RENEWABLE ENERGY DEVELOPMENTS AND POTENTIAL IN THE GREATER MEKONG SUBREGION

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Note: In this report, "$" refers to US dollars, B is baht, MK is Myanmar kyat, and VND is Vietnamese dong.

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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.

James A. Nugent
Director General
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Acknowledgments

The Asian Development Bank (ADB) carried out the regional technical assistance project in collaboration with the following government agencies: the Ministry of Mines and Energy, Cambodia; the Ministry of Energy and Mines, the Lao People's Democratic Republic; the Ministry of Energy, Myanmar; the Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand; and the Electricity Regulatory Authority of Viet Nam.

In ADB, Jong-Inn Kim, lead energy specialist, Energy Division, Southeast Asia Department (SERD), initiated the report and gave technical advice. Peer reviewers of this report were Neeraj Jain, senior advisor, Office of the Director General, SERD and Hyunjung Lee, energy economist, Energy Division, SERD. Ma. Trinidad Nieto, associate project analyst, Energy Division, SERD, provided administrative support during the implementation of the technical assistance project. David Husband served as economics editor and Maria Cristina Pascual as publishing coordinator. James Nugent, director general, SERD, and Chong Chi Nai, director, Energy Division, SERD, provided guidance in the preparation of this report.

Lahmeyer International GmbH, headquartered in Germany, was contracted by the Asian Development Bank to assess the low-carbon renewable and energy efficiency potential in five of the Greater Mekong Subregion countries (Cambodia, the Lao PDR, Myanmar, Thailand and Viet Nam). Further, Lahmeyer International lead a series of workshops in the five countries, to share experiences and to advance technical knowledge on the opportunities and challenges. The assessment of renewable and energy efficiency potential in the subregion was based on earlier reports, secondary research, and available data. The assessment included review of business models to operationalize the identified opportunities. Because of changing weather patterns and data uncertainties, Lahmeyer recommends that the research and findings - particularly those pertaining to renewable energy - be used as indicative guidelines rather than as a basis for specific investments.

Abbreviations

ADB	–	Asian Development Bank
AEDP	–	Alternative Energy Development Plan (Thailand)
ASEAN	–	Association of Southeast Asian Nations
BOI	–	Board of Investments (Thailand)
PRC	–	People's Republic of China
DEDE	–	Department of Alternative Energy Development and Efficiency (Thailand)
DNI	–	direct normal irradiation
EDC	–	Electricité du Cambodge
EdL	–	Electricité du Laos
EGAT	–	Electricity Generating Authority of Thailand
EPPO	–	Energy Policy and Planning Office (Thailand)
EVN	–	Electricity of Viet Nam
FAO	–	Food and Agriculture Organization of the United Nations
GDP	–	gross domestic product
GHI	–	global horizontal irradiation
GMS	–	Greater Mekong Subregion
IPP	–	independent power producer
Lao PDR	–	Lao People's Democratic Republic
LCOE	–	levelized cost of electricity
LIRE	–	Lao Institute for Renewable Energy
MAF	–	Ministry of Agriculture and Forestry (Lao PDR)
MAFF	–	Ministry of Agriculture, Forestry and Fisheries (Cambodia)
MARD	–	Ministry of Agriculture and Rural Development (Viet Nam)
MEM	–	Ministry of Energy and Mines (Lao PDR)
MIME	–	Ministry of Industry, Mines and Energy (Cambodia)
MOAC	–	Ministry of Agriculture and Cooperatives (Thailand)
MOAI	–	Ministry of Agriculture and Irrigation (Myanmar)
MOE	–	Ministry of Energy (Myanmar, Thailand)
MOEP	–	Ministry of Electric Power (Myanmar)
MOF	–	Ministry of Finance (Viet Nam)
MOIT	–	Ministry of Industry and Trade (Viet Nam)
MOST	–	Ministry of Science and Technology (Myanmar)
NEDO	–	New Energy and Industrial Technology Development Organization (Japan)
NEDS	–	National Energy Development Strategy (Viet Nam)
NEPC	–	National Energy Policy Council (Thailand)
PV	–	Photovoltaic
R&D	–	research and development
REE	–	rural electricity enterprise
REF	–	Rural Electrification Fund (Cambodia)

