Research Article

The Potential of Concentrated Solar Power for Remote Mine Sites in the Northern Territory, Australia

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The Northern Territory (NT) is among the regions in Australia and the world with the highest solar radiation intensities. The NT has many mine sites which consume significant amount of fossil fuel with consequent greenhouse gas (GHG) emissions. The environmental concern related to the fossil fuel consumption and availability of immense solar energy resource in the NT open the possibilities for considering the provision of power to the mining sites using proven solar technologies. Concentrating solar power (CSP) systems are deemed as the potential alternatives to current fossil fuel based generating systems in mining industry in the NT. The finding is based on consideration of the major factors in determining the feasibility of CSP system installation, with particular reference to the NT mine sites. These are plant design requirements, climatic, environmental, and other requirements, and capital and operating costs. Based on these factors, four mine sites have been identified as having the potential for CSP plants installation. These are McArthur River Mine, Ranger Mine, Northern Territory Gold Mines, and Tanami Operations. Each site could be served by one CSP plant to cater for the needs of mining operation and the local communities.

1. Introduction

Like many other nations, Australia is committed to reducing its carbon footprint by reducing its greenhouse gas (GHG) emissions by 20% by 2020 and an additional target of reducing them to half by 2050 [1]. Australia's annual GHG emissions for the year to December 2012 were estimated to be 551.9 Mt CO₂-e [2]. Australia generates only 1.5% of global GHG emissions; however, for the year to June 2012, the national inventory emissions per capita were about 24.4 tonnes CO₂-e [3]. On a per capita basis, Australia is one of the world's highest GHG. Australia's main sources of GHG pollution are electricity generation, transport, agriculture, industrial processes, land use, and waste [4]. Among these sectors, electricity generation is the biggest GHG emitter with a 36% share [3].

Australia's electricity generation in 2011-2012 is 253,851 GWh, a 0.5% increase from 2010-2011 [5], with coal (69.1%) and

gas (19.3%) being the main fuels. The share of all renewable energy sources is 9.4% with hydro (5.5%) and wind power (2.4%) being the main contributors.

NT's electrical generation can be classified into (1) regulated network and (2) unregulated network which consists of off-grid, pastoral properties, mines, and other. The regulated networks of Alice Springs, Darwin-Katherine, and Tennant Creek [6] generated 1814 GWh in 2010-2011 [7] with a total generating power of 522 MW. The unregulated network generated 1600 GWh with total generating capacity of 555 MW, of which mining sector generated 430 MW and 1230 GWh. These figures show that NT mining sector represents the largest electricity consumer within the unregulated network; on a territory level it also represents significant portion of the overall electricity consumption. In addition mining operations are among NT's biggest consumers of fossil fuels with significant GHG emissions (BREE, 2013). Almost 99% of the electrical generation in the NT is fuelled by gas [8].

The NT is among the regions with richest solar energy resources in the world. The NT has an immense amount of solar energy throughout the year which remains largely untapped. To date, less than 1% of the Territory's electrical energy generation (and consumption) comes from renewable source [6, 8].

With the above background, this paper explores the potential of CSP technology in supplying energy to the mining industry in the NT. NT has abundant solar energy resource and there have been success stories of the CSP technology in a similar environment elsewhere in the world which can be useful in realising this potential in the NT. There has been a recent initiative by the Australian Renewable Energy Agency (ARENA) to provide funding to deployment of solar PV systems to provide power to mining sites (e.g., [9]). An earlier initiative from the same agency has seen the allocation of significant funding "to deliver the next wave of cost reductions, novel technologies, know-how, publications and patents, and concepts ready for development and commercialisation" of the CSP [10]. It is in the anticipatory spirit of the outcome of that latter that this research was conducted.

2. CSP Technologies and Prospects

This section presents an overview of the CSP technologies and their prospects being a precursor to the discussion on the feasibility study of CSP in the NT (Section 3).

2.1. CSP Technologies: An Overview. CSP technologies can be classified into (1) parabolic trough systems, (2) central receiver (tower) systems, (3) linear Fresnel systems, and (4) parabolic dish systems. Table 1 presents a summary of main features of various CSP technologies. This summary is used in this research to aid in selecting the relevant CSP technology under the relevant atmospheric, environmental, and economic conditions in this study. Detailed information on these technologies can be found in [14, 15].

As shown in Table 1, each technology listed has its own ranges of capacity, operating temperature, the type of power cycles and heat transfer fluids it can work on, water and land requirements, and so forth. The table also lists the advantages and disadvantages of each technology. All these factors must be taken into account when selecting the most appropriate technology for a particular site with its own environmental factors.

