RENEWABLE ENERGY DEVELOPMENTS AND POTENTIAL IN THE GREATER MEKONG SUBREGION

ADB

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Contents

Foreword

In 2010, the Asian Development Bank (ADB) initiated the regional technical assistance project Promoting Renewable Energy, Clean Fuels, and Energy Efficiency in the Greater Mekong Subregion (GMS), to assist the countries in the GMS—Cambodia, the Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand, and Viet Nam (the GMS countries)—in improving their energy supply and security in an environmentally friendly and collaborative manner. The Yunnan Province and Guangxi Zhuang Autonomous Region of the People's Republic of China, which are also part of GMS, are not included in this study due to difficulties of segregation of national level data. The project was cofinanced by the Asian Clean Energy Fund and the Multi-Donor Clean Energy Fund under the Clean Energy Financing Partnership Facility of ADB.

The study prepared three reports: (i) Renewable Energy Developments and Potential in the Greater Mekong Subregion, (ii) Energy Efficiency Developments and Potential Energy Savings in the Greater Mekong Subregion, and (iii) Business Models to Realize the Potential of Renewable Energy and Energy Efficiency in the Greater Mekong Subregion.

The first report provides estimates of the theoretical and technical potential of selected renewable energy sources (solar, wind, bioenergy) in each of the countries, together with outlines of the policy and regulatory measures that have been introduced by the respective governments to develop this potential. The second report addresses the potential savings for each of the countries from improved energy efficiency and conservation measures. The third report outlines business models that the countries could use to realize their renewable energy and energy efficiency potential, including the deployment of new technologies.

The renewable energy report concludes that, apart from Thailand, the GMS countries are at an early stage in developing their renewable energy resources. To further encourage renewable energy development, the GMS countries should provide support for public and private projects investing in renewable energy. Solar energy is one which is being actively promoted in the region. While the cost of solar power is still high relative to conventional sources, it is a cost competitive alternative in areas that lack access to grid systems. Large-scale solar systems are being developed in Thailand whilst home- and community-based solar systems are increasingly becoming widespread in the GMS. Large-scale development of wind power depends on suitable wind conditions and an extensive and reliable grid system as backup; Viet Nam has the required combination and is gradually developing the potential. Biofuel production raises questions concerning the agriculture–energy nexus, but Cambodia, the Lao PDR, and other GMS countries are striving to reduce their dependence on imported oil and gas by promoting suitable biofuel crops. Biogas production from animal manure has been hampered by the difficulty of feedstock collection and the frequent failure of biodigesters. The gradual move to larger-scale farming techniques and new biodigester technologies has led to expanded biogas programs—especially for off-grid farm communities. The GMS countries have learned that maintenance and technology support is of vital importance in sustaining investments in renewable energy.

The energy efficiency report presents the steps each of the five countries has taken in this regard, noting that much greater gains in energy savings are possible while their efficiency measures are progressive. Most of the GMS countries envisage energy efficiency savings of at least 10% over the next 15–20 years except Thailand which is targeting 20%. Thailand and, to a lesser extent, Viet Nam have advanced policy, institutional, and regulatory frameworks for pursuing their energy efficiency savings targets, while Cambodia, the Lao PDR, and Myanmar are less well structured to reach their goals.

The renewable energy and energy efficiency reports chart a way for the GMS countries to become less dependent on imported fuels and more advanced in developing "green" economies. Global climate change concerns dictate greater attention to renewable energy and energy efficiency. National interests are served by both, offering a win–win outcome from investment in renewable energy and energy efficiency measures. The report on business models indicates ways in which these investments can be made through public–private partnerships, providing a basis for further dialogue among stakeholders.

In collaboration with the governments of Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam, ADB has published these reports with the objective of helping to accelerate the development of renewable energy and energy efficiency in the Greater Mekong Subregion.

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Executive Summary

Renewable energy is a challenge and an opportunity. In response to the climate change threat, the world community has to meet the challenge of sharply reducing dependence on carbon-based energy sources (notably oil and coal). While this is a daunting challenge, it also presents great opportunities; new industries and employment opportunities, new ways to reduce dependency on fuel imports and for providing electricity to poor remote areas, and new ways to reduce air pollution (including indoor) and provide healthier environments.

In recognition of both the challenge and the opportunities, five countries in the Greater Mekong Subregion (Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam) coordinated with the Asian Development Bank (ADB) in undertaking a study of their respective progress in promoting and facilitating the development of renewable energy. The study, which began in 2010, focused on solar, wind, biomass, and biogas forms of renewable energy, rather than the huge hydropower resources in the region.

Data on renewable energy developments in the region were drawn from various sources, including previous studies with somewhat dissimilar methodologies and technical assessments. But the same basic steps were followed in assessing the potential of solar, wind, biomass, and biogas energy. The technical potential of solar energy is based largely on the degree and intensity of solar irradiation, the estimated land area suitable for photovoltaic (PV) installations, and the efficiency of the solar systems. The economic potential of solar power is what can be developed commercially, given the cost of solar power relative to that of the least cost power available from the grid.

To calculate the technical potential of wind power, areas with sufficient average wind speeds (at least 6 meters per second [m/s]) were first determined. On the basis of current technology, the installed capacity of wind turbines is about 10 megawatts per square kilometer (MW/km^2). The economic potential was found to be much lower than the technical potential because of the high cost of wind power relative to energy alternatives, and the limited capacity or stability of the grid systems (the variability of wind power makes it necessary to have backup power).

The potential of biomass energy depends on the amount of agricultural land that can be devoted to feedstocks suitable for the production of biofuels (biodiesel and ethanol), and on the oil equivalent yield of the feedstocks. The potential varies widely: some GMS countries have agricultural land to spare without compromising food sources, while for others the food–energy–water nexus is more problematic. Crop yields also vary widely among the GMS countries. Cost is another issue, as it has been difficult to produce biofuels on a commercial basis without government subsidies in some form. Biogas production from animal manure could be considerable, since most farm households have sufficient numbers of farm animals to fuel biodigesters. Improved biodigester technology and lessons learned concerning the importance of maintenance support have led to expanded biogas programs.

Following are summaries of the analyses of the five countries, highlighting their renewable energy potential, targets, and development support.

Cambodia

The development of renewable energy resources in Cambodia has been hampered by the lack of technical knowledge and funds. Renewable energy initiatives are mostly research and demonstration projects. While renewable energy development is strongly encouraged by the government, appropriate policies and financial support are still evolving.

Electricity prices in Cambodia are very high, thereby opening opportunities for the development of solar, wind, biofuel and biogas options. Cambodia has substantial solar resources that could be harnessed on a competitive basis, especially since so much of the country is without a grid system. The government, with international assistance, has installed some 12,000 solar household systems. Attention to maintenance support will be needed to ensure sustainable results. Wind energy, on the other hand, is limited by inadequate wind speeds and the weakness of the grid and load system. Nonetheless, there are areas where wind energy would be commercially viable, as illustrated by a pilot wind turbine project in Sihanoukville.

Cambodia's biomass energy potential is diverse, with large concentrations of agricultural residues in the lowland corridor, extensive tracts of land suitable for growing feedstocks for biodiesel and ethanol production, and many farms with sufficient livestock and collectible manure for the operation of biodigesters. The government's long-term target of substituting 10% of diesel imports with domestic biodiesel production and 20% of gasoline imports with domestic ethanol production appears achievable. Some 230,000 hectares (ha) would need to be devoted to *Jatropha curcas* and cassava cultivation to meet the targets. Cambodia's biogas potential from animal manure is hampered by the difficulty of collecting sufficient manure regularly. Improved biodigesters and backup services have nonetheless been provided to 18,000 households during the past decade.

Lao People's Democratic Republic

The government is targeting renewable energy resources to provide 30% of the Lao PDR's energy needs by 2025. Minihydropower projects will be the main contributor; solar, wind, biomass, and biogas sources will also have a major role.

Large-scale solar and wind systems are limited by gaps in the Lao grid network and lack of connectivity for most of the rural population. This situation, though, means that small-scale solar or wind power is an option for those without other sources of electricity – albeit the cost of electricity would be high. According to the Lao Institute for Renewable Energy, as of 2011, about 285 kilowatts peak (kWp) of solar PV installations had been completed in pilot plants. Additionally, about 20,000 solar home systems had been installed. No wind power systems have so far been developed. Extensions of the grid system, financial support, credit access, and regular maintenance are critical factors in harnessing solar and wind energy in Lao PDR.

The government has set ambitious targets for biodiesel and bio-ethanol production, which is expected to provide 10% of transportation fuel requirements by 2025. The considerable land requirement could, however, displace food crops and grazing areas for cattle. Safeguard provisions must be followed to minimize dislocation and negative consequences for farm households. Biofuel projects have largely failed to meet expectations, in part because low crop yields have resulted in poor investment returns. However, the Lao PDR has significant biofuel potential and the government has created a positive regulatory and support framework for biofuel production.

Biogas could be an important energy source for farm households. Most of them have enough supply of manure for biodigesters, even if the mostly free-range livestock farming complicates collection. A project launched in 2006, which would have installed 6,000 biodigester systems by 2012, was only partially successful. Cultural, financial, and other factors have held back the adoption of the technology. Still, the government is planning to extend biogas use to 10,000 households in five provinces. As in the case of solar and wind power, financial support and technical and maintenance backup will be needed.

Myanmar

Myanmar's recent sweeping political and economic reforms include preparation of a renewable energy strategy. To date, little of the country's solar, wind, and biomass energy potential has been developed. The focus has been on hydropower investments.

While large areas of Myanmar have high solar irradiation levels, the largely mountainous terrain and protected areas and the limited grid system weaken the energy potential from this source. No large-scale solar systems have been installed in Myanmar. Solar power is costly and is currently an option only for rural and off-grid applications. Solar-powered battery charging stations, solar lighting, solar home systems, and village solar minigrids are common in Myanmar, but there are no data on their overall capacity and extent.

Average wind speeds in most of Myanmar are too low for modern wind turbines. Further, as noted above, the grid system, a critical factor in large-scale wind generation, is limited. Like solar energy, wind energy in Myanmar costs considerably more than grid-supplied electricity. More research is needed to determine the cost competitiveness of small-scale or off-grid wind power.

Myanmar's biofuel potential is high, a reflection of the importance of the country's agriculture sector and its large land mass. Domestically produced biodiesel and bio-ethanol could substitute for 10% of imported oil and gasoline by 2020. But measures are needed to improve seed quality, soil nutrient value, and technical skills in marketing and processing. Also, questions concerning food security and tilling rights must be addressed.

Myanmar's biogas potential is high—some 600,000 farm households and 5,000 village groups have sufficient livestock manure for small- to medium-scale biodigesters, according to the Food and Agriculture Organization of the United Nations (FAO) and the Netherlands Development Organization (SNV)—but the sustainability of past investments has been poor, because of lack of technical and maintenance support.