RPR	–	residue-to-product ratio
SHS	–	solar household system
SNV	–	Netherlands Development Organization
WTG	–	wind turbine generator

Weights and Measures

GW	–	gigawatt
GWh	–	gigawatt-hour
ha	–	hectare
kg	–	kilogram
km^2	–	square kilometer
kW	–	kilowatt
kWh	–	kilowatt-hour
kWp	–	kilowatt-peak (unit most commonly used for measuring the maximum output of a solar energy plant)
kWp/m^2	–	kilowatts-peak per square meter (average installable capacity)
m/s	–	meter per second (wind speed measurement unit)
MLPD	–	million liter per day
MW	–	megawatt
MWh	–	megawatt-hour
MW/km^2	–	megawatt per square kilometer (measure of power density: amount of power produced per unit volume)
MWp	–	megawatt-peak (unit for measuring the maximum output of a solar energy plant)
TWh/yr	–	terawatt-hour per year (a measure of theoretical production capacity)

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.

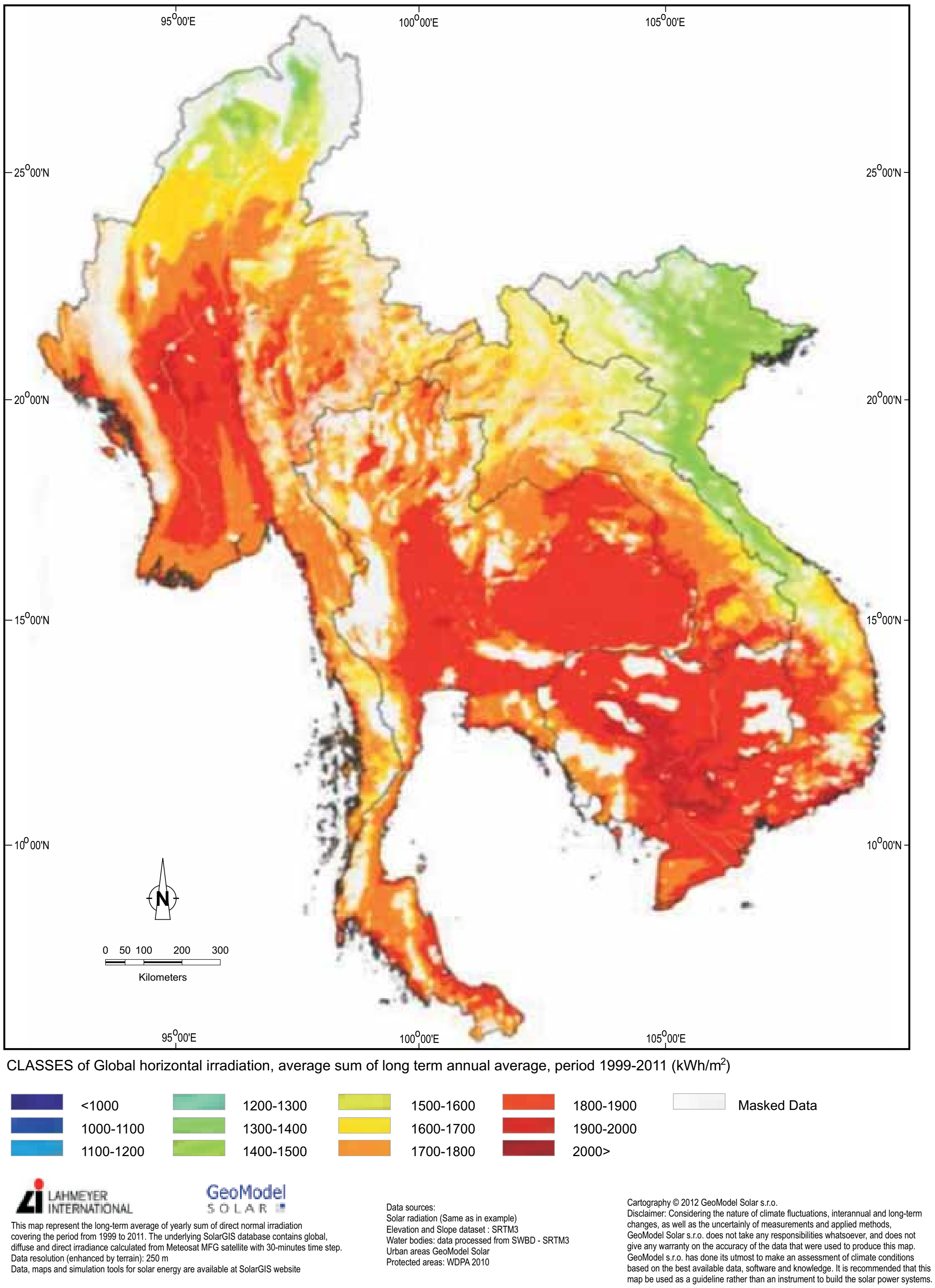
The potential for solar energy is based largely on the degree of solar irradiation, the estimated land area suitable for PV development, and the efficiency of the solar energy systems. This potential can be assessed in theoretical, technical, and economic terms. The theoretical potential is the upper 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.

