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This is the Published version of the following publication

Woo, Heesung, Moroni, Martin, Park, Joowon, Taskhiri, Mohammad Sadegh and Turner, Paul (2020) Residues and bio-energy generation: a case study modelling value chain optimisation in Tasmania. Energy, 196. ISSN 0360-5442

The publisher’s official version can be found at
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Energy 196 (2020) 117007

Contents lists available at ScienceDirect

Energy

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

Residues and bio-energy generation: A case study modelling value chain optimisation in Tasmania

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ARTICLE INFO

Article history:
Received 6 July 2018
Received in revised form
5 December 2019
Accepted 20 January 2020
Available online 23 January 2020

Keywords:
Biomass supply chain
Biomass plant
Forest residue
Socio-economic
Residue utilisation
Value chains

ABSTRACT

Internationally biomass residues, primarily from forestry and agricultural production cycles, are increasingly being used to produce bio-energy. This case study presents modelling of the potential socio-economic impacts from a proposed co-generation bio-energy plant (under 50 MW) in the Valley Central Industrial Precinct (VCIP) in Northern Tasmania. The modelling uses data related to residue availability and bio-energy generation output to examine and evaluate potential impacts under a range of scenarios. Potential bio-energy residue feedstock is categorised into viable onsite and offsite sources and quantified in terms of their different bio-energy outputs for different sized bio-energy plants. To complete the evaluation of the potential socio-economic impact of the proposed plant, analysis is conducted using the JEDI (Jobs and Economic Development Impact model). The results of the modelling indicate that the location, quality and quantity of biomass residue feedstock and optimal socio-economic impacts are best aligned with the local supply chain by a bio-energy plant of (10 MW). Importantly, the modelling presented in this paper excludes consideration of forest harvest residues as a potential source of biomass residues due to the lack of certainty on the viability of commercial supply to the VCIP. In this context, it is anticipated that the underlying assumptions and approach used in this case study will be of value to other regions exploring the viability of bioenergy generation from biomass residues.

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1. Introduction

Over the last ten years, there has been an increased focus on utilising biomass residues including from forestry and agricultural production cycles to produce bio-energy. In Australia, despite some government support to encourage biomass utilisation for bio-energy, uptake has been relatively slow and limited in scale. One major inhibiting factor in the utilisation of biomass residues for bio-energy has been the lack of data on the quality and quantity of available biomass and accurate socio-economic modelling highlighting the potential benefits and returns from investments in this type of energy generation. While cost-efficient designs for bio-energy plants exist, understanding how they can be integrated into locally available residue supply chains remains problematic. This research paper aims to contribute to on-going investigations to address some of these challenges by modelling the potential socio-economic impacts of a proposed co-generation bio-energy plant (under 50 MW) in the Valley Central Industrial Precinct (VCIP) in Northern Tasmania. The modelling uses data related to residue availability and bio-energy generation output to examine and evaluate potential impacts under a range of scenarios. In preparing this case study, reviews of studies conducting similar modelling of biomass residues in bio-energy supply chains internationally have been evaluated [1].

In Australia, the Australian Renewable Energy Agency (ARENA) supports projects that advance renewable energy technologies and systems [2]. On the island of Tasmania, several studies have been conducted into the feasibility of individual biomass projects, and there have also been some reviews of opportunities for bio-energy

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https://doi.org/10.1016/j.energy.2020.117007
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on the island [3–6]. Significantly most of this previous work has focused primarily on options for the use of forest harvest residues, rather than forest processing residues or other types of wet and dry biomass residues currently available in Tasmania.

While these previous Tasmanian studies have concluded that forest biomass residues are available in sufficient quantities to support bio-energy generation, they have also acknowledged several barriers exist to their intensive and commercialised use. Importantly, this focusing on only technical issues related to the establishment of bioenergy plants [3] has tended to marginalise consideration of many important socio-economic and environmental aspects related to biomass residues supply chains. One of the most important social dimensions, especially in regional areas of Tasmania, is the effects of residue utilisation for bio-energy on employment [7]. This can be measured by the number of accrued local jobs (full-time equivalent per year) [8]. The more local jobs that are created, the higher the likely social benefits arising from any proposed bio-energy initiatives [9]. Another aligned social dimension worthy of consideration involves the need for open discussion of environmental and sustainability issues related to the utilisation of biomass residues for bio-energy generation. Indeed, ensuring all stakeholders and decision-makers understand the lifecycle impacts of biomass residue systems on their local economy (with or without bio-energy generation) is very important [10].

Internationally the majority of studies have also tended to consider either economic (techno-economic and optimisation studies) [11–14] or environmental (life cycle assessment studies) [15–20] aspects of bioenergy projects primarily in European and North America countries. Although recognition of the need to explore the complex intersection between the two is growing along with public interest in sustainable and environmentally sound business practices in bioenergy production and consumption.

Richgro biogas renewable energy plant in West Australia (WA), approximately 35,000 ton/annual of organic food waste and biomass waste were processed to generate heat and electricity energy. This is one of the first commercial biomass power plants in Australia. It is able to produce up to 2 MW of electricity and 2.2 MW of heat energy. Electricity is grid-connected, and excess heat is used in a hothouse, where blueberries are grown [21]. The biogas plant generated income from the gate fee for diverting the waste from landfill and the bio-fertiliser by-product. Also, there was a revenue of AUD 500,000 a year when it had sold on the power, and that is not including income from sales of the byproduct of energy generation such as bio-fertiliser. Also, Based on Kelly lake biomass plant in British Columbia (BC), Canada, the 10 MW biomass fire-power plant employ 24 total full-time employees including operators, material managers, and maintenance [22]. The examples of the WA biogas plant and Kelly lake bioenergy plant indicated that the benefit and revenue from the bioenergy industry in the local region is significant. In this context, developing a bioenergy plant in MVCIP region is highly recommended.

