-productive time by working on the pipe on that stand (Al Asy'ari et al, 2022).

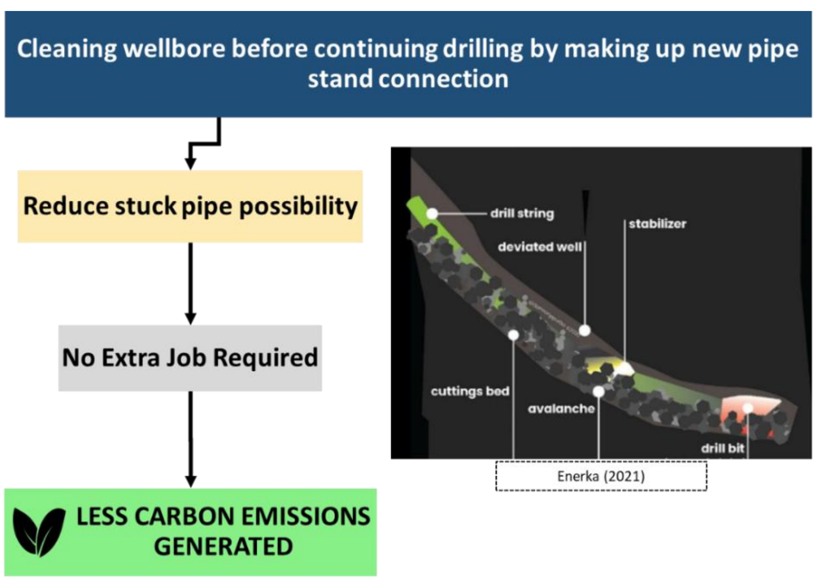

Figure 16: Frequent hole cleaning concept and implication (modified from Al Asy'ari et al., 2022; Enerka, 2021)

- Drilling campaign that use directional drilling of multiple wells in the same pad also can highly contribute in emission reductions. Benefit of directional drilling generally is the reduction of the carbon footprint from land transportation, as fewer trips are required to transport personnel and equipment to the drill site. It also reduces the need for helicopter transportation, which is a significant source of greenhouse gas emissions in remote areas. In addition, the reduced need for multiple drilling sites and associated infrastructure can result in less deforestation, and reduce the risk of soil erosion, and other negative impacts on the local ecosystem (US Forest Service, 2011). But, as show in Figure 17 that there was several arguable benefits and limitation regarding directional drilling. It should be noted that directional drilling plan need to be elaborated ans ensured with main subsurface objective.

