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Critical Literature Review
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Electricity in Isolation: the progress of power generation in Antarctica.

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Abstract:

This review outlines the development of power generation technologies in Antarctica, their downfalls and the increasingly popular eco-friendly alternatives to traditional methods. Power generation in Antarctica is a rapidly developing field considering its relatively short history. Demonstrated in this review is how quickly power generating technologies have developed in less than 100 years on the continent. Generation has progressed from the heroic age in Antarctica where blubber was burnt, to a diesel dominated lifestyle where diesel generators were utilised in almost every base as the predominant means of power supply. Management of diesel and dealing with the effects of its use were not fully realised until the rise of environmental awareness. Here alternative, eco-friendly power generation methods were investigated. With a range of renewable energy generation methods considered, solar and wind generation have, thus far, been selected as the emerging energy technologies on the continent. These new technologies require less maintenance, are cheaper to run long term, and produce fewer emissions so are ultimately better for both the environment and humans alike.

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Introduction

In a world in crisis, environmentally friendly practices are becoming increasingly important in preserving both the environment and human presence in it. With human activity having the potential to be highly detrimental to the environment, managing human-environment interactions has become vital. This has become explicitly clear in the Antarctic where evidence of human activity is able to be both preserved and lost in the environment. Realising this, the manner in which humans operate in the Antarctic has undergone much change since early exploration in the heroic age. Human settlement on the continent has developed from simple huts, occupied short term by a handful of people, to sophisticated research facilities, with capacities ranging up to 1000 people. With the increasing number of scientific facilities being established on Antarctica, there is the growing potential for humans to impact negatively upon the environment. In order to more effectively manage this impact alternative energy generation sources are investigated. Traditionally, diesel fuels have been burnt to generate warmth and electricity for the occupants of Antarctic stations. Investigation into the impact burning fossil fuels has both directly and indirectly on the environment has lead to the consideration and implementation of alternative electricity sources with varying degrees of success. This review overviews existing relevant literature in order to demonstrate the impacts of traditional power generation methods in Antarctica. This scope includes the methods reliability and cost, both economically and environmentally. Also considered are alternative sources and forms of energy to determine their viability and effectiveness as future generation methods.

The Early Days

Heat and power generation in Antarctica has been necessary since the advent of permanent or semi-permanent structures on the continent. In the heroic era this saw the harvesting of seals and penguins for blubber. Shackleton (2001) explains how the blubber from these animals was burnt in the huts to generate heat. This did cause slightly declining populations of animals in the areas of harvest. The blubber itself when burnt created a greasy film on the surfaces within the hut creating an unpleasant living environment for the occupants. Blubber was used as an early form of heating in Antarctica due to its ready availability as a free fuel source.

Diesel Driven

Scientific stations in Antarctica came into prominence in 1957, coinciding with the International Geophysical Year. The locations of research stations as of 2010 can be seen in Figure 1. Total occupation of these 75 research stations can see 4000 people living on the continent at any one time (Tin et al., 2010). The distribution of solid circles shows that there is 12 month occupation of both coastal and inland settlements. These research stations almost universally use diesel as their predominant source of power generation (Spinks, 1992). As such, overseeing the use and distribution of diesel in Antarctica is key to ensuring not only its economic viability, but to managing its environmental impacts.

