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Wind energy in Vietnam: Resource assessment, development status and future implications

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Abstract

The aim of this study is to estimate the technical potential of wind energy in Vietnam and discuss strategies for promoting the market penetration of wind energy in the country. For the wind resource assessment, a geographical information system (GIS)- assisted approach has been developed. It is found that Vietnam has a good potential for wind energy. About 31,000 km^2 of land area can be available for wind development in which 865 km^2 equivalents to a wind power of 3572 MW has a generation cost less than 6 US cents/kWh. The study also proves that wind energy could be a good solution for about 300,000 rural non-electrified households. While wind energy brings about ecological, economic and social benefits, it is only modestly exploited in Vietnam, where the main barrier is the lack of political impetus and a proper framework for promoting renewable energy. The priority task therefore is to set a target for renewable energy development and to find instruments to achieve such a target. The main instruments proposed here are setting feed-in tariff and providing investment incentives.

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1. Introduction

During the last 10 years (1994–2004), the electricity demand in Vietnam has been growing at a rate of more than 15% per year, significantly higher than the GDP in the same period, 7.1% (IE, 2005). Nevertheless, in absolute terms, Vietnam is still among countries with the lowest per capita consumption level of electricity in the world, 563 kWh in 2004 (NM, 2005). With 75% of the population living in rural areas and about 20% of them have not yet been provided with electricity (EVN, 2005), it is expected that Vietnam would have a prolonged electricity strain due to electrification, urbanization and population growth. Furthermore, economic growth, industrialization and globalization of trade as results of economic development also directly affect the electricity demand of the country (IE, 2005). Such a development raises a number of questions concerning the availability of energy resources as well as environmental degradation.

Increased reliance on renewable energies could be a solution (Nguyen, 2004). Of several alternative renewable energies, wind is one of the most important and the most technically suitable. It has a competitive production cost ranging from 4 to 8 US cents/kWh in comparison to 50–100 US cents/kWh for solar photovoltaics and 12–30 US cents/kWh for solar thermal electricity (Pitz-Paal, 2004). It saves land since land area within a wind farm is still available for cultivation (AGORES, 2004). It creates more employment, in particular for the local workforce, because the installation, operation and maintenance of wind turbines and wind farms are almost exclusively in rural areas and generally of modest scales. In environmental terms, it has a very little impact (about 10 tonnes of CO_2 per GWh while that of coal is between 830 and 920 tonnes per GWh on a lifecycle basis) (Akermann and Söder, 2002). Thus, development of wind energy has been strongly pursued in many countries. Between 1997 and 2004, its capacity grew at 30% per year and in 2004 the world total installed capacity reached 48 GW (BP, 2005).

Geographically, Vietnam is expected to have a good potential for wind energy, but so far no systematic study

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has been carried out to quantify this potential. The data provided from permanent long-term monitoring stations, which are originally designed for collection of meteorological data, is not representative for large areas, and consequently, cannot be applied for the assessment of wind energy. In light of this problem, the World Bank in 2001 initiated a project on the establishment of the wind energy resource atlas for four countries—Cambodia, Laos, Thailand and Vietnam—as a support for wind development for the region. The result of this effort was a grid file of wind speed at 65 and 30 m above ground level (TW, 2000).

The purpose of this study is to estimate the technical potential of wind energy in Vietnam on the basis of the World Bank data. As another important goal, the present study gives an overview on the current status of wind energy development in Vietnam, and finally discusses the necessary framework for the development of wind energy for the country.

2. Wind energy resource assessment in Vietnam

2.1. Methodology

The evaluation of wind potential is conducted by a sequence of steps which represent restrictions on the exploitation of the potential. In the first step, the theoretical potential, which is defined as the maximum wind energy output in a region, is estimated. It is determined by using a reference wind turbine, available wind speed data and the available sites in that region. No availability or technological restriction is considered (Voivontas et al., 1998). The technical potential is then assessed by introducing restrictions grouped as social constraints and technical constraints. Social constraints help eliminate areas not suitable for the exploration of wind energy such as high-altitude areas or protected areas whereas technical constraints define "basic" conditions for the operation of wind turbines such as the arrangement of wind turbines and the minimum level of wind resource.

To satisfy all of the above conditions, it is ideal to use a geographical information system (GIS) for the assessment. The approach is as follows. First, a reference wind turbine is selected. A new layer of energy output is then created using this reference wind turbine and the wind speed grid layer. This layer is afterwards displayed together with other layers of land cover, elevation and water areas to remove unsuitable areas such as cities, water areas, high-altitude areas and protected areas. The resulting map, which inherits attributes of all layers, now represents areas that can be used for wind development. With assumptions on the land requirement and the minimum level of wind resource for the reference wind turbine, the technical potential can be estimated. Data necessary for this effort are given in Table 1.

