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Assessment of the Environmental Impact of Biomass Electricity Generation in Thailand

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Abstract- This paper presents the results of the environmental impact assessment into the electricity generation process by means of bagasse fuelled biomass power plants in Thailand, using the life cycle assessment (LCA) tool. The environmental aspects of concern included Human Health, Ecosystem Quality and Resource Depletion. The environmental impact results were calculated in terms of eco-points (Pt) per functional unit of 1 kWh. The characterised data for 1 kWh of bagasse electricity generation was compared with data for 1 kWh of combined cycle and thermal electricity generation in Thailand, using the same set of characterisation factors. Two scenarios for bagasse were evaluated: production of bagasse and usage of bagasse. In production of bagasse, environmental impacts depended significantly upon the diesel consumption for tractors on farms, fertilizers and pesticides used for cane cultivation, diesel consumption for cane and bagasse transportation. Overall this stage was found to have a greater impact upon the environment when compared to the second stage of generating electricity using bagasse. Furthermore, the overall environmental impact caused by bagasse electricity generation was found to have the lowest environmental impact when compared with combined cycle and thermal electricity generation in Thailand.

Keywords Biomass power plant, life cycle assessment, environmental impact, bagasse electricity generation.

1. Introduction

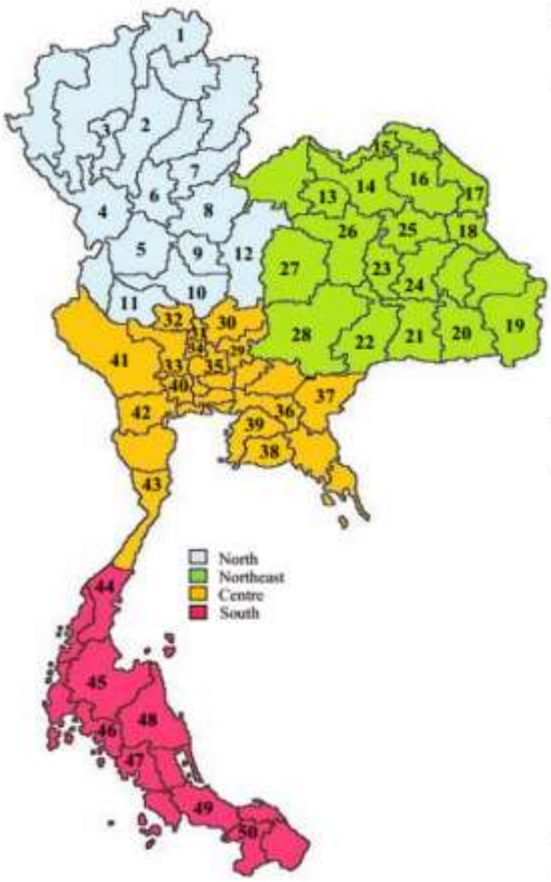
Biomass is biological material derived from living, or recently living organisms [1]. In the context of biomass as a resource for generating energy, it most often refers to plants or plant-based materials, which are not used for food or feed [2]. There are many advantages to generating electricity using biomass when compared to fossil fuels, including lower greenhouse gas emissions, energy cost savings, improved security of supply, waste management/reduction opportunities and local economic development opportunities [3 - 5]. Biomass can be converted into electricity through several methods. The most common is direct combustion of biomass. Other methods include gasification, pyrolysis, and anaerobic digestion. In a direct combustion system, biomass is burned in a furnace to generate heat, which is then fed into a boiler to generate steam, which is expanded through a steam turbine to produce electricity [6].

Biomass can be produced abundantly within the Thailand. The country's predominantly agricultural economy has long made biomass the traditional energy source in rural areas, which constitute the majority of the country. Biomass can be divided into top trashier, bagasse, paddy husk, rice straw, maize stalk, cassava stalk, cassava root, oil palm, coconuts shell, coconuts husk, coconuts frond, groundnuts shell, cotton stalk, soybeans stalk, soybeans leaves, soybeans shell, sorghum leave, sorghum stem, charcoal, fuel wood, frond, sawdust and pineapple stalk. The majority of biomass is consumed as heat energy. The remainder is electricity. Thailand increasingly relies upon biomass to supply its consumption needs, and over the last five years biomass has grown at a much greater rate proportionally than traditional forms of electricity generation, due to government initiatives such as Thailand Power Development Plan 2015-2036 (PDP2015) and Alternate Energy Development Plan 2015-2036 (AEDP2015).

The Thailand Power Development Plan 2015-2036 (PDP2015) lays out Thailand's energy and investment plans for the next 21 years. The aim is to double Thailand's installed energy capacity in the next two decades to reach 70,410 megawatts by 2036. This will involve developing not only traditional production, but also significant and longterm investment in alternative energy and energy conservation [7]. The Alternative Energy Development Plan 2015–2036 (AEDP2015) was developed to analyze Thailand's current renewable energy use and potential, and develop ways to increase future production, with an aim to reducing dependence on fossil fuels. By developing extra capacity, it is hoped that within 20 years the percentage of the country's total electricity demand supplied by alternative energy generation will rise from 8% to 20% - representing an increase of 19,635 MW [8]. Under the AEDP2015, renewable energy will be used in the production of power, heat and biofuels. Common to both power and heat production will be municipal solid waste (MSW), biomass, biogas, and solar power. Power generation will also utilize hydro and wind power, whilst geothermal power will contribute to heat production. For the production of biofuels, booth ethanol and biodiesel will be used. The installed capacity of alternative energy under the AEDP2015 is set to rise from 7,490 MW in 2014, to 19,634 MW in 2036 [9].

