Life Cycle Assessment of Power Generation from Renewable Energy in Thailand

Wasin Khaenson, Somchai Maneewan, and Chantana Punlek

Abstract— *The aim of this study was to assess and compare the environmental impact of power generation from solar energy and biomass in Thailand, by using the 'Life Cycle Assessment' tool at each stage of the process. Power generated from solar energy is composed of five main processes: the solar cell array, inverter stations, transformer stations, a control center and substations. Power generated from biomass using bagasse is also composed of five main processes: combustion, steam generation, electricity generation, a control center and substations. The functional unit used for this study was 1 kWh of power generation. Two of the largest and most powerful solar cell power plants in Thailand were studied, one in the north of Thailand (which generates 90 MW) and one in central Thailand (generating 55 MW). Similarly, two bagasse fuelled biomass power plants were studied, one in the north of Thailand, (generating 60 MW) and one in the northeast of Thailand (generating 10 MW). The Eco – indicator 99 method was used in the analysis. This study examines the impact upon Human Health, Ecosystem Quality and Resource Depletion. After analyzing the results, it can clearly be shown that the biomass power plants had by far the greatest impact on the environment, with the northeastern and northern plants registering 3.65E-03 Point and 2.27E-03 Point respectively. By comparison the solar cell power plants had an impact of only 1.14E-03 Point (for the central plant) and 9.93E-04 Point (for the northern plant). Of the five main biomass processes, the combustion stage was the most detrimental, especially with regards to Human Health which registered 1.64E-03 Point in the northeastern plant. This included a substantial increase in the release of carcinogens into the atmosphere, which measured 2.25E-06 DALYs. The second greatest impact of the northeastern plant was on the Ecosystem Quality (1.32E-03 Point) where ecotoxicity levels were 2.96E-06 PDF*m^2*yr. Lastly, Resource Depletion was measured at 6.89E-04 Point, with a corresponding impact on fossil fuel of 1.73E-06 MJ surplus.*

Keywords— **Renewable energy, solar cell power plant, biomass power plant, life cycle assessment.**

1. INTRODUCTION

In recent years Thailand's final renewable energy consumption has increased continuously, due to the policy of renewable energy development, the goal of which is to increase renewable energy consumption in all sectors. There is a particular emphasis on renewable energy which can be produced within the country, such as solar energy, wind energy, small hydro power, biomass, municipal solid waste (MSW), biogas and biofuels (ethanol and biodiesel). The aim is to generate more energy from renewable sources, and therefore decrease both fossil fuel consumption and energy imports. Currently, Thailand consumes domestic renewable energy in the form of electricity, heat and biofuels. In 2014, Thailand's final energy consumption was 75,804 ktoe, an increase of 0.78% from the previous year. Of this, a total of 9,025 ktoe can be attributed to renewable energy, or 11.91%, which is an increase of 9.6% on the previous year. This has resulted in both a decrease in energy imports (amounting to 215,065.75 million Baht), and also a decrease in CO_2 emission (amounting to 27.68 million tons) [1]. Of the total final renewable energy consumption, heat energy was the greatest, followed by biofuels (ethanol and biodiesels) and lastly, electricity. This can be seen in Fig. 1.

The power generation from renewable energy can be broken down into biomass, solar energy, biogas, wind energy, hydro power and MSW. In 2014 the total amount of power generated from renewable energy was 4,494 MW, up 18.6% from the previous year [2]. As demonstrated in Table 1, biomass power plants have consistently provided the greatest share, followed by solar energy, biogas, wind, small hydro power and MSW respectively.

Table 1. The total amount of power generation from renewable energy

Technology	Amount of Power Generated		
	2012	2013	2014
Biomass	1,959.95	2,320.78	2,451.82
Solar Energy	376.72	823.46	1,298.51
Biogas	193.40	265.23	311.50
Wind Energy	111.73	222.71	224.47
Hydro power	101.75	108.80	142.01
MSW	42.72	47.48	65.72
Total (MW)	2,786	3,788	4,494

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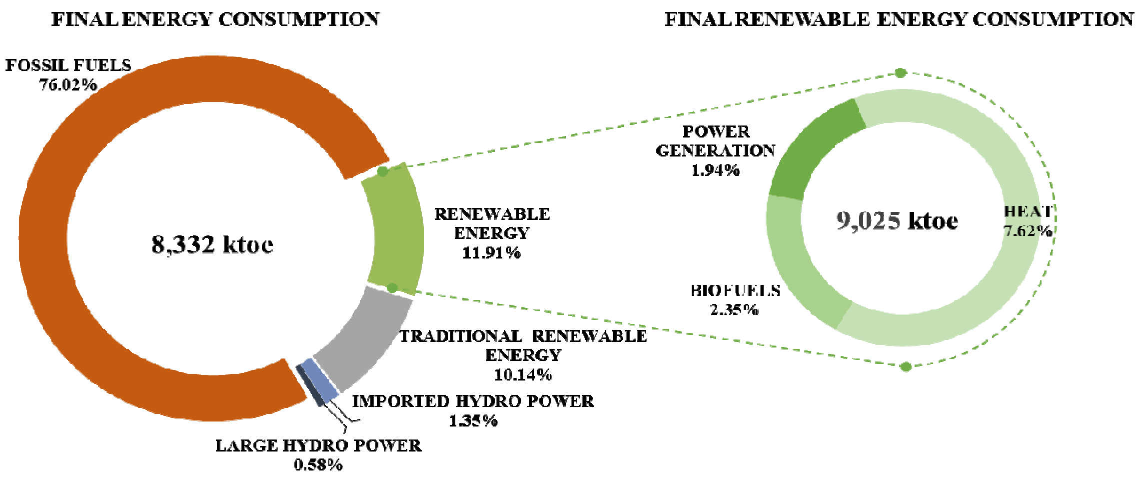

Fig. 1. Energy consumption. [1]

The policy of renewable energy is the "Alternative Energy Development Plan 2015 – 2036 (AEDP 2015)" which aims to increase the proportion of alternative energy generation from 8% to 20% of total electricity demand by 2036, raising alternative energy generation capacity by 19,635 MW within 20 years. The plan gives assistance to power generators specializing in alternative power [3].

The task of this paper is to carry out a comparative study of the main environmental impact of power generated from biomass and solar energy (these being the two processes which provide the majority of Thailand's renewable energy today) at each stage of the process, using the Life Cycle Assessment (LCA) tool. LCA is a technique for assessing various aspects associated with the development of a product and its potential impact throughout a product's life [4]. LCA includes definition of goal and scope, inventory analysis, impact assessment and interpretation.

