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EVALUATING THE AVAILABILITY OF FOREST BIOMASS RECOURSES FOR BIOENERGY USAGE IN QUEENSLAND USING A GIS-BASED TOOL

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Abstract

The potential contribution of using forest biomass as renewable bioenergy is proven not only cost-effective but also know to mitigate effects of climatic change. This study aims to measure the availability of forest biomass for bioenergy production and climate change mitigation with a focus on forest in Queensland. Forest biomass has economic and environmental benefits, and a more energy efficient production system with optimal placement of these resources can be created. This research indicates the potential energy availability of forest biomass of the current forest estate in Queensland. This project aimed to: (1) estimate the total harvestable forest footprint in Queensland, (2) estimate the annual availability of forest biomass residues and (3) estimate the annual energy potential of forest biomass and identify the energy hotspots. The study uses a geographical information systems (GIS) based approach that focuses on the location of current hard- and softwood plantation and native forest available for production within Queensland and their corresponding energy contents. Data sets for this study are derived from the Australian Renewable Energy Mapping Infrastructure (AREMI), Queensland Government, private native forestry owners and plantation owners. Forest biomass volumes are converted into annual residue weight (dry tonnes) and later converted to energy (MJ) according to international energy conversion factors. Results indicate that a total area of 13.5 Mha of forest could potentially be available for biomass retention. This area can currently provide an average total of 1.17 million dry tonnes of biomass per year which equals a total energy content of 28 petajoules. Hot spot analysis indicates areas of interest for future bioenergy planning according to lows and highs in energy of forest biomass.

Introduction

Queensland, Australia's second largest state, has a total forest area of 51,034,000 ha or 41% of the national forest footprint [1]. Based on tenure types and potentially commercial species, an area of 17.4 Mha of native forest is commercially available for timber harvest together with 216,000 ha of plantations [2,3]. The total timber production in the financial year 2015-2016 equalled 2,946,580 m^3 [1]. The majority of this harvest has been from softwood plantation with the biggest density of forestry happening in southeast Queensland. The state has a total of 77 sawmills, six panel mills and two paper mills with a total capacity of 3,744,000 m^3 log input.

Bioenergy covers about 1.4% of the total energy use in Australia [4]. Of all the states Queensland has the lowest renewable energy penetration (5%) in Australia [4]. In order to reach renewable energy targets of 26% by 2030, the state needs to invest in both large and small-scale renewables.

Forest biomass is a valuable resource to produce bioenergy and mitigate climate change by replacing fossil fuels [5,6]. The large forest estate in combination with emerging renewable energy markets in Queensland, pushes for opportunities in the use of forest biomass for bioenergy production.

Estimating the potential of forest bioenergy is dependent on the available land, production levels and the energy levels. Several studies estimated the potential of different biomass resources in Australia and can be considered rough estimates [7,8]. The later [8], filled a research gap between nationwide studies [7,9,10] and regional cases such as studies by [11,12] in the Fitzroy Catchment or [13] in the Sunshine Coast council region in Queensland whom considered the area and feedstock for special purpose. Information on distribution, location, spatial density and seasonal supply of multiple biomass feedstocks is included in the above study [8] on a nationwide scale. This study present forest data in a non-consistent way as plantation forest represented by National Plantation Inventory (NPI) region and native forest is present on a statistical division (SD) level [8]. Additionally, native forest data only include areas for sawlog production and exclude all pulpwood harvest which restricts the area of interest to southeast Queensland only [8]. On a national scale, the SD or NPI level might provide some indication of forest biomass potential but on a state level this gives very little indication of where the actual forests and biomass resources are located and how this can be implemented in planning in design of efficient and sustainable supply chain management. Thus, the knowledge gaps around harvested forest area, production levels and energy levels of forests and forest biomass for bioenergy in Queensland remains.

This research aims to assist the forest industry and energy sector in better understanding location and availability of forest biomass. Assessment of forest biomass availability is based on research methods used in previous studies in Queensland [7,8,11,13,14] and data derived from the Australian and Queensland Government [15,16] accessed on the Australian Renewable Energy Mapping Infrastructure (AREMI) (https://nationalmap.gov.au/renewables/). Outcomes will present the potential availability of forest biomass but are likely to be overestimated since the use of forest residues will be considered for bioenergy purposes only. Quality and quantity measures of forest biomass will be considered according to data availability and several assumptions will be made in order to assess the potential availability. Specific objectives are set to: (1) map the footprint of harvestable forests in Queensland covering plantation and native forest estates both state and privately owned; (2) determine the annual harvestable biomass using optimised methods specified for each type of forest; and (3) estimate the annual energy potential of the total biomass availability and identifying energy hotspots for further development and planning of bioenergy facilities and supply chain optimisation.

