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Energy Policy 35 (2007) 2579–2589

ENERGY POLICY

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# Alternatives to grid extension for rural electrification: Decentralized renewable energy technologies in Vietnam

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Received 13 July 2006; accepted 3 October 2006
Available online 13 November 2006

**Abstract**

This paper examines the economic viability of stand-alone, household-sized renewable energy technologies, namely wind generator and solar PV for application in remote and rural areas of Vietnam. Three reference technologies are chosen. These are two solar PV systems of 130 and 100 Wp for solar conditions in the North and the South, respectively, and one 150 W wind turbine. It is found for all regions that levelized costs of PV energy are lower than the cost of energy from gasoline gen-set, and are cost-competitive with grid extension, especially for areas with low load density and low number of households to be electrified. Regarding wind energy, the viability is dependent on the location due to the wide variation of wind resource to topography. However, in locations with proper resources, wind energy is even more cost-competitive than solar PV. Thus, the use of either wind generator or solar PV is economically feasible in rural villages and remote areas of Vietnam. Policy recommendations for promoting the market development of renewable energy technologies are discussed in the final section of the paper.


*Keywords:* Decentralized renewable energy technologies; Rural electrification; Vietnam

## 1. Introduction

Energy plays an important role in the socio-economic development of a country. Economic growth and improvement of people's living standard are all directly or indirectly related to the increasing utilization of energy, of which electricity is the most important.

Vietnam is a developing country in South East Asia. Its population is about 82 million, of which more than 70% live in rural areas (GSO, 2005). To improve the living conditions for people in rural areas, provision of electricity is a must. In light of this challenge, over the last several decades, the government of Vietnam has made tremendous efforts to bring electricity to rural areas. At the end of 2005, 95% communes or 88% households had access to electricity. The remaining of about 2 million households lived in 413 communes (EVN, 2005). Many of these households were sparsely living in remote regions where grid extension is too costly, sometimes impossible. In this context, provision of electricity to them by using stand-alone, household-sized renewable energy technologies such as solar photovoltaic and wind generator could be a solution.

Decentralized renewable energy technologies have several advantages over grid extension. They can be located closer to the demands so distribution and transmission cost and consequently energy and capacity loss are reduced. They avoid the need for high cost utility generation because rural households consume at peak times when the demand on the grid is highest and the most expensive generation has to be brought on-line. They do not require fuel, i.e., their operation is independent from fuel supply availability. From a social point of view, they create more employment, in particular for the local workforce, because the installation, operation and maintenance of renewable energy technologies are almost exclusively in rural areas and generally of modest scales. In environmental terms, they are clean. Thus, the use of renewable energy for rural electrification will provide the benefits of reducing emissions of air pollutants, including greenhouse gas (GHG), increasing employment opportunities and strengthening

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0301-4215/$ - see front matter 
doi:10.1016/j.enpol.2006.10.004

the economy by effective and sustainable utilization of local resources.

The purposes of this study are to examine the feasibility of decentralized, household-sized renewable energy technologies, namely solar photovoltaic and wind generator for rural electrification in remote areas in Vietnam, and to discuss a necessary policy framework for the successful development of these technologies for the country.

## 2. Methodology for examining the feasibility of decentralized renewable energy technologies for rural electrification

The feasibility evaluation of decentralized renewable energy potential for rural electrification is conducted by a sequence of steps. First, reference renewable energy technologies are selected. Power outputs of these technologies under meteorological conditions of Vietnam are then estimated. This information is afterwards used together with economic and financial data of the selected technologies to conduct levelized costs per unit of electricity produced. Finally, these levelized costs are compared with that of grid-based electricity.

### 2.1. Selection of technology

Typical stand-alone, household-sized renewable energy systems include solar photovoltaic (PV) and wind generators. Also common are micro-hydro generators. However, they are not considered in the present study because most of them are of the "run of river" type; their availability to generate power is limited during stream flooding periods and during dry seasons (EVN, 1999). In addition, the cost of hydro in Watt scales could be relatively high and may not compete with solar and wind, if hydro generation sites are not located close to the demand centers.

The major components of a stand-alone, household-sized renewable energy system are an energy conversion system (a PV module or a wind turbine) and the balance-of-system (BOS). The energy conversion system converts kinetic energy from wind into mechanical energy and then into electric power in the case of wind turbine or sunlight directly into electricity in the case of a solar PV. The BOS includes: a rechargeable lead-acid battery that stores electricity to provide energy on demand, a controller that manages energy storage to the battery and deliver power to the load, and the structure required to mount or install the systems.

### 2.2. Output estimation

The determination of power output of the selected renewable energy technologies for a location in Vietnam is done on the ground of yearly average data of resource (average wind speed for wind energy and annual average daily solar radiation for solar energy), which were made available by other studies (TW, 2000; NASA, 2002). This means the resource is assumed to be uniform within a resource cell.

For wind turbine, in addition to average wind speed it is necessary to know the wind speed distribution as power output from the wind varies with the cube of the wind speed. To determine the wind speed distribution for a given wind $V_m$ the Rayleigh function is used. This function expresses the possibility $f(v)$ to have a wind speed $v$ during a year according to

$$f(v) = \frac{\pi v}{2(V_m)^2} \exp\left(\frac{-\pi}{4}\right)\left(\frac{v}{V_m}\right)^2, \tag{1}$$

where $V_m$ is the average wind speed.

It has been concluded from experience that this function represents well enough the real wind speed distribution (Cavallo et al., 1993).

The delivered yearly energy output then can be calculated by integrating the power curve:

$$E(v_m) = \sum_{v=1}^{v=25} \eta f(v) P(v) \times 8760, \tag{2}$$

where $v_m$ is the average wind speed; $P(v)$ the turbine power at wind speed $v$; $f(v)$ the Rayleigh probability density function for wind speed $v$, calculated for average wind speed $v_m$; $\eta$ the system efficiency (battery, charge controller, loss in wiring) and 8760 the number of hours per year.

For PV, the output depends strongly on the average daily solar radiation incident upon the module, which in turn depends on its orientation and tilt. Thus, firstly it is assumed that the standard tilted angle for the PV module is equal to the latitude of the location where the PV module is installed. This is the slope, which in general maximizes the annual radiation in the plane of the PV module and consequently its power output. The estimation of energy output ($E$, kWh) then follows (IE, 2000):

$$E = \eta W_p \frac{Q}{Q_0} \times 365, \tag{3}$$

where $\eta$ is system efficiency (battery, charge controller and loss in wiring); $W_p$ is peak capacity of the PV module; $Q$ is the annual average daily solar radiation W/m$^2$/day; $Q_0$ is the standard solar radiation (1000 W/m$^2$), and 365 is the number of days per year.

