A Metropolitan Wind Resource Assessment for Bangkok, Thailand Part 2: GIS Analysis and Technical Wind Resource Potential

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Abstract: This paper describes the second part of the work entitled "A Metropolitan Wind Resource Assessment for Bangkok, Thailand." It estimates the technical potential for electricity generation from wind energy and suggests how it should be utilized, based on wind power density results from the first paper. Here, a number GIS (geographical information system) layers were prepared to exclude areas deemed not suitable for turbine installation, and they were used with the developed wind resource maps to estimate annual energy production (*AEP*) from winds. It was found that largest contributions to total *AEP* come from very small turbine installations in low density urban, medium-to-high density urban, and non-urban areas (1,453, 700, and 689 GWh, respectively). Potential turbine capacity factors are most promising for very small turbines installed on tall buildings (an estimated 25-35%). The total *AEP* given by wind energy over the province was found to be 3,719 GWh, equivalent to up to 10% of total consumption in the province. This amount of energy is considered substantial from an economic viewpoint since Bangkok alone already shares up to approximately a quarter of national electricity consumption.

Keywords Wind energy; urban zones; exclusion criteria; wind turbine.

1. Introduction

Wind turbines have recently been surfacing in and around Bangkok, Thailand, as has been occurring in other cities worldwide. The presence of tall buildings in an urban area allows potential integration of turbines on or within structures as well as alongside them. Although unique aesthetic, safety and cost issues challenge urban wind, we are improving our understanding of urban wind flows and performance of wind turbines in urban environments. Some turbines have even been specially designed for aesthetics and performance in the urban high wind shear environment [1-2].

As urban wind energy is a relatively new concept [3], few attempts have been made to characterize the wind resource potential over cities. Mithraratne (2009) [4] demonstrated integration of mean wind data, a typical turbine power rating, and simple spatial allocation of turbine installations to estimate wind resource over urban houses over New Zealand. McIntyre et al. (2011) [5] assessed the upper-limit wind resource potential over Guelph, a city in Canada, using available detailed wind data with extrapolation to desired heights and a few turbine specifications. While McIntyre et al.'s approach was more comprehensive than Mithraratne in the use of spatial wind data, they calculated the total for electricity generation from wind from an evenly spaced array over the city at a fixed height, which is not realistic given the presence of buildings.

Our first paper presents 1-km resolution wind resource mapping results. Here, we continue to estimate the total technical wind resource potential over Bangkok, which is useful information for policy makers and also to those planning to install wind turbines in the province. In doing so, a set of GIS (geographical information system) layers was prepared to help identify areas feasible for turbine installation. The potential over the province was quantified with the simulated wind maps, GIS layers, and selected turbine specifications. The methodology demonstrated here could be considered relatively intensive for an assessment over a city or metropolis containing tall buildings and highly diverse land cover.

2. Experimental

We designed a collection of 12 GIS layers to exclude areas not feasible for turbine installation, referred to here as "exclusion layers" or "layers" (Table 1). We slightly modified seven from Manomaiphibon et al. [6]: airport, railway, street, major

Table 1. Exclusion layers for very small (V), small (S), and medium-to-large (L) turbines and corresponding buffer distances.

Layer	Buffer(m)			Reason	Source
	V	S	L		
Airport[a]	6,000 & 15,000[b]	6,000 & 15,000	6,000 & 15,000	Legal	[6]
Cultural heritage precinct	-[c]	-	-	Visual	[7]
Major underground natural gas pipeline[a]	500	500	500	Technical	[6]
Mangrove forest	-	500	500	Preservation	[7-8]
Marsh/swamp[a]	-	200	200	Technical, preservation	[6,8]
Park	IA[d]	50	300	Safety, noise	[7-10]
Port	-	-	-	Technical	[8]
Railway[e]	-	50	200	Technical, safety	[6,8,10]
Rural and agricultural preservation zone	IA	-	-	Preservation	[7]
Street	-	50	200	Technical, safety	[6,10]
Urban area[a]	IA	50	300	Safety, noise	[6,8]
Water body[e]	-	100	100	Technical, preservation	[6,8,10]

[a] Adapted from Manomaiphiboon et al. [6]
[b] Buffer width dependent on direction from runway
[c] A dash indicates that no buffer width is added to the layer
[d] IA: Installation allowed within layer
[e] Adapted from Manomaiphiboon et al. with some modification/addition

underground natural gas pipeline, urban, water body, and marsh/swamp. We combined maps from various other sources (Table 1) to generate another five layers: mangrove forest, rural and agricultural preservation zone, cultural heritage precinct, park, and port. Although not comprehensive, these 12 layers are the most pertinent land constraints to consider in Bangkok.