CSP systems, also known as solar thermal power plants (STPPs), are flexible to be hybridized with other renewable and conventional systems such as biodiesel fired boilers, wind, and photovoltaic systems. CSP technology is also capable of providing process heat for industrial applications such as water desalination at coastal freshwater-scarce utilities.

STPPs are capable of providing base load power to areas that have high direct solar insolation at costs similar to fossil fuel power generation but with significant reduction in greenhouse gas (GHG) emissions. In addition, power can be transported from insolation rich regions to insolation poor regions. For example, transportation of power to 3000 km is possible with only 11.5% losses using 800 kV direct current transmission technologies [16].

CSP systems are versatile and can be integrated with existing or new fossil fuel based power plants to curb the GHG emissions and to extend plant life to a low-emission energy future [1]. Various CSP systems emit much lower GHG compared to conventional fuels (oil, gas, and coal) and roughly the same as the tidal, wave, and PV systems [17].

In order to ensure uninterrupted power supply necessary for mining operations, the CSP systems have to be supplemented with thermal storage. In addition, such systems are generally installed with fuel power backup capacity offering reliable power production to utilities and grid operators.

2.2. CSP Prospects

2.2.1. CSP Deployment Worldwide. The first solar thermal power plant became operative in Egypt in 1912 [18]. CSP is considered a proven technology with CSP plants operating in California from 1984 to 1991 [19]. Due to the steep decline in the prices of fossil fuels the support for CSP (including tax incentives and mandatory power purchase) was withdrawn by the government. CSP market reemerged in 2006 in response to the new government incentives such as feed in tariff in Spain and policies requiring utilities to include renewable power. This led to the construction of new CSP plants, raising the global stocks of CSP plants to nearly 1 GW in 2010 [19]. Since then many other countries have invested in CSP with a projected increase in total capacity of up to 15 GW after the completion of the plants that are currently under construction [19].

According to NREL online database [20], to date 18 countries have constructed (or are constructing) CSP systems. The total installed capacity of all the 77 operational CSP plants is 3478.16 MW as of October 2013 (more than twice the capacity in 2012). Of these, 90% are parabolic trough systems, 8% linear Fresnel reflector systems, around 2% central tower systems, and less than 1% parabolic dish systems. Leading in terms of installed capacity are Spain (60%) and US (23%) while the remaining 17% is in other countries. Additional 17 GW CSP plants are under construction (20%) or under feasibility and planning stages with approximately half of these in the USA and another half in Spain and China [21].

2.2.2. CSP Deployment in Australia and the NT. Australia enjoys the position as the world leader in terms of solar resources and is contributing relatively well from a research and development point of view. A 100 kW CSP system called Step 100 was built in Meekatharra in WA in 1981-1982 [1]. The system employed an Organic Rankine Cycle (ORC) system and operated for only a short time; hence performance data is limited. A 25 kW steam engine generator powered by a 14-dish system in White Cliffs in the New South Wales was designed by the Australian National University (ANU) and installation completed in 1981 [22]. In 1998, this system was taken over by Solar Systems Pty Ltd. and converted to CPV receivers. However, later in 2008, despite the dishes remaining in fair condition, company decided to decommission the plant [1].

Another Australia's research success was a solar dish with 500 m² aperture area designed and built by ANU in

TABLE 1: Comparison of CSP collecting technologies [1, 11–13].