For this study, Tasmania provided an interesting case study. It has had few, if any, technical and cost-efficient designs for forest biomass supply chains and currently has no operating biomass plants in Tasmania or production of electricity using forest biomass. Beyond pure economics, environmental activism in Tasmanian over many years has raised public awareness on the need for a consideration of sustainability issues. This, in turn, has increased the pressure on decision-makers to understand the impacts of forest biomass industry on the local society, economy and environment. Finding ways to understand and mitigate undesirable impacts, while increasing the benefits associated with the use of forest biomass, and ensure the sustainability of new projects that attract community, government and investors' interest and support has to-date proven challenging for conventional economic or environmental approaches to bio-energy.

In this context, this research provides an in-depth study of availability, logistic efficiency and feasibility of forest residue utilisation for bio-energy in the MVCIP region, Tasmania, Australia. More specifically, this research has focused on identifying and analysing available evidence to address key questions of interest to the Tasmania biomass energy industry that are underpinned by an investigation into how the evolving forest residue might contribute to enhancing biomass energy feedstock and related issues for biomass energy supply chains in Tasmania.

The paper highlights how quantitative modelling techniques can support stakeholders and decision-makers to better understand and balance socio-economic and environmental factors in specific locations where bio-energy generation through locally sourced biomass residue supply chains is being considered. It is anticipated that enhanced understanding generated through the approach presented may contribute to mitigating undesirable impacts, increase the benefits associated with the use of biomass residues, and ensure the sustainability of new projects in ways that will garner community, government and investors' interest and support over the short, medium and longer-term.

2. Methodology

This section of the paper describes the methodological approach utilised to conduct the modelling of potential socio-economic impacts from a proposed co-generation bio-energy plant (under 50 MW) in the VCIP in Northern Tasmania. The approach is comprised of three key steps illustrated in Fig. 1.

The methodology aims to produce results for the optimal location of a biomass plant in VCIP. The first step involves the collection and analysis of data on potentially available biomass residues for bio-energy generation compiled from local industrial business sources and published reports. These potential biomass residues were classified into onsite and offsite feedstock options according to their distance from feedstock sources. The onsite feedstocks identified related to industrial waste from existing local industrial businesses (LIBs). The offsite feedstocks primarily focused on wood-based residues (processing residues) and non-wood dry material (agriculture and green waste). The modelling presented in this paper excludes consideration of forest harvest residues as a potential source of biomass residues due to the lack of certainty on the viability of commercial supply to the VCIP. The second step involves modelling of current and prospective energy demand and supply scenarios based on data from engagements with LIBs. In exploring options for meeting the estimated energy demands of VCIP, a series of scenario-based supply models were investigated that compare feedstock utilisation rates in different types of bio-energy plant types (boiler, electricity, and co-generation heat and power). This simulation modelling allows for a comparison of the total potential energy supply and the total energy demand for each bioenergy process. The different options provide additional detail on the supply scenarios, particularly the disaggregation of energy demand into gas and electricity. The third and final step completes the evaluation of the potential socio-economic impact of the proposed plant. This analysis was conducted using the JEDI (Jobs and Economic Development Impact model). In conducting this analysis, costs relating to permits, engineering, construction, equipment, and all development fees from planning to construction have been included [23–34]. The modelling also uses the data discussed above related to residue availability and bio-energy generation output to examine and evaluate potential socio-economic impacts under a range of scenarios.

The location of this case study is VCIP in Northern Tasmania, Australia. This precinct is located approximately 1 km north of the

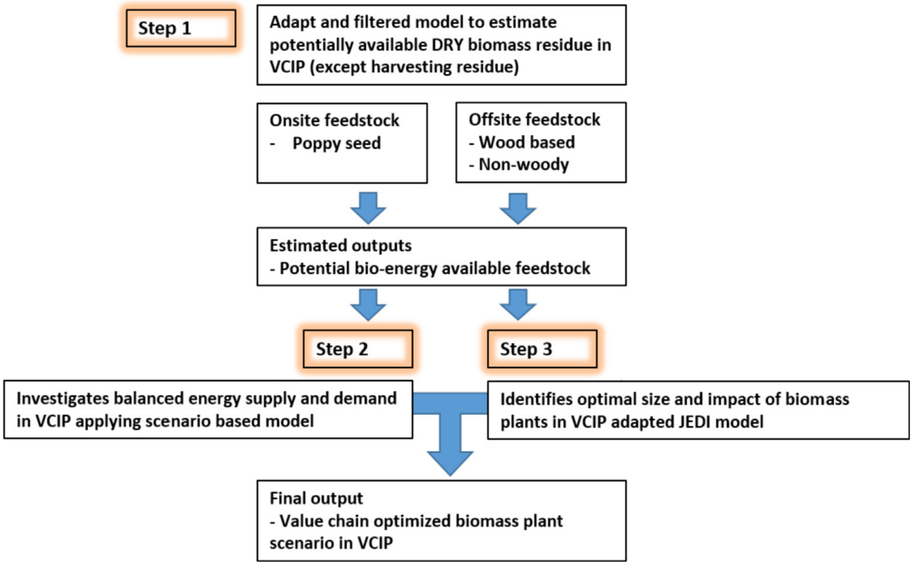

Fig. 1. The methodological approach used in the Valley central industrial precinct study.

small regional township of Westbury in the Meander Valley municipality (Fig. 2). Westbury and the VCIP are themselves located halfway between the two major northern Tasmanian cities of Launceston and Devonport. The total population of Meander Valley is around 20,000, with approximately 5700 working in the municipality. The major industries in the region are manufacturing, agriculture, forestry and fishing/aquaculture, construction, rental, hiring and real estate services, and arts & recreation services [35].