Thailand

Thailand is heavily dependent on imported energy sources (notably oil, gas, and electricity). To reduce this dependency and to reduce Thailand's emissions of greenhouse gases, the national energy policy has the underlying objective of an "Energy Sufficiency Society" and "Green Growth". Alternative energy sources (solar, wind, biomass, biogas, and minihydropower) now account for only 12% of overall energy use in Thailand; the government is targeting to raise this to 25% by 2021. The main policy and regulatory framework for reaching this target is the Alternative Energy Development Plan (AEDP) announced in 2012. The projected quadrupling of installed alternative energy capacity by 2021 is expected to derive from dramatic advances in solar and wind power, a doubling of biomass energy, and a multifold increase in minihydropower. The main support for renewable energy in Thailand is the feed-in tariff premium, differentiated according to technology, capacity, and location. Other support mechanisms for renewable energy investments are financial incentives in the form of grants and low-interest loans, and fiscal incentives such as import duty exemptions and special income and corporate income tax provisions.

Thailand has excellent solar power potential, and the government's target of nearly 2,000 megawatts (MW) of solar PV installations by 2021, accounting for 20% of Thailand's installed renewable energy, appears achievable. Solar power is being supported by a well-structured institutional framework and financial and fiscal incentives. For off-grid applications, solar PV is increasingly competitive.

Thailand's wind resources, on the other hand, are relatively modest, although there has been significant development of wind power projects. Wind parks tended to be small scale until the recent commissioning of several larger grid-connected wind projects, drawing on the favorable adder tariff system and other incentives. Thailand's well-established grid and robust load systems are also critical factors in facilitating the expansion of wind power.

The government is strongly encouraging the increased production and use of biofuels. Domestic biodiesel production is expected to reach 2,628 million liters by 2021, and bio-ethanol production, 3,275,000 million liters—increasing current production many times over. The extensive land requirements, more than double the amount of land now under cultivation for biofuel feedstocks, raises concerns about food security and the implications for farm communities.

Biogas energy accounts for 4% of Thailand's renewable energy mix, far below the government's target. In response, the government has strengthened its promotion of biogas energy, offering subsides of up to 33% of the total investment in biodigester installations and favorable adder rates to biogas producers who sell electricity to the national grid. Pig farms are becoming large-scale, providing ready supplies of manure, more than 50% of which is now used in biodigesters. For small farms, however, the problem of collecting sufficient manure as feedstock, together with the up-front investment cost, continues to discourage the adoption of the technology. Firewood and agricultural residues are still the primary energy sources in much of rural Thailand.

Viet Nam

The government's renewable energy plans appear to be centered on wind energy and biomass production. Biogas is also widely promoted. The government's renewable energy targets for 2020 and 2030 are modest and seem achievable, especially with regard to wind energy.

Conditions favor wind power development in Viet Nam: suitable wind speeds in the southern coastal areas and offshore, and an extensive grid system and strong load capacity enabling more grid-connected wind power. The declining cost of electricity generation by wind power has made it a competitive alternative or supplement to conventional generation (hydro, coal, and diesel). Further, Viet Nam's financial and other incentives in support of wind power, notably the favorable feed-in tariff rate, are proving effective in promoting investment in wind power. Installed wind capacity has increased rapidly, from only 8 MW in 2008 to almost 50 MW currently. Although the data are limited, it is estimated that more than 1,000 residential wind turbines have been installed in Viet Nam since 2000. Further, 11 grids and 6 hybrid wind systems have been installed in various parts of the country, including offshore. A number of large-scale grid-connected wind projects are in the planning stage.

The government's renewable energy targets make no reference to solar power despite the relatively high solar irradiation levels in the southern half of the country, where more than 60% of Viet Nam's solar potential is located. Solar energy continues to be costly (three to four times the cost of conventional electricity) and hence its development is largely restricted to off-grid areas. An estimated 4,000 families have nonetheless installed home systems, and a number of small-scale grid-connected PV plants have recently been developed.

Biomass production raises concerns about food security, as up to 1 million ha, or 9% of the total area under cultivation, would need to be used for feedstock production to reach the government's targets for 2025. Biogas, however, offers a win–win outcome, both as a clean fuel and as a response to the animal waste problem. The government has been promoting biodigesters for industry and household use.

Conclusion

Several imperatives are driving the development of renewable energy. First and foremost is the global need to reduce greenhouse gas emissions, which arise primarily from the use of fossil fuels in industry and transportation. Another is the need to reduce the vulnerability of developing countries caused by heavy reliance on imported fossil fuels. Third is the need for inclusive growth through electricity and other basic amenities extended to the rural poor.

Renewable energy alternatives in the form of solar, wind, biomass, and biogas address these imperatives, not as solutions but as nonetheless important steps toward sustainable and inclusive growth. To varying degrees, Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam have considerable potential in these forms of renewable energy. Generally, however, the potential has only begun to be tapped. The limited technical and financial resources of the public and private sectors in the GMS countries are major impediments to the development and use of renewable energies. Moreover, solar, wind, biomass, and biogas sources of energy are still costly compared with grid power, where it is available.

Renewable energy is a public good whose benefits (including reduced greenhouse gas emissions) are not fully captured by investors or users, leading to underinvestment or low use relative to the socially desirable level. There is a strong rationale for public sector support for the development of renewable energy, including subsidies and support for research and pilot projects. While renewable energy is an increasingly vital public good, the tools needed for its rapid development are lacking. Most obvious is the gap in knowledge. Basic data simply are not available. The public also needs to be fully informed about the urgency of developing and using renewable energy. Knowledge sharing could help the GMS countries chart the course ahead. Regional economic cooperation contributes to identifying the most cost-efficient and effective manner for meeting energy security in an environment-friendly manner. The GMS countries should strive to be models of what can be done in response to the threat of climate change, and the call for sustainable and inclusive growth.

ADB and the GMS governments, working together, are actively promoting investments in renewable energy and energy efficiency. ADB is also partnering with the private sector to leverage scarce financial resources for maximum renewable energy and energy efficiency results. Public–private partnerships combine public and private interests, a model of cooperation essential for achieving what is possible and what is needed. As a knowledge bank, ADB is helping to inform key ministries and business and community leaders about international best practices and expertise in renewable energy and energy efficiency. As a highly operational bank backed by substantial technical and investment resources, ADB is helping its developing member countries meet their targets for renewable energy and energy efficiency savings.

This report on renewable energy developments and potential in GMS countries gives grounds for optimism: the potential is considerable and, more initiatives are being undertaken to develop that potential. ADB is encouraging the GMS countries to step up development and is committed to helping to mobilize the necessary expertise and financial resources. ADB's support toward the twin goals of renewable energy and energy efficiency in the GMS countries is inclusive, ensuring that the benefits embrace the poor and that the private sector is fully engaged in the investment opportunities.

1 Introduction

Cambodia, the Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand, and Viet Nam are in markedly different stages of economic development and energy provision, but they share common goals concerning energy security and environmental protection. Given each country's individual energy needs and varying resource endowments, a regional approach allows for the identification of the most cost-efficient projects and the diversification of sources to enhance energy security in an environment-friendly manner. Clearly, advances in energy supply and management are vital to inclusive and sustainable economic growth and to climate change mitigation. Some countries in the Greater Mekong Subregion (GMS) have made significant progress in promoting and facilitating the use of renewable energy, clean fuels, and energy efficiency. Their experience and lessons learned should be shared and serve as a basis for advancing green energy throughout the region.

Generally, however, regional cooperation on green energy has lagged, partly because of the lack of a shared vision for its development and a regional platform for promoting enhanced cooperation. In response, the Asian Development Bank (ADB) designed its regional technical assistance (TA) project to support the GMS Road Map for Expanded Cooperation in the Energy Sector and the GMS Sustainable Energy Forum. The TA project was also designed to support climate change mitigation efforts by promoting environment-friendly energy supply options. It coincided with the continued reduction in poverty and rapidly improving economic status of GMS countries, thereby facilitating accelerated public and private sector investment in green energy supply and management.

The renewable energy alternatives addressed in this publication are wind, solar, biomass, and biogas energy resources in Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam. By design, hydropower is not included in this survey, as its importance, with regard to what has already been developed and the huge potential for further development, calls for stand-alone analysis. While firewood and charcoal collected from forest areas are primary energy sources for rural populations in GMS countries, alternative renewable energy sources could be developed to reduce this dependence.

2 Renewable Energy Developments in the Greater Mekong Subregion: An Overview

All five GMS countries covered by this survey have introduced measures to promote renewable energy, and most have ambitious targets for further development. Solar, wind, biomass, and biogas energy resources are especially suited to reaching out to the rural poor, who, for the most part, are remote from the national power-grid systems.

The government of Cambodia has targeted full electrification of villages by 2020, and electricity services to 80% of the population by 2030. Renewable energy sources are expected to play an important role in meeting this target, notably through minigrids and individual solar home systems. Over the past decade, the government, with the assistance of the World Bank and other donor agencies, has provided grants and financing programs to encourage off-grid rural electrification programs. Cambodia has good solar resource potential but relatively low wind resource potential. Because electricity rates are so high in Cambodia, solar energy can be an economically feasible option. As of 2012, however, only 2 megawatts-peak (MWp) of solar photovoltaic (PV) installations had been completed. The government has announced plans in support of biomass development and has widely promoted biogas through the National Biodigester Program, with the assistance of the Netherlands Development Organization (SNV).

In 2011, the Government of the Lao People's Democratic Republic (Lao PDR) issued its Renewable Energy Development Strategy, whereby the country expects to meet 30% of its total energy consumption from renewable energy sources by 2025. To reach this ambitious target, the development strategy sets out a series of short- to long-term renewable energy investments and measures, including fiscal and financial incentives for private sector investment in renewable energy projects. the Lao PDR has strong technical wind resource potential, but it is limited in practice by the lack of a national grid system. Electric power through solar energy is not the most cost-effective option except in special situations. Some 20,000 small solar home systems have nonetheless been set up, in addition to solar plants with about 285 kilowatts-peak (kWp) installed. The government's biofuel production goals call for substituting 10% of transportation fuel consumption with biodiesel and bio-ethanol by 2025. The Lao PDR is also projected to become a net exporter of biofuel, raising concerns about land grants and land use in general. Biogas is a potential energy source for farm households, but investment in biodigesters has been slowed down by issues of affordability, maintenance, the difficulty of collecting sufficient manure, and the continued availability of low-cost alternative fuels (firewood and charcoal).

Myanmar's recent sweeping political and economic reforms provide the framework for its Five-Year National Development Plan (2011–2015) and measures to promote private sector investment in renewable energy technologies. Related institutional reforms by the government have included merging the two power ministries and drafting a new Electricity Law to replace the 1984 version. Further institutional reform is needed to help focus planning and support for renewable energy initiatives. A renewable energy development strategy is being prepared. As in the case of the Lao PDR, solar energy would be a cost-effective source of electric power only for off-grid applications. Large-scale solar plants have not yet been installed, but solar-powered battery-charging stations, solar home systems, and village minigrids with solar components are increasingly common. Myanmar's wind resource potential is low and irregular, and has not been harnessed so far. Biomass production is constrained by the agriculture–energy nexus. Biogas use has been slow to develop for the same reasons experienced in the Lao PDR—the cost of installing biodigesters, maintenance problems, the difficulty of collecting sufficient manure, and the continued availability of firewood and charcoal.

