An Evaluation of Human Health Risk from Biomass Power Plant in Thailand

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Abstract: In Thailand, several biomass power plants are facing considerable opposition from local communities due to their concern over the perceived adverse health effects the pollutants they emit may generate. To address this issue, this study focuses on a small rice husk power plant (less than 10 MW) located in Surin province. The ISCST3 dispersion modeling tool was used to predict the concentration of stack emissions of SO_2 and PM_{10} at varying distance from the source of emission. To assess potential health impacts on local communities, the risk assessment methodology was followed. The results showed that for the 3 communities targeted in these investigations, exposures to both SO_2 and PM_{10} are safe with exposure concentration for the existing situation in the range, 0.083-0.171 μg/m^3 and 0.062-0.121 μg/m^3 respectively. It was also found that the exposure concentrations of SO_2 and PM_{10} in ambient air that would lead to exceed the safe limit for health risk are 16.5 μg/m^3 and 41.5 μg/m^3 respectively. Since the concentrations of SO_2 and PM_{10} in air are contributed by all sources of emissions and the rice husk power plant investigated in this study was found to contribute a minimal share, care in assessing inputs from all other emitting sources is required.

Keywords: Human health risk, PM_{10}, SO_2, Biomass power plant, Thailand.

1. Introduction

Energy is an indispensable fundamental input to modern life and expected to increase demand in future. In Thailand, the electricity demand is forecasted to increase by 66% over the next 20 years [1]. Several researchers have predicted that fossil fuel will become exhausted in the next 100-120 years [2]. The world therefore cannot depend solely on fossil fuels as a source of energy. Thailand strongly depends on energy import to satisfy the demand with about 60 percent of its total energy need coming from outside [3]. In terms of power generation, about 70 percent of electricity is produced from natural gas [3], a resource that is predicted to be depleted in the next 10 years in Thailand [4]. Energy security is therefore a major challenge for Thailand to address. Also, there is increasing awareness and concern about the effects of global warming which are partly contributed from fossil emissions of greenhouse gases. There is therefore an increasing cooperation from countries worldwide including Thailand to attempt reducing such emissions and contribute to mitigating global warming.

Since the energy sector is one of the main contributors of fossil carbon dioxide emissions, the energy industry is looking for alternative technologies and sources of energy to reduce such impacts. As Thailand is an agricultural country, it is rich in biomass resources and there is increasing interest in using such domestic feedstock for energy. The Thai government in its AEDP 2012-2021 has set a target of having renewable energy satisfying 25% of total energy consumption by the year 2021 [5]. At present, about 82% of renewable energy in Thailand is powered by biomass, accounting for 1,397 MW out of a total of 1,698 MW [1]. This biomass is promoted to reduce dependency on fossil fuels and help reducing global warming impacts. However, the development of biomass power plants in Thailand although supported by the central government is facing considerable opposition from the community and several projects are facing legal problems. A major reason for rejection of planning permission by the community is due to the fact that many biomass power plants of capacity less than 10 MW are not required to report the potential environmental impacts and health impacts of their activities [6]. This leads to serious public concerns about the perceived adverse health impacts of such biomass projects.

To contribute addressing such an issue, this study aims therefore at assessing the potential health risks posed by inhalation of PM_{10} and SO_2 emitted from a rice husk biomass power plant located in the north east of Thailand to nearby communities.

2. Experimental

2.1 Rice husk power plant

In this study, a rice husk power plant located in Surin province was investigated. The technical features of this power plant are summarized in Table 1.

Table 1. Key technical features.

Gross Power Generation	9.9 MW (<10MW)
The net power generation	8.8 MW (<10MW)
Rice husk consumed	270 tonnes/day (8,500 tonnes/year)
Air Pollution control system Multi Cyclone efficiency ESP efficiency	 60% 98% (Technical spec 99.6%)
Exhaust gas flow rate	~ 64,704 Nm^3/hr
Total Suspended Particulate (TSP) concentration from combustion	~ 12,797 mg/Nm^3
The stack emission TSP SO_2	< 108 mg/m^3 <54 ppm

Source: [7]

The plant consists of 1 unit with total net power generation of 8.8 MW with 8 MW sold to EGAT and 0.8 MW used in the plant itself. The plant consumes 8,500 tonnes per year or 270 tonnes per day of rice husk. The flue gas which is produced from the combustion process passes through an air pollution treatment system. The treatment system consists of two main treatment technologies: a Multi-cyclone and an Electrostatic Precipitator Unit (ESP). After treatment, the exhaust gas is released to ambient air with a flow rate of 64,704 Nm^3/hr and stack emission concentrations of total suspended particulate (TSP) and SO_2 of less than 108 mg/m^3 and 141.5 mg/m^3 (54 ppm) respectively. Measurements of these emissions are performed every 6 months and reported to the Pollution Control Department of the Ministry of Natural Resources and Environment, Thailand.