Technology	Parabolic trough system	Central tower system	Linear Fresnel system	Parabolic dish system
Sketch
Description	(i) Sun rays focused by parabolic through reflectors (ii) Pipes containing heat transfer fluid run through the reflector focal points	(i) Arrays of heliostats focus sunlight on a central receiver (ii) Heat transfer fluid runs through the receiver and generates steam	(i) Sun rays are focused by an array of linear mirror strips on a line receiver (ii) Linear fixed receiver is mounted on a tower	(i) An array of point-focus collectors tracks the sun in two axes (ii) Sun rays are focused on a receiver at the dish focal point
Maturity (2012)	Commercially proven (over 25 years), 3124 MWe installed as at 2013	Pilot commercial projects (medium to high maturity), 64 MWe installed as at 2013	Pilot projects (medium maturity), 288 MWe installed as at 2013	Demonstration projects (low maturity), 1.5 MWe as at 2013
Typical capacity (MW)	10–300	10–200	10–200	0.01–0.025
Operating range (°C)	150–550	250–1200	150–500	300–1500
Power cycles considered	Steam Rankine Organic Rankine	Steam Rankine Brayton cycle	Steam Rankine Organic Rankine	Stirling engine Steam Rankine
Plant peak efficiency (%)	14–20	23	18	30
Annual solar to kWh efficiency net (%)	11–16	7–20	13	12–25
Maximum slope of solar field	Up to 2%	Up to 4%	Up to 4%	10% or more
Water requirement (m ³ /MWh)	3 (wet cooling) 0.3 (dry)	2–3 (wet) 0.25 (dry)	3 (wet) 0.2 (dry)	0.05–0.1 (mirror washing)
Land occupancy	Large	Medium	Medium	Small
Typical surface area (m ²)	300–900	100–200	30–300	50–100
Heat transfer fluid	Water/steam and synthetic oil	Water/steam, air, and molten salt	Water/steam	N/A (Stirling engine or microturbine)
Storage system demonstrated	Molten salt	Molten salt	Pressurized steam	Only indirect storage
Other storage options	Molten salt, concrete, and phase change materials	Concrete, ceramics, and phase change materials	Molten salt, concrete, and phase change materials	Concentrated heat to catalytically break NH ₃ into N ₂ and H ₂ for storage to recombine for release of heat

TABLE I: Continued.

Technology	Parabolic trough system	Central tower system	Linear Fresnel system	Parabolic dish system
Advantages	(i) Mature steam cycle systems (ii) Success record of 354 MW (California) (iii) Simple design (single axis tracking) (iv) Hybridization with natural gas is attractive and functional (v) Ability to connect with thermal storage	(i) High temperatures and high thermal efficiency (dual axis tracking) (ii) High capacity factor and molten salt that can be used as direct HTF (iii) Simple network (single tower) (iv) Flat mirrors easy to construct and inexpensive	(i) Understood steam cycle systems (ii) Simple design (single axis tracking) (iii) Hybridization is possible (iv) Ability to connect with thermal storage (v) Flat mirrors easy to construct and inexpensive	(i) High temperatures and high thermal efficiency (dual axis tracking) (ii) Costs benefits in mass production compared to other technologies (iii) Does not require levelled surface
	(i) Water requirements may become a site specific constraint (ii) Maximum temperature is limited (iii) Surface has to be flattened for troughs to be installed (iv) Sun tracking is limited in single axis systems (v) Curved mirrors are sophisticated and require special manufacturing	(i) Water requirements may become a site specific constraint (ii) Requires high capital investment (iii) Only sufficiently large units are cost effective and feasible (iv) Sun tracking can be a complex job (v) Surface has to be flattened for troughs to be installed	(i) Water requirements may become a site specific constraint (ii) Sun tracking is limited in single axis systems (iii) Surface has to be flattened for troughs to be installed	(i) Requires very high capital investment (ii) Manufacturing of parabolic dish is very sophisticated and incurs very high costs (iii) O&M costs could be very high (iv) Thermal storage is not possible (v) Surface roughness has a limitation
Disadvantages				

association with a commercial company, Wizard Power. The “Big Dish” was completed in 2009. The National Solar Energy Centre (NSEC) at Newcastle has recently commissioned a central tower plant in collaboration of joint funding by CSIRO. This plant has a 30 m central tower with 450 heliostats over 4000 m² collector field for a 500 kW system [1]. The aim of this research facility is to test solar reforming of natural gas and solar steam generating systems and to investigate solar Brayton cycle systems.

In Australia there are only 5 currently operating CSP systems with a total capacity of 5 MW. Few other research-based CSP projects are also underway [23].

It is estimated that a 10 GW capacity would be able to reduce Australia's emissions by approximately 30 Mt CO₂ per year which constitutes 15% of current electricity sector emissions. In addition, every 100 MW system is expected to create roughly 500 temporary construction related jobs and 20 ongoing operation related jobs. Last but not least, CSP technology offers to preserve precious natural resources which are being exploited for power production. This creates further opportunities for international trade of fossil fuel resources to the parts of the world which are less suitable and/or ready for renewable energy infrastructure. This study predicted that, considering the demand for dispatchable clean energy, CSP market potential would likely strengthen. According to the same study, CSP could provide 30% of Australia's average total current electricity which is 15 GW [1].

Through ARENA, CSIRO is partnering with 6 universities in Australia, 2 universities in US, and the NREL in the Australian Solar Thermal Research Initiative (ASTRI) with the goal “to lower the cost of solar thermal power to 12 cents a kilowatt hour; targeting 20 cents a kilowatt hour by 2016 and 12 cents by 2020, whilst providing a power source that can be adjusted to demand (dispatchable generation)” [24].