### 2.3. Economic evaluation

Power outputs calculated above together with financial and economic data are then used to conduct levelized cost per unit of electricity produced (LC). Accordingly, costs incurred over the span of the evaluation period for renewable energy systems are estimated. Discounted cost streams, combined with energy values, are used to calculate levelized cost in order to compare various energy options. LC is calculated as (Bhuiyan et al., 2000):

$$LC = \frac{C_{pw} + M_{pw} + F_{pw} + R_{pw}}{E_{pw}}, \tag{4}$$

where *pw* is a subscript and indicates the present worth of each factor.

*Capital cost* ($C$) represents initial costs for purchasing equipments and installation that should be spent before the system operation starts (year 0).

*Maintenance cost* ($M$) represents recurring costs spent every year for maintenance and operation of the system:

$$M_{pw} = \text{Annual Maintenance cost} \times \left(\frac{(1+e_0)}{(d-e_0)}\right)\left[1-\left(\frac{(1+e_0)}{(1+d)}\right)^N\right], \tag{5}$$

where $e_0$ represents general escalation, $d$ represents discount rate and $N$ is the evaluation period in year.

*Fuel cost* ($F$), commonly expressed as the annual fuel expenditure, which is defined from the equation:

$$F_{pw} = \text{Annual Fuel cost}\left(\frac{(1+e_f)}{(d-e_f)}\right)\left[1-\left(\frac{(1+e_f)}{(1+d)}\right)^N\right], \tag{6}$$

where $e_f$ is fuel cost escalation.

*Replacement cost* ($R$) represents costs spent for replacement of major components or systems, which have a lifetime shorter than the evaluation period. The replacement costs are calculated by the equation:

$$R_{pw} = \sum_{i=1}^{v}\left[item \ \ \cos t\left(\frac{1+e_0}{1+d}\right)^{RY}\right], \tag{7}$$

where *item cost* is a replacement cost at point of replacement; $RY$ is the year of replacement and $e_0$ is the general escalation rate.

*Energy output* ($E$) represents the present worth of an annual energy output ($A$) received over a time period ($N$ years) at the discount rate $d$

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

### *2.4. Comparison of the cost of renewable energy system against grid extension*

The levelized costs of electricity of stand-alone renewable energy technologies arrived at are then compared with that of grid-based electricity for typical communities in the rural areas of Vietnam to determine their feasibility for rural electrification.

## 3. Results and analysis

### *3.1. Household load definition*

The present study assumes that a rural household would like to receive 0.3 kWh/day. This amount is determined from appliance inventories and household reports of average daily use (IE, 2000), and is a base for the selection and dimension of relevant technologies in the next section.

### *3.2. Resource evaluation*

Based on country's topography and the technical capacity, small wind turbines with 10 m height can be considered feasible. However, wind data are available only for 30 and 65 m heights (TW, 2000). Therefore, for this study, an extrapolation method as suggested by Cavallo et al. (1993), as given in Eq. (9) is used to calculate wind velocity data for 10 m height.

$$u(10) = u(30)\frac{\ln(10/z_0)}{\ln(30/z_0)}, \tag{9}$$

where $u(10)$ and $u(30)$ refers to wind velocity at 10 and 30 m height and $z_0$ refers to the roughness index. Result of this calculation is shown in Fig. 1.

As for Solar, monthly global solar radiation and ambient temperature data at a spatial resolution of $1^\circ \times 1^\circ$ are obtained from National Aeronautics and Space Administration (NASA, 2002). These data indicate that Vietnam receives close to $5.2 \times 10^{14}$ kWh of solar energy every year, i.e., more than 1000 times higher than the energy consumed in the country in 2005 (IE, 2005). Apparently, solar radiation is better in the south. The annual average daily global radiation for southern locations is as high as 5.32 kWh/m$^2$ day while the corresponding figure for the north is as low as 3.33 kWh/m$^2$ day (Fig. 2).

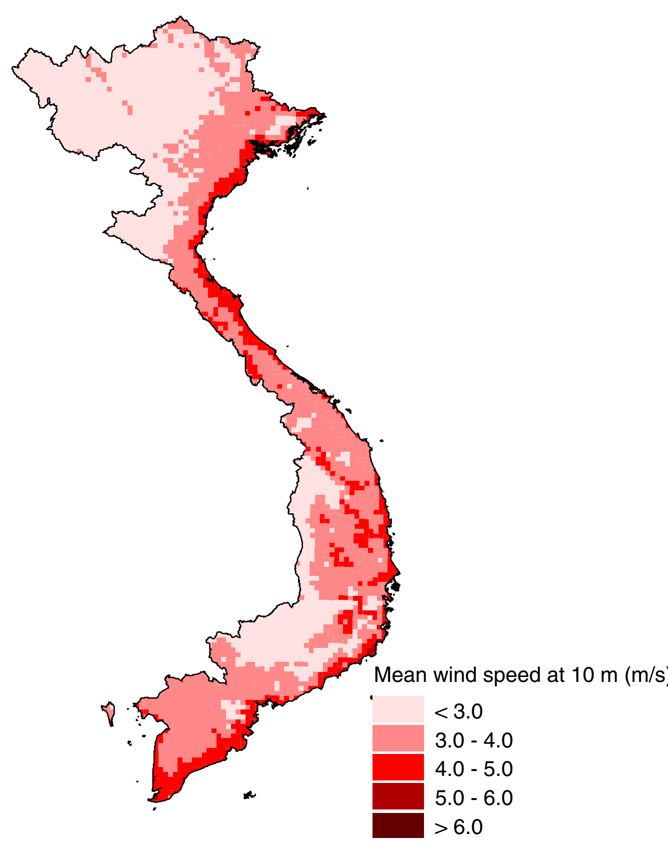


Fig. 1. Wind resource at 10 m high (m/s) in Vietnam.

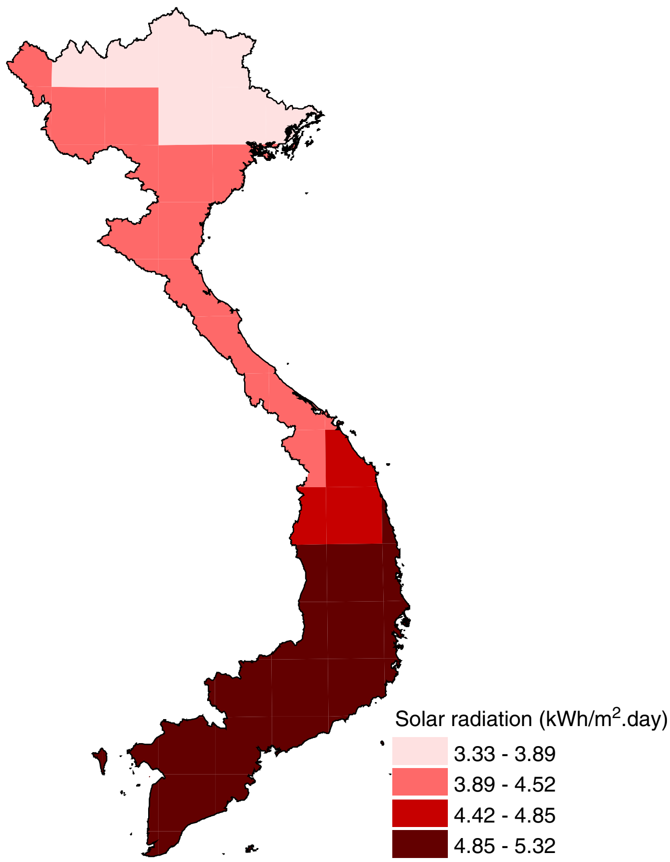


Fig. 2. Solar resource (kWh/$m^2$ day) in Vietnam.

