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Techno-economic assessment of an industrial prosumer with biomass investment and time varying tariffs: An Australian case study[☆]

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ABSTRACT

This paper investigates the potential for a value chain framework to deliver impact through innovation across the timber manufacturing process. A new and efficient combustion technology that converts timber waste to energy is considered for this study. The framework to estimate the new energy costs and savings derived from the new technology, compared with current supply and demand scenarios, as well as the value generated by waste streams. The opportunity of selling excess energy to the grid or local area has been investigated. Two alternatives of time-varying tariffs and time-varying tariffs with biomass, are used for assessing the costs. According to the numerical results, tariff 3, with 25,000 tonnes of biomass feedstock per year, is the best option for the mill. The price efficiency index is reduced by approximately 40% compared to this option's usual business. In addition, the investor can save the whole energy bill compared to the current business as usual. The investor could make a profit of $460,401 per year by selling energy to the grid. The annual saving is around six times higher than the savings gained using a time-varying tariff alone. However, this option requires $1,811,635 as annual life cycle cost, with a payback period of ten years. The lowest levelised cost of energy of 0.14 c/kWh is also obtained for this option.

1. Introduction

Australia has made modest progress in biomass to its energy mix. With the increase in the push towards a more renewable and cleaner energy mix, various local institutions have looked into biomass prospects. According to the Clean Energy Council, the long-term potential of biomass contribution in the electrical energy mix could be up to 73,000 GWh/year. In addition, the Australian business round table on climate change has stated in the affirmative that the share of biomass in Australia's total electricity pie would be around 30% by 2050 (Stucley, 2010). Recent trends, however, do not affirm the previously predicted scale of uptake. In Khorshidi et al. (2013), the Australian government introduced renewable energy certificates, which aimed to reduce the costs of biomass by co-firing with coal. However, the initiative was less successful than the expectation. The uptake of biomass systems strongly depends on the economics and profitability of the technology. Biomass technology costs are still high compared to solar PV and wind. Various techno-feasibility studies can be conducted to understand the economics of deploying biomass into the energy mix at various industrial, governmental and commercial entities in Australia. Several commercial and industrial consumers are considering biomass technologies for reducing waste and emissions and making profits by selling energy to the grid. However, very few studies have considered the by-product of the forest product industry and the utilisation of solid fuel biomass generator (Herr and Dunlop, 2011).

Biomass generators, particularly those utilising biomass byproducts from industries like timber processing, offer significant environmental benefits. By converting biomass waste into energy, these systems reduce the need for fossil fuels, thereby lowering greenhouse gas emissions. Additionally, they help in waste management by utilising byproducts that would otherwise be disposed of, reducing landfill use and associated methane emissions (Padi et al., 2022). However, it is essential to consider potential challenges, such as the emissions from biomass combustion, which, although generally lower than fossil fuels, still require careful management. Furthermore, the lifecycle environmental impact, including aspects like resource use and emissions during production and operation, should be assessed to ensure that biomass systems contribute positively to sustainability goals (Salas et al., 2024).

[☆] This paper has been developed based on the tool that has been published in SoftwareX (Ibrahim et al., 2024).

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Nomenclature

Abbreviations

AEMC	Australian energy market commission
AEMO	Australian energy market operator
ALCC	Annual life-cycle cost
AMI	Advanced metering instrument
BAU	Business-as-usual
CHP	Combined heat and power
DBSCAN	Density-based spatial clustering of applications with noise
DNSPs	Distribution network service providers
EDA	Exploratory data analysis
ESM	Essential services commission
FiT	Feed-in tariff
HOMER	Hybrid optimization of multiple energy resources
HV	High-voltage
LV	Low-voltage
LCOE	Levelised cost of energy
LERT	Large-scale renewable energy targe
NIFPI	National institute for forestry products innovation
NMI	National meter identifier
NPV	Net present value
NREL	National renewable energy laboratory
PEI	Price efficiency index
SAM	System advisory model
SRES	Small-scale renewable energy scheme
TOU	Time of use
VEET	Victorian energy efficient target

Symbols

A	Annual uniform series
A_k^{Cap}	Annual uniform series of the capital investment unit cost for equipment k
A_k^F	Annual uniform series of any future value for equipment k
$A_k^{O\&M}$	Annual uniform series of the replacement cost for equipment k
A_k^{Rep}	Annual uniform series of operations and maintenance costs for equipment k
A_k^S	Annual uniform series of the salvage value for equipment k
d	General discount rate
η_e	Biomass generator combined electrical efficiency
FV	Future value
G_F	Syngas fuel consumption of the biomass gasifier
j	General inflation adjusted discount rate
Q_H	Lowest heating power of the fuel
PV	Present value
f	General inflation rate

Units

c	Cents
GWh	Gigawatt-hour
kVA	Kilovolt–ampere
kVar	Kilovolt–ampere reactive
kV	Kilovolt
kW	kilowatt
kWh	Kilowatt-hour
V	Volt
W	Watt

Biomass projects, particularly in regional areas, can have substantial social impacts that are essential to consider alongside economic metrics. These projects often contribute to local job creation, both directly through the operation and maintenance of the facilities and indirectly through supporting industries (Shahbazi and Rahimpour, 2024). Moreover, the successful implementation of biomass projects can enhance community acceptance and foster a sense of ownership, particularly when local resources, such as biomass byproducts, are utilised. This can also strengthen the social license to operate, as communities may be more supportive of projects that align with their values and contribute to local development (Jahanshahi et al., 2023).

The successful adoption and expansion of biomass projects are significantly influenced by the policy frameworks in place. Supportive regulations and incentives can play a pivotal role in promoting biomass investments, particularly in industries like timber processing that produce considerable biomass byproducts (Daneshmandi et al., 2022). Policies such as feed-in tariffs, renewable energy certificates, and tax incentives can make biomass projects more financially viable by reducing upfront costs and providing ongoing revenue streams. Additionally, government mandates or targets for renewable energy adoption can create a market demand that encourages investment in biomass. However, it is equally important for policymakers to address potential barriers, such as regulatory complexities or the need for infrastructure development, which can hinder project implementation (Wu and Pfenninger, 2023).

1.1. Literature survey

In light of the current work, the concern is the techno-economic feasibility studies of implementing solid fuel biomass energy systems in the forest product industry (i.e., timber mill) and assessing the impact of the various tariff structures on the overall system operation. Therefore, the authors have conducted a comprehensive survey of literature summarising the existing feasibility studies in various industries, the type of technology utilised the economic parameters, and the geographical locations of the studies. The summary of the literature survey is given in Table 1.

A number of feasibility studies have been conducted regarding alternative energy sources. In Middelhoff et al. (2022), the energy demand of a local Australian beef abattoir in New South Wales was determined. A feasibility study was presented using solar thermal technology to meet the energy requirements. Biomass generation has been combined with solar PV (Huang et al., 2013; Borello et al., 2013). The biomass load generation was combined with solar to reduce the generation cost. At the same time, dispatchable biomass could reduce the intermittency issues of solar power. In Huang et al. (2013), Bakos et al. (2008) and Williams and McMullan (1996), biomass is the only energy source. The main focus of these works was enhancing the thermal efficiency issue of biomass rather than the value stack. Most of the studies have been conducted for commercial consumers.

Modelling for such techno-economic analyses requires the use of competent tools. Hybrid optimisation of multiple energy resources (HOMER) is the widely used tool for techno-economic analysis developed by the National Renewable Energy Laboratory (NREL). HOMER is

Table 1
Literature review on the feasibility of alternate energy technologies.

Technology	Location	Focus	Economic parameters	References
Solar thermal	Australia	Beef abattoir	LCOE	Middelhoff et al. (2022)
Biomass	Europe	Buildings	LCOE	Huang et al. (2013)
Biomass & solar PV	Brazil	Town	LCOE	Soria et al. (2015)
Biomass & solar pv	Generic	Hotel	N/A	Borello et al. (2013)
Biomass & solar thermal	Generic	Community	LCOE and NPV	Khalid et al. (2017)
Biomass	Greece	Farm	Discounted cash flow	Bakos et al. (2008)
Biomass	UK	Generic	N/A	Williams and McMullan (1996)

widely used to simulate any microgrid scenario with various renewable energy sources. It optimises the costs of initiating and building power systems based on economic factors such as the net present value (NPV) and the levelised cost of energy (LCOE). In Suresh et al. (2020), an off-grid hybrid energy microgrid has been studied. The optimal size has been determined for three rural villages in India using LCOE and NPV. Moreover, Anssari et al. (2020) proposes a techno-economic feasibility study of a microgrid to mitigate the power shortage problems in Iraq. The use of waste for electricity generation was considered for this study concerning LCOE and NPV.

The study presented in Behzadi et al. (2023) explores a hybrid system that incorporates biomass generation for buildings. To achieve this, the study developed an intelligent energy management system that takes into account thermal comfort, energy price, weather data, and energy usage. Biomass generation and other renewable energy sources were considered for a rural electrification project, as presented in Kumar et al. (2023) and Tehrani et al. (2023). The focus of this study was on the techno-socioeconomic aspect. Grey wolf optimisation was used to investigate the feasibility of electrifying a remote hilly community using PV/biomass-based systems (Saha et al., 2023). However, the load considered for this study is relatively small compared to the large industrial consumers and lacks a sophisticated tariff structure. It would be worth noting that the LCOE, payback period and NPV are the most used economic indices in techno-economic studies. In addition, the annual life-cycle cost (ALCC) has been used due to the robustness of the index in economic modelling. The ALCC is a composition of all the relevant equipment costs required for sound techno-economic analysis. Moreover, it provides flexibility for selecting parameters associated with every equipment cost.

Several studies have been conducted on biomass generation, focusing on various aspects such as environmental impact, life cycle assessment, syngas and natural gas mixing (Bui et al., 2023; Ghiami et al., 2021). However, most of these studies in the literature have only looked at the economic impact of these technologies rather than their overall energy management in commercial or industrial consumers (Bui et al., 2023; Ghiami et al., 2021).

1.2. Research gaps and contributions

The prior literature survey shows extensive work on biomass as an alternative energy source for various load centres. However, most of these works overlooked the industry that produces significant biomass as a byproduct (i.e., sawmills and timber mills). These industries tend to have massive biomass production and are generally treated as waste (sell as firewood with lower price). Various studies have explored the potential of using pyrolysis and gasification to produce bio-oil, biogas or bio-char from materials like rice husk, microalgae, orange and date seeds (Naveen et al., 2023). These studies have also indicated that pinewood can be used to generate bio-oil (Naveen et al., 2023). However, none of these works have examined the possibility of directly using the byproducts from timber mills for electricity production. In contrast, the research conducted in Filho et al. (2021) evaluates various biomass electricity generation technologies based on technology readiness level criteria. This study primarily focuses on steam radial turbines, Piston steam engines, and conventional Rankine Cycle. However, it fails to consider the potential of solid-fuel biomass generators. The potential for such byproducts to contribute to the energy mix is enormous, and the options to tap into the resource need to be explored. Furthermore, studies have been done by researchers in various geographical locations. However, only a few studies have been done in the Australian and Victorian contexts. As reported in Herr and Dunlop (2011), the biofuels available in the country can replace up to 140% of the total traditional fuels in commercial and industrial sectors. This includes power generation from fossil fuels. An investigation is yet to be made on the potential value stack of supplying the electricity from biomass to the grid and the profits that can be made considering the time-varying tariff structures. The research gaps can be summarised below:

- There is no significant research work done on the potential of implementing biomass power plants as a local energy generation source in industrial customers with high biomass outputs.
- There are no studies on the potential economic benefits of exporting electricity from biomass to the grid using time-varying tariffs.
- The potential of implementing such projects in Australia, particularly in Victoria, has not been explored.

This study focused on a typical timber mill in regional Australia to address the gaps mentioned earlier. The study analysed and mapped the energy consumption costs and current price patterns to recommend new supply options. The first step was to assess the new HV tariffs as an alternative to existing ones (Tariff 1, Tariff 2, and Tariff 3). Next, these tariff scenarios were combined with local generation to assess their value stack.

1.3. Organisation

The rest of this paper is organised as follows: Section 2 presents the different models used for this study, such as the energy demand model, tariff structure model, biomass model and economic models. Section 3 presents the methodology of the proposed techno-economic assessment. Section 4 demonstrates how such an approach can be applied to an Australian context for any generic biomass-producing industry, particularly regional Australia. Then, the results from the case study have been illustrated in Section 5. Finally, Section 6 gives the conclusions and main findings.