2. BIOMASS POWER PLANTS IN THAILAND

Biomass is biological material derived from living, or recently living organisms. In the context of biomass as a resource for making energy, it most often refers to plants or plant-based materials which is not used for food or feed [5]. There can be many advantages to using biomass instead of fossil fuels for power generation, including lower greenhouse gas (GHG) emissions, energy cost savings, improved security of supply, waste management / reduction opportunities and local economic development opportunities [6]. The power generated from biomass is composed of five main processes: combustion, steam generation, electricity generation, a control center and substations.

- Combustion: Biomass is burned (Direct combustion) as fuel [7].
- Steam generation: This process utilizes a high pressure boiler or steam generator to create steam [7].
- Electricity generation: The steam drives the steam turbine, which is then used to generate electricity [7].
- Control center: The control center controls all processes for generating power.
- Substations: Substations transforms voltage from high to low voltage so it can flow to the consumer.

In 2014, of the total power generated from renewable energy, the greatest share was produced using biomass, amounting to 2,451.8 MW, (up 5.6% from the previous year). This is shown in Fig. 2. The power generated using biomass has been steadily growing, since biomass has long been the traditional energy source in rural Thailand and is a key instrument in the policy of developing renewable energy.

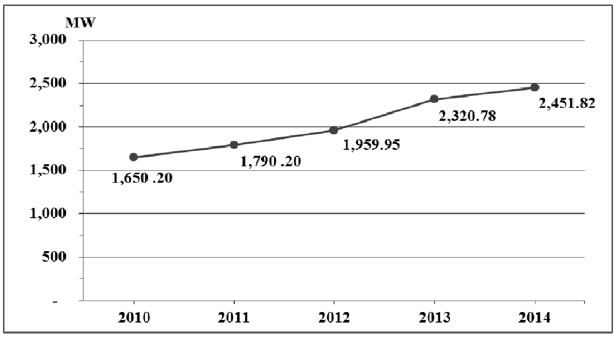

Fig. 2. The total installed capacity of power generation by using biomass. [1]

Table 2. The potential of power generation by using biomass in Thailand

Zone	Capacity (MW)	Province	Capacity (MW)
Northern	534.1	Nakhon Sawan	221
Northeastern	1,029.5	Kalasin	174
Central	818.6	Suphan Buri	174.3
Southern	69.6	Chumphon	16
Total	2,451.8	Total	585.3

Analyzing the potential of biomass power generation in the various geographical regions of Thailand, the potential of the northeast was found to be the most conducive, with a total of 1,029.5 MW - the main focus being on Kalasin province (174 MW) due to this area composing largely of agricultural land. In contrast to this, the potential in the south was the least, with a total of just 69.6 MW. This is shown in Table 2.

3. SOLAR CELL POWER PLANT IN THAILAND

Solar energy is the conversion of sunlight into electricity using photovoltaics (PV). Photovoltaics convert light into an electric current using the photovoltaic effect [8]. A solar cell, or photovoltaic cell (PV), is a device that converts light into electric current using the photovoltaic effect. There are 5 processes for generating power from solar energy. These are the solar cell array, inverter stations, transformer stations, a control center and substations.

- Solar cell array: This process consists of solar cells, or photovoltaic cells, which are wired together to form an array. They convert the energy of light directly into electricity by the photovoltaic effect.
- Inverter stations: This process consists of inverters which change the direct current (DC) from the solar cells into alternating current (AC) [9].
- Transformer stations: This process consists of transformers that are used to increase or decrease the voltages of alternating current to the appropriate level.
- Control center: The purpose of the control center is to control all processes for generating power, from the array right through to the substations.
- Substations: Substations are where electricity lines are connected and switched, and where the voltage is changed by transformers [10].

In 2014, the total power generated by using solar energy in Thailand was 1,298.5 MW or 17.6 MJ/m^2.day, up 57.7% from the previous year (See Fig. 3). Analyzing this geographically, the share of classified solar energy potential in the north was 333.1 MW or 17.3 MJ/m^2.day, in the northeastern it was 371.9 MW or 17.6 MJ/m^2.day, in the centre 586.8 MW or 17.8 MJ/m^2.day and the south received 6.7 MW or 17.6 MJ/m^2.day [1]. Solar energy potential in central Thailand was the leader, followed by the northeast, the north and lastly the south (depending on solar radiation and landscape).

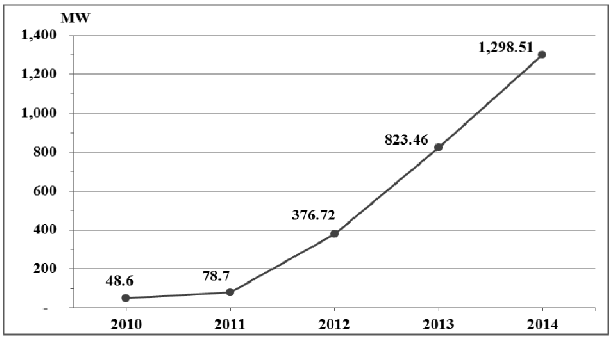

Fig. 3. The total installed capacity of power generation by using solar energy. [1]

4. LIFE CYCLE ASSESSMENT

Life Cycle Assessment or LCA is a technique that evaluates the environmental impact of every stage of a product's life, from birth to death, thus enabling a quantitative estimation of it's environmental impact at each stage of it's life cycle. The LCA provides a comprehensive view of the various environmental aspects of the product or process, therefore creating a more accurate picture of the environmental trade-offs in product and process selection, thus ensuring a more accurate decision making process [11, 12]. The four stages of an LCA are: (1) Goal and Scope Definition, (2) LCI (Life Cycle Inventory), (3) LCIA (Life Cycle Impact Assessment), and (4) Interpretation [13] - [15].

4.1 Goal and scope of the case study

This study assessed the environmental impact of power generation from the two leading types of renewable energy at each processes, using the 'Life Cycle Assessment' tool. The functional unit used for this study was 1 kWh of power generation. Two solar cell power plants and two bagasse burning biomass power plants were studied; one solar cell power plant in northern Thailand (the largest solar cell power plant in the area, generating 90 MW), one solar cell power plant in central Thailand (again, the largest solar cell power plant in the area, this time generating 55 MW), one biomass power plant in northern Thailand (the largest biomass power plant in the area, generating 60 MW) and one biomass power plant in northeastern Thailand (generating 10 MW.) The process of solar energy power generation is composed of the solar cell array, inverter stations, transformer stations, a control center and substations. The process studied is shown in Fig. 4. The process of biomass power generation is composed of combustion, steam generation, electricity generation, a control center and substations. This is shown in Fig. 5.

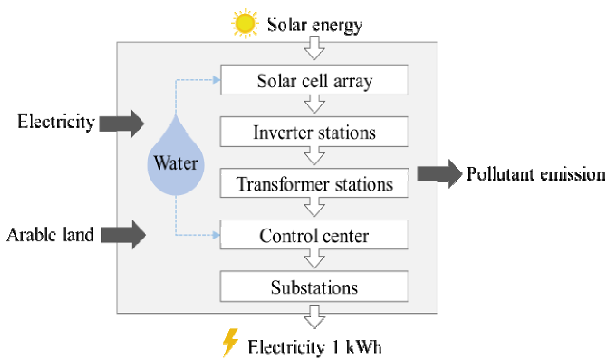

Fig. 4. The scope of power generation from solar energy.