For the NT, the Green Energy Taskforce [6] concluded that “while the costs for solar thermal are still high and the commercial scale is currently too big for the Territory to accommodate, it is approaching a stage where it could be deployed in the NT. It is considered that the best prospects would be in combination with gas generation (to overcome the intermittency).”

Considering the availability of high insolation in NT (see Section 3.2), the potential of STPP is not limited to remote mining sites; surplus power can also be transported locally and internationally, such as to neighboring islands of Indonesia through an intercontinental grid interconnection [25].

3. Feasibility Parameters of a CSP Plant

Based on the information presented in Table 1, there are 3 major groups of parameters that need to be considered in assessing the feasibility of a CSP plant installation in a location: (1) plant design requirements including auxiliary services, (2) environmental parameters, and (3) capital and operating costs. This section provides a brief insight into the nature of these parameters and complications associated with them in the context of mining industry in the Northern

Territory, and specific examples are discussed in the following section.

3.1. CSP Design Requirements

3.1.1. Optimum Size of CSP Plant and Its Operating Life. One of the main criteria for a CSP plant is the ability to gain sufficient environmental and economic credits over its lifespan. Recommended size of plants varies for different CSP technologies as summarised in Table 1. Most of the commercial central tower plants built so far are in the range of 10–20 MW whilst the commercial parabolic trough plants in operation are in the range of 30–250 MW. All the commercial CSP plants which are currently in operation have a life between 20 and 35 years. Precise estimation of economically viable size of a CSP plant may require extensive modelling using specific design values for a certain location [26]. As will be discussed in the following section, majority of the operating mines in the Northern Territory would have sufficient power load and lifespan to sustain CSP plant.

3.1.2. Operating Temperatures. Each of the four CSP technologies discussed in Section 2 generates electricity at different operating temperature (Table 1). Higher operating temperature can be achieved with the central tower systems or parabolic dish systems. This temperature can further be used to cater for some of the process requirements, for example, in minerals processing. High temperatures are achieved through the use of heat transfer fluids (e.g., CO₂) in integrated solar combined cycle power systems [27]. Most of the on-site ore processing does not involve high temperatures; however in some cases such integrated systems would be required.

3.2. Atmospheric, Environmental, and Other Requirements. According to Masters [28], the most suitable areas for CSP plants include North Africa, the Middle East, Southern Africa, Australia, and the western side of South America. Rigorous analysis of the conditions in each of these locations reveals that the most crucial factors for CSP plants are the suitable direct normal irradiance (DNI), water availability, land topography, and low risk of extreme weather. Availability of backup power has also to be considered where it is important to ensure uninterrupted operations such as in mines.

The average DNI and the number of days of low DNI (cloudy days) at a location are used in calculating the solar multiple which is required to calculate the mirror area required [29]. In addition, the number of complete cloud cover days at a location is very important in deciding whether a CSP plant is suitable for dispatchable power or only for peak load power and hybridization with other power generating systems [30]. The minimum economically viable value for DNI is between 1800 and 2000 kWh/m² per year [31, 32].

Figure 1 shows the contour of the average annual solar energy in Australia [33]. As shown, most of the NT regions receive more than 2000 kWh/m² annually (averaged over 2007–2012 period) with the Central Australia receiving over 2300 kWh/m². This intensity is considerably higher than that

FIGURE 1: Average annual total of solar energy per square meter in Australia [33].

FIGURE 2: Australia's June average solar radiation [34].

of Spain, one of the world's leading countries in solar power technology.

Even during the peak “winter” season in the NT, the mean daily solar radiation ranges from $5.3 \text{ kWh/m}^2 \cdot \text{d}$ (central region) to $6.7 \text{ kWh/m}^2 \cdot \text{d}$ (Figure 2).

Since CSP systems rely on the availability of high DNI, it is worth looking at this data for the NT. As seen in Figure 3, which shows Australia's average daily DNI map, the values for the NT range from 22 to $27 \text{ MJ/m}^2 \cdot \text{d}$.

FIGURE 3: Average daily direct normal irradiance in Australia [34].

FIGURE 4: Average annual direct normal irradiation in Australia [33].

On an annual basis, the DNI values for the NT range from around 2000 kWh/m^2 at the northern coast to around 2800 kWh/m^2 at the central region, Figure 4, which is well above the minimum viable economic value for CSP installation mentioned earlier.