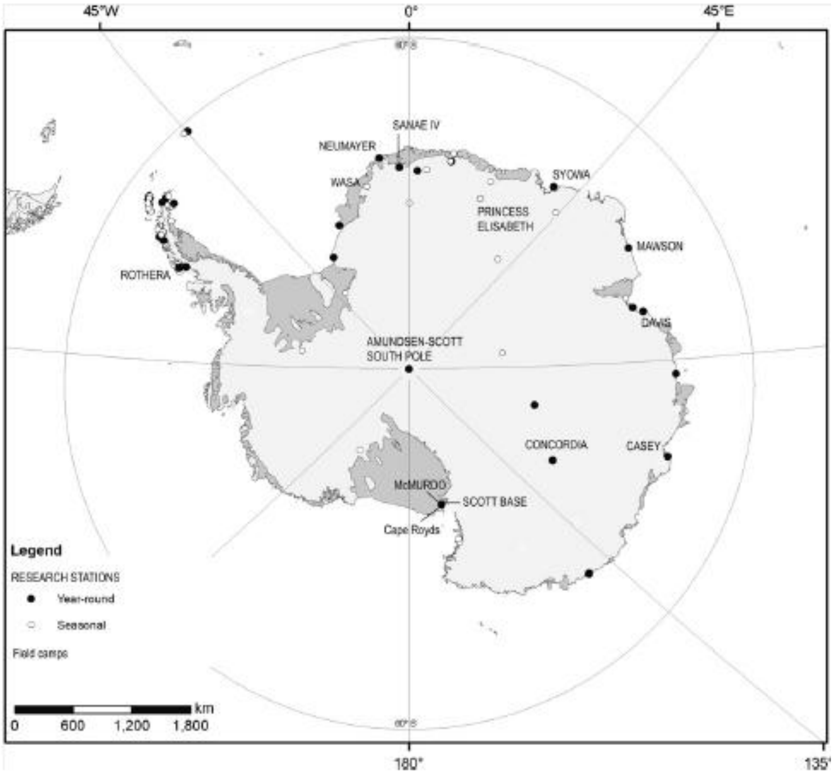

Figure 1: Map of Antarctic research stations (Source: Tin, Sovacool, Blake, Magill, El Naggar, Lidstrom, Ishizawa & Berte, 2010)

Generators

Diesel generators have traditionally been the most common form of power generation in Antarctica. When Scott Base opened in 1957 six 6kVA generators provided lighting and heating (Harrowfield, 1997). These initial generators were only intended to last the stations proposed first life of three years (Thomson, 1991). The subsequent proposal to maintain the base for a minimum of five further years saw the upgrade of these generators to a 48KVA system in the early 1960's. The need for a continued Antarctic presence to cement New Zealand's Antarctic claim saw extensive renovations at Scott Base and an eventual reconstruction of almost the entire base. To cope with the increased demands for the Base, both in terms of powering more buildings and servicing a larger population, the generation system was upgraded progressively in accordance with the operating life of the generators themselves. Summer 1966 saw the installation of two 65kVA generators, in summer 1978 the system was again increased, this time to a 135kVA system and then upgraded again in the summer of 1986 to a 180kVA system (Harrowfield, 1997). McMurdo Station has experienced similar upgrades periodically too. In summer 1964 McMurdo Station commissioned a new 200Kw diesel generator plant to better cope with the increasing power demands of the base (Harrowfield, 1997). Diesel generators have a limited capacity to adapt to increased demands. Larger requirements require larger generators. Not only are larger generators required but there are also the increased costs for running a larger generator, the maintenance costs to keep it functional and the costs to transport the old and new generators to and from Antarctica.

Fuel Consumption
Due to a lack of alternative traditional means of generation, diesel is heavily relied on to provide heat and electricity to bases. Historically, diesel has been the only means of powering Scott Base. Consumption of diesel has always been high due to sole reliance on it as an energy source. The first wintering over party (1957) at the Base went through 550 40 gallon drums of diesel. This is equivalent to 83,279.1 litres, or enough diesel to fill three dual trailer petrol tankers. Beyond extreme conditions, in an average week Scott Base could consume 500 gallons (1892.71 litres) of diesel (Harrowfield, 1997). This huge reliance on it as a source can be considered inconvenient as there is no locally available source of diesel due to mining for resources being prohibited under the Antarctic Treaty System framework. To get fuel to Scott Base it was initially all transported in barrels from McMurdo Station, which is supplied once annually by a fuel transporting ship. This involved regular trips to McMurdo to collect. As such a considerable dedication to loading, transporting and unloading the drums of diesel was necessary. The construction of a 5,000 gallon fuel tank, at Scott Base, built in the summer of 1967 reduced this need (Harrowfield, 1997) as fuel could be stored more economically onsite. Elsewhere in Antarctica the trend for high diesel usage is replicated. McMurdo Station uses nearly 5 million litres of fuel per annum (Harrowfield, 1997) and the combined Australian bases of Casey, Mawson and Davis have an annual consumption of 2.1 million litres to provide power and heating for 200 residents (Tin et al., 2010). Most Antarctic bases are kept at a warm 18°C. This need to keep bases warm as well as providing lighting for a continuous dark in winter ensures that the decreased winter population is balanced by increased heating needs.

