Energy 68 (2014) 698–711

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Concentrating solar power/alternative fuel hybrid plants: Annual electricity potential and ideal areas in Australia

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ARTICLE INFO

Article history:
Received 28 October 2013
Received in revised form
13 January 2014
Accepted 18 February 2014
Available online 20 March 2014

Keywords:
Bioenergy
Concentrating solar power
Hybrid plants
Resource assessment
CO_2 abatement potential
Australia

ABSTRACT

Australia's extensive solar resource is underexploited especially in the CSP (concentrating solar power) arena because of the high investment and lack of stable investment incentives. CSP hybrid plants provide an option to improve returns from CSP installations because of lower specific investment. This paper investigates the generation potential and most prospective regions for 5–60 MWe CSP hybrids using forestry residues, bagasse, stubble, wood waste and refuse derived fuels in locations with a direct normal irradiance >18 MJ/m^2/day. Different plant efficiencies are used to identify the overall electricity potential for single and multiple feedstocks systems. The EfB (energy from biomass) or EfW (energy from waste) components of the hybrid plants considered are assumed to allow base load operation with the CSP components providing additional capacity during the day.

The total CSP-EfB & EfW hybrid potential in Australia, within 50 km of existing transmission and distribution infrastructure, is 7000 MWe which would require an investment of AU$ 39.5b to annually generate 33.5 TWh. This is equivalent to 12.8% of all electricity generated in 2008–2009 or 74% of Australia's 2020 renewable energy target. The CO_2 abatement potential of CSP-EfB & EfW hybrids is up to 27 Mt or 4.8% of all 2009–10 CO_2 emissions.

1. Introduction

Australia has one of the best solar resources in the world, however the historically low electricity prices compared with most other OECD (Organisation for Economic Co-operation and Development) countries has constrained the broader implementation of CSP (concentrating solar power) and other renewable energy plants. There are currently no standalone CSP plants in Australia and the two significant projects that were offered state/federal funding, being AU$ 464m for 250 MWe SolarDawn and AU$ 60m for 40 MWe SolarOasis projects, had their offers withdrawn in 2012 and 2013 as neither project was able to secure the remaining funding [1,2]. While solid biomass and waste feedstocks are available for power generation [3], few plants operate at commercial scale, total installed capacity of 170 MWe [4], and only one new 36 MWe industrial scale facility in Mackay, Queensland [5], commenced operation in the last four years.

The comparatively high cost of CSP and continuous/significant cost reductions of PV (photovoltaic) systems has in recent times put pressure on CSP. The decision to switch the first 500 MWe phase Blythe (USA) parabolic trough project to PV is the most prominent example of the competition with PV so far and it is likely that the second 500 MWe phase will be PV too [6]. In order to remain competitive, the CSP industry has to further demonstrate the grid value and other benefits of CSP arising from energy dispatchability as well as reduce plant costs. High renewable energy scenarios modelling in Australia identified CSP as a key technology to provide grid stability [7].

The hybridisation of CSP with forestry residues, bagasse, stubble, wood waste and RDF (refuse derived fuels) is one promising option to realise these two objectives and is endorsed globally [8] and in Australia [9]. Such hybridisation, not only with biomass or

Abbreviations: CSP, concentrating solar power; PV, photovoltaic; EfB, energy from biomass; EfW, energy from waste; DNI, direct normal irradiance; AU$, Australian dollar (AU$/US$ = 0.96).

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http://dx.doi.org/10.1016/j.energy.2014.02.068
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waste, can provide distributed renewable/low-emission dispatchable power, capacity factors of up to 91%, CSP uptake in DNI (direct normal irradiance) areas lower than the usual >20 MJ/m^2/day, and investment reductions up to 28% [10] through the joint use of equipment and avoidance of currently capital intensive thermal storage.

Currently, several CSP hybrid plants operate as solar add-ons to coal and gas plants worldwide. Compared to the deployment of standalone CSP plants around the world, Australia deployed only CSP hybrids. In particular, the 9.3 MWth CSP-coal at Liddell is in operation [11], the 44 MWe CSP-coal at Kogan Creek is under construction [12], and new hybrids under investigation are a 30 MWe CSP-natural gas hybrid at Collinsville [13] and 35.5 MWe CSP-biomass hybrid in Ipswich [14].

In contrast to fossil fuels, forestry residues, bagasse, stubble, and wood waste are renewable resources. Only the non-renewable RDF fraction is fossil derived but consists largely of non-recyclable materials that would otherwise go to landfill. Including avoided fugitive landfill gas emissions EfW and EfB systems can be a greenhouse gas negative form of power generation [15]. Late in 2012, the first commercial scale CSP-EfB hybrid plant, 22.5 MWe Termosolar Borges using parabolic trough technology, commenced operation near Barcelona, Spain [16], which is significantly higher latitude and therefore has a lower solar resource than all other CSP plants in Spain [17]. The Termosolar Borges plant is built in an agricultural area with a DNI of 18 MJ/m^2/day and is using forest and agricultural residues [18].