In 2015, the total energy generated by renewable sources was 10,077 ktoe. The majority of this, just over 5,990.20 ktoe, was consumed as heat energy from biomass. The total installed capacity of electricity generation using biomass was 532.80 ktoe. The remainder was split between biofuels (ethanol and biodiesels), electricity (large hydro power, solar energy, biogas, wind energy, small hydro power and MSW) and heat energy (biogas, MSW and solar energy), which amounted for 1,942 ktoe, 1,023 ktoe and 589 ktoe respectively. Biomass investment by government and private sectors was 33.237 billion Baht. The installed capacity of electricity generated from biomass was 532.80 ktoe or 2,726.60 MW, up 11.20% from the previous year. Analyzing the potential of biomass electricity generation in the various geographical regions of Thailand, the potential of the northeast was found to generate the most, with a total of 1,189.29 MW, followed by the centre, the north and the south generating 830.72 MW, 611.76 MW and 94.83 MW respectively [10]. Nakhon Sawan province had the greatest installed capacity, as shown in Fig. 1.

This study therefore focuses on evaluating the environmental impact of electricity generation using biomass. The environmental impact was measured using life cycle assessment or LCA [11]. This is a technique that evaluates the environmental impact of each stage of a product's life, from cradle to grave, thus enabling a quantitative estimation of its environmental impact at every stage of its life cycle [12]. The LCA provides a comprehensive view of the various environmental aspects of the product or process, thus creating a more accurate picture of the environmental trade-offs in product and process selection, and ensuring a more accurate decision making process [13, 14]. The four stages of the LCA are: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation [15 - 17].



No.	Province	Installed capacity (MW)	No.	Province	Installed capacity (MW)
1	Chiang Rai	0.16	29	Saraburi	49.50
2	Lampang	8.00	30	Lop Buri	68.60
3	Lamphun	9.50	31	Sing Buri	14.00
4	Tak	16.00	32	Chai Nat	9.00
5	Kamphaeng Phet	110.00	33	Suphan Buri	174.30
6	Sukhothai	36.00	34	Ang Thong	6.20
7	Uttaradit	23.30	35	Ayutthaya	9.90
8	Phitsanulok	20.50	36	Chachoengsao	81.80
9	Phichi	49.40	37	Sa Kaeo	160.12
10	Nakhon Sawan	230.90	38	Rayong	1.00
11	Uthai Thani	68.00	39	Chon Buri	42.40
12	Phetchabun	40.00	40	Nakhon Pathom	20.40
			41	Kanchanaburi	123.00
			42	Ratchaburi	46.50
			43	Prachuap Khiri Khan	24.00
	North	**611.76**		**Centre**	**830.72**
13	Nong Bua Lam Phu	38.00	44	Chumphon	9.50
14	Udon Thani	44.99	45	Surat Thani	16.70
15	Nong Khai	9.90	46	Krabi	19.60
16	Sakon Nakhon	1.20	47	Trang	12.83
17	Nakhon Phanom	0.30	48	Nakhon Si Thammarat	8.40
18	Mukdahan	33.00	49	Songkhla	17.90
19	Ubon Ratchathani	30.40	50	Yala	9.90
20	Si Sa Ket	9.00			
21	Surin	78.00			
22	Buri Ram	139.40			
23	Maha Sarakham	36.00			
24	Rio Et	60.10			
25	Kalasin	186.00			
26	Khon Kaen	192.00			
27	Chaiyaphum	162.00			
28	Nakhon Ratchasima	169.00			
	Northeast	**1,189.29**		**South**	**94.83**

Fig. 1. Installed capacity of biomass electricity generation by province [10].

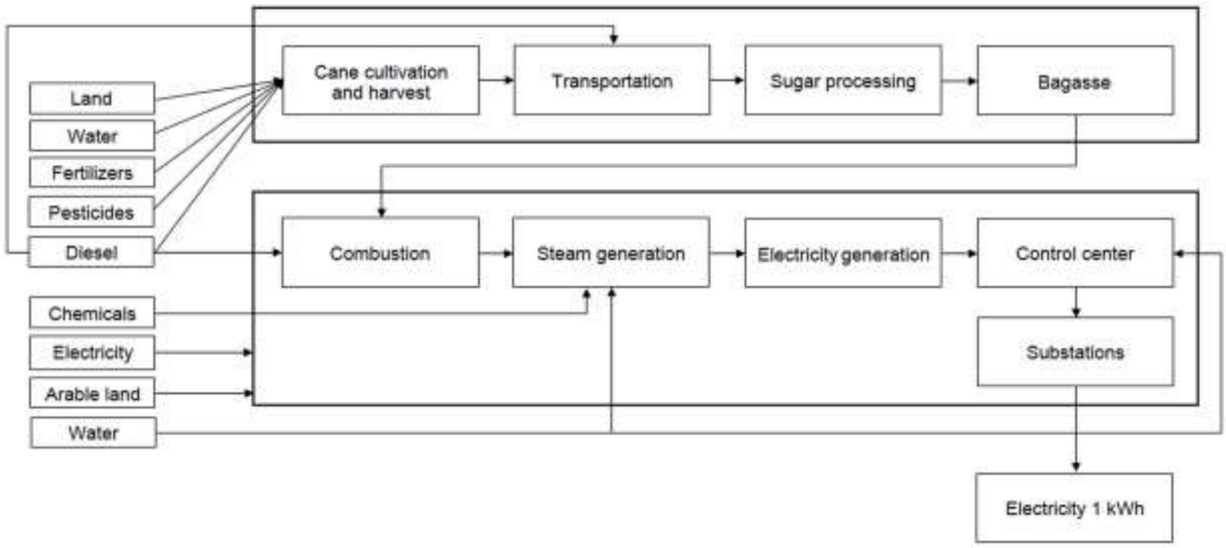


Fig. 2. The system boundary of electricity generation from bagasse [19].