### 3.3. *Levelized cost analysis*

Three household-sized renewable energy technologies have been selected based on the above-defined loads, the availability of resources and the available sizes of renewable energy technologies. These are two solar PV systems of 130 and 100 $W_p$[1] for solar conditions in the North and the South, respectively, and one 150 W wind turbine. The PV systems use imported panels, which have a lifetime of 20 years. The wind system in this case is the locally made model PD 170.6 of the Research Center for Thermal Equipment and Renewable Energy (RECTERE). This pitch type turbine has 6 blades of composite, which operates at the height of 10 m. It starts at 3 m/s, reaches rated output of 150 W at 8 m/s and shuts down at wind speed over 16 m/s. It has an expected lifetime of 10 years.

All systems use locally made batteries and charge controllers. Battery lifetime is 3 years while that of charge controller is 10 years.

For comparison, a gasoline generator suitable for household use (450 W) is also examined. This generator—Model EM650—is made in Japan and available in the local market. This generator is assumed to operate for 4 h per day and consume 0.43 l of fuel per kWh. The market price for gasoline is presently 11,000 VND/l (1 USD = 16,000 VND). The delivery cost for this fuel to remote areas varies by distance. In the present study, it is assumed that the average delivery cost would add 50% to the market price of gasoline. The delivered price for the item thus would be 16,500 VND/l. Table 1 describes all these assumptions.

The annual energy value in this analysis is determined in two ways. The first approach uses a production perspective in which annual energy value is set equal to the system net production (i.e., net of losses due to storage, power conversion, etc.). For a renewable energy system, this largely depends on the availability and energy density of the resource. For gen-sets, the major determinant is operating hours. A second approach adopts a demand or end-use perspective in which annual energy value equals actual household energy consumption. However, since resource availability establishes a cap on household energy consumption level in the case of renewable energy technologies, system net production is used as the annual energy value if potential household demand exceeds the generation capacity of the system.

To calculate the levelized cost we also need data on evaluation period. Here, the evaluation period is taken to be the longest lifetime of a component or technology (Pokharel, 2002). Accordingly, 20 years, the lifetime of PV module, is the longest. This time span is, however, still shorter than the lifetime of distribution network (40 years) with which these selected renewable energy technologies are expected to compare. Hence, in the present study, 40 years is actually used as the evaluation period. This means all other technologies or components with lifetime shorter than 40 years need to be replaced repeatedly within the evaluation period. In addition, the following economic factors are considered:

- *Discount rate*: 10%. This rate is recommended by the World Bank for analysis of the technological choices in Vietnam (IE, 2005).
- *Fuel cost escalation*: 4% (for gasoline genset).
- *General escalation*: 3%. This rate is based on the trend of inflation in Vietnam between 1991 and 2004 (IE, 2006) and is used as O and M escalation rate.

Levelized costs of electricity production from compared rural energy alternatives are provided in Table 2. From this table one would see that the levelized costs of electricity production from wind generators vary widely. This implies a big difference in resource availability of wind. The further away the levelized costs are from the lower-end, the lower the output the system can produce than the household demand. Similar to that of wind generator, levelized costs

[1]One hundred and thirty $W_p$ systems are actually used for areas having the annual average daily global radiation below 4.5 kWh/$m^2$ day while 100 $W_p$ systems are for areas with the annual average daily global radiation above 4.5 kWh/$m^2$ day.

Table 1
Technical and economic parameters of household-sized energy systems

| System characteristics and cost items | Electric generation technologies | | | |
|---|---|---|---|---|
| | SHS1 | SHS2 | WHS | GG |
| Capacity (W) | 100 | 130 | 150 | 450 |
| System total capital cost (VND) | 9,440,000 | 11,840,000 | 4,320,000 | 5,760,000 |
| Annual O&M cost (VND/yr$^{-}$) | 47,200 | 59,200 | 48,000 | 288,000 |
| System lifetime | 20 years | 20 years | 10 years | 8000 h |
| Battery capacity (Ah) | 100 | 100 | 100 | |
| Investment cost (VND) | 640,000 | 640,000 | 640,000 | |
| Battery lifetime (year) | 3 | 3 | 3 | |
| Charge controller (VND) | 480,000 | 480,000 | 480,000 | |
| Charge controller lifetime (year) | 10 | 10 | 10 | |
| Fuel tank investment cost (VND) | | | | 448,000 |
| Fuel tank lifetime (year) | | | | 3 |
| Unit cost of delivered fuel (VND/liter) | | | | 16,500 |

SHS: Solar photovoltaic; WHS: wind generator; GG: gasoline generator.
*Source*: IE (2000).

Table 2
Levelized costs (VND/kWh) of solar PV, wind generator and gasoline gen-set

| Technology | Value |
|---|---|
| Wind generator | 10,100–165,390 |
| Solar PV-South | 14,170 |
| Solar PV-North | 17,150–17,690 |
| Gasoline gen-set | 30,560 |

of solar PV for the North vary, but, within a much smaller range.

However, for comparison, it is required that all selected technologies produce an equivalent level of energy service. The analysis with this condition indicates that the locally made wind turbine appears to be the most cost-effective system among the three for providing electricity to remote families. Given sufficient resource level, it can produce electricity at as low as 10,100 VND/kWh. PVs are the next least cost systems due to high investment costs. They can meet the given demand at 14,170 VND/kWh at the sunshine level in the South and 17,150 VND/kWh at the sunshine levels in the North. Gasoline generator has a levelized cost of 30,560 VND/kWh, thus represents the most expensive system. Gasoline generator does not have a high investment cost but its annual fuel cost and low capacity factor prevents it from providing electricity with cost effectiveness. In terms of application of this technology, the availability of gasoline must be seriously considered.

