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GIS-based evaluation of multifarious local renewable energy sources: a case study of the Chigu area of southwestern Taiwan

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Abstract

The issue of regulating greenhouse gas emissions of developing countries is one of the main reasons for the US's retreat from ratifying the Kyoto Protocal, and this deserves particular attention in order to ensure that a robust international climate policy exists in the future. Enabling developing countries to move toward low-carbon energy systems would enhance the feasibility for their participation in mitigating greenhouse gas emissions. This study evaluates wind, solar, and biomass energy sources in a rural area of Chigu in southwestern Taiwan by means of analyzing technical, economic, environmental, and political implications in order to establish an evaluation model for developing local renewable energy sources. The adopted approach evaluates local potentials of renewable energy sources with the aid of a geographic information system according to actual local conditions, and allows the assessment to consider local potentials and restrictions such as climate conditions, land uses, and ecological environments, thus enabling a more-accurate assessment than is possible with evaluations on an approximate basis. These results may help build a developmental vision for sustainable energy systems based on locally available natural resources, and facilitate a transition of national energy and environmental policies towards sustainability.

Keywords: Renewable energy; Potential evaluation; Geographic Information System

1. Introduction

The issue of global warming is becoming a great challenge which the international community must face in this century. The latest report of the IPCC (Intergovernmental Panel on Climate Change) in 2001 indicated that development heavily relying on fossil fuel energies will raise global mean temperatures by about 4.5 °C during the 21st century. Only with a transition toward a low-resource-consuming economy and the use of clean energy sources and technologies will it be possible to mitigate temperature increases to about 2 °C (IPCC, 2001). In other words, cutting energy consumption and facilitating a transition of energy structures towards renewable energy sources have become necessary alternatives for humanity in order to stabilize the global climate system. This holds for both developed and developing countries.

Substituting fossil fuels with renewable energy sources is regarded as a significant measure for cutting global carbon emissions (Brown, 2003; Houghton, 1997; IPCC, 2001). Full use of these sources can help mitigate global warming in environmental terms, meet energy needs in economic terms, and provide employment for rural areas in socioeconomic terms (Thothathri, 1999; UNCSD, 2002; Yue et al., 2001). All these indicate their sustainability for global and local development. In addition to a legislative framework set at the national level for their promotion, locally based evaluations for developing renewable energy sources can provide a vital

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basis for evaluations at the national level, and thus enhance political effectiveness.

In this context, this study attempted to investigate the Chigu area of southwestern Taiwan as an example, and to establish a procedure for evaluating local renewable energy sources. With geographic information system (GIS)-based analyses, multifarious renewable energy sources were evaluated according to actual local land uses in order to provide more-integrated and accurate decision-making information for policy-makers and investors. The established model may help localities explore their exploitable resources, and this can possibly be expanded to conduct comprehensive surveys at the national level in order to estimate the entire potential of a country. These represent indispensable information for decision-making in order to build a sustainable energy system which enhances climate protection.

2. The study area and analysis of its renewable energy sources

The study area of Chigu is located in the southwestern coastal region of Taiwan, as depicted in Fig. 1. The region of Chigu covers an area of 12,560 ha, and contains a population of 25,769 currently. The absolute elevation in the entire area is no more than 10 m, while the average gradient is less than 5%. An ordinary agricultural area is located in the western part of the region (Fig. 2). This area has mostly been exploited as fish farms for many decades, among which many are falling into disuse. Overexploitation of groundwater for fish farming has since long led to land subsidence. The ‘‘special agricultural area’’ is cropland of good quality, and is used for food production. The main habitat where over half of the known population of the globally endangered migratory bird, the Black-faced Spoonbill

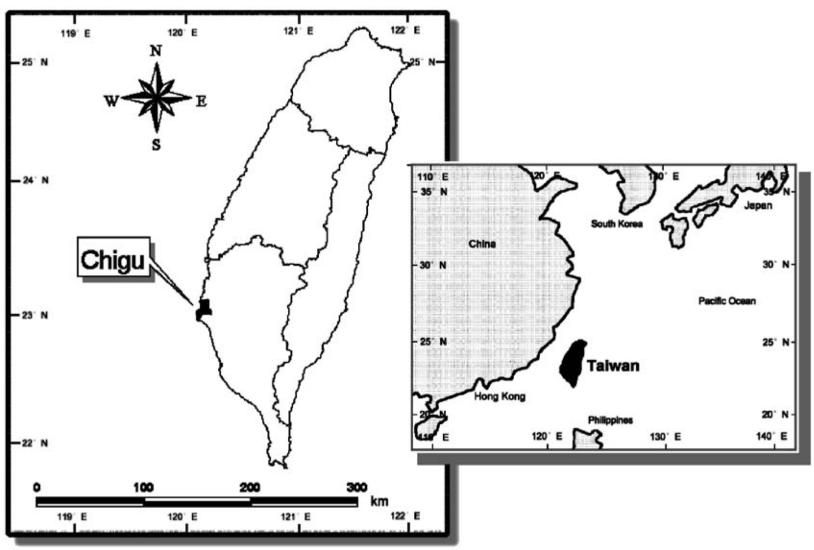

Fig. 1. Geographic location of the Chigu region in southwestern Taiwan.