2. Goal and Scope Definition

2.1. Goal

This study assessed the environmental impact, at each stage of the process, of electricity generation from biomass using bagasse as a fuel, to develop an environmental profile. Two biomass power plants were analyzed; one biomass power plant in Nakhon Sawan province, northern Thailand, the largest in the region (generating 60 MW), and one biomass power plant in Buri Ram province, northeastern Thailand (generating 10 MW).

2.2. Functional Unit

The functional unit used for this study is 1 kWh of electricity generated from bagasse.

2.3. Allocation

Bagasse is a product of the sugar refinement process and biomass power plants are often built in tandem with refineries [18]. The electricity produced generates significant revenue for Thailand's sugar industries and is now considered an important by-product rather than waste. Hence, when the environmental impact of bagasse burning biomass stations is analyzed, the impact of the sugar refining process (hence production of bagasse) must also be assessed, in addition to the electricity generation process.

2.4. System Boundaries

The main stages of the electricity generation process from biomass are therefore production of bagasse and usage of bagasse, as shown in Fig. 2.

The initial stage, production of bagasse, involved sugar cane production, and sugar refining. Life cycle assessment for bagasse production encompassed all stages, from cane cultivation to sugar processing. The system boundaries of bagasse production were cane cultivation and harvest, road transportation and sugar processing. (See Fig. 3.)

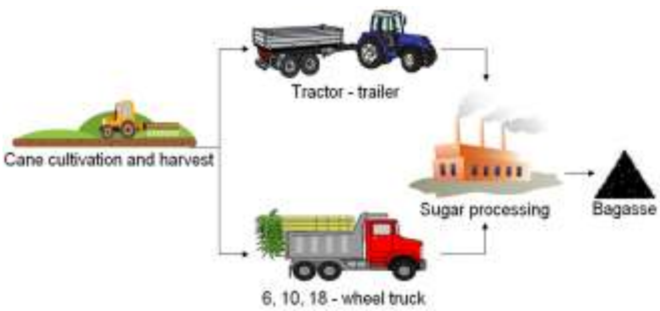


Fig. 3. The system boundaries of production of bagasse [20, 21].

Land, water, fertilizers, pesticides and diesel were used for cane cultivation and harvest. Land requirements for cane cultivation and harvest measured 120.573 m^2/t of cane. Fertilizers for cane cultivation measured 7.54 kg/t of cane. Pesticides for cane cultivation measured 0.061 kg/t of cane. Diesel consumption by tractors on farms measured 1.797 l/t of cane [22].

Road Transportation involved moving the cane from the fields to the factory. Cane transportation was classified according to the size of vehicle appropriate to the distance. For example, tractor-trailers and 6-wheel trucks were used when cane was produced in close proximity to the mill, consuming a limited quantity of diesel, whilst 10-wheel and 18-wheel trucks were used for longer distance because of their greater load capacity. Table 1 shows the size of cane transportation vehicles and diesel consumption.

The sugar processing stage was composed of extraction of juice from the cane, juice treatment, filtration and clarification, boiling, moulding and packaging [23]. Bagasse is a product of the filtration and clarification of the juice.

Table 1. The size of cane transportation and diesel consumption of vehicles [22]

Vehicle	Quantity (t of cane/vehicle)	Diesel Consumption of Vehicle (km/l)	
		Without Cane	With Cane
Tractor-trailer	29.75	3.25	2.75
6-wheel truck	12.50	3.70	2.65
10-wheel truck	21.50	3.00	2.47
18-wheel truck	36.00	5.05	2.84

The second main stage, usage of bagasse, is where the bagasse is used to generate electricity in the biomass power plant. The system boundaries of bagasse usage encompassed combustion, steam generation, electricity generation, the control center and substations, as shown in Fig. 4.

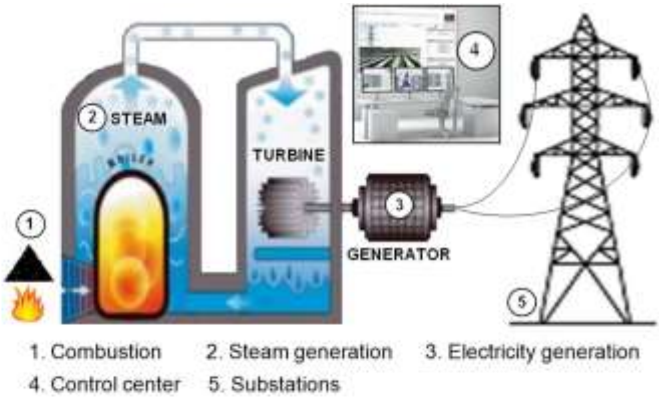


Fig. 4. The system boundaries of usage of bagasse [24 - 28].

Bagasse from sugar processing is burned (direct combustion) as fuel. The heat from bagasse combustion flows to a high pressure boiler or steam generator to create steam. The steam drives the steam turbine, which is then used to generate electricity [29]. Finally, substations transforms voltage from high to low voltage so it can flow to the consumer [30]. All processes for generating electricity are controlled by the control center.

3. Life Cycle Inventory

Life cycle inventory (LCI) was the tool used to analyze the data input and output from the various processes. The input and output data was obtained from surveys of the two plants (system studies, material measurement and accounting). Table 2 lists the data used in the analysis for the production of bagasse per 1 kWh of electricity generated. There was a marked difference between input and output data for the northern and northeastern power plants and this can be explained by the greater efficiency of the northern plant. In order to generate 1 kWh of electricity, the northeastern plant required more than double the amount of bagasse (5.88 kilograms) compared to the northern plant (2.17 kilograms). Table 3 shows the data accrued from the second stage, the usage of bagasse per kWh of electricity. At the steam generating process, the northern and northeastern plants again had notably different results. This was owing to the two plants use of different techniques to generate their steam - only the northern plant required chemicals to control the water quality in the boiler.