### 3.4. Decentralized renewable energy technologies versus grid-based power supply

The comparisons above shows that the selected decentralized renewable energy technologies are more cost-competitive than gasoline gen-set. An interesting question then is how competitive they are against that of grid-based power for typical communities in rural areas of Vietnam. To answer this question, load profiles of these rural communities, which are characterized by the following points must be clarified first (WB, 1996):

- *Household service level*: the daily energy consumption of the average household to be served.
- Total number of household to be served.
- *Load density*: the number of households to be served per unit service area (household/km$^2$).
- *Productive load*: the number and power requirements of productive loads such as rice mills, water pumping and service sector loads.
- *Load growth*: the annual increase in the load that results from increases in both the number of customers served and the demand for energy.
- Distance from MV substation or MV line.

The approach for the assessment is thus as follows. First, typical load profiles are defined. An empirical model for grid extension is then developed. Based on the cost required, levelized cost per unit of electricity received is estimated which is then compared with that of renewable energy technologies.

*Load profile definition*. It is assumed that an average household would consume 0.3 kWh/day as has been defined in Section 3.1. In addition, it is also assumed that there is no load growth and productive load. The load profiles then would be a combination of the followings: (i) number of households to be served: from 50 to 1000 households; (ii) load density: from 50 to 150 households/km$^2$, and (iii) distance to MV line: from 5 to 20 km. These ranges are selected as being representative for rural areas in Vietnam.

*Grid model development*. An empirical grid model is then built to help develop a power system for the above-defined communities. Typically, a grid-based power system consists of (i) a medium tension line (usually 22 kV) which transports power from the nearest grid at the long run marginal cost (LRMC) to the load center, (ii) a transformer which steps down the voltage to 0.38 KV, and (iii) a local LV distribution network which is hierarchically structured, i.e., at the first level is the main LV line. Then comes branch LV lines and finally household connection wires.

To enable a comparison with renewable energy options to be carried out, the levelized cost of electricity supply of this grid option is calculated. For this, the same method for levelized cost calculation and economic parameters as has been applied to renewable energy technologies is used. Assumptions for the main components necessary for the calculation are given in Table 3.

The results presented in Table 4 indicate that levelized cost of the grid-based option varies strongly with respect to the number of customers, customer density (load density), and the distance to MV grid. Among these, however, customer number has the greatest impact. With the same customer density (150 customers/km$^2$) and distance to MV grid (20 km), the levelized cost could vary between 55,340 and 9220 VND/kWh, i.e., 6 times along with the customer quantity of 50 and 1000, respectively. The influence of MV line length ranks second. The levelized cost could change from 19,790 to 55,340 VND/kWh, i.e., 2.8 times, corresponding to MV line length of 5 and 20 km, respectively, for the same number of customer (50 customers) and load density (150 customers/km$^2$). Load density has the least influence. However, the difference between the highest and the least value with the same MV length and customer number is as large as 2.3 times.

Of all load profiles examined, load profile corresponding to customer number, load density (household/km$^2$) and MV length (km) of 50, 50 and 20, respectively has the highest cost (63,970 VND/kWh) while load of 1000 customers with density of 150 and located 5 km away from the MV transformer or MV line has the lowest cost (7440 VND/kWh). The main contributor to this high cost is the capital cost which varies strongly with the number of customer, load density, and distance to MV line. For spatially settled and isolated communities, the capital cost is as high as 45,920,000 VND per connection (Table 5).

In comparison with that of renewable energy technologies analyzed above, one would recognize that there are cases where renewable energy technologies are more competitive and there are cases where grid-based options are more competitive. The general observation is that renewable energy technologies are often least-cost options where population number and load density are low. The separation depends on which technology is used and the available resources in that region. For example, for communities of 200 households, 5 km away from an existing MV line, the market niche for solar PV would vary significantly—from all communities with load density less than 60 household/km$^2$ to communities with load density less than 80 household/km$^2$, corresponding to solar resource in the north and the south, respectively. However, for these same communities, wind generator would be the least-cost options given sufficient wind resources (Table 4).

Table 3
Technical and economic parameters of grid-based option for economic evaluation[a]

| Item description | Value |
|---|---|
| *Incoming MV* | |
| LRMC of supply (VND/kWh)[b] | 1180 |
| MV line cost (VND/km) | 90,000,000 |
| Annual O&M cost of MV line (VND/km/yr) | 2,700,000 |
| Lifetime (yr) | 40 |
| *Transformer* | |
| Transformer cost (VND/trans.) | 64,000,000 |
| Annual O&M cost of transformer (VND/trans/yr) | 1,920,000 |
| Lifetime (yr) | 40 |
| *LV section* | |
| LV line length per km$^2$ load area (km/km$^2$) | 4.00 |
| LV line length per transformer (km/trans.) | 4.00 |
| LV line cost (VND/km/yr) | 103,008,000 |
| Annual O&M cost of LV line (VND/km/yr) | 5,150,400 |
| Connection and wiring cost (VND/customer) | 720,000 |
| Lifetime (yr) | 40 |
| Overall loss (% electricity supply) | 10% |

[a] *Source*: Author estimation based on various sources.
[b] *Notes*: The LRMC of supply at MV calculated to the year 2025 is 1073 VND/kWh (IE, 2005). The present study adds 10% to this value to account for a longer evaluation period.

### 3.5. Economic potential of stand-alone, household-sized renewable energy technologies

The analysis above shows that decentralized renewable energy technologies are cost-competitive with grid extension especially for areas with low load density and low number of households to be electrified. The comparison is however relative, as the geographical data of the communities is not integrated in the analysis. Thus, as a further step, this section attempts to locate areas that can be effectively served by either wind generator or solar PV. In other words, the economic potential of these renewable energy technologies for rural electrification is determined. To reach this goal, the approach, ideally should be as follows. First, non-electrified communities are searched for. Cost of electricity supply for these communities by grid extension is then estimated. This cost is afterwards compared with that of renewable energy-based options to decide whether it is economical to use renewable energy technologies. This approach however, cannot be carried out due to the lack of a digital map of the non-electrified areas and a digital map of existing distribution network. Therefore, a rough estimate of potential is carried out. According to EVN (2005), at the end of 2005, about 2 million households did not yet have access to electricity.

