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Life cycle assessment and feasibility study of small wind power in Thailand

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A B S T R A C T

The Thai government's renewable energy plan to help increase energy independence and reduce emissions includes a component from wind. Due to Thailand's wind regime, small wind turbines that can operate in low wind speeds are needed to meet this goal. This study assesses the environmental implications and economic feasibility of small wind turbines. Using a functional unit of producing 50 kWh per month for 20 years, a Life Cycle Assessment was conducted comparing the global warming potential (GWP100), embodied energy, energy payback period (EPP) and levelized cost of electricity (LCOE) of four small wind turbines (≤20 kW), a diesel generator, and the Thai grid. The turbines had a lower overall GWP100 compared to the diesel generator and Thai grid in areas with reasonable wind resources; the same was true for embodied energy when compared to the diesel generator. Interestingly, in most available wind speed categories in Thailand the LCOE for wind turbines was lower than for the diesel generator. However, neither could compare to the selling price of the Thai grid, except in the areas with the highest average wind speeds (7.0–9.4 m/s). Because of the increased cost relative to the Thai grid, implementation of wind turbines in Thailand was not found to be economically feasible without government incentive.

Introduction

The Thai government's goal of 25% renewable energy production by 2021 is an attempt to reduce national dependence on non-domestic energy sources as well as reduction of the environmental burdens associated with domestic energy production. These green energy objectives include an ambitious goal of harvesting at least 1200 MW of energy from the wind. At present, Thailand receives less than 8 MW of electricity from wind power (DEDE, 2011). The majority of Thailand has low average wind speeds, meaning that multi-megawatt installations of large wind turbines like those in the United States and Europe are not currently be feasible (Annex Power, 2010). Small wind turbines, on the other hand, are better suited to areas with weaker wind regimes because they generally have a lower cut-in wind speed than large wind turbines. With a lower cut-in wind speed, small turbines can capture more energy per watt of turbine capacity than large turbines in an area with low average wind speeds. For this reason, the feasibility of small wind turbines for application in Thailand was investigated. This goal was accomplished using Life Cycle Assessment (LCA) framework to compare the environmental and economic feasibility of several small wind turbines. These findings will be compared to already established practices of grid electricity use and small diesel generator use for household electricity.

Small wind turbines will have to be effectively utilized in Thailand in order to meet the goal of 1200 MW of installed capacity by 2021. Because of the relatively modest power rating of small wind turbines (≤20 kW) compared with the energy consumption of the average urban household in Thailand (over 800 kWh per month), this paper focuses on implementation at rural households (~69 kWh per month). In rural areas a small wind turbine has the potential to supply a significant portion of the electricity demand of an average household. Depending on the wind resource available, it is even possible to exceed this electricity demand.

Personal or small community electricity production from clean energy sources like wind and solar could prove to be valuable means to accomplish Thailand's goals for renewable energy production. The feasibility of small wind turbines will be investigated with this study.

The most important factors for determining the feasibility of small wind turbines as a means to accomplish the goal of clean power production in Thailand are the environmental burdens and energy requirements associated with the turbine system's life cycle and the cost of electricity produced by the turbine system. This paper provides information regarding small wind power implementation. Though this sort of study has been done before, this paper is unique because it supplies information about a growing industry to a particular area, Thailand.

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The specificity of this paper is its strength. Access to data regarding not only environmental burdens associated with small wind energy but also to its economic potential is important for government organizations, large companies, and individual investors. Providing results that account for life cycle considerations will allow these groups to make more informed and accurate decisions regarding small wind implementation in Thailand, generating more effective investments that can help Thailand reach its goal of 1200 MW of installed wind power by 2021.

Materials and methods

Goal

The goal of this study is to assess the life cycle global warming impacts and embodied energy of four small wind turbines with power ratings of 400 W, 2.5 kW, 5 kW, and 20 kW. Using information published by Thailand's Department of Alternative Energy Development and Energy Efficiency (DEDE) regarding the average wind speed in ten wind classes in Thailand, the amount of energy that can be produced by each of the turbines in various areas of the country is assessed. From this analysis GWP100 and embodied energy of the turbines is compared to that of the diesel generator. In addition, GWP100 of the turbines is compared to that of the Thai grid. The levelized cost of electricity (LCOE) from each of the turbines is compared with that of the diesel generator and the selling price of the Thai grid. From this comparison, the feasibility of a rural household or community investing in any of these small wind turbines as their primary means of electricity production is assessed.