Table 2. Input and output associated with the production of bagasse per kWh electricity generated from biomass power plants

Description	Subsystems	Unit	Power Plant in the North	Power Plant in the Northeast
Input				
Land requirement	Cane cultivation and harvest	m^2	3.6630	9.9254
Water	Cane cultivation and harvest	m^3	0.0436	0.1182
Fertilizers	Cane cultivation and harvest	kg	0.1714	0.4645
Pesticides	Cane cultivation and harvest	kg	0.0067	0.0182
Diesel	Cane cultivation and harvest	kg	0.0623	0.1688
Diesel	Transportation	kg	0.0558	0.1511
Package	Sugar processing	kg	0.0020	0.0053
Lime	Sugar processing	kg	0.0202	0.0547
Biocides	Sugar processing	kg	0.0002	0.0006
Lubricant oil	Sugar processing	kg	0.0001	0.0002
Antiscale	Sugar processing	kg	0.0004	0.0012
Flocculant	Sugar processing	kg	0.0002	0.0006
NaOH	Sugar processing	kg	15.7833	42.7676
Output				
Ash and cane burning emissions	Cane cultivation and harvest	kg	5.2929	14.3419
Harvested cane	Cane cultivation and harvest	kg	30.4605	82.5382
Bagasse	Sugar processing	kg	2.17	5.88

Table 3. Input and output associated with the usage of bagasse per kWh electricity generated from biomass power plants

Description	Subsystems	Unit	Power Plant in the North	Power Plant in the Northeast
Input				
Bagasses	Combustion	kg	2.17	5.88
Electricity	All	kWh	1.09E-01	2.02E-01
Arable land	All	m^2	1.43E-04	1.82E-03
Diesel	Combustion	kg	2.71E-03	4.41E-03
Humidity	Combustion	kg	1.16E+00	3.16E+00
Carbon	Combustion	kg	1.25E+00	3.39E+00
Hydrogen	Combustion	kg	1.71E-01	4.64E-01
Sulphur	Combustion	kg	6.56E-02	1.78E-01
Nitrogen	Combustion	kg	2.34E-02	6.35E-02
Chloride	Combustion	kg	1.00E-04	3.00E-04
Water	Steam generation / Control center	m^3	1.79E+03	2.35E+03
Hydrazine	Steam generation	kg	6.07E-06	-
Trisodium phosphate	Steam generation	kg	6.07E-06	-
Sulfuric acid	Steam generation	kg	6.07E-06	-
Anionic polymerization	Steam generation	kg	1.21E-03	-
Sodium hypochlorite	Steam generation	kg	8.89E-05	-
Polyaluminium chloride	Steam generation	kg	6.98E-04	-
Hypersperse MDC702	Steam generation	kg	2.75E-05	-
Non-Oxidizing Biocides	Steam generation	kg	5.90E-05	-
Sodium hydroxide	Steam generation	kg	3.70E-06	-
Hydrochloric acid	Steam generation	kg	1.43E-06	-
Steam	Electricity generation	kg	5.20E+00	1.41E+01
Output				
Ash	Combustion	kg	8.82E-02	2.39E-01
Arsenic	Combustion	kg	2.80E-07	7.69E-07
Cadmium	Combustion	kg	2.24E-09	5.99E-09
Chromium	Combustion	kg	1.54E-06	2.18E-06
Copper	Combustion	kg	1.04E-06	2.82E-06
Lead	Combustion	kg	2.20E-07	5.89E-07
Ammonia	Steam generation	kg	7.58E-06	-
Carbon dioxide	All	kg	3.96E-02	7.33E-02
Methane	All	kg	1.88E-03	3.51E-03
Nitrogen	All	kg	4.56E-01	8.42E-01
Oxygen	All	kg	8.21E-02	1.52E-01
Nitric oxide	All	kg	5.51E-06	1.02E-05
Nitrogen dioxide	All	kg	4.44E-07	8.22E-07
NO_X	All	kg	8.89E-06	1.64E-05

4. Life Cycle Impact Assessment

Both systems, the production of bagasse and the usage of bagasse, were analyzed using the Eco–indicator 99 (H, A) end-of-point impact assessment method to assess their environmental impact. The Eco-indicator 99 methodology is the impact assessment method which is fully consistent with the requirements stated in ISO 14042. (H, A) is the Hierarchist damage model and normalisation with the Average weighting. The impact categories examined were Human Health, Ecosystem Quality and Resource Depletion [31, 32]. Human Health included studies on carcinogenic effects on humans, respiratory effects on humans caused by organic substances, respiratory effects on humans caused by inorganic substances, climate change, ionising radiation and ozone layer depletion. The Human Health impact was measured in DALYs, short for Disability Adjusted Life Years. This measures the impact of a process on a population's life expectancy and burden of disease or disability. A rating of 1 means that one healthy life year of one individual is lost, whether it is due to premature death or time spent disabled [33]. The study of Ecosystem Quality was comprised of ecotoxic emissions, the combined effect of acidification and eutrophication, and land occupation and land conversion. Ecosystem Quality is measured as PDF*m^2*yr. PDF is short for Potential Disappeared Fraction of Species, and measures the species loss (extinction rate) in an area of land over a period of time. A rating of one means that all species disappear from one m^2 during one year. Lastly, Resource Depletion measured the extraction of minerals and fossil fuels. The unit of study is MJ surplus energy, and represents the surplus energy needed for future extractions of mineral and fossil fuels [34].