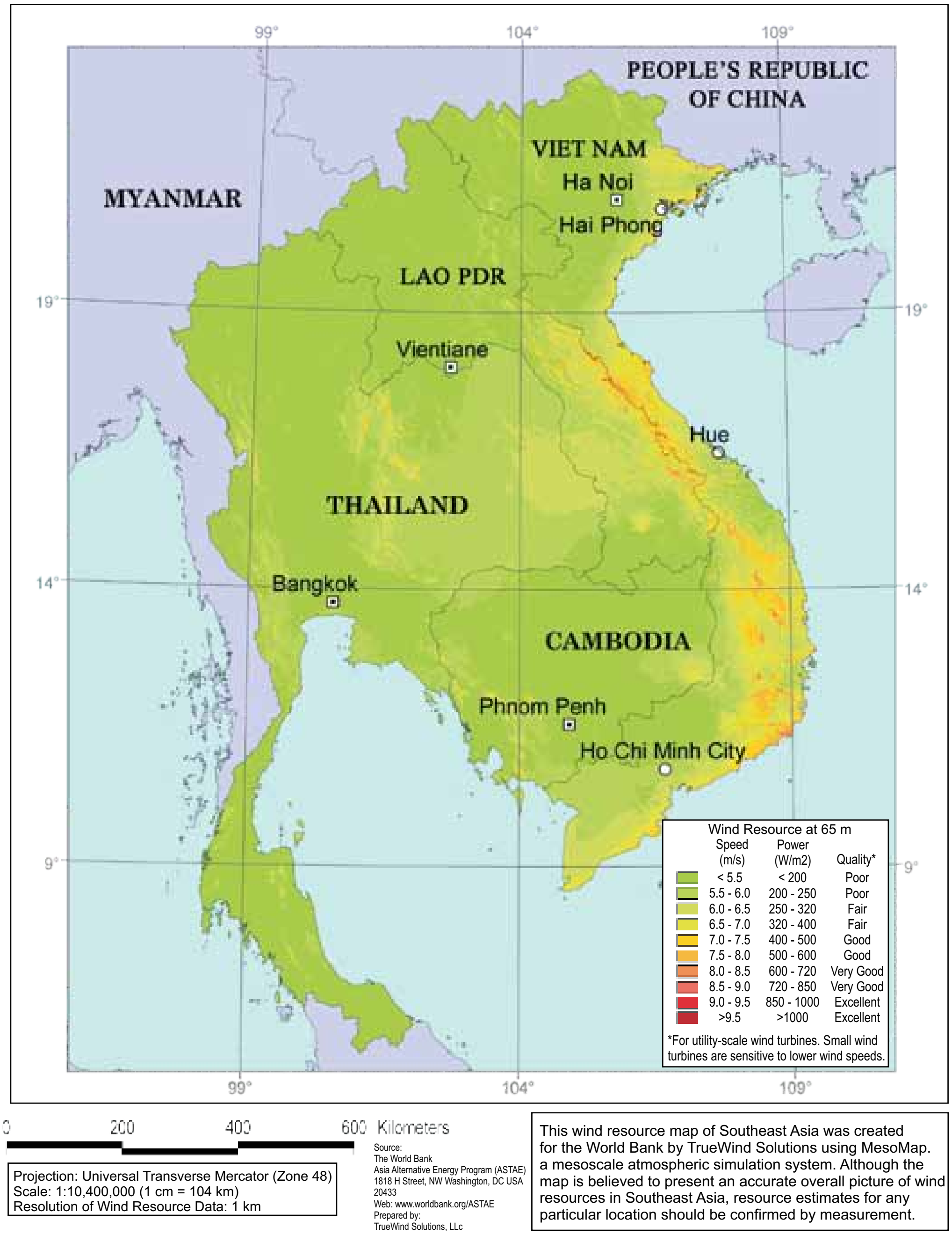
Wind energy potential is similarly assessed in terms of the theoretical, technical, and economic potential. To calculate wind power potential, average wind speeds over specific land areas, in meters/second (m/s), and wind turbine generator (WTG) installation capacity (or wind power density), in megawatts 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.