Three representative turbine size categories—based on rated power—were set after consultation with literature [11-13]: very small (V, <10 kW), small (S, 10-100 kW), and medium-to-large (L, >100 kW). A turbine model was selected for each based on hub height, power curve, and availability in the market during the time of the study (Table 2). We assigned buffer widths for each turbine size category to each exclusion layer according to literature review and our own judgment. Individual layers were then combined to create a single merged layer for each turbine size **(**Figure 1**)**.

Table 2. Representative turbine models for each size category.

Size category	Model	Rated power	Tower hub height (m)
Very small, V	Prapai PWT-3000	3 kW	15-21
Small, S	Wind Energy Solutions WES 18	80 kW	18-29
Medium-to-large, L	Vestas V82-1.65	1.65 MW	70-80

Figure 1. Total excluded (black) and available (white) areas for installation.

We used the three urban spatial zones created in the first paper (tall building, T; medium-to-high density, M; and low density, L) and designated all remaining area in the province as a non-urban spatial zone (N). The zones were then matched to turbine size according to technical suitability, resulting in six unique combinations **(**Figure 2**)**: 1) tall-building with very small turbines, TV, 2) medium-to-high density urban with very small turbines, MV, 3) low density urban with very small turbines, LV, and 4-6) non-urban with very small, small, and medium-to-large turbines, NV, NS, and NL. Medium-to-large turbines were allocated first where possible, followed by small and then very small turbines.

As in previous works [5,14-15], turbines were placed in rectangular arrays, here with inter-turbine spacing of seven times the rotor diameter. Table 3 gives effective hub heights used in this study. Turbines were set as standalone in non-urban areas. In low-density urban areas, the hub height was set to 20 m above ground level (AGL), which is reasonable for both rooftop and standalone installations. In medium-to-high density urban areas, where rooftop installations are more practical than standalone, a typical building height of 15-20 m was added to the original hub height.