2. Modelling overview

The techno-economic assessment requires a mix of technical and economic models and well-defined criteria. The models of load profile, tariff structure, biomass plant, and economic criteria are described in this section.

2.1. Energy demand

Energy demand modelling is crucial to analyse and map the energy profile of the prosumers to understand the business-as-usual energy patterns and assess the reliability and economic viability of the investment option. This model requires a high resolution of energy demand data (i.e., hourly, half-hourly, 15-minute) (Meng et al., 2018; Elliston et al., 2013). The actual demand and peak load data can be acquired via an advanced metering instrument (AMI). The energy demand data at the customer level mostly lack consistent data patterns. An exploratory data analysis (EDA) approach is required to ensure the data set is ready for use in the techno-economic assessment. In addition, the actual measured data mostly have outlier points, which may affect the analysis results. Therefore, a proper clustering method is required to clean the data from the outlier points. In this paper, the energy demand data are cleaned and pre-proceeded using density-based spatial clustering of applications with noise (DBSCAN) method (Kong et al., 2019). The DBSCAN is employed to detect outlier points and check the load's consistency.

2.2. Tariff structure models

Tariffs are premium prices that a utility provider charges retailers (i.e., entities that buy energy from the grid and supply consumers). The tariff contains several patterns to cover the costs of energy generated, the use of the network, and the distribution of the energy to the presumes. These costs also account for the jurisdictional costs imposed by the territory. These tariffs can be broadly classified based on voltage level i.e., high-voltage (HV) and low-voltage (LV) tariff for large and small residential, industrial and commercial customers. In more concrete terms, the Australian and Victorian tariff structure can be defined as follows (Wang et al., 2020; Young et al., 2019):

- Energy charges ($/Day): These are the charges which contain the pool-pass-through charges imported into the site, along with the service and admin charges. The pass-through pool charges could be a constant value defined by the retailers. This is also called a flat rate tariff. It is defined as the constant price that allows a consumer to use electricity up to a certain amount. It is charged based on power consumed rather than the energy consumed by the consumer (Young et al., 2019; Elliston et al., 2013). The charged values could be varied based on the spot market price. In addition, it contains the service and admin charge ($/Day). These charges are primarily constant charges during the year.
- Network charges: The Australian Energy Market Commission (AEMC) updates these charges once every six months. Network charges contain several charges, including standing charge ($/yr), time-of-use (TOU) charges (i.e., peak, off-peak and shoulder) (c/kWh), demand critical peak charges and demand capacity charges. The standing charge is a fixed yearly fee, while TOU demands critical peak charges and demand capacity charges. The TOU can be considered a broad range of payment structures based on different time windows. The ToU encourages consumers to use electricity when it is more economical based on the demand and supply of the energy in the network (Young et al., 2019; Elliston et al., 2013). Apart from that, the operator and market regulator may have certain charging parameters based on factors such as the TOU of energy, connection point voltage, and environmental factors. These charges can be defined in detail as follows:
    - Demand charges ($/kW/month): The energy demand at any time (for instance, peak times and off-peak times or summer and winter months).
    - Capacity charges ($/kVA/year): These charges are related to the HV and sub-transmission cables ratings at the point of customer connection to the grid.
    - Critical peak demand charges ($/kVA/year): This demand charge is based on the average of the customer's highest active power recorded on the five nominated peak demand weekdays during the defined critical peak demand period.
- Market charges ($/month): These charges contain several environmental factors (e.g., Victorian energy efficient target (VEET) charge, small-scale renewable energy scheme (SRES) charge, large-scale renewable energy target (LRET) charge, Australian energy market operator (AEMO) pool charge (GST exempt), and ancillary services).
- Other charges ($/year): These charges relate to the metering charges and the current transformer testing levy charge. They are usually fixed and defined ahead of time.

2.2.1. Feed-in tariff

The feed-in tariff (FiT) scheme represents the energy price that a local energy source can acquire by feeding any excess of its generated electrical energy into the grid. In the Australian and Victorian context (Victoria State Government, 2022), the energy retailers should provide potential FiT customers at least the minimum rates to export electricity to the grid as dictated by the independent regulator, the Essential Services Commission (ESC). The FiT for a large-scale renewable resource can be calculated based on the ESC (Essential Services Commission, 2022) as:

$$FiT = Spot\ market\ price\ (\mathrm{c/kWh}) \cdot Exported\ generation\ (\mathrm{kWh}), \tag{1}$$

In (1), the $Spot\ market\ price$ stands for the energy price in c/kWh based on the energy market signal, and $Exported\ generation$ represents the amount of the energy exported from the renewable energy resources into the grid in kWh.

2.3. Biomass generator model

A model reflecting all the distinct characteristics of a biomass generation for techno-economic study. The generic mathematical model of a biomass power plant can be stated as (Mednikov et al., 2018):

$$Power\ output = Q_H \cdot G_F \cdot \eta_e, \tag{2}$$

In (2), Q_H is the lowest heating power of the fuel, G_F is the syngas fuel consumption of the biomass gasifier, and η_e is the combined electrical efficiency.

The generic biomass profiling model has been developed in stages and can be presented as shown in Fig. 1. Two different analytical tools are considered to validate the output profiles. The generic model has been developed in stages, which can be explained as follows:

- **Stage 1. Data Input:** This is the first stage of modelling a biomass system. It involves inputting data such as ambient weather conditions, biomass feedstock properties, system parameters, biomass financial parameters, and project financial assumptions required for both the main and secondary software models.
- **Stage 2. Scenarios Generation:** In the second stage, various scenarios are generated for simulation in HOMER and the secondary software model, based on the specific input data and parameters. These scenarios are used to analyse the load data time series for both models.
- **Stage 3. Validation:** The third stage involves validating the results obtained from the simulation models by comparing outputs from the main and secondary software models. This includes analysing power generation time series to identify any discrepancies or abnormalities. If no significant differences are found, the results are considered validated.
- **Stage 4. Final Output Data:** Once validation is completed without discrepancies, the final time series output profiles for all scenarios are generated using the main software model. These profiles are then available for further analysis.

A biomass generation system was initially modelled using HOMER Pro to generate different scenarios for comprehensive studies under different tariffs. The load characteristics are the first parameters to model any system on HOMER Pro. Accurate load demand data are obtained from six NMIs from the consumer, and the hourly resolution has been considered to determine the overall annual load demand characteristics. The gasification ratio of 1.24 and the lower heating value of biomass of 13.49 MJ/kg are used for the modelling. Furthermore, it is considered that the fuel contains 44% carbon (Peter Lock and Whittle,

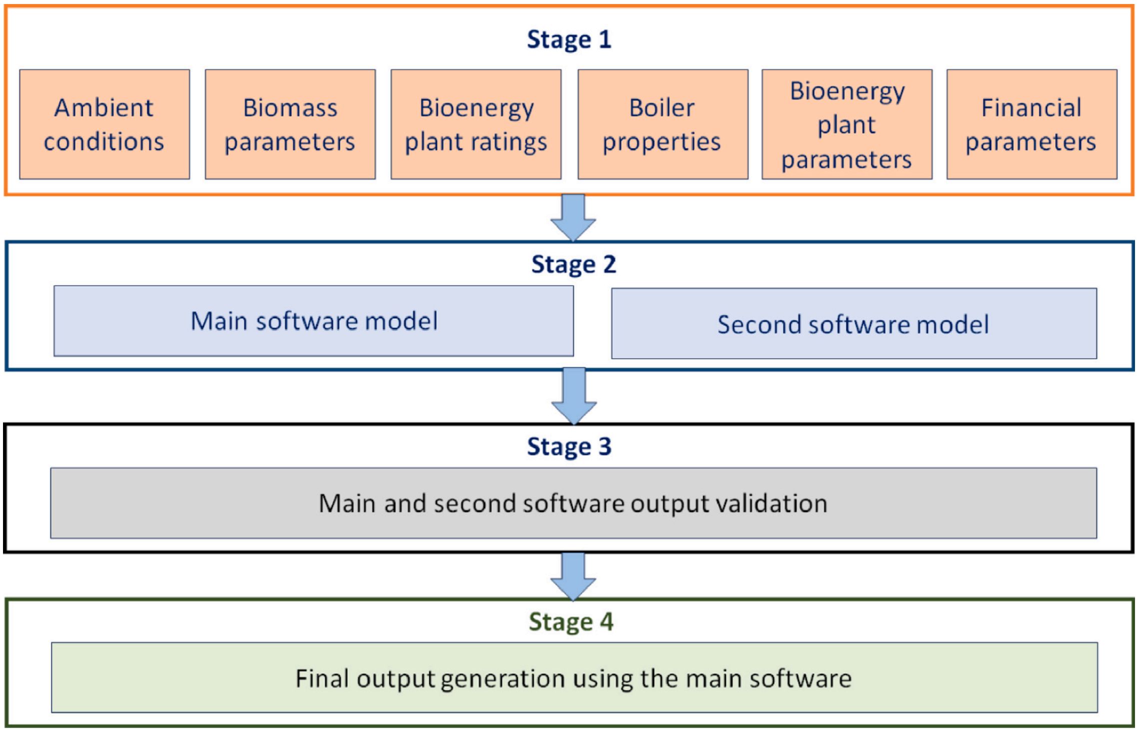


Fig. 1. Generic biomass system design.

2018; U.S. Energy Information Administration (EIA), 2020; Nugent, 2021).

The parameters and information related to the biomass generator used in the modelling are detailed in Table A.15.

2.4. Economic model

The essence of developing an economic model is to assess the business case of an investment. The model is used to judge whether the initial investment costs can be returned within the expected period with an acceptable levelised cost of energy (LCOE). The following economic indicators are deemed to be the most appropriate for building an economic model (Ibrahim et al., 2021):

- Annual life-cycle cost (ALCC): The ALCC is a method used for the comprehensive economic analysis over the project's life (e.g., 25 or 30 years). The ALCC is reported to be one of the most important factors for judging the annual life cycle costs of a project, which can be expressed as (Ibrahim et al., 2021):

  $$ALCC\ (\$/\text{year}) = \sum_{k\in K}(A_k^{Cap} + A_k^{O\&M} + A_k^{Rep} + A_k^{F} + A_k^{S}), \tag{3}$$

  In (3), A_k^{Cap} is the annual uniform series of the capital investment unit cost for equipment k, $A_k^{O\&M}$ is annual uniform series of operations and maintenance costs for equipment k, A_k^{Rep} is the annual uniform series of the replacement cost for equipment k, A_k^{F} represents the annual uniform series of any future value for equipment k, and A_k^{S} is the annual uniform series of the salvage gain for equipment k.

  To obtain the ALCC of the investment over the life cycle of the project or the period of analysis, several factors should be defined as follows (Blank and Tarquin, 2018):

  - General inflation adjusted discount rate (j): The financial cost of an investment is often adjusted to reflect a reasonable amount of the expected general price inflation. Therefore, a discount rate that accounts for the inflation rate can be used. This can be expressed as in (4).

    $$j = (d + f) + (d \cdot f). \tag{4}$$

  - Annual uniform series of a present value:

    The uniform series of the annual equivalent value of end-of-period cash flows (i.e., investments) (A) of a present value (PV) can be obtained as:

    $$A/PV = \left(\sum_{k\in K} PV_k\right) . \left(\frac{j.(1+j)^N}{(1+j)^N - 1}\right). \tag{5}$$

    The above formula can be used to find the annual uniform series of the capital investment unit cost (A_k^{Cap}).

  - Annual uniform series of a fixed annual value:

    The A of a fixed annual value (FAV) can be calculated as:

    $$A/FAV = \left(\sum_{k\in K}\sum_{n=1}^{N} FAV_{kn} . \left(\frac{(1+f)^n}{(1+j)^n}\right)\right) . \left(\frac{j.(1+j)^N}{(1+j)^N - 1}\right). \tag{6}$$

    This equation can be applied to obtain the annual uniform series of operations and maintenance costs ($A_k^{O\&M}$).

  - Annual uniform series of a future value:

    The A of a future value (FV) can be calculated as:

    $$A/FV = \left(\sum_{k\in K}\sum_{n\in N} \frac{FV_{kn}}{(1+d)^n}\right) . \left(\frac{j.(1+j)^N}{(1+j)^N - 1}\right). \tag{7}$$

    This formula can be used to calculate the annual uniform series of replacement cost (A_k^{Rep}), any future value (A_k^{F}) and salvage gain (A_k^{S}).