4.2 Life Cycle Inventory of the case study (LCI)

Life Cycle Inventory (LCI) was the tool used to analyze the data input and output from the various processes.

The data was collected during mass and energy flow analysis for each of the processes. The results are summarized in Table 3 – 6.

Table 3. Mass and energy stream analysis for solar cell power plant in northern Thailand

Description	Unit	Quantity				
		Solar cell array	Inverter stations	Transformer stations	Control center	Substations
Input						
Solar energy	kWh/kWh	4.87E+00	0	0	0	0
Electricity	kWh/kWh	2.00E-04	10.7E-04	7.10E-04	9.50E-04	9.20E-04
Water	cm^3/kWh	7.31E+01	0	0	2.79E+01	0
Arable land	m^2/kWh	1.48E-02	1.61E-05	8.06E-06	4.03E-05	4.84E-05
Output						
Carbon Dioxide	$kgCO_2$/kWh	1.66E-04	7.74E-04	5.17E-04	6.96E-04	6.66E-04
Methane	$kgCH_4$/kWh	0.68E-05	3.10E-05	2.07E-05	2.79E-05	2.66E-05
Nitrogen	kgN_2/kWh	0.17E-02	0.89E-02	0.60E-02	0.80E-02	0.77E-02
Oxygen	kgO_2/kWh	0.30E-03	1.61E-03	1.07E-03	1.43E-03	1.38E-03
Water Vapor	kgH_2O/kWh	0.11E-03	0.61E-03	0.41E-03	0.54E-03	0.53E-03
Nitric Oxide	kgNO/kWh	0.20E-07	1.08E-07	0.72E-07	0.96E-07	0.93E-07
Nitrogen Dioxide	$kgNO_2$/kWh	0.16E-08	0.87E-08	0.58E-08	0.77E-08	0.75E-08
NOx	kgNOx/kWh	0.33E-07	1.74E-07	1.16E-07	1.55E-07	1.50E-07

Table 4. Mass and energy stream analysis for solar cell power plant in central Thailand

Description	Unit	Quantity				
		Solar cell array	Inverter stations	Transformer stations	Control center	Substations
Input						
Solar energy	kWh/kWh	9.46E+00	0	0	0	0
Electricity	kWh/kWh	0	1.67E-03	1.14E-03	0.83E-03	1.32E-03
Water	cm^3/kWh	4.74E+01	0	0	2.88E+00	0
Arable land	m^2/kWh	1.67E-02	2.81E-05	1.41E-05	4.21E-05	5.61E-05
Output						
Carbon Dioxide	$kgCO_2$/kWh	0.16E-04	12.1E-04	8.29E-04	6.06E-04	9.56E-04
Methane	$kgCH_4$/kWh	0.06E-05	4.84E-05	3.31E-05	2.43E-05	3.82E-05
Nitrogen	kgN_2/kWh	0	1.40E-02	0.96E-02	0.70E-02	1.10E-02
Oxygen	kgO_2/kWh	0	2.52E-03	1.72E-03	1.26E-03	1.99E-03
Water Vapor	kgH_2O/kWh	0	0.96E-03	0.65E-03	0.48E-03	0.75E-03
Nitric Oxide	kgNO/kWh	0	1.69E-07	1.16E-07	0.84E-07	1.33E-07
Nitrogen Dioxide	$kgNO_2$/kWh	0	0.14E-07	0.09E-07	0.07E-07	0.11E-07
NOx	kgNOx/kWh	0	2.72E-07	1.86E-07	1.36E-07	2.15E-07

Table 5. Mass and energy stream analysis for biomass power plant in northern Thailand

Description	Unit	Quantity				
		Combustion	Steam generation	Electricity generation	Control center	Substations
Input						
Bagasses	kg/kWh	2.17E+00	0	0	0	0
Electricity	kWh/kWh	1.10E-03	1.60E-03	4.53E-02	2.66E-02	3.46E-02
Water	cm^3/kWh	0	1.78E+03	0	7.10E+00	0
Steam	kg/kWh	0	0	5.20E+00	0	0
Arable land	m^2/kWh	4.13E-05	4.93E-05	4.43E-06	4.60E-05	1.70E-06
Diesel	kg/kWh	2.71E-03	0	0	0	0
Output						
Carbon Dioxide	$kgCO_2$/kWh	4.00E-04	6.50E-04	1.64E-02	9.60E-03	1.25E-02
Methane	$kgCH_4$/kWh	1.91E-05	3.10E-05	7.81E-04	4.57E-04	5.95E-04
Nitrogen	kgN_2/kWh	4.50E-03	6.50E-03	1.89E-01	1.11E-01	1.45E-01
Oxygen	kgO_2/kWh	8.00E-04	1.20E-03	3.41E-02	2.00E-02	2.60E-02
Nitric Oxide	kgNO/kWh	5.47E-08	7.86E-08	2.29E-06	1.34E-06	1.75E-06
Nitrogen Dioxide	$kgNO_2$/kWh	4.41E-09	6.34E-09	1.84E-07	1.08E-07	1.41E-07
NOx	kgNOx/kWh	8.83E-08	1.27E-07	3.69E-06	2.16E-06	2.82E-06

Table 5. (Continued)

Description	Unit	Quantity				
		Combustion	Steam generation	Electricity generation	Control center	Substations
Humidity	kg/kWh	1.16E+00	0	0	0	0
Carbon	kg/kWh	1.25E+00	0	0	0	0
Hydrogen	kg/kWh	1.71E-01	0	0	0	0
Sulphur	kg/kWh	6.56E-02	0	0	0	0
Nitrogen	kg/kWh	2.34E-02	0	0	0	0
Chloride	kg/kWh	1.00E-04	0	0	0	0
Ash	kg/kWh	8.82E-02	0	0	0	0
Arsenic	kg/kWh	2.80E-07	0	0	0	0
Cadmium	kg/kWh	2.24E-09	0	0	0	0
Chromium	kg/kWh	1.54E-06	0	0	0	0
Copper	kg/kWh	1.04E-06	0	0	0	0
Lead	kg/kWh	2.20E-07	0	0	0	0
Ammonia	kg/kWh	0	7.58E-06	0	0	0
Hydrazine	kg/kWh	0	6.07E-06	0	0	0
Trisodium phosphate	kg/kWh	0	6.07E-06	0	0	0
Sulphuric Acid	kg/kWh	0	6.07E-06	0	0	0
Anionic Polymer 100	kg/kWh	0	1.21E-03	0	0	0
Sodium hypochlorite	kg/kWh	0	8.89E-05	0	0	0
Poly Aluminium Chloride	kg/kWh	0	6.98E-04	0	0	0
Hypersperse MDC702	kg/kWh	0	2.75E-05	0	0	0
Non-Oxidizing Biocide	kg/kWh	0	5.90E-05	0	0	0
Sodium hydroxide	kg/kWh	0	3.70E-06	0	0	0
Hydrochloric acid	kg/kWh	0	1.43E-06	0	0	0