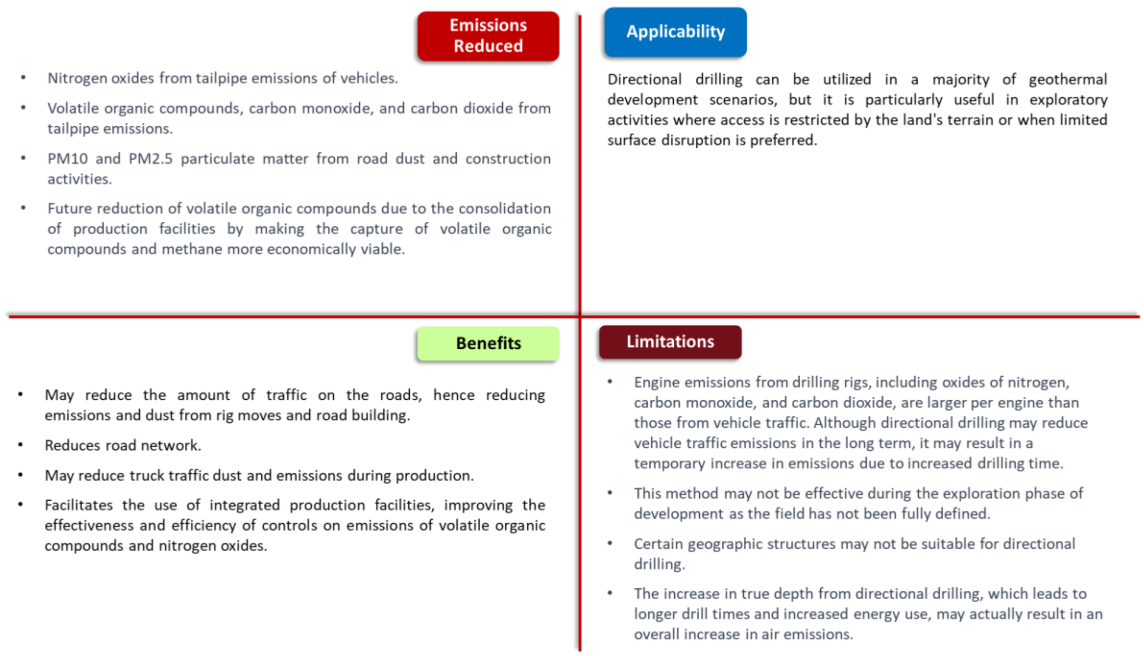

Figure 17: Frequent hole cleaning concept and implication (modified from US Forest Service, 2011)

- The use of a mud motor or rotary steerable system for directional drilling can reduce overall drilling time by eliminating the need for sliding, as it allows for continuous pipe rotation (non-pipe rotation). This results in lower fuel consumption for the drilling rig. In geothermal drilling, a clear understanding of the drilling objectives can also contribute to increased efficiency.

- In the case of geothermal exploration, where the primary objective is subsurface data collection in an area of high uncertainty, the use of slim-hole drilling, which requires less equipment and resources but still achieves the drilling objective, can be considered to increase operational efficiency while still achieving the drilling objective (Adityatama et al., 2020). This relates to the topic because a smaller amount of equipment and personnel necessitates less mobilization and electricity to run the drilling, thereby reducing the total amount of fuel consumed and emissions produced (Al Asy'ari et al., 2022).

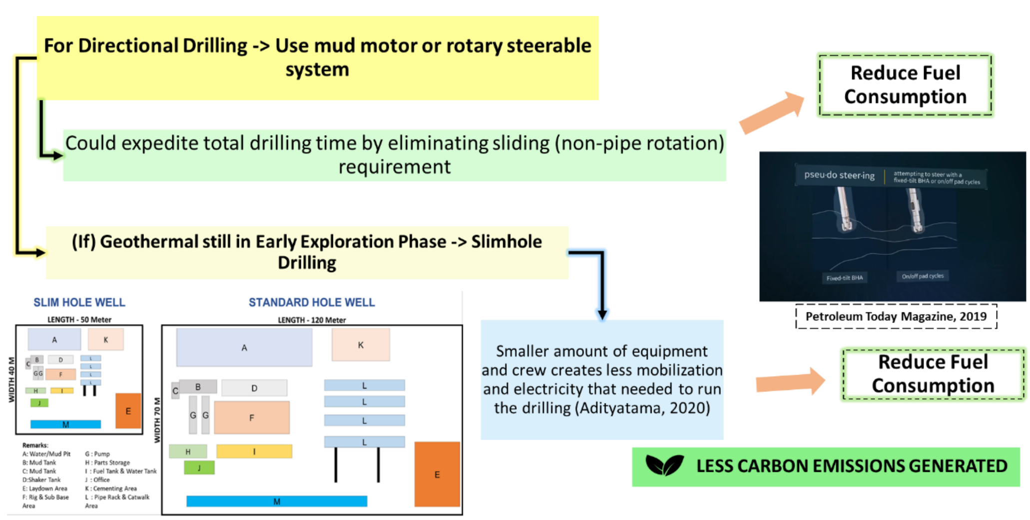

Figure 18: Mud motor utilization concept and slimhole exploration strategy (Al Asy'ari et al., 2022; Adityatama et al., 2020)

In line with this study, case study that issued by (Tobing, J., et al, 2022) related well engineering and operation optimization have significiant impact in reducing carbon emissions generated during drilling campaign. The holistic view of the concept is the performance of drilling is typically evaluated based on Health, Safety, and Environment (HSE), duration, and cost. It can be enhanced by continuously learning from past experiences and optimizing well engineering and operations. Since carbon emissions during drilling activities are directly proportional to operational duration, it is crucial to have a thorough understanding of the Non-Productive Time (NPT) history across all drilling projects.

In short, Well engineering and operation optimization have a direct impact on reducing Non-Productive Time (NPT) and carbon dioxide equivalent (tCO2e) emissions from drilling activities. These areas should be a priority for reducing carbon emissions from drilling. A baseline target for NPT drilling should be established to track the progress of emissions reduction efforts (Tobing, J., et al, 2022) .