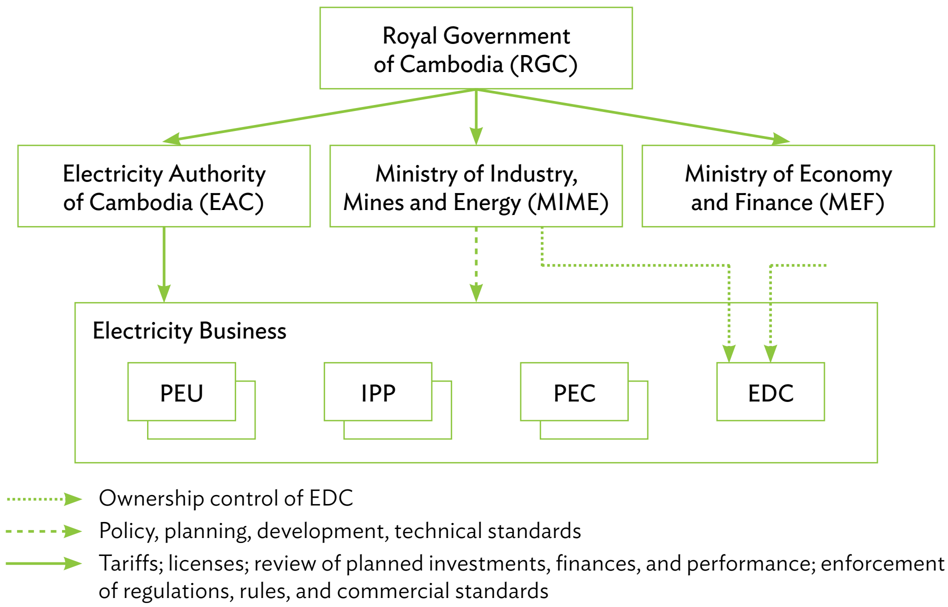
Cambodia has an estimated hydropower potential of 10,000 MW, but only 223 MW has been installed (MIME 2012). It has one of the lowest degrees of electrification in Asia, with annual per capita consumption of electricity of only about 160 kWh. Cambodia imports electricity from the Lao PDR, Thailand, and 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.