Table 6. Mass and energy stream analysis for biomass power plant in northeastern Thailand

Description	Unit	Quantity				
		Combustion	Steam generation	Electricity generation	Control center	Substations
Input						
Bagasses	kg/kWh	5.88E+00	0	0	0	0
Electricity	kWh/kWh	2.02E-02	1.33E-02	6.21E-02	4.84E-02	5.79E-02
Water	cm^3/kWh	0	2.34E+03	0	1.37E+01	0
Arable land	m^2/kWh	1.31E-03	1.82E-04	3.64E-05	3.64E-05	2.55E-04
Diesel	kg/kWh	4.41E-03	0	0	0	0
Output						
Carbon Dioxide	$kgCO_2$/kWh	7.30E-03	4.98E-03	2.25E-02	1.75E-02	2.10E-02
Methane	$kgCH_4$/kWh	4.00E-04	2.08E-04	1.10E-03	8.00E-04	1.00E-03
Nitrogen	kgN_2/kWh	8.42E-02	5.55E-02	2.59E-01	2.02E-01	2.41E-01
Oxygen	kgO_2/kWh	1.52E-02	1.00E-02	4.67E-02	3.64E-02	4.35E-02
Nitric Oxide	kgNO/kWh	1.02E-06	6.7E-07	3.13E-06	2.44E-06	2.92E-06
Nitrogen Dioxide	$kgNO_2$/kWh	8.22E-08	5.40E-08	2.53E-07	1.97E-07	2.36E-07
NOx	kgNOx/kWh	1.64E-06	1.08E-06	5.05E-06	3.94E-06	4.71E-06
Humidity	kg/kWh	3.16E+00	0	0	0	0
Carbon	kg/kWh	3.39E+00	0	0	0	0
Hydrogen	kg/kWh	4.64E-01	0	0	0	0
Sulphur	kg/kWh	1.78E-01	0	0	0	0
Nitrogen	kg/kWh	6.35E-02	0	0	0	0
Chloride	kg/kWh	3.00E-04	0	0	0	0
Ash	kg/kWh	2.39E-01	0	0	0	0
Arsenic	kg/kWh	7.69E-07	0	0	0	0
Cadmium	kg/kWh	5.99E-09	0	0	0	0
Chromium	kg/kWh	4.18E-06	0	0	0	0
Copper	kg/kWh	2.82E-06	0	0	0	0
Lead	kg/kWh	5.89E-07	0	0	0	0
Polycyclic Aromatic Hydrocarbon	kg/kWh	4.85E-04	0	0	0	0
Methyl ester	kg/kWh	6.62E-05	0	0	0	0
Crude oil	kg/kWh	4.90E-03	0	0	0	0

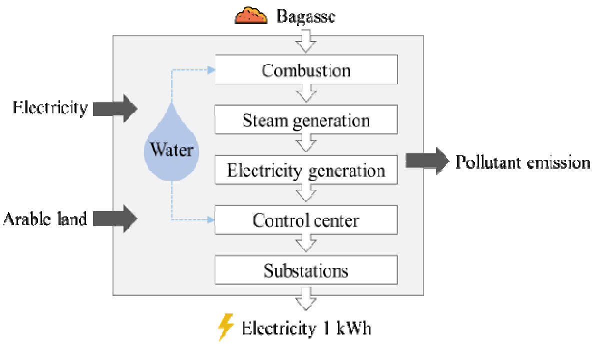

Fig. 5. The scope of power generation from biomass.

It should be noted that at the solar cell array stage, the northern and central solar cell power plants have notably different results. This is because the two plants use different designs of solar cell array to generate their electricity - namely multicrystalline silicon solar cells in the north and thin film amorphous silicon solar cells in the centre. Only multicrystalline cells require an electrical input, and these results in the emission of Nitrogen, Oxygen, Water Vapor, Nitric Oxide, Nitrogen Dioxide and NOx (See Table 3). None of these gases are produced in the central plant because thin film amorphous cells require no such electrical input (See Table 4).

4.3 Life Cycle Impact Assessment of the case study (LCIA)

The Eco – indicator 99 method was also used in the analysis. The impact categories examined were Human Health, Ecosystem Quality and Resource Depletion [16, 17]. Human Health included studies on the carcinogenic impact, the respiration of both organic and inorganic substances, radiation, climate change and ozone depletion. The Human Health impact is 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 be due to premature death or time spent disabled [18]. The study of Ecosystem Quality is comprised of acidification and eutrophication, ecotoxicity and land use. Ecosystem Quality damages 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 all species disappear from one m^2 during one year. Lastly, Resource Depletion measures the depletion of mineral 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.

LCIA of solar cell power plant in the north of Thailand

When the northern solar cell plant was analyzed, the power generation processes were found to have a detrimental effect on the respiration of organic substances, the respiration of inorganic substances, climate change, acidification and eutrophication, and land use (See Fig. 6). By far and away, the greatest impact was on land use, measuring 2.45E-06 Person*year. This was followed, to a much lesser extent, by climate change (7.07E-08 Person*year), the respiration of inorganic substances (7.26E-09 Person*year), acidification and eutrophication (1.40E-09 Person*year) and the respiration of organic substances (9.40E-11 Person*year). Of the various processes the solar cell array had by far the largest impact on land use measuring 2.43E-06 Person*year (See Fig. 7).

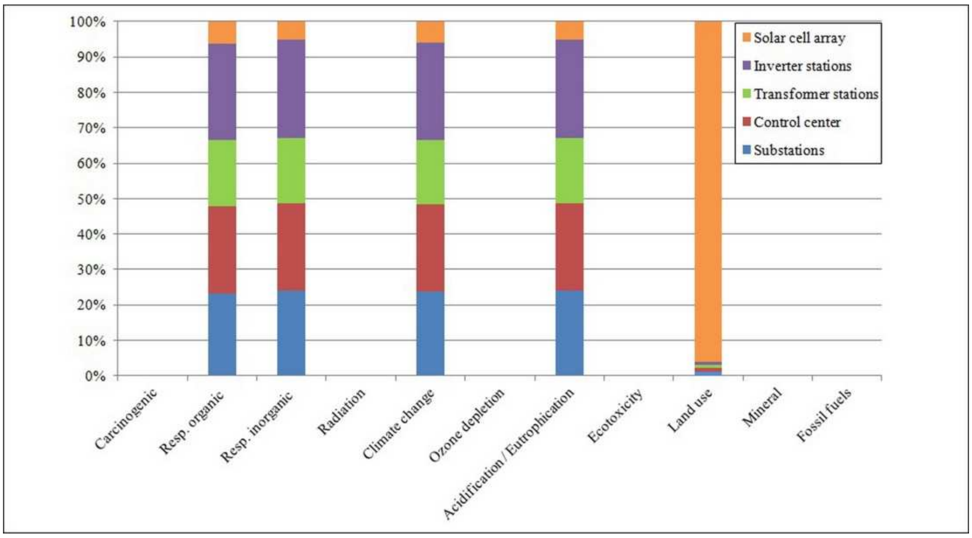

Fig. 6. Characterized impacts of solar cell power plant in the north.