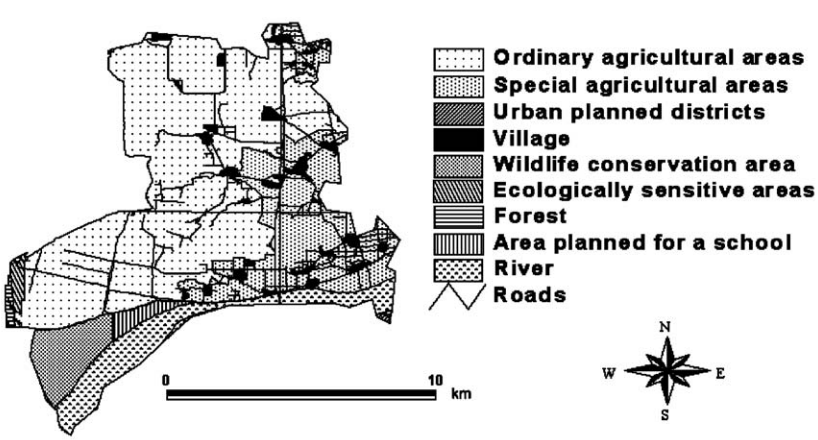

Fig. 2. Land use zoning at Chigu.

(*Platalea minor*), overwinters is located in the southwestern part of Chigu, and has been designated a "Wildlife conservation area". These birds migrate south from northeast Asia to Chigu in autumn every year, and migrate north from this region back to northeast Asia in spring the following year. The reasons for selecting this locality for the case study are as follows:

- There is relatively excellent wind potential due to its location along the coast;
- There is ample insolation in the southwestern region of Taiwan for the exploitation of solar energy;
- A low population density in this rural area provides good conditions for the development of wind energy and biomass;
- The local government intends to exploit renewable energy sources and requires information related to their evaluation; and
- Reconciliation between the development of renewable energy sources and protection of habitat of endangered species can be addressed by this case in order to explore possible solutions.

Among various renewable energy sources, wind energy presents a particularly promising value for application due to its technological ripeness and relatively low cost at present (Brown et al., 2002; IPCC, 2001). A recent study indicated excellent wind potential in the western coastal areas of Taiwan in spite of the lack of effective policies for promoting its development (ECROC, 1999b).

Biomass is regarded as an ideal complement to wind energy, because it not only can coexist with wind turbines in terms of land use, but it also complements wind energy in compensating for longer calm times. Photovoltaics also present a significant potential when considering ample insolation year round in southern Taiwan. One disadvantage is its current high costs, but it is expected that they will continue to drop in the future. In the context of these climatic and technological considerations, this study evaluates the wind, biomass, and photovoltaic energy based on local wealthy resources.

3. Methodology for evaluating energy potentials

The methodology used for evaluating the potentials of local renewable energy sources was as follows.

3.1. Wind energy

According to recommended guidelines for wind turbine installation (DWIA, 2003a; ECROC, 1999a; ITRI, 2001; Kaltschmitt and Wiese, 1994; Voivontas et al., 1998), the evaluation in this study was conducted by the following procedure.

(1) The potential was evaluated under the consideration of the following restrictions:
- A minimum allowable wind speed of 4 m/s;
- A minimum distance from urban planned districts of 500 m;
- A minimum distance from villages of 250 m;
- A minimum distance from wildlife conservation areas of 500 m;[1]
- A minimum distance from forests of 250 m; and
- A minimum distance from ecologically sensitive areas of 250 m.

(2) The following areas were not considered for the installation of wind turbines:
- Floodplains and
- Roads

(3) The distance between wind turbines was set as three times the rotor diameter, calculated using the Vestas V80 wind turbine with a diameter of 80 m and a rated capacity of 2 MW.

(4) Annual output was calculated with mean wind speed and roughness class 1.5 by means of the "Wind Turbine Power Calculator" from the Danish Wind Industry Association (DWIA, 2003a).

3.2. Photovoltaics

The installation area was set to be 25% of the rooftop area of buildings to calculate the energy output.

(1) (Building lot size) = [(Urban planned districts) + (Area of villages) − (Road area in urban planned districts) − (Road area in villages)] × 70%.[2]
(2) (Floor area) = (Building lot size) × (60% of the building coverage ratio).[3]
(3) The area of installed PV panels was set as (Floor area) × 25%.
(4) The installation capacity was set as 0.133 kW/m^2.
(5) The annual output was set at 1540 kWh/kW to calculate the total annual output.

3.3. Biomass

The potential was evaluated by estimating that half of the designated "ordinary agricultural areas" would be

[1]In treating the probable disturbance of wind turbines on the habitat of birds, a setback of 200 m from bird habitats is generally recommended. In the case of a conservation area for birds particularly worthy of protection, a distance of 500 m would be maintained. Since the endangered Black-faced Spoonbill is categorized as a bird particularly worthy of protection, a setback from the conservation area of 500 m is adopted here in order to retain a sufficiently wide buffer zone between the wind turbines and the conservation area.

[2]Building lot size generally accounts for approximately 70% of settlement areas exclusive of road areas in non-urban areas in Taiwan.

[3]The building coverage ratio of building lots in non-urban sites on average is not allowed to exceed 60% in Taiwan.

planted in sugar cane for energy crop cultivation, ethanol would be extracted from the sugar cane, and electricity would be generated from the bagasse (Boyle, 1996). Planting sugar cane in parts of the ordinary agricultural areas which are currently used as fish farms is intended to search for ways to deal with the many disused fish farms on ordinary agricultural areas on the one hand, and of mitigating land subsidence due to overexploitation of groundwater by aquaculture on the other. Although the fallow area in the "special agricultural area" at Chigu currently encompasses 1100 ha and comprises 40% of the total designated "special agricultural area" of 2718 ha, this area is not slated to grow energy crops in this study under the consideration of reserving good-quality farmland for food production as a priority.

(1) The following areas will not be considered for use as land area available for planting energy crops as "ordinary agricultural areas":
- wildlife conservation areas;
- ecologically sensitive areas;
- a buffer zone from the coastline of 1.5 km considering the salinity of the soil;
- the area planned for a school; and
- roads outside of villages and urban planned districts.

(2) The area for planting energy crops should be (Land area available for planting energy crop) × 50% in order to reserve the scope for agricultural extension, the planting of chemical and technical raw materials, and fish farms.