Table 4
Levelized cost (thousand VND/kWh) of solar PV, wind generator and grid-based power supply by load profiles

| Load density (household/km$^2$) | Number of households | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| 1. MV line length = 5 km | | | | | | | | | | | |
| 50 | 28.43 | 22.50 | 19.54 | 18.55 | 18.06 | 17.76 | 17.57 | 17.43 | 17.32 | 17.24 | 17.17 |
| 60 | 26.27 | 20.34 | 17.38 | 16.11 | 15.69 | 15.44 | 15.13 | 15.03 | 14.95 | 14.80 | 14.76 |
| 70 | 24.73 | 18.80 | 15.42 | 14.57 | 13.94 | 13.56 | 13.45 | 13.24 | 13.20 | 13.07 | 13.05 |
| 80 | 23.57 | 17.65 | 14.26 | 13.14 | 12.57 | 12.40 | 12.15 | 11.97 | 11.83 | 11.82 | 11.73 |
| 90 | 22.67 | 15.91 | 13.36 | 12.24 | 11.67 | 11.33 | 11.11 | 10.95 | 10.83 | 10.73 | 10.66 |
| 100 | 21.95 | 15.19 | 12.22 | 11.24 | 10.74 | 10.45 | 10.25 | 10.11 | 10.00 | 9.92 | 9.85 |
| 110 | 21.36 | 14.60 | 11.64 | 10.65 | 10.15 | 9.86 | 9.66 | 9.52 | 9.41 | 9.24 | 9.18 |
| 120 | 20.87 | 14.11 | 11.15 | 10.16 | 9.66 | 9.20 | 9.03 | 8.91 | 8.82 | 8.75 | 8.69 |
| 130 | 20.46 | 13.69 | 10.73 | 9.74 | 9.04 | 8.78 | 8.62 | 8.49 | 8.30 | 8.24 | 8.19 |
| 140 | 20.10 | 13.34 | 10.37 | 9.11 | 8.68 | 8.43 | 8.26 | 8.02 | 7.94 | 7.88 | 7.75 |
| 150 | 19.79 | 13.03 | 10.07 | 8.80 | 8.37 | 8.12 | 7.81 | 7.71 | 7.63 | 7.48 | 7.44 |
| 2. MV line length = 10 km | | | | | | | | | | | |
| 50 | 40.27 | 28.43 | 22.50 | 20.53 | 19.54 | 18.95 | 18.55 | 18.27 | 18.06 | 17.90 | 17.76 |
| 60 | 38.12 | 26.27 | 20.34 | 18.09 | 17.17 | 16.62 | 16.11 | 15.87 | 15.69 | 15.46 | 15.35 |
| 70 | 36.57 | 24.73 | 18.38 | 16.55 | 15.42 | 14.74 | 14.43 | 14.09 | 13.94 | 13.73 | 13.64 |
| 80 | 35.42 | 23.57 | 17.23 | 15.11 | 14.05 | 13.59 | 13.14 | 12.81 | 12.57 | 12.48 | 12.32 |
| 90 | 34.52 | 21.83 | 16.33 | 14.21 | 13.15 | 12.52 | 12.10 | 11.79 | 11.57 | 11.39 | 11.25 |
| 100 | 33.80 | 21.11 | 15.19 | 13.21 | 12.22 | 11.63 | 11.24 | 10.95 | 10.74 | 10.58 | 10.45 |
| 110 | 33.21 | 20.52 | 14.60 | 2.62 | 11.64 | 11.04 | 10.65 | 10.37 | 10.15 | 9.90 | 9.77 |
| 120 | 32.72 | 20.03 | 14.11 | 12.13 | 11.15 | 10.38 | 10.02 | 9.76 | 9.56 | 9.41 | 9.28 |
| 130 | 32.31 | 19.62 | 13.69 | 11.72 | 10.52 | 9.97 | 9.60 | 9.34 | 9.04 | 8.90 | 8.78 |
| 140 | 31.95 | 19.26 | 13.34 | 11.08 | 10.16 | 9.61 | 9.25 | 8.86 | 8.68 | 8.54 | 8.34 |
| 150 | 31.64 | 18.95 | 13.03 | 10.77 | 9.86 | 9.31 | 8.80 | 8.56 | 8.37 | 8.14 | 8.04 |
| 3. MV line length = 15 km | | | | | | | | | | | |
| 50 | 52.12 | 34.35 | 25.46 | 22.50 | 21.02 | 20.13 | 19.54 | 19.12 | 18.80 | 18.55 | 18.36 |
| 60 | 49.96 | 32.19 | 23.31 | 20.06 | 18.65 | 17.81 | 17.10 | 16.72 | 16.43 | 16.11 | 15.95 |
| 70 | 48.42 | 30.65 | 21.34 | 18.52 | 16.90 | 15.93 | 15.42 | 14.94 | 14.68 | 14.39 | 14.24 |
| 80 | 47.27 | 29.49 | 20.19 | 17.09 | 15.53 | 14.77 | 14.12 | 13.66 | 13.31 | 13.14 | 12.91 |
| 90 | 46.37 | 27.75 | 19.29 | 16.19 | 14.64 | 13.70 | 13.08 | 12.64 | 12.31 | 12.05 | 11.84 |
| 100 | 45.65 | 27.03 | 18.15 | 15.19 | 13.71 | 12.82 | 12.22 | 11.80 | 11.48 | 11.24 | 11.04 |
| 110 | 45.06 | 26.45 | 17.56 | 14.60 | 13.12 | 12.23 | 11.64 | 11.21 | 10.90 | 10.55 | 10.37 |
| 120 | 44.57 | 25.95 | 17.07 | 14.11 | 12.63 | 11.57 | 11.00 | 10.60 | 10.30 | 10.06 | 9.88 |
| 130 | 44.15 | 25.54 | 16.65 | 13.69 | 12.00 | 11.15 | 10.59 | 10.19 | 9.78 | 9.56 | 9.38 |
| 140 | 43.80 | 25.18 | 16.30 | 13.06 | 11.64 | 10.80 | 10.23 | 9.71 | 9.42 | 9.20 | 8.94 |
| 150 | 43.49 | 24.88 | 15.99 | 12.75 | 11.34 | 10.49 | 9.79 | 9.40 | 9.12 | 8.80 | 8.63 |
| 4. MV line length = 20 km | | | | | | | | | | | |
| 50 | 63.97 | 40.27 | 28.43 | 24.48 | 22.50 | 21.32 | 20.53 | 19.96 | 19.54 | 19.21 | 18.95 |
| 60 | 61.81 | 38.12 | 26.27 | 22.04 | 20.13 | 18.99 | 18.09 | 17.57 | 17.17 | 16.77 | 16.54 |
| 70 | 60.27 | 36.57 | 24.31 | 20.50 | 18.38 | 17.11 | 16.41 | 15.78 | 15.42 | 15.04 | 14.83 |
| 80 | 59.11 | 35.42 | 23.15 | 19.06 | 17.02 | 15.96 | 15.11 | 14.51 | 14.05 | 13.79 | 13.50 |
| 90 | 58.21 | 33.68 | 22.25 | 18.16 | 16.12 | 14.89 | 14.07 | 13.49 | 13.05 | 12.71 | 12.44 |
| 100 | 57.50 | 32.96 | 21.11 | 17.16 | 15.19 | 14.00 | 13.21 | 12.65 | 12.22 | 11.90 | 11.63 |
| 110 | 56.91 | 32.37 | 20.52 | 16.57 | 14.60 | 13.41 | 12.62 | 12.06 | 11.64 | 11.21 | 10.96 |
| 120 | 56.42 | 31.88 | 20.03 | 16.08 | 14.11 | 12.75 | 11.99 | 11.45 | 11.04 | 10.72 | 10.47 |
| 130 | 56.00 | 31.46 | 19.62 | 15.67 | 13.48 | 12.34 | 11.58 | 11.03 | 10.52 | 10.21 | 9.97 |
| 140 | 55.65 | 31.11 | 19.26 | 15.03 | 13.13 | 11.98 | 11.22 | 10.56 | 10.16 | 9.86 | 9.53 |
| 150 | 55.34 | 30.80 | 18.95 | 14.72 | 12.82 | 11.67 | 10.77 | 10.25 | 9.86 | 9.46 | 9.22 |
| Solar PV[a] | 14.1 | 14.1 | 14.1 | 14.1 | 14.1 | 14.1 | 14.1 | 14.1 | 14.1 | 14.1 | 14.1 |
| | 17.1 | 17.1 | 17.1 | 17.1 | 17.1 | 17.1 | 17.1 | 17.1 | 17.1 | 17.1 | 17.1 |
| Wind generator | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 | 10.1 |