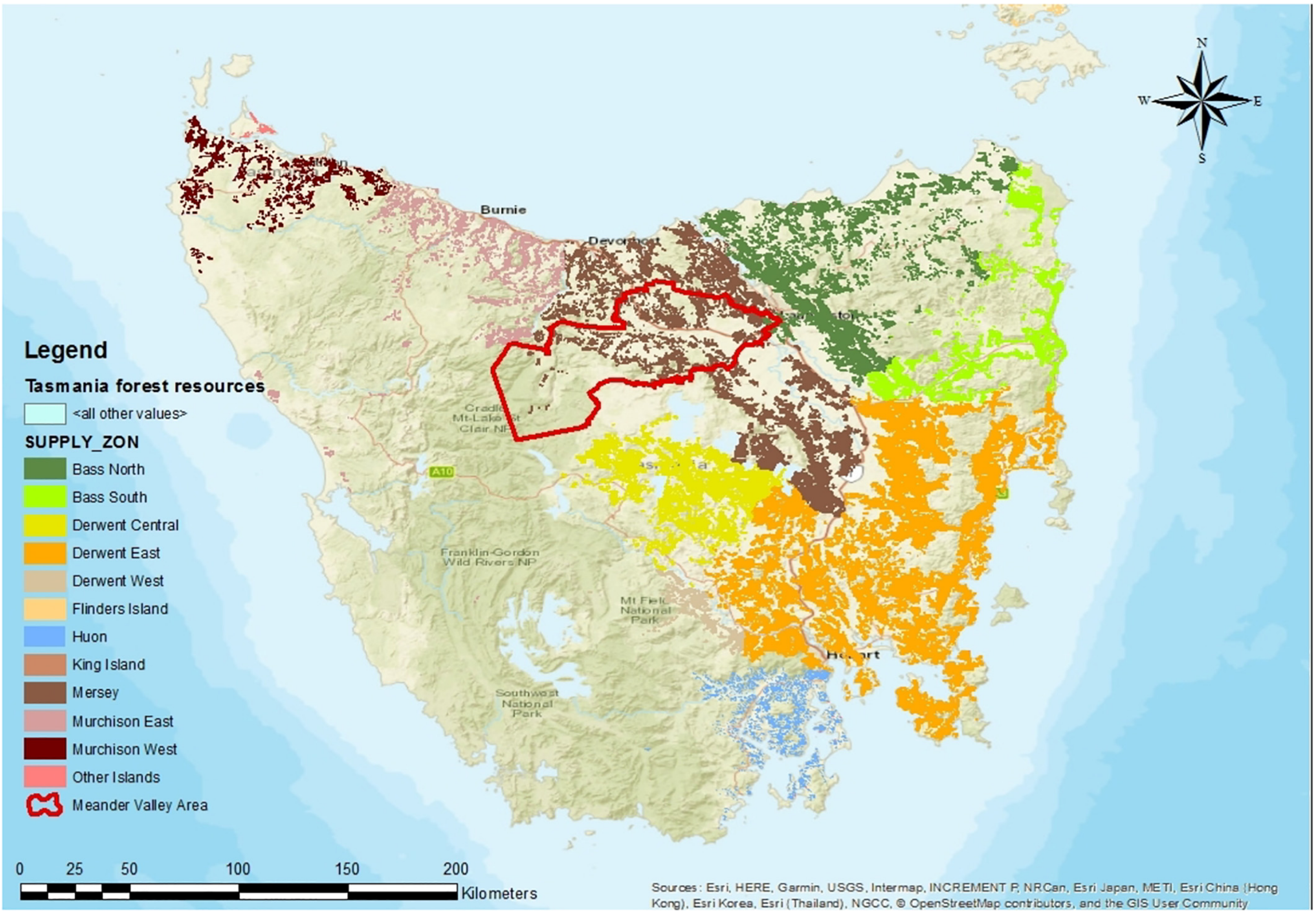

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Fig. 2. Location of the valley central industrial precinct (VCIP) in northern Tasmania, Australia.

Currently, 22 KV of electricity is supplied to the VCIP area via the main provider of electricity on the island, the TasNetworks' electricity company. Also, natural gas is available using the Tasmania Gas Pipeline. Importantly, the island has a history of hydro-electric power generation following large scale investments in infrastructure dating back to the 1950s and 1960s and more recently, additional alternative energy sources have seen investment including some wind-farms.

It is in this context that there has been recent interest in investigating the potential for a co-generation bio-energy plant at VCIP site to innovatively utilise industrial wet and dry biomass residues being produced by some LIBs as well as to potentially convert community food organic and green organic (FOGO) waste into energy. The potential future energy demand of Valley Central is assumed to be approximately 650,000 GJ/year by 2020 [21]. While the VCIP initiative is continuing to consider a range of bio-energy generation options including an anaerobic digester, this paper is primarily focused on modelling of a biomass co-generation combustion plant (i.e. using a boiler to co-generate heat and electrical power).