Of the five Mekong countries reviewed here, Thailand is the most advanced in promoting private sector investment in renewable energy resources. Over the past 20 years, the government has introduced various support mechanisms, while continuing to improve its policy measures and raise its development targets. Financial incentives have been combined with technical information, capacity-building, and awareness campaigns. A feed-in adder (or bonus) system for grid-connected renewable energy projects was instituted in 2006, and supplemented recently with a feed-in tariff system for rooftop and community-based solar PV systems. The Ministry of Energy and the National Energy Policy Committee estimate that almost 700 megawatts (MW) of new solar PV power was installed in 2013. However, sustainability, a goal that early solar initiatives widely failed to achieve, demands proper maintenance. Independent of public sector support, the competitiveness of renewable energy sources vis-à-vis conventional energy sources has greatly strengthened, particularly for wind energy. Despite Thailand's relatively weak wind resources, wind power accounted for 223 megawatt-hours (MWh) in 2013 (DEDE, 2014); 54 MW had been installed and 82 MW of additional capacity was under construction. Since Thailand enjoys a high degree of food sufficiency, the energy–food nexus is less of a constraint on the domestic production of biofuels. The country's heavy dependence on imported transportation fuels and its concerns about climate change have prompted the government to target multifold increases in biodiesel and bio-ethanol production by 2021. An estimated 2.5 million hectares (ha) of agricultural land will be needed for the cultivation of biofuel feedstocks to meet the government's targets. Thailand has also been generally successful in adopting biogas technology on a national scale.

Viet Nam's target is 20 gigawatts (GW) of installed capacity from renewable energy sources[1] by 2020. In support of this goal, the government has introduced a feed-in tariff system for wind generation. The extensive grid system of the country facilitates an increase in wind generation. Large-scale grid projects with an estimated capacity of 1,400 MW are now being developed. Other renewable energy technologies are guaranteed a benchmark reference tariff based on avoided generation costs for the national utility; this reference

[1] The vast majority (19.2 GW) from hydropower.

tariff is relatively low and project developers appear to be waiting for an increase in the tariff rate. Electrical power through solar PV in Viet Nam costs between $0.17 per kilowatt-hour (kWh) and 0.22/kWh, higher than domestic tariffs, which range from $0.03/kWh to 0.158/kWh. A number of small-scale grid-connected PV plants in the 100–200 kWp range, as well as about 4,000 solar home systems, have been installed. Financial incentives and other support mechanisms may be needed to leverage private sector participation in renewable energy investment more effectively. Food security concerns may arise from the government's biofuel production goals, however, as up to 1 million ha would need to be cultivated solely for biodiesel and bio-ethanol feedstocks. The government has been widely promoting the adoption of biodigesters to advance the production of biogas for industry and household use.

In summary, with the exception of Thailand, the GMS countries are at an early stage in developing their renewable energy resources. Solar energy is being extensively promoted in the region, and while the cost of solar power is still high relative to conventional sources, further development offers economies of scale and use of newer, lower-cost technologies. This is also the case for wind power, which will benefit from extensions of the transmission grids and feed-in adder or bonus systems. Biomass energy is generally small-scale and its expansion critically depends on the availability of agricultural land. Where food sufficiency has largely been achieved, or where there is underused land, the agriculture–energy nexus is less of a constraint on the farming of appropriate crops for the production of biofuels. Biogas from animal manure is also small-scale and a suitable energy source for off-grid farm communities.

3 Determining the Potential of Selected Renewable Energy Resources in the Greater Mekong Subregion

To assess the potential of selected renewable energy resources in each of the five GMS countries reviewed in this study, data were collected from a number of sources, which used differing methodologies and technical assessments. To keep the focus of the report on the study findings, the details of the methodology used in estimating the renewable energy potential for each type of resource are provided in the annexes. Following is a brief outline of the methodologies employed; each of the country sections provides specifics relevant to the local circumstances.

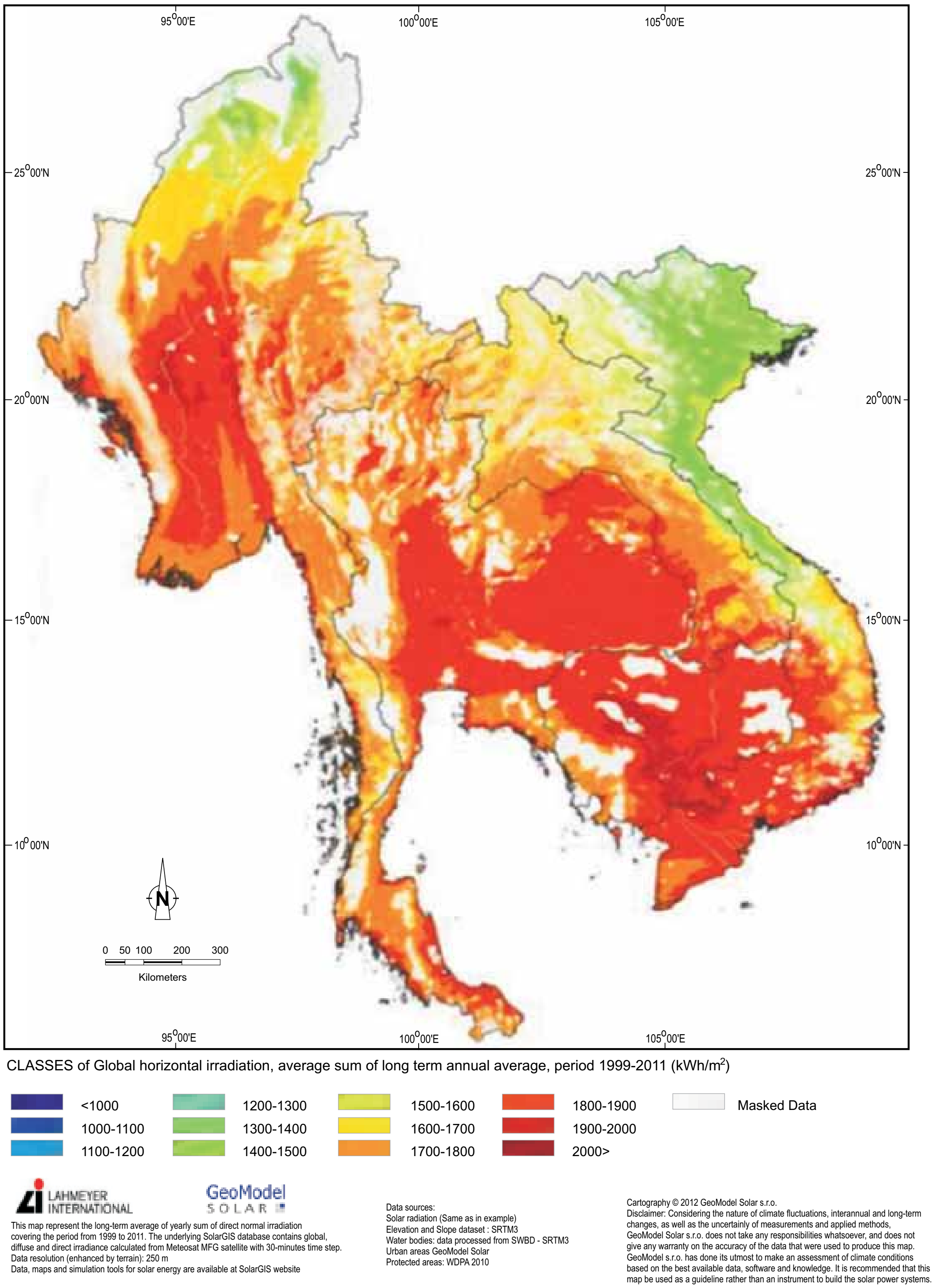
The potential for solar energy is based largely on the degree of solar irradiation, the estimated land area suitable for PV development, and the efficiency of the solar energy systems. This potential can be assessed in theoretical, technical, and economic terms. The theoretical potential is the upper limit possible, given the land area and current scientific knowledge. Solar resource maps prepared by GeoModel Solar[2] represent the long-term yearly averages (from 1999 to 2011) of direct normal irradiation (direct sun rays) and global horizontal irradiation (GHI); significant shortwave radiation,[3] both measured in kilowatt-hours per square meter per year (kWh/m^2/yr). Map 3.1 illustrates the GHI averages for the five countries, with the extensive areas in red and deep red signaling the highest levels of solar irradiation. It should be noted that the local terrain and other factors contribute to uncertainty of measurement; the map should, therefore, serve only as an indicative guideline of the varying levels of solar irradiation.

The technical solar potential addresses what would be possible under ideal conditions, but is currently limited by the efficiency of conversion technologies, the suitable land area, and other factors. Land areas with a steep slope or high elevation, as well as water bodies, are deemed unsuitable for PV projects. To calculate each country's technical potential for solar energy, the total suitable land area in square meters (m^2) was multiplied by the installable capacity per land area of 0.06 kilowatt-peak per square meter (kWp/m^2), which represents the average capacity based on current conversion technologies. According to Table 3.1, the combined five-country technical potential for solar energy is almost 80,000 megawatt-peak (MWp), with Myanmar having the largest potential. These estimates, however, are only indicative and intercountry comparisons are subject to differences in the degree to which land is deemed suitable for PV installations. Other factors also warrant caution in making intercountry comparisons.

2 http://geomodelsolar.eu/

3 GHI levels below 1,000 kWh/m^2/year were excluded from the analysis.

Map 3.1: **Solar Irradiation Levels: Greater Mekong Subregion**



Source: GeoModel Solar; Lahmeyer International.

Table 3.1: **Technical Solar Potential: Greater Mekong Subregion** (MWp)

Country	Technical Potential (MWp)
Cambodia	8,074
Lao PDR	8,812
Myanmar	26,962
Thailand	22,801
Viet Nam	13,326
Total	**79,975**

Lao PDR = Lao People's Democratic Republic, MWp = megawatt-peak.

Source: Lahmeyer International, based on GeoModel Solar data.

The economic potential is defined as what can be exploited commercially, that is, solar energy that is competitive with other locally available resources. In much of the GMS region the electrical grid is not extensive and, therefore, PV technologies are often used for off-grid applications such as battery-charging stations, pumping stations, or small island grids. The economic viability of these applications is significantly different from that of standard grid electricity. What would be considered economic potential can vary not only between countries and between provinces, and even within local areas.

The levelized cost of electricity (LCOE), that is, the cost of producing 1 kWh of electricity from solar PV, was calculated on an area-wide basis, incorporating data on the intensity of irradiation.[4] In most of the area under study, it costs about $0.17/kWh to generate electricity from solar energy. This is higher than the cost of generation from grid-connected conventional sources, limiting the use of solar energy to areas where it may be the only viable alternative, especially in remote rural areas.