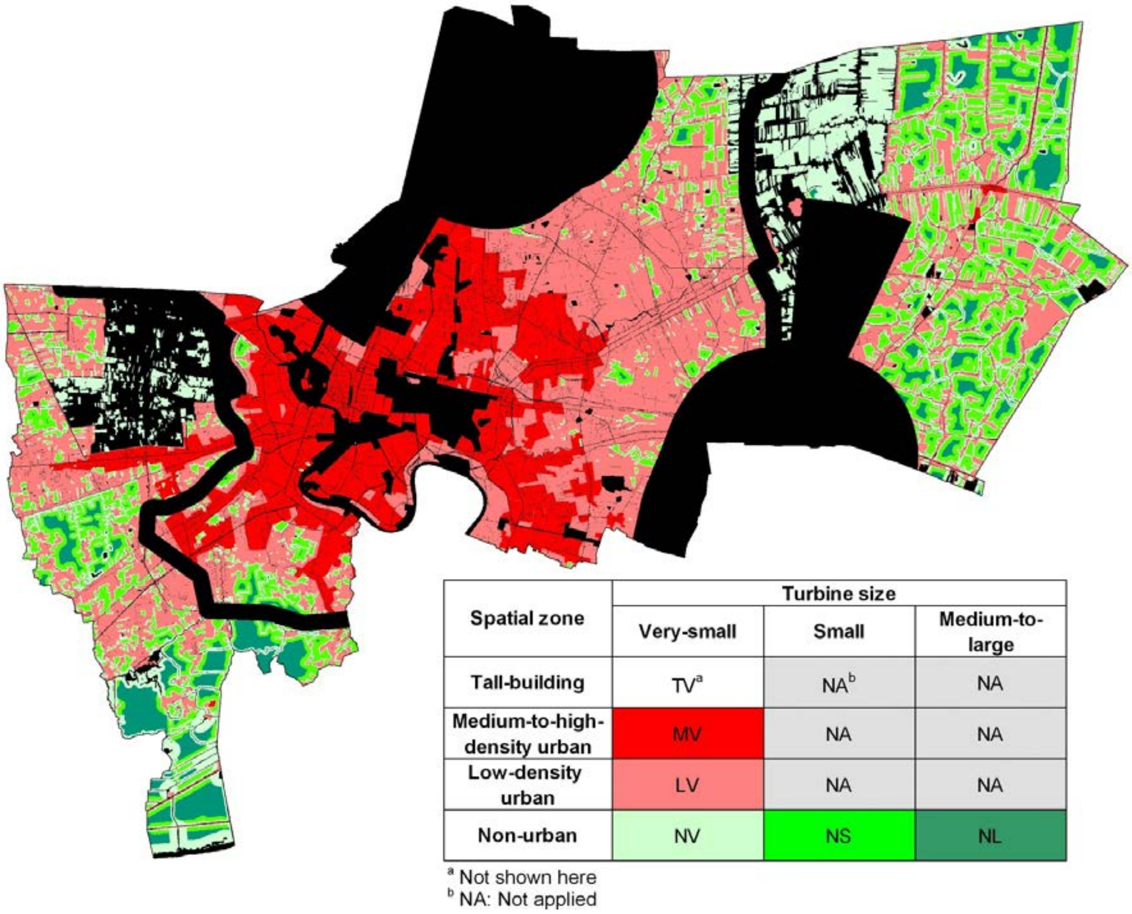

Figure 2. Matching of selected turbine sizes to spatial zones in Bangkok. Both table (inset) and figure use the same color shadings, while black shading in the figure represents areas excluded from turbine installation (except for those on tall buildings if present within).

Table 3. Estimated technical potentials over Bangkok.

Zone-turbine combination[a]	Hub height (m AGL[b])	No. of turbines	*AEP*[c] (GWh)	Mean AEP_{turb} (MWh)	Capacity factor (%)
LV	20	463,623	1,453	3.1	11.9
MV	30	201,437	700	3.4	13.2
NV	20	214,531	689	3.2	12.2
TV	100	720	4.7	5.5	24.5
	150	326	2.6	8.1	30.9
	200	60	0.5	9.0	34.2
	250	8	0.07	9.1	34.5
	300	2	0.02	9.0	34.1
	Subtotal	**1,116**	**8**		
NS	30	9,754	491	50.3	7.2
NL	80	184	378	2,060	14.2
Total			**3,719**		

[a] NL: Non-urban with medium-to-large turbines
NS: Non-urban with small turbines
NV: Non-urban with very small turbines
LV: Low density urban with very small turbines
MV: Medium-to-high density urban with very small turbines
TV: Tall-building with very small turbines
[b] AGL: Above ground level
[c] *AEP*: Annual energy production

For turbines on tall buildings, we created a special database containing building locations and heights. Here, basic information (number of floors, rooftop height, and location) was manually collected for 235 buildings in the provinces using online databases [16-17] and then cross-checked for consistency with satellite imagery [9]. Rooftop height (H) in meters was directly available for 85 of the buildings, and using these we found a relationship with the number of floors (F) to approximate the height of the remainder:

$$H = 3.3F + 24.3. \quad (1)$$

We identified another 325 tall buildings that did not have height or floor information available. For these, we approximated their heights through field surveys and building shadow lengths in satellite imagery. To determine the final hub heights (AGL) of very small turbines on tall buildings, we added turbine tower heights to building heights, and rounded them to 100, 150, 200, 250, and 300 m AGL. Rounding to the nearest 50 m AGL is sufficient for the estimation here given that the variation of wind resource is relatively low at the heights of interest. Also, although tower hub heights for rooftop installation may differ from those used for standalone, the uncertainty in building heights is greater than this difference. We conservatively allocated two turbines per roof (based on investigation of satellite imagery to determine typical tall building rooftop configuration in Bangkok).

Hourly model output from the first paper and representative turbine power curves were used in the following formula to calculate annual energy output from a single turbine (AEP_{turb}, Wh):

$$AEP_{turb} = \sum_{h}^{8760} \frac{\rho_{sim,h}}{\rho_{curve}} \times P_{turb}\{u_{sim,h}\}, \quad (2)$$

where ρ_{curve} is the air density at the reference conditions of a turbine power curve, $\rho_{sim,h}$ is the simulated air density at hour h, and $P_{turb}\{u_{sim,h}\}$ is the hourly turbine-generated power as a function of the simulated wind speed at the hub height, $u_{sim,h}$. To find *AEP*, total annual energy production over an area, AEP_{turb} was summed over all turbines allocated to that area, and reduced by 10% to account for array wake losses [18].