2.1. Estimation of available biomass residues for bioenergy generation

Estimation of potentially available biomass residues that could be used as feedstocks for a co-generation bio-energy plant draws on data compiled by independent consultants working on behalf of the local Meander Valley Council. The data used in the estimation of available biomass residues feedstock included information provided by local industrial businesses already based at the VCIP [21]. Other data sources included were:

a) Valley Central Industrial Precinct – Bio-energy Hub, Meander Valley Council; 2017 [21].
b) Forest Biomass for Energy in Tasmania, Dr Andreas Rothe, 2013 [4].
c) Energy from waste in Australia: a state by state update, Clean Energy Finance Corp, 2016 [36].
d) Stage 1 Residue Options Identification and Analysis, URS Australia 2014 [5].
e) Stage 2 Forest Residues Solutions Study, Indufor Asia Pacific 2016 [6].

In preparing to utilise these data as input into the modelling presented in this paper, potential biomass residues feedstock were divided into feedstocks available from local LIBs onsite at VCIP and those feedstocks that would require transport classified as offsite feedstocks. The onsite feedstock supply estimates relate to industrial waste from existing and proposed LIBs that are currently and likely to be available into the near future. The offsite feedstock supply estimates relate to both wood and non-wood materials that were identified as being potentially available for use in the bio-energy plant. These offsite feedstock estimates rely on data provided by businesses, researchers, consultants and estimates from residues generated by wood processors. As indicated above, while the VCIP is exploring a range of bio-energy generation options, the primary focus of this paper is modelling of a biomass co-generation combustion plant (i.e. using a boiler to co-generate heat and electrical power). As a result, non-woody and wet residues (aquaculture processing, dairy processing, and wastewater treatment) have not been included in this paper to conduct the modelling. On-going research is examining these offsite wet biomass residues, and this will be published in a subsequent research paper.

2.1.1. Wood-based biomass residues: processing and harvesting

2.1.1.1. Processing residues. Wood-based biomass residues can be generated from both forest harvesting operations and wood processing at mills. These woody biomass residues can be sourced from native hardwood, hardwood plantations and softwood plantations. In this study, processing residues are defined as residues created from the sawing or peeling of sawlogs into a range of wood products including bark, solid wood losses as well as offcuts from processing timber (Fig. 3). Importantly, for the modelling conducted in this research, it is assumed that:

a) Woodchips are not available as a biomass feedstock, as they are under existing supply chains and contracted into export markets
b) Other types of wood processing residues including sawdust, shavings, fuelwood and domestic firewood) are including as potential sources of biomass residues in this paper

2.1.1.2. Harvest residues. Woody harvest residues are defined as non-merchantable wood that is usually left in the forest, including the stumps, limbs, branches, and wood chunks. Unlike pulpwood, harvest residues tended not to be removed and utilised from operational harvesting sites [37]. Based on data in the URS Stage 1 report (2014), the estimated available harvesting residues in the whole of Tasmania were approximately 1 million tonnes per year in 2013/14. However, there is currently no actual industrial scale woody harvesting residue utilisation in Tasmania. The vast majority of woody harvesting residues from forestry operations are left on the ground frequently to be burnt and/or left to decay over time to return some nutrients to the forest soils. Major factors that have inhibited any utilisation of woody harvest residues for bioenergy include:

a) The lack of market demand for woody harvest residues for use in bioenergy generation in Tasmania – currently there is no major industrial-scale generation of bio-energy;
b) The relatively high supply chain costs for collecting, managing, and transporting harvest residues given the current operational harvesting techniques being deployed in Tasmania and the challenges of moisture management of slash piles;
c) Limited knowledge of how best to address environmental concerns related to the removal of significant volumes of harvesting residues from forest sites due to potential concerns about (soil nutrient depletion, and adverse impacts on wildlife habitats, etc.).

Significantly, there currently remains insufficient certainty about these factors, and as a result, it is not sensible or reasonable at this stage to include harvest biomass residue estimates into the modelling presented in this paper. Harvesting biomass residues were therefore not considered as potential bioenergy feedstocks in past and current assessments or relied upon for future business

Fig. 3. Processing and harvesting residues in Northern Tasmania a) Processing residues from the mill, b) Harvesting residues from forest operation sites.

case development.

As a result of these exclusions, the approach to generating actual biomass residue feedstock data in this research used a set of filters and criteria to produce the input data for the modelling. The primary filters used for assessing biomass feedstocks were distance and materiality. The distance of feedstocks to the VCIP was primarily limited to a 100 km radius. The only exception being for the inclusion of some woody processing residues that were included beyond this 100 km radius where pre-existing direct transport links for other products could be accessed. The secondary filters used reflected issues related to the potential sustainability of supply, energy value, availability, transport cost, handling cost, and regulation [21].

2.2. *Bio-energy supply and demand scenarios for the VCIP*

The current primary sources of energy being used by current and prospective VCIP stakeholders are electricity and natural gas. Electricity is mainly for lighting, heating, pumps, and industrial equipment operational requirements. The majority of natural gas is used for heating water using boiler combustion and generating steam. At present, identified energy demands in the VCIP are 11,081 Mhw/year of electricity and 34,342 Mwh/year of natural gas [21].