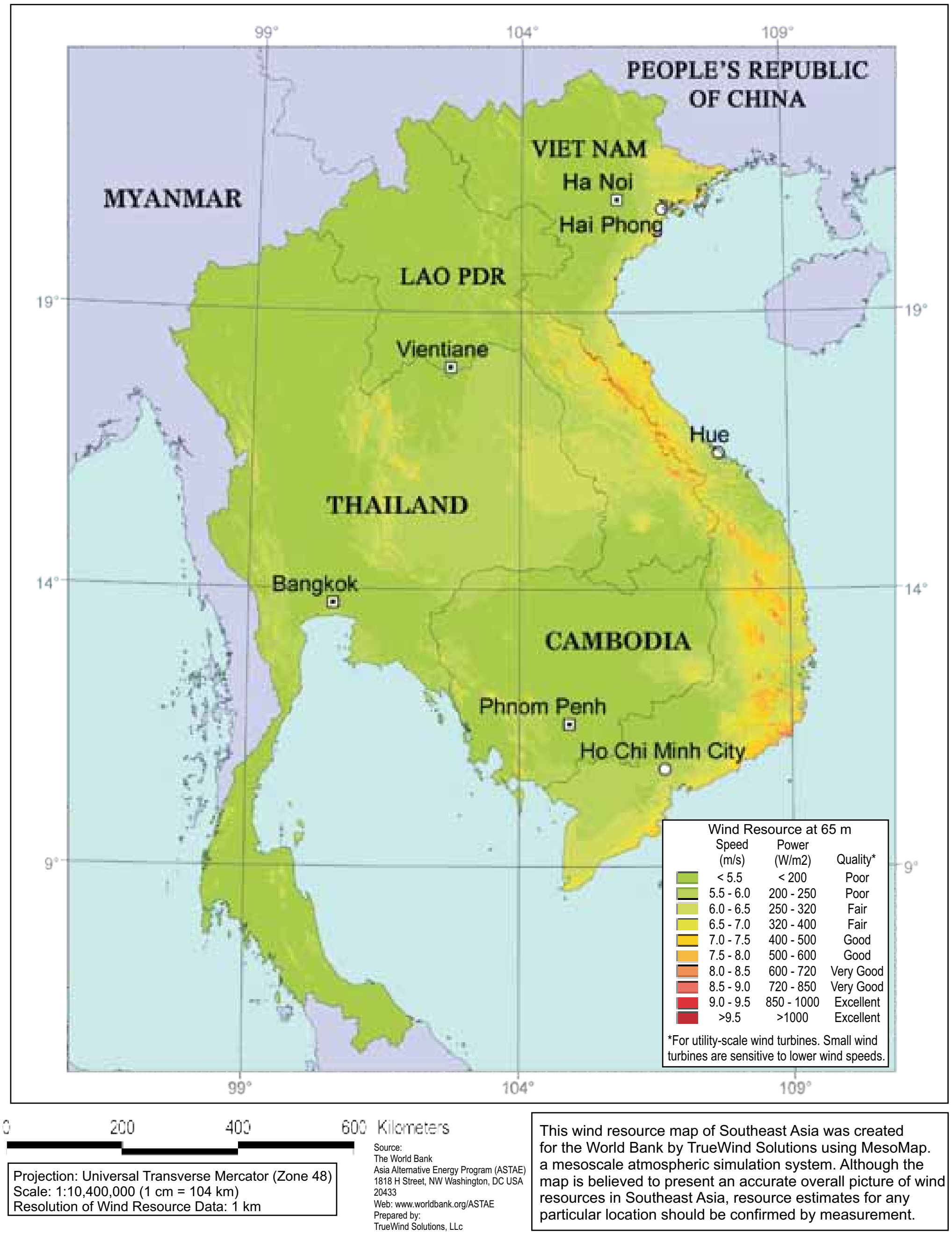
Wind energy potential is similarly assessed in terms of the theoretical, technical, and economic potential. To calculate wind power potential, average wind speeds over specific land areas, in meters/second (m/s), and wind turbine generator (WTG) installation capacity (or wind power density), in megawatts per square kilometer (MW/km^2), were calculated. Technological advances over the past decade have increased WTG installation capacity to about 10 MW/km^2. This capacity was multiplied by the land area with average wind speeds higher than 6 m/s to arrive at the indicative theoretical energy production potential.

A World Bank study in 2001 provides the most extensive survey of wind resources in the GMS, excluding Myanmar.[5] As shown in Map 3.2, land areas in Cambodia, the Lao PDR,

4 The average LCOE ranges from $0.154/kWh for the highest GHI irradiation levels to just over $0.30/kWh for the lowest levels. The majority of the solar potential in the GMS region has a GHI ranging between 1,700 and 1,900 $kWh/m^2/yr$, leading to an LCOE of about $0.17/kWh–$0.18/kWh. The assumptions used in calculating the LCOE can be found in Annex 1.

5 Lahmeyer International created a separate wind resource map for Myanmar by using a data set calculated with the mesoscale model Klima Model Mainz (KLIMM) and calibrated with the modern-generation reanalysis tool Modern-Era Retrospective Analysis for Research and Applications (MERRA). (http://gmao.gsfc.nasa.gov/research/merra).

Map 3.2: **Wind Resources: Greater Mekong Subregion**



Lao PDR = Lao People's Democratic Republic.
Note: The spelling of country names was altered slightly to conform to ADB standards.
Source: World Bank (2001).

Thailand, and Viet Nam were classified according to annual average wind speeds, the main parameter for determining wind energy potential. A minimum wind speed of 6 m/s is needed for modern wind turbines; land areas with lower average wind speeds were therefore excluded from the analysis.

On this basis, the theoretical installed wind capacity potential for Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam was estimated to be 888 gigawatt (GW), and the theoretical production capacity, 2,310 terawatt-hours per year (TWh/yr). However, this theoretical potential is largely academic, as it does not consider limiting factors, including land availability or suitability, and the capacity or stability of the grid systems.

Much of the land area, especially protected forest areas and mountainous and remote areas, is unsuitable for wind turbines. Urban settings can be sites for wind turbines but only on a restricted basis. While topographic and geographic factors are important, the primary technical constraint on wind power in the five countries is the degree to which the grid network can accept the inclusion of intermittent wind energy. This ability varies between systems and regional locations.

Limiting the amount of wind generation in relation to the total grid load is needed to ensure that the grid can maintain stability and that the system has enough firm capacity in case the wind turbine facilities lose power. The required level of generation depends on the structure of the system, including the type and size of the power generation capacities in the system and the robustness of the transmission grid. Another issue is the load and its variation over time (daily, monthly, and seasonally) and the availability of wind energy supply to meet the load. It is necessary to have sufficient balancing power available so that alternative generation units are able to compensate in a timely manner when wind energy is not available. In the absence of information on grid capacities, two limits to load input through wind energy were assumed.[6] On a 5% limit basis, it was estimated that the five countries could have a total installed wind capacity of 3.3 GW. If their grid systems were more robust, allowing wind power to meet 20% of total installed capacity, the five countries could have a total installed wind capacity of 13.5 GW. Because Thailand and Viet Nam have the most extensive grid systems, they account for more than 90% of the technical potential (Table 3.2). Again, however, the total is only indicative; because of differing underlying data assumptions, intercountry comparisons cannot be made. In the case of Viet Nam, some land areas unsuitable for power generation were excluded before the theoretical potential was calculated. Moreover, the height at which the mean wind speed was measured differs between the countries. Table 3.2 shows the significant difference between theoretical wind power potential (based on wind resource) and the much-smaller technical wind power potential (based on the limit of 5%–20% of current total grid capacity).

The economic potential of wind power depends on the cost of generation, as compared with the cost of other alternatives. As in the case of solar energy, the LCOE (LCOE was calculated to determine the estimated cost of producing 1 kWh of electricity). In the

[6] The electric grid systems of the five countries vary significantly; the range of 5%–20%, instead of a single value, was therefore used. To determine a more precise value, modeling of each system would be necessary.

Table 3.2: **Theoretical and Technical Wind Capacity Potential: Five GMS Countries**

Item	Cambodia	Lao PDR	Myanmar
Theoretical potential (MW)[a]	65,000	455,630	33,829
Installed grid capacity (MW)[b]	360	1,895	1,713
Potential share of wind energy (%)	5–20	5–20	5–20
Total technical potential (MW)	**18–72**	**95–379**	**86–343**
Item	**Thailand**	**Viet Nam**	**Five Countries**
Theoretical potential (MW)[a]	380,980	26,763	962,202
Installed grid capacity (MW)[b]	48,237	15,209	67,414
Potential share of wind energy (%)	5–20	5–20	5–20
Total technical potential (MW)	**2,412–9,647**	**760–3,042**	**3,371–13,483**

Lao PDR = Lao People's Democratic Republic, MW = megawatt.

[a] Based on 10 MW/km^2 installed in areas of greater than 6 m/s.

[b] Installed capacity in 2010. www.eia.gov (accessed 31 August 2013).

Sources United States Department of Energy; Lahmeyer International.

case of wind energy, generation costs are highly project specific; standardized LCOEs for wind energy corresponding to each category of average wind speed were therefore used. On the basis of this methodology (see Annex 2), the estimated LCOE ranges from \$0.114/kWh for medium-range wind speeds, down to \$0.066/kWh for the highest speeds. Most usable wind potential in the region has an annual average wind speed of 6–7 m/s, indicating an LCOE of about \$0.114/kWh–\$0.093/kWh. In the five countries considered, the generation cost of wind energy is very close to that of other alternatives. Wind power can be an economically feasible option in Cambodia at wind speeds of over 6 m/s, and in the Lao PDR, Myanmar, Thailand, and Viet Nam at winds speeds of over 7 m/s. At this juncture, though, the potential for wind energy in the GMS appears to be limited primarily to those countries with well-developed grid systems, which are technically able to incorporate wind power.

Another source of low-carbon renewable energy is biomass or the biofuels into which it can be converted, notably biodiesel and bio-ethanol, which are blended with transportation fuels. The Lao PDR, Thailand, and Viet Nam have mandated blending targets ranging from 5% to 20%; Cambodia and Myanmar also have plans to introduce biofuels. The twin objective is to reduce dependence on fuel imports and to promote the use of green energy. The biofuel potential of the GMS is considerable, reflecting the importance of the agriculture sector for all countries in the region.

Of concern, however, are the implications for the agriculture sector. Considerable tracts of agricultural land would be required to meet the biofuel targets of the Lao PDR, Thailand, and Viet Nam, and the plans of Cambodia and Myanmar could further deepen the agriculture–energy nexus. For example, Thailand could require more than 1.4 million ha of land for oil palm plantations to meet its biodiesel target for 2021. Similarly, Viet Nam could need about 1 million ha of land to meet its biodiesel target if the feedstock is sourced from Jatropha plantations with average seed yield per hectare.

Crop yields will be a determinant of biofuel potential. To minimize food security concerns, marginal agricultural lands are sometimes used for biofuel production. Their low productivity, though, means that significantly larger agricultural tracts would be required to achieve the biofuel production targets. Increased biofuel production calls for improved agricultural extension services in support of the use of high-yielding oil seed crop varieties and best practices.

Agricultural residues are relatively simple and straightforward sources of biomass energy for power generation. Large-scale rice, sugarcane, and oil palm mills offer power generation potential, especially for Thailand and Viet Nam. For Myanmar, on the other hand, oil palm residue could become an important source of biomass for power generation.

Biogas is another renewable energy resource reviewed in this study. Biogas feedstock is derived mainly from cattle, buffalo, swine, and poultry manure. Small holdings characterize the five countries, although Thailand and Viet Nam have significant numbers of large-scale livestock farms. Biogas promotion programs mostly support household use in Cambodia, the Lao PDR, and Myanmar; in Thailand and Viet Nam, medium- to large-scale farms are encouraged to generate electricity from biogas and feed it into the grid system.

The theoretical potential for biogas production was estimated on the basis of the daily available quantity of animal manure, and technical potential, on the basis of the minimum number of farm animals per household, below which biogas production would be unworkable. Biogas promotion targets and programs for each country were considered in estimating market potential. The incentives offered by such programs to households and commercial livestock farms to generate biogas for domestic use and commercial energy generation have boosted the biogas potential of all five countries. Because of the widespread household ownership of pigs in Thailand and Viet Nam, as well as the presence of large-scale pig farms, the initial development targets for biogas production in those countries are focused mainly on pig manure feedstock. Thailand's success with its biogas programs has prompted attention to other feedstock possibilities, including community effluents.