The impact of extreme weather on the CSP design is associated with the construction and building codes that affect the construction costs. NT is one of the parts of the world which is repeatedly affected by tropical cyclones. The extreme tropical cyclones may be seen in an interval of 500 to 1000 years; however less severe cyclones are more

common [35]. The pattern of wind speed at a location has a direct impact on the capital and ongoing maintenance costs of the collector field of CSP plants. In Solar Energy Generating System (SEGS) plant in USA at least 3000 mirrors are replaced each year which get broken by winds [36]. This information is of utmost importance if a CSP plant is considered in coastal and cyclone prone areas of the NT. The available data for the severity and frequency of cyclones in this region is somewhat scarce [37]. Fortunately, the regions most prone to destructive winds in Australia are well known and most lie within 50–100 km of the coastline [38]. Majority of the mining operations and thus potential CSP sites lie further inland outside this boundary. Specific locations are discussed in more detail in the following section.

Flooding is another potential environmental hazard which could obstruct accessibility to a power station for routine operations and maintenance and may cause malfunctions in the power systems at a power generation facility. Each potential site would have to be thoroughly investigated for such possibility, and backup power supply would have to be considered.

In CSP plants, water is required for cooling and cleaning purposes. Around $2\text{--}3\text{ m}^3/\text{MWh}$ of water is required for various CSP systems [1, 17] as summarised in Table 1. Washing water is not required to be of high quality and the discharged/treated waters from elsewhere can be used. In some cases, dry cooling systems may be applicable [29, 39]; however, this may be more expensive and may reduce annual production by 7% and increase cost of electricity production by 10% [17]. The majority of CSP plants installed to date are generally in desert environments having water scarcity issues. Therefore, there is increased interest in dry cooling condenser technologies such as MACCSol air cooled condenser technology [40]. The Jemalong Solar Thermal Station (6 MW_{th}) in Australia will be the first in the world to deploy MACCSol air cooled condenser technology [41]. Situation in the NT is similar to most of the mining operations of interest being located in dry inland areas (see Figure 5, Section 4).

The general requirement for land area is 20,000 to 30,000 m^2 per MW of electricity produced through parabolic trough systems [16, 17]. However, large-scale solar power plants require roughly 2 hectares of land per MW of power [23]. The optimum topography and therefore orientation of the solar collector fields can be estimated from the slope limits presented in Table 1. Northern Territory of Australia is characterised by a very stable landscape with minimal slopes in most regions [42]. Thus it is deemed suitable for large-scale installations such as CSP plants. Availability of land may be a serious issue due to the strict regulations around the Aboriginal land rights [43]; however it is not unprecedented that such land is developed. In fact, absolute majority of mining tenements are located on Aboriginal land.

3.3. Capital and Operating Costs of CSP. Investment costs are a major factor in determining the size and the economically viable life time of a CSP. For commercial power generation, Hinkley et al. [39] indicated that the cost effective size of CSP tower plants is 50 MW and 150 MW for parabolic

FIGURE 5: The mineral sites map for the NT [46].

trough plants. The investment costs of CSP plants differ from a region to another depending on solar intensity and its uniformity in that region. A region with less uniform and low amount of solar irradiation will require higher solar multiple and, hence, larger solar collector field. Similarly, the maintenance/operating costs are higher for a low solar irradiation area, as they consume higher amount of backup fuel for producing power.

Considering the cost breakdown presented in the literature [28, 39], heliostats are more economically attractive compared to trough systems, and the initial cost of installing a thermal storage system for central tower is almost half of the initial cost for installing a thermal storage system for trough system. However, there are additional costs associated with tower and receiver construction for tower plants.

In the context of mining operations in the NT, installation of CSP plants could be economically viable. Although individual mines (power requirement in the order of 20 MW [44, 45]) may not have sufficient demand for power to sustain their own plants, mine clusters can be identified which would underpin the cost effectiveness (see Section 3.3).

4. Results and Discussion

4.1. NT Mining Operations. There are at least 76 mining operations in the NT of which 28 are operating, 8 care and maintenance mines, and 40 feasibility mines (as of June 2013) [46]. In the NT context, the crucial factors identified in Section 3 combined with the data provided in [46] lead to the following observations.