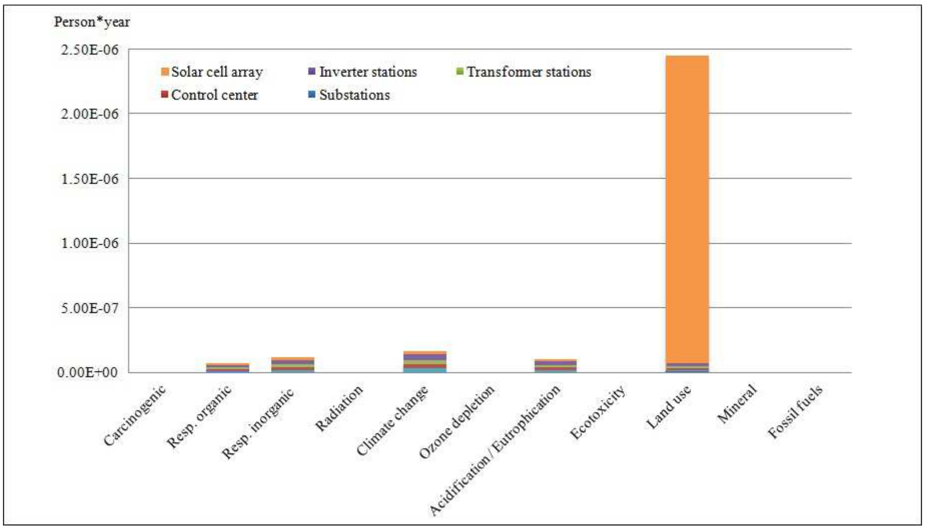

Fig. 7. Normalized impacts of solar cell power plant in the north.

Of the impact categories studied, the most negative effects were found to be on the Ecosystem Quality, which was found to be 9.77E-04 Point due to the use of vast quantities of arable land for the solar cell array. Conversely, Human Health was measured at only 1.60E-05 Point, while no processes were found to be detrimental to Resource Depletion (see Fig. 8).

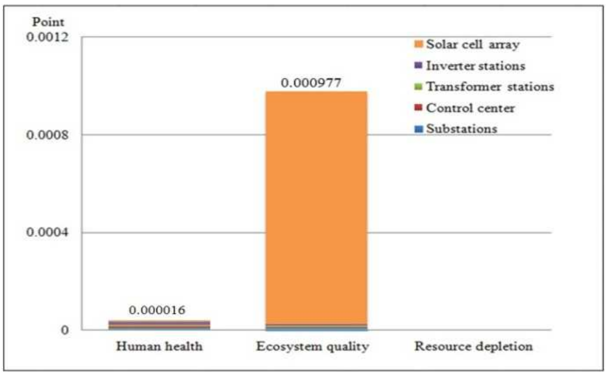

Fig. 8. Weighted impacts of solar cell power plant in the north.

LCIA of solar cell power plant in the centre of Thailand

Like its sister plant in the north, the central solar power plant was found to have a detrimental effect on the respiration of organic substances, the respiration of inorganic substances, climate change, acidification and eutrophication and land use (See Fig. 9).

Again, the greatest impact was on land use, which measured 2.76E-06 Person*year. Less significant was the effects on climate change (9.06E-08 Person*year), the respiration of inorganic substances (9.36E-09 Person*year), acidification and eutrophication (1.80E-09 Person*year) and, lastly, the respiration of organic substances (1.20E-10 Person*year). Again, the solar cell array had the largest impact on land, this time measuring 2.74E-06 Person*year (See Fig. 10).

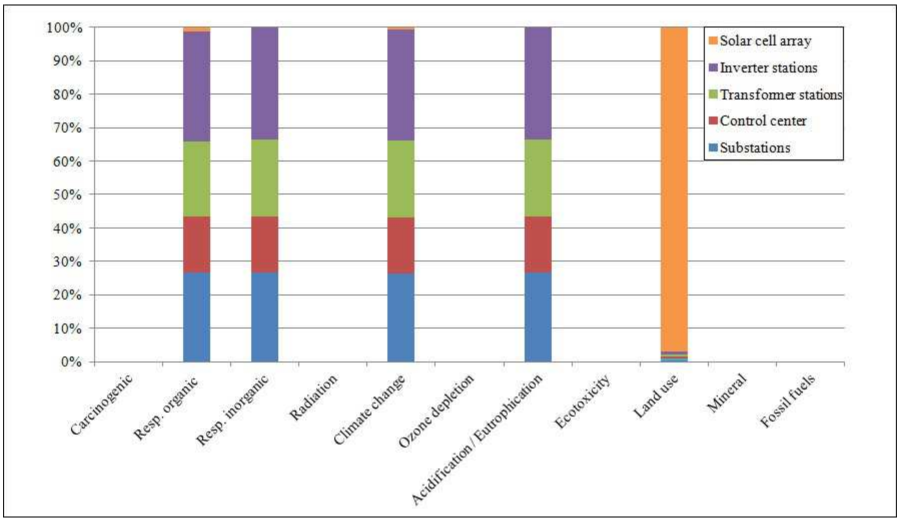

Fig. 9. Characterized impacts of solar cell power plant in the centre.

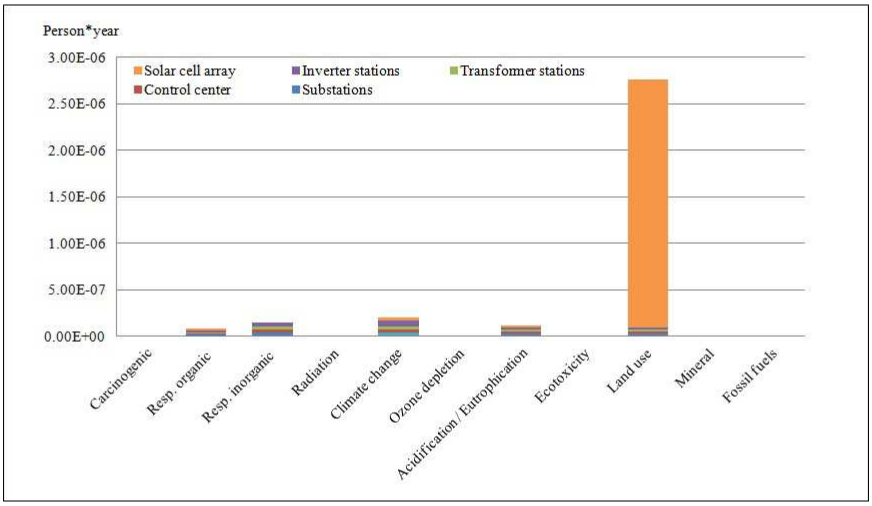

Fig. 10. Normalized impacts of solar cell power plant in the centre.