Based on recently completed contracts, expected demand for electricity is going to increase to 47,980 Mwh/year and for natural gas demand to 132,811 Mwh/year under a business as usual scenario. This means that the projected demand increases for electricity and gas will be 333% and 287% respectively. These assumptions are based on normal working hours (one or two shifts per workday) and operations running five days per week. That stated it was also noted during this research that some VCIP stakeholders had indicated a desire to increase operations across 24 h and seven days per week, suggesting the increased demand for energy is likely to be even greater than the estimates used above.

To aid in understanding the analysis presented and to ease comparison of data in the tables below, data extracted from secondary data sources reported in GJ/year have been converted to Mwh/year using a conversion factor (1 GJ = 0.277778 Mwh). In exploring options for meeting the estimated energy demands of VCIP, a series of scenario-based models were produced that compare feedstock utilisation rates in different types of bio-energy plant types (boiler, electricity, and co-generation heat and power) (Table 1).

2.3. *Modelling bio-energy plant impacts using the JEDI model*

Any investment to build and operate a bio-energy plant must balance total construction costs versus total energy output capacity once operational. Estimating these costs relies on several assumptions, including the plant size and capacity, geographical factors and local energy demand. Fortunately, as bio-energy generation has matured internationally most of these costs are well understood and can be modelled for Australian settings relatively easily. This stated, understanding the potential socio-economic effect of a bio-energy power plant in a specific location does depend on a number of variable costs that require careful consideration during modelling. These input costs include labour costs, biomass feedstock costs, and the pricing rate for heat and electricity energy in the broader energy marketplace.

In conducting this analysis, costs relating to permits, engineering, construction, equipment, and all development fees from planning to construction have been included. The modelling also uses the data discussed above related to residue availability and bio-energy generation output to examine and evaluate potential socio-economic impacts under a range of scenarios. The primary model used in the analysis is the (JEDI) jobs and economic development model [38]. This model has been developed based on assumptions and default values derived from a number of sources, including studies on bio-power, plant cost estimation, industry statistics and cost indexes. The list of data sources is presented below:

- Introduction to Biopower. Presentation to the NCSL Advisory Council on Energy [23].
- Biopower Technical Assessment: State of the Industry and Technology [24].
- Cost and performance data for power generation technologies [25].
- Renewable Energy Technical Assessment Guide [26].
- Renewable Power Generation Costs in 2012: An Overview [27].
- Conceptual Cost Estimating Manua [28].
- UC Davis technology assessment for advanced biomass power generation [29].
- Power Catalog of Technologies [30].
- Lessons Learned from Existing Biomass Power Plants [31].
- UK jobs in the bioenergy sectors by 2020 [32].
- Quantification of employment from biomass power plants [33].

Table 1
Description of detailed utilisation rates across six different Scenarios.

Scenarios[a]	Utilisation rate (%)	Utilisation rate (%)	Utilisation rate (%)
	Feedstock distribution (dry tonne/year)	Feedstock distribution (dry tonne/year)	Feedstock distribution (dry tonne/year)
	Boiler (heat only)	Electricity (power only)	Combined heat & power
S1	0%	0%	100%
	0	0	102,515
S2	0%	100%	0%
	0	102,515	0
S3	100%	0%	0%
	102,515	0	0
S4	25%	25%	50%
	25,629	25,629	51,258
S5	50%	50%	0%
	51,257.5	51,257.5	0
S6	30%	30%	40%
	30,754.5	30,754.5	41,006

[a] Series of scenario-based models were generated that compare feedstock utilisation rates in different types of bioenergy plant types (boiler, electricity, and co-generation heat and power).

- Jobs and Economic Development Impact (JEDI) User Reference Guide: Fast Pyrolysis Biorefinery Model [34].

The JEDI analysis requires several data such as regional-specific input-output multipliers, project-specific data, and personal expenditure patterns, and price deflators. The lack of any pre-existing biomass industry in Tasmania led to operational expenditure, salaries and wages and other key operating costs being benchmarked against a similar scale (10 MW) of biomass power generation feasibility study report conducted for the region of Lawrence, Kansas, US [39]. Project cost and job data used in this analysis were derived from the current cost estimation in a design case developed by Pacific Northwest National Laboratory (PNNL), NREL and Tasmania forestry input-output analysis reports [34,38,40]. Local revenue and supply chain impacts are estimated using economic multipliers derived from the REMPLAN and forestry socio-economic study in Tasmania [40]. Similarly, the lack of a pre-existing bio-energy market in Tasmania led to the adoption of the cost of feedstock ($/dry tonne) being based on US market prices for October 2017.

The analysis leveraged economic input-output (IO) analysis developed by Leontief (1986) as a key quantitative technique [41]. IO analysis is a system of linear formula that presents the distribution of each industry product to the other industries in an economy [42]. For example, equipment purchased by new bio-energy plant increase in other industries such as products from metal industries and equipment manufacturers. To determine the socio-economic impact of developing biomass energy plant using the JEDI model, three phases impacts were examined for each phase of expenditure. In the JEDI model, the effects were referred to as direct, indirect, and induced impacts [34].

- Direct impacts (project development and on-site labour impacts) is the on-site effects created by expenditure. For instance, the contractors and construction workers are counted as direct impacts.
- Indirect impacts (local revenue and supply chain impacts) include the impacts brought about by the bankers who finance the project, and metal industries and equipment manufacturers that provide the necessary materials to the biomass power plant.
- Induced impacts are the effects driven by spending of household earnings by direct and indirect beneficiaries.