The technical potential arrived at is then classified into categories based on their production costs to

Table 1
Sources of GIS data for wind resource assessment

| Data type	Data source	Data format
Average wind speed at 65 m	(TW, 2000)	Grid file
Average wind speed at 30 m	(TW, 2000)	Grid file
Water	(DCW, 2002)	.e00 format
Administration boundaries	(DCW, 2002)	.e00 format
Roads	(DCW, 2002)	.e00 format
Railroads	(DCW, 2002)	.e00 format
Aeronautical	(DCW, 2002)	.e00 format
Protected areas	(DCW, 2002)	.e00 format
Population	(GSO, 2001)	Table
Land cover	(DIVA, 2002)	Grid file
Elevation	(DIVA, 2002)	Grid file
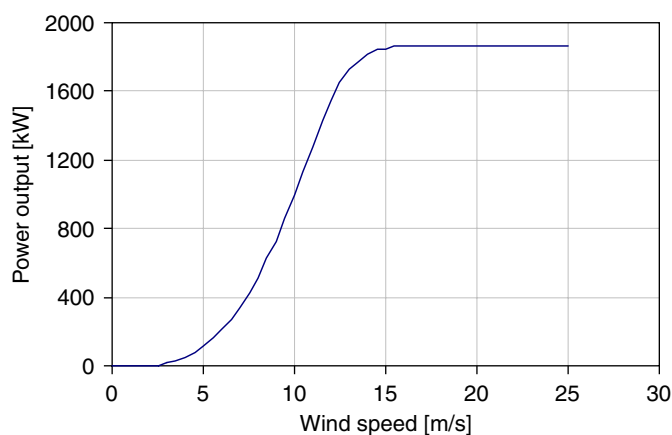
Fig. 1. Power curve of V66-1650 kW wind turbine (*Source*: BWE, 2001).

facilitate the establishment of a wind energy development strategy.

2.2. Selection of a reference wind turbine

For the assessment, a wind turbine from Enercon of 1800 kW (E-66) is chosen. This turbine is selected mainly because (i) it represents the typical size currently most demanded in the market, (ii) it comes from a manufacturer with a proven record in wind turbine manufacturing, and (iii) it suits the local conditions with respect to available transportation and installation facilities, as well as the possibility of manufacturing accessories locally. Certified power curve and other specifications of E-66 are provided in Fig. 1 and Table 2, respectively (BWE, 2001).

2.3. Creation of the wind potential layer

Wind speed is not constant with time. Power from the wind, in turn, varies with the cube of the wind speed. Thus, for the determination of energy output and consequently, theoretical potential, in addition to average wind speed it is of importance to know the wind speed distribution. So far, the Weibull function is most widely used to represent the

Table 2
Detailed specifications of Enercon E- 66/ 1870 kW

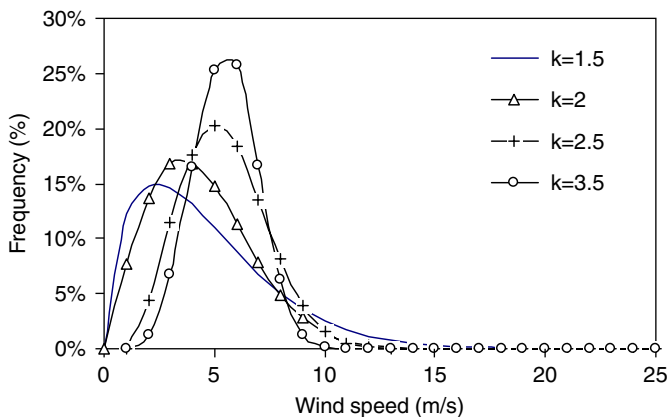| Indicator	Value
Rotor diameter	70 m
Swept area	3848 m^2
Rated power	1800 kW
Power regulation	Pitch
Starting wind speed	3 m/s
Rated wind speed	12 m/s
Cut out wind speed	28–34 m/s
Endurance wind speed	60 m/s
Generator	Synchronous
Number of blades	3 of Epoxyharz
Tower height	65 m

Source: BWE, (2001).

Fig. 2. Wind speed frequency distributions based on the Weibull curve for a mean wind speed of 5 m/s and various k values.

distribution of wind (Cavallo et al., 1993). This function expresses the possibility $f(v)$ to have a wind speed v during a year according to

$$f(v) = \left(\frac{k}{A}\right)\left(\frac{v}{A}\right)\exp\left(\frac{-v}{A}\right)^k, \qquad (1)$$

where k is the shape factor which typically ranges from 1 to 3. For a given average wind speed v ($\geqslant 0$), the higher the shape factor is, the narrower the distribution of wind speed around the average value (Fig. 2). Because wind power varies with the cube of wind speed, a lower shape factor normally leads to higher energy production at a given average wind speed. A gives the scale of the curve. It is > 0 and is often estimated as

$$A = \frac{v_m}{\Gamma\left(1 + \frac{1}{k}\right)}, \qquad (2)$$

where v_m is the average wind speed; Γ is the gamma function.