A minimum economic life time of an application is the first and possibly the major parameter that decides whether a CSP plant will be economically viable or other (renewable) energy system options should be considered for power production. Majority of the mines (Figure 5) in the NT have sufficient lifespan to sustain CSP applications. Initial estimations of the lifespan for many were in the order of 10–15 years' lifespan; however in most cases this has been extended to 25 years and beyond as the new and improved exploration and production technologies became available. For example, the Bootu Creek mine [47, 48] producing manganese has been operating between 1955 and 1963 and has been abandoned for decades after. However, it reopened in 2005 and in 2009 its expected lifespan has been further extended by over 13 years. McArthur River Mine has been in operation since 1995 and the initial estimated lifespan was in the order of 25 years [49]. In 2013, this period was extended by a further 11 years.

4.2. Temperature and Power Requirements. Most of the on-site treatment in mining industry is limited to crushing and leaching which do not involve extremely high temperatures [50]. For example, gold extraction process rarely encounters temperatures higher than about 100°C [51]. However, high temperature roasting, up to 980°C according to some sources [52–54], is often employed at uranium and bauxite/Al processing facilities. An appropriate CSP technology can therefore be identified from Table 1.

When considering the type of the load (peak load versus base load) and the required size of the power plant, it becomes obvious that many mines will not be able to sustain a CSP plant of their own. For example, zinc and lead production at McArthur River Mine requires 45–50 MW [55]. Tanami gold operations consume 30 MW and the nearby granites gold mine requires a further 40 MW capacity [56]. It is worth mentioning that currently the power can be supplied to these mines from at least 3 independent sources: power grid, diesel, and the nearby gas pipeline; however diesel is by far the major source of energy. However, the mining sites tend to form regional clusters (Figure 5), and CSP technology seems to be a convenient solution to provide power to particular regions. These are Darwin-Katherine region which is also called Pine Creek area, the Tennant Creek area, and the Alice Springs region. There are also few mining operations in the central-west area of the NT, known as Tanami region, in the east of the NT in McArthur River region, and few individual mining operations at Jabiru and Tiwi Islands. Nhulunbuy sites were considered in this study initially, but the results are not presented here due to the announcement made by Rio Tinto to cease operations in this region.

4.3. Environmental Considerations. Interestingly, these mine clusters also sit within particular climatic areas: tropical/coastal (McArthur River Mine), monsoonal (Ranger Mine), tropical/inland (Northern Territory Gold Mines), and arid/desert climates (Tanami Operations). Each of these is characterised by a particular set of atmospheric conditions such as DNI, average cloud cover, and susceptibility to severe weather including strong winds and flooding. In accordance with the data discussed in the previous section, preliminary analysis of feasibility of CSP installation can be conducted. The DNI maps provided in the previous section indicate that the average DNI in all regions is 2200–2800 kWh/m² which is sufficiently higher than that required for a CSP plant. Only the tropical coastal areas fall under the requirement for cyclone-proof structures; however, being sufficiently far from the coast (at least 70 km) the winds rarely exceed 20 km/hr, and therefore associated risks are relatively low. This region also has the highest rainfall; however, the existing infrastructure allows for uninterrupted operation of the mine in terms of road communication. Desert environment is on the other end of extremes, and the available water resources are extremely scarce. However, most of SCP installations exist in similar environments and utilise dry cooling as discussed in the previous section.

This preliminary evaluation suggests that four CSP plants could be constructed to cater for the needs of mining operations and local communities in each of the four areas identified above. However, a more thorough study will have to be conducted in order to investigate the details of each of these installations such as to provide an insight into the best suitable CSP technology and possible complications. This will form the scope for a future research where a simple algorithm will be developed for quick assessment of feasibility of CSP in each location.

5. Conclusion

The potential application of concentrated solar power for remote mine sites in the Northern Territory has been discussed. The following are the main conclusions.

- (i) NT mining sector represents the largest electricity consumer within the unregulated network as well as on a territory level and is among NT's biggest consumers of fossil fuels with significant GHG emissions.
- (ii) Renewable energy share in the NT electricity generation is still quite low at 0.65% with solar as the major contributor. As such, solar energy, which is abundant in the NT, can play an important role in reducing the reliance on fossil fuels in the mining sector.
- (iii) Based on the CSP's main feasibility parameters, the study recommended that CSP plant installation be considered at the regional cluster level rather than at individual mine sites.
- (iv) The following clusters have been identified for potential CSP plant installation: McArthur River Mine, Ranger Mine, Northern Territory Gold Mines, and Tanami Operations. The CPS plant installed at each

cluster should serve to provide power to the mining operation and the local communities.

- (v) A more thorough study will have to be conducted in order to investigate the details of each of these installations so as to provide an insight into the most suitable CSP technology and likely implications. This will form the scope for a future research.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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