Issues with using Diesel
Using diesel in an extreme and pristine environment comes with many risks. Disposing of diesel barrels after use became an ongoing issue, especially for isolated bases. On the coastal front; following the installation of storage tank at Scott Base, Harrowfield (1997) reports no effort was made to clear away the empty barrels until years later. He also reports that in summer 1963, over 400 discarded, empty barrels were collected from around McMurdo Station for disposal. Hasllett Station also had issues with discarded fuel barrels. One survey, conducted by Pascoe in 1983, found 134 empty barrels discarded around the station. Attributed to these barrels, stacks of full barrels and leaky seals on the outlets of a 100,000 gallon (378,541.18 litres) tank were attributed to the wide evidence of seepage into the snow and soils they were located on. This poses potential risks to any animals in the area should they be exposed. The exhaust from combusting diesel also has a detrimental effect to the environment, with the release of toxic oxides into the atmosphere. Another environmental condition needing to be considered is temperature. Diesel was found to turn to jelly at -36°C (Harrowfield, 1997). This became an issue during midwinter as it could no longer be pumped or poured, posing a threat to humans reliant on it. It is also highly expensive to provide diesel to Antarctic bases. Fuel is being supplied to small populations in an isolated part of the world; this makes transport costs, storage, and the cost to supply fuel highly expensive, along with the associated environmental risks (Hossain, 1988; Olivier, Harms & Esterhuyse, 2007; Tin et al., 2010; Spinks, 1992). In a specific example, from Olivier et al. (2007), the cost to transport the Special Antarctic Blend diesel to SANAE IV Base from Cape Town results in an estimated point-of-use cost triple to that of the purchase price. Improper disposal of diesel waste and carelessness with spills can cause pollution in the local environments from seepage. It is also highly expensive to ship the fuel to Antarctica.

Enhancing diesel operations
Energy production using diesel generators is not overly efficient, so innovation is vital to maximise benefit. A study conducted by Fey in 2009 at McMurdo found that, of the electricity produced, 1/3 is lost to the exhaust stacks, 1/3 is given off as heat by the generators radiators and 1/3 becomes electricity. To reduce quantity of energy lost, waste heat was then redistributed throughout the town using a piping system. This system was capable of heating buildings in conditions down to -17°C. Improved insulation and the addition of double and triple glazing (as opposed to single) aids in the ability for bases to retain heat and improves energy budgets, reducing energy expenditure (Harrowfield, 1997). Staff education and encouragement of behavioural change were found to be simple and effective ways of reducing the use of fossil fuels at stations. Modern buildings in Antarctica have incorporated building management systems, improved boilers and other engineering equipment to maximise efficiency and reduce fuel burn (Tin et al., 2010). To enhance the efficiency of diesel generators in Antarctica there has been an increase in waste heat use and a culture shift in terms of electricity use within the bases.

Alternative energy sources

With an increased awareness of environmental impacts, there has been a culture shift away from traditional, more pollutant heavy forms of power generation to environmentally friendly practices. PC Magazine Online (2009) reported that renewable energies are gaining a foothold in Antarctica, curbing fossil fuel use despite problems faced by the harsh climatic conditions, including cold and darkness. The long term benefit and cost-return has also been analysed, and it has been found that over ten years of operation the cost benefit of running a renewable energy source exceeds that of operating a diesel powered base (Teetz, Harms & von Backstrom, 2003; Tin et al., 2010). Hossain (1988; 91) suggested that “the availability of a local source of energy can go a long way in making the continent more hospitable.” This theory is one that has been embraced. In 2007, less than 20 years later, 14 bases were making use of wind and solar energy as renewable energy sources (Olivier et al., 2007). With developing technologies, Belgium’s Elisabeth Research Station aims to be the first Antarctic Station aims to be entirely reliant on only renewable energy (PC Magazine Online, 2009). Tin et al. (2010) agree that operation on 100% renewable energy is increasingly likely. Alternative energy sources to diesel generation are both feasible and increasingly common in Antarctica.

Solar
Due to the abundance of sunshine in the summer months, many bases are equipping themselves with solar panels. Solar panels are widely used in Antarctica. The Japanese utilise them at their Syowa Base, the British use them on their Rothera Base where use results in a saving of more than 1,000 litres of fuel per annum (PC Magazine Online, 2009). PC Magazine Online (2009) has also indicated that solar panels, properly positioned on the Antarctic Peninsula, can collect as much energy per annum as European nations. Usually solar power is used for hot water production and is often combined with wind turbines and diesel generators to meet energy needs (Tin et al., 2010). Olivier et al. (2007) determined that the utilisation of solar energy can be economically viable. Solar energy can be a viable source of energy both in isolation, with extensive panelling, and in conjunction with other sources of generation.

Wind

Wind is a readily available energy source in Antarctica. Katabatic winds are typical for the continent and have proven to be a fantastic resource to harness. To be viable for wind energy generation, a location has to have an average annual wind speed higher than 5 m/s. The maximum wind speed encountered in Antarctica is 40 m/s, lower than the threshold wind speed of the typical wind turbine (Hossain, 1988). Katabatic winds are characterised by very high wind speeds, especially in winter months. This conveniently coincides with high energy generation needs resultant from low temperatures (Hossain, 1988). The second annual peak for generation requirements for a 12 month station is during the summer, when occupation is at its peak. This fortunately coincides with high solar energy availability, so combining these two forms can prove an effective way of powering a base. Australia was the first country to obtain a significant electrical supply for its Antarctic stations via wind. Two 300 megawatt wind turbines have been at Australia's Mawson Station since 2003. Together the turbines have cut the operational cost of Mawson Station by 35% (Tin et al., 2010). Teetz et al. (2003) and Olivier et al. (2007) similarly concluded that wind generation can meet up to 35% of the electricity needs at the South African SANAE IV Base. Specialist turbines are used in the Antarctic which are highly sensitive, therefore able to generate energy at very low wind speeds. Despite being highly sensitive, the turbines are still able to handle high wind speeds without detrimental effect to the equipment (Tin et al., 2010).