The three damage categories had different units so these damage categories were made to use a set of dimensionless weighting factors from the panel. This was done using a normalization step. It should be noted that normally in LCA the normalization took place after characterization, as usually the normalized effect scores were presented to the panel. The modeling was extended to the damage categories and presented the damage categories to the panel for weighting [31]. The final result was measured in eco-points (Pt). The value of 1 Pt corresponded to a one thousandth of the total annual environmental load attributable to one European citizen [35].

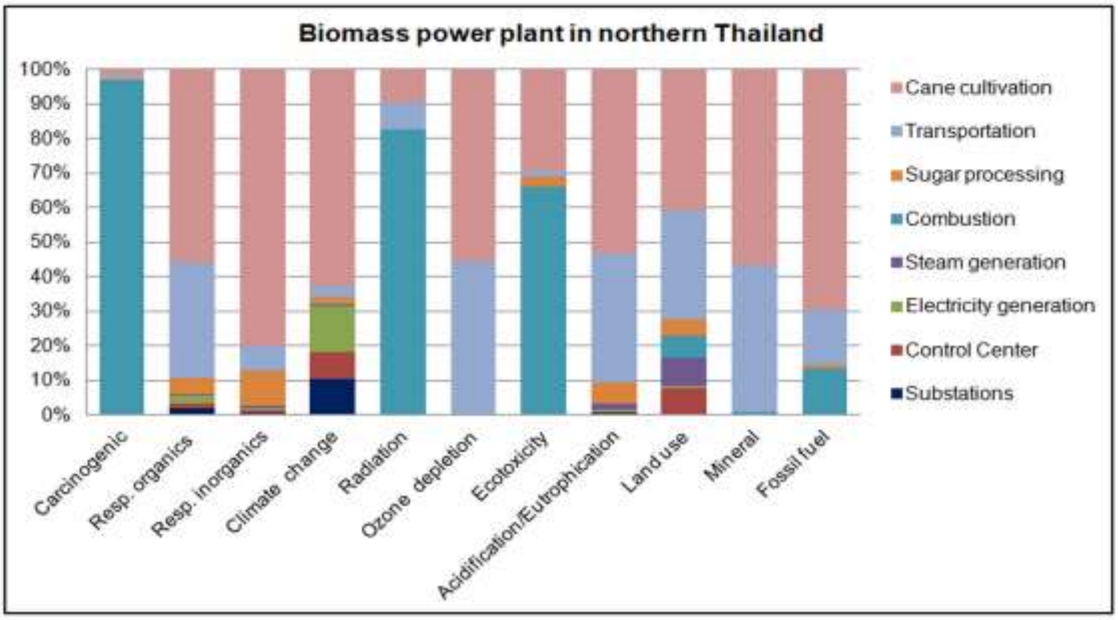
In the subdivision of the environmental index by impact category, analysis of both power plants showed the initial stage of bagasse production to have an adverse effect upon each of the main impact categories and sub-categories. This was similarly true for usage of bagasse, the only exception being that ozone depletion was unaffected. This can be seen in Tables 4 and 5. In order to compare the various environmental impact categories, the data was scaled to 100% (see Fig. 5) and weighted into the eco-point (Pt) indicator.

Table 4. Characterized impacts of the electricity generation process from biomass power plant in the north of Thailand

Impact Category	Unit	Production of Bagasse			Usage of Bagasse				
		Cane cultivation	Transport-ation	Sugar processing	Combus-tion	Steam generation	Electricity generation	Control center	Sub-stations
Carcinogenic	DALYs	5.14E-10	3.14E-10	1.06E-10	2.71E-08	0	0	0	0
Resp. organics	DALYs	2.30E-10	1.36E-10	1.99E-11	2.45E-13	5.90E-13	1.00E-11	5.85E-12	7.62E-12
Resp. inorganics	DALYs	3.62E-08	5.90E-09	8.45E-09	1.57E-11	6.67E-10	6.57E-10	3.82E-10	5.03E-10
Climate change	DALYs	1.79E-08	5.73E-10	4.71E-10	1.68E-10	2.73E-10	6.65E-09	4.03E-09	5.25E-09
Radiation	DALYs	3.09E-11	2.43E-11	1.12E-13	2.62E-10	0	0	0	0
Ozone depletion	DALYs	8.41E-11	6.60E-11	4.84E-13	0	0	0	0	0
Ecotoxicity	PDF*m^2*yr	3.81E-03	2.21E-04	3.93E-04	8.63E-03	0	0	0	0
Acidification/ Eutrophication	PDF*m^2*yr	3.62E-03	2.54E-03	4.10E-04	5.19E-06	1.19E-04	4.23E-05	2.47E-05	3.23E-05
Land use	PDF*m^2*yr	2.12E-04	1.65E-04	2.44E-05	3.47E-05	4.14E-05	3.98E-06	3.86E-05	1.43E-06
Mineral	MJ surplus	6.35E-05	4.75E-05	1.71E-07	9.37E-07	0	0	0	0
Fossil fuel	MJ surplus	4.14E-02	9.30E-03	6.33E-04	8.03E-03	0	0	0	0

Table 5. Characterized impacts of the electricity generation process from biomass power plant in the northeast of Thailand

