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Original Article

The economic feasibility of renewable energy for off-grid mining deployment

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ABSTRACT

As renewable energy technologies emerge, it is important to determine the economic feasibility of introducing such technologies at mines. We present a case study of a mine in the Canadian territory of Nunavut, where extreme climatic conditions exist. It was determined that nearly 47,500 L of diesel could be saved annually during the exploration phase with the proposed installations applied in the residential facility of the mine. This represents a savings of approximately 10% in diesel consumption relative to the base case. Solar thermal technologies also were considered for the residential facility, with a payback period of approximately 5 months. Simple energy efficiency strategies can have a payback period as short as 2.3 months. Reductions in energy consumption and carbon dioxide emissions are estimated at 25% by pursuing the proposed efficiency strategies. If the mining company invests in wind turbines for the processing plant, approximately 35 million litres of diesel could be saved annually during the extraction phase. In addition, 9.7% of the carbon dioxide emissions can be reduced during the exploration phase and 50% during the extraction phase by utilizing renewable energy sources.

1. Introduction

In remote communities that typically lack access to conventional transmission lines, power is often delivered by diesel generators. Transport costs to remote sites increase the price of diesel and, consequently, the final price of energy delivery (Manchester et al., 2014). In such cases, environmental costs are linked to the exclusive use of diesel generators to satisfy the electricity demand.

A study (Arriaga et al., 2013) revealed that more than 175 communities in Northern Canada generate their own electricity off-grid using diesel-fuel generators. According to the authors, approximately 100,000 persons reside in these communities, and have an average energy cost of $1.3 USD per kWh. With their increasing electricity demands, the replacement or upgrade of current power generation systems becomes imminent, presenting an opportunity for renewable energy sources.

The Canadian territory of Nunavut has a population 36,600 (Statistics Canada, 2014). According to the Government of Nunavut, the territory's total petroleum product consumption is in the range of 171.7 million litres annually, of which 38% corresponds to heat and 20% to electric consumption (The Government of Nunavut, 2007). The largest share of consumption is for transportation, at 42% of total petroleum-based consumption. The purchase of petroleum products accounted for 20% of the Government of Nunavut's annual budget during the 2005–2006 fiscal year (The Government of Nunavut, 2007). The government has committed to providing economic incentives to both communities and companies that adopt renewable sources and improve their energy efficiency.

The Government of Canada previously provided incentives for the deployment of renewable energy technologies in the country. For example, the *Wind Power Production Incentive* offered one cent (CAD) per kilowatt-hour for 10 years for wind-powered electrical generation commissioned. This programme was discontinued on 31 March 2007 and replaced by a similar programme (Natural Resources Canada, 2005).

The proportion of energy costs in mineral extraction and processing accounts for approximately 15% and 19% of the production costs for metals and non-metals, respectively (Levesque et al., 2014). Mining extraction itself represents 60% of total energy consumption (Natural Resources Canada, 2013). The view here is that the introduction of renewable energy sources would lower the costs identified by Natural Resources Canada (NRCan). The implementation of the proposed measures could

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deliver benefits not only to mining companies but also to the First Nations communities affected by activities. Aboriginal participation has been encouraged by NRCan as part of the *Minerals and Metals Policy of the Government of Canada*.

The Diavik Diamond Mine is a case in point of successful renewable energy technology deployment in the mining industry. The company installed a wind farm consisting of four Enercon E70 wind turbines, with a total capacity of 9.2 MW, and an annual production of 17 GWh. This represents 8.5% of the mine's power needs (Diavik Diamond Mines Inc., 2014). Another successful example is the nickel and copper Raglan mine in Northern Quebec. Considering an additional power generation requirement of almost 100%, a waste heat recovery scheme was applied to capture the exhaust heat from their diesel generators. This measure reduced the foreseen installed power supply and its associated greenhouse gas emissions by approximately 50% (Levesque et al., 2014).

Our industrial partner, whose identity will not be disclosed, is a mining company with a residential facility in North West Nunavut and a processing plant scheduled to be built in the next 3 years. Typically, the residential facility operates between February and October and closes when there are extreme weather conditions. Management is interested in reducing diesel consumption by including renewable sources in its energy budget. Our partner also plans to reduce generation costs by identifying ways to increase the efficiency of their residential facility.