(3) The annual energy output was calculated according to the ethanol yield from the sugar cane planted per hectare and year, and to the energy output extracted per cubic meter of ethanol. Electricity generation was calculated based on sugar cane yields in tons per hectare per year, and on the electricity generated per ton of cane.

4. Results of the potential evaluation

4.1. Wind energy

The excluded and available areas for installing wind turbines in Chigu are depicted in Fig. 3. Based on the data of the annual mean wind speed (Fig. 4), the annual energy output was calculated and is indicated in Table 1. Totally, about 1178 wind turbines of 2 MW of unit capacity would be allowed to be installed. The total

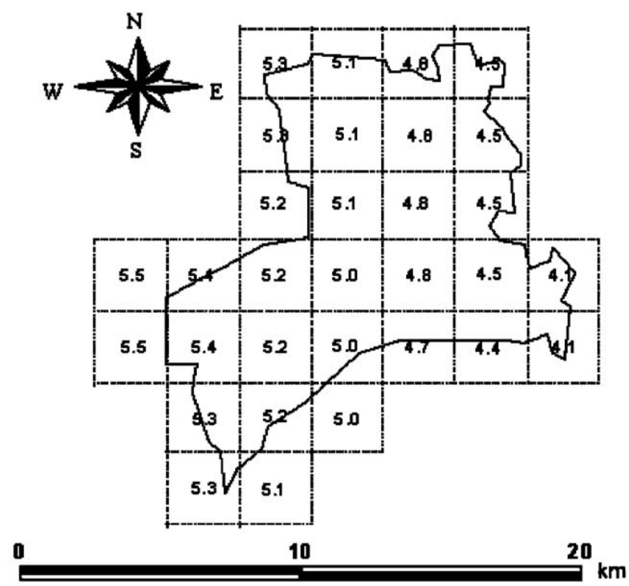

Fig. 4. Distribution of mean annual wind speed in Chigu in m/s (*Source: ITRI, 2001*).

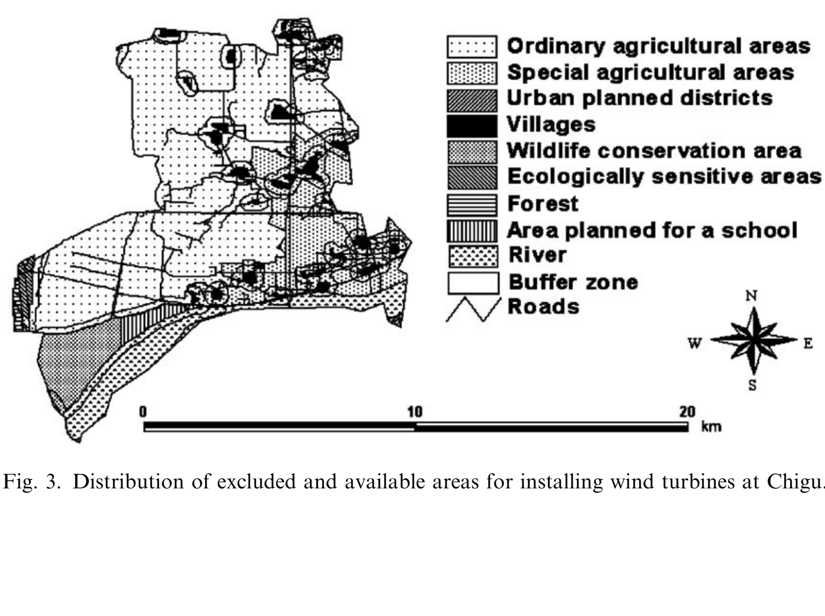

Fig. 3. Distribution of excluded and available areas for installing wind turbines at Chigu.

installation capacity amounts to 2356 MW. These turbines would be capable of generating approximately 3255 GWh annually.

4.2. Photovoltaics

The potential of photovoltaics in Chigu was calculated by installing PV panels on 25% of the roof area of buildings in villages and urban planned districts. The distribution of human settlements is depicted in Fig. 5. Energy output was calculated as follows:

(1) (Building lot size) = [(Urban planned districts) + (Area of villages) − (Road areas in urban planned districts) − (Road area in villages)] × 70% = (375.44 + 10.95–13.22) × 70% = 261.22 ha.
(2) (Floor area) = (Building lot size) × (60% of the building coverage ratio) = 261.22 × 60% = 156.73 ha.
(3) The area of installed PV panels was set as (Floor area) × 25% = 156.73 × 25% = 39.18 ha.
(4) The current installation capacity is about 0.133 kW/m^2. The installation capacity in Chigu thus amounts to 52 MW.
(5) The annual output achieves about 1540 kWh/kW. The total energy output of PV in Chigu was thus calculated to be 80.2 GWh.

Table 1
Technical potential of wind energy at Chigu

Mean wind speed annually (m/s)	Annual energy output per wind turbine (MWh)	Sum of wind turbines allowed to be installed	Total energy output annually (MWh)
4.1	1586	32	50,760
4.4	2027	9	18,242
4.5	2159	212	457,723
4.7	2423	16	38,775
4.8	2600	332	863,101
5.0	2908	131	380,966
5.1	3040	150	456,049
5.2	3217	152	488,920
5.3	3393	77	261,248
5.4	3569	67	239,128
Total		1178	3,254,913

4.3. Biomass

The potential of biomass was evaluated by planting sugar cane on land for energy crop cultivation, extracting ethanol from the cane after fermentation, and generating electricity from the bagasse. The area for planting is depicted in Fig. 6. The potential was calculated as follows.