Materials and methods

Mapping the footprint of harvestable forest in Queensland

Mapping of the forest footprint is performed using multiple forest dataset available on http://qldspatial.information.qld.gov.au/catalogue/custom/index.page and http://www.agriculture.gov.au/abares in ArcGIS Version 10.5.1. All datasets are clipped to the Queensland boundary. Forest ware separated into four different datasets: plantation softwood, plantation hardwood, hardwood native forest and softwood native forest. Dataset of plantation forest both soft and hard are readily available online and do not need further modification. For native forest the ‘Agricultural land audit - potential native forest – Queensland’ layer is used [2]. This layer indicates the commercial potential of native forest in three different classed (low - medium – high) and is created based on presence of commercial timber species in each regional ecosystem [17] in combination with LIDAR data on height of vegetation. Any area with a foliage projected cover of 15% or more is considered commercial. This can still be considered largely overestimated with a total area covering 17.4 Mha. This area is reduced by intersecting this layer with the ‘Forests of Australia (2013) v2.0’ and only remaining following species classification: Eucalypt Medium Closed, Eucalypt Medium Open, Eucalypt Medium Woodland, Eucalypt Tall Closed, Eucalypt Tall Open, Eucalypt Tall Woodland and Cypress [18]. The area is further reduced by only selecting those attributes with following tenures: Leasehold, Private and Multi-Use Forest. The final footprint is then separated into a native softwood layer containing only Cypress and a native hardwood layer containing all Eucalypt forest types. All individual land parcels classified as forests with a total area < 5 ha are excluded.

Estimating harvestable biomass in Queensland

All estimates of forest biomass are based on harvested log volumes published by the Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES) [19]. Data is available for hardwood native forest, hardwood plantation and softwood. The later category includes plantation softwood (Pine) and native softwood (Cypress). To extract the native softwood from the total softwood volumes, data from the Queensland Departure of Agriculture and Fisheries is used [20]. Volumes over a 5-year period (2011-2016) are averaged for each forest and residue type. Wood volumes are converted into dry mass using weighted average densities (air-dry) of sawlog and pulp logs for the most prominent species [21]. Volumes of sawlogs and other logs are used to estimate the availability of in field residues and mill residues. Pulp logs are reported as separate values and considered readily accessible as an additional source of forest biomass but are only extracted from hardwood and softwood plantations. Biomass availability is presented as dry tonnes per year (DMt yr^{-1}) with moisture content of 12% (air-dry).

Table 1: Dry density, proportion of WT and CTL harvest, Proportion of recovered field residue, sustainability proportion, proportion of sawmill residues and energy content of the four different forest types.

	Softwood plantation	Hardwood plantation	Softwood native forest	Hardwood native forest
Air-dry density (kg/m^3)	552.5	1039	675	1010
Proportion WT harvest	28%	28%	0%	0%
Proportion residues after WT harvest on site	10.8%	5%	N/A	N/A
Proportion CTL harvest	72%	72%	100%	100%
Proportion residues after CTL harvest	18.8%	16.3%	45%	40%
Sustainability	5%	5%	30%	30%
Proportion residues in sawmill	53%	65%	65%	60%
Energy conversion factor (MJ/kg)	21	20	21	20

For the field residue fraction of plantations, it is assumed that 28% of the plantation estate (soft- and hardwood) is harvested using a whole-tree (WT) harvest and 72% harvested using a cut-to-length (CTL) harvest according to information received from forest growers (HQP). All native forest is harvested using CTL method. The amount of residue left on site after WT and CTL harvest in softwood plantation is 10.8% and 18.8% respectively [22]. For hardwood plantation amounts of residues left on site after WT harvest are 5% and for CTL 16.3 % is left on site (Ghaffariyan, 2018). A total of 5% of the above ground biomass is retained for sustainability purposes in plantation [22,23]. This results in 13.8% above ground biomass available for bioenergy in softwood plantation and 11.3% in hardwood plantation. For hardwood native forest 40% of the total above ground biomass is considered residue [24,25]. Residues in softwood native forest compromise 45% of the total above ground biomass [26,27]. There is no current sustainability measure in Queensland indicating the quantity of residues that need to be left on site to secure nutrition and biodiversity. In this study a 30% sustainability measure is used in native forest according to literature and personal communication [7,8]. Total biomass availability is presented on a Statistical Area level 2 (SA2). A list of conversion factors is provided in Table 1. Sawmill residue recovery rates are estimated using data from available literature and presented in Table 1. Residues include chips, bark, sawdust and shavings [26,28,29].