[a] *Notes*: Two values are given for solar PV to represent the solar PV cost for South and North region, respectively. In reality, the costs for solar system and wind system get cheaper with a large quantity (due to economy of scale). In this table, this effect has been ignored for simplicity.

Table 5
Capital cost per connection (thousand VND/connection) of solar PV, wind generator and grid-based power supply by load profiles

| Load density (household/km$^2$) | Number of households | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
| 1. MV line length = 5 km | | | | | | | | | | | |
| 50 | 18,920 | 14,420 | 12,170 | 11,420 | 11,045 | 10,820 | 10,670 | 10,563 | 10,483 | 10,420 | 10,370 |
| 60 | 17,547 | 13,047 | 10,797 | 9834 | 9512 | 9319 | 9084 | 9007 | 8949 | 8834 | 8805 |
| 70 | 16,566 | 12,066 | 9496 | 8853 | 8371 | 8082 | 7996 | 7843 | 7809 | 7710 | 7696 |
| 80 | 15,830 | 11,330 | 8760 | 7904 | 7475 | 7346 | 7154 | 7016 | 6913 | 6904 | 6832 |
| 90 | 15,258 | 10,118 | 8188 | 7331 | 6903 | 6646 | 6475 | 6352 | 6261 | 6189 | 6132 |
| 100 | 14,800 | 9660 | 7410 | 6660 | 6285 | 6060 | 5910 | 5803 | 5723 | 5660 | 5610 |
| 110 | 14,426 | 9286 | 7036 | 6286 | 5911 | 5686 | 5536 | 5429 | 5348 | 5215 | 5172 |
| 120 | 14,114 | 8974 | 6724 | 5974 | 5599 | 5246 | 5117 | 5025 | 4956 | 4903 | 4860 |
| 130 | 13,850 | 8710 | 6460 | 5710 | 5175 | 4982 | 4853 | 4761 | 4612 | 4567 | 4532 |
| 140 | 13,623 | 8483 | 6233 | 5270 | 4948 | 4755 | 4627 | 4443 | 4386 | 4341 | 4241 |
| 150 | 13,427 | 8287 | 6037 | 5074 | 4752 | 4559 | 4324 | 4247 | 4189 | 4074 | 4045 |
| 2. MV line length = 10 km | | | | | | | | | | | |
| 50 | 27,920 | 18,920 | 14,420 | 12,920 | 12,170 | 11,720 | 11,420 | 11,206 | 11,045 | 10,920 | 10,820 |
| 60 | 26,547 | 17,547 | 13,047 | 11,334 | 10,637 | 10,219 | 9834 | 9650 | 9512 | 9334 | 9255 |
| 70 | 25,566 | 16,566 | 11,746 | 10,353 | 9496 | 8982 | 8746 | 8486 | 8371 | 8210 | 8146 |
| 80 | 24,830 | 15,830 | 11,010 | 9404 | 8600 | 8246 | 7904 | 7659 | 7475 | 7404 | 7282 |
| 90 | 24,258 | 14,618 | 10,438 | 8831 | 8028 | 7546 | 7225 | 6995 | 6823 | 6689 | 6582 |
| 100 | 23,800 | 14,160 | 9660 | 8160 | 7410 | 6960 | 6660 | 6446 | 6285 | 6160 | 6060 |
| 110 | 23,426 | 13,786 | 9286 | 7786 | 7036 | 6586 | 6286 | 6071 | 5911 | 5715 | 5622 |
| 120 | 23,114 | 13,474 | 8974 | 7474 | 6724 | 6146 | 5867 | 5668 | 5519 | 5403 | 5310 |
| 130 | 22,850 | 13,210 | 8710 | 7210 | 6300 | 5882 | 5603 | 5404 | 5175 | 5067 | 4982 |
| 140 | 22,623 | 12,983 | 8483 | 6770 | 6073 | 5655 | 5377 | 5086 | 4948 | 4841 | 4691 |
| 150 | 22,427 | 12,787 | 8287 | 6574 | 5877 | 5459 | 5074 | 4890 | 4752 | 4574 | 4495 |
| 2. MV line length = 15 km | | | | | | | | | | | |
| 50 | 36,920 | 23,420 | 16,670 | 14,420 | 13,295 | 12,620 | 12,170 | 11,849 | 11,608 | 11,420 | 11,270 |
| 60 | 35,547 | 22,047 | 15,297 | 12,834 | 11,762 | 11,119 | 10,584 | 10,293 | 10,074 | 9,834 | 9705 |
| 70 | 34,566 | 21,066 | 13,996 | 11,853 | 10,621 | 9882 | 9496 | 9129 | 8934 | 8710 | 8596 |
| 80 | 33,830 | 20,330 | 13,260 | 10,904 | 9725 | 9146 | 8654 | 8302 | 8038 | 7904 | 7732 |
| 90 | 33,258 | 19,118 | 12,688 | 10,331 | 9153 | 8446 | 7975 | 7638 | 7386 | 7189 | 7032 |
| 100 | 32,800 | 18,660 | 11,910 | 9660 | 8535 | 7860 | 7410 | 7089 | 6848 | 6660 | 6510 |
| 110 | 32,426 | 18,286 | 11,536 | 9286 | 8161 | 7486 | 7036 | 6714 | 6473 | 6215 | 6072 |
| 120 | 32,114 | 17,974 | 11,224 | 8974 | 7849 | 7046 | 6617 | 6311 | 6081 | 5903 | 5760 |
| 130 | 31,850 | 17,710 | 10,960 | 8710 | 7425 | 6782 | 6353 | 6047 | 5737 | 5567 | 5432 |
| 140 | 31,623 | 17,483 | 10,733 | 8270 | 7198 | 6555 | 6127 | 5729 | 5511 | 5341 | 5141 |
| 150 | 31,427 | 17,287 | 10,537 | 8074 | 7002 | 6359 | 5824 | 5533 | 5314 | 5074 | 4945 |
| 2. MV line length = 20 km | | | | | | | | | | | |
| 50 | 45,920 | 27,920 | 18,920 | 15,920 | 14,420 | 13,520 | 12,920 | 12,492 | 12,170 | 11,920 | 11,720 |
| 60 | 44,547 | 26,547 | 17,547 | 14,334 | 12,887 | 12,019 | 11,334 | 10,936 | 10,637 | 10,334 | 10,155 |
| 70 | 43,566 | 25,566 | 16,246 | 13,353 | 11,746 | 10,782 | 10,246 | 9772 | 9496 | 9210 | 9046 |
| 80 | 42,830 | 24,830 | 15,510 | 12,404 | 10,850 | 10,046 | 9404 | 8945 | 8600 | 8404 | 8182 |
| 90 | 42,258 | 23,618 | 14,938 | 11,831 | 10,278 | 9346 | 8725 | 8281 | 7948 | 7689 | 7482 |
| 100 | 41,800 | 23,160 | 14,160 | 11,160 | 9660 | 8760 | 8160 | 7732 | 7410 | 7160 | 6960 |
| 110 | 41,426 | 22,786 | 13,786 | 10,786 | 9286 | 8386 | 7786 | 7357 | 7036 | 6715 | 6522 |
| 120 | 41,114 | 22,474 | 13,474 | 10,474 | 8974 | 7946 | 7367 | 6954 | 6644 | 6403 | 6210 |
| 130 | 40,850 | 22,210 | 13,210 | 10,210 | 8550 | 7682 | 7103 | 6690 | 6300 | 6067 | 5882 |
| 140 | 40,623 | 21,983 | 12,983 | 9770 | 8323 | 7455 | 6877 | 6372 | 6073 | 5841 | 5591 |
| 150 | 40,427 | 21,787 | 12,787 | 9574 | 8127 | 7259 | 6574 | 6176 | 5877 | 5574 | 5395 |
| Solar PV[a] | 9440 | 9440 | 9440 | 9440 | 9440 | 9440 | 9440 | 9440 | 9440 | 9440 | 9440 |
| | 11,840 | 11,840 | 11,840 | 11,840 | 11,840 | 11,840 | 11,840 | 11,840 | 11,840 | 11,840 | 11,840 |
| Wind generator | 4320 | 4320 | 4320 | 4320 | 4320 | 4320 | 4320 | 4320 | 4320 | 4320 | 4320 |