(1) (Land area available for planting energy crop) = (-Designated ordinary agricultural areas) − (Wildlife conservation area) − (Ecologically sensitive areas) − (1.5-km buffer zone from the coastline) − (Area planned for a school) − (Area of roads outside villages and urban planned districts) = 4767.9 ha.
(2) The area for planting energy crops was set as (Land area available for planting energy crops) × 50% = 2384 ha.
(3) Planting of sugar cane could yield approximately 6200 L/year/ha of ethanol. One cubic meter of ethanol would yield 24 GJ of heat energy. Thus, the annual yield of heat energy at Chigu was calculated to be 355 TJ (= 38.1 GWh).
(4) Planting of sugar cane would yield 35 tons/year/ha of cane. Burning bagasse from 1 ton of cane would generate 260 kWh of electricity.
(5) The annual yield of electricity in Chigu was calculated to be 21.7 GWh.

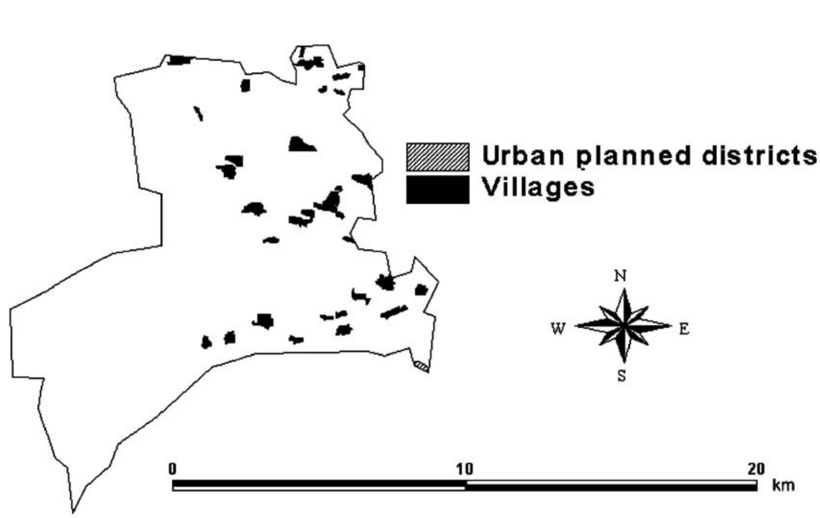

Fig. 5. Distribution of the urban planned districts and villages at Chigu for installing PV panels.

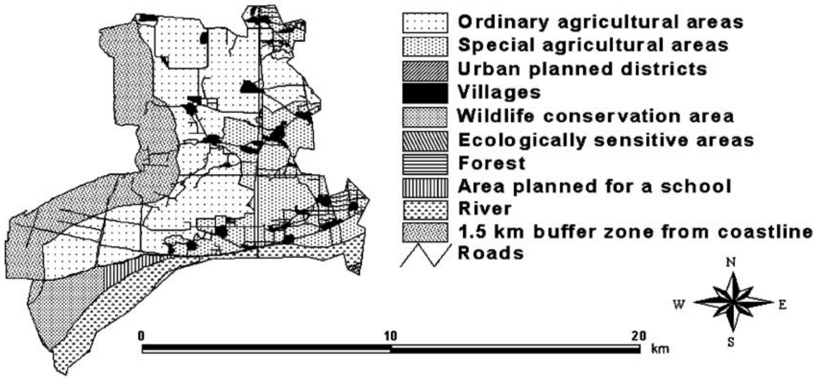

Fig. 6. Distribution of excluded and available areas for energy crop planting at Chigu.

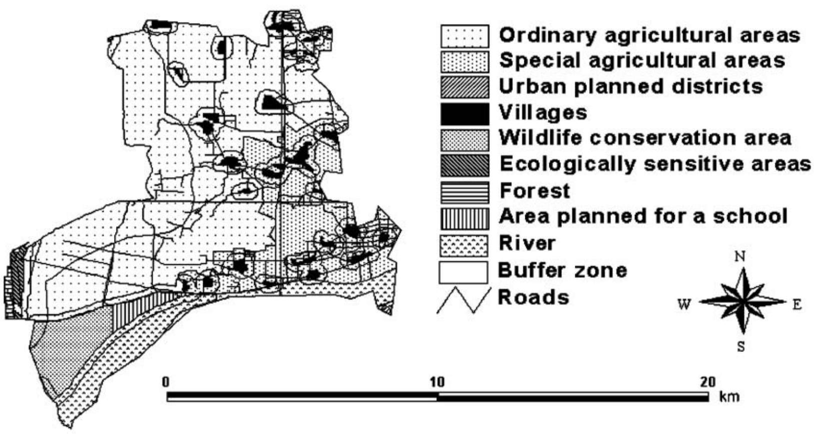

Fig. 7. Distribution of excluded and available areas for installing wind turbines and planting energy crops at Chigu under scenario R.

5. Scenario analysis

Scenario analysis was adopted in this study in order to assess energy-economic and environmental implications for different extents of exploiting renewable energy sources in the study area. Two developmental scenarios were conducted as follows.

5.1. Scenario R (Renewable energy prioritized)

This scenario is devoted to exploiting renewable energy sources in the study area according to the potential evaluation. Distribution of excluded and available areas for installing wind turbines and planting energy crops are depicted in Fig. 7.

5.2. Scenario W (Wildlife prioritized)

This scenario was set up to avoid disturbing the endangered Black-faced Spoonbill to a greater extent. Black-faced Spoonbills occasionally feed north of the wildlife conservation area besides their main habitat. In addition to the setback measures adopted in scenario R, the exploitation of wind energy and biomass would not be considered in the northern fish farm area covering an area of 1230 ha in scenario W in order to further avoid disturbing the migration of the Black-faced Spoonbills, and to protect this area which they use for feeding. The location of the northern fish farm area is depicted in Fig. 8.