- Net Present Value (NPV): The net present value is the estimation that predicts the net costs of the total investment from the initial time until the end of the project's life cycle or period of the analysis. It can be defined as (Blank and Tarquin, 2018):

  $$NPV\ (\$) = ALCC \cdot \left(\frac{(1+j)^N - 1}{j \cdot (1+j)^N}\right). \tag{8}$$

- Levelised cost of energy (LCOE): The LCOE is one of the paramount parameters to measure the feasibility of any energy project. It is defined as the measure of the average net present cost of electricity generation by a generation unit during the entire life cycle cost of the electrical energy alternative. It can be represented as (Council, 2022):

$$LCOE\ (\$/\mathrm{kWh}) = \frac{\sum_{n=0}^{N} \frac{C_n}{(1+d)^n}}{\sum_{n=0}^{N} \frac{E\cdot(1-g)^n}{(1+d)^n}}, \tag{9}$$

  where C_n stands for the cost in year n, E represnts the energy generation in the first year, and g is the system degradation rate. The system degradation rate of 0% is considered for the biomass generator as reported by Aurecon in Aurecon Australasia Pty Ltd (2022).
- Simple Payback Period (SPP): The payback period is the amount of time required to recover the cost of an investment. It can be expressed as:

$$SPP\ (year(s)) = \frac{Cost\ of\ initial\ investment\ (\$)}{Annual\ savings\ and\ revenues\ (\$/\mathrm{year})}. \tag{10}$$

- Price efficiency index (PEI): The PEI reflects the economic operation of an individual site within a specific time period (e.g., monthly, quarterly, or yearly). The PEI term is useful to explore the outcomes of energy consumption mapping and energy charges to: (i) understand current electricity consumption patterns; (ii) trade-off between several cost-effective solutions; and (iii) explore the opportunities to reduce the energy cost by implementing various demand management strategies to current consumption. The PEI can be defined as (Hasan et al., 2020):

$$PEI = \frac{VWAPE\ (\$/\mathrm{kWh})}{TWAPEM\ (\$/\mathrm{kWh})}, \tag{11}$$

  where $VWAPE$ stands for the volume weighted average price of electricity at the site, and $TWAPEM$ is the time weighted average cost of the wholesale energy market.

  Greater PEI value (>1) indicates higher energy cost, while the lesser value (<1) indicates the effective economic operation of the site (i.e., low energy costs).

3. Techno-economic approach

The techno-economic approach is developed to analyse the feasibility of different tariff structures and the potential of biomass investment for timber and related industries. This work incorporates biomass and new HV tariff structures into their existing energy supply. The proposed approach has been developed and tested in a timber mill located in regional Australia. The demand data has been collected via the national meter identifiers (NMIs). The approach is also tested based on two aspects: HV tariffs; and HV tariffs with local generation. Depending on the availability of the resources a number of time series outputs are generated. The process for the rest of the analysis in the tool remains the same. The input parameters required have been completed by incorporating retailer and network data. the retailer and network data are used as input parameters. Furthermore, the spot market price, network charges under different tariff structures and costs of equipment are also used as input. The output consists of the computed energy bills and the estimated economic parameters. This approach is generalised for any similar large or medium-scale industry with similar loads, energy consumption and renewable energy targets.

The techno-economic approach consists of five main stages as illustrated in Fig. 2, described below:

- Stage I: Data collection and pre-processing

  The required data are collected at this stage, including load data, energy bills, network tariffs and spot market price. If a model's input feature space is constructed blindly, the usefulness of data use may be limited. Therefore, the collected data is analysed using auto-correlation. The auto-correlation coefficient determines the auto-correlation, periodicity, trend, and relationship between the load data and other external factors. It helps to determine the input time steps by looking at the lag relationship between the most current load data and its initial values. In addition, the outlier point measures and load consistency are analysed in this stage. One efficient density-based clustering method is the DBSCAN method. The DBSCAN considers outliers without considering any specific number of clusters in the data. As a result, DBSCAN is utilised to find the outliers among a collection of load profiles to ensure load consistency. The consistency will be higher if the daily load profile contains fewer outlier points.
- Stage II: Business-as-usual (BAU) energy consumption and cost mapping

  The load profiles for several NMIs are analysed at this stage. This analysis involves applying energy heat maps. The heat maps show the average hourly energy demand data variation from day to day and from year to year. The main idea of using energy mapping is to spot anomalous energy patterns as a function of time, which leads to selecting the cost-effective tariff structure, source of energy charges, and renewable energy investment. During the operation stage, it can be used to schedule the local generation and limit the import and export to the grid. The selection of the cost-effective decision is not just linked with the energy patterns as a function of time. It is also related to the operation of an individual load within a specific period. Therefore, the PEI is calculated for each load to ensure constancy in the investment decision. The PEI can be calculated based on the mathematical expression given in Eq. (11).
- Stage III: Select the cost-effective tariff structure only

  The selection criteria of the cost-effective tariff structure depend on securing the highest savings compared to BAU at a lower PEI and payback period. Therefore, the effectiveness of each tariff structure needs to be analysed by considering the energy market model and LCC assessment. In this context, extra costs may need to be considered to cover the equipment to upgrade the voltage level to enable various tariff structure options. In this stage, the LCC for each piece of equipment is considered and analysed based on the analysis period. This includes capital, installation, replacement, and O&M costs as in (3). Finally, the annual worth approach is implemented to calculate the effectiveness of each tariff structure. In addition, the simple payback period is calculated for each tariff structure based on Eq. (10).
- Stage IV: Biomass investment and selecting the cost-effective tariff structure

  Investing on biomass options is analysed in this stage. The power output from the biomass generated is modelled on a 30-min basis as in (2). In addition, a time-series data set is generated based on various feed-stock amounts and moisture levels. Also, various tariff structures due to the scale of load and generator size. Here, the energy flow is analysed to characterise the behaviour of the import/export of the energy at the site. Therefore, the amounts of excess and deficit energy are calculated. The excess energy is considered to be sold to the grid with a specific FiT, as in (1). In contrast, the deficit energy is considered to be imported to the site based on various tariff structures. In this context, the PEI, savings, LCC, LCOE and simple payback period are calculated for each scenario.
- Stage V: Decision criteria and measures of economic evaluation

  Life cycle costing is the best evaluation criterion to determine the economic viability of renewable energy systems. Engineering economy studies built on economic worth focus on life cycle costing. As mentioned in Section 2.4, primary and supplementary

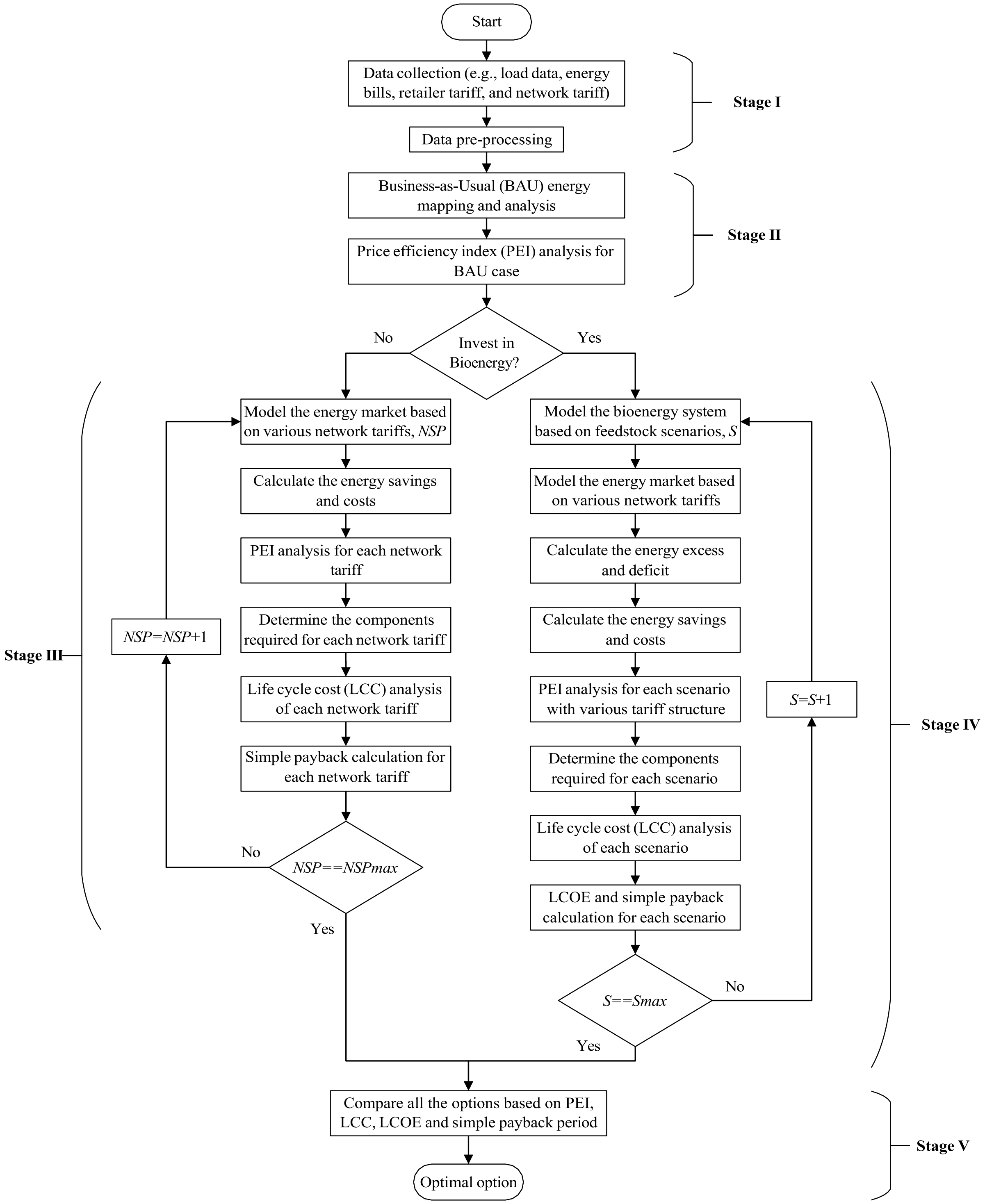
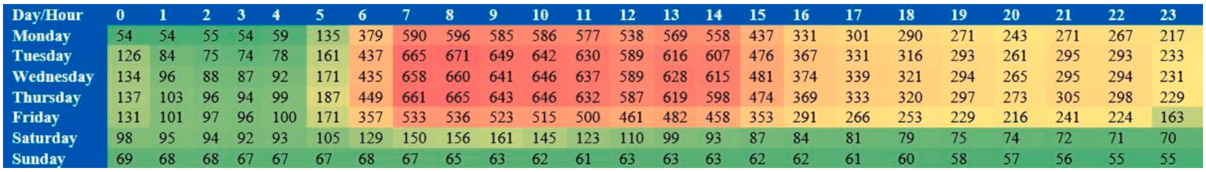


Fig. 2. Proposed techno-economic assessment approach.

measurements are frequently used to evaluate the economic success of investment. The discount rate is selected at the discretion of the investor. However, it should be estimated as a minimum standard to cover the costs of investment. A financial investment's cost is frequently changed to reflect a reasonable level of anticipated general price inflation. Estimating specific inflation rates for each technology is recommended to reduce the uncertainty of the outcomes. This is because technology maintenance and replacement costs most likely rise at the rate distinct from normal inflation. The cost of energy falls under this. Therefore, the economic evaluation is based on the LCC analysis to find the LCOE and simple payback period. Hence, the best investment option is selected based on the ranking the options following the order of lowest PEI, LCC, simple payback period, and LCOE. As mentioned earlier, the option that ranked first with the lowest amount of the criteria is selected.



Day/Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Monday	54	54	55	54	59	135	379	590	596	585	586	577	538	569	558	437	331	301	290	271	243	271	267	217
Tuesday	126	84	75	74	78	161	437	665	671	649	642	630	589	616	607	476	367	331	316	293	261	295	293	233
Wednesday	134	96	88	87	92	171	435	658	660	641	646	637	589	628	615	481	374	339	321	294	265	295	294	231
Thursday	137	103	96	94	99	187	449	661	665	643	646	632	587	619	598	474	369	333	320	297	273	305	298	229
Friday	131	101	97	96	100	171	357	533	536	523	515	500	461	482	458	353	291	266	253	229	216	241	224	163
Saturday	98	95	94	92	93	105	129	150	156	161	145	123	110	99	93	87	84	81	79	75	74	72	71	70
Sunday	69	68	68	67	67	67	68	67	65	63	62	61	63	63	63	62	62	61	60	58	57	56	55	55

Fig. 3. Energy heat map for both small and large timber mills in 2020.