[a] *Notes*: These investment costs are for a 100 $W_p$ PV system and a 130 $W_p$ PV system corresponding to the South and North, respectively.

Considering the complex topography, low population concentration of most of the unelectrified areas, and the unequal distribution of the resources among these areas, it would be realistic to assume that 10% of presently unelectrified households could be effectively served by solar PV and a further 5% by wind generator. Here a smaller percentage is assumed for wind generator because of the uncertainty with the wind resource. The map of wind resource used in this study is actually too broad while wind resource can change within meters of horizontal and vertical distance. Power from the wind, in turn, varies with the cube of wind speed. Despite this, wind speed measurement is necessary to confirm this potential. Translating into capacities, these figures would be equivalent to 15 MW of wind energy and 20 MW of solar PV[2]. These technologies could produce 66 GWh per year, and as a result would avoid 60,213 ton of $CO_2$ yearly if they were used in displacement of coal-fired power plants[3]. Total investment capital for these technologies would be 2320 billion VND.

## 4. Strategic implications

The analysis presented above confirms the existence of economical renewable energy applications to meet household electricity needs in remote and mountainous areas in Vietnam. Studies in similar circumstances in other developing countries arrived at a similar conclusion (WB, 1996; Bugaje, 1999; Bhuiyan et al., 2000). Until concrete, plausible policies are formulated, there would be problems with the deployment of these technologies. On the power utilities' side, although these systems are economically viable they are still more expensive in terms of energy cost than that of grid electricity for urban areas. Thus, given the uniform electricity tariff set by the government, power utilities would not be hurried to invest in these systems. Furthermore, it would be cumbersome from an organizational point of view to deal with such small systems. On the customers' side, these systems are unfortunately financially unattractive[4]. This is added by (i) the high initial investment cost which low-income rural household cannot readily afford, and (ii) the people's expectation that grid will arrive in the future. Thus, to overcome these barriers and to take advantages of benefits that these renewable energy technologies would bring about, governmental intervention is needed. With the hope of creating a base for the development of this sector, details of this interference is discussed below.

### 4.1. Setting a target for renewable energy

The first step that the government can do is to set a target and timetables for increasing the use of renewable energy technologies to provide electricity service in areas where grid extension is too costly and where opportunities for the use of renewable energy is economically warranted. In this regards, it is important that government clearly communicate to rural communities the infeasibility of grid-service to distance areas. Such communication can speed market penetration of renewable energy systems, which might otherwise face resistance as remote communities continue to expect grid connection in the near future.

### 4.2. Modes for deployment

There are several modes of deployment that can be used to attain such a target. These include providing subsidy, providing consumer credit, and setting up an Energy Service Company (ESCO).

*Providing subsidy*. Under this scheme, the government would provide subsidies to users to reduce capital cost of the system. Advantages of this approach include low initial cost for the users while the users still feel involved and responsible, as they have to contribute a considerable part of the costs. The idea of subsidy is also to promote market development for a particular technology. After a particular number of units, tertiary employment and resource utilization might be promoted so that such technologies become less costly to the installers in the later years. A successful example of this mode is the solar home system program of Nepal. Accordingly, the government of Nepal provided 200 USD (about 3,200,000 VND) as subsidy for each solar home system installed. Although the grant was reduced to 105 USD in 2001 with an annual reduction in this amount by 10%, it is still a major driving factor in increasing the number of solar systems installed in remote areas. So far, about 10,000 units have been installed under this scheme (Pokharel, 2003). Subsidy level is a big question to be decided by the decision makers. To give a hint to them regarding this, the levelized costs of electricity from solar PV as a function of subsidy levels are provided in Fig. 3.