5.3. Comparison of energy benefits

The installation capacity of wind energy at Chigu amounts to 2356 MW in scenario R which would generate 3255 GWh annually. For scenario W, the installation capacity of wind turbines was calculated to be 2008 MW. The annual output would be 2672 GWh, as shown in Table 2. Regarding the energy output from biomass, the area for planting energy crops was calculated to be 2384 ha under scenario R and 1941 ha under scenario W. Thus the annual yield of heat energy was calculated to be 355 TJ (= 38 GWh) for scenario R, and 289 TJ (= 31 GWh) for scenario W. The annual yield of electricity was calculated to be 22 GWh for scenario R and 18 GWh for scenario W. The potential contribution of Chigu's renewable energy to the national energy supply is summarized in Table 3.

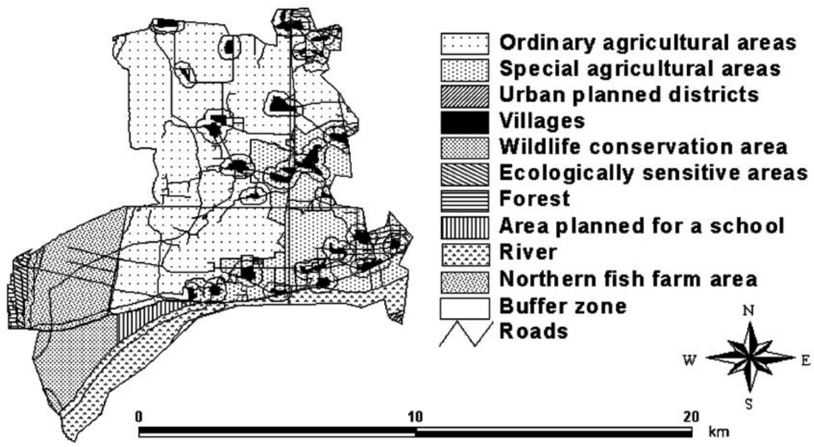

Fig. 8. Distribution of excluded and available areas for installing wind turbines and planting energy crops in Chigu under scenario W.

Table 2
Technical potential of wind energy in Chigu under scenario W

Mean wind speed annually (m/s)	Annual energy output per wind turbine (MWh)	Sum of wind turbines allowed to be installed	Total energy output annually (MWh)
4.1	1586	32	50,760
4.4	2027	9	18,242
4.5	2159	212	457,723
4.7	2423	16	38,775
4.8	2600	332	863,101
5.0	2908	131	380,966
5.1	3040	150	456,049
5.2	3217	45	144,746
5.3	3393	77	261,248
Total		1004	2671,611

6. Economics

6.1. Energy benefits

An analysis of the technical potential for renewable energy sources in Chigu indicated that wind energy, photovoltaics, and biomass would jointly generate 3357 GWh of electricity annually under scenario R, covering 1.9% of the 2001 electricity consumption of 175,909 GWh. As to scenario W, total electricity yield would be 2770 GWh annually, accounting for 1.6% of 2001's electricity consumption. With regard to the yield of heat energy, ethanol production from sugar cane planting would generate about 38 and 31 GWh of energy in scenarios R and W, respectively, both of which would account for about 0.1% of the transport-related oil demand of 57,927 GWh for 2001 in Taiwan. Calculated with the method of substitution, about 8777 and 7242 GWh of primary energy supply could be substituted in scenarios R and W, respectively. This equals 2% and 1.7% of the primary energy supply of 438,490 GWh for 2001.

6.2. Capital costs

As noted above, the installation capacities from wind energy in scenarios R and W are 2356 and 2008 MW, respectively. Based on the current capital cost of wind turbines in Taiwan at US$1060/kW (ECROC, 2000), the capital costs of the wind energy for scenarios R and W are US$2.5 and 2.1 billion, respectively.

Based on the capital cost of US$6364/kW for photovoltaics, the installation of 52 MW necessitates US$331 million. With regard to ethanol production from biomass, the capital costs are approximately US$0.303/L. The planting of sugar cane on 2384 ha of land would cost US$4.5 million for scenario R, and on 1941 ha of land with US$3.6 million for scenario W.

6.3. Investment incentives

The incentives for investment in exploiting renewable energy sources in Taiwan are analyzed in Table 4. The state-run utility, Taiwan Power Company (Taipower), remunerates electricity from hydropower and wind energy at US$0.062/kWh by a contracted price. The remunerations recommended in this study are US$0.062/kWh for wind power, US$0.185/kWh for power from photovoltaics, and US$0.60/LOE (liter oil equivalent) for ethanol from biomass.

The costs of wind power and ethanol are lower than the remuneration, thus we do not suggest that a subsidy for investment costs of wind power and ethanol production be instituted with the aim of spending limited public funds on subsidizing other uncompetitive renewable energy sources like photovoltaics. Subsidies for power from photovoltaic are suggested to be set at 50% of total investment costs in order to help the

Table 3
Potential contribution of Chigu's renewable energy to the national energy supply for the reference year 2001

Energy technology	Scenario	Electricity (GWh)	Heat (GWh)	Primary energy[a] (GWh)	CO_2 reduction[b] ($\times 10^3$ ton)
Wind	R	3255		8463	1888
	W	2672		6947	1550
PV		80		208	46
Biomass	R	22	38	106	25
	W	18	31	86	20
Total	R	3357	38	8777	1959
	W	2770	31	7242	1616
Share in 2001 (%)	R	1.9	0.1[c]	2.0	0.9[d]
	W	1.6	0.1[c]	1.7	0.7[d]

[a]By the method of substitution.
[b]CO_2-reducing factor: 0.58 kg CO_2/kWh of electricity; 0.315 kg CO_2/kWh of heat.
[c]The share of heat energy from ethanol of the heat energy from gasoline consumed for transport.
[d]The reference year is 2000.