With this background, the following sections contain country-by-country assessments of renewable energy developments and potential in Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam.

4 Renewable Energy Developments and Potential in Cambodia

4.1 Institutional and Policy Framework for Renewable Energy Initiatives

4.1.1 Institutional Framework

The General Department of Energy of the Ministry of Industry, Mines and Energy (MIME) is the main agency responsible for energy policies, plans, development strategies, and technical standards in Cambodia. The agency has three core departments: (i) the Department of Energy Development, which is responsible for energy and electricity planning; (ii) the Department of Hydropower, which is mainly concerned with hydropower sector development; and (iii) the Department of Technical Energy, which is responsible for renewable energy (other than hydropower) and energy efficiency. To promote the development of biomass energy, the government has formed a ministerial bioenergy program committee, which includes the Ministry of Economy and Finance; the Ministry of Environment; and the Ministry of Agriculture, Forestry and Fisheries, in addition to MIME.

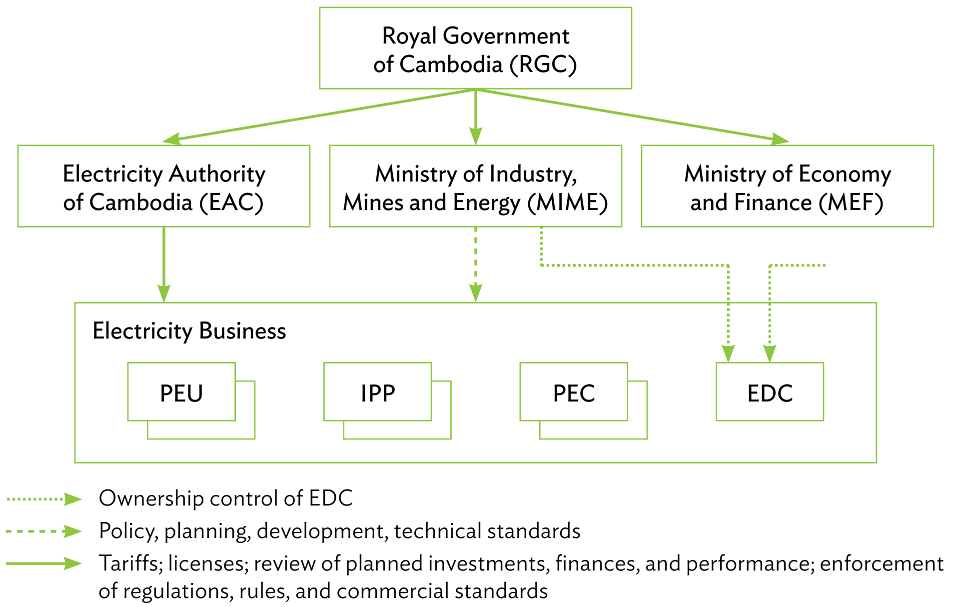
Cambodia has an estimated hydropower potential of 10,000 MW, but only 223 MW has been installed (MIME 2012). It has one of the lowest degrees of electrification in Asia, with annual per capita consumption of electricity of only about 160 kWh. Cambodia imports electricity from the Lao PDR, Thailand, and Viet Nam, and generates it locally mainly with diesel-powered generators. Overall demand is increasing by more than 20% yearly.

The Electricity Law (2001) regulates the operations of the electric power industry and service providers. The law has two key objectives: (i) to establish an independent regulatory body; and (ii) to liberalize generation and distribution in order to facilitate private sector participation. The Electricity Law created the Electricity Authority of Cambodia (EAC), an autonomous government agency responsible for regulating electricity services. All power service suppliers must be licensed by the EAC.

The Electricité du Cambodge (EDC) is a state-owned utility responsible for power generation, transmission, and distribution. It is owned jointly by MIME and the Ministry of Economy and Finance. The EDC accounts for more than 50% of installed generating capacity, but its coverage is largely limited to the country's major centers (Phnom Penh, Sihanoukville, Siem Reap, Kampong Cham, Takeo, and Bayyambang). It serves about 16% of households in Cambodia, mostly in Phnom Penh. About 600 rural electricity enterprises

(REEs) provide electricity to off-grid customers. REEs are usually small, locally owned enterprises serving local households and businesses with diesel-powered low-voltage distribution systems. In addition, a number of REEs provide battery-charging services to local households and businesses. The institutional framework for the power sector in Cambodia is shown in Figure 4. 1.

Figure 4.1: **Power Sector Institutional Framework: Cambodia**



EDC = Electricité du Cambodge, IPP = independent power producer, PEC = Private Electricity Company, PEU = Provincial (or joint with Private) Electricity Utility.

Source: MIME.

4.1.2 Renewable Energy Development and Rural Electrification Policies and Targets

Cambodia's renewable energy development and rural electrification policies are linked. The government's energy policy is aimed at: (i) supplying adequate energy at affordable rates; (ii) ensuring the reliability and security of electricity supply to facilitate investments and advance national economic development; (iii) encouraging the socially acceptable development of energy resources; and (iv) promoting the efficient use of energy and minimizing detrimental environmental effects resulting from energy supply and consumption.

The goals of the government's rural electrification program are as follows:

- providing safe, reliable, and affordable electricity to rural communities in a way that minimizes negative impact on the environment;
- providing a legal framework that encourages the development of renewable energy sources by the private sector to supply electricity to rural communities;
- supporting renewable energy initiatives;
- promoting the adoption of renewable energy technologies by setting electricity rates in accordance with the Electricity Law (2001);
- promoting the use of least-cost forms of renewable energy in rural communities, through research and testing of grid and off-grid options; and
- supporting electrification in disadvantaged rural communities through funding assistance, training, and other means.

The government is targeting to achieving full electrification of villages by 2020, and 70% household electrification by 2030. The village electrification target involves about 14,000 villages (with almost 2.5 million households). The main components of rural electrification are an expanded power grid; diesel stand-alone, mini-utility systems; cross-border power supply from neighboring countries; and renewable energy (solar, wind, mini and micro hydro, biogas, biomass). In the short- and medium-term, small village hybrid grid systems will also have an important role.

4.1.3 Incentive Framework

To help meet its rural electrification targets, the government has established the Rural Electrification Fund (REF) with the help of a loan from the World Bank and a grant from the Global Environment Facility. The fund administers grants in support of rural electrification, using both conventional technology and renewable energy technologies such as solar, mini and micro hydro, and biomass. Since 2008, the REF has carried out the following initiatives:

- To encourage electricity licensees to expand their networks, the REF has provided them with grant assistance of $45 for each newly connected household.
- To assist rural households living in remote areas:
  - The REF has purchased in bulk 12,000 units of solar household systems (SHSs) on a tax-exempt basis and sells them to rural households in remote areas at cost, less a subsidy of $100, to be repaid in installment without interest;
  - The REF bears the transportation and installation fees, and repayment charges;
  - The REF bears the yearly maintenance fee until repayment (or the supplier bears the fee for the first year), while the purchaser is responsible for the replacement of defective parts; and
  - Once the required installments are made, ownership of the SHS is transferred to the household.

The REF was integrated with the EDC in 2012 and they are now implementing three joint programs:

- Solar home system program, retaining the above incentive mechanism;
- Power to the Poor Program, which provides interest-free loans of $120 per household to cover the expenses for connection, deposit, meter installation, and wiring, to be repaid in 36 monthly installments; and
- Assistance for the improvement of existing electricity infrastructure in rural areas or the development of new infrastructure, involving loan guarantees, interest-free loans of up to $100,000, or a combination of grants and interest-free loans.

4.2 Solar Energy Resources Potential

As summarized in Section 3 and detailed in Annex 1, a country's solar energy resource potential depends largely on the degree of solar irradiation, the estimated land area suitable for PV development, and the efficiency of the solar energy systems. The solar energy potential can be assessed in theoretical, technical, and economic terms.

Cambodia has a high degree of solar irradiation and thus has strong solar resource potential. Its Global Horizontal Irradiation (GHI) ranges between 1,450 and 1,950 kWh/m^2/yr; some 65% of the country is estimated to have GHI levels of 1,800 kWh/m^2/yr or more. Direct normal irradiation (DNI) is also high, with most of the country having DNI levels of 1,100–1,300 kWh/m^2/yr.

As shown in Map 4.1, Cambodia has about 134,500 square kilometers (km^2) of land area that could be suitable for photovoltaics (PV) development. This corresponds to a technical potential of about 8.1 gigawatt-peak.[7] The white areas on the map represent water bodies, protected areas, or areas unsuitable for PV development because of slope and elevation.

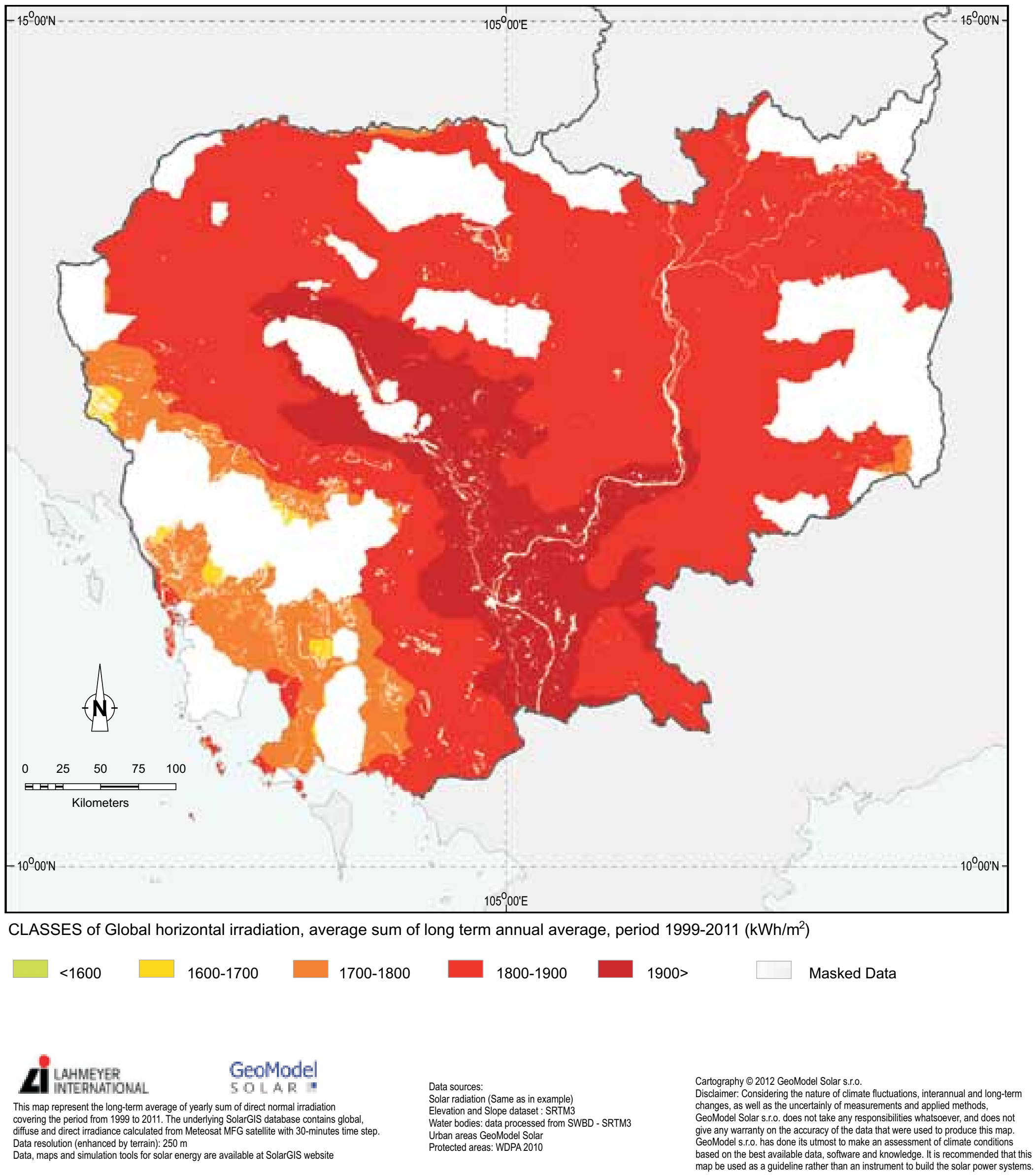
The maximum technical solar energy potential of Cambodia is estimated to be just under 12 TWh/yr,[8] the vast majority which would be generated in areas within the 1,800–1,900 GHI range.