*Consumer credit*. Provision of consumer credit is another tool for widespread deployment of household renewable

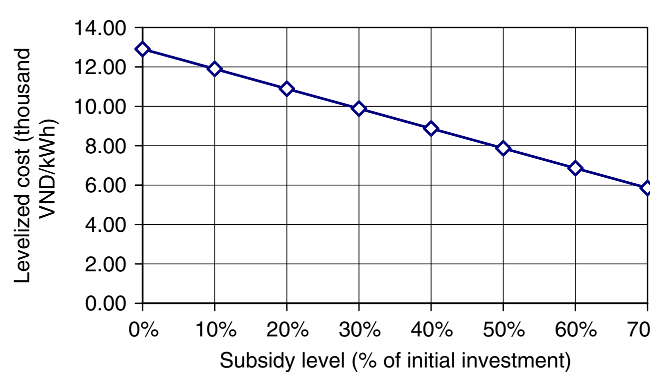


Fig. 3. Levelized costs of electricity from solar PV as a function of subsidy level.

[2]Assuming capacity of wind generator is 150 Wp and that of solar PV is 100 Wp.

[3]The calculation is done on the basis that electricity from renewable energy technologies would replace that of grid which in turn are produced by coal-fired power plant; Wind generator and solar PV each would produce on average 110 kWh/year. Coal fired power plant has an efficiency of 40% which burns coal with $CO_2$ coefficient of 96.3 kg/GJ.

[4]The Net Present Value (NPV) would be negative if electricity was valued at the current tariff of 608 VND/kWh as has been applied to conventional electricity (IE, 2005). This is exacerbated by the high initial investment, which low-income rural families cannot readily afford.

energy technologies. Under this scheme, users can obtain financing assistance from financial institutions or local banks for the purchase of renewable energy technologies. An advantage for user under this scheme is that the investment cost is spread over a number of years. Thus, this improves affordability for large part of the population.

However, local banks are often reluctant to provide loan for non-productive investment. When bank financing is available, interest rates are high. Therefore, most credit facilities are linked with external parties who provide either seed fund for establishing a revolving fund or financial guarantee, generally up to 100%. For this program to be successful, often a body to promote and control the installation of the systems on behalf of the local banks must be established.

A successful example of this scheme is Sudimara in Indonesia, which sold 7000 solar home systems in 2.5 years on a 4-year credit terms (Nieuwenhout et al., 2001). In Vietnam, Solar Electric Light Fund (SELF), an international NGO, in association with the Vietnams Women's Union (VWU) had sold more than 240 solar home systems on this basis to rural communities under a project launched in February 1994 (EVN, 1999).

*ESCO*. An alternative is to set up an ESCO, which will act on behalf of EVN in electrifying the areas concerned. ESCO will buy systems in bulk, install the systems, retain ownership, and bill for services. The main advantages of this approach are the spreading of costs to the users over a long period (10 years or more), the easy access of ESCO to capital and the potential for cost reduction through economy of scale. This mode can thus reach a larger customer base than other schemes.

### 4.3. Tax and duty removal

Along with the above instruments, the government should adjust duty and tax structure for components or renewable energy technologies that are imported. Relatively high import duties and other taxes can severely limit the potential for commercial viable, market driven renewable energy programs. At the same time, subsidies for rural grid services should be minimized. While these subsidies may be justified for social or development objectives, they can create distortions that hinder household renewable energy technologies where renewable energy technologies are clearly the least-cost economic option.

### 4.4. Consumer awareness

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, cost effectiveness of renewable energy technologies, and the infeasibility of grid-service to distant areas. 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. Information and training in simple maintenance and safe operating procedures should be targeted to those persons in the households who will have primary responsibility for the system. Users need to understand that good operating practices minimize recurring costs and enhance battery life.

### 4.5. 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 planning, promotion, training, and feasibility studies, planning and fixing targets for renewable energy contribution, establishing financial mechanisms for renewable energy projects for isolated and disadvantageous areas, setting standards for different renewable energy technologies, setting up R&D programmes to make renewable energy more competitive and organizing technology demonstrations.

## 5. Conclusions

Rural electrification is an essential element for rural development in Vietnam. This study examines the feasibility of stand-alone, household-sized renewable energy technologies namely wind generator and solar PV for remotely located areas in Vietnam. Three reference technologies have been chosen. These are two solar PV systems of 130 and 100 $W_p$ for solar conditions in the North and the South, respectively, and one 150 W wind turbine. It is found for all regions that levelized costs of PV energy are lower than the cost of energy from gasoline genset, and are cost-competitive with grid extension, especially for areas with low load density and low number of households to be electrified. Regarding wind energy, the viability is dependent on the location due to the wide variation of wind resource to topography. However, in locations with proper resources, wind energy is even more cost-competitive than solar PV. Thus, the use of either wind generator or solar PV is economically feasible in rural villages and remote areas of Vietnam. These technologies are clean and can be constructed even at the remotest corners of Vietnam within a short period of time. The potential number of households qualified for these renewable energy technologies have been preliminarily estimated at 300,000 with a smaller share for wind generator due to the uncertainty with the wind resource. The reason is the map of wind resource used in this study is actually too broad while wind resource can change within meters of horizontal and vertical distance. Power from the wind, in turn, varies with the cube of wind speed. Despite this, wind speed measurement is necessary to confirm this potential.

The study reports, however, that due to high initial investment cost of these technologies, there should be policies for the development of this sector. These should be first by setting a target for renewable energy development and using instruments to achieve such a target. The instruments that can be applied to encourage renewable energy technology deployment are providing subsidy, providing consumer credit, and setting up an Energy Service Company. Along with these instruments, removal of taxes, organization of information programs and setting up a promotional body are also needed.

In addition to wind and solar energy, attention should also be paid to other renewable energy sources such as biomass, biogas, hydro, geothermal energy. At the same time, other scales of exploitation such as grid-connected renewable energy projects, hybrid systems, and cogeneration should be explored. At present, Vietnam is still among countries with the lowest per capita consumption level of energies in the world, 256 kgoe in 2003 (IEEJ, 2006). However, the rapid population growth and economic development as has been seen in Vietnam will change this position. While the fossil reserves are limited, the promotion of renewable energy is considered a strategic move for benefits of economic growth, energy security, and local environment protection. It is thus recommended that an integrated energy planning study, which considers equally the role of renewable energies, be carried out.

It is expected that this study would help energy planner and policy makers understand the advantages of decentralized renewable energy technologies. Based on these results, planners and policy makers can visualize proper policies and guidance to promote renewable energy technologies for a more sustainable and secure energy system. It is however necessary to note that the study is based on a very rough resource data. The purpose is for broad-based policy decision. Thus, caution should be taken in using the results for a specific location. It is recommended to validate the resource by carrying out measurement. Furthermore, construction cost for grid items depends on the topography, which needs to be confirmed by field survey as well.

## Acknowledgements

The author would like to thank an anonymous reviewer for his/her helpful comments and suggestions on an earlier version of the paper. However, the author only is responsible for any remaining errors.

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