Day/Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Monday	43	43	43	43	53	142	410	655	659	650	648	641	595	618	632	524	381	344	331	327	302	304	327	286
Tuesday	173	71	64	61	70	161	452	717	713	701	698	691	642	668	679	561	414	371	352	356	332	330	361	316
Wednesday	200	89	79	76	85	189	488	745	739	734	723	706	655	684	701	580	418	371	358	355	324	330	358	315
Thursday	193	92	84	80	87	176	471	729	724	709	699	693	644	670	684	568	420	371	354	354	329	329	359	312
Friday	187	89	82	78	84	143	336	485	488	480	475	457	419	412	384	304	256	233	221	208	202	218	196	136
Saturday	81	73	71	69	70	80	105	125	139	139	128	105	91	80	70	68	65	62	60	59	59	58	56	56
Sunday	56	55	55	55	54	53	52	51	50	48	47	46	47	47	46	45	44	44	44	45	45	44	44	43

Fig. 4. Energy heat map for both small and large timber mills in 2021.

4. Case study

The parameters from the timber industry in regional Australia have been considered for this study. A comprehensive inspection has been carried out to understand the plant layout and accurately estimate project-related costs. The site-specific demand characterisation has been done. The selected timber mill has two sites, considered as large and small mill sites. The energy profiles of the two sites are generated using 30-minute resolution load data. The operations of the timber mill are classified into three types: (i) BAU (ii) HV tariff option and (ii) incorporating biomass with HV tariff option. Nonetheless, AusNET's Tariff 1, Tariff 2, and Tariff 3 are the more comprehensive tariff structures used for large consumers. Therefore, the AusNet Services tariff structure for large consumers is used for this case study. In the BAU case, energy heat maps are utilised to assess the current energy expenses based on the Victorian Tariff structure.

The techno-economic study has been conducted using the CEREI tool (Ibrahim et al., 2024), which aids industries in reducing energy consumption, transitioning to renewables, and enhancing sustainability. Developed in a JAVA environment, CEREI is stable for managing large data volumes and operates with a single-threaded design, processing tasks sequentially for straightforward and manageable execution. This makes it suitable for applications with basic concurrency needs. CEREI helps organisations make informed energy decisions that lead to cost savings and a sustainable future by supporting industrial and commercial customers in reducing energy bills through optimised on-site generation. It also assists decision-makers in identifying cost-effective renewable energy solutions in line with local market regulations and facilitates the integration of renewable energy sources into existing power systems.

4.1. BAU

The existing operations of a typical timber industry in regional Australia are first analysed to suggest recommendations for implementing biomass, including investments. It is also required to analyse the energy bills of the timber mill as these help to understand the tariff structures and the associated charges. A detailed explanation has been presented in the following subsection.

4.1.1. Energy mapping

Tariff structures in Victoria are designed based on the brackets of consumption, such as the peak and off-peak hours and the shoulder hours of energy consumption. Based on the market, the rates are set such that during the hours of the day when the overall system load demand is high, consumers must pay a premium to access energy. It is the opposite for off-peak hours. During the off-peak hours, energy is available at lower prices due to lower overall system demand. The shoulder hours represent the beginning and ending hours of a typical workday. For the timber industry, this would be between 5 am and 6 am and between 2 pm and 4 pm. Energy heat maps have been used in this case study with an hourly average for a year with a resolution of 24 h to highlight the period and length of these charges applied to the consumer. A typical timber mill in Victoria has shoulder hours between 5 am and 6 am and then again between 3 pm and 4 pm. The peak hours occur between 7 am and 2 pm while the off peak hours are all the day's remaining hours. This is demonstrated in Figs. 3 and 4 for 2020 and 2021, respectively.

4.1.2. Current tariff model and energy bills

Two main tariff structures are currently used by the consumer (i.e., timber mill) in regional Victoria: small industrial and commercial tariff class (i.e., NASN21) and large industrial and commercial tariff class (i.e., NSP76). The NASN21 is designed for small business customers with annual consumption ranging from 40 MWh to 160 MWh. Meanwhile, NSP76 caters to customers the consumption between 750 MWh and 2 GWh annually, while the demand exceeds 280 kVA. The selection of both NASN21 and NSP76 tariffs is primarily based on the customer's site energy patterns and consumption levels in the BAU case (AusNet Services, 2021). The network charges are defined by the local operator of the region, in this case, AusNet Services. The tariff structures and the chargeable components of NASN21 and NSP76 are detailed in Table 2.

The actual charges, irrespective of the tariff structure used in Victoria, are listed in the energy bills. The first type of charges is the energy charges, which contain the dynamic charges related to purchasing the energy from the generation and the fixed charges that cover the service and admin as listed in Table 3.

Each of these tariff structures has various charging parameters as defined by AusNet Services (AusNet Services, 2021). The values are presented in Table 4. It should be worth noting that these charges are relevant for 20202 and 2021.

The market charges are charged to the customer due to environmental charges. This also includes the charges associated with various schemes currently run by the Victorian and Australian governments to increase the uptake of renewable in the grid. The market charges are summarised as in Table 5.

The final charges also include other charges such as charge customers for metering, compliance testing for current transformer and others. These charges are presented in Table 6.

Table 2
BAU tariff structures considered for this study.

Tariff structure	Tariff component	Unit	Charging parameters
NASN21	Standing charge	$/yr	Fixed value
	Peak	c/kWh	7:00 AM to 11:00 PM Monday to Friday
	Off peak	c/kWh	All other times
	Demand	$/kW/mth	3:00 PM to 9:00 PM AEST Monday to Friday. Peak season – December to March, Off peak season – All other months
NSP76	Standing charge	$/yr	Fixed value
	Peak	c/kWh	7:00 AM to 10:00 AM and 4:00 PM to 11:00 PM Monday to Friday
	Shoulder	c/kWh	10:00 AM to 4:00 PM Monday to Friday
	Off peak	c/kWh	All other times
	Capacity	$/kVA/yr	Fixed value
	Critical peak demand	$/kVA/yr	Average of five recorded day between 3:00 PM and 7:00 PM AEST on five days nominated in advance

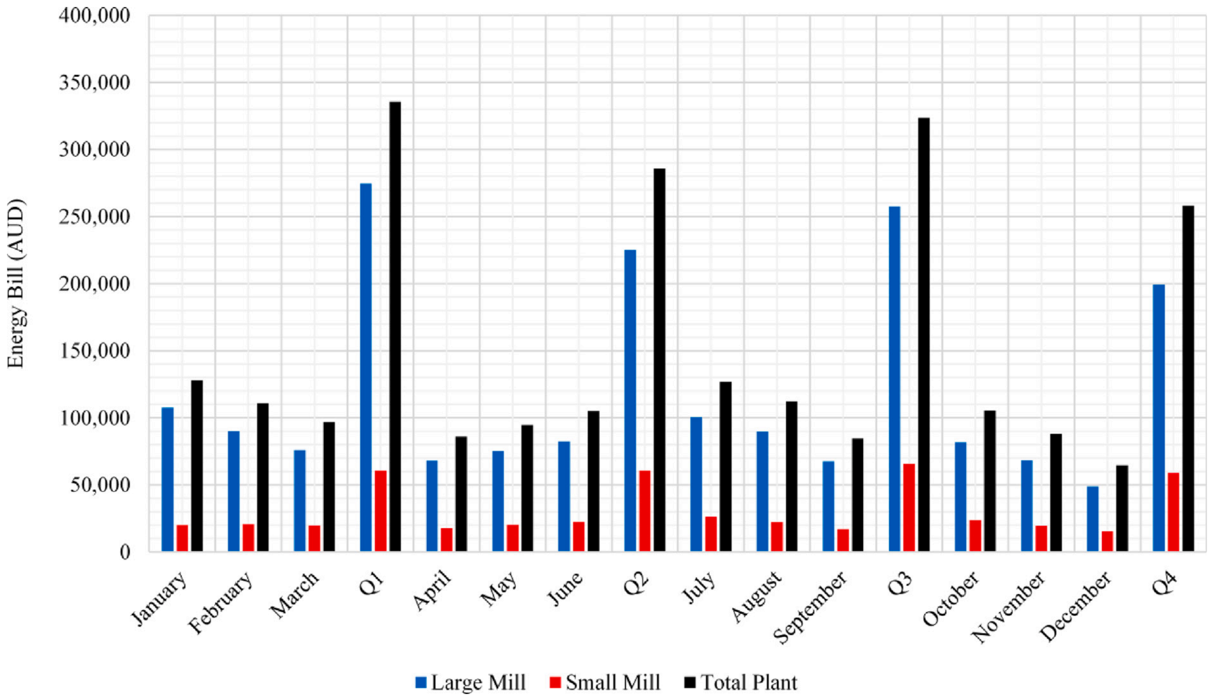


Fig. 5. Energy bill for a typical timber industry in regional Australia in 2020.

Table 3
Current tariff structure energy prices.

Charge class	Charge structure	Value
Pool pass through charges import to site	Dynamic	Based on the retailer price (c/kWh)
Service and admin charge	Fixed	1.9 $/Day

Based on all this information, the typical energy bills of the chosen site over the period of two years are calculated and presented in Figs. 5 and 6 respectively. The data has been presented in periods of monthly and quarterly bills.

It can be noticed that the energy bills increase as the year progresses and reach a maximum of $335,601 in 2020 in the first quarter of the year for the timber mill. A different trend is observed in the following year (i.e., 2021), when the costs mount to a peak of $394,517 in the second quarter, representing the winter months.

4.2. HV tariff structure

Three HV tariff structures, i.e., Tariff 1, Tariff 2 and Tariff 3, are applied to the energy consumption patterns as an initial solution to reduce the energy bills and improve the economic operation. The tariff structure is similar to the one used in BAU case. The pool-pass through charges import are considered dynamic charges based on the 30-minute basis, provided by AEMO (AEMO, 2022; Middelhoff et al., 2022). A 10% safety factor has been considered in calculating the fixed charges, including the service and admin charges, meter and CT compliance testing Levy and others. Finally, the market charges are considered as those used in BAU. The details regarding the tariff structures are given next:

- Energy charges, which includes pool-pass through charges import to site and service (dynamic amount) and admin charge, plus 10% safety factor (fix amount) as shown in Table 7.
- Network charges for HV connection option are given in Table 8. These tariff classes are applied to all the NMIs separately. The tariff components and charging parameters are specified for each tariff structure by AusNet Services as illustrated in Table 9. The indicative price levels of each tariff component for 2020 and 2021 are determined by the distribution service providers according to the tariff structure statement with indicative prices for the remaining regulatory years, listed in Table 10.
- Market charges in HV tariff structure are the same as those used in BAU, which is specified by AEMO (given in Table 5).

Table 4
Tariff structures charging parameters.

Tariff class	Charging parameters	Jan–Dec 20	Jan–Jun 21	Jul–Dec 21
NASN21	Fixed ($)	118	106	111.11
	Energy-peak (c/kWh)	17.01	15.59	15.84
	Energy off peak (c/kWh)	4.15	3.87	4.07
	Demand peak season ($/kW/month)	5.8	6.91	7.38
	Demand off-peak season ($/kW/month)	1.45	1.73	1.84
NSP 76	Fixed ($)	5962	5372	6233.42
	Energy-peak (c/kWh)	5.05	4.80	5.03
	Energy-shoulder (c/kWh)	4.01	3.88	4.01
	Energy-off peak (c/kWh)	1.69	1.59	1.68
	Demand capacity ($/kVA/year)	49.12	43.96	487.39
	Demand critical peak ($/kVA/year)	83.07	74.34	81.83

Table 5
Current tariff structure market charges.