Table 4
Investment incentives for exploiting renewable energy sources

Source	Costs in US$	Suggested remuneration in US$	Suggested subsidy of the total investment costs (%)	Amortization period (years)	Period over which the investment is to be recovered (years)
Wind	0.051/kWh	0.062/kWh	0	13	20
PV	0.329/kWh	0.185/kWh	50	19.7	25
Biomass[a]	0.529/LOE[b]	0.60/LOE[b]	0	9	15

[a]Includes only ethanol production from sugar cane planting; electricity generation from bagasse is not included.
[b]LOE: liter oil equivalent; 1 LOE = 3.7674×10^7 J.

uncompetitive photovoltaics penetrate the market in the initial stage. Under these premises, wind turbines could be amortized for 13 years, photovoltaics for 19.7 years, and ethanol from biomass for 9 years. Compared to the longer periods over which these investment are to be recovered of 20, 25 and 15 years, respectively, it is hoped that the shorter periods of amortization will provide incentives for investment.

6.4. Comparison of energy costs

Without considering the social and environmental costs, wind power generation cost approximately US$0.051/kWh by 1999 in Taiwan. This cost is higher than that of fossil fuel oil at US$0.048/kWh, coal at US$0.03/kWh, nuclear energy at US$0.026/kWh, and is lower than that of natural gas at US$0.068/kWh, and photovoltaics at US$0.329/kWh. The costs of ethanol from sugar cane planting at US$0.529/LOE are lower than the market price of gasoline at US$0.648/LOE. Full use of bagasse residues for electricity generation could further offset the costs, making this energy crop even more cost-competitive.

Conventional economic analysis cannot handle costs of pollution and of the depletion of common property resources because common property cannot be privatized and thus is outside of the market place (Hill et al., 1995; Tietenberg, 2000; Wenz, 2001). Comparison of energy costs without considering the externality of energy use is thus misleading. This distortions of cost calculations resulting from externalities can explain why the costs of electricity from nuclear energy at US$0.10–0.12/kWh in the US are much higher than that at US$0.026/kWh in Taiwan (Owen et al., 1998), although Taiwan's nuclear power plant was imported from the US.

Based on the current energy prices not including the external costs of electricity generation, the costs of wind power approximate those of oil, but are lower than those of natural gas. Due to the relatively lower costs of wind power, its exploitation should be prioritized among renewable energy sources.

Although the costs of ethanol production from biomass are currently already lower than those of gasoline on the market in Taiwan, the obstacles of substituting gasoline with this clean fuel still have to be removed through market establishment for ethanol as vehicle fuels with institutional promotion. The costs of photovoltaics are still high, making it necessary to rely on governmental subsidies for its use. As the costs of this energy source are expected to drop in the near future, if the external costs of energy utilization can be internalized, then the subsidies would become unnecessary.

6.5. Finance of subsidies

Governmental interference in markets with subsidies could be used to correct a distorted marketplace with externalities (Brown, 2001; Goulder, 2000b). The subsidies to utilities are to balance the lower energy price compared to the remuneration price, and those for investment costs are to be covered in the short term in Taiwan by the following sources:

- Annual funding of US$91 million arranged from the budget and dictated by the draft of "The Special Action Plan for a Non-Nuclear Country" passed in September 2003 for promoting energy savings and renewable energy sources; and
- Revenue from the fees for preventing air pollution levied on gas consumption since 1995.

The long-term funding is suggested to be combined with distortion-correcting taxes by means of the following measures:

- Expansion of "The Fees for Preventing and Remedying Air Pollution", levied since 1995 for SO_x and NO_x pollutants, to contain carbon as a pollutant in proportion to carbon contents of various energy sources; or
- Taxation of carbon in proportion to the carbon content of various energy sources.

In implementing either of these measures, partial revenue could be used to finance cuts in income taxes for low-income people in order to relax the burden on the poor while internalizing the environmental and social costs of using carbon-containing energy sources (Barrow, 1999; Goulder, 2000a; Smith, 2000).

7. Environmental benefits and impacts

7.1. Environmental benefits

7.1.1. CO_2 reduction

The substitution of fossil fuels by wind energy, photovoltaics, and biomass would reduce pollution resulting from local SO_x and NO_x emissions on the one hand, and help mitigate global warming by CO_2 reduction on the other. About 0.63 kg of CO_2 was produced per generated kilowatt-hour in 1998 in Taiwan (Young, 1999). Calculated with a CO_2-reducing factor of 0.58 kg CO_2/kWh for electricity and of 0.315 kg CO_2/kWh for heat (BMU, 1999), about 2 million tons of CO_2 emissions could be avoided annually for scenario R, and 1.6 million tons for scenario W, as calculated in Table 3. In order to respond to implementation of the United Nations Framework Convention on Climate Change, Taiwan's EPA aims to set a target of maintaining Taiwan's CO_2 emissions in the year 2020 at the level of that in the year 2000 with 223 million tons from the predicted 501 million tons as the reference emissions amount according to a resolution of the National Energy Conference held in 1998 (Yue et al., 2003). The annual CO_2 reduction of 2 million tons based on scenario R would amount to 0.9% of the planned emissions by 2020, while that of 1.6 million tons based on scenario W would amount to 0.7%.

7.1.2. Protecting agricultural land

Agricultural area is increasingly subjected to pressure of being converted into nonagricultural land due to the drop of the agricultural output value in Taiwan after accession to the WTO. Using ordinary agricultural areas to plant energy crops could protect agricultural land from being converted to land for construction and urban facilities, and help supplement underground water.

7.2. Environmental impacts

The criterion for evaluating the potential of renewable energy sources in this study excludes improper areas and sets buffer zones between potentially exploitable areas and sensitive areas in order to consider the environmental impacts in the phase of planning. Taiwan's EPA in 2001 added wind energy proposals to the list of public and private projects that may require assessment for their potential impacts on the environment, while the proposals for exploiting photovoltaics and biomass are not subject to such requirements. The environmental impacts of exploiting related renewable energy sources are discussed in the following sections.