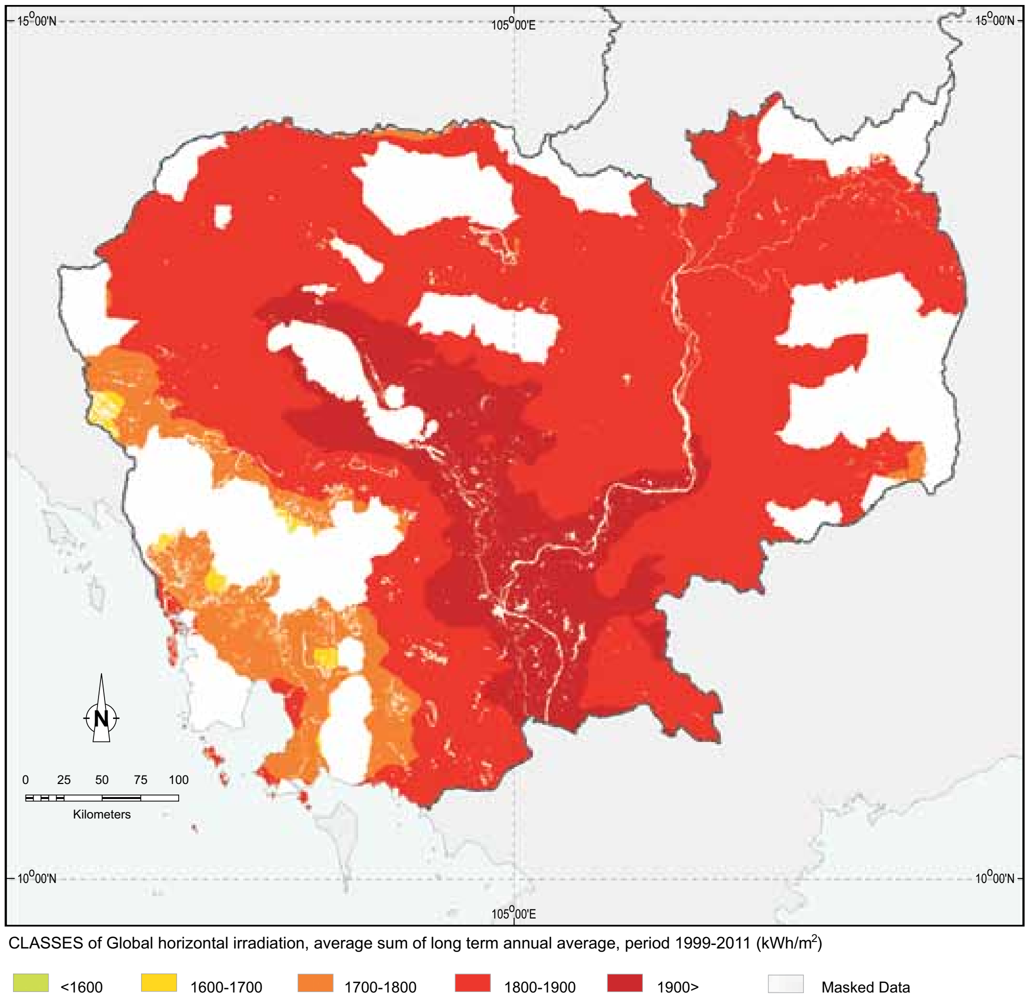
The maximum technical solar energy potential of Cambodia is estimated to be just under 12 TWh/yr,[8] the vast majority which would be generated in areas within the 1,800–1,900 GHI range.

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**



LAHMEYER INTERNATIONAL

GeoModel SOLAR

This map represent the long-term average of yearly sum of direct normal irradiation covering the period from 1999 to 2011. The underlying SolarGIS database contains global, diffuse and direct irradiance calculated from Meteosat MFG satellite with 30-minutes time step.
Data resolution (enhanced by terrain): 250 m
Data, maps and simulation tools for solar energy are available at SolarGIS website

Data sources:
Solar radiation (Same as in example)
Elevation and Slope dataset : SRTM3
Water bodies: data processed from SWBD - SRTM3
Urban areas GeoModel Solar
Protected areas: WDPA 2010

Cartography © 2012 GeoModel Solar s.r.o.
Disclaimer: Considering the nature of climate fluctuations, interannual and long-term changes, as well as the uncertainly of measurements and applied methods, GeoModel Solar s.r.o. does not take any responsibilities whatsoever, and does not give any warranty on the accuracy of the data that were used to produce this map. GeoModel s.r.o. has done its utmost to make an assessment of climate conditions based on the best available data, software and knowledge. It is recommended that this map be used as a guideline rather than an instrument to build the solar power systems.

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 (km^2)	Potential Suitable Area ('000 km^2)	% of Total Area	Technical Potential		LCOE ($/kWh)
			MWp	MWh/yr	
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, km^2 = 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/m^2/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.