Several solar resource studies have been undertaken for Cambodia, most of them based on the United States National Renewable Energy Laboratory database and showing similar results. Of particular note is the study Sustainable Energy in Cambodia: Status and Assessment of the Potential for Clean Development Mechanism Projects (Williamson 2004), which appears to be the only study that extrapolated solar potential in terms of electricity generation, estimating the technical potential at 7,470.54 gigawatt-hours per year.

[7] Wide variations in estimates of current energy consumption make a comparison of potential vs. current consumption unrealistic. Estimates by the Association of Southeast Asian Nations Plus Three (ASEAN+3), by the Economic Research Institute for ASEAN and East Asia (ERIA) in 2009, and by the World Bank in 2011 were arrived at through different data collection methods and are not comparable. Most Cambodians use biomass as their primary fuel source, complicating the task of estimating energy demand.

[8] Based on the calculation method described in Annex 1.

Map 4.1: **Areas Potentially Suitable for Solar Photovoltaic Development: Cambodia**



Sources: GeoModel Solar; Lahmeyer International.

To assess the extent to which this technical potential could be developed on an economically viable basis, the estimated levelized cost of electricity (LCOE) of solar power in Cambodia was compared with the current cost of alternative sources of energy. Most solar power generation in Cambodia has an estimated LCOE of $0.166/kWh–$0.175/kWh. Cambodia has the highest energy prices in Southeast Asia, ranging from $0.18/kWh to $1/kWh in the rural areas. It has an electricity import rate of $0.71/kWh and battery-charging stations can cost up to $4/kWh (MIME 2013).

Table 4.1: **Technical Solar Energy Potential: Cambodia**

Area (km²)	Potential Suitable Area ('000 km²)	% of Total Area	Technical Potential MWp	MWh/yr	LCOE ($/kWh)
Unsuitable area	46.54	25.70	...	...	...
Less than 1,000	...	...	...	...	...
1,000–1,100	...	...	...	...	0.308
1,100–1,200	...	...	...	...	0.281
1,200–1,300	...	...	...	...	0.259
1,300–1,400	...	...	...	...	0.240
1,400–1,500	...	...	...	...	0.223
1,500–1,600	0.00	0.00	0.19	234	0.209
1,600–1,700	0.85	0.47	51.00	67,224	0.196
1,700–1,800	13.24	7.31	794.51	1,110,844	0.185
1,800–1,900	95.73	52.86	5,743.87	8,489,649	0.175
1,900–2,000	24.73	13.66	1,484.08	2,312,096	0.166
Over 2,000	...	...	...	...	0.162
Total			**8,074**	**11,980,046**	

... = data not available, km² = square kilometer, kWh = kilowatt-hour, LCOE = levelized cost of electricity, MWh = megawatt-hour, MWp = megawatt-peak, yr = year.

Sources: GeoModel Solar; Lahmeyer International.

At these electricity rates, the development of solar potential in areas with GHI levels above 1,800 kWh/m²/yr could be considered potentially economically feasible. This includes the majority of Cambodia's solar resource of roughly 7.2 MWp, corresponding to 10.8 TWh/yr.

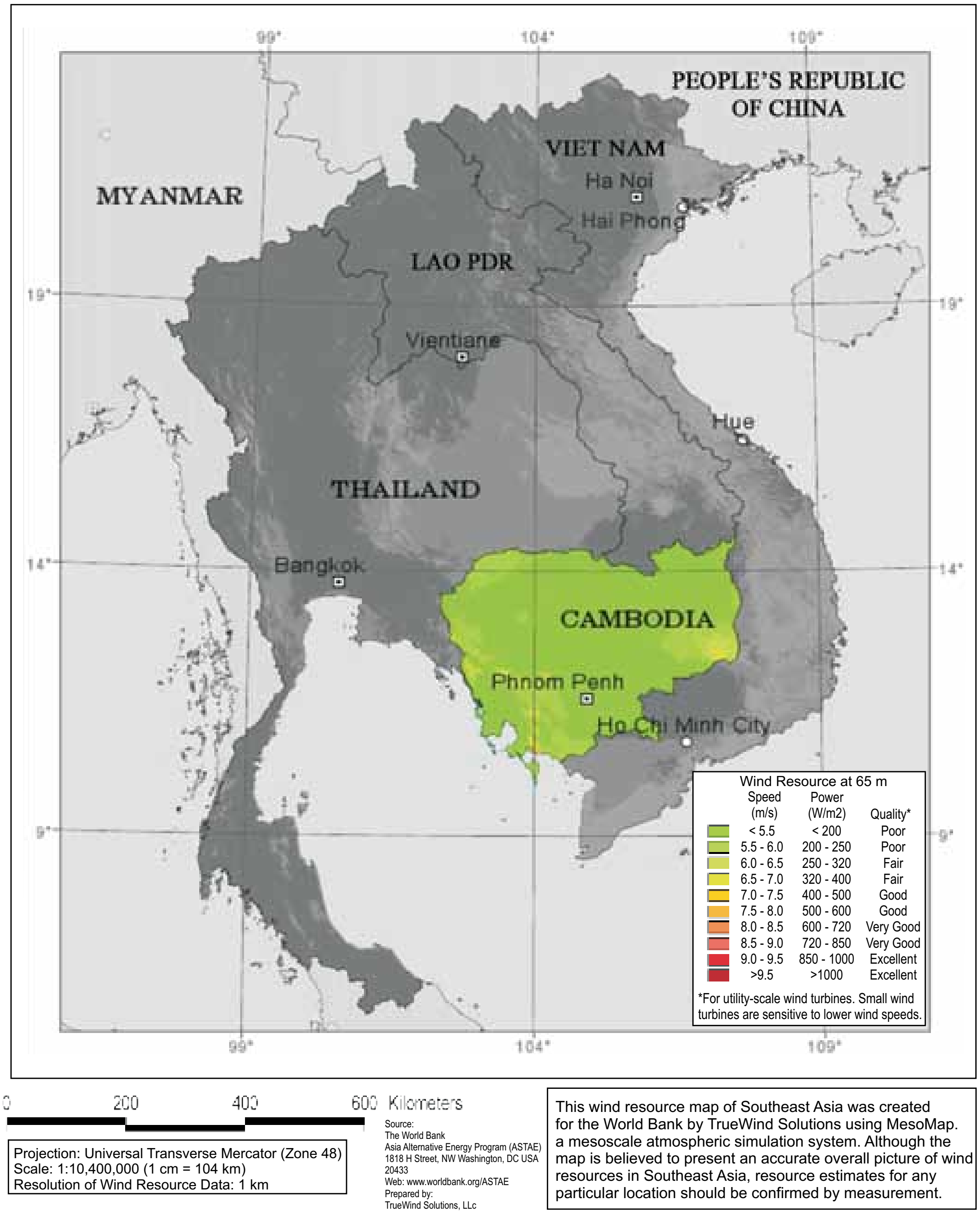
Solar development in Cambodia is in the pilot stage. As of 2012, the country had about 2 MWp of solar PV installed (Pock, 2013). A World Bank–funded project for 12,000 solar household systems is now being implemented by the Lao PDR company Sunlabob.

In summary, Cambodia has substantial solar resources that could be harnessed on a competitive basis. As described above and in Section 4.3, Cambodia provides generous support to households, villages, and businesses in adopting solar power. Economies of scale and maintenance services can be expected to improve with increasing use of solar power in Cambodia; weakness in both has contributed to disappointing results for solar projects.

4.3 Wind Energy Resources Potential

As summarized in Section 3 and detailed in Annex 2, the wind energy potential of Cambodia is dependent on the average wind speed, the land area suitable for wind turbine generator (WTG) installations, the efficiency of these generators, and the load capacity of the grid system. The wind resources of Cambodia are low in most parts of the country, reflecting its topography of basins and lowlands rimmed by mountain ranges. As indicated in Map 4.2, areas with higher elevation in the southwest near the coast and in the eastern

Map 4.2: **Wind Resources: Cambodia**



Lao PDR = Lao People's Democratic Republic.

Note: The spelling of country names was altered slightly to conform to ADB standards.

Source: World Bank (2001).

Table 4.2: **Theoretical Wind Energy Potential: Cambodia**

Item	Average Wind Speed					Total
	Low (< 6 m/s)	Medium (6–7 m/s)	Relatively High (7–8 m/s)	High (8–9 m/s)	Very high (> 9 m/s)	
Area (km²)	175,468	6,155	315	30	0	...
Area (%)	96.4	3.4	0.2	0.0	0.0	...
Theoretical potential (MW)[a]	...	61,550	3,150	300	0	65,000
Indicative theoretical potential (TWh/yr)	...	144.64	9.14	1.05	...	154.83

... = data not available, km^2 = square kilometer, m/s = meter per second, MW = megawatt, TWh = terawatt-hour, yr = year.
[a] Assuming a wind turbine installation density of 10 MW/km^2.
Sources: World Bank (2001); Lahmeyer International.

part of the country have wind resources of medium intensity. Wind speeds range from 6 to 7 m/s over about 6,155 km^2 and between 7 and 8 m/s over about 315 km^2 and would therefore be sufficient for wind turbines; combined, however, these areas represent only 3% of Cambodia's total land area.

Given the land area with sufficient wind speeds, Cambodia has a theoretical potential wind capacity of 65 GW and a potential production capacity of 154 TWh/yr.

Cambodia's technical wind energy potential (Table 4.2) is much less than the theoretical because of its low grid-connected system capacity. As detailed in Annex 2, the robustness of the grid system and its load configuration is a critical determinant of the technical potential for wind energy. It is estimated that Cambodia's technical potential is 18 MW at the lower limit (5% of grid capacity) or 72 MW at the upper limit (20% of grid capacity).