2.2.5 Drilling Digitalization and Real Time Operation

Digitalization refers to the integration of digital technologies into a business model to create new revenue and value-producing opportunities. It involves transitioning to a digital business. (Gartner, 2022). In general, digitalization that applied in drilling shall be safe, usable and lowering cost of drilling activity, then additional cost to implement drilling digitalization shall improve overall performance of existing method that will lead to lower overall drilling cost while contributing in low carbon emission aspiration (Tobing, J., 2021).

In drilling projects, digitalization could improve operation efficiency and well deliverability with fewer operation hours, resulting in less fuel consumption and fewer emissions in a variety of ways, such as reducing the number of drilling time which the detailed as follows (BCG, 2021; Al Shayaa et al., 2019):

- **Accelerated and automated well design improvement**.

  Automated well design that improved and lower-cost design in well planning by: 1) automate well-design process, leveraging machine learning and historical information, 2) Streamline discipline interfaces and implement design changes automatically, 3) Visualize tradeoffs, hazards, cost impacts of options, and changes (BCG, 2021).

  Digitalization enables the analysis and exchange of information from previous drilling projects in order to improve workflow. This includes the enhanced ability to visualize scenarios, potential risks, and impact cost options. The revised workflow enhanced crew efficiency, equipment dependability, and compliance and safety procedures (MacGregor, 2017). Implementing digitalization in the planning phase can reduce carbon emissions because preparation for optimal well design and planning will be accomplished faster than in the past (reducing planning day). It involves optimizing labor needs in order to reduce the carbon footprint of each individual (Al Asy'ari et al., 2022). Figure 19 shows the well construction cycle concept and implication on digitalization.

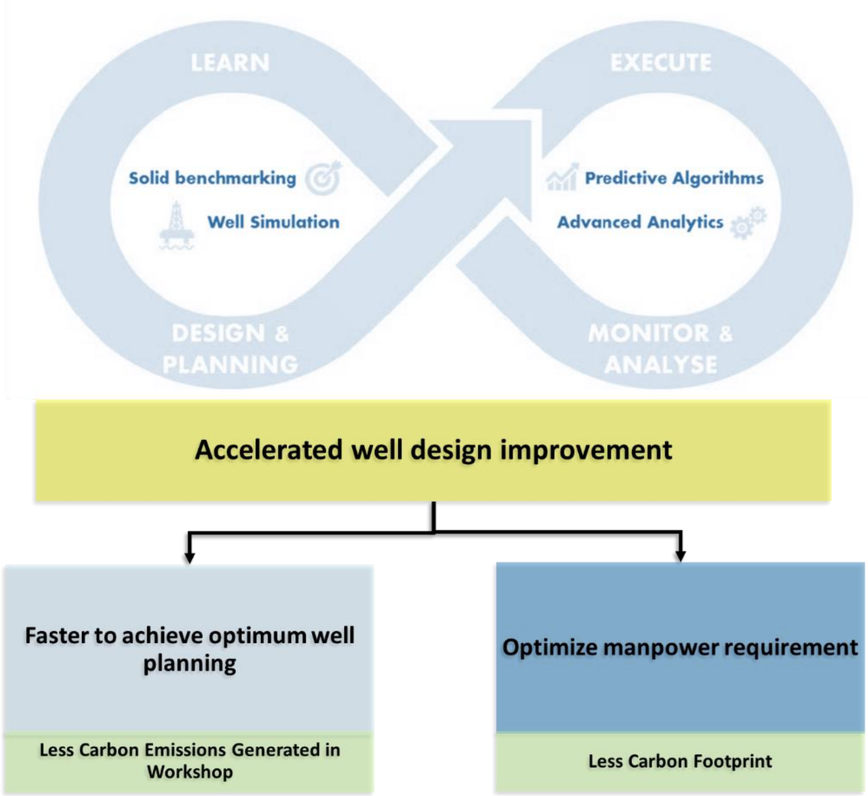

Figure 19: Well construction cycle concept and implication on digitalization (Al Asy'ari et al., 2022; Cappuccio et al., 2020)

The digitalization also can help to optimize well planning and supply chain that impact to high efficiency logistics and supply chain in drilling preparation by doing optimization on well-delivery planning and logistics and connecting to suppliers' systems to optimize delivery planning and inventories.

