Solar-biomass synergies: A story on how hybrid concentrated solar biomass plants can support Australia's energy transition

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Solar-biomass synergies

A story on how hybrid concentrated solar biomass plants can support Australia’s energy transition.

‘Australia, the renewable energy superstar’ was the title of a research report that caused a sensation and sparked discussions in 2019 [1]. The report's authors claim that Australia is installing renewable energy faster than other countries and is therefore on track to meet its climate targets five years early. Unfortunately, as pointed out by several published responses to the report (e.g., [2]), this is not true. Despite the recent growth of variable renewable energy (VRE) technologies such as solar PV and wind power plants, only 6.2% of the total energy generation in 2017/18 in Australia was derived from renewable resources [3]. The pressure to act is growing as the direct effects of climate change, including droughts, crop failures and extreme bush fires, have hit the country particularly hard in the past few years. As discussed in the most recent IPCC report [4], these events are probably only harbingers of future disasters caused by climate change.

> *“For an orderly and successful energy transition several challenges need to be overcome.”*

For an orderly and successful energy transition, not just in Australia, but around the world, several challenges need to be overcome. *How can the electricity market guarantee continuous energy generation, even in times of diminished solar and wind resources?* Figure 1 (a) shows the Australian half-hourly electricity prices , which follow a ‘duck curve’, illustrating the imbalance between energy demand (before sun rise and after sun set) and VRE generation.

Another question is: *How can renewable energy be provided to industrial processes (including the harder-to-abate sector)?* Australia has a high demand for heat, electricity and fuels. The sectorial demand is shown for NSW, Australia’s most populated state in Figure 1 (b). Where electrification and energy efficiency improvements come to their limits, industries and commercial buildings need to be able to deploy efficient and mature renewable technologies for all types of energy.

> *“.. industries need to be able to deploy efficient and mature renewable technologies.”*

Solar and biomass synergies

One technology that can address these challenges , is hybrid concentrated solar biomass (HCSB) plants, shown in Figure 2. HCSB plants combine concentrated solar power (CSP), a technology that concentrates and captures thermal energy from the sun, with bio-energy [5]–[7]. Energy generation is from two independent resources and the integration of up to two different storage systems [thermal energy