Impact Category	Unit	Production of Bagasse			Usage of Bagasse				
		Cane cultivation	Transport-ation	Sugar processing	Combus-tion	Steam generation	Electricity generation	Control center	Sub-stations
Carcinogenic	DALYs	1.12E-09	6.81E-10	2.30E-10	3.46E-08	0	0	0	0
Resp. organics	DALYs	4.97E-10	2.95E-10	8.59E-11	1.50E-11	2.12E-12	8.69E-12	4.45E-12	7.29E-12
Resp. inorganics	DALYs	7.30E-08	8.30E-09	1.38E-08	2.85E-10	1.77E-10	8.60E-10	6.63E-10	8.01E-10
Climate change	DALYs	2.14E-08	1.32E-09	1.10E-10	2.74E-09	1.58E-09	8.03E-09	5.66E-09	7.27E-09
Radiation	DALYs	6.71E-11	5.27E-11	2.43E-13	7.12E-10	0	0	0	0
Ozone depletion	DALYs	1.83E-10	1.43E-10	1.05E-12	0	0	0	0	0
Ecotoxicity	PDF*m^2*yr	6.81E-03	2.80E-04	6.32E-04	1.51E-02	0	0	0	0
Acidification/ Eutrophication	PDF*m^2*yr	6.86E-03	3.51E-03	8.90E-04	1.62E-05	1.24E-05	5.57E-05	4.25E-05	5.14E-05
Land use	PDF*m^2*yr	4.58E-04	2.57E-04	5.30E-05	1.10E-03	1.53E-04	3.06E-05	3.06E-05	2.14E-04
Mineral	MJ surplus	1.38E-04	1.03E-04	3.71E-07	1.10E-04	0	0	0	0
Fossil fuel	MJ surplus	6.87E-02	1.70E-02	1.16E-03	1.46E-02	0	0	0	0



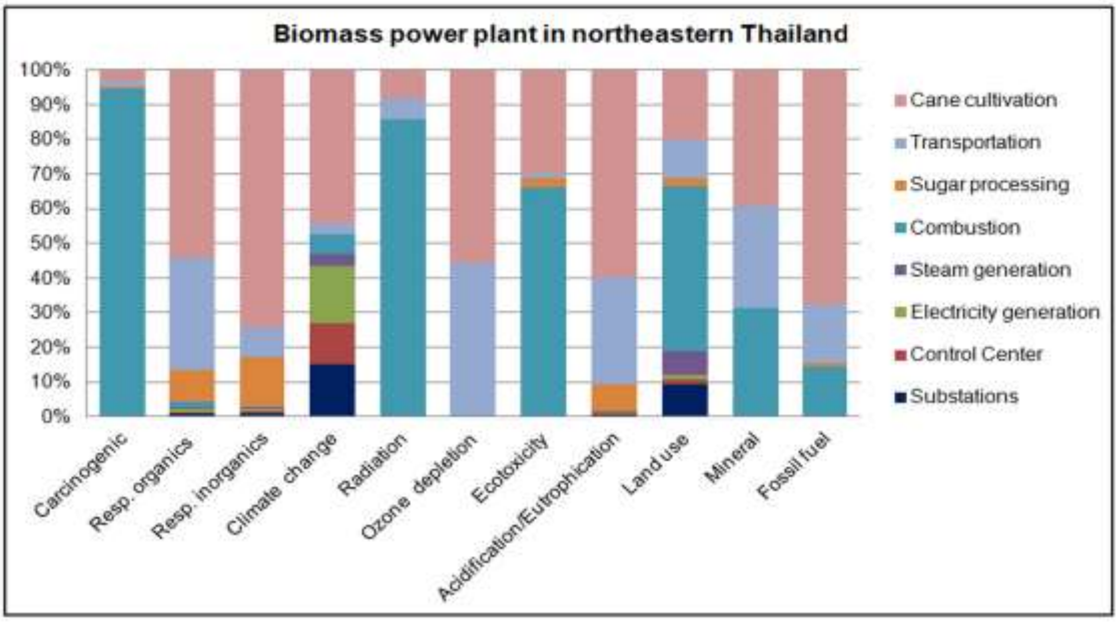


Fig. 5. Characterised results of biomass electricity generation process.

At the both plants, fossil fuel, the respiration of inorganic substances, climate change, acidification / eutrophication, carcinogens and ecotoxicity were the main impact categories effected. Fossil fuel depletion was the most significant impact, measuring 2.06E-03 Pt in the north and 3.70E-03 Pt in the northeast, as shown in Figs. 6 and 7. This was the result of the diesel consumed by tractors on farms, fertilizers and pesticides used for cane cultivation, diesel consumption for cane, and bagasse transportation.

In both power plants, the production of bagasse and the usage of bagasse had an adverse effect upon all of the main impact categories. Human Health was the main end-of-point impact category, followed by Resource Depletion and Ecosystem Quality respectively, as shown in Fig. 8. When the total environmental impact was assessed, it is clear that the production of bagasse is about twice as harmful as that of the usage of bagasse. This is shown in Fig. 9. When the two plants were compared, the environmental impact from the initial stage, bagasse production, in the northeast was more than double that of the northern plant. This was due to higher efficiency in the northern plant, resulting in a lower bagasse requirement. Analysis of the second stage, bagasse usage, showed the environmental impact of the northeastern plant to again be higher, but this time only marginally so. This reduction in relative efficiency in the northern plant was due to the environmental effects of using chemicals in the northern plant to control the water quality. In final analysis, the overall environmental impact of the northeastern plant was higher than that of the northern plant by 4.03E-03 Pt, the two plants measuring 9.89E-03 Pt and 5.86E-03 Pt respectively.