In this study stack emissions of PM_{10} and SO_2 from the biomass power plant in Surin were studied, their transport to nearby communities modeled, and associated potential health risks assessed.

2.2 Air modeling of SO_2 and PM_{10} emissions

Air dispersion model uses mathematical formulation to characterize the atmospheric processes that disperse toxic substances emitted from a particular source. These mathematical constructs are coded into computer programs to facilitate the computational process. The Industrial Source Complex Short-Term Model (ISCST3) developed by the Trinity Consultants Inc**.,** was used to predict ground level concentrations of SO_2 and PM_{10}.The ISCST3 model generally recommends conducting air dispersion and deposition modeling for use in a risk assessment and is therefore widely accepted as a model for this assessment [8]. The stack emission data (exhaust gas flow rate, concentration of SO_2 and TSP from the stack and temperature) were estimated using the emission report of the rice husk power plant. In this study, the stack emissions of TSP are assumed to be those of PM_{10} since emission control technologies (Bag Filter and ESP) are in place to remove particles of size larger than PM_{10} [9]. Based on this information, 3 communities referred to as A, B and C were identified that are most prone to exposure to higher level of PM_{10} and SO_2, as shown in Figure 1. These communities were surveyed to evaluate potential health risks.

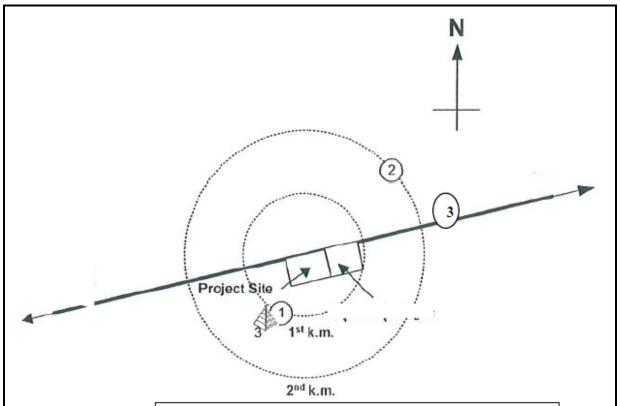

Figure 1. Schematic representation of locations of the biomass power plant and nearby communities (referred to as community A, B and C).

2.3 Health risk assessment

2.3.1 Representative exposure concentration

To assess health impacts related to exposure to SO_2 and PM_{10}, the representative exposure concentrations of such pollutants for the communities investigated in this study need to be determined. This requires information about the concentrations of SO_2 and PM_{10} in air at the points where the communities are located and determined as part of the air modeling step described in the previous section. It also requires information on representative exposure of the communities to such pollutants, i.e. daily time activity patterns. These activity patterns were determined based on face-to-face interviews (questionnaire survey) where a representative sample of people for the communities investigated was surveyed. For this study, the sample size was determined based on the Taro Yamane's concept [10], which simplified formula is as shown below.

$$n = \frac{N}{1 + N(e)^2} \qquad (1)$$

Where:

n	is	the sample size
N	is	population size
e	is	level of precision.

Based on Equation (1), a sample of 122 people for the 3 communities considered was surveyed (the population size for the 3 communities investigated is 16,465 people and the level of precision is 10%). Information about their respective daily activity pattern is reported in Table 2.

Table 2. Representative daily activity pattern of community A, B and C.

Activity (hrs)	Time exposure details		
	Community A	Community B	Community C
At Home	15.12	15.12	12.24
At Work	6.00	5.04	9.84
Other	2.64	3.6	0.72
Travel	0.24	0.24	1.2

From the above Table, it is observed that people of such communities spend most of their time at home, around 12-15 hours, followed by their working place, around 5-10 hours. This information combined with the PM_{10} and SO_2 concentrations determined from the modeling step enables to calculate the representative exposure concentration of the communities investigated following Equation (2), as shown below.

$$EC_a = \frac{1}{T}\left(\sum C_{a,j} \times t_j\right) \qquad (2)$$

Where:

EC_a: adjusted average exposure concentration of pollutant 'a' (μg/m^3),

T : Daily average time spent at location 'j' (T = 24 hours)

$C_{a,j}$: Average concentration of pollutant 'a' at location "j" (μg/m^3), and

t_j : time spent at location "j" (hours/day).