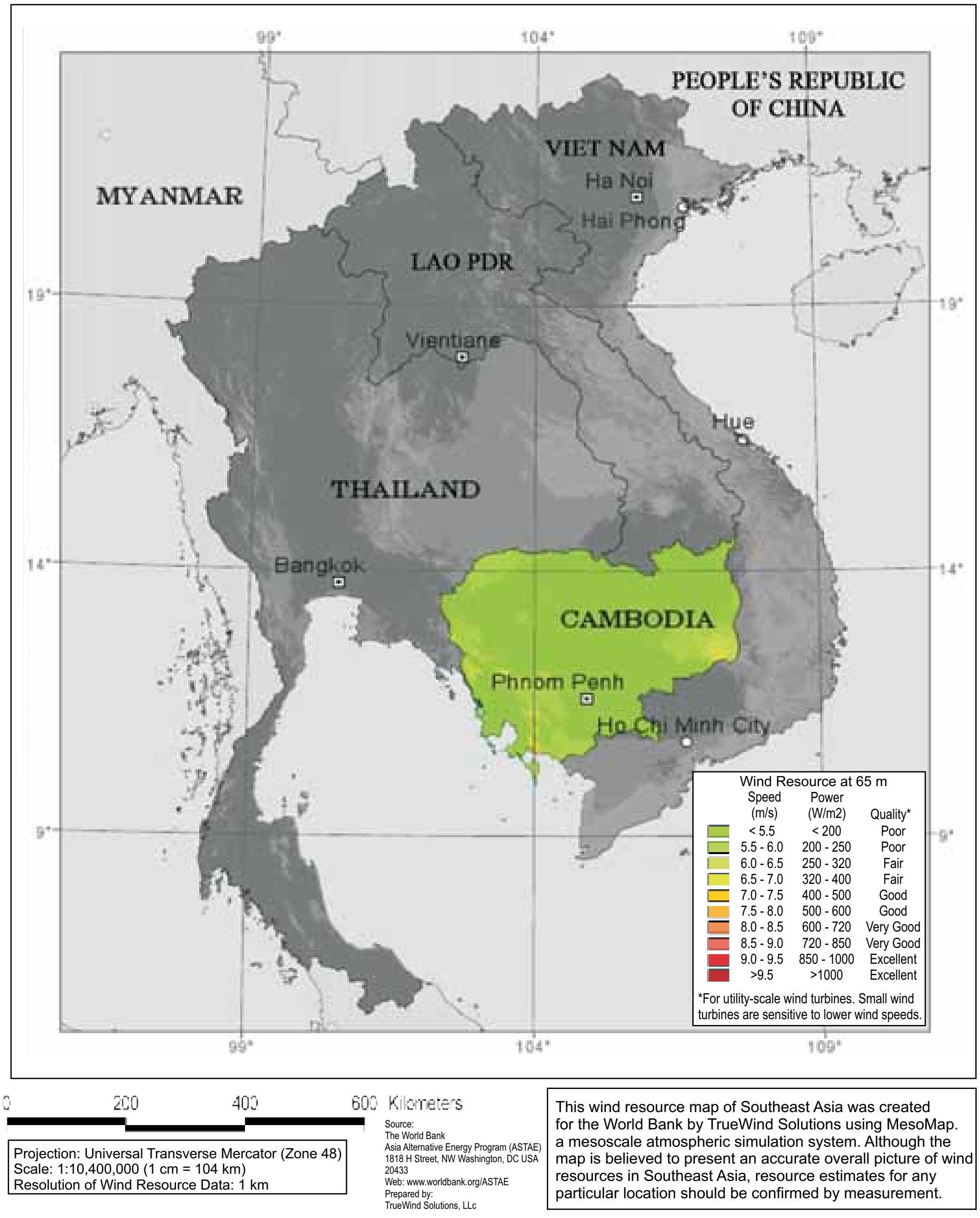
Solar development in Cambodia is in the pilot stage. As of 2012, the country had about 2 MWp of solar PV installed (Pock, 2013). A World Bank–funded project for 12,000 solar household systems is now being implemented by the Lao PDR company Sunlabob.

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: 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)	Total
Area (km^2)	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.