Scope

The functional unit is 50 kWh of electricity per month for 20 years, taking into account the efficiencies of the turbine/generator, the inverter, and the storage batteries. This time period was chosen because the lifespan of the turbines is assumed to be 20 years (Martínez et al., 2008). The geographical limitations of this study are limited to Thailand because of the modest wind resource and the current grid mix. The temporal limitations only extend as far as the end of our functional unit, assuming stable costs for electricity from the Thai grid and for diesel fuel.

This LCA assesses the embodied energy and GWP100 of the life cycles of the various wind turbines from extraction of raw materials, through processing and refining, transportation, manufacture, operation, maintenance, and disposal. Estimates for expected energy output from the four turbines were calculated by two separate methods: the power curve method and the swept area method. These expected outputs are then compared to the embodied energy in order to determine the energy payback period. Similar calculations were performed for the diesel generator system.

The wind system in this study was composed of a wind turbine, an inverter, and batteries, and in some cases, a turbine tower. Four wind turbines were analyzed in the study with rated power outputs of 400 W, 2.5 kW, 5 kW, and 20 kW. These turbines were selected because they represent a range of power outputs that are still considered to be within the small turbine range. Furthermore, a reasonable amount of background data was available for each turbine.

The diesel generator system consists of a generator, diesel fuel, and a battery bank. The fuel tank was excluded because the impacts associated with the fuel tank were considered negligible. Additionally, the inverter was not included because diesel generators generally produce alternating current. Generator sizing and fuel consumption were based on average data of similarly sized generators that are of the correct size to fulfill the functional unit.

Tables 1, 2, 3, and 4 include disposal assumptions for the wind turbines, diesel generator, battery, and inverter. There is little, if any, information about wind turbine system disposal that is specific to Thailand. Consequently, current practice wind turbine system disposal assumptions were taken from around the world. Where possible, assumptions were taken from studies of small wind turbines (Fleck and Huot, 2009; Kabir et al., 2012). Disposal assumptions for aluminum, concrete, epoxy, glass fiber, and all forms of steel for the turbines and diesel generator were taken from Kabir et al. (2012). Disposal assumptions for the plastic in the wind turbines were taken from Martínez et al. (2008). Battery disposal assumptions were taken from Fleck and Huot (2009). The same assumptions were used for the inverter. Sources for burdens and credits associated with disposal are shown in Tables SI 8.1, 8.2, and 8.3 in the Supporting Information.

Table 1
Wind turbine disposal.

Material	Disposal method		
	Recycling	Landfilling	Incineration
Aluminum	95%	5%	0%
Concrete	0%	100%	0%
Copper	95%	5%	0%
Epoxy	0%	100%	0%
Galvanized steel	90%	10%	0%
Glass fiber	0%	100%	0%
Plastic	0%	0%	100%
Stainless steel	90%	10%	0%
Steel	90%	10%	0%
Steel rebar	90%	10%	0%

GWP100 was calculated using the guidelines from the IPCC, 2007: Fourth Assessment Report (IPCC, 2007). Embodied energy was calculated from “Inventory of Carbon and Energy” published by the University of Bath (Hammond and Jones, 2008). The cost of electricity in Thailand and the grid mix were taken from “The Annual Report: Electric Power in Thailand 2011” (DEDE, 2011).

This study could be useful for policy makers and concerned consumers who are interested in investigating how wind power can best be implemented in Thailand. Though this study was done specifically using information for application in Thailand, the methodology could easily be adapted to any other country interested in assessing wind turbine feasibility.

Inventory assessment

Wind turbines

Inventory data for the four turbines studied in this report were obtained from previously conducted wind power LCAs (Fleck and Huot, 2009; Kabir et al., 2012; Skarvelis-Kazakos et al., 2009). Tables SI 4.1, 4.2, 4.3, and 4.4 in the Supporting Information display material inputs for each of the four turbines. Turbines were assumed to have been transported by diesel truck from their place of manufacture to the nearest large port in the country of manufacture. They were then transported on freight ships by way of common international shipping lanes to Bangkok. From there, the turbines were assumed to have been transported by diesel truck over a distance of 1000 km. Approximately 1000 km from Bangkok represents the maximum possible distance that the turbines could be transported within Thailand. This was used in order to determine the maximum possible impact from

Table 2
Diesel generator disposal.

Material	Disposal method		
	Recycling	Landfilling	Incineration
Aluminum	95%	5%	0%
Copper	95%	5%	0%
Steel	90%	10%	0%