2.3.2 Toxicity values

The toxicity factors of PM_{10} and SO_2 in air, referred to in risk assessment as Reference Concentration or "R*f*C", were determined based on information from the WHO (World Health Organisation) Air Quality Guidelines [11]. The toxicity values are shown in Table 3.

Table 3. Reference exposure levels of SO_2 and PM_{10} for protection of health according to WHO.

Parameter	Air Quality Guidelines* (μg/m^3)	Reference Concentration (mg/kg-day)
Sulfur dioxide (SO_2)	20	0.006
Particulate Matter (PM_{10})	50	0.014

*Source: [11]

Such toxicity values represent the intake benchmark not to exceed for the health risk to remain safe. This means that if the ratio of a pollutant intake to that of its corresponding toxicity factor (R*f*C) is less than one, then there is no risk. The assessment of pollutant intake via inhalation is detailed in the section below.

2.3.3 Average daily intake

To evaluate the health risk, the intake of PM_{10} and SO_2 by the communities is to be determined based on representative exposure concentration and exposure timing as shown in Equation (3).

$$\text{ADI (mg/kg-day)} = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT} \qquad (3)$$

Where:

ADI = Average Daily Intake (mg/kg-day)

CA = Pollutant Concentration in Air (mg/m^3)

IR = Inhalation Rate (m^3/day)

ET = Exposure Time (hours/day)

EF = Exposure Frequency (days/year)

ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging Time (period over which exposure is averaged - days)

The values of exposure time, frequency and duration (ET, EF and ED in Equation 3) were obtained using standard values from USEPA (1991) [12]. These are 24 hours/day exposure time, 350 days/year exposure frequency and 30 years of exposure duration.

2.4 Scenarios for health risk assessment

In this study 3 scenarios were considered to evaluate health risks of the communities studied as described below:

Base-case scenario: This corresponds to the existing situation; the assumptions are for communities inhaling PM_{10} and SO_2 from biomass power plant based on predicted representative exposure concentrations for each community and standard exposure characteristics, i.e. 24 hours a day exposure over 350 days per year for 30 years.

Worst-case scenario: This is the worst-case situation; the assumptions are for communities inhaling PM_{10} and SO_2 from biomass power plant based on predicted maximum exposure concentration and for exposure conditions identical to those of the base-case scenario.

Risk-case scenario: In this scenario, the exposure concentration level leading to a health risk higher than 1 is assessed based on all sources of emissions (ambient air quality) for exposure conditions identical to those of the base-case scenario. For this scenario, data of ambient air concentrations of PM_{10} and SO_2 were retrieved from a monitoring station located in that region and providing hourly measurements of such pollutants on a daily basis all year round.

3. Results and Discussion

3.1 Results from questionnaires survey

Basic information collected from the community people sampled in this questionnaire survey, including time activity patterns, is reported in Table 4. The people interviewed were between 15 to 85 years of age, mostly farmers working within the vicinity of their home (workplace less than 3 km away from home for 68% of the interviewees on average).

3.2 Results from modeling

In this study, concentrations were predicted for the year 2010 because it is the year where the most complete and recent information for surface and upper air measurements is available. The meteorological data used for the study area where the biomass power plant is located were derived for surface observations (wind direction, wind speed, ceiling height, temperature and cloud cover) from the Surin meteorological station and for upper air measurements (mixing height) from the Bangkok meteorological station as provided by the Meteorological Department.

From the dispersion modeling results, it was found that the predicted concentration values of SO_2 and PM_{10} are quite low within short distances from the biomass power plant (less than 1 km) and start to pick up at a distance of 1.5 km to 4.5 km from the plant (See Figure 2 and 3). These modeling results appeared to be in good agreement with those of simulations using 10 years wind data from the Surin meteorological station (2003-2012).