To accomplish an analysis, demanded products and services to operate bioenergy plants (during construction and operation periods respectively) were identified for each expenditure, and the appropriate local multipliers were derived from REMPLAN and a forestry socio-economic study in Tasmania to apply in JEDI model [34,40]. The required multipliers, earnings (wage and salary), output (economic activity), and personal expenditure patterns were derived from the NREL default value (IMPLAN Professional model version 3.0) [43].

In the JEDI application, the initial version of the model developed uses multipliers for the year 2012 for inter-industry relationships and householding consumption patterns. Also, for default cost data in JEDI, the model automatically adjusts (inflation or deflation) costs during the model calculations to ensure costs are consistent with the multipliers. Inflators and deflators utilised in the JEDI model have assumed an average annual inflation rate of 2.0% [34]. The final outputs of the model (earnings and output) are then automatically recalibrated (deflated or inflated) and presented in the same dollar values as the project data costs. Table 2 presents derived data used for this research along with modelling for three different size bio-energy plants (50 MW; 25 MW; and, 10 MW).

3. Results and discussions

3.1. Potential bio-energy feedstocks for the proposed VCIP bio-energy plant

Table 3 presents the results of the investigation to estimate viable onsite and offsite bio-energy feedstock sources and to quantify the available energy content of these feedstocks for a co-generation bio-energy combustion plant.

The results highlight the significance of mill biomass residues for the overall potential supply of feedstocks for the bio-energy plant. Poppy production residues are the next biggest portion of available feedstock due to the output of one of the key stakeholder industries already based at the VCIP site. Based on these estimates, the total potential available biomass feedstock is estimated to be: 102,515 dry tonnes/year. Based on a default value of feedstock consumption being 57,242 dry tons/year (Table 2), the maximum capacity of an available biomass plant is therefore limited to 10 MW scale.

To operate and maintain a larger size of bio-energy plant (25 MW and 50 MW) poses significant challenges in terms of readily available feedstocks, transportation costs over distances greater than 100 kms and a requirement to include woody harvesting residues. Given the analysis already presented in this paper, it appears unlikely that these issues can be overcome in short to medium-term. As a result, this analysis concludes that only a 10 MW bioenergy plant is a viable option for the VCIP site.

3.2. Modelled energy supply and demand scenarios in the VCIP

The energy demand scenario includes the average and projected energy demands of the current and prospective VCIP site up until mid-2020. The scenario assumes a consistent energy demand of 180,790 Mwh/year from that point forward. The results present the combined scenarios of potential energy supply under the three bio-energy processes (heat-only boiler, electricity power only, and combined heat and power) and energy demand. A bio-energy plant has the potential to deliver a significant proportion of the onsite energy demand for VCIP stakeholders, subject to the bio-energy process selected and feedstock availability. Based on the modelling completed, the total energy demand in VCIP is 180,790 Mwh/year. Many industries in VCIP require heat and steam energy to operate and process their products (dairy, poppy seed, and processed meat). The heat and steam energy 132,810 Mwh/year (73.4%) is the most significant energy demands in VCIP. Focusing on the potential energy supply model, running solely with a boiler (heat only) would produce the most energy (424,657 Mwh/year). However, this would overwhelm the onsite demand for steam, which is shown from the gas demand (132,810 Mwh/year) (Table 4).

In Table 5 below scenario 3 (S3) would deliver the highest energy output (424,657 Mwh/year), at two times more than onsite total energy demand (180,790 Mwh/year) under the energy demand scenarios. However, S3 was developed only focusing on heat energy generation without electricity energy. Because of this lack of electricity energy generation, S3 is not the best scenario for energy supply to meet the energy demands at the VCIP. If a boiler was developed as the energy technology only for the generation of heat and steam the potential supply energy output could be delivered, given the better heat rates than can be achieved from combined heat and power generation (Table 4).

In scenario 1 (S1), a combined heat and power (CHP) plant has the potential to exceed the onsite energy demand both in electricity (power) and gas scenarios (heat and steam), and also in the highest energy output to satisfy both heat and power energy demand.

Table 2

Default value data used in the jobs and economic development impact (JEDI) analyses.

Size of the biopower plant	50 MW	25 MW	10 MW
Project Location	Tasmania	Tasmania	Tasmania
Year Construction Starts	2017	2017	2017
Construction Period (Months)	24	24	24
Project Size (MW)	50.0	25.0	10.0
Plant Cost (USD/KW)	3741	4606	6063
Plant Type	DC[a]	DC[a]	DC[a]
Plant Capacity Factor (Percent)	80%	80%	80%
Heat Rate (Btu/kWh)	14,000	14,000	14,000
Boiler Type	Stoker	Stoker	Stoker
Feedstock (Type)	FR[b]	FR[b]	FR[b]
Feedstock Consumption (Dry Tons/Year)	286,208	143,104	57,242
Cost of Feedstock (USD/Dry Ton) (US-california[c])	24.52	24.52	24.52
Produced Locally (Percent)	100	100	100
New Production or Sales (Percent)	100	100	100
Feedstock Supplier	On/off sites (VCIP)[d]	On/off sites (VCIP)[d]	On/off sites (VCIP)[d]
Farmer/Harvester (Percent)	100	100	100
Wholesaler (Percent)	0	0	0
Fixed Operations and Maintenance Cost (USD/kW/Yr)	19.99	27.70	45.76
Maintenance Cost - Non Fuel (USD/MWh/Yr)	4.36	6.01	9.35
Consumables Cost (USD/MWh/Yr)	3.69	3.69	3.69
Feedstock Cost (USD/Yr)	7,017,813	3,508,906	1,403,563
Annual Electricity Generation (MWh/Yr)	350,400	175,200	70,100
Money Value (Dollar Year)	2017	2017	2017
Project Construction Cost (USD)	187,052,000	115,144,012	60,629,412
Local Spending (USD)	18,691,600	11,506,029	6,058,533
Total Annual Operational Expenses (USD)	31,626,208	18,697,072	9,512,335
Direct Operating and Maintenance Costs (USD)	10,839,519	5,901,364	2,774,718
Local Spending (USD)	8,226,018	4,329,954	1,937,675
Other Annual Costs (USD)	20,786,689	12,795,708	6,737,617
Local Spending (USD)	0	0	0
Debt and Equity Payments (USD)	0	0	0
Property Taxes (USD)	0	0	0
Land Purchase or Lease (USD)	0	0	0