When $k = 2$ it is called the Reyleigh function. It has been concluded from experience that $k = 2$ represents well enough the real wind speed distribution. It is then possible to derive the wind speed distribution when yearly average

wind speed is known. The scale parameter is then calculated by

$$A = \frac{2}{\sqrt{\pi}}v_m, \qquad (3)$$

where v_m is the average wind speed.

The distribution function then becomes

$$f(v) = \frac{\pi v}{2(V_m)^2}\exp\left(\frac{-\pi}{4}\right)\left(\frac{v}{V_m}\right)^2. \qquad (4)$$

With the distribution function and the power curve given above, the yearly energy production can be calculated by integrating the power output at every bin width:

$$YEY(v_m) = \sum_{v=1}^{v=25} f(v)P(v)\,8760, \qquad (5)$$

where v_m is the average wind speed; $P(v)$ is the turbine power at wind speed v; $f(v)$ is the Weibull probability density function for wind speed v, calculated for average wind speed v_m and 8760 is the number of hours per year.

The layer of energy output in the form of hours of full power for each cell is thus created and represents now the base for the next steps (Fig. 3).

2.4. Determining areas unsuitable for wind development

For the exploitation, the theoretical potential of wind energy presented above is, however, restricted by some topographical, political and technical reasons. The wind potential layer is therefore displayed together with other layers to remove unsuitable areas. Specifically, unsuitable areas are (i) high altitude areas, due to access difficulties and high investment cost, (ii) political areas (cities, urban centres, road, railway, airport, etc.), due to safety and visibility reasons (iii) water areas, due to arising costs, (iv) protected areas (forest, national parks, conservation areas), due to legal constraints, and (v) living areas, due to noise and visual impact. These areas are usually added with the so-called buffer zones and are dealt with separately. For the constraint of living areas, a digital map with living areas of proper quality is currently not readily available; hence in the present study, the population density is used instead. In particular, population density is classified into different categories, and the possible proportion of land use for the development of wind energy is determined accordingly (Fig. 4) (Aretz, 2002). The detailed exclusion criteria with the constraint factors and, consequently, exclusion areas are shown in Table 3 (Baban and Parry, 2001; Voivontas et al., 1998).