Of the three impact categories, Ecosystem Quality was the most significantly effected, registering 1.10E-03 Point - again, this was due to use the large amount of arable land used for the solar cell array. Human health was only 4.00E-05 Point, and no processes were found to be detrimental to Resource Depletion (See Fig. 11)

LCIA of biomass power plant in the north of Thailand

With regards to the biomass power plants, while they were found to effect the same LCA categories as the solar cell plants, there were additional impacts in five areas -namely, carcinogens, radiation, ecotoxicity, and depletion of both minerals and fossil fuels (See Fig. 12).

In biomass plants, by far and away the greatest impact is carcinogens, which registered 1.77E-06 Person*year in the northern plant. This was followed by ecotoxicity (1.68E-06 Person*year), climate change (1.06E-06 Person*year), fossil fuel depletion (9.54E-07 Person*year), the respiration of inorganic substances (1.44E-07 Person*year), acidification and eutrophication (4.36E-08 Person*year), land use (2.35E-08Person*year), radiation (1.70E-08 Person*year), the respiration of organic substances (1.58E-09 Person*year) and finally mineral depletion (1.11E-10 Person*year). Of the various power generation processes, the one with the largest impact on carcinogen production was the combustion process, which measured 1.77E-06 Person*year (See Fig. 13).

Furthermore, while the greatest impact of solar cell power tended to be on Ecosystem Quality, power generated from biomass plants had the greatest effect on Human Health (1.19E-03 Point) because bagasses are burned as fuel (direct combustion). Ecosystem Quality was found to be 7.00E-04 Point, while Resource Depletion measured 3.79E-04 Point (See Fig. 14).

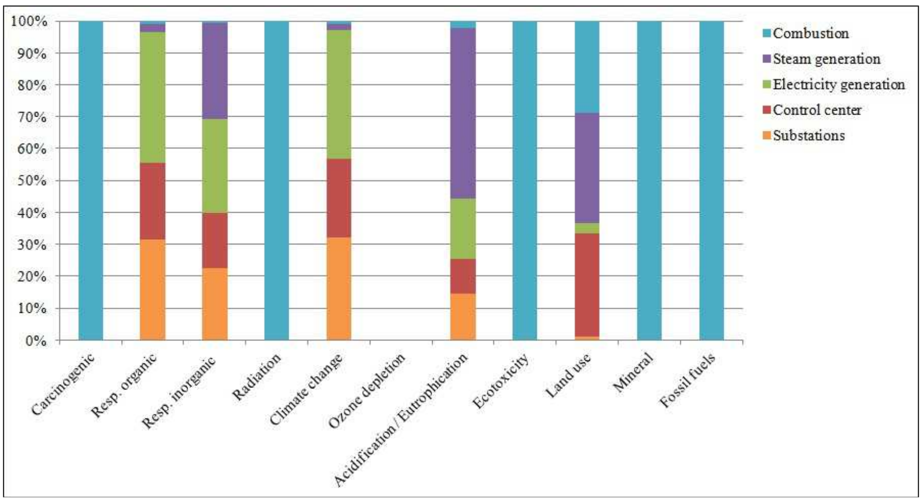

Fig. 12. Characterized impacts of biomass power plant in the north.

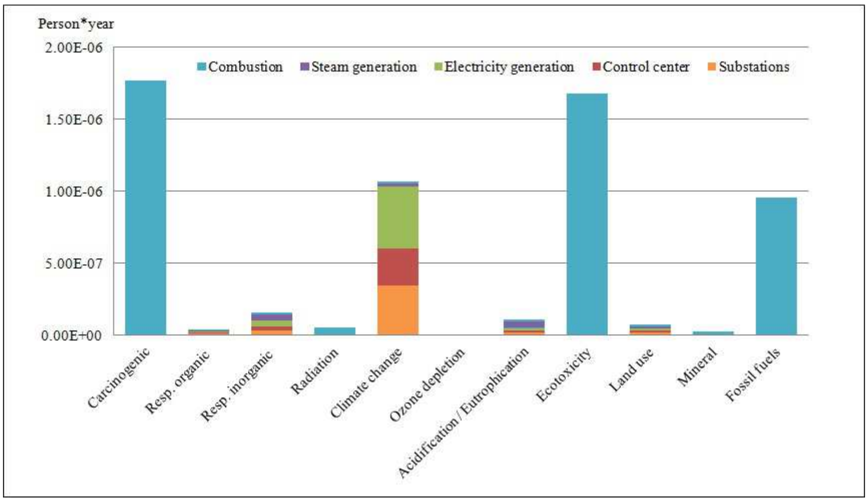

Fig. 13. Normalized impacts of biomass power plant in the north.

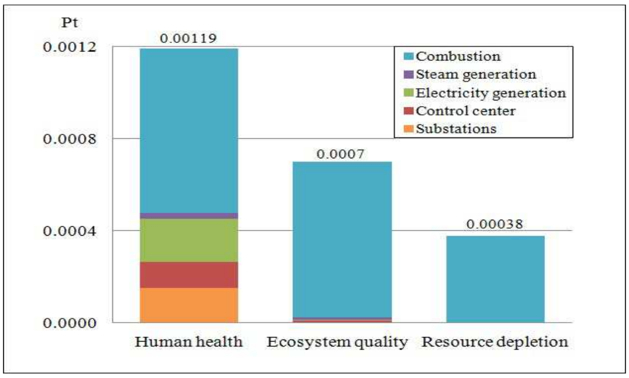

Fig. 14. Weighted impacts of biomass power plant in the north.

LCIA of biomass power plant in the northeast of Thailand

The northeastern biomass power plant followed a similar pattern to that of the north (See Fig. 15).

Ecotoxicity had the greatest impact (2.96E-06 Person*year), followed by carcinogens (2.25E-06 Person*year), fossil fuel depletion (1.73E-06 Person*year), climate change (1.64E-06 Person*year), land use (2.99E-07 Person*year), the respiration of inorganic substances (1.81E-07 Person*year), radiation (4.61E-08 Person*year), acidification and eutrophication (3.46E-08 Person*year), mineral depletion (1.31E-08 Person*year) and lastly, the respiration of organic substances (2.44E-09 Person*year). Again, the combustion process had the largest impact upon the production of ecotoxicity, this time measuring 2.96E-06 Person*year (See Fig. 16).