Mapping energy availability of forest biomass in Queensland

Total biomass availability of each forest type is converted into an annual energy value (MJ yr^{-1}) using energy conversion factors (Table 1) derived from literature [30]. Biomass availability is then combined with the previously mapped harvestable forest footprint. Total residues of field, sawmill and pulp log are proportioned according to the area of each forest parcel (polygons). This combination of polygons is then used for a hotspot analysis in ArcGIS version 10.5.1. The hotspot analysis creates a map of statistically significant hot and cold spots using the Getis-Ord Gi* statistic. It evaluates the characteristics of the input feature class (energy content of each forest parcel) to produce optimal results. This tool identifies statistically significant spatial clusters of high energy values (hot spots) and low energy values (cold spots).

Results and discussion

Estimating harvestable forest area and forest biomass availability in Queensland

The total harvestable area of forest in Queensland is estimated to be 13,582,799 ha including both plantation and native forest (Figure 1). The estimate of total harvestable for each forest type has been calculated according to parcels bigger than 5 ha. Estimated total potential availability of forest biomass over the period 2011-2016 is 1,177,373 DMt yr^{-1} (Table 2). Softwood plantation provide nearly half of the total residue (775,618 DMt yr^{-1}) where hardwood plantation values are considerably lower. This value is comparable with the 738,000 DMt yr^{-1} for 2010 presented for NPI regions in Queensland in previous studies [8]. Hardwood plantation are a fairly new term in Queensland. Many of the privately-owned hardwood plantations have failed and are converted into agricultural land. It is therefore hard to estimate the standing area of hardwood plantations. The overall contribution of this resource is low and would have very low impact on the total energy value of forest biomass. Maintaining a 30% sustainability in native forest is not assumed an official guideline in Australia. Information in terms of sustainability is low and opinions vary. Although the 30% is a considerable value according to guidelines used by United States Department of Agriculture. Field and sawmill residues of the native hardwood forest estate provide a large proportion of the total biomass (303,170 DMt yr^{-1}). The total area of hardwood native forest is very large and most likely still overestimated. The quantity of residues is however calculated based on the amount of sawlogs processed and thus the actual footprint has no direct effect on the calculations of forest biomass availability. The estimation of total native forest biomass (soft- and hardwood) is 391,077 DMt yr^{-1} and is about the double of what is published in the past (290,000 DMt yr^{-1}) for the state [8]. This later research only focussed on 5 statistical divisions in the southeast and exclude large amounts of native forest towards the north of Queensland.

Total biomass availability from all forest types was combined and presented in Figure 2 on a statistical area level 2. The amount of residues per SA2 varied from 0.18-186,092.54 DMt yr^{-1} and are classified into 40,000 DMt yr^{-1} intervals. Statistical areas such as Cape York and Maryborough Region – South appear to have the highest amount of residues followed by regions such as Roma, North Rockhampton, Cooloola and Gympie (Figure 2). Cape York however, is considered a very inaccessible area with poor infrastructure and thus it will be very unlikely to have biomass or timber harvest on a commercial scale. Areas in the south west (white) have no forest or residues availability.

Table 2: Results of total area (ha) estimates and residues (dry tonnes) (pulp log, field residue and sawmill residue) present as separate values for each forest type.

	Total area (ha)	Pulp log (DMt yr^{-1})	Sawmill residues (DMt yr^{-1})	Field residues (DMt yr^{-1})	**Total residues (DMt yr^{-1})**
Softwood plantation	**190,542**	194,060	447,412	135,146	**776,618**
Hardwood plantation	**41,187**	7,422	1,880	376	**9,678**
Softwood native forest	**459,309**	0	44,976	42,931	**87,907**
Hardwood native forest	**12,891,741**	0	176,472	126,698	**303,170**
Total	**13,582,779**	**201,482**	**670,740**	**305,151**	**1,177,373**

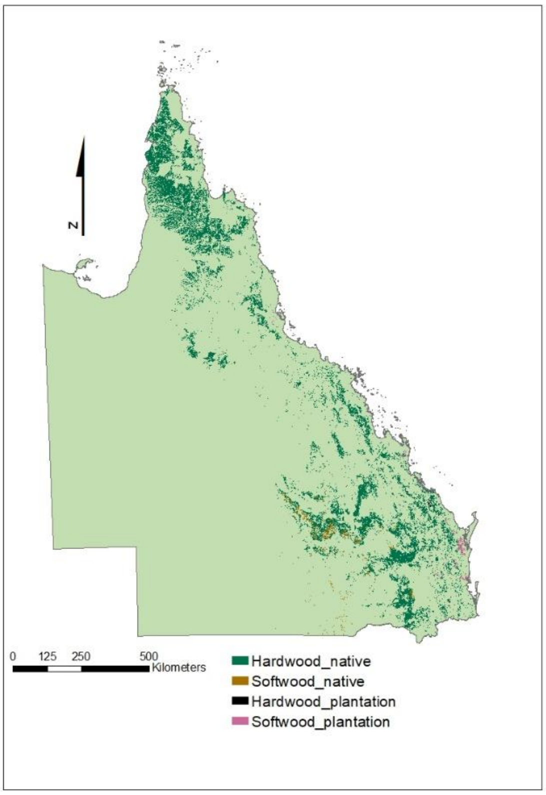

Figure 1: Forest footprint in Queensland, divided into four different forest types. Each forest estate is bigger than 5 ha.