2.5. Land requirement

The map of the remaining areas (31,678 km^2) now represents areas that can be used for wind development; the next question is how many wind turbines could be
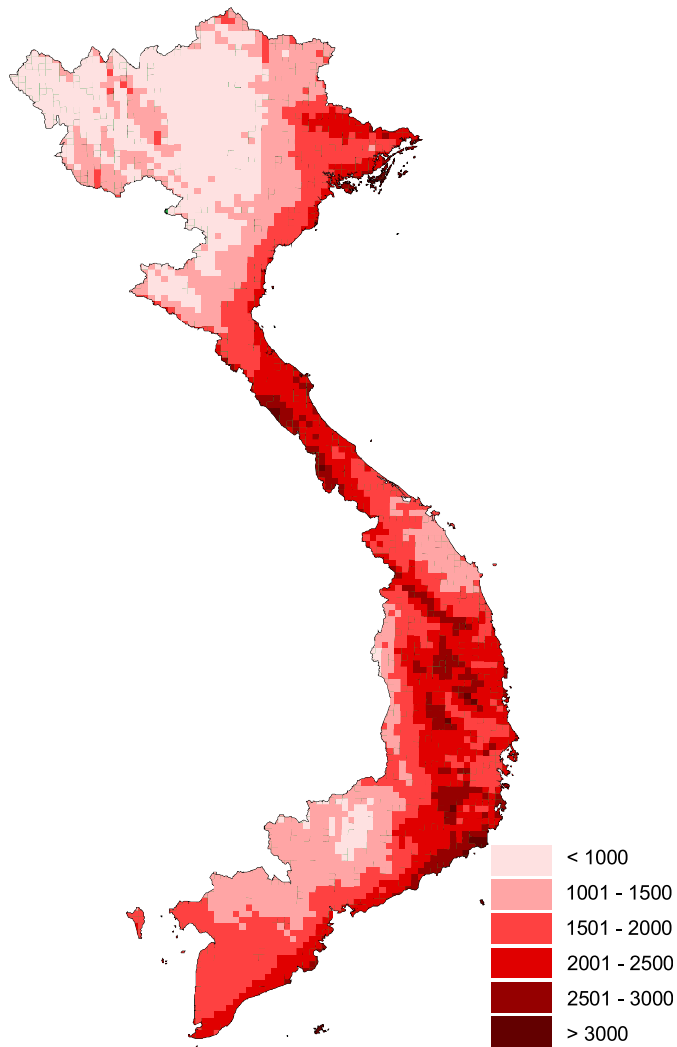
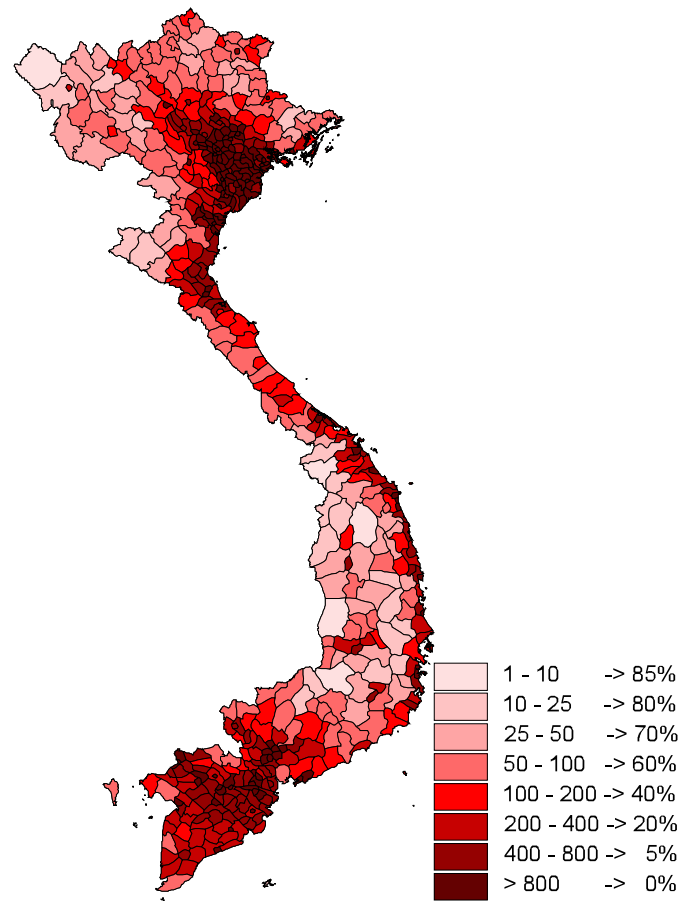Fig. 3. Theoretical potential of wind energy in Vietnam (representing in hours of full power per year).

Fig. 4. Population density (person/km^2) and the possible proportion of land use for wind development in Vietnam.

Table 3
Unsuitable areas for wind development

Exclusion criteria	Constraints	Exclusion areas [km^2]
Rail ways plus 100 m away from them	Safety, visual	1016
Road ways plus 100 m away from them	Safety, visual	8511
Cities, urban centres plus 2000 m away from them	Safety, visual	14,436
Water areas plus 400 m away from them	Cost	2832
Forests plus 500 m away from them	Land use	150,925
Protected areas plus 500 m away from them	Land use	37,837
Airports plus 2500 m away from them	Safety, visual	3158
High-altitude areas	Cost	124,162

erected in these areas, keeping in mind that if turbines are located too closely they will interfere with each other and, consequently, output of those locating downwind will be reduced (Nguyen, 2001). Extensive theoretical and wind-tunnel studies indicate that under typical conditions, interference increases quite rapidly when turbines are at distances less than 10 rotor diameters (10D) (Table 4). For an infinite number of wind turbines with 10D spacing, the limiting array efficiency is about 60% (Grubb and Meyer, 1993). But for a finite number of turbines, the average loss is much lower, and a closer distribution is practical. A rule of thumb puts the distance at 5–9 rotor diameters in the main wind direction and at 3–5 rotor diameters in the perpendicular direction (DWIA, 2002).

For simplicity, the present study takes 10D as the standard distance between two wind turbines. Thus, the area requirement for each model E-66 wind turbine will be 0.436 km^2, which means wind turbine density will be 2,295 kW/km^2.