- **Boosting decision by Real-Time Operation.**

  Digitalization plays a significant role in managing and analyzing abundance data from downhole to surface instrument during drilling operations which the concept illustrated in Figure 20 Real-time monitoring enables individuals and technologies to analyze data pertaining to drilling conditions, advise operators, and improve risk prediction in relation to complex drilling challenges with less personnel on-site to prevent over-time operation (MacGregor, 2017).

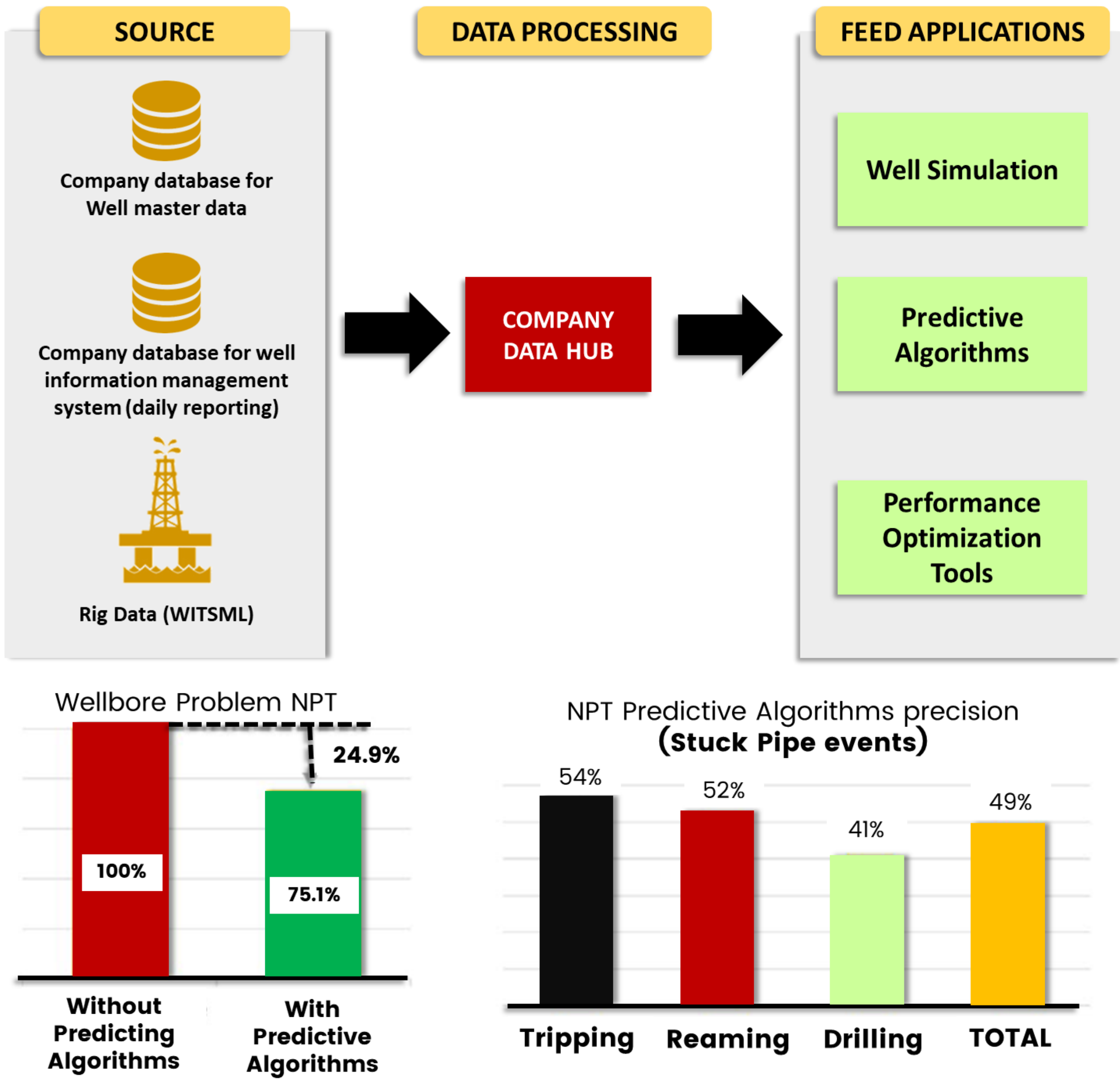

Figure 20: Company Data Hun (upper part), the Impact of Predictive Algorithms (lower part) (modified from Cappuccio et al., 2020)

Real-time operating is the automation of the drilling operation, and it entails the delivery of real-time suggestions for quick decision-making during the drilling operation for the purpose of problem/risk avoidance and operation optimization. This concept is depicted in Figure 21 and Figure 22. This type of operation will improve decision-making based on machine learning-generated insights from real-time data to make drilling operations more valuable, efficient, and safe, and hence reducing carbon emissions in Scopes 1 and 2.