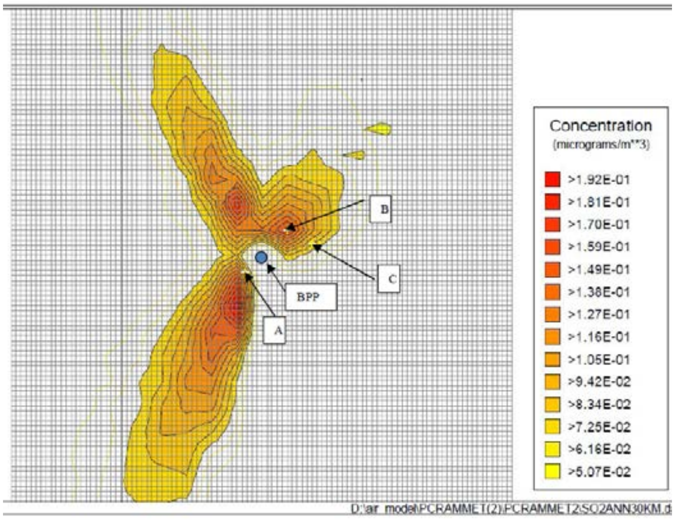

Figure 2. Contour map of predicted SO_2 average annual concentration.

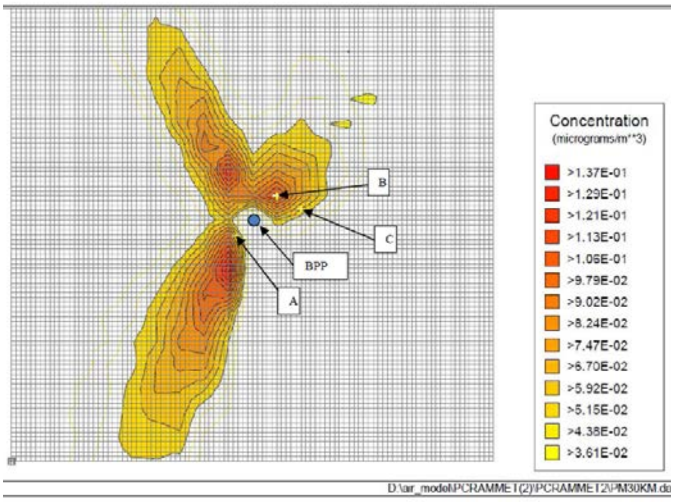

Figure 3. Contour map of predicted PM_{10} average annual concentration.

Table 4. Basic characteristics of the community groups sampled

Characteristics	Community A	Community B	Community C	Average for the three communities
Weight (number of persons)	<45kg: 2 45-55kg: 20 56-70kg: 11 >70kg: 1	<45kg: 2 45-55kg: 8 56-70kg: 7 >70kg: 2	<45kg: 4 45-55kg: 45 56-70kg: 20 >70kg: none	<45kg: 7% 45-55kg: 60% 56-70kg: 31% >70kg: 2%
Daily Activity pattern (hrs)	Home: 15.12 Work: 6.0 Transit: 2.64 Other: 0.24	Home: 15.12 Work: 5.04 Transit: 3.60 Other: 0.24	Home: 12.24 Work: 9.84 Transit: 0.72 Other: 1.2	Home: 59% Work: 29% Transit: 10% Other: 2%
Work-home distance (km)	<1: 17 1-3: 6 3-5:1 >5: 10	<1: 7 1-3: 6 3-5: none >5: 6	<1: 25 1-3: 22 3-5:4 >5: 18	<1: 40% 1-3: 28% 3-5: 5% >5: 34%

The results of predicted annual average concentration of SO_2 and PM_{10} for each community are presented in Table 5.

Table 5. Predicted and ambient annual average concentration of SO_2 and PM_{10}.

Receptor	**Distance from power plant**	**Predicted Concentration**	
	Kilometers	SO_2 (μg/m³)	PM_{10} (μg/m³)
Community A	1.4	0.171	0.121
Community B	2.1	0.166	0.118
Community C	3.1	0.083	0.062
Maximum concentration	1.7	0.249	0.177

Table 5 reveals that that the highest concentration of SO_2 and PM_{10} was found at a distance of about 1.7 km (south west) from the biomass power plant. Among the three communities investigated, community A was found to be the one exposed to the highest concentration of SO_2 and PM_{10}. However, compared to the ambient air quality standard defined by WHO (see Table 3), all the concentration values determined through this modeling step were found to be lower. This implies that the predicted stack emissions of SO_2 and PM_{10} are likely to be safe for the local communities studied. This health risk is quantified in the section below.