Charge class	Charge structure	Value
VEET charge	Fixed on a monthly basis	Based on AEMO price (c/kWh)
SRES charge	Fixed on a monthly basis	Based on AEMO price (c/kWh)
LRET charge	Fixed on a monthly basis	Based on AEMO price (c/kWh)
AEMO pool charge (GST Exempt)	Fixed on a monthly basis	Based on AEMO price (c/kWh)
Ancillary services	Fixed on a monthly basis	Based on AEMO price (c/kWh)

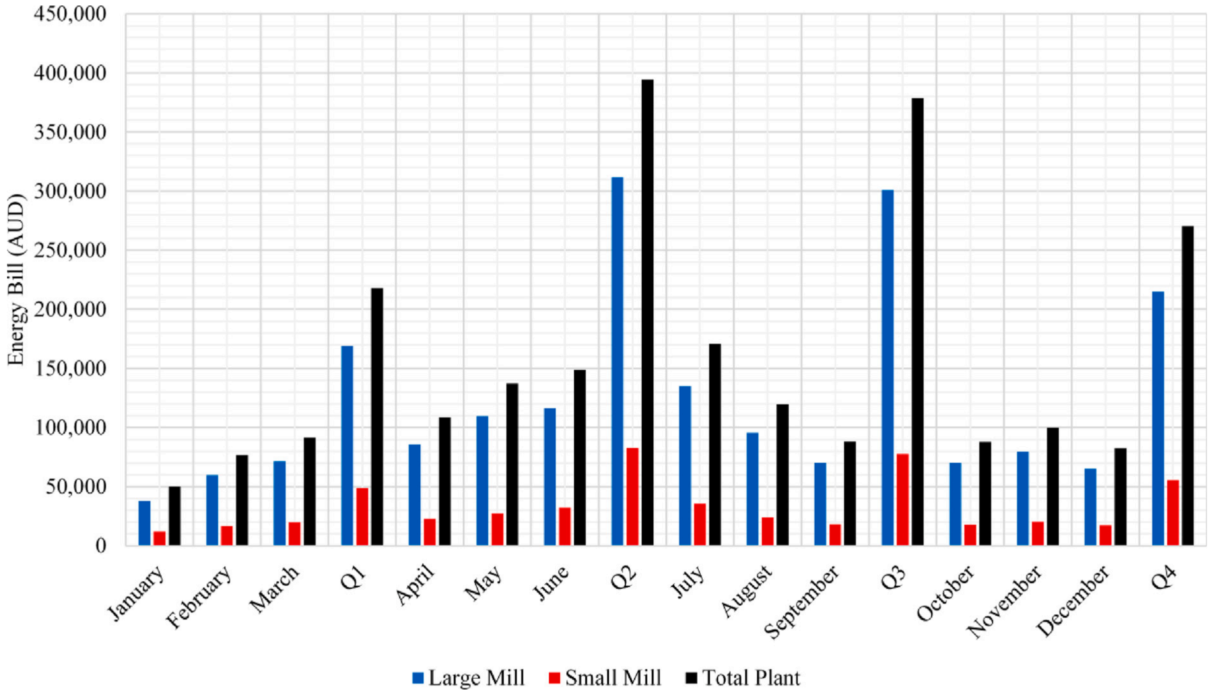


Fig. 6. Energy bill for a typical timber industry in regional Australia in 2021.

Table 6
Other charges.

Charge class	Charge structure	Value
Meter charge	Fixed	945 $/year
CT compliance testing Levey	Fixed	110 $/year

- Other charges are fixed per year and usually pre-defined by the retailer. A 10% safety factor is considered for both charges to ensure that the values of the calculated energy bills remain within the margin of the actual energy bills, as shown in Table 11.

4.3. Biomass generation model

A biomass generator was initially modelled using HOMER. The primary parameters required to model any system on HOMER are the load characteristics. Accurate load data are obtained from the timber mill, and the 30-min resolution has been considered to determine the overall annual load demand characteristics. Once these parameters were determined, the biomass feedstock was estimated. Each of these parameters was of the essence for the development of the biomass feedstock model and, ultimately, for modelling the generation profiles. Based on the sawdust in the timber mill, five scenarios were developed to understand the possible power outputs. These scenarios have been summarised in Table 12. The feedstock amounts available for these five scenarios were the inputs into the developed model to generate the 30-min time series data of power outputs.

5. Results and discussions

This section presents the results obtained from the HV tariff structures and incorporating the on-site biomass power generation. The

Table 7
Energy charges in HV structure.

Charge class	Charge structure	Value pool
Pass through charges import to site	Dynamic	Based on the AEMO spot market price
Service and admin charge + 10% safety factor	Fix	2.09 $/Day

Table 8
Network charges in HV tariff structure.

Tariff class	Tariffs	Tarif structure	Definition	NMIs
High voltage 1 industrial & commercial	Tariff 1	14	Available to large HV industrial & commercial customers (6.6 kV, 11 kV and 22 kV)	All NMIs
High voltage 2 industrial & commercial	Tariff 2	13	Available to large HV industrial & commercial customers (6.6 kV, 11 kV and 22 kV)	All NMIs
High voltage 3 industrial & commercial	Tariff 3	13	Available to large HV industrial & commercial customers (6.6 kV, 11 kV and 22 kV)	All NMIs

Table 9
Tariff structure and charging parameters - tariff structure 13 and 14.

Tariff structure	Tariff component	Unit	Charging parameter
13	Standing charge	$/yr	Fixed value
	Peak	c/kWh	7:00 AM to 10:00 AM and 4:00 PM to 11:00 PM Monday to Friday
	Shoulder	c/kWh	10:00 AM to 4:00 PM Monday to Friday
	Off peak	c/kWh	All other times
	Capacity	$/kVA/yr	Fixed value
	Critical peak demand	$/kVA/yr	Average of five recorded days between 3:00 PM and 7:00 PM AEST on five days nominated in advance
14	Standing charge	$/yr	Fixed value
	Peak	c/kWh	7:00 AM to 11:00 PM Monday to Friday
	Off-peak	c/kWh	All other times
	Capacity	$/kVA/yr	Fixed value
	Critical peak demand	$/kVA/yr	Average of five recorded day between 3:00 PM and 7:00 PM AEST on five days nominated in advance

Table 10
Indicative charges in HV tariff structure.

Tariff	Charging parameters	Jan.–Dec. 20	Jan.–Jun. 21	Jul.–Dec. 21
Tariff 1	Fixed ($)	5962.00	5372.00	6233.42
	Energy - peak (c/kWh)	2.62	2.63	2.64
	Energy - off-peak (c/kWh)	0.80	0.80	0.81
	Demand capacity ($/kVA/year)	38.77	34.70	38.27
	Demand critical peak ($/kVA/year)	63.54	56.86	62.72
Tariff 2	Fixed ($)	5962.00	5372.00	6233.42
	Energy - peak (c/kWh)	2.56	2.81	2.58
	Energy - shoulder (c/kWh)	2.56	2.58	2.58
	Energy - off-peak (c/kWh)	1.01	0.98	1.01
	Demand capacity ($/kVA/year)	35.54	31.81	35.08
	Demand critical peak ($/kVA/year)	58.16	52.05	57.41
Tariff 3	Fixed ($)	5962.00	5372.00	6233.42
	Energy - peak (c/kWh)	11.7	10.76	11.52
	Energy - shoulder (c/kWh)	5.43	5.14	5.38
	Energy - off-peak (c/kWh)	1.62	1.53	1.61
	Demand capacity ($/kVA/year)	4.14	3.70	4.08
	Demand critical peak ($/kVA/year)	6.84	6.12	6.74

Table 11
Other charges as HV tariff structure.

Charge class	Charge structure	Value
Meter charge + 10% safety factor	Fix	1039.50 $/Year
CT compliance testing Levey + 10% safety factor	Fix	121.00 $/Year

Table 12
Sensitivity of feed stock availability.

Scenario number	Feed-stock available (tons/yr)	Feed-stock type
S1	7000	Green sawdust
S2	8000	Dry sawdust
S3	10,000	Dry sawdust
S4	16,000	Green and dry sawdust
S5	25,000	Green and dry sawdust

energy flow and bills have been analysed for all three HV tariffs and later, incorporated the biomass power generation with those tariff structures. The economic savings for each scenario have been computed and analysed. In addition, LCC is obtained for each scenario with respect to equipment requirement and the life of service for each component within a given period of analysis. Accordingly, the simple payback period and LCOE for each of the scenarios have been calculated and utilised as investment decision criteria.

Even though the data presented here are only for 2020 and 2021, the data is generic and only representative of any actual operation of such an industry. Furthermore, the data may be extrapolated to cover each year of the project's entire lifetime. The effect of introducing new HV tariff structures and biomass power generation on the energy bills and the economic indicators have been presented and compared in this section with the annual BAU case for 2020 and 2021.

5.1. HV tariff case vs. BAU

The HV connection for a typical timber industry in regional Australia is a proposed solution to reduce energy bills. This option requires initial investments to upgrade the infrastructure to connect at the HV connection point. In this option, the optional HV tariff structure

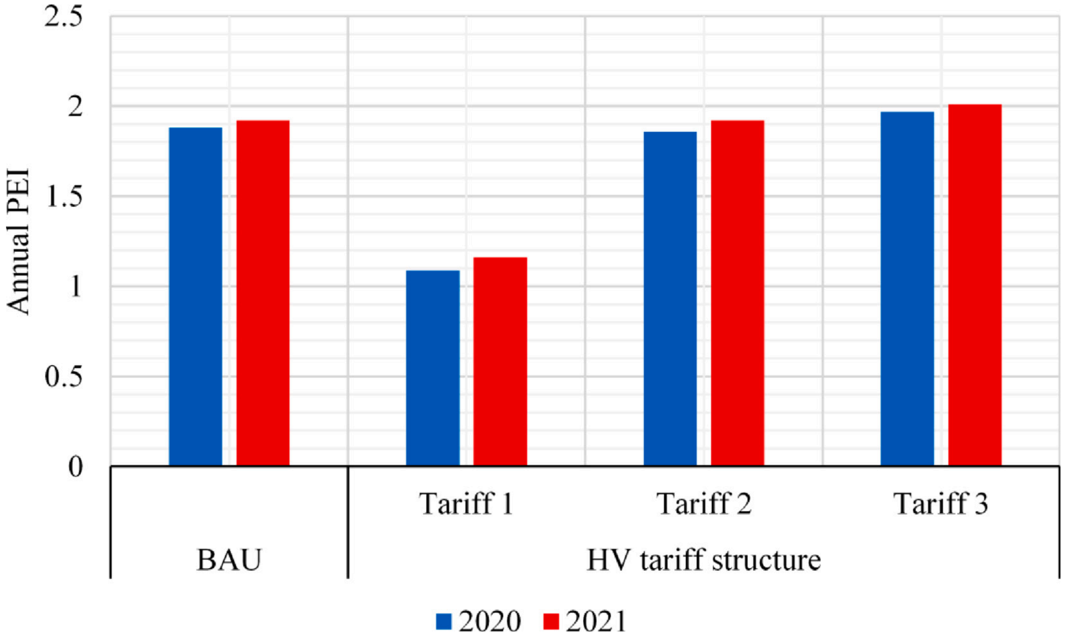


Fig. 7. Annual PEI compared for HV tariffs.

is applied and validated based on the amount of savings, PEI, and simple payback period calculation. The three HV tariffs mentioned in Section 4.2, i.e., Tariff 1, Tariff 2, and Tariff 3, are used in the case study. The analysis results are recorded and presented next.

5.1.1. PEI

PEI is an essential indicator of the economic operation of the timber mill. Fig. 7 shows the PEI values for HV tariffs. The PEI values of the BAU option using data from 2020 and 2021 are 1.88 and 1.92, respectively. The PEI values for Tariff 1 are 1.09 (in 2020) and 1.15 (in 2021). These are lower than those of the BAU for both years. On the other hand, the PEI values of Tariff 2 are 1.86 (in 2020) and 1.92 (in 2021), which were higher than those of Tariff 1 and slightly lower than the PEI values of the BAU. The PEI values for Tariff 3, 1.97 (in 2020) and 2.01 (in 2021), are higher than those of the BAU for the other tariff structures. It can be observed that Tariff 1 would ensure the best PEI and, thereby, the most cost-effective energy solution among the tariff structures in terms of PEI.

5.1.2. Savings

The annual energy bill for 2020 and 2021 has been analysed with HV tariffs. It can be seen in Fig. 8 that the energy bills for all three HV tariffs are less than the BAU case. Tariff 3 would result in the highest energy bill of the three HV tariffs. This means the Tariff 1 structure would pledge the highest savings for the timber mill among all the considered HV tariffs. As a result, the Tariff 1 structure is more cost-effective than BAU due to dynamic spot prices. Furthermore, Tariff 1 outperforms Tariffs 2 and 3 regarding energy bill reduction as the network charges for Tariff 1 are lower than Tariffs 2 and 3.