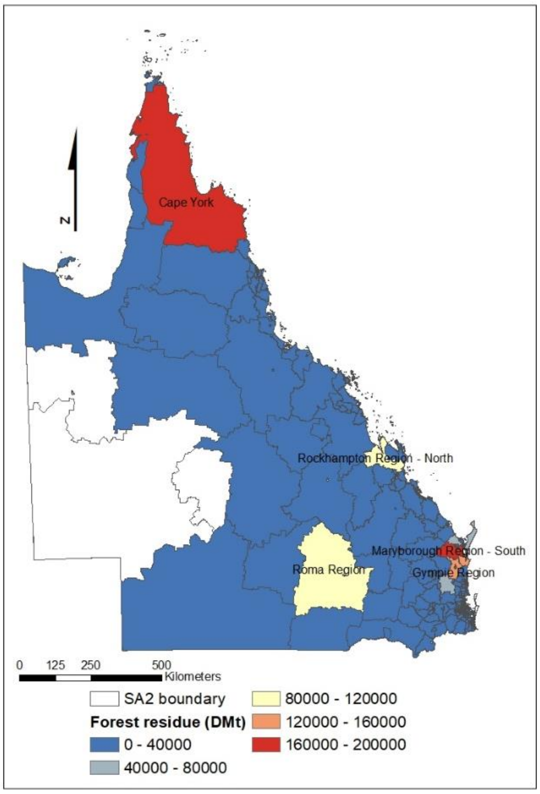

Figure 2: Total forest residue (DMt) including pulp log, field residue and sawmill residue of the entire forest estate divided into SA2.

Total biomass values (DMt yr^{-1}) are converted into energy values (MJ yr^{-1}) using intenrationally published energy conversion factors (MJ/kg) by the Food and Agriculure Organisation (FAO). All forest types with respective energy contents are then merged with a total enenergy availability of 28 E^9 MJ yr^{-1} (28 Petajoule yr^{-1}). Optimized hot spot analysis using ArcGIS is then performed to indicate hot spot energy zones with significant confidence levels of 90% - 95% - 99% (Figure 3). This method identifies location of forest with densest energy content. Information like this can support industry in further planning and development of the biomass supply chain and provide geografic suggesiton on where powerplants can be inplemented.

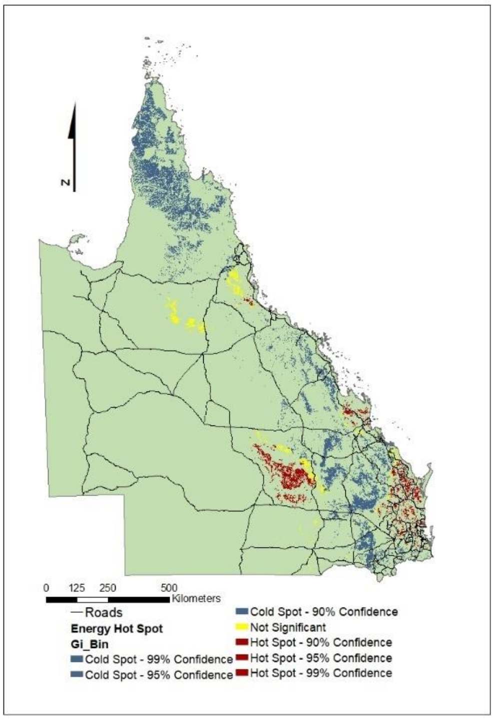

Figure 3: Optimized hot spot analysis map created in ArcGIS version 10.5.1 overlayed with the major roads in the state of Queensland. Hot spots are divided into three categories of confidence level (90%-95%-99%) and indicated in red.

Conclusion

This project provided a broad assessment of forest biomass availability in Queensland in softwood and hardwood plantation, softwood native forest and hardwood native forest with increased resolution in the used harvesting techniques and residues proportion left on site after respective harvest. The total harvestable area was estimated based on commerciality, species and tenure of the forest area. There was no clear guideline in Australia or Queensland regarding the amount of biomass that must be left on site for sustainability and nutrient cycling purposes. The research implemented a more international guideline. Total biomass availability was converted into an energy value before processing that should simplify decision making in further planning and development of the biomass supply chain. Future research should investigate more in-depth information with regards to sustainability of forest biomass use in Queensland, adopt and optimise cost and logistics of supply chain based on hot spot location of forest biomass and respective energy content.

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