2.6. Results and analysis

By dividing the available area with the wind turbine density determined above and slightly limiting the areas afterwards by assuming that 1000 h of full power is the feasible threshold for the exploitation of wind energy as generally assumed (Aretz, 2002), the technical potential of

Table 4
Typical array efficiencies for different sizes and spacings of square arrays (*Source*: Grubb and Mayer, 1993)

Array size	Turbine spacing					
	4D	5D	6D	7D	8D	9D
2 × 2	81	87	91	93	95	96
4 × 4	65	76	82	87	90	92
6 × 6	57	70	78	83	87	90
8 × 8	52	66	75	81	85	88
10 × 10	49	63	73	79	84	87

Table 5
Technical potential of on-land wind energy in selected countries

Potential	China[a]	India[a]	Germany[b]	Vietnam
Technical potential (GW)	8450	277		120.5
Technical potential (TWh)	11977	349	128	224
Total land area (Million km²)	9.571	3.287	0.349	0.331
Technical potential/Total land area (MWh/km²)	1251	106	367	676

[a]Aretz, 2002.
[b]Kraemer, 2002.

wind energy in Vietnam can be determined. It is 120.5 GW, equivalent to some 67,000 turbines of the E-66 series in this case. This potential is equivalent to some 224 TWh of electricity per year or more than 4 times the country's electricity production in 2004.

In comparison with other countries, where wind energy sectors are developing, this potential is rather good, even better than that of Germany—a current leading country in wind energy exploitation (Table 5). This is a good news for Vietnam considering the benefits that wind energy could bring about.

To further facilitate wind development, this potential is then classified into groups according to the levelized costs (LC). In other words, "dynamic" economic potential is estimated. This, in reality requires a consideration of the distance from the specific wind farm to the existing transmission line, since investment cost for the transmission line as part of the total investment cost is quite high. Here it is assumed that all sites would locate within the allowable distance from the transmission lines. The argument is that the transmission network in Vietnam is currently quite scattered. Thus, more transmission lines must be built to meet the growing demand irrespective of wind development programs. Besides, a more exact estimation of the connection cost to the transmission grid could not be carried out due to the lack of a digital map of the transmission network.

Table 6
Parameters for production cost estimation

Parameter	Value
Specific investment cost	1000 USD/kW
O&M cost	23.7 USD/kW.year
Lifetime	20 years
Wind farm efficiency	94%
Wind farm availability	98%
Discount rate	10%

LC is calculated as follows (El-Kordy et al., 2001):

$$LC = \frac{TC_{pw}}{E_{pw}}, \tag{6}$$

where pw is a subscript that indicates the present worth of each factor, TC is the total cost arisen during the construction and operation of the wind farm. The formula for converting an amount of money (F) in a given future year (n) at a given discount rate (i) to present value is given by

$$P_{pw} = \sum_{t=1}^{n} \frac{F_t}{(1+i)^t}. \tag{7}$$

E represents the present worth of an annual energy output (A) received over a time period (20 years in this case) at the discount rate $i = 10\%$.

$$E_{pw} = A \left[\frac{1 - (1+i)^{-n}}{i} \right]. \tag{8}$$

Parameters necessary for this calculation are given in Table 6 which are assumed with reference to the actual values from other developing countries such as India and China (Aretz, 2002; Tang, 2001; ASTAE, 2001).The results of wind potential classification are summarized in Table 7.

In total, seven groups corresponding to a production cost from 5 to 8 US cent/kWh with a step of 0.5 US cent have been defined. For each group, sites with a production cost less than the corresponding value are counted. The first value of 5 US cent/kWh represents the author's proposed feed-in tariff, proposed on the ground of the average feed-in tariff for wind energy in some developing countries and the present average feed-in tariff for conventional power plants in Vietnam due to the absence of a similar value in Vietnam (Aretz, 2002; IE, 2005). The others are given to indicate the corresponding potentials in case higher feed-in tariffs are adopted. Thus, with this argument, Vietnam would have an economic potential of 294 MW equivalents to some 163 turbines of the E-66 series, at the feed-in tariff of 5 US cent/kWh. These wind turbines could produce 963 GWh per year and, as a result, could avoid about 0.87 million tons of CO_2 yearly if they were used in replacement of coal-fired power plants. Total investment capital for these turbines would be 294 million USD.