To assess the portion of technical potential that could be economically feasible, the estimated LCOE of wind energy was compared with the current cost of alternative energy sources. As noted earlier, Cambodia has the highest energy prices in Southeast Asia, ranging from $0.18/kWh up to $1/kWh in the rural areas. Most of the wind resources in Cambodia have an estimated LCOE of $0.077/kWh–$0.114/kWh. At these electricity rates, grid-accessible areas with a wind resource of more than 6 m/s could be considered as potentially economically feasible. Wind energy would also be possible in off-grid areas, but on a small-scale basis.

So far, only one wind project, a single wind turbine installed in Sihanoukville in 2010, has been pilot-tested in Cambodia. The project, supported by Sihanoukville's port authority (48%), Belgium (28%), and the European Union (24%), supplements energy from diesel generators for the town.

In summary, wind energy in Cambodia is limited by the lack of adequate wind and the weakness of the grid system. Nonetheless, there are areas where wind energy would be viable on a competitive basis.

4.4 Biomass and Biofuel Energy Resources

The use of biomass or biofuel as a source of low-carbon renewable energy is at the planning or initial implementation stage in Cambodia. Biomass and biofuel resources have two variants. The simpler variant is the use of agricultural residues for household cooking and heating and for commercial purposes to generate electricity. The other is the growth of oilseed crops to produce biodiesel, and sugar- or starch-concentrate crops to produce bio-ethanol.

4.4.1 Energy Potential of Agricultural Residues

Greater use of agricultural residues as a source of energy would help lessen the unsustainable dependence on forest resources in the rural areas of Cambodia. Business Monitor International (2011) has estimated that the burning of wood and other organic fuels accounted for 75% of primary energy demand in 2010.

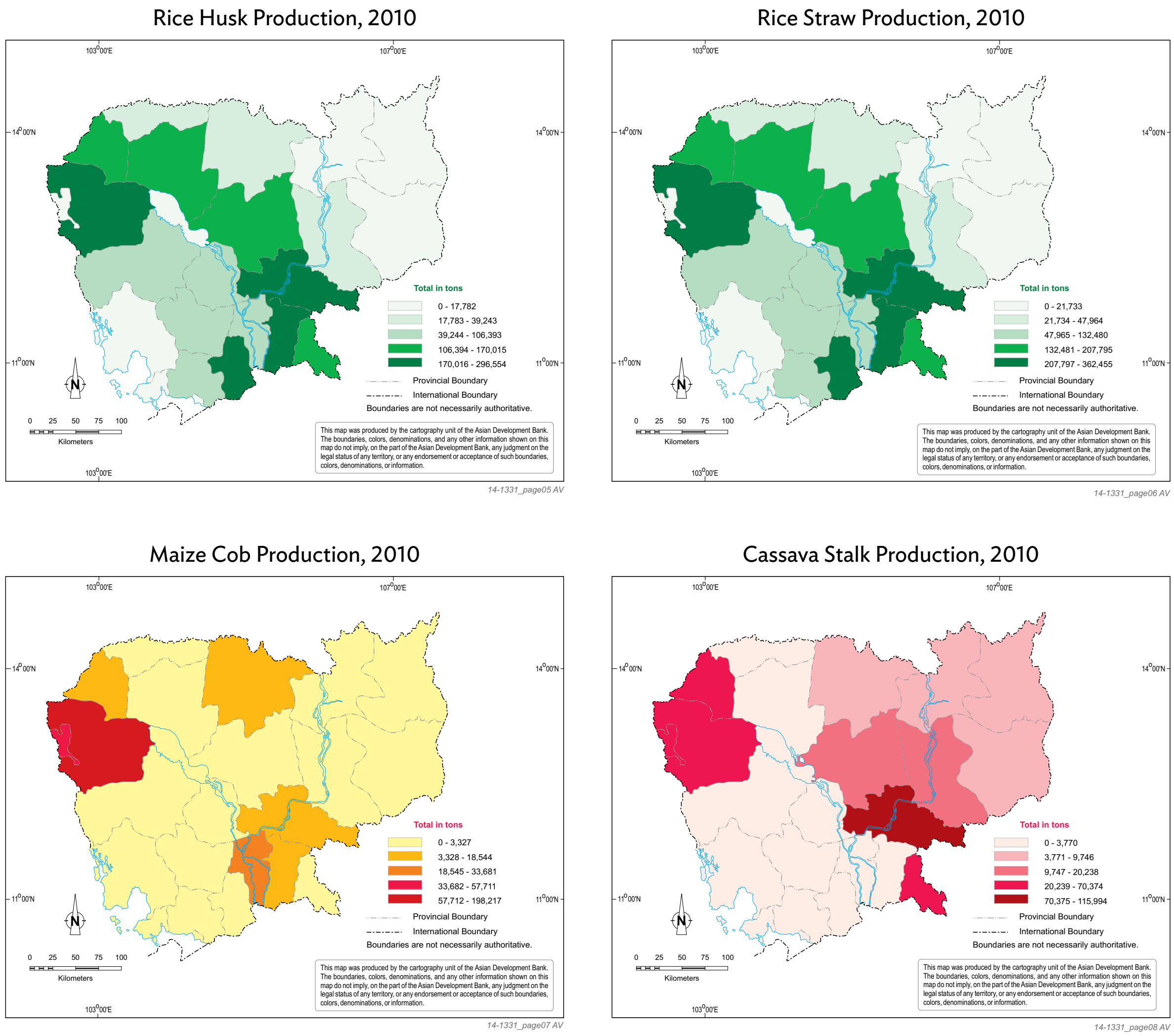
Agricultural residues are a ready source of energy in Cambodia, where some 80% of the population is rural and dependent on agriculture. About 30% of the country's gross domestic product (GDP) comes from agriculture, and over half of agricultural output, from crop production. Rice is the most important crop, followed by maize, cassava, mung bean, and soya bean. Most households have landholdings of less than 1 ha and crop yields are low: while the total area devoted to rice cultivation in 2010 was 2.8 million ha, yields averaged less than 3 tons of paddy per hectare. To raise crop productivity, the government built and supported the maintenance of irrigation facilities, upgraded water resource management, made fertilizer more accessible to local farmers, introduced higher-yield seeds, and increased mobility by improving transport connectivity. Since 2000, rice and sugarcane production has doubled, cassava production has increased tenfold, and maize production is four times as large.

The predominance of rice production in Cambodia contributes to the high availability of rice residues, such as rice husk and rice straw. These residues could be an option for a variety of biomass energy systems. Maize and its residue, the second-largest crop after rice, is also a suitable feedstock for several energy generation methods.

Map 4.3 shows the rice, maize, and cassava crop residues by province for Cambodia, in tons of residue.

As summarized in Section 3 and detailed in Annex 3, the energy potential of agricultural residues depends on specific residue-to-product ratios (RPRs), the energy use factor, surplus availability, and the heating value of the biomass. Also of importance is the geographic concentration of the biomass residues. Long-distance transportation of biomass residues limits their economic value. Cambodia's population is heavily concentrated (70%) along the lowland corridor from the Thai border in the northwest to the Vietnamese border in the southeast. Rice, maize, and sugarcane production is concentrated along this corridor. Large-scale mills for processing these crops offer the potential for power generation from biomass residues.

Map 4.3: **Main Crop Residues: Cambodia**



Source: Ministry of Agriculture, Forestry and Fisheries, Cambodia.

Data for 2010 obtained from the Ministry of Agriculture, Forestry and Fisheries (MAFF) was used to estimate the annual potential of biomass energy from the combustion of rice husk, rice straw, corn cob, cassava stalk, and sugarcane bagasse. Residue-to-product ratios were drawn from international studies and data from the Lao PDR and Thailand. As shown in Table 4.3, the annual theoretical biomass energy potential of agricultural residues is about 15,000 GWh. Residues from rice crops account for more than 80% of this potential.

4.4.2 Biofuel Energy Potential of Biodiesel and Bio-ethanol

Because of its heavy reliance on agriculture and relatively large land area suitable for agriculture, Cambodia has considerable theoretical potential for bio-ethanol and

Table 4.3: **Theoretical Biomass Energy Potential of Agricultural Residues: Cambodia**

Biomass Residue	Total Yearly Biomass Production (10^3 tons)	Total Theoretical Energy Potential (10^6 GJ)	Total Theoretical Energy Potential (GWh)
Rice husks	2,227	28.62	7,950
Rice straw	2,722	16.44	4,567
Maize or corn cobs	356	5.11	1,421
Cassava stalks	374	2.59	718
Sugarcane tops and trash	110	0.74	206
Sugarcane bagasse	91	0.59	163

GJ = gigajoule, GWh = gigawatt-hour.

Sources: Lahmeyers International; MAFF (2010).

biodiesel production. However, in light of the large tracts of land that would be needed and Cambodia's vulnerable rural population, biofuel targets must be conservative and pursued with safeguard provisions.

The Cambodian Working Group for Analysis of Energy Saving Potential in East Asia, under the Economic Research Institute for ASEAN and East Asia (ERIA), has proposed the following biofuel targets: "by 2030, 10% of road transport diesel and 20% of road transport gasoline will be displaced respectively by biodiesel and bio-ethanol" (ERIA 2013). Meanwhile, Cambodia is expected to develop plans and policies for achieving these targets.

In light of the projected increase of almost 5% yearly in the consumption of transport fuel, Cambodia's consumption of diesel is expected to reach 1.3 billion kilotons of oil equivalent per year (ktoe/yr) by 2030, and its consumption of gasoline, 493 million ktoe/yr. If the 10% and 20% displacement targets cited above were to be applied to these results, Cambodia would have to produce 131 million liters of biodiesel and almost 100 million liters of bio-ethanol by 2030.

A number of academic research organizations, nongovernment organizations, and development agencies[9] have initiated pilot biodiesel projects and supported private sector plantations providing the feedstocks for biodiesel and bio-ethanol. In particular, the International Institute for Energy Conservation (IIEC) has been working with Cambodian partners since 2007 to develop a sustainable business model for off-grid rural electrification based on biofuel. This project is being undertaken in partnership with the Energy Sector Management Assistance Program of the World Bank. The IIEC has analyzed the possibility of biofuel substitution in diesel-based electricity generation systems. The Japan Development Institute has looked into promoting Jatropha-based biofuel for

[9] For example, the Royal University of Agriculture, the Institute of Technology of Cambodia, the Japan Development Institute, the Japan Bio-Energy Development Corporation, the International Institute for Energy Conservation, the World Bank, and ADB.

electricity generation, and the Japan BioEnergy Development Corporation (JBEDC) has established a bioenergy development company in Cambodia, initially investing in a 200 ha Jatropha plantation. The Cambodian Council of Ministers has also requested JBEDC to help develop a bioenergy plan and regulatory framework.

An MIME report in 2012 noted that more than 10 companies, mostly small-scale, have about 1,000 ha in Jatropha plantations. A Korean company is producing about 36,000 liters per year of ethanol from 100,000 tons of cassava. MIME also reported current biofuel production from 4,000 ha of palm oil, with plans to extend this up to 10,000 ha. About 20,000 ha of sugarcane could be an additional source of biofuel.

Research and biofuel projects so far point to the use of *Jatropha curcas* for biodiesel, and cassava for bio-ethanol. *Jatropha curcas* grows commonly in Cambodia, even in marginal soils. Its seeds contain up to 35% nonedible oil, which is similar in energy content to diesel oil and can thus be substituted directly in most types of diesel engines. The oil can also be used for a range of other applications, such as lubrication, and the seedcake residue can be used as a high-grade fertilizer.