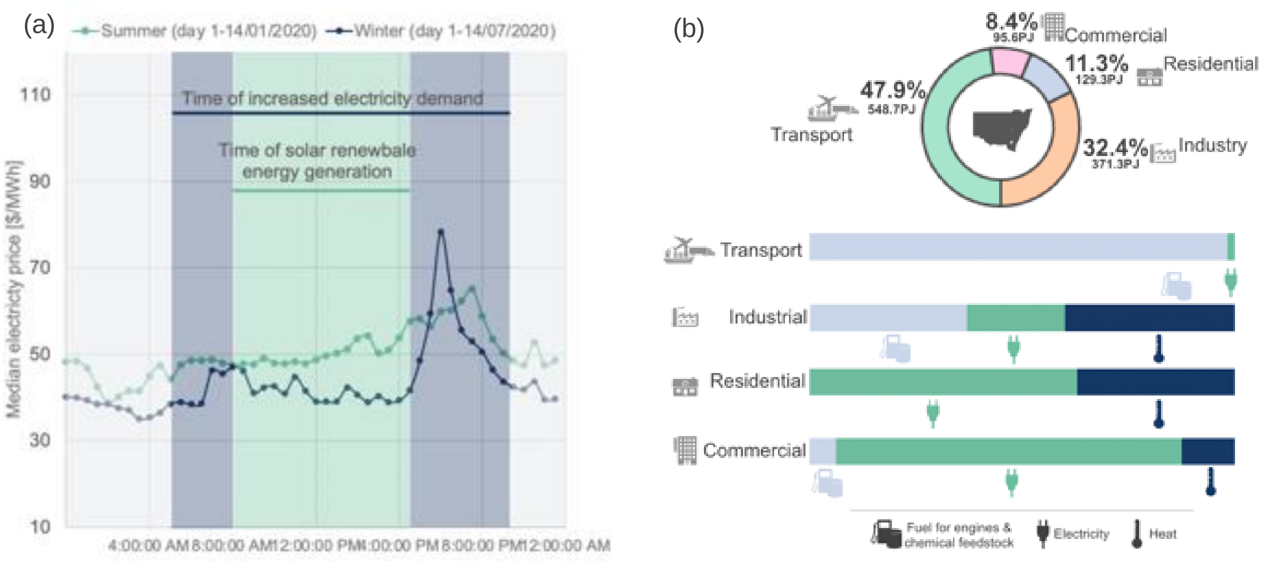

Figure 1: New South Wales, Australia: Half-hourly summer and winter electricity prices [$/MWh] (a) & sectorial energy demand (b).

storage (TES) and physical biomass storage] allows for dispatchable renewable energy generation. HCSB plants can thereby continuously generate electricity, even after sunset. The technology encompasses a wide range of technical options, designed for electricity generation [8]–[10], industrial process heat [11], [12] or fuel production [13], [14]. By offering different energy outputs, HCSB plants can be easily integrated with diverse industries.

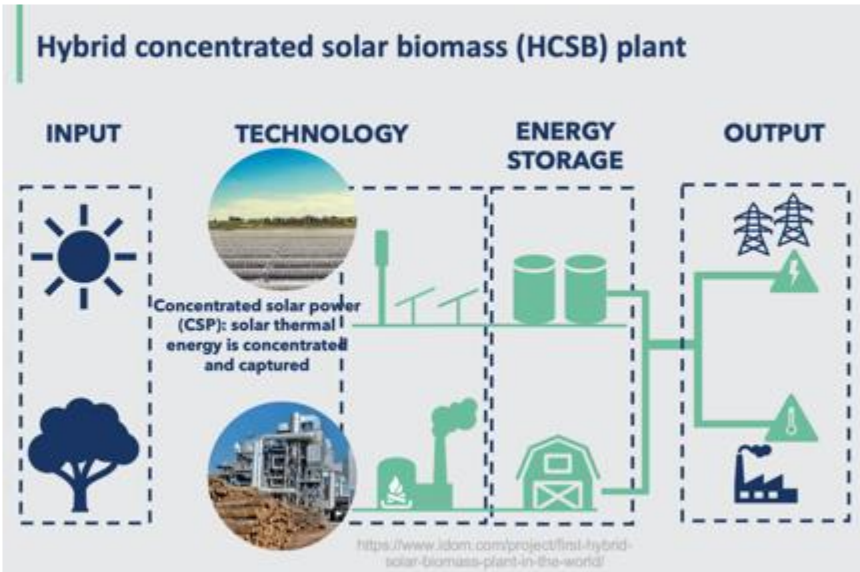

Figure 2: Graphical illustration of hybrid concentrated solar biomass (HCSB) plants.

"HCSB plants allow dispatchable renewable energy generation and can easily be integrated into industries [, however they are] a novel technology in the context of Australia."

As a novel technology only few HCSB plants are operating worldwide, e.g. the 22.5 MW_e Termosolar Borges plant in Leida, Spain [15] and the 16.6 MW_{th} Aalborg CSP plant in Brøderslev, Denmark [16]. In Australia HCSB is yet to be demonstrated, and the deployment potential and benefits will be discussed in the following Section.

Resources assessment for HCSB plant deployment

To understand the siting potential of any renewable energy technology it is important to assess the availability of the resources. For HCSB plants these are solar and biomass resources.

It is common knowledge that Australia has one of the best solar resources in the world (see Figure 3 (a)) – but what about biomass resources? Previous biomass resource mapping has focussed on a specific region or narrow selection of biomass types. The Australian Government recognised this knowledge gap and has concluded that it may be one reason why Australia is lagging behind other jurisdictions in supporting the development of a bioenergy industry [14]. In other OECD countries, bioenergy and energy-from-waste are contributing around 2.4% of electricity output, compared to only 1.4% in Australia [14].

