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Technical and economic evaluation of the utilization of solar energy at South Africa's SANAE IV base in Antarctica

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Abstract

The technical and economic feasibility of utilizing solar energy at South Africa's SANAE IV station in Antarctica was evaluated in order to estimate potential financial and external savings, and to alleviate the programme's dependence on the special blend of diesel shipped annually from Cape Town. The average global horizontal and tilted insolation rates at the base were studied, energy consumption data of the station was investigated, technical performance characteristics of devices for harnessing solar energy were assessed and an economic analysis was completed. It was shown that at SANAE IV flat-plate solar thermal collectors could potentially be used in conjunction with the snow smelter (a device that meets the station's fresh water demand) and that photovoltaic modules could feasibly be used to reduce the station's electrical demand. Flat-plate solar thermal collectors could collect solar energy at an average of 3.13 R/kWh (viz. 0.49 US$/kWh) from a suggested 143 m^2 array, while comparatively a 40 kWp photovoltaic system would be less economically sound and only able to pay back costs at the end of the system's expected 25-year lifetime, generating electricity at an estimated 3.20 R/kWh (annual electrical consumption at SANAE IV amounts to more than 1062 MWh). The total diesel savings of the solar thermal and photovoltaic systems were estimated at approximately 12 245 and 9958 l, respectively, which represent savings in externalities of R67 338 and R55 879 each.

Keywords: Solar energy; Antarctica; Feasibility study; SANAE IV; Technical analysis; Economic analysis

1. Introduction

A significant cost component of operating South Africa's Antarctic SANAE IV research station currently depends on the volatile price of oil. Each year the station's electrical consumption is generated from roughly 297 872 l of Special Antarctic Blend (SAB) diesel that can only be transported from Cape Town with considerable logistical and financial effort, resulting in an estimated point-of-use cost triple that of the purchase price. Growing concern about future oil security, a continued effort to improve the performance of the station with reduced financial commitment, but above all the Antarctic Treaty's 1959 mandate, re-emphasized through the Protocol on Environmental Protection of 1991, ratified in 1998 [1], to protect the unspoiled environment, motivate an investigation of utilizing solar energy at South Africa's SANAE IV station (70°40′ South and 2°49′ West). Taylor et al. [2] record the following emissions per annum from the station's three combined heat and power (CHP) diesel generator systems: volatile organic compounds 0.341 tonnes, carbon monoxide 0.533 tonnes, nitrous oxides 13.451 tonnes, sulphur dioxide 0.076 tonnes, carbon dioxide 744 tonnes and particulate matter 0.190 tonnes. In the light of the international treaty endeavour to minimize the environmental footprint of Antarctic activities, investigations into alternative energy supply options which would have the potential to reduce such emissions are decidedly warranted.

Thus, progress in the utilization of renewable energy resources on Antarctica has taken place. Fourteen stations are at present utilizing renewable energy on the continent, mainly wind, of which six bases employ solar energy systems [3]. Continued research pertaining to the Australian

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Nomenclature

B/C	benefit cost ratio
C	capital investment (R)
F	fuel costs (R)
i	interest rate (%)
IRR	internal rate of return (%)
kW_p	kilowatt captured by a photovoltaic array at Standard Test Conditions (1000 W/m^2 irradiation and a module temperature of 25°C) (kWp)
L	labour costs (R)
M	maintenance costs (R)
MARR	minimum attractive rate of return (%)
n	number of years (years)
NAW	net annual worth (R)
NPV	net present value (R)
PW	present worth (R)
PWF	present worth factor
Rand	Rand (South African currency abbreviated as R)
E	externalities (R)

Antarctic Division [4] has also shown that solar thermal devices can perform satisfactorily in these conditions, as is currently the case at the Australian Davis station, while large photovoltaic arrays have been installed at the American McMurdo and Japanese Syowa stations (323 and 236 m^2, respectively).

This paper presents results from the study of factors relevant to the utilization of solar energy at SANAE IV. Global horizontal and tilted insolation rates at SANAE IV are calculated, the station's energy systems and annual average electrical consumption are analysed, performance estimates of photovoltaic and flat-plate solar thermal devices are given, and financial and external savings are established in the economic evaluation.

The *a priori* motivation to focus on solar energy exclusively stems further from the facts that while in the Antarctic summer the heating load at the base is at a minimum, this is well compensated for by the energy demand resulting from much higher occupancy during this time (e.g., water generation). Also, an earlier study by Teetz et al. [5] examined the feasibility for using wind energy at the base.

2. Analysis procedure

The investigation was undertaken by considering four criteria in turn, namely, availability, demand, devices and costs. That is, the availability of the solar energy resource at SANAE IV, total energy demand at the station, potential solutions to harnessing the solar energy in the given conditions, and the complete system lifecycle costs.

The results from each of these four criteria were used to establish and compare potential savings that could be generated for the programme, and the details of this investigation have been discussed here under the sections of solar radiation analysis, station energy demand analysis, device characteristics and energy production, and economic analysis, respectively.

Costs have been expressed in Rand values (South African currency) of December 2005, but can be converted to the equivalent American Dollar amounts of that time by multiplying with 0.158 (US$/ZAR). Furthermore, the economic analysis has been presented in *real* terms (that is as December 2005 Rands).

3. Complete data capture

During a field trip to SANAE IV (in the summer season of 2004/2005) the following data were acquired:

- Eighteen consecutive days of January radiation measurements obtained using two Kipp & Zonen CM5, and a Kipp & Zonen SP-Light pyranometer (which included measurements of global horizontal, horizontal diffuse global tilted radiation).
- Corresponding temperature measurements of the pyranometers, photovoltaic module and ambient conditions using T- and K-type thermocouples.
- Energy production data from a 5 W Liselo-Solar photovoltaic module.
- Historical data of electricity generation and the corresponding diesel consumption during 2000, 2001, 2002, 2003 and 2004.
- An investigation of the station's fresh water consumption and the production rates of the snow smelter (a device used to melt snow in order to create fresh water for the station).
- General information regarding all the power systems and power distribution was collected and compiled into an energy audit of the station.

4. Solar radiation analysis

A critical component of the feasibility study was an assessment of the solar radiation expected throughout the year at SANAE IV. Significantly, however, there was no historical data available for analysis from the station, except for measurements obtained during a field trip in January 2005 (detailed in the previous section and subsequently referred to in context). Not being able to use long-term averages to estimate insolation rates, a number of other sources were consulted. These included the Langley Research Center's of the National Aeronautic and Space Agency (NASA) Surface Meteorology and Solar Energy Dataset (SSE dataset), compiled from satellite data,