The saving for each HV tariff structure is expressed as the difference between the energy bill of each tariff structure and the BAU. This is a straightforward indicator to determine the most cost-effective tariff structure. To understand the savings for employing the three HV tariff structures compared with those obtained in BAU, the savings have been quantified and presented in Fig. 9. After incorporating Tariff 1, the annual savings are estimated as $234,620 (in 2020) and $271,285 (in 2021). Implementing Tariff 2 would create savings of $188,422 for 2020 and $217,562 for 2021. In contrast, the Tariff 3 structure reduced the annual savings in both years compared to Tariff 1 and Tariff 2, $24,143 and $53,074 in 2020 and 2021, respectively. Accordingly, the Tariff 1 HV tariff structure has higher savings. Therefore, it is the best tariff structure among the other considered HV tariffs in terms of savings.

5.1.3. LCC and economic parameters

For the HV tariff option, the LCC has been analysed by considering the required equipment, unit costs, number of equipment, installation costs, replacement and annual O&M costs. The period of the analysis is considered to be 30 years. The discount rate, inflation rate, and inflation-adjusted discount rate are considered to calculate the NPV and ALCC. The baseline costs for the considered equipment are given in Table 13.

The annual baseline costs contain the annual O&M costs and the annual costs of investments and salvage values. Accordingly, the NPV and ALCC for this option are $2,763,504 and $214,575, respectively. The investment and the annual savings are required to calculate the payback period. In this context, the investment costs are $2,461,648. In addition, the average savings are calculated based on a monthly discount rate of 0.3037%. The average savings are a more accurate indicator of the savings, and the savings for Tariffs 1, 2 and 3 are $245,881, $197,321 and $37,225, respectively. The payback of Tariff 1, in this case, is also the best, approximately 10 years, compared to 13 years of Tariff 2 and 66 years of Tariff 3.

5.2. Biomass with HV tariff option vs. BAU

Investing in large-scale biomass requires an upgrade and/or new equipment to integrate such a generator into the grid. The biomass generator selected for this study is considered to be connected to the HV level. Therefore, the HV tariff structure should be considered. Incorporating a biomass power plant with the HV tariff structures differs in all the economic parameters. In this context, Five scenarios with different levels of feed-stock presented in Section 4.3 are utilised to model the power output from the biomass generator.

5.2.1. PEI

The PEI trends with respect to biomass and HV tariffs are given in Fig. 10. The lowest PEI is obtained for scenario 1 in 2021 under Tariff 1. It should be worth noting that a significant PEI reduction could be observed for Tariff 1 with respect to BAU. The lower PEI values are

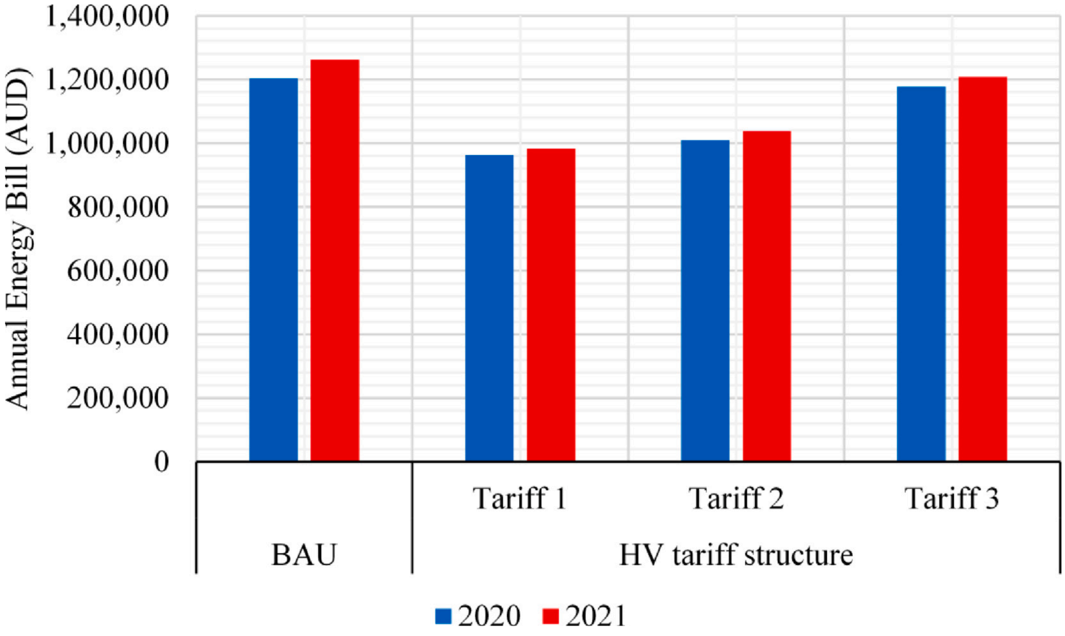


Fig. 8. Annual energy bills compared for HV tariffs.

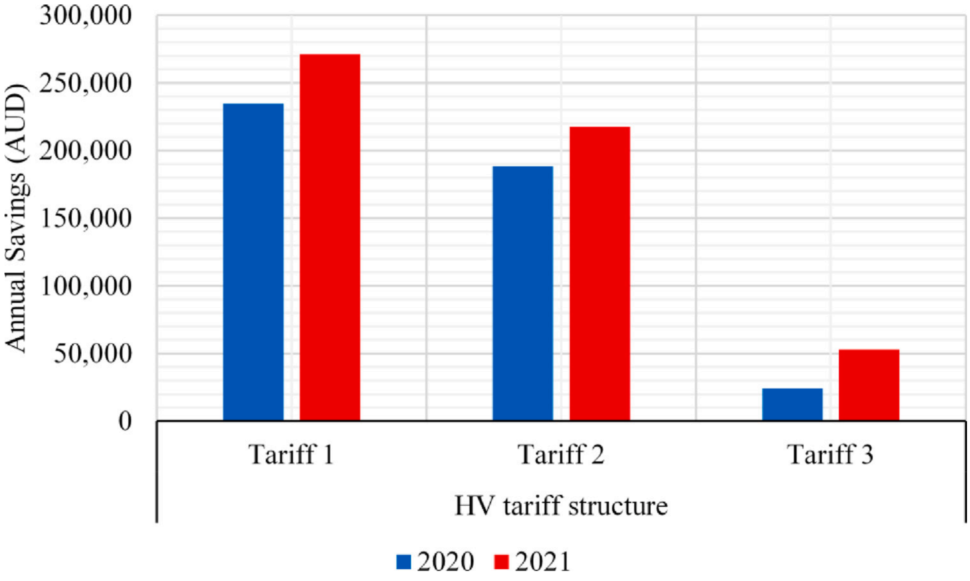


Fig. 9. Annual savings for HV structures compared to BAU.

observed for Tariff 2 and Tariff 3 only under scenario 5. The PEI values for all other scenarios under Tariff 2 and Tariff 3 are higher than the BAU. Generally, the monthly, quarterly, and yearly PEIs for scenario 5 (S5) under all tariff structures are better than those at BAU and other scenarios.

5.2.2. Savings

The annual energy bills of the mill with biomass generation under HV tariff 1–3 are given in Fig. 11. For all cases, the lowest bill could be achieved for S5. Furthermore, S5 under Tariff 3 shows the best value. The timber mill can expect to make a profit of $268,577 by using the current setup for the data of 2020. Also, the energy bill (in 2021) would be significantly lower than the BAU. The Tariff 2 tariff structure would ensure that the energy bill would be less than Tariff 1 (i.e., the energy bill for S5 is $279,778 in 2020). In this case, Tariff 2 would result in a lower energy bill than Tariff 1 with S5. This is because Tariff 2 has a shoulder tariff component, which makes the peak energy price for Tariff 2 lower than Tariff 1. The Tariff 3 tariff with S5 has the lowest energy bill, allowing the timber mill to save the entire energy bill compared to the BAU. Moreover, the mill can make a profit of $388,072 (using data from 2020) and $73,329 (using the data from 2021) by selling energy to the grid. In general, S5 with Tariff 3 is the most cost-effective option for reducing the energy bill compared to the other two tariffs. Tariff 2 has higher prices for demand critical peak and demand capacity than Tariff 3. Here, the savings are calculated and presented in Fig. 12.

According to the results in Fig. 12, Tariff 3 with S5 is the best option. Here, the obtained savings were $1,556,200 in 2020, and $1,300,003 in 2021.

Generally, the Tariff 3 with S5 option is more cost-effective for reducing energy bills than Tariff 1 and Tariff 2 with S5, respectively. The shoulder component of Tariff 2 and Tariff 3. Therefore, the peak energy price for Tariff 3 is lower than Tariff 1. Furthermore, Tariff 2 has a higher price for demand critical peak and demand capacity than Tariff 3.

Table 13
Baseline LCC for HV tariff structures.

Cost code	Component	Unit cost	Unit	No of units	Payment (Years)	Year of analysis (Years)	Total cost ($)	*d* (%)	*f* (%)	*j* (%)	NPV ($)	ALCC ($)
1	**Transformer (6000 kVA)**											
1.1	Capital cost (1500 kVA)	320,000	$/unit	4	0	30	1,280,000	5.50	1.79	7.39	−1,280,000	−107,205
1.2	Installation cost	128,000	$/unit	4	0	30	512,000	5.50	1.79	7.39	−512,000	−42,882
2	**Underground cables**											
2.1	Capital cost	32,400	$/km	1.8	0	30	58,320	5.50	1.79	7.39	−58,320	−4885
2.2	Installation cost	12,960	$/km	1.8	0	30	23,328	5.50	1.79	7.39	−23,328	−1954
3	**Ring main unit**											
3.1	Capital cost	300,000	$/unit	1	0	30	300,000	5.50	1.79	7.39	−300,000	−25,126
3.2	Installation cost	120,000	$/unit	1	0	30	120,000	5.50	1.79	7.39	−120,000	−10,050
3.3	Replacement cost	420,000	$/unit	1	20	30	420,000	5.50	1.79	7.39	−143,946	−12,056
4	**MV switchgear**											
4.1	Capital cost	120,000	$/unit	1	0	30	120,000	5.50	1.79	7.39	−120,000	−10,050
4.2	Installation cost	48,000	$/unit	1	0	30	48,000	5.50	1.79	7.39	−48,000	−4020
4.3	Replacement cost	168,000	$/unit	1	20	30	168,000	5.50	1.79	7.39	−57,578	−4822
5	**General switchyard protection maintenance**											
5.1	OM cost	7000	$/yr	1	1,2,3, …,29	30	7000	5.50	1.79	7.39	−100,332	−8403
6	**Total**										**−2,763,504**	**−214,575**

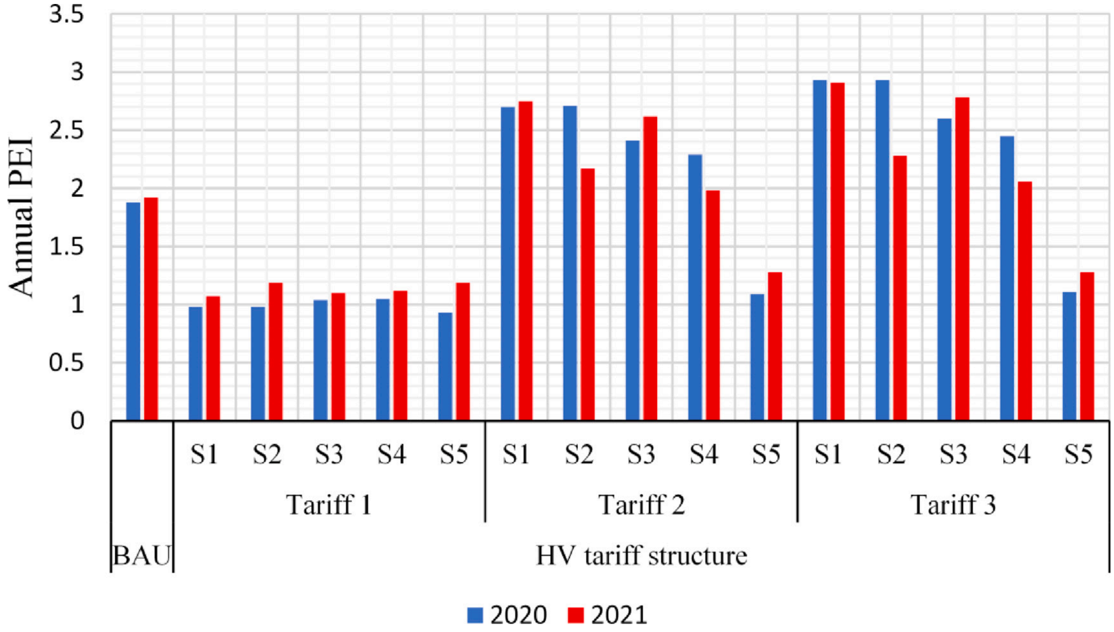


Fig. 10. Annual PEI for biomass with HV tariffs.