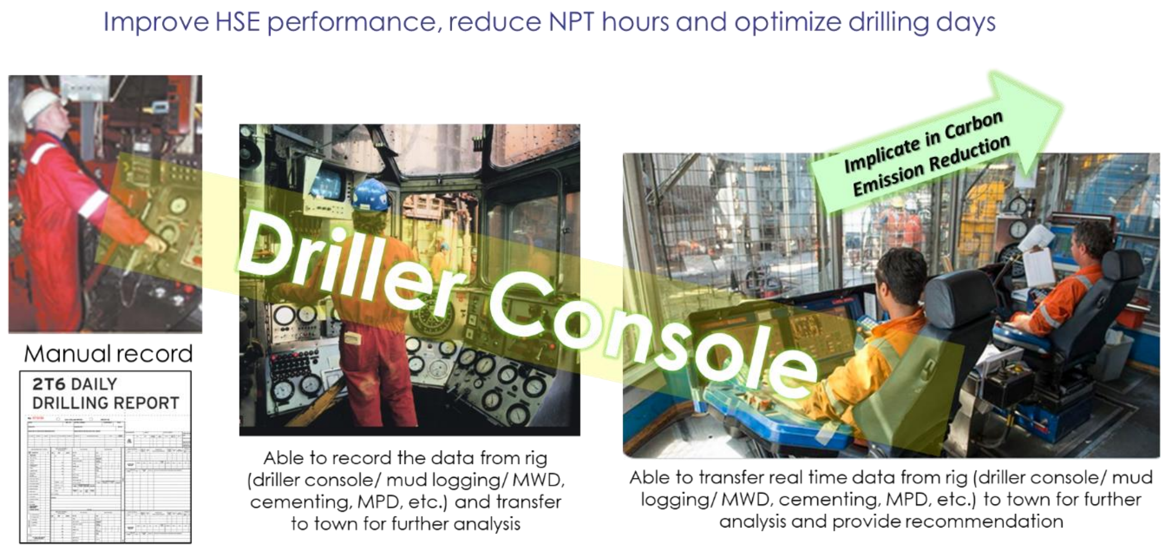

Figure 21: Example of real time operation in drilling operation (Al Asy'ari & Tobing., 2022)