Like the northern plant, Human Health was most severely impacted, measuring 1.64E-03 Point, again because of the burning of bagasses as fuel (direct combustion) as fuel. The impact on the Ecosystem Quality was measured at 1.32E-03 Point, and Resource Depletion was 6.89E-04 Point (See Fig. 17).

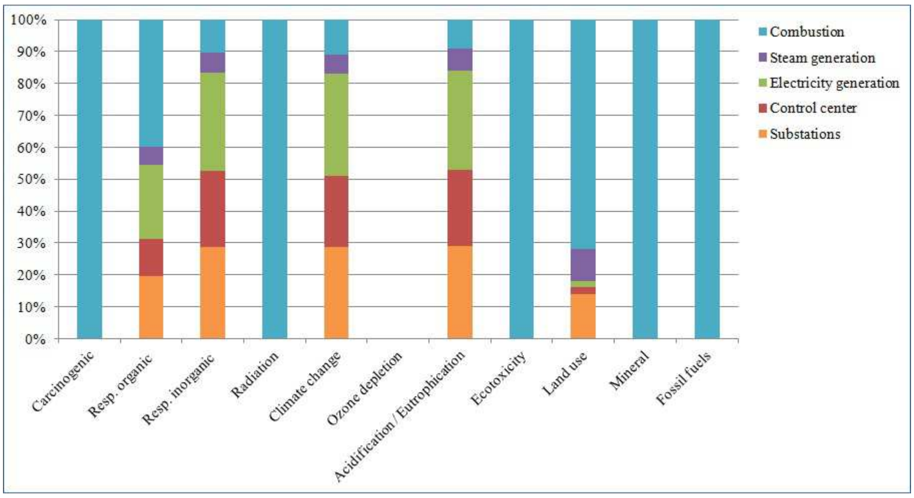

Fig. 15. Characterized impacts of biomass power plant in the northeast.

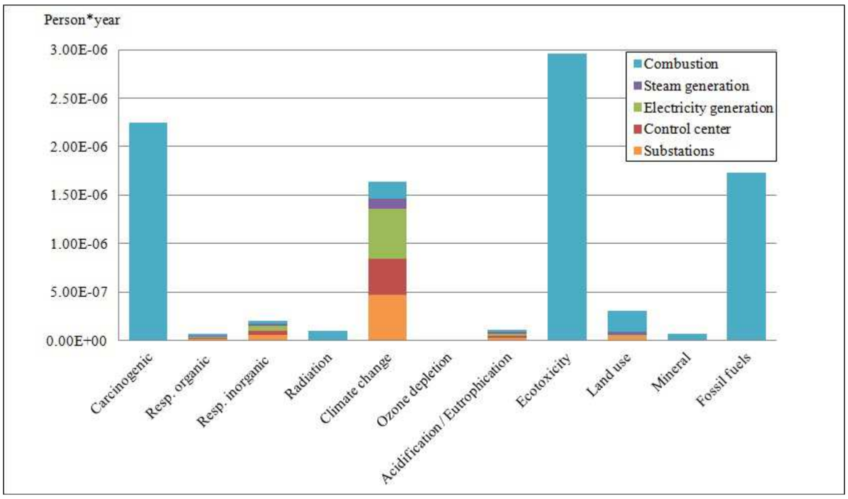

Fig. 16. Normalized impacts of biomass power plant in the northeast.

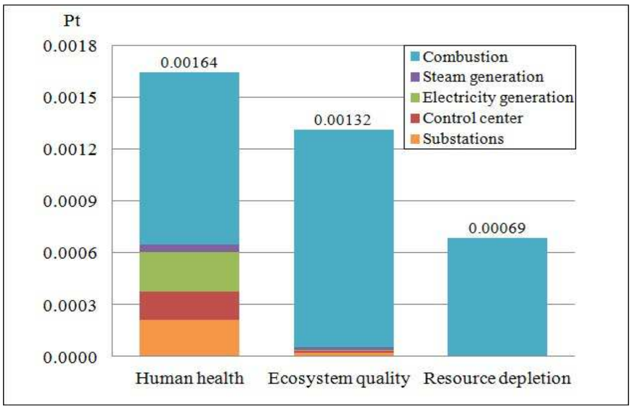

Fig. 17. Weighted impacts of biomass power plant in the northeast.

4.4 Interpretation of the case study

Looking at the solar cell power plant in the north of Thailand, the most detrimental effect of the power generation process was on the respiration of organic substances, which measured 1.46E-12 DALYs. The next most significant effect was on inorganic substance respiration, which measured 1.12E-10 DALYs, followed by climate change, measuring 1.09E-09 DALYs, acidification and eutrophication, measuring 7.19E-06 PDF*m^2*yr and land use which measured 1.25E-02 PDF*m^2*yr. Due to the use of vast quantities of arable land for solar cell arrays, Ecosystem Quality was the most impacted, measuring 9.77E-04 Point, of which 2.45E-06 Person*year was land use. Lower was the impact on Human Health, which measured 1.60E-05 Point, while there was no effect on Resource Depletion. Finally, the amount of power generated by 1 kWh impacted upon the environment at 9.93E-04 Point.

The solar cell power plant in central Thailand followed a similar pattern. The respiration of organic substances measured 1.85E-12 DALYs, the respiration of inorganic substances measured 1.44E-10 DALYs, climate change measured 1.40E-09 DALYs, acidification and eutrophication measured 9.27E-06 PDF*m^2*yr, while land use measured 1.41E-02 PDF*m^2*yr. Again, Ecosystem Quality was the most significantly effected, this time measuring 1.10E-03 Point, of which 2.76E-06 Person*year can be accounted for by land use. Human Health was measured at 4.00E-05 Point, while once again, no processes were found to be detrimental to resource depletion. Finally, the amount of power generated by 1 kWh impacted upon environment at 1.14E-03 Point.

In contrast, the biomass power plants had a much greater effect upon the environment than the solar cell plants. Analyzing the northern plant, the most detrimental effect was the production of carcinogens, these measuring 2.71E-08 DALYs. Next was the effect upon organic and inorganic substance respiration, which measured 2.43E-11 DALYs and 2.22E-09 DALYs respectively, followed by radiation, at 2.62E-10 DALYs, and climate change at 1.64E-08 DALYs. Acidification and eutrophication were found to be 2.23E-04 PDF*m^2*yr, while there was also an impact upon ecotoxicity, measured at 8.63E-03 PDF*m^2*yr. Land use was 1.20E-04 PDF*m^2*yr, and there was also an impact upon mineral and fossil fuel depletion, which measured 9.37E-07 MJ surplus and 8.03E-03 MJ surplus respectively. The high levels of carcinogens were produced because of the burning of bagasses (direct combustion) as fuel, with the result that of the three impact categories, Human Health was by far the most effected, registering 1.19E-03 Point (of which 1.77E-06 Person*year were carcinogens). With a much lesser impact was Ecosystem Quality, registering 7.00E-04 Point, and Resource Depletion which registered 3.79E-04 Point. Finally, the amount of power generated by 1 kWh impacted on environment at 2.27E-03 Point.