5.2.3. *LCC and economic parameters*

The ALCC is estimated for this option as in the HV tariff case. The details of the numerical values are presented in Table 14.

The initial investment cost for all the components is $13,776,294. For this case, the NPV and ALCC are $22,789,656 and $1,811,635, respectively.

The annual savings for several biomass generation options with HV tariff structures are calculated based on a monthly inflation-adjusted discount rate of 0.3037%. Annual savings are given in Fig. 12. It can be seen that Tariff 3 with S5 outperformed the rest in terms of annual savings ($1,556,200 in 2020 and $1,300,003 in 2021).

The payback period is calculated using the initial investment and annual O&M costs from the baseline costs given in Table 13. The payback period for every scenario and tariff structure are computed using the cash flows and presented in Fig. 13. It can be observed that Tariff 3 with S5 has a lower payback period of approximately 10 years. Additionally, S5 results in the lowest payback period across all HV tariffs.

Finally, the LCOE has been calculated for each of the biomass generation scenarios as a ratio of the average annual energy generated by each biomass scenario over the ALCC. Accordingly, Fig. 14 shows the sensitivity analysis of the LCOE for each scenario. According to the presented results in Fig. 13, the Lowest LCOE is obtained for S5 under Tariff 3.

5.3. *Technology readiness level*

The combined heat and power (CHP) technology and biomass boiler are in the advanced stage of development, TRL8-9. These technologies are commonly used in the forest product industry (i.e., timber mill) for energy and power production. Meanwhile, the solid fuel gas turbine is the emerging technology at TRL 6–7. Therefore, it will likely be deployed in the agricultural/forest product industry within 2–3 years. There are relatively low risks associated with deploying biomass-based heating and CHP technology. However, significant risks would be associated with solid fuel gas turbine deployment in the forest product industry. As the solid fuel gas turbine technology matures, the costs would come down; therefore, this technology would become attractive to the forest product industry for their ability to use some existing

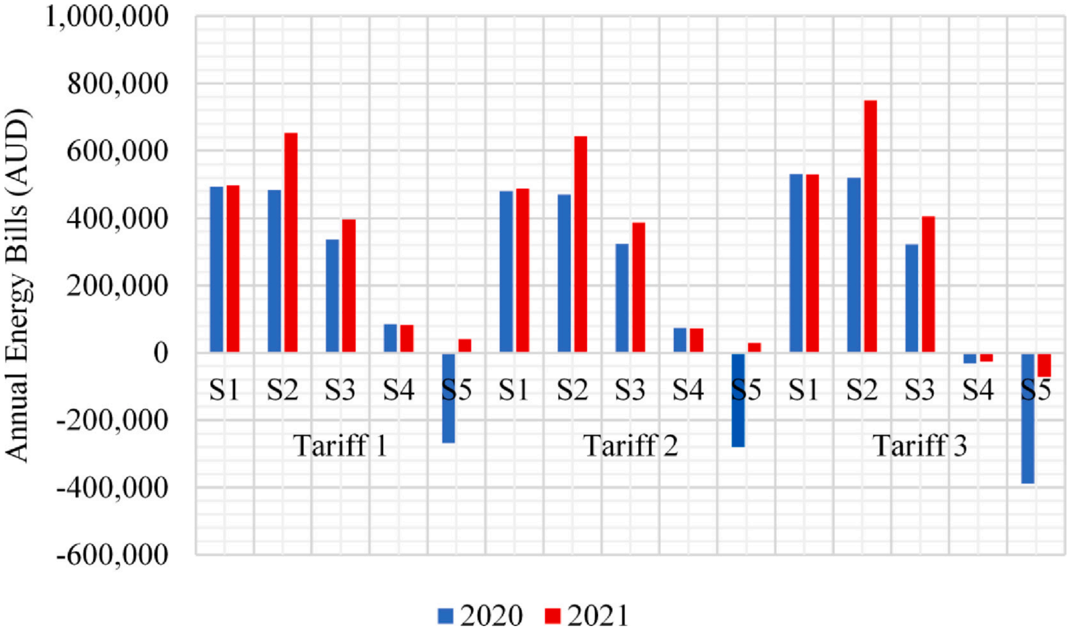


Fig. 11. Annual energy bills for biomass with HV tariffs (negative values mean the savings).

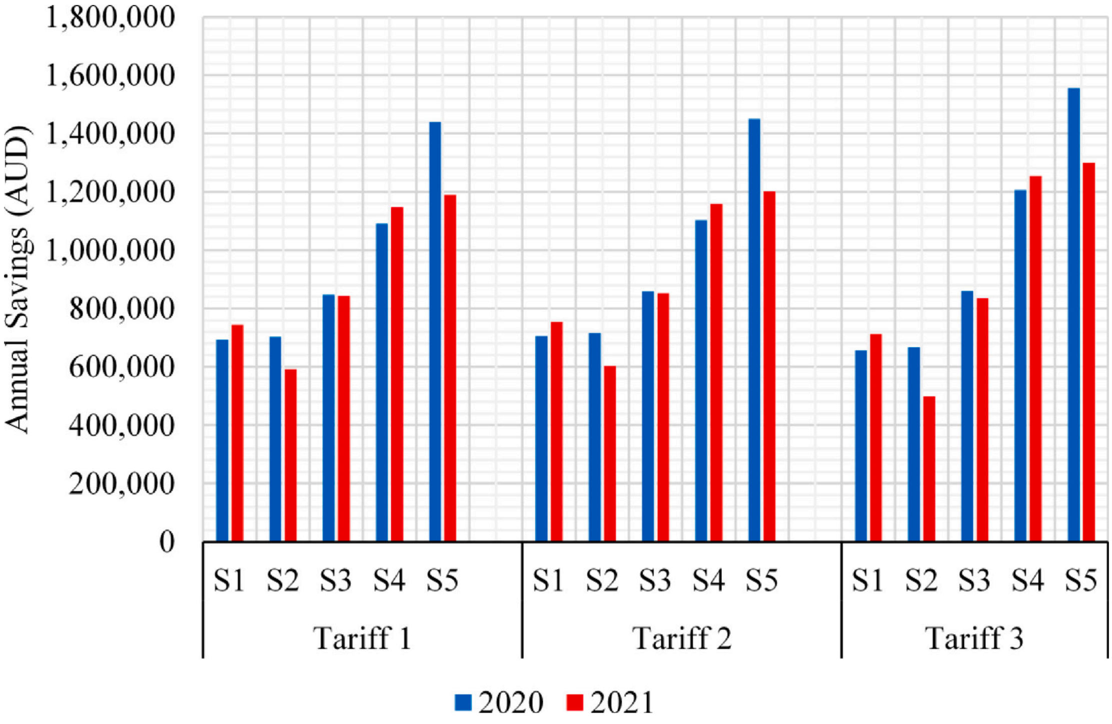


Fig. 12. Annual savings for biomass with HV tariff structures compared to BAU.

infrastructure and direct use of timber mill by-products. Anaerobic digestion is another alternative for the forest product industry for power and energy. However, this technology is only feasible for a small scale and requires a little pre-processing compared to solid-fuel gas turbines. Furthermore, the solid fuel gas turbine yields are higher than anaerobic digestion-based technology.

5.4. Opportunities for further work

The research has paved the way for using HV tariff structures and biomass systems to achieve energy savings and better energy pricing efficiency for large industrial consumers in Australia. The findings suggest that a similar study can be conducted using hybrid renewable power generation. However, it should be noted that the capital costs of implementing biomass remain high and have not reduced significantly over the years due to the lack of technological advancements. To further reduce capital costs and make the combination of HV tariff structures with hybrid renewable energy sources more economically viable, it is suggested to consider solar power as a viable addition to the biomass power plant. Additionally, a separate study should be conducted to explore other HV tariff structures for other distribution system service providers in Victoria, and a comparison can be made with the HV tariff structures in other states and territories in the country. As previous studies on this topic are limited, conducting thorough

Table 14
Baseline LCC for biomass with HV tariff structures.

Cost code	Component	Unit cost ($)	Unit	No of units	Payment (years)	Year of analysis (Years)	Total cost ($)	d(%)	f (%)	j (%)	NPV ($)	ALCC ($)
1	**Transformer at generation bus (2000 kVA)**											
1.1	Capital cost	185,000	$/unit	2	0	30	370,000	5.5	1.79	7.38845	−370,000	−30,989
1.2	Installation cost	40,000	$/unit	2	0	30	80,000	5.5	1.79	7.38845	−80,000	−6700
2	**Transformer (6000 kVA)**											
2.1	Capital cost (1500 kVA)	320,000	$/unit	4	0	30	1,280,000	5.5	1.79	7.38845	−1,280,000	−107,205
2.2	Installation cost	128,000	$/unit	4	0	30	512,000	5.5	1.79	7.38845	−512,000	−42,882
3	**Underground cables**											
3.1	Capital cost	32,400	$/km	1.8	0	30	58,320	5.5	1.79	7.38845	−58,320	−4885
3.2	Installation cost	12,960	$/km	1.8	0	30	23,328	5.5	1.79	7.38845	−23,328	−1954
4	**Ring main unit**											
4.1	Capital cost	300,000	$/unit	1	0	30	300,000	5.5	1.79	7.38845	−300,000	−25,126
4.2	Installation cost	120,000	$/unit	1	0	30	120,000	5.5	1.79	7.38845	−120,000	−10,050
4.3	Replacement cost	420,000	$/unit	1	20	30	420,000	5.5	1.79	7.38845	−143,946	−12,056
5	**MV switchgear**											
5.1	Capital cost	120,000	$/unit	1	0	30	120,000	5.5	1.79	7.38845	−120,000	−10,050
5.2	Installation Cost	48,000	$/unit	1	0	30	48,000	5.5	1.79	7.38845	−48,000	−4020
5.3	Replacement cost	168,000	$/unit	1	20	30	168,000	5.5	1.79	7.38845	−57,578	−4822
6	**Biomass genset system**											
6.1	Capital cost	1,860,890	$/unit	1	0	30	1,860,890	4.9	1.79	6.77771	−1,860,890	−146,628
6.2	Installation cost	744,356	$/unit	1	0	30	744,356	4.9	1.79	6.77771	−744,356	−58,651
6.3	Fixed OM costs	260,081	$/yr	1	1,2,3,…,14, 16,17,…,29	30	260,081	4.9	1.79	6.77771	−3,855,238	−303,771
6.4	Replacement cost	2,605,246	$/unit	1	15	30	2,605,246	4.9	1.79	6.77771	−1,271,207	−100,164
7	**Biomass gasifier system**											
7.1	Capital cost of gasifier and storage	5,980,000	$/unit	1	0	30	5,980,000	4.9	1.79	6.77771	−5,980,000	−471,191
7.2	Installation cost	2,272,400	$/unit	1	0	30	2,272,400	4.9	1.79	6.77771	−2,272,400	−179,053
7.3	Replacement cost	8,252,400	$/unit	1	20	30	5,980,000	4.9	1.79	6.77771	−2,297,161	−181,004
8	**Biomass pumps system**											
8.1	Capital cost	5000	$/unit	1	0	30	5000	4.9	1.79	6.77771	−5000	−394
8.2	Installation cost	2000	$/unit	1	0	30	2000	4.9	1.79	6.77771	−2000	−158
8.3	Replacement cost	7000	$/unit	1	15	30	7000	4.9	1.79	6.77771	−3416	−269
9	**Biomass system other OM cost - pumps and gasifier**											
9.1	Biomass system other OM cost	83,892	$/yr	1	1,2,3, …,29	30	83,892	4.9	1.79	6.77771	−1,284,484	−101,210
10	**General switchyard protection maintenance**											
10.1	OM cost	7000	$/yr	1	1,2,3, …,29	30	7000	5.5	1.79	7.38845	−100,332	−8403
11	**Total**										**−22,789,656**	**−1,811,635**

literature reviews with the consultation of various industrial players across Australia is recommended. This will help publish up-to-date, relevant and comprehensive data for all the equipment used in these projects.

6. Conclusions

This paper presented the comprehensive assessment results for various industrial consumers in Victoria. This paper has further analysed and incorporated a biomass power plant that can be installed on-site along with the new tariff structures to achieve the maximum possible energy bill savings for a traditional timber mill in Australia. While several studies have been conducted worldwide with biomass systems, few have focused on Australia, particularly regional Victoria. Many studies have used hybrid energy technologies to recommend the most economical solutions. This paper has shown that there can be long-term benefits even though the initial capital costs of incorporating biomass are high.