[a] Direct Combustion.
[b] Forest Residues from the industrial mill.
[c] Source, and.
[d] Valley Central Industrial Precinct [38].

Table 3

Estimation of potential bioenergy feedstock.

Feedstock	Wet weight tonnes	Moisture content	Dry weight tonnes
Mill residue[b]	122,100	45%	67,155
Green Waste[b]	14,300	45%	7865
Shredded pallet[b]	128	20%	102
Poppy seed-Tas[b] Alkaloids[a]	6860	7%	6380
Poppy seed-GSK[b]	10,000	7%	9300
Bran[b]	4560	7%	4241
Spent Mushroom[b] substrate[b]	5044	56%	2219
Grape Marc[b]	2250	7%	2093
Feedlot Waste[b]	4560	30%	3192
Total[b]	169,802	40%	102,515

[a] Onsite feedstock is located in meader valley council industrial precinct area.
[b] Offsite feedstocks are located within 100 km radius of meander valley council industrial precinct area.

Based on these results S1, combined heat and power process is the most suitable biomass energy process option for use at the VCIP.

However, the further detailed analysis would be required to determine the appropriate mix of bio-energy outputs (electricity and steam and hot water) and to assess the impact of distribution losses on the Valley Central site between the bio-energy plant and the industries in VCIP. Fig. 3 allows a comparison of the total potential energy supply and the total energy demand for each bio-energy process and scenario. Table 5 provides additional detail on these scenarios, particularly the disaggregation of energy demand into gas and electricity. Most of the combinations of co-generation of bio-energy options (S1, S4, and S6) and also the heat intensified energy generation scenario (S5) satisfy the demand of heat and electricity energy in VCIP (Fig. 4).

3.3. *Estimating the socio-economic impact of biomass plants at the VCIP site*

The results from the JEDI modelling across the three sizes of proposed bio-energy plant are as follows:

a) Employment Creation during construction: 411, 253, and 134 respectively for a 50 MW, 25 MW, and 10 MW bioenergy plant
b) Employment Maintenance during operation: 143, 81, and 41 respectively for a 50 MW, 25 MW and 10 MW bioenergy plant

Table 4
Estimated potential energy demand and supply capacity in Valley Central Industrial Precinct (VCIP).

Potential energy demand in VCIP				
		Gas(for heat and steam) (Mwh/year)	Electricity (power) (Mwh/year)	Total (Mwh/year)
		132,810	47,980	180,790
Potential energy supply scenario in VCIP				
		Energy output Boiler – heat only (Mwh/year)	Electricity (Mwh/year) – Power only	Combined heat & power (Mwh/year)
Scenarios (S)	Sum of Energy output (Mwh/year)	Utilisation rate (%) Energy output (Mwh/year)	Utilisation rate (%) Energy output (Mwh/year)	Utilisation rate (%) Energy output (Mwh/year)
S1		0%	0%	100%
	372,881	0	0	372,881
S2		0%	100%	0%
	111,984	0	111,984	0
S3		100%	0%	0%
	424,657	424,657	0	0
S4		25%	25%	50%
	320,600	106,164	27,996	186,440
S5		50%	50%	0%
	268,320	212,328	55,992	0
S6		30%	30%	40%
	310,144	127,397	33,595	149,152

Table 5
The results of the meander valley council region socio economic impact analysis.

	Created jobs[b]			Earnings[c] (million USD in 2017)		
During construction period	50 MW	25 MW	10 MW	50 MW	25 MW	10 MW
Construction Labor	121	74	39	$13.10	$8.00	$4.20
Construction Related Services	36	22	12	$2.20	$1.40	$0.70
Total Project Development and Onsite Labor Impacts	157	97	51	$15.30	$9.40	$5.00
Equipment and Supply Chain Impacts	49	30	16	$3.10	$1.90	$1.00
Induced Impacts	48	30	16	$3.00	$1.90	$1.00
Total Impacts	411	253	134	$36.70	$22.60	$11.90
During operational years	50 MW	25 MW	10 MW	50 MW	25 MW	10 MW
Onsite Labor Impacts	25	19	13	$1.1	$0.9	$0.6
Agricultural/Forestry Sector Only[a]	20	10	4	$1.5	$0.7	$0.3
Other Industries[a]	28	15	7	$2.2	$1.2	$0.6
Total Local Revenue and Supply Chain Impacts[a]	49	26	11	$3.7	$1.9	$0.8
Induced Impacts[a]	21	11	6	$1.3	$0.7	$0.4
Total Impacts	143	81	41	$9.8	$5.4	$2.7

[a] Local Revenue and Supply Chain Impacts.
[b] Created jobs refers to full-time equivalent (FTE) employment for a full year. One FTE equals 2080 h.
[c] Earnings refers to the wage and salary compensation paid to employees as well as benefits (e.g. health, retirement, legal mandate, etc.).