The biomass power plant in the northeast of Thailand followed an identical pattern to the northern plant in its impact upon the environment. This time, carcinogens were found to be 3.46E-08 DALYs, organic substance respiration was 3.76E-11 DALYs, inorganic substance respiration was 2.79E-09 DALYs and radiation and climate change were 7.12E-10 DALYs and 2.53E-08 DALYs respectively. Acidification and eutrophication were 1.78E-04 PDF*m^2*yr, ecotoxicity was 1.51E-02 PDF*m^2*yr, while land use was 1.53E-03 PDF*m^2*yr.

Mineral and fossil fuel depletion were measured at 1.10E-04 MJ surplus and 1.46E-02 MJ surplus respectively. Again, because of the burning of bagasses, carcinogens had the greatest impact on Human Health, which measured 1.64E-03 Point (carcinogens were 2.25E-06 Person*year). Lesser impacted was Ecosystem Quality (1.32E-03 Point) and Resource Depletion (6.89E-04 Point). Finally, the amount of power generated by 1 kWh impacted on the environment at 3.65E-03 Point.

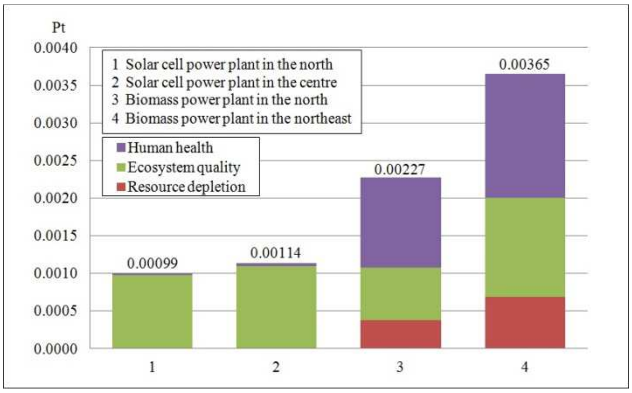

Fig. 18. Total environmental impacts from power generated.

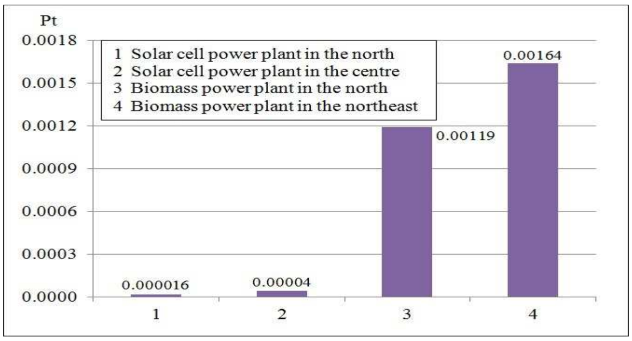

Fig. 19. The impact on Human Health from power generated.

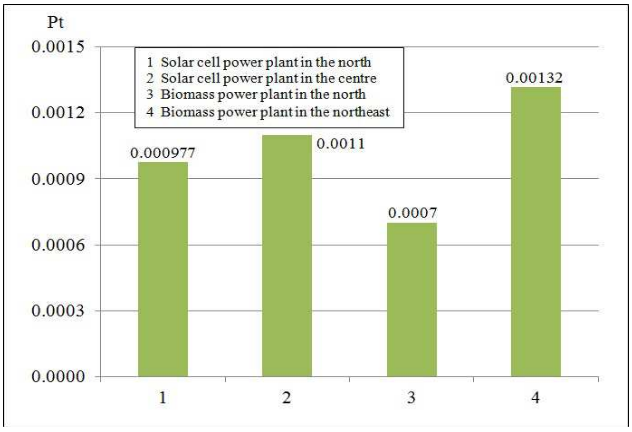

Fig. 20. The impact on Ecosystem Quality from power generated.

So, to summarize, by analyzing the environmental impact created by generating 1 kWh of power, the biomass power plant in northeastern Thailand had the greatest impact upon the environment, followed by the biomass power plant in northern Thailand, the solar cell power plant in central Thailand and finally, the solar cell power plant in northern Thailand. This can be seen in Fig. 18. The biomass power plant in northeastern Thailand had the greatest impact on Human Health, Ecosystem Quality and Resource Depletion, as shown in Fig. 19, 20 and 21.

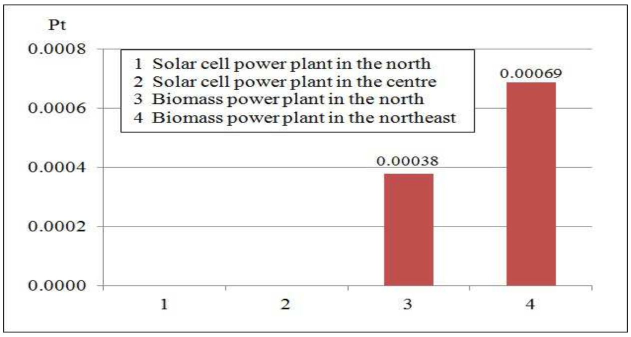

Fig. 21. The impact on Resource Depletion from power generated.

5. CONCLUSION

From this study, it can clearly be shown that biomass power plants have a much more detrimental effect upon the environment when compared to solar cell power plants. When you analyze the environmental impact using the Life Cycle Assessment tool, both the biomass plants in the northeast and north had a significant impact, measuring 3.65E-03 Point and 2.27E-03 Point respectively. By comparison, the solar cell plants in central and northern Thailand had a much lesser impact, measuring only 1.14E-03 Point and 9.93E-04 Point respectively.

Of the various processes involved in biomass power generation, by far and away the greatest overall impact was caused by the combustion process. Of the three impact categories analyzed, Human Health was the most effected, measuring 1.64E-03 Point in the northeastern plant, with the production of carcinogens being the greatest problem, measuring 2.25E-06 Person*year. The second most effected was Ecosystem Quality, which measured 1.32E-03 Point in the northeastern plant, of which ecotoxicity levels were the most effected and measured 2.96E-06 Person*year. Lastly, both biomass power plants were found to have a detrimental effect on Resource Depletion, and in particular upon the the depletion of fossil fuels, which measured 6.89E-04 Point and 1.73E-06 Person*year respectively in the northeastern plant.

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