Ross Island wind farm

In 2009 the Ross Island wind farm was completed. The farm is located on Crater Hill between McMurdo Station and Scott Base, where average annual wind speeds range between 7.9 m/s and 28.4 m/s (Meridian Energy Ltd., 2011). This three turbine farm was established to provide renewable energy power to Scott Base and McMurdo Station. The wind farm links the electrical grids of both bases and reduces the carbon footprint of the Antarctic operations, with fewer emissions as well as less environmental risks compared to those associated with transporting diesel fuels to Antarctica (Meridian Energy Ltd., 2011). The wind farm has cut fuel consumption between the bases by approximately 463,000 litres per annum, or 11%. This also equates to a reduction of greenhouse gases by 1,242 tonnes of CO_2 annually (Meridian Energy Ltd., 2009; 2011; 2012). Measured production from February 2011 to February 2012 delivered 111% of the production target (Meridian Energy Ltd., 2012), showing that renewable resource use has the potential to exceed expectations. One turbine operating at full capacity has the potential to provide Scott Base's entire electrical load. Completion of stage two of the wind farm would see additional turbines added with the ability to offset power consumption across the entire Ross Island by 40% (Unknown, 2010).

Benefits

Using renewable energy resources has many benefits over using diesel generators. Switching to renewable energies helps cut pollution and greenhouse gas emissions from burning fossil fuels and curbs enormous transport costs in getting fuel to one of the most remote places on the planet (PC Magazine Online, 2009). Olivier et al. (2007) found that a fuel saving of only 3.5% translates into approximately 10,425 litres of diesel, 0.012 tonnes of volatile organic compounds, 0.019 tonnes of carbon monoxide, 0.471 tonnes of nitrous oxides, 0.003 tonnes of sulphur dioxides, 26 tonnes of carbon dioxide and 0.007 tonnes of particle matter. Using renewable energy sources also serves to commit to the protection of the environment under both the Protocol of Environmental Protection 1991 and the Antarctic Treaty 1959 to minimise the environmental footprint of Antarctic activities (Olivier et al., 2007). Benefits from using renewable energy resources include environmental, financial and political.

Considered options
While solar and wind generation were chosen as the preferred methods of renewable energy generation, they were not the only choices considered. In the early 1960's American scientists made a foray into nuclear generation in Antarctica. A nuclear plant with a core the size of a 44 gallon drum was established in Antarctica. 438 recorded malfunctions later, in 1973, the plant was decommissioned, a move prompted by the detection of a pressure leak (The Southland Times, 2011). This leak resulted in the need to remove 7,700m^3 of radioactive rock and dirt from Antarctica. Following this incident, nuclear power has since been excluded from use in Antarctica due to cost and environmental considerations (Lawrence, Ashley & Storey, 2005). The feasibility for powering Scott Base through geothermal energy was also investigated. Geothermal power would enable savings in fuel, reduce emissions of CO_2 and nitrogen oxide (Spinks, 1992). Spinks (1992) decided, during his study, that a geothermal source within 60km of Scott Base would be suitable for harnessing to power Scott Base. Mt Erebus was the obvious choice for this source as it lies at 40km from the Base. Geothermal generators would be cooled using seawater that would then undergo reverse osmosis for use within Scott Base. Borehole drilling around Scott base found no geothermal pressure extending to the base, and so it was determined that it would be less economical to construct piping from Mt Erebus to Scott Base to provide geothermal activity than it would to construct turbines.

Conclusion
Power generation in Antarctica is faced with many challenges due to the continents isolation and the nature of its climate. Demonstrated in this review is how rapidly power generating technologies in Antarctica have developed in less than 100 years. From the heroic age where animal blubber was used to provide heating, to the industrial period in Antarctica, where diesel generators were used in every base as the predominant means of power supply. With the rise of environmental awareness, alternative, more eco-friendly power generation methods were investigated. Solar and wind generation have, thus far, been selected as the emerging technologies on the continent after a failed attempt at nuclear power, and investigations to utilise geothermal energy proved fruitless. These new technologies require less maintenance, are cheaper to run long term, and produce fewer emissions so are ultimately better for both the environment and humans alike.

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