"..Australia has three main biomass resources types: bagasse, stubble, and forestry residues."

The Australian Biomass for Bioenergy Assessment (ABBA) project, which provides reliable information on biomass feedstocks and bioenergy projects across Australia between 2015 – 2021 is the most up to date and detailed biomass assessment. Beside municipal solid waste (MSW) and sewage, Australia has three main biomass resource types: bagasse, a residue after sugar cane extraction, straw, after cereal crop harvest and forestry residues (e.g., from sawmills). The spatial resolution of the ABBA data remains low and in order to make assumptions about bio-energy (and HCSB plant) deployment potential, it is essential to increase the spatial resolution.

One option to increase the spatial resolution of low-resolution biomass resources maps is combining them with land-use data at a higher spatial resolution. For the Australian continent this can be achieved for a spatial resolution of 5 x 5 km. Figure 3 (b) shows the resource map for stubble.

From these high-resolution solar and biomass resource maps the siting potential at specific sites (e.g., close to a local industry or grid integration points) can be identified. Following previous studies, the minimum direct normal irradiation (DNI) threshold for HCSB plant deployment is assumed to be >1,800 kWh/m^2/year. The requirements for biomass feedstock depends on numerous factors, including maximum feedstock transport distance, and scale of operation.

NSW's potential for grid integrated HCSB plants

In order to reduce the pressure on the Australian electricity grid during the evening hours, HCSB plants can be integrated into the grid to produce dispatchable renewable energy.

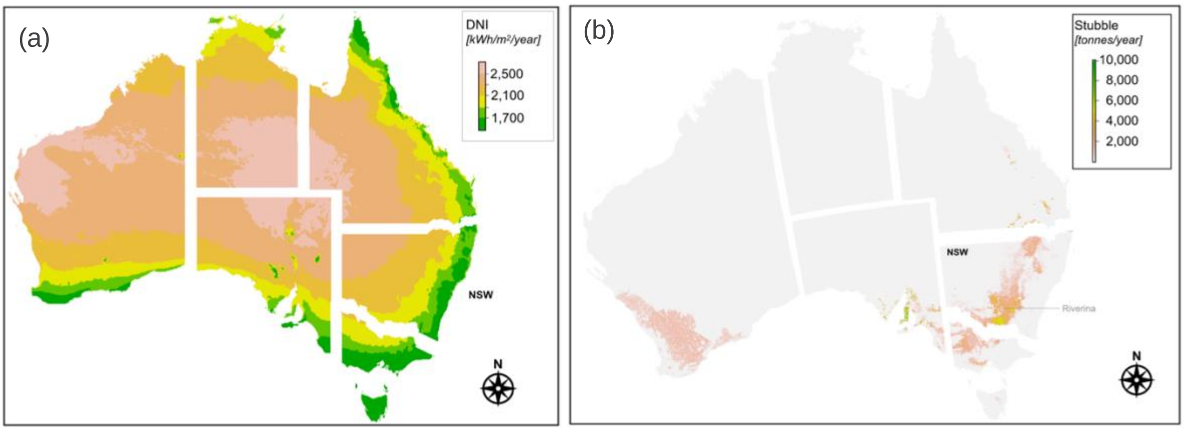

Figure 3: DNI [kWh/m^2/year] (left) and stubble resources [tonnes/year] (right) in all states of Australia.

Substations with new connection capacity are the cheapest and most practical option for integration. Based on the maximum new connection capacity at substations and the maximal transport distance of 50 and 100 km (to maintain sustainability) it is possible to obtain biomass volumes for each of the substation sites. By adding the consideration of a the minimum DNI threshold of >1,800 kWh/m2/year, the deployment potential of HCSB plants can be determined.

> *"The total installed capacity at these suitable grid connection locations was calculated to be 874 MW$_e$. "*

Figure 4 shows the substations that can be used for HCSB deployment in NSW. The study found that 138 substations in NSW were suitable for the connection of HCSB plants. The total installed capacity at these suitable grid connection locations was calculated to be 874 MW$_e$. The costs for this installed capacity was estimated to be about AU$ 6.3 billion. Carbon emission abatement potential was estimated to be about 6 billion kg of CO_{2-e} per year, this is equivalent to 3.7 % of NSW's greenhouse gas emissions (considering power generation in 2019).