7.2.1. Wind energy

According to the pronouncement of Taiwan's EPA, the proposals for wind energy require an environmental impact assessment if the projects are (EPAROC, 2001):

- sited in a national park;
- sited in a wildlife conservation area;
- newly established or expanded facilities on urban land with a generation capacity or cumulative generation capacity of more than 25,000 kW; or
- newly established or expanded facilities on non-urban land with a generation capacity or cumulative generation capacity of more than 50,000 kW.

There is no national park located in Chigu. Whether it is necessary for wind energy proposals to implement an environmental impact assessment depends on the scale of the project. The potential impacts of exploiting wind energy in allowable areas are discussed in the following section.

(1) *Impact on flora and fauna.* Under scenario R, the designated wildlife conservation area is excluded

from the exploitable area, and is further set back 500 m from its boundaries. These considerations aim to avoid disturbing the activities of the Black-faced Spoonbill and other birds in the wildlife conservation area. Scenario W further excludes the northern fish farms in order to avoid disturbing the migration of the Black-faced Spoonbills between the study area and northeast Asia. The designation of a 250-m buffer zone from ecologically sensitive areas is intended to avoid affecting the flora and fauna in those areas.

(2) *Sound*. The allowable areas for exploitation maintain a minimum distance of 500 m from urban planned districts, and 250 m from villages. The source sound level of the selected wind turbine of Vestas V80 approximates 101 dBA under a wind speed of 8 m/s. Calculating sound level by distance from source indicates that the noise level 224 m away would be approximately 42 dBA, and at 282 m away would be 40 dBA (DWIA, 2003b). This meets the standard for inviting bids for the installation of a demonstration system of wind power in Taiwan at 45 dBA 300 m away.

7.2.2. Photovoltaics

(1) *PV module recycling*. The basic material from which 99% of cells are made, silicon, is not harmful. In the case of PV modules containing small quantities of toxic metals, safe recycling will have to be developed so that the substances in the PV modules are not released into the environment. The corporation between the Taiwanese authority, such as the EPA or the Ministry of Economic Affairs, and the PV manufacturer is recommended to develop such a recycling program.

(2) *Visual amenities*. Whether rooftop arrays are visually pleasing or not depends on individual aesthetic tastes. PV modules in the form of special roof tiles could blend into roof structures more unobtrusively, and even make rooftops more attractive.

7.2.3. Biomass

(1) *Farming intensity*. This consideration concerns the potential increase in intensive farming with high inputs of fertilizers and pesticides. For providing long-term nutrients on the fields used to grow energy crops, biomass power plants or processing facilities are recommended to be located near the land where the biomass is grown (Scheer, 2002). This would return nutrients taken from the fields by means of spreading the residues from biomass processing back on the fields used to grow it, so that nutrients they contain are not lost.
Another recommended measure would be the use of sewage sludge. Sewage sludge would provide a slow-release fertilizer for the fields. The water content of sewage sludge would reduce the demand for irrigation. This would simultaneously reduce the demand for chemical fertilizer and water.

(2) *Possible reduction of biological diversity*. The planting of energy crops would be restricted to within agricultural land. The wildlife conservation area, ecologically sensitive areas, and buffer zones along the coastline are excluded from planting. These would minimize the impact on biological diversity. This study takes sugar cane as an example to evaluate the potential of biomass. This does not mean that other energy crops ought to be excluded in future planning. It is recommended that different energy crops be grown in order to provide better habitat conditions for biodiversity, and to avoid outbreaks of disease.

8. Political implications

The experiences of developing renewable energy sources in countries indicate that the essential factor of development does not so much lie in the form of remuneration regulation, i.e., the price or quantity regulation, but rather in the level of the remuneration price (BMU, 1999). The Netherlands, Denmark, and Germany provide higher remuneration and are accordingly successful in the implementation, while the remuneration in Sweden, Austria, and the UK is low, and low implementation rates have been demonstrated. Combination of a quota system with the advantage of minimum price regulation, similar to the Non-Fossil Fuel Obligation adopted in the UK, would be promising since the technical and economic status of various technologies for deploying renewable energy sources could be matched.

Whether the policies provide a framework to arrange sufficient incentives for private investors has been shown to be the key for developing domestic renewable energy sources. The most significant measures include the following.

8.1. Legislatively stipulated grid connection and premium prices

The use of legislatively stipulated premium prices paid per generated energy has been shown to be the most effective tool for stimulating markets of renewable energy sources in India, Denmark, Spain, and Germany (ECDGE, 1998; Hinsch, 1999). Utility companies that operate grids for public power are obliged to connect installations for the generation of electricity from renewable energy sources to their grids, to purchase electricity available from these installations as a priority, and to compensate the suppliers of this electricity in accordance with these provisions. These obligations can be seen in the drafted "Regulation of Developing Renewable Energy Sources" in Taiwan that is still in the legislative process (ECROC, 2002). The remunerations with a contract price is currently being appraised by governmental agencies on a project base according to the "Operational principles of the Economic Ministry for appraising and selecting the target of receiving and purchasing electricity generated from renewable energy sources". On this basis, the state-run electricity utility, Taipower, would remunerate electricity generated from renewable energy sources with contract prices. The passage of the regulation is urgently needed in order to provide greater assurances of incentives for investment in renewable energy sources in place of the current system through an appraisal and selection process.