3.3 Health risk characterization

3.3.1 Assessment for the base-case scenario

The level of risk associated to SO_2 and PM_{10} was assessed based on the 3 scenario conditions detailed in section 2.4. The results are presented below for the base-case scenario and then all other scenarios together.

For the base-case scenario, the assessment was based on the representative exposure concentration people from each of the 3 communities studied were determined to be subject to. Based on this information, the health risk referred to as Hazard Quotient or "HQ" in risk assessment terminology was determined. The results are shown in Table 6.

From this Table, it is observed that the HQ values related to stack emissions of SO_2 and PM_{10} from the rice husk power plant are below the threshold of 1 for all 3 communities. This means that those emissions are below the safe limit, not posing any health threats. It is also observed that the highest HQ values for both SO_2 and PM_{10} are found for community A and B followed by community C. For SO_2, the safe level is 111 to 200 times lower than the threshold while it is even lower for PM_{10}, about 333 to 1000 times.

3.3.2 Assessment for other scenarios

For the worst-case scenario, as shown in Table 7, the results also show that there are no health risks associated to exposure to either the predicted maximum annual average concentration of SO_2 or PM_{10}. For the risk-case scenario, based on the estimated concentration of PM_{10} and SO_2 that could lead to an exceedance of the safe limit for health risk, in accordance with standard exposure characteristics as defined by USEPA (2011) [13], and based on a yearly average, the concentration of SO_2 and PM_{10} in ambient air should not exceed 16.5 μg/m³ and 41.5 μg/m³ respectively.

These results also show that for the two scenarios (base-case and worst-case) the risk associated to exposure to SO_2 is higher than PM_{10} (even though much below the safe limit). However, in the risk-case scenario, it is observed that on a yearly average basis, the concentration of SO_2 and PM_{10} in ambient air should not exceed 16.5 μg/m³ and 41.5 μg/m³ respectively. Looking more closely at these 2 scenarios, it is noticed that the representative exposure concentrations of PM_{10} and SO_2 for the worst case-scenario represents only 0.4% and 1.5% of the values obtained for the risk-case scenario. This implies that the stack emissions of PM_{10} and SO_2 from the rice husk biomass power plant are small contributors to air concentration levels that would lead to some potential health risks. It is therefore important to clearly inform communities about such results to avoid unreasonable opposition to biomass power plant development projects. Also, one should take a close look at all emission sources contributing to ambient air quality to identify which sources are contributing most to it and which pollutants are concerned so that appropriate strategies for improvement in the future can be identified and implemented.

4. Conclusions

This study aimed at investigating the stack emissions of SO_2 and PM_{10} from a rice husk power plant in Surin Province and assessing the potential health risks for communities surrounding the plants. Three communities located near the power plant were investigated. The air dispersion modeling was used to evaluate exposure concentration and health risk assessment performed to evaluate the risk. The results showed that there are no health risks for all 3 communities investigated in this study. It was also found that the predicted concentration values of SO_2 and PM_{10} were quite low as compared to the risk level concentration of the same pollutants. However, since the risk concentration is related to all sources of emissions, and as the rice husk power plant was found to contribute only a minimal share to the overall emissions, care in properly informing communities is necessary to avoid opposition to the rice husk power plant operation and identify suitable measures to improve air quality.

Table 6. Health risk characterization for the base-case scenario.

Receptor	Contaminants	Representative Exposure Concentration (μg/m³)	Average Daily Intake (mg/kg-day)	Reference Concentration (mg/kg-day)	HQ
Community A	SO_2	0.145	5.05×10^{-5}	0.006	0.009
	PM_{10}	0.104	3.62×10^{-5}	0.014	0.003
Community B	SO_2	0.143	4.97×10^{-5}	0.006	0.009
	PM_{10}	0.104	3.62×10^{-5}	0.014	0.003
Community C	SO_2	0.076	2.64×10^{-5}	0.006	0.005
	PM_{10}	0.055	1.91×10^{-5}	0.014	0.001

Table 7. Health risk characterization for the worst-case and risk-case scenarios.

Receptor	Contaminants	Representative Exposure Concentration (μg/m³)	Average Daily Intake (mg/kg-day)	Reference Concentration (mg/kg-day)	HQ
Worst-case scenario	SO_2	0.249	8.65×10^{-5}	0.006	0.015
	PM_{10}	0.177	6.15×10^{-5}	0.014	0.004
Risk-case scenario	SO_2	16.5	0.006	0.006	1
	PM_{10}	41.5	0.014	0.014	1

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