3. Results and Discussion

Based on the exclusion layers described in Section 2, 71% (1,120 km^2) of Bangkok's total area is available for installing very small turbines while 14% (219 km^2) and 4% (62 km^2) are available for small and medium-to-large turbines, respectively (Figure 1). The largest buffered exclusion layers for each of very small, small and medium-to-large turbines are airport (20% of total area), urban area (75%), and urban area (93%), respectively. As seen in the figure, the installable areas for very small turbines spread relatively evenly over most of the province. Those for small turbines are seen in three clusters: in the west/southwest, in the middle (to the east of the city center), and in the east. For medium-to-large turbines, only a few areas remain, mostly in outskirts to the east and the southwest, which fortuitously coincides with the largest wind resource near the coast.

Table 3 shows the technical wind energy potentials (i.e., the potentials given that all turbines are installed) for each of the six combinations of delineated spatial zone and turbine size. Each of these potentials reflects the upper limit of possible electricity generated for the selected turbine technology. Very small turbines in low density urban areas contribute the most to annual energy production (*AEP*) with 1,453 GWh (39% of total *AEP*), followed by very small turbines in both medium-to-high density urban areas and in non-urban areas (19% for each).

These three combinations together, which commonly use very small turbines, yield 76% of total *AEP*. This is due to the large sum of area available for these combinations and the relatively small inter-turbine spacing necessary for turbines of this size that allows more turbines per unit area. The average capacity factor is somewhat low for these combinations (11.9-13.2%). When placed on the rooftops of tall buildings, capacity factors for very small turbines increase to 25-35%, with an 8 GWh contribution to total *AEP* over the province (i.e., <1%). The moderate contribution (13%) to total *AEP* from small turbines installed in non-urban areas is limited by low energy-conversion efficiency of the selected small turbine model and the background wind resource at its recommended hub height (30 m AGL). For medium-to-large turbines installed in non-urban areas, the capacity factor is 13-15%, which is better than all other combinations except very small turbines on tall buildings. As expected, the largest portion of *AEP* from medium-to-large turbines in non-urban areas is seen in the southwest coastal portion of the province because large installable area is available and relatively large wind resource exists. The *AEP* from all installations of this type amounts to 378 GWh (10% of total *AEP*).

Given all installations from all spatial zone and turbine combinations, the total technical wind resource over Bangkok is as large as 3,719 GWh, equivalent to 10% of annual electricity consumption in the province [19]. This wind resource amount is considered substantial since Bangkok alone consumes one quarter of electricity in Thailand [20].

4. Conclusions and Recommendations

In this paper, we estimated overall technical wind energy potential for Bangkok. The following summarizes the key findings from this study along with our recommendations.

Although we gave careful treatment in preparing individual exclusion layers for the GIS analysis, they cannot be claimed as comprehensive. We faced difficulty and uncertainty in allocating buffers, based on the few available guidelines and regulations, which we interpreted conservatively. Also, while sufficient for the initial estimation of overall wind resource as used here, the layers are not precise enough for use in site selection. We thus encourage future refinement of these, particularly in the urban environment where few previous studies exist.

Given the methodology used here to assess technical wind resource potential for Bangkok, very small turbines installed in low density urban, medium-to-high density urban, and non-urban areas contribute the most (1,453 GWh, 700 GWh, and 689 GWh, respectively) to potential annual energy production (*AEP*), followed by small turbines installed in non-urban areas (491 GWh). The contribution to *AEP* (378 GWh) by medium-to-large turbines is confined by the extensive urban area in the province, with highest capacity factors found in southwest Bangkok.

Tall-building installations have favorable predicted capacity factors (25-35%), however, the total potential from such installations is small (8 GWh). This value is conservative, since we only considered those which would be easiest to install—only very small wind turbines as rooftop retrofits. This potential could be increased using turbines with larger capacity and/or those aerodynamically built in to building design. We therefore encourage extension of the method used here to investigate a variety of turbine sizes, examine types of wind turbine more suited to the urban environment (i.e., vertical-axis, building-integrated, and arrayed micro turbines), and consider structural engineering constraints and detailed roof configurations. Also, this work gives a first estimation of the wind potential on tall buildings, but is not intended to be accurate. Although buildings in Bangkok are relatively well-spaced, wind flows are still strongly influenced by nearby buildings, so we recommend using data from a model which incorporates these flows to estimate the potential for a particular location.