Table 7
Economic potential of wind energy in Vietnam

| Production cost	Useable area (km²)	Installed capacity (GW)	Number of turbine E-66 (Unit)	Energy production (TWh/yr)	Average hours of full power (h/yr)	**Total investment cost (Mill. USD)**
(US cent/kWh)						
5.0	71.1	0.294	163.0	963.0	3280.0	293.6
5.5	296.7	1.225	680.0	3727.0	3043.0	1224.9
6.0	865.0	3.572	1984.0	10110.0	2830.0	3571.7
6.5	3260.0	13.460	7478.0	34904.0	2593.0	13460.2
7.0	5731.0	23.659	13144.0	58608.0	2477.0	23659.1
7.5	9326.0	38.501	21389.0	90653.0	2355.0	38500.7
8.0	12,520.0	51.689	28716.0	117320.0	2270.0	51689.3
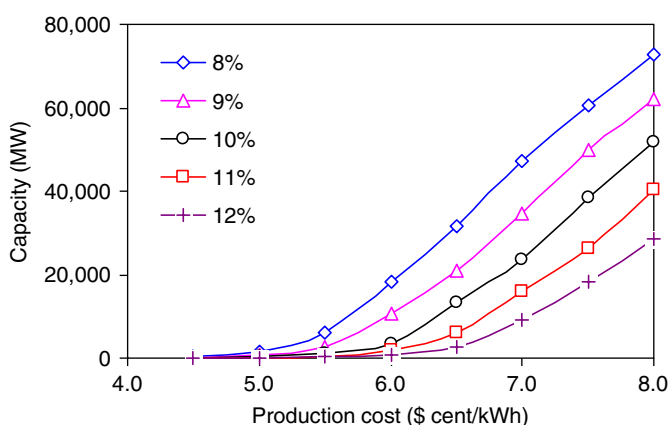
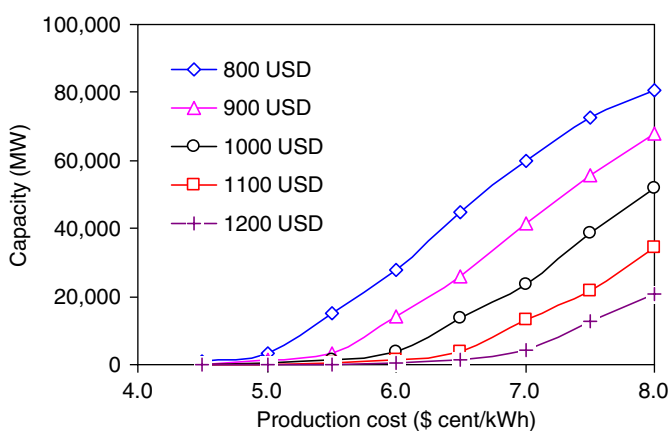Fig. 5. Sensitivity of the potentials to the discount rates.

Fig. 6. Sensitivity of the potentials to the specific investment costs.

These potentials primarily depend on the assumed discount rate and specific investment cost. Thus, to give policy makers more exact information on the potential, a sensitivity analysis of the potential corresponding to a wide range of discount rates (i.e. from 8% to 12%) and specific investment costs (i.e. from 800 USD to 1200 USD) is carried out. The results are presented in Figs. 5 and 6, respectively.

3. Current development of wind energy in Vietnam

Vietnam has a long tradition of wind application. Among the first applications were simple water pumping systems in salt production sites along the coast. These windmills are, however, quite low in efficiency and rudimentary and the water pumps are often simply a water-drawing chain. In the 1980s, the more sophisticated modern water pumping windmills have been introduced with higher efficiencies.

The national experience with small wind generators started in the late 1980s and focused on the development of household energy systems with power ranging from 100–150 to 500 Watt peak (Wp). These systems have been designed and manufactured in Vietnam under R&D programs. The main institution in this sector is Research Center for Thermal Equipment and Renewable Energy (RECTERE) of Ho Chi Minh City Technical University. RECTERE has installed to date about 900 wind systems (150 and 200 Wp). These systems have been disseminated among rural families mostly via government grants (90%) and only 10% of them have been purchased directly by users. The 150 Wp unit, which supplies energy for a few lights, TV and radio, has a cost of about 270 USD. It is quite popular among users and RECTERE extends its maintenance and after sales service through a network of technicians present in each province (EVN, 1999). The second is the Institute of Energy (IE). IE is entrusted by Ministry of Industry to review the implementation of wind turbines for power generation with the purpose of installing them on islands and remote areas as part of the governmental rural electrification program. IE has manufactured wind turbines with capacity of 150 Wp and has installed so far 35 units. The Hanoi University of Technology (HUT), as a centre of renewable energies, should be counted. HUT has installed 20 units so far, mostly 150 Wp systems.

In summary, about 1000 units have been installed nationwide (Table 8). These are, however, far lower than the potential of some 300,000 units which were determined on the basis of the rural non-electrified households and