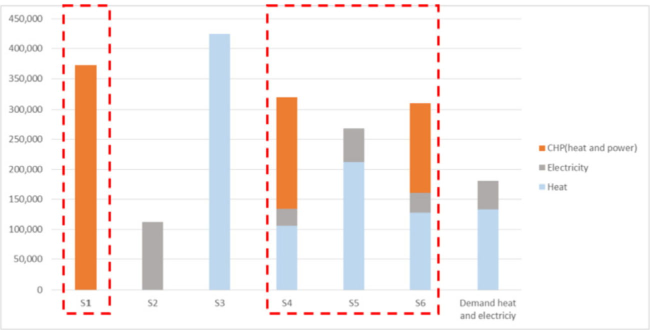

Fig. 4. Potential energy supply and demand balance scenarios.

The largest component of employment generation is during the construction period including total project development and onsite labour impacts. The results also reveal earnings from bio-energy industry will be USD 36.7 m, 22.6 m, and 11.9 m during construction and USD 9.8 m, 5.4 m, and 2.7 m USD during operational years including local revenue and supply chain impacts across the 50 MW, 25 MW, and 10 MW respectively.

The results indicate that total project development and onsite labour impact created most benefits both in the construction and operation periods (Table 5). Unsurprisingly the most significant local impact from biomass plant size was 50 MW, but the plant construction cost is three times more expensive than 10 MW biomass plant (Table 2). Given the feedstock capacity, the small scale (10 MW) of biomass plant is suitable for VCIP. The results indicated that 25 MW Project Construction Cost is multiple of that for the 10 MW (50 MW is multiple more than the 25 MW). However, when considering job creation, the construction of two 10 MW biomass plants would produce more jobs than one 25 MW biomass plant.

4. Conclusions

This case study has presented modelling that investigates potential socio-economic impacts from a proposed co-generation bioenergy plant of under 50 MW capacity, using data related to biomass residue feedstock and energy requirements at the VCIP in

Tasmania. Potential biomass residue feedstocks were categorised into viable onsite and offsite feedstock sources and quantified in terms of the available energy content of these feedstocks for a co-generation bio-energy combustion plant. Using a series of scenarios this paper has modelled bio-energy demand and supply under a variety of conditions and using various feedstock utilisation rates for different bio-energy generation processes (boiler, electricity, and co-generated heat and power). Based on the results, most scenarios with the different sized co-generation plant easily satisfy current and projected demands for heat and electricity at the VCIP site.

Importantly, the results confirm that based on readily available biomass feedstocks and excluding any woody harvest residues, and there are sufficient residues that can be accessed economically enough to satisfy energy demands at the VCIP site. The results also demonstrate that based on the available quality and quantity of biomass feedstocks and their associated supply chains, a small scale (10 MW) co-generation plant is likely to produce the best balance of socio-economic and sustainable environmental impacts.

As has been discussed in the manuscript, in Tasmania there few, if any, technical and cost-efficient designs for forest biomass supply chains. There has also been no comprehensive research into modelling socio-economic and environmental factors within the assessment of forest biomass supply chains in Tasmania. This manuscript is the first to specifically identify the key opportunities and challenges in Tasmania to support biomass energy implementation and linked it to the best International evidence and previous preliminary research that has been conducted into bio-energy supply chain opportunities in Tasmania and Australia.

Specifically, this paper has aimed to address the lack of detailed modelling on the potential of Tasmanian biomass residues to supply energy feedstock from forests managed on both public and private land for bioenergy operations. This is the first Tasmanina study focused on using agriculture, and mill residue as biomass feedstock based on an accurate availability estimation approach conducted in the Meander valley council industry precinct (MVCIP).

This research provides an original and novel in-depth study of availability, logistical efficiency and feasibility of forest residue utilisation for bio-energy in the MVCIP region, Tasmania. More specifically, this research has focused on identifying and analysing available evidence to address key questions of interest to the Tasmanian biomass energy industry that are underpinned by an investigation into how the evolving forest residue may directly contribute to enhancing biomass energy feedstocks and mitigate related issues in contemporary biomass energy supply chains in Tasmania.

The paper highlights how quantitative modelling techniques can support stakeholders and decision-makers to better understand and balance socio-economic and environmental factors in specific locations where bio-energy generation through locally sourced biomass residue supply chains is being considered. It is anticipated that enhanced understanding generated through the approach presented may contribute to mitigating undesirable impacts, increase the benefits associated with the use of biomass residues, and ensure the sustainability of new projects in ways that will garner community, government and investors' interest and support over the short, medium and longer-term.

Acknowledgement

This research used in this paper is funded through a major Australian Research Council (ARC) research project called: The ARC Centre for Forest Value <www.utas.edu.au/arc-forest-value> and Korea Forest Service (Korea Forestry Promotion Institute) project called: R&D Program for Forest Science Technology (Project No. 2019149C10-1923-0301).

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