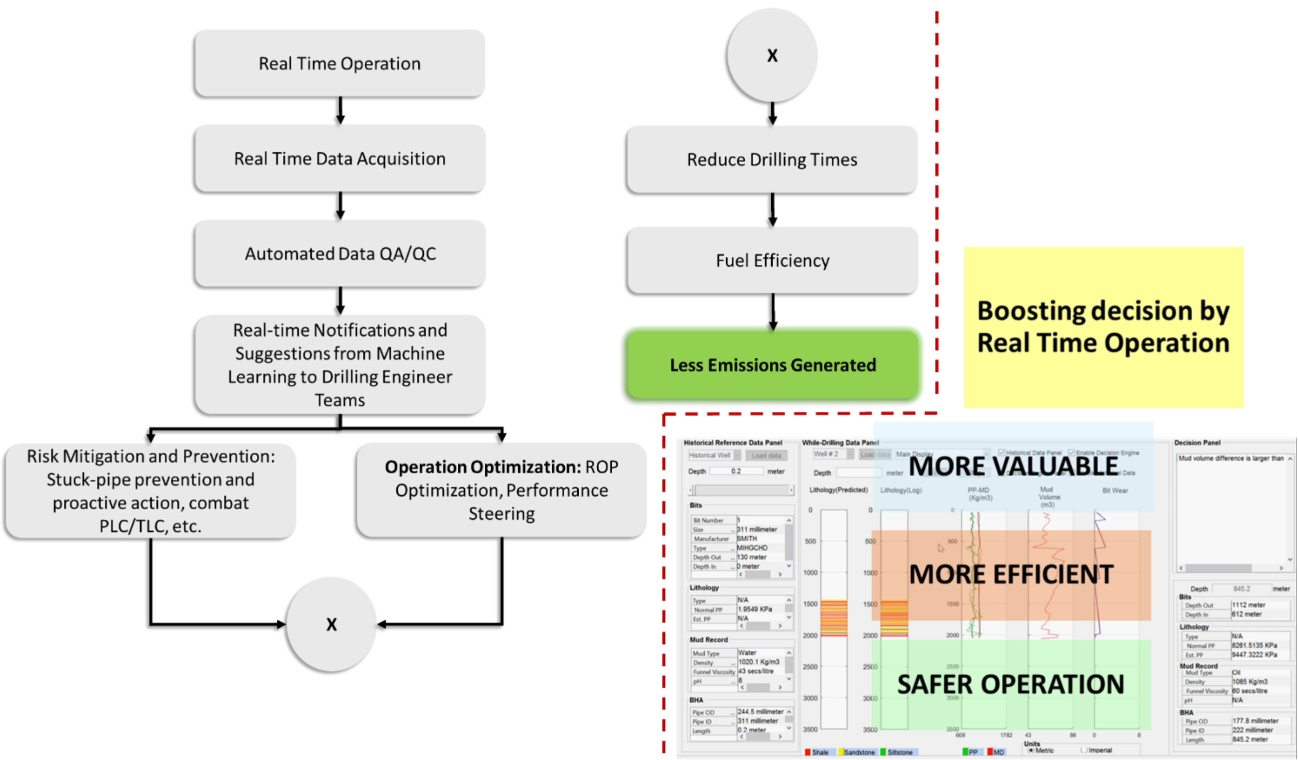

Figure 22: The impact assumption of Real-Time Operation on the carbon emissions reduction campaign (modified from Al Asy'ari et al., 2022)

In short Automated well execution that impacts to higher quality wells and safer operations in drilling execution by: 1) Improve decision making based on machine-learning generated insight. 2) Automate drilling activities, leveraging machine-learning and real-time data, 3) potential to robotize drill floor operations.

It should be noted that drilling activities involve several stakeholders and many activities that are not under the control of the geothermal developers. Therefore, further research and improvement are needed to monitor and regulate carbon emissions from these parties. Carbon emissions encompass fuel efficiency, emissions from vented sources such as well testing, completion, and unloading, emissions from land transportation, and electricity usage in workshops, reducing equipment and personnel's carbon footprint through digitalization and automation, and utilizing renewable energy in geothermal drilling projects by replacing existing power systems with more efficient dual or multi-systems in future rig tenders and contracts.

3. CONCLUSION

Several conclusions that can be drawn from this research are:

- The reduction of carbon emissions is particularly vital to maintain environmental sustainability, which was repeated by the Paris Agreement 2015 and COP 26 Glasgow to keep incremental global warming below 2 degrees in 2030. This effort is aligned with the goals of a number of extremely large energy businesses, which include achieving net-zero emissions.
- This study was able to effectively establish a preliminary idea of the carbon emissions calculation approach that would be used in the geothermal drilling project from the planning phase all the way through to the operational phase. As a result, this research has the potential to become very useful for the energy business in realizing low-carbon future drilling operations and dealing with future carbon tax policy.
- Integrated solutions need to be implemented in order to reduce the amount of carbon emissions that are produced by drilling operations. These solutions include conducting detailed tracking on the emissions that are produced, replacing diesel power generation with renewable energy sources integrated with energy storage and using biodiesel for transportation, implementing efficient drilling operations, and implementing digitalization technology to optimize the actual drilling duration.

Path Forward:

- There are very few articles that examine the measurement, strategy, and reduction of carbon emissions in Indonesian geothermal drilling operations. This research can be used as a reference for calculating carbon emissions in geothermal drilling, from the design phase to project completion. The collecting of data regarding fuel usage records from a third party is still extremely uncommon, despite the fact that it is crucial for future monitoring and mitigation of carbon emissions.
- The numerical approach for carbon emissions in industry can be implemented as mobile-desktop software for more exact data collecting for tracking emissions. For better data management, the concept of software need to be integrated with cloud database system.
- Briefly, the results of this study can be extensively implemented and serve as the first stage in an integrated effort to produce lower carbon geothermal drilling operations through best practices in order to attain a net-zero emissions goal.

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