Comparing bagasse, stubble and forestry waste residues - cereal and non-cereal straw have the best spatial overlay with solar resources and network opportunities, making up the predominant feedstock for potential HCSB plants (Figure 4). HCSB plants in NSW could use around 200,000 tonnes of bagasse, 5.2 million tonnes of stubble or 1.3 million tonnes of forestry residues per year.

Local benefits of standalone HCSB plants

The Riverina-Murray is in the central-southern part of NSW and is one of the largest agricultural regions of Australia [17]. Agricultural industries are producing large amounts of residues and waste materials which are currently barely utilized for waste-to-energy. Also, current management practices involve on-field burning of cropping wastes (e.g. stubble), with adverse impacts for the local communities and the environment (Figure 5).

An alternative to on-field burning could be selling the agricultural waste residues to a local electricity generation plant. Selling cropping residues to a local bio-energy facility is an option for income diversification for local farmers, especially attractive in years of crop failure and/or drought. A case study evaluated HCSB plant grid integration at substations with new connection capacity in the Riverina-Murray region. The plant could make use of rice-straw residues as feedstock and also exploit the excellent solar resources (DNI, 1,900 – 2,150 kWh/m2/year).

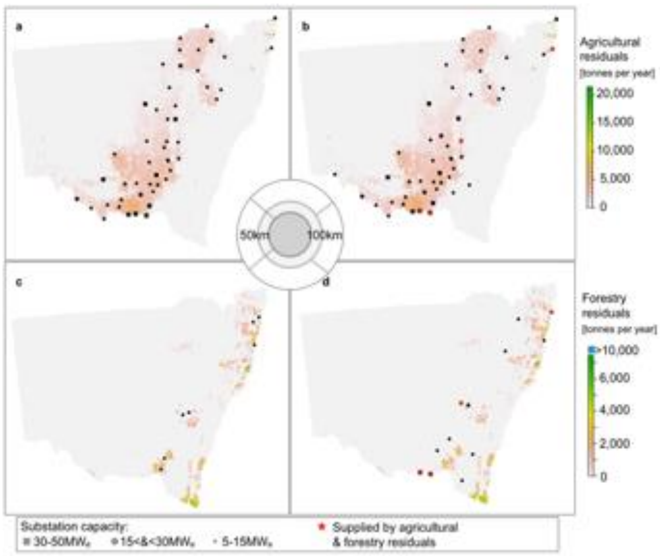

Figure 4: Residual agricultural (a and b) and forestry (c and d) biomass resources [tonnes/year] in NSW and locations of substations for HCSB plant

Figure 5: On-field burning of agricultural wastes on the East coast of Australia; photos taken by author in 2019.

Annual straw yields are highly impacted by seasonal variation as well as extreme weather events, e.g., during drought the stubble amounts decrease dramatically. HCSB plants have a reduced resource supply risk, because biomass feedstock is offset with solar energy. This also reduces the overall biomass feedstock transport need and associated emissions. For the local community this means fewer truck movements that is an important consideration for the Riverina-Murray that is the top producer of agricultural goods in Australia with associated heavy traffic movement.

Compared to stand-alone CSP plants, HCSB plants have a smaller solar field and reduced need for thermal energy storages (TES), with significant economic benefits. For the same annual power generation (e.g. 220,000 MWh/year) the investment costs for HCSB plants (AU$ 167 – 230 million) are 24 – 45% lower than for standalone CSP plants (AU$ 303 million). The solar field for the above described standalone CSP plant requires about 320 ha of land (75 % more than the HCSB plant). At this size, and despite excellent solar resource, the Riverina-Murray would likely be unsuitable for siting a standalone CSP plant because the land is so valuable for agriculture. Power purchase agreements (PPA) for VRE are typically fixed at AU$ 50 – 80 /MWh in NSW. This price is significantly lower than required prices for HCSB plants, ranging between AU$ 120 – 350/ MWh (depending on feedstock prices and scale).