The objective of this paper is to assess the economic feasibility of deploying renewable energy sources at mines. Energy efficiency measures also are considered in an attempt to identify potential further savings in energy consumption. Typical climate constraints of the regional study are considered to assess the feasibility of installing photovoltaic modules and wind turbines at the study site. Specifically, we analysed the economic feasibility of implementing two renewable energy sources: solar photovoltaics (PV) and wind energy. We also included a bank of batteries for energy storage in the system. To analyse the feasibility of solar PV, wind energy and energy storage, we used the software package, Homer Energy, developed by the National Renewable Energy Laboratory (NREL, USA) (National Renewable Energy Laboratory, 2014). Findings from an additional study on solar thermal are included. This study aims to reduce diesel used to heat water for human consumption. Energy efficiency strategies were also studied to identify opportunities to reduce power consumption for lighting. The remote facility does not have an energy storage system or an energy monitoring system. For this reason, the analysis was carried out using the average energy consumption data compiled for remote facilities in Canada (Natural Resources Canada, 2011), rather than the historic power consumption data. The mining project is divided into two stages: (1) the exploration phase (approximately 3 years in length); and (2) the extraction phase (projected at 10 years). The interest rate considered in this study was 6%, but a sensitivity analysis considered a wider range.

2. Exploration phase

2.1. Methodology

The electric load at the camp was estimated based on the average consumption per person in remote off-grid Canadian communities of 27.7 kWh per day (Natural Resources Canada, 2011), along with the daily load profile of an Alaskan camp which was taken from the database of HOMER. In other words, we rearranged the consumption in the case example provided by Homer and used the annual average for Canadian remote communities to ascertain the annual profile. The fuel consumption data of the remote community during the operation time of the exploration camp in 2014 were provided by our industrial partner. These data are presented in Table 1, and they do not include the breakdown of the consumption of the mining equipment located at the facility, only the residential facility. It is shown only to compare the real diesel consumption with that expressed in our results; they were not used as the input of our model. The residential facility accommodates a variable population ranging from 40 to 127 people. The largest population was observed in the operation period of 2013, according to the collected data. Fuel consumption history for 2014, the consumption per capita and the variable monthly heating load were used to calculate the annual power demand of the 2013 population profile. As a result, we obtained a model that works for an operational year from February to October and the largest population profile that has lived in the exploration camp.

Three generators are set up in the facility (two for main power generation and one for emergencies). For the purpose of this study, only the two main generators will be considered. The remote location will remain confidential, as will the equipment details. The heating system is the component of the residential facility that consumes the most significant amount of energy. The vast majority of heaters operate with electricity, and only a few of them operate with propane and diesel.

Two diesel generators (G1 and G2) are considered in the study and their characteristics are detailed in Table 2. Load variability is the range in which the operator controls the generator's load, depending on the power consumption. The average fuel efficiency considered is valid for the load variability illustrated in the same table. The company's reported cost per litre of diesel, including transportation, is approximately $2.94 in 2013 USD (Financial Markets Department, 2013), which is more than double the regular cost in urban areas as of August 2014 ($1.41 USD per litre, according to Statistics Canada). We used USD as the study's currency with the 2013 average exchange rate by the Bank of Canada of $1 USD equivalent to $1.03 CAD (Financial Markets Department, 2013). Considering the price per litre and the generator's fuel efficiency illustrated in Table 2, the energy cost can be considered as $0.79 USD per kWh.

The average daily peak power consumption in the remote community was found to be 238 kW, as illustrated in Fig. 1. The seasonal profile is illustrated in Fig. 2, where the annual average energy consumption was calculated as 3047 kWh per day and 548 kW peak power consumption. These load profiles were configured as the main loads in the software Homer Energy. For the exploration phase, we did not consider part-load efficiency of the diesel generators. We assumed the generators were running at 80% all the time, as this is the normal operative condition in the

Table 1
Sample of diesel consumed in the remote facility (year: 2014). We adjusted this numbers to calculate the fuel consumption in 2013.

	April	May	June	July
Average population [persons]	44	58	58	36
Generators [L]	35,206	30,628	16,778	4210
Heating [L]	8414	3948	2580	243
Incinerator [L]	12,653	9310	7276	1853
Monthly [L]	56,273	43,886	26,634	6306
Daily average [L]	1876	1416	859	203

Table 2
Characteristics of the two generators that supply the power in the study site.

Generator	Power rating [kW]	Load variability [%]	Average fuel efficiency [kWh L^{-1}]
G1	442	40–80	3.7
G2	400	40–80	3.7