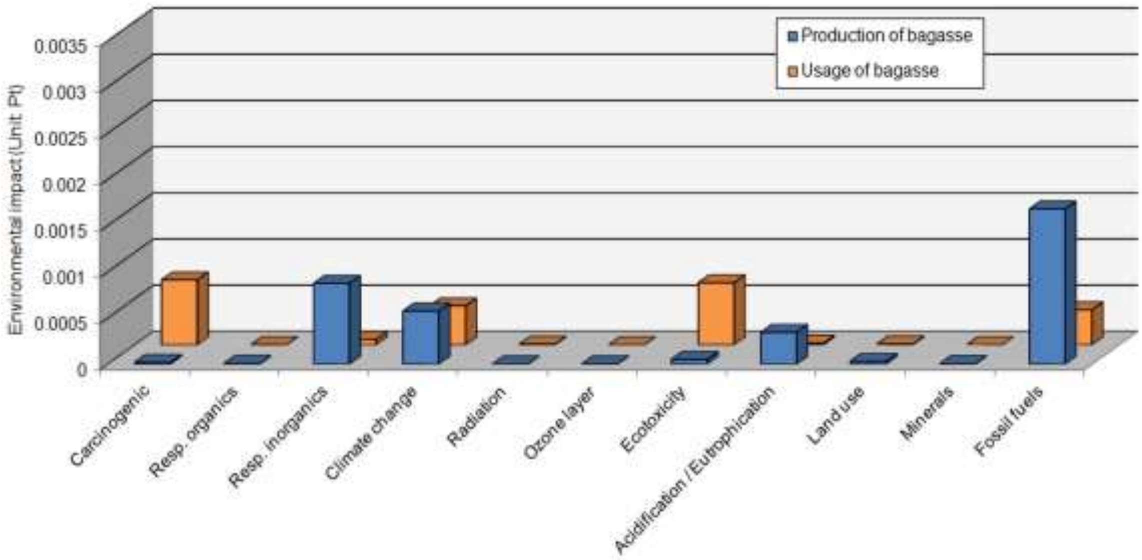


Fig. 6. Impact categories from biomass power plant in the north of Thailand.

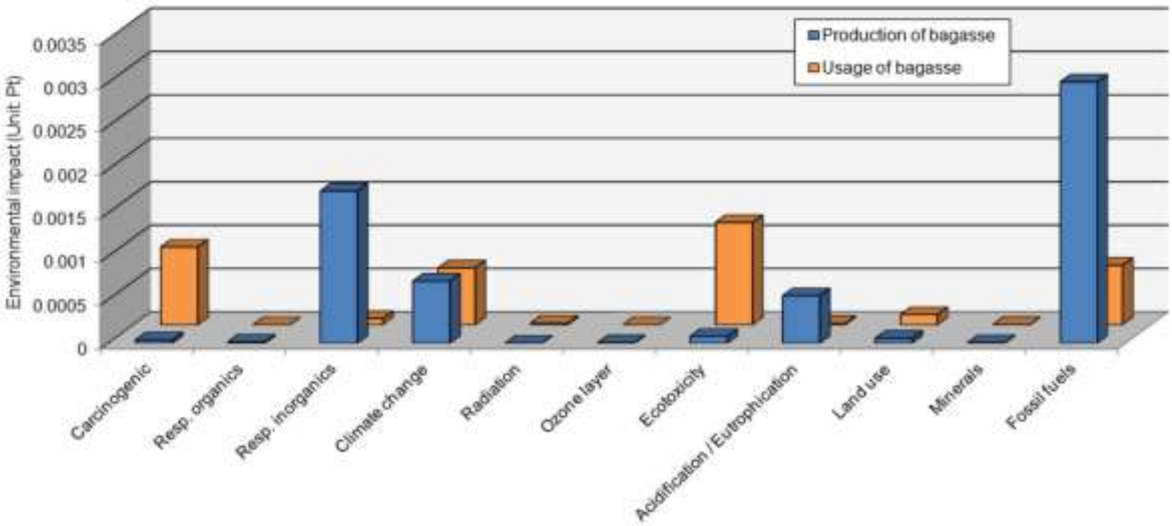


Fig. 7. Impact categories from biomass power plant in the northeast of Thailand.

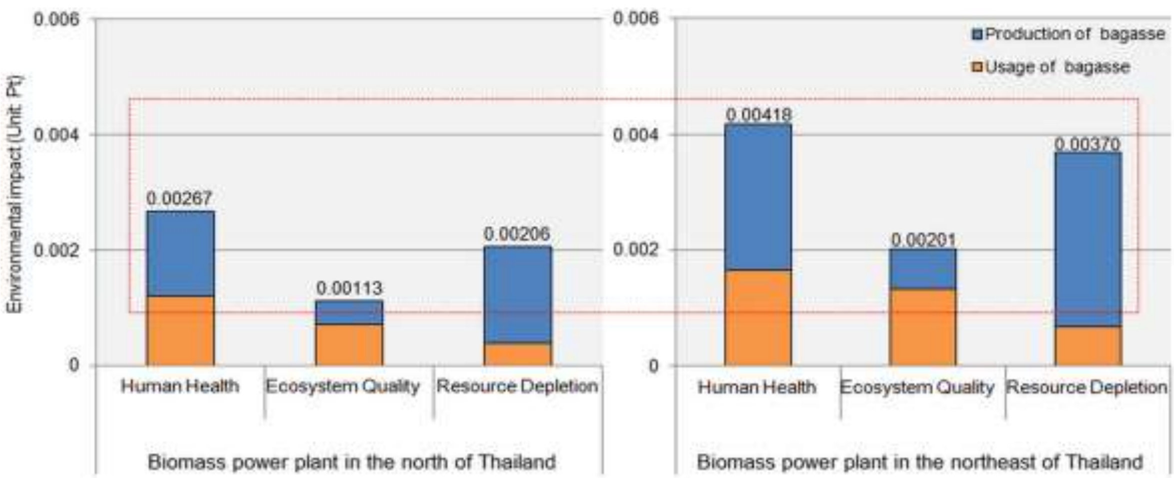


Fig. 8. End-of-point impact categories from biomass power plant in Thailand.