Crop productivity and oilseed yields are important determinants of Cambodia's biofuel potential. Estimates concerning this vary widely.[10] An environmental assessment conducted in 2010 in the Lao PDR reported Jatropha seed yields of 2 tons per hectare per year. Field tests and practical field experience accumulated by experts in the GMS indicate an extraction ratio of 0.9 and a seed oil content factor of 0.35 per ton of Jatropha seeds. These data were used to calculate the amount of hectares in *Jatropha curcas* needed to reach Cambodia's 10% displacement target for diesel. In view of the findings that 131 million liters of biofuel would be needed to meet the diesel displacement target, and given a crude oil–biodiesel conversion factor of 0.94, the amount of Jatropha-based oil required to meet the target would be 140 million liters. If it is assumed that Jatropha seed yields average 2 tons per hectare and the extraction ratio is 35%, more than 400,000 tons of Jatropha seeds would have to be produced yearly by 2030. Since Cambodia's crop productivity is generally low, somewhat more than 200,000 ha would need to be committed to *Jatropha curcas* cultivation for biodiesel purposes; this is about 2,000 km of land, or 3.6% of Cambodia's agricultural land (55,550 km^2).

Cassava cultivation would have to continue to rise sharply to meet the bio-ethanol target. Currently, about 337,000 ha of land is under cassava cultivation, or double the level in 2008, reflecting increased foreign investment by the People's Republic of China (PRC) and the Republic of Korea to expand cassava production for energy purposes. Cambodia's first ethanol factory is a joint venture with a Korean company; it has a design output of 36,000 tons (~36 million liters) of ethanol fuel annually. To sustain this output, the plant requires about 100,000 tons of dry cassava flour each year (or roughly 400,000 tons of

[10] One study (Heller 1996) estimated seed yield of 3 tons per hectare per year, producing about 0.8 ton of Jatropha oil (at 28% to 42% Jatropha oil content in the seeds). The Plant Research International of Wageningen in the Netherlands reports between 0.5 and 12 tons per hectare per year, depending on soil conditions, temperature, and rainfall amounts. The University of Hohenheim in Germany has reported seed yield ranging from 1 to 3 tons per hectare per year in conditions of poor soils, low nutrient content, cold temperatures, and low rainfall.

cassava).[11] Cambodia's conversion ratio of 90 liters of bio-ethanol per ton of cassava is low compared with Thailand's 180 liters per ton and other international benchmarks.[12] The fuel is exported to European markets, as the Cambodian market for ethanol products is currently very limited. However, in step with the government's bio-ethanol targets, a shift is under way to develop the domestic market for ethanol.

In estimating the quantity of cassava production needed to meet the gas displacement target of almost 100 million liters by 2030, the following assumptions were made:

- cassava yield of 20 tons per hectare;
- cassava-to-bio-ethanol conversion factor of 150 liters per ton (assuming improved variety of feedstocks and improved technological processing); and
- overall harvest of 660,000 tons of cassava.

On this basis, some 33,000 ha would need to be committed to cassava production for bio-ethanol purposes. Given the already extensive area under cassava cultivation and Cambodia's experience so far with ethanol production, the 20% gas displacement target would appear to be achievable. If cassava crop and conversion yields were to improve considerably, only some 27,000 ha would be needed for this purpose. On the other hand, if crop and conversion yields do not improve, the amount of land required would be substantially more than 33,000 ha.

4.4.3 Impediments to Biofuel Development

Biofuel development in Cambodia is impeded by the following factors:

- Dependence on foreign technology through joint ventures and partnerships with foreign companies (from the Republic of Korea, Thailand, and Viet Nam, among others). Equipment for biofuel factories is imported, and where secondhand equipment is used frequent maintenance and repair is required.
- Lack of skilled personnel and training facilities. There is a lack of skilled labor in Cambodia; biofuel production companies need to hire engineers and other technical staff from either Thailand or Viet Nam. There is also a lack of Cambodian experts to train the local staff.
- Limited information and lack of technical standards for biofuel blending. The use of bioenergy has been generally limited to pilot projects and other small-scale applications. There is need for more research and development (R&D) programs in the use of biofuel blends in the transport sector.
- Inadequate or limited access to capital, as well as lack of technical and financial support.
- Lack of a mandatory policy for use of biofuels and lack of specific targets on production and use of biofuels.
- Concerns regarding land-use rights and displacement of farm households by domestic and foreign plantation developers.

[11] According to the FAO, a ton of cassava flour can be derived from 4 to 5 tons of cassava (roots).

[12] Ministry of Energy, Thailand, 2012. Indonesia has reported a ratio of 155 liters per ton.

In summary, there is strong potential for biofuel production in Cambodia and the government's 2030 targets for biodiesel and bio-ethanol appear achievable. While providing the feedstocks to meet the targets would mean devoting some 230,000 ha to *Jatropha curcas* and cassava cultivation, this allocation is possible if managed in the public interest and safeguard standards apply to affected farm households.

4.5 Biogas Energy Resources Potential

Biogas, particularly that from livestock manure, is another renewable energy option for Cambodia.

Cambodia's biogas programs promote the use of cattle, buffalo, and pig manure as biogas feedstock, particularly for household cooking and electricity generation. The potential for biogas production in Cambodia is high.

As detailed in Annex 4, the theoretical potential for biogas production is based on the daily amount of available animal manure as feedstock for biodigesters. The technical potential is estimated based on a minimum number of livestock per household, below which biogas production is deemed unworkable. The market potential is projected on the basis of the biogas promotion targets and programs of Cambodia, which include incentives for households and commercial livestock farms to generate biogas for domestic use and commercial energy production.

Smallholders dominate livestock raising in Cambodia and their livestock usually roam freely; stabling during the day or night is not usual. According to MAFF data, Cambodia's livestock population in 2011 consisted of 3.4 million cattle, 2.1 million pigs, 700,000 buffalo, and 22 million poultry. Except in the case of poultry, the livestock population has increased by less than 10% over the past decade. On the basis of this livestock data and conversion factors for biogas yields from different animal manure substrates, described in Annex 4, the theoretical energy potential for biogas production was calculated for each livestock group. According to Table 4.4, Cambodia could produce as much as 4.5 million cubic meters of biogas daily. However, this theoretical production level greatly overstates

Table 4.4: **Theoretical Biogas Energy Potential, 2011: Cambodia**

Livestock	Number (million heads)	Daily Manure Production Factor (kg/animal)	Substrate Quantity (kg/day)	Dry Matter Factor (%)	Total Dry Matter Available (kg/day)	Mean Biogas Yield Factor (m^3/kg dry matter)	Daily Biogas Production (m^3/day)
Buffalo	0.69	8.00	5,512,000	16	881,920	0.250	220,480
Cattle	3.41	8.00	27,248,000	16	4,359,680	0.250	1,089,920
Pig	2.10	2.00	4,198,000	17	713,660	4.200	2,997,372
Chicken	22.04	0.08	1,762,880	25	440,720	0.575	253,414
Total							**4,561,186**

kg = kilogram, m^3 = cubic meter.

Source: Authors' calculations.

the potential. Among the limiting factors are the nature of farming and the lack of stabling in Cambodia, and hence the limited availability of animal dung for biodigesters.

Although the theoretical level greatly overstates the potential, the National Biodigester Programme of Cambodia reports very favorable conditions for biodigesters, including the country's warm climate, the availability of biodigester input (water and dung), the local availability of construction materials and technical skills for plant installation, and the competitiveness of biogas, given the high price of electricity and the lack of alternative energy sources in the rural areas. However, as already noted, the technical potential for biogas production in Cambodia is limited by the nature of farming practices and their small-scale. Estimates of the technical potential are based on feasibility studies made by SNV in Cambodia in 2004 and in the Lao PDR in 2006. SNV (2006) estimated that household biogas plant systems require stabling at least three to nine cattle or buffalo during part of the day or night to ensure sufficient manure collection of at least 20 kilograms (kg) per day. If pig manure is the feedstock, households should have 7 to 30 mature pigs. As shown in Table 4.5, the calculation of the technical energy potential of biogas in Cambodia was derived from the number of farm holdings with sufficient livestock.

Although Cambodia has favorable conditions for biogas production, its experience with biogas projects has been mixed. In 2004, it was reported that most biodigesters (some 400 had been installed up to that time) were not operating because of the low quality of the biodigesters and lack of support. In 2006, the SNV/MAFF National Biodigester Programme was established with the target of distributing high-quality biodigesters to 18,500 families in 12 provinces.

Table 4.5: **Technical Biogas Energy Potential: Cambodia**

Livestock	No. of Households Considered[a]	Ave. No. of Animals per HH[b]	Daily Manure Production Factor (kg/animal)	Substrate Quantity (kg/day)	Dry Matter Factor (%)
Cattle and buffalo	539,292	6.5	8	28,043,202	16
Pigs	66,725	12.0	2	1,601,400	17
Total					

Livestock	Net Dry Matter Available (kg/day)	Biogas Yield Factor (m^3/kg)	Daily Biogas Production (m^3/day)	Energy Content per Day[c] (kWh/m^3)	Energy Content per Day[d] (GJ/m^3)
Cattle and buffalo	4,486,912	0.25	1,121,728	6,730,369	24,229
Pigs	272,238	4.20	1,143.400	6,860,398	24,697
Total	**4,759,150**		**2,265,128**	**13,590,766**	**48,927**

GJ= gigajoule, HH = household, kg= kilogram, kWh= kilowatt-hour, m^3= cubic meter

[a] The households considered were those with 3 or more buffalo and cattle, or more than 10 pigs.

[b] Figure derived by taking the mean average of household groups considered in the No. of Households column.

[c] Based on 1 cubic meter (m^3) of biogas = 6 kilowatt-hours (kWh) per cubic meter.

[d] Based on 1 kWh = 3.6 megajoules (MJ).

Source: SNV 2006. Lahmeyer International.

4.6 Summary of Renewable Energy Potential and Developments

Cambodia is lagging behind other Southeast Asian countries in the development of renewable energy resources, partly because of a lack of experience, funds, and data. Renewable energy initiatives mainly take the form of research and demonstration projects. While renewable energy is strongly encouraged by the government, appropriate policies and financial support are still evolving.

Electricity prices in Cambodia are very high, thereby opening opportunities for the development of solar, wind, biofuel, and biogas options. Cambodia has substantial solar resources that could be harnessed on a competitive basis. The government, supported by the World Bank, is now installing 12,000 solar household systems. Attention to maintenance support will be needed for sustainable results. Wind energy in Cambodia is limited by inadequate wind speeds and the weakness of the grid and load system. Nonetheless, there are areas where wind energy would be cost competitive, as the pilot wind turbine project in Sihanoukville.

The biomass energy potential of rice, maize, and other agricultural residues is concentrated along the lowland corridor from the Thai border in the northwest to the Vietnamese border in the southeast. Large-scale processing mills for these crops offer the potential for power generation from agricultural residues. The government's long-term target of producing biodiesel and bio-ethanol to displace 10% of diesel consumption by 2030, and 20% of gas consumption, appears achievable. Some 230,000 ha would need to be devoted to *Jatropha curcas* and cassava cultivation to provide the feedstocks for production. Cambodia's biogas potential from animal manure is largely limited to generation at the household level, given the small land and livestock holdings of most farmers. Since 2006, improved biodigesters and backup services have been provided to 18,000 households.