Biomass generators have dispatching capability. Therefore, they can be used to smooth the variation of wind and solar, including participation in the ancillary service market. With the increasing penetration of non-dispatchable renewable generators and the retirement of large conventional generators, the electric power system required minimum dispatchable generators to be in the system. These biomass-based generators could meet this requirement. A minimum of 1 MW biomass capacity should be installed on commercial consumer premises to allow them to participate in grid services.

In this context, there were several key findings and recommendations. Firstly, Tariff 1 (HV tariff structure) emerged as the most cost-effective solution compared to Tariff 2, 3, and the BAU. This is evident regarding savings, PEI, and payback period (specifically for the HV tariff structure). It offers the fastest return on the initial capital investment and guarantees more significant savings. The study also delved into biomass generation possibilities, examining various scenarios to understand the effects of fluctuating feed-stock quantities and moisture contents. Combining biomass with the Tariff 3 HV tariff structure under scenario 5 (S5) appears to be the most cost-efficient energy solution (as determined by savings, PEI, and the payback period). Therefore, it is recommended to employ biomass and Tariff 3 (HV tariff structure) with S5 for long-term planning and maximised savings. The analysis also found that utilising dry feed-stock over wet feed-stock guarantees enhanced energy output. Future research should focus on comparing smaller biomass generation with the BAU case for a holistic comparison.

Several lessons can be derived from this research. The HV tariff structure offers substantial savings when stacked against the BAU. In terms of long-term planning and savings, combining biomass with the

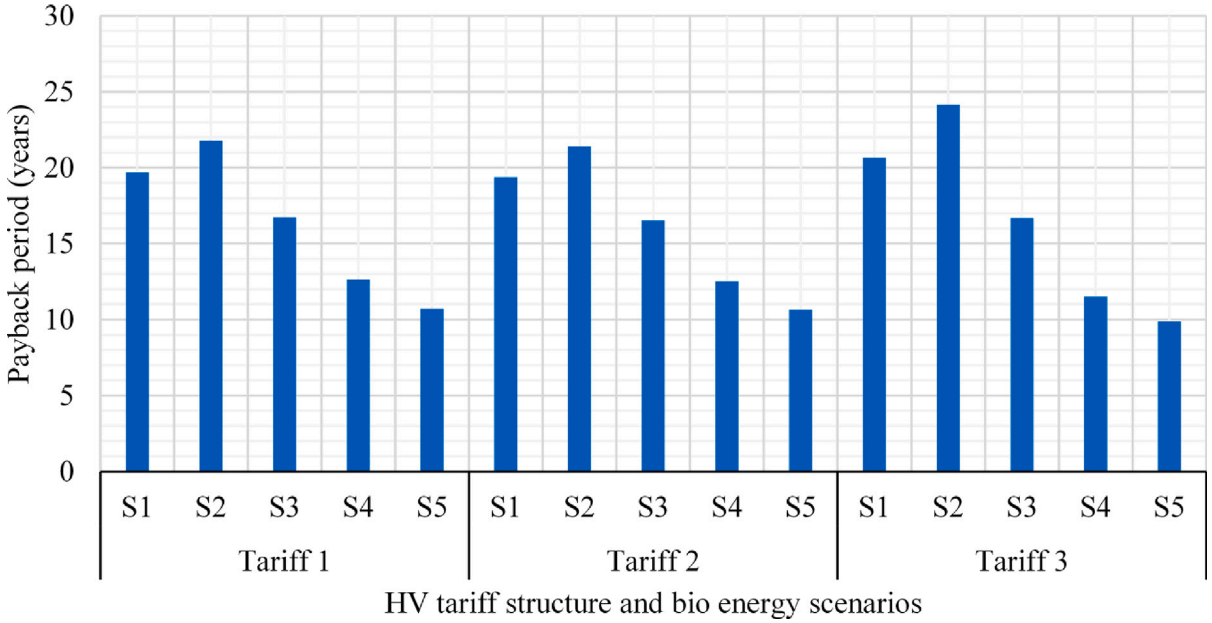


Fig. 13. Sensitivity analysis of payback period for HV tariff structures with biomass scenarios.

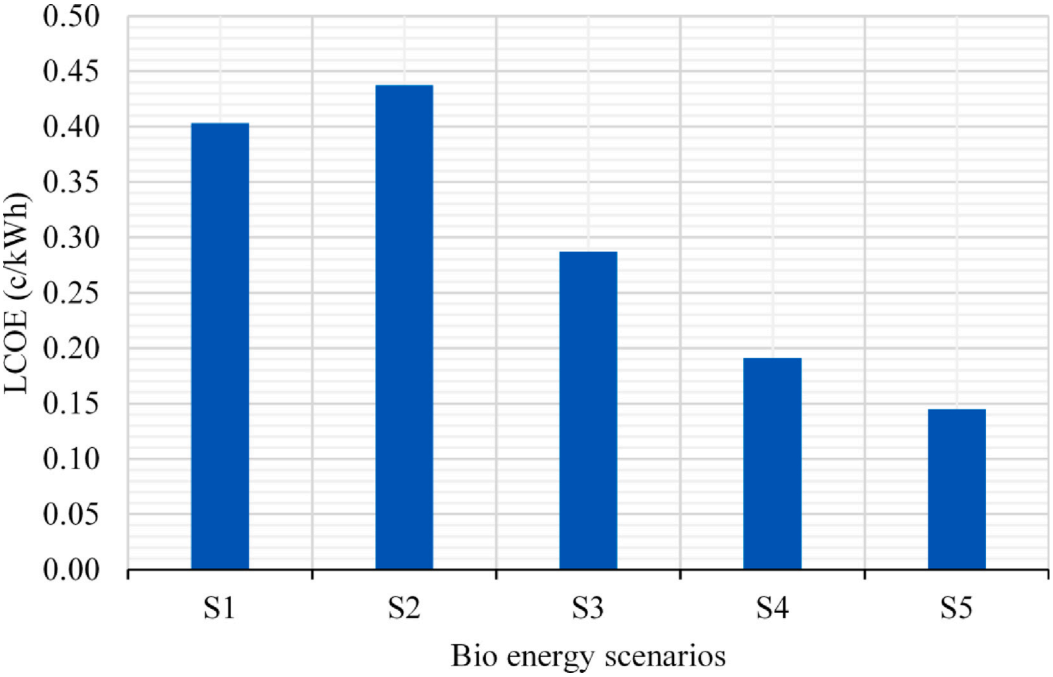


Fig. 14. Sensitivity analysis of LCOE for all biomass scenarios.

HV tariff structure could result in significant financial benefits for businesses, also introducing energy flexibility for end-users. However, it should be worth noting that further capital investment is required for HV connection. The incorporation of new HV connection tariffs would necessitate the installation of a new HV ring main unit. A project's profitability ultimately hinges on its Savings, PEI, and Payback Period. Therefore, a comprehensive economic and technical evaluation is vital to determine the most lucrative scenario.

Despite the thoroughness of this study, certain barriers and challenges were encountered. A significant obstacle was the absence of dependable cost data for all the equipment. Estimating the payback period requires the annual cash flow for the entire project life considered in this study. Consequently, several assumptions had to be made to derive the payback periods. Lastly, the scheduling data provided pertained only to the timber mill operations, with no feasible way to integrate these schedules into the tools used for biomass system modelling.

CRediT authorship contribution statement

Ibrahim Anwar Ibrahim: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft. **Tan Nhat Pham:** Visualization, Writing – review & editing. **Rakibuzzaman Shah:** Project administration, Resources, Writing – review & editing. **M.J. Hossain:** Project administration. **Syed Islam:** Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix. Biomass generator design parameters

Table A.15 provides a comprehensive overview of various parameters related to the modelling of a biomass system, including ambient conditions, feedstock details, plant specifications, and financial parameters.

Table A.15
Biomass generator design parameters.

Number	Description	Value-2020	Value-2021	Unit	Reference
1	**Ambient conditions**				
1.1	Weather data years	2	2	–	Nugent (2021)
1.2	Location	Hayfield VIC	Hayfield VIC	–	Nugent (2021)
2	**Feedstock details**				
2.1	Biomass collection radius	0	0	–	Dataset from consumer
2.2	Biomass moisture content	51 for normal pellets, 5 for green pellets	51 for normal pellets, 5 for green pellets	%	Dataset from consumer
2.3	Primary mill residues	15,100	15,100	bone dry tons/yr	Dataset from consumer
2.4	Urban wood residues	0	0	bone dry tons/yr	Dataset from consumer
2.5	Biomass Heating Value (HHV)	8761.42	8761.42	btu/dry lb	Dataset from consumer
3	**Plant specification**				
3.1	**Boiler parameters**				
3.1.1	Steam grade	752 & 5946.54	752 & 5946.54	F & psiq	Dataset from consumer
3.1.2	Percent excess fed air	20	20	%	National Renewable Energy Laboratory (NREL) (2021)
3.1.3	Number of boilers	1	1	–	Dataset from consumer
3.1.4	Flue gas temperature	390	390	F	Dataset from consumer
3.1.5	Boiler overdesign factor	1 & 1.5 & 2 & 2.5 & 3	1 & 1.5 & 2 & 2.5 & 3	%	National Renewable Energy Laboratory (NREL) (2021)
3.1.6	Design capacity of each boiler	899.54	899.54	Lb/hr steam	Dataset from consumer
3.2	**Steam rankine cycle**				
3.2.1	Rated cycle conversion efficiency	0.33	0.33	Fraction of nameplate capacity	National Renewable Energy Laboratory (NREL) (2021)
3.2.2	Minimum load	0.25	0.25	Fraction of nameplate capacity	National Renewable Energy Laboratory (NREL) (2021)
3.2.3	Max overdesign operation	1.1	1.1	Fraction of nameplate capacity	National Renewable Energy Laboratory (NREL) (2021)
3.2.4	Power cycle design temperature	77	77	F	National Renewable Energy Laboratory (NREL) (2021)
3.2.5	Temperature correction mode	Dry Bulb	Dry Bulb	Nil	National Renewable Energy Laboratory (NREL) (2021)
4	**Parasitic load**				
4.1	Parasitic load (% of nameplate)	10	10	%	National Renewable Energy Laboratory (NREL) (2021)
5	**System costs**				
5.1	**Indirect capital costs**				
5.1.1	Engineer, procurement & construction (EPC) & fixed costs	20 & 0	20 & 0	% & $	Aurecon Australasia Pty Ltd (2022)
5.1.2	Project, land, misc (PLM) & fixed costs	20 & 0	20 & 0	% & $	Aurecon Australasia Pty Ltd (2022)
5.1.3	Sales tax application as a percentage of load	80	80	%	National Renewable Energy Laboratory (NREL) (2021)
5.2	**Operation & maintenance costs**				
5.2.1	Fixed annual cost & escalation rate (above inflation)	181.31 & 0	184.12 & 0	$/yr & %	Aurecon Australasia Pty Ltd (2022)
5.2.2	Fixed cost by capacity & escalation rate (above inflation)	131.6 & 0	133.64 & 0	$/kw-yr & %	Aurecon Australasia Pty Ltd (2022)
5.2.3	Variable cost by generation & escalation rate (above inflation)	8.42 & 0	8.55 & 0	$/MWh & %	Aurecon Australasia Pty Ltd (2022)
6	**Feedstock costs (Annual Biomass Fuel Costs)**				
6.1	Distance-fixed delivery cost	0	0	$/dry ton	Dataset from consumer
6.2	Distance-variable delivery cost	0	0	$/dry ton-mile	Dataset from consumer
6.3	Primary mill residues	15,100	15,100	dry tonnes/yr	Dataset from consumer
7	**Financial parameters (Project Parameters)**				

(*continued on next page*)

Table A.15 (*continued*).

Number	Description	Value-2020	Value-2021	Unit	Reference
7.1	**Analysis parameters**				
7.1.1	Analysis period	20	20	Years	Aurecon Australasia Pty Ltd (2022)
7.2	**Project tax & insurance rates**				
7.2.1	Federal income tax rate	26	26	%	Australian Taxation Office (2021)
7.2.2	State income tax rate	0	0	%	Australian Taxation Office (2021)
7.2.3	Real discount rate	0.3037	0.3037	%	Australian Taxation Office (2021)

Data availability

Data will be made available on request.

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