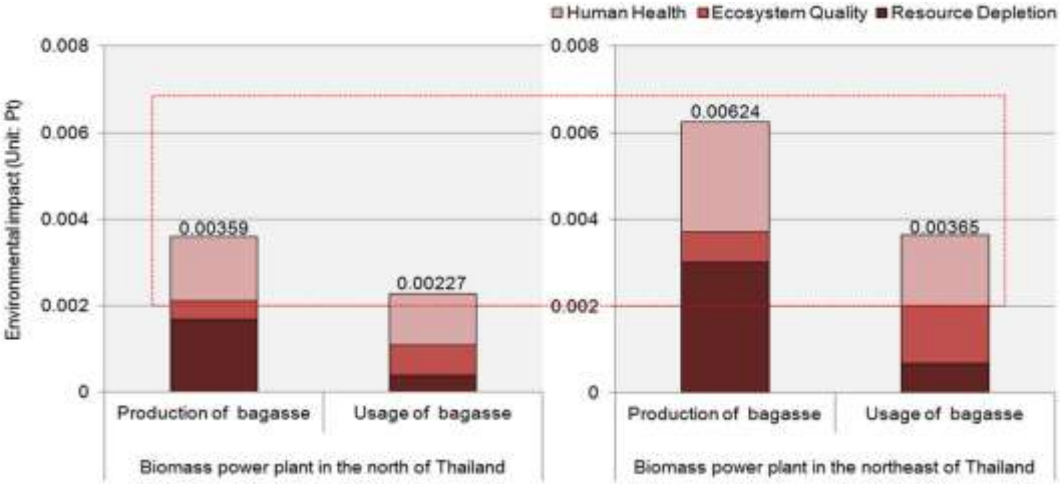


Fig. 9. Environmental impact from biomass power plant in Thailand.

5. Sensitivity Analysis

A sensitivity analysis determined the parameters that had the largest effect on the results and the impact of estimated data on the conclusions. Moreover, this also provided the policy to improve the environmental impact of electricity generation from biomass in Thailand. The production of bagasse was of the most significant concern, due to it having the largest effect upon the environment, especially Resource Depletion. This was the result of diesel consumption for tractor in farms, fertilizers and pesticides used for cane cultivation, diesel consumption for cane and bagasse transportation. However, Human Health was the main end-of-point impact from using bagasse to generate electricity, because bagasse was burned (direct combustion) as fuel. Policies have since been developed with the aim of reducing the environmental impact. These include:

- Improving soil quality by reducing chemical fertilizers used and switching to biomass fertilizers.
- Improving cultivation technology by using cultivation machines and leaving agricultural wastes in farmland to prevent moisture loss and increase soil nutrients.
- Reducing leaf burning after cultivation by using sugar cane leaves in covering farm area to prevent moisture loss and increase soil nutrients.
- Locating farmland close to the sugar industry.
- Identifying of transportation routes throughout the product life cycle.
- Classifying appropriate size of transportation vehicles for appropriate distance and greater loading capacity.
- Improving combustion technology such as using gasification.

6. Comparison with Electricity Generation from Various Systems in Thailand

Using the characterized data for 1 kWh of electricity generation, the environmental impact of the biomass power plants were compared with that of combined cycle and thermal power plants in Thailand [36]. Fig. 10 demonstrates that of all the forms of electricity generation studied, the biomass power plants had the least impact upon the environment.

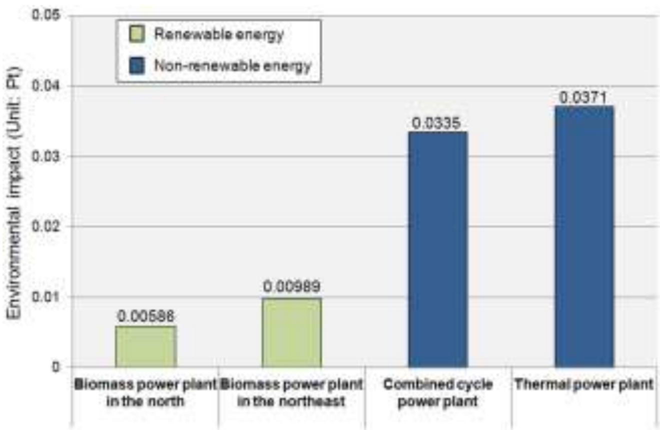


Fig. 10. Total environmental impact comparison with the power plants in Thailand.

7. Conclusion

Based on the inventory analysis and impact assessment, the results as to the contribution of each process to the impact categories considered can be concluded as follows:

- Both stages of the electricity generation process from bagasse (production of bagasse and usage of bagasse) were found to have a detrimental impact upon every category and sub-category studied (with the exception of ozone depletion during electricity generation).
- In the bagasse production process, fossil fuel depletion, the respiration of inorganic substances, climate change and acidification/eutrophication were the main impact categories. These were due to fuel used for tractors in farms, fertilizers and pesticides used for cane cultivation, fuel used for cane transportation and fuel used for bagasse transportation.

➢ In the usage of bagasse process, carcinogens, ecotoxicity, climate change and fossil fuels were the main impact categories because of fly-ash emissions from the bagasse combustion.

➢ Over the whole process of bagasse electrical generation, the greatest impact was upon Human Health, followed by Resource Depletion and Ecosystem Quality respectively.

➢ The environmental impact caused by the production of bagasse was much greater than that of bagasse usage.

➢ Consequently, the northern plant had the least impact because it required only 2.17 kilograms bagasse to generate 1 kWh of electricity. In comparison, the northeastern plant was less efficient, requiring 5.88 kilograms, and therefore had the greater environmental impact.

➢ In comparison with combined cycle and thermal plants in Thailand, the total environmental impact for 1 kWh of electricity generated by biomass power plants was found to have the lowest environmental impact. The greatest impact was that of the fossil fuel power plant, where the most significant impact category was Resource Depletion due to the use of fossil fuel to generate electricity.

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