> *"HCSB plants have a reduced resource supply risk, because biomass feedstock is offset with solar energy."*

Considering the important role of dispatchable renewable energy in supporting the energy transition, the relatively high cost of HCSB plants (compared to VRE) highlights a need for policy incentives that recognise the value of dispatchable renewable generation and encourage deployment. As the need for dispatchable electricity in the NEM increases, it can be expected that the additional value will justify the additional costs of dispatchable energy. PV with battery or pumped hydro requires PPAs between AU$ 50–100/MWh. At these costs HCSB plants become a cost-competitive technology.

HCSB plants for industrial co-generation

As shown in Figure 1 (b), NSW has a large demand for industrial process heat. One of the industries with heat demand are abattoirs (e.g., for sterilization and rendering). Australia is the third biggest meat exporter globally and 22 % of meat is produced within NSW. HCSB plants have been investigated as renewable energy option for abattoirs in NSW.

Similar to the application for grid integrated electricity generation, HCSB plants for industry integration can be designed to optimise thermal efficiency, technical maturity, land footprint and/or cost. Recognising these trade-offs, there is a long list of technical options for integrating HCSB plants with abattoirs for the supply of combined heat and power (CHP) plant design needs to be tailored on a case-by-case basis. Traditionally, abattoirs deploy a diverse mix of energy resources, including coal, gas, solid biomass or biogas (derived from anaerobic digestion).

A case study shows one possible option of HCSB plant integration into an abattoir in the Northern part of NSW. The abattoir is already deploying a small biomass boiler (Figure 6 (a)), which for the purpose of the case study is hybridized with a

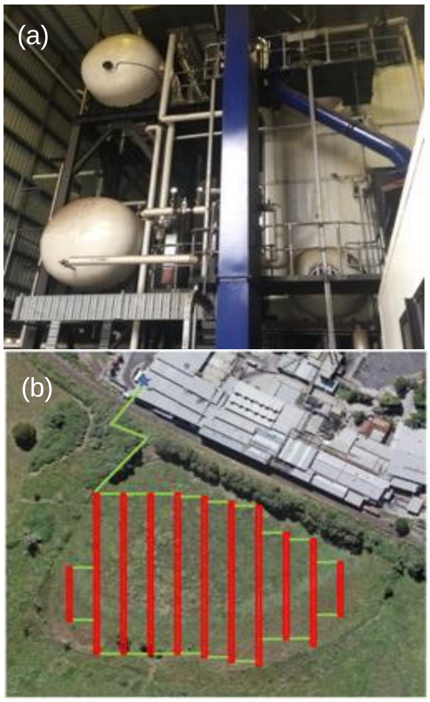

Figure 6: Photo of existing biomass boiler (left) and one potential design of a CSP field (right); photos taken by author in 2021.

CSP field (Figure 6 (b)). The HCSB plant integration allows for 100% renewable energy supply, by not only accounting for the heat demand, but also producing additional electricity that can be exported.

Conclusions

The following table summarises the significance of the results:

Maturity	While lots of attention is going into the development of new dispatchable renewable solutions (e.g., hydrogen or batteries), there are **mature, dispatchable, ready-to-deploy and economic technologies, like HCSB plants**, that could be integrated (not only into the grid but also for hard-to-abate industries).
Technical design	The research discusses different HCSB plant design options and gives detailed insights into technical design elements for maximising thermal **energy efficiency.**
Technology potential	Although the focus is on a specific case study region (NSW), we present a methodology that can be applied to other regions (including Europe) to **investigate siting potential – with consideration of available resources, grid and industry integration** – of HCSB plants.
Local benefits	The research gives examples on how HCSB plants can effectivly be deployed to use **local waste materials** to generate electricity with direct benefits to the local communities and the environment. Specifically, reduced truck movements, income diversification and new local employment opportunities.

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