Table 8
Wind energy applications in Vietnam

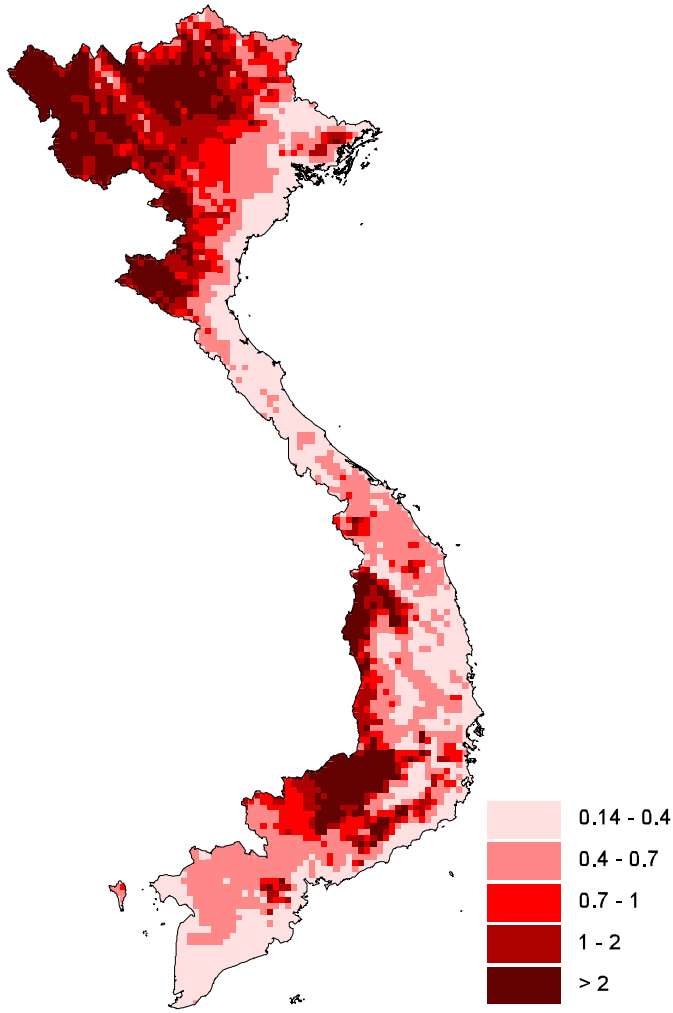| Application	Typical power (Wp)	Installed systems
Wind home system	100–500	About 1000
Water pumping		About 120
Large wind turbine	800,000	1

Source: IE, (2000).

Fig. 7. Levelized cost (USD/kWh) of electricity from wind turbine PD 170.6 at various locations in Vietnam.

their willingness to pay. This is a pity since wind turbine is the most cost competitive among typical household-sized power technologies—solar photovoltaics, wind home system, micro hydro and gasoline generator—under the typical meteorological conditions in Vietnam (Nguyen, 2004). Its LC ranges mainly between 14 and 70 US cents/kWh (Fig. 7).

As for large wind generator installations, there is presently no wind farm in operation except one turbine of 800 kW in Bach Long Vi island. Although, a number of wind farms are planned such as the 15 MW wind farm in Binh Dinh, the 15 MW wind farm in Qui Nhon and the 625 kW wind farm in Ninh Thuan, whether these wind farms will be constructed is not clear. The reason is EVN; the single wholesale power buyer in Vietnam seems not interested in buying electricity from wind turbines. This is indicated by the prices that EVN is willing to pay investors so far, often less than 4 US cent/kWh, not sufficient for the investors to proceed with their investments (IE, 2001). This treatment is unfair, as the ecological and social benefits of wind energy are not taken into consideration at all. It is thus necessary to create a mechanism to ensure a fair playing field for wind energy. This definitely requires governmental intervention. With the hope of creating a base for wind development, details of this interference specific to the Vietnam conditions is discussed in the next section.

4. Strategic implications

In this part, we would like to propose the most necessary conditions and instruments the government can do for the successful exploitation of renewable energies in Vietnam in general and wind energy in particular. These are based on the experiences of countries that have successfully introduced wind energy in their power market.

4.1. Setting a target for renewable energy technologies

The first step that the government can do in promoting renewable energy is to set a target. The key idea is a requirement that a certain percentage of Vietnam's electricity supply should come from renewable energy resources and specifically a certain number of rural households should be electrified by renewable energy technologies. Examples of such targets are Denmark, Spain and Germany. In Denmark, the national plan "Energy 21" sets the target of 12–14% of total energy consumption be renewable energies by 2010. Similarly, Spain aims to have renewable energies contribute at least 12% to total energy demand by 2010. In Germany, the goal is to double the share of renewable energy by 2010 (ASTAE, 2001). These strategies of member countries would help the European Union achieve its objective of 12% renewable energies by 2010 (EC, 1997). As a developing country, China represents a typical example. It has pledged to double its reliance on renewable energy by 2020 (from the present 7% to 15%) (Guardian, 2005).

4.2. Feed-in tariff for renewable energies

There are several instruments that can be used to attain such a target. One of which is through setting a premium price for power from wind turbines. Tariffs are defined by the government and are guaranteed for a specific period of time. Utilities are obliged to buy electricity from wind turbines in their areas and give wind turbines with priority dispatch.