8.2. Capital grants

This measure has been widely used to stimulate private investment in developmental fields promoted by policy, particularly in the initial stage of development. The government in Taiwan currently offers no more than 50% of the total investment costs for projects of wind energy and photovoltaics that are selected by a governmental agency through an appraisal and selection process. The funding of US$91 million yearly has been announced in the draft of "The Special Action Plan for a Non-Nuclear Country" for promoting energy savings and renewable energy sources. This source, along with "The Fees for Preventing and Remedying Air Pollution" levied since 1995, could be used to finance part of the installation costs for exploiting renewable energy sources.

8.3. Financial incentives

Since many renewable energy sources, such as wind and biomass, are mostly generated in extensive rural areas, farmland is the location which provides the most land available for developing these energy sources. Considering that the capital costs of wind turbines are prohibitively high for farmers, low-interest loans would be significant incentives for private investors. A number of countries provide lower interest loan of 1–2% lower than that on the market for wind power, and zero interest loans for photovoltaics for the first 10 years. In addition, only a third of the turnover tax must be paid for products and services of renewable energy resources. All these could increase incentives for investment in renewable energy sources.

8.4. Incentives for the integration of PV and buildings

The prevailing custom of having level roofs on buildings in Taiwan fosters the problem of providing the possibility of building illegal stories onto the structure which in turn damages building safety. The Construction and Planning Agency (CPA) in Taiwan has the intention of stipulating that all new buildings adopt a form of sloping roof in order to prevent such a problem. It is recommended that the CPA propose a program to promote integration of sloping roofs, facades, and photovoltaics for new buildings with economic incentives such as grants calculated on the basis of the installed PV panel area. This would remove the possibility for building illegal stories, increase the roof surface available for installation of PV arrays, and beautify rooftops of buildings.

8.5. Reconciliation of long-term agricultural, energy, and environmental imperatives

Trade liberalization of agricultural products driven by accession to the WTO has led to a drop in agricultural output value in Taiwan. Areas of fallow land and land converted to nonagricultural ends are estimated to have reached 80,000 ha or about 2.2% of the entire country's area. In response to this development, agricultural policy in Taiwan is set to release agricultural land. In addition to retaining agricultural land in an appropriate quantity for agricultural development, portions of agricultural land are to be converted to nonagricultural use in order to meet the needs of economic development, and to facilitate rational use of land resources. Agricultural land with lower productivity is to be reforested. Agricultural land lacking productivity is to be changed to nonagricultural uses (COAROC, 2003).

Since it has not been clearly determined how much the "appropriate quantity for agricultural development" really refers to, two points are worthy of attention. First, the necessary quantity of agricultural land for food production needs to be defined so that it can be protected in order to ensure self-sufficiency of the food supply in situations of price rises on the international food market, and of supply shortages due to international political, economic, or ecological instability. Many countries regard the significance of being self-sufficient in food to the furthest extent possible as a national security issue (Beatley, 2000). Second, the released agricultural land should be used for planting energy crops, and chemical and technical raw materials rather than for construction and other urban facilities due to a number of ecological considerations, such as avoidance of carbon release into the atmosphere and supplementation of underground water.

9. Conclusions

This survey of renewable energy sources in the Chigu area has reached the following conclusions.

- The installation capacity of *wind* energy amounts to 2356 MW with a generation capacity of 3255 GWh annually in scenario R. For scenario W, installation capacity is calculated to be 2008 MW with a generation capacity of 2672 GWh. These demonstrate a far greater potential for the development than photovoltaics and biomass. This can to a great extent be attributed to the advantageous geographical conditions of a windy coastal area and of a low-density population distribution.
- The installation capacity of *photovoltaics* of 52 MW with an annual energy output of 80 GWh is restricted to the application on rooftops rather than for extensive land areas under the consideration of reserving the limited land resources in Taiwan. Its potential is none the less greater than that of biomass. The introduction of this technology should, however, be promoted since its application can be expanded to building facades and other facilities on the one hand, and its electricity generation (supply side) is close to consumers (demand side) which enhances the value of the generated electricity on the other.
- *Biomass* energy could be used to generate ethanol with energy values of 38 and 31 GWh for scenarios R and W, respectively, which could serve as fuels for motorized vehicles. In addition, about 22 and 18 GWh of electricity could be generated from fully using the bagasse in scenarios R and W, respectively. Despite the relatively lower potential, the production of this energy source is not subject to climate-induced fluctuations that would be imposed on energy from wind and photovoltaics. This makes biomass energy an ideal complement for energy produced from wind and photovoltaics.

The approaches adopted in this study have the following implications for exploiting local renewable energy sources:

- The GIS-based approach of evaluating local potential of renewable energy sources adopted in this study takes into account actual local conditions and restrictions such as climate conditions, land uses, and ecological environments which produces a more-accurate assessment than evaluations on an approximate basis.
- The process of evaluating local renewable energy sources adopted in this study using technical, economic, environmental, and political analyses can serve as an example to investigate local and domestic renewable energy sources with vertical integration. The results of such surveys can help formulate local and national long-term energy and environmental policies.
- The simultaneous evaluation of multifarious sources in this study could help combine various renewable energy sources with horizontal integration in order to provide complementary and more-sufficient power supplies, and consequently enhance their capability for supplying electricity.
- The scenario analyses adopted in this study could be used to assess energy-economic and environmental implications of exploiting renewable energy sources under different considerations in the study area, whether prioritizing renewable energy or wildlife. This information is valuable for both governmental decision-making and political debate at the local level.
- Based on the methodologies adopted in this study, other renewable energy sources and criteria of exploitation could be evaluated according to actual conditions at the local level.

With the aid of GIS, an evaluation of multifarious renewable energy sources according to local real land uses is able to provide more-integrated and accurate decision-making information for policy-makers and investors. This approach can further be expanded to conduct a comprehensive survey at the national level in order to grasp the entire potential of a country. These implications may help build a developmental vision for sustainable energy systems based on locally available natural resources, and facilitate a transition of national energy and environmental development towards sustainability.

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