Similar or equivalent regions, in terms of combined biomass production and DNI >18 MJ/m^2/day, exist in Australia. Agriculture and forestry in Australia produce significant quantities of biomass and some of it could be used as feedstocks for electricity generation as well as biofuels [3,19,20]. Investigations show that due to Australia's high carbon intensity electricity mix significantly greater greenhouse gas mitigation can be realised by using biomass for electricity generation, 30 Mt CO_2 equivalent, rather than biofuels, 9 Mt CO_2 equivalent [3]. The high solar irradiation in many Australian agriculture/horticulture areas offers the unique possibility to use both energy sources in designated plants. Non-recyclable and renewable waste materials, such as RDF, can be used in CSP hybrid plants, would increase the overall feedstock potential, divert waste from landfill, and reduce fugitive landfill emissions.

Different studies used GIS (geospatial) modelling to identify suitable regions and sites for standalone CSP power plants [21–26] and CSP retrofits to existing fossil fuel plants [27] in Australia but the objective of this paper is to identify regions in Australia which may be suitable to site CSP-biomass hybrid plants with different power generation capacities. It provides a broad scale assessment of Australia's CSP-EfB & EfW hybrid potential and forms a basis for project developers and researcher to investigate specific sites within the most prospective regions identified. No such work has been undertaken to date in Australia, and the information is a critical pre-commercial step required to underpin future commercial feasibility assessments of CSP plant locations.

2. Methods

This assessment applies thermal analysis and GIS modelling to identify the electricity potential and the most prospective regions for CSP-EfB & EfW hybrid plants. The modelling includes specific technical, environmental and economic constraints as well as performance differences in regards to power plant feedstock and capacity.

2.1. GIS modelling

Globally geospatial/GIS modelling is widely used in the energy sector to identify the best sites and resources for new renewable and fossil power plants, including wind [28–30], biomass [31,32], standalone CSP [21–26,33,34] as well as CSP retrofits to existing fossil fuel plants [27,35]. Various proven software packages are available and for this paper the public domain software R (www.r-project.org) provided the capacity for the spatial biomass analysis and ArcMap (www.esri.com) enabled the map production. The daily average DNI (direct normal irradiance) for Australia was derived from 1995 to 2011 gridded hourly solar exposure data from the Bureau of Meteorology Australia [36]. Road and rail infrastructure stem from topology 250K data [37], and population estimates are based on the 2006 census data [38]. Biomass production and potential availability is based on a recent Australian assessment of biomass for bioenergy [3] and stubble [39,40], while RDF data derived from several publications [41–43] combined with population estimates. The CSP and biomass resource data/maps in Section 3 derive from the combination of this information.

Transmission lines were identified with information from Geoscience Australia [44], Australian Energy Market Operator Australia [45], the Energy in Australia 2011 report [46] and Western Power [47]. The exact GIS locations of transmission lines in Australia are not publicly available and therefore had to be approximated. This assessment considers transmission lines ≥66 kV as they can technically absorb the output of 5–60 MWe CSP hybrid plants. A 50 km buffer around transmission lines was included in the GIS model as this is a viable transport distance for biomass [3].

To identify plant capacities, annual generation, and investment shown in Section 3, local biomass quantities were combined with the power plant modelling results (Tables 1–4), considering environmental, technical and economic constraints (2.3). Multiplying the locally available feedstocks with conversion efficiencies, capacity factors and costs lead to final investment requirements, e.g.

- stubble availability in a particular area of 42,500 t/a * conversion efficiency of 0.94 MWhe/t (Table 4) = 40,000 MWhe/a biomass generation
- 40,000 MWhe/a/8000 h biomass capacity factor (constraint in 2.3) = 5 MWe biomass capacity
- biomass capacity equals CSP capacity = 10 MWe hybrid plant capacity
- 1577 h/a CSP capacity factor (constraint in 2.3) * 5 MWe CSP capacity = 7885 MWhe/a CSP generation
- 7885 MWhe/a CSP + 40,000 MWhe/a biomass = 47,885 MWhe/a total generation, and
- 10 MWe hybrid capacity * AU$ 7.2m/MWe (Table 1) = AU$ 72m investment.

The Australia wide potential for CSP-biomass hybrids is identified by combining all areas that met the constraints. Additionally,

Table 1
Specific investment data for different CSP hybrid plants sizes in AU$m/MWe for the >21–24 MJ/m^2/day DNI category.

Feedstock	10 MWe	20 MWe	30 MWe	40 MWe	50 MWe	60 MWe
Forestry residues + CSP	7.0	5.6	4.8	4.4	4.3	4.2
Bagasse + CSP	7.1	5.7	4.9	4.5	4.4	4.3
Urban wood waste + CSP	7.5	6.0	5.2	4.7	4.6	4.5
Refuse Derived Fuels + CSP	7.6	6.1	5.3	4.8	4.7	4.6
Stubble + CSP	7.2	5.8	5.0	4.4	4.4	4.3