This instrument has been applied in Germany. Accordingly, the utilities in Germany are obliged to pay the generator of wind energy 9 EURO cent/ kWh for 5 years. Thereafter, the tariff is reduced to a lower rate, depending on the quality of the site (Pfaffenberger et al., 2003). The effects of this instrument introduction were that between 1997 and 2004, wind installed capacity in Germany grew from 2.1 to 16.6 GW, attaining an annual growth rate of 35%. Presently, Germany leads the world in terms of wind installed capacity (BP, 2005). In Vietnam, currently there is no feed-in tariff for wind energy. However, as already analysed, a fixed remuneration price of 5 US cent/kWh already produces an incentive for investment.

4.3. Investment incentives

In addition to the guaranteed feed-in tariff, financial incentives such as special loans, preferential interest rates, subsidies or exemption from import tax for components or renewable energy technologies that are imported can help develop this market. In Germany, wind turbine developers might get soft loans with federal subsidized interest rates at 1–2% below normal interest rates. Typical loan terms are 10–12 years. About 90% of wind turbine projects completed in Germany in 1999 benefited from cheap loans (ASTAE, 2001). In developing countries, incentives-based programmes are the World Bank's renewable energy programmes in Indonesia, Srilanka, Laos and the own incentive-based renewable energy programmes in China, India (Painuly, 2000). In Vietnam, the Vietnam Women Union's solar home system program is a typical example. Micro-credits were provided to consumers through revolving funds. This program has been shown to be very successful (EVN, 1999).

For the decentralized wind turbine market, this kind of incentive appears to be the ultimate instrument because firstly, electricity from stand-alone wind turbines is not fed into the grid but rather consumed on site (feed-in tariff instrument cannot be applied). Secondly, the investment cost of 270 USD for a typical small size wind turbine is still too high for rural households whose annual income is less than 541 USD (GSO, 2005).

4.4. Taking advantage of the Clean Development Mechanism (CDM)

In addition to the above instruments, Vietnam can have wind energy by taking advantage of the CDM, a flexible mechanism for Annex I countries to fulfil their committed CO_2 reduction target set in the Kyoto Protocol. According to this, enterprises in industrialized countries invest in the establishment of state-of-the-art technologies in developing countries. The lower technology baseline in developing countries would imply that such an investment would result in greater potential reductions in CO_2 that would have a similar investment in Annex I countries. In return for this investment, the Annex I countries would get

benefits in the form of CO_2 reduction as compared to the host country baseline (UNEP, 2002). Vietnam ratified the Protocol on 25/09/2002 and is thus qualified for CDM projects (IE, 2005). However, it is necessary to have an internationally accepted energy development baseline for evaluating mitigation options such as wind energy.

4.5. Awareness campaigns

Renewable energies can also be promoted through information programmes. The objective is to educate potential developers on the advantages of renewable energy technologies and to convince users on the reliability and cost effectiveness of renewable energy technologies. For developers, this can be achieved by supplying them with the necessary tools to evaluate the technologies. For users, it can be done by demonstration and propagation activities.

4.6. Institutional measures

Finally, a specialized agency to plan and promote renewable energy technologies should be established. This agency should act on behalf of the government on such activities as financing for feasibility studies, planning and fixing targets for renewable energy contribution, proposing the feed-in tariffs, making resource assessment for renewable energy at regional and national levels, sitting of renewable energy systems, setting up R&D programmes to make renewable energy more competitive and organizing technology demonstrations.

5. Conclusions

The aim of this study is to estimate the technical potential of wind energy in Vietnam and discuss strategies for promoting the market penetration of wind energy for both on-grid and off-grid applications for the country. For wind resource assessment, a GIS-based approach has been developed. For the second task, examples from successful countries in wind energy exploitation have been referred. Some major conclusions of this study are as follows:

- Wind energy brings about ecological and social benefits and contributes to sustainable energy development. Using electricity from wind turbine instead of electricity from coal power plant could save an average of about 820–910 tonnes of CO_2 for every GWh.
- Vietnam has a good potential of large-scale wind energy. About 31,000 km^2 of land area can be available for wind development in which 865 km^2 equivalents to a wind power of 3572 MW has a production cost less than 6 US cents/kWh (at the discount rate of 10% and the specific investment capital of 1000 USD/kW).
- Vietnam has developed a sufficient technological base for small wind turbine, which appears to be one of the best options for isolated rural areas. There is a good

potential market for small wind turbines, estimated at 300,000 units.

- Current development of wind energy, however, does not correspond to its potential due to the lack of political impetus and a proper framework for promoting renewable energy.
- There should be strategies for the development of this sector if a certain share of renewable energy in the energy supply mix is desired. These should be first by setting a target for renewable energy development and using instruments to achieve such a target. Here the main instruments proposed are setting feed-in law and providing investment incentives.

Acknowledgements

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