We found the upper limit for total annual energy production from wind turbines in Bangkok to be 3,719 GWh. This amount of energy corresponds to 10% of the current electricity consumption in Bangkok. This is significant considering that Bangkok alone contributes to one-quarter of national electricity consumption. With careful planning, wind energy development is potentially feasible technically and economically over certain areas, especially southwest Bangkok. Furthermore, although not covered in the scope of this particular study, these results also indicate that similar feasibility may be found in the neighboring seaside provinces of Samut Prakan and Samut Sakhon.

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References

[1] Encraft, *Warwick Wind Trials Project* (2009) Final Report. Available online: http://www.warwickwindtrials.org.uk.

[2] Dutton AG, Halliday JA, Blanch MJ, *The Feasibility of Building-Mounted/Integrated Wind Turbines (BUWTs): Achieving their potential for carbon emission reductions* (2005) Final report, May 2005.

[3] Knight J, Urban Wind Power: Breezing into town, *Nature* 430 (2004) 12-13.

[4] Mithraratne N, Roof-top wind turbines for microgeneration in urban houses in New Zealand, *Energy and Build.* 41 (2009) 1013-1018.

[5] McIntyre JH, Lubitz WD, Stiver WH, Local wind-energy potential for the city of Guelph, Ontario (Canada), *Renew. Energy* 36 (2011) 1437-1446.

[6] Manomaiphiboon K, Prabamroong A, Chanprasert W, Pajpreeja N, Phan TT, *Dual Database System of Wind Resource for Thailand* (2010) Final report of project: Wind Resource Assessment using Advanced Atmospheric Modeling and GIS Analysis, Conducted by the Joint Graduate School of Energy and Environment (King Mongkut's University of Technology Thonburi), Available online: http://complabbkt.jgsee.kmutt.ac.th/wind_proj [accessed 18 Apr 2011].

[7] Bangkok Metropolitan Administration, *Regulation and Zoning*. Available online: http://cpd.bangkok.go.th/default.asp?ID=001 [accessed 26 October 2010].

[8] Land Development Department (Ministry of Agriculture and Cooperatives), *Land Use and Land Cover Data for Thailand for the Years 2006-2007* (2007) [CD-ROM].

[9] Google, *Google Earth* (Version 6.0.3.2197) [Software]. Mountain View, CA. Available online: http://earth.google.com.

[10] ESRI (Thailand), *ArcData Thairoads Lite* (2006) [CD-ROM].

[11] European Wind Energy Association, *Wind energy – the facts: a guide to the technology, economics and future of wind power* (2009). Earthscan: Sterling, VA, US.

[12] Prapai Technologies Co. Ltd, *Wind Turbine Technology*. Available online: http://www.prapai.co.th/eng/knowledgeview.php?nid=29 [accessed 18 Apr 2011].

[13] Gipe P, *Wind Energy Basics: A Guide to Home- and Community-scale Wind Energy Systems* (2009). Second ed., Chelsea Green.

[14] Dvorak MJ, Archer CL, Jacobson MZ, California offshore wind energy potential, *Renew. Energy* 35/6 (2010) 1244-1254.

[15] Nguyen KQ, Wind energy in Vietnam: Resource assessment, development status and future implications, *Energy Policy* 35 (2007) 1405-1413.

[16] Emporis Corporation, *Commercial Real Estate and Construction Data*. Available online: http://www.emporis.com [accessed 19 Jan 2010].

[17] Skyscraper Source Media, *Bangkok Skyscraper Diagram*. Available online: http://skyscraperpage.com/diagrams/?cityID=592 [accessed 26 Nov 2009].

[18] Manwell JF, McGowan JG, Rogers AL, *Wind Energy Explained* (2002) Wiley.

[19] Metropolitan Electricity Authority (2011). Available online: http://www.mea.or.th [accessed 31 May 2011].

[20] Department of Alternative Energy Development and Efficiency (Ministry of Energy), *Electric Power in Thailand 2010* (2011). Available online: http://www.dede.go.th/dede/images/stories/060554_circular/electric_53_1.pdf [accessed 6 Oct 2011].