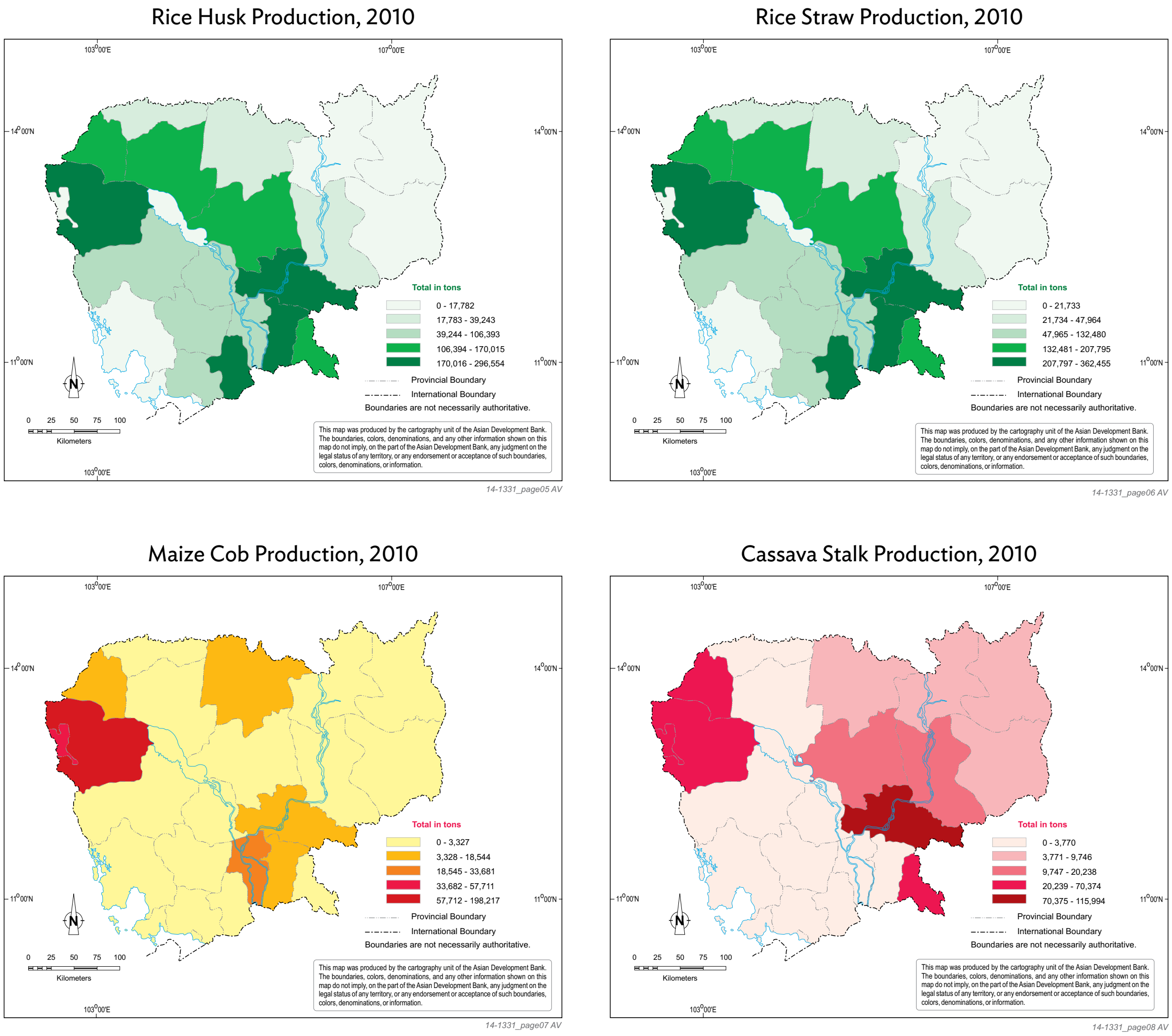
Agricultural residues are a ready source of energy in Cambodia, where some 80% of the population is rural and dependent on agriculture. About 30% of the country's gross domestic product (GDP) comes from agriculture, and over half of agricultural output, from crop production. Rice is the most important 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.

5 Renewable Energy Developments and Potential in the Lao People's Democratic Republic

5.1 Institutional and Policy Framework for Renewable Energy Initiatives

5.1.1 Institutional Arrangements

The Ministry of Energy and Mines (MEM) is the main agency responsible for the Lao PDR's energy sector (Figure 5.1). The Department of Energy Policy and Planning sets national policies and regulations (including those for tariffs), monitors compliance by public and private energy suppliers, and develops strategic plans for generation, transmission, distribution, rural electrification, renewable energy development, and the export of energy. The Department of Energy Promotion and Development, on the other hand, negotiates agreements and other legal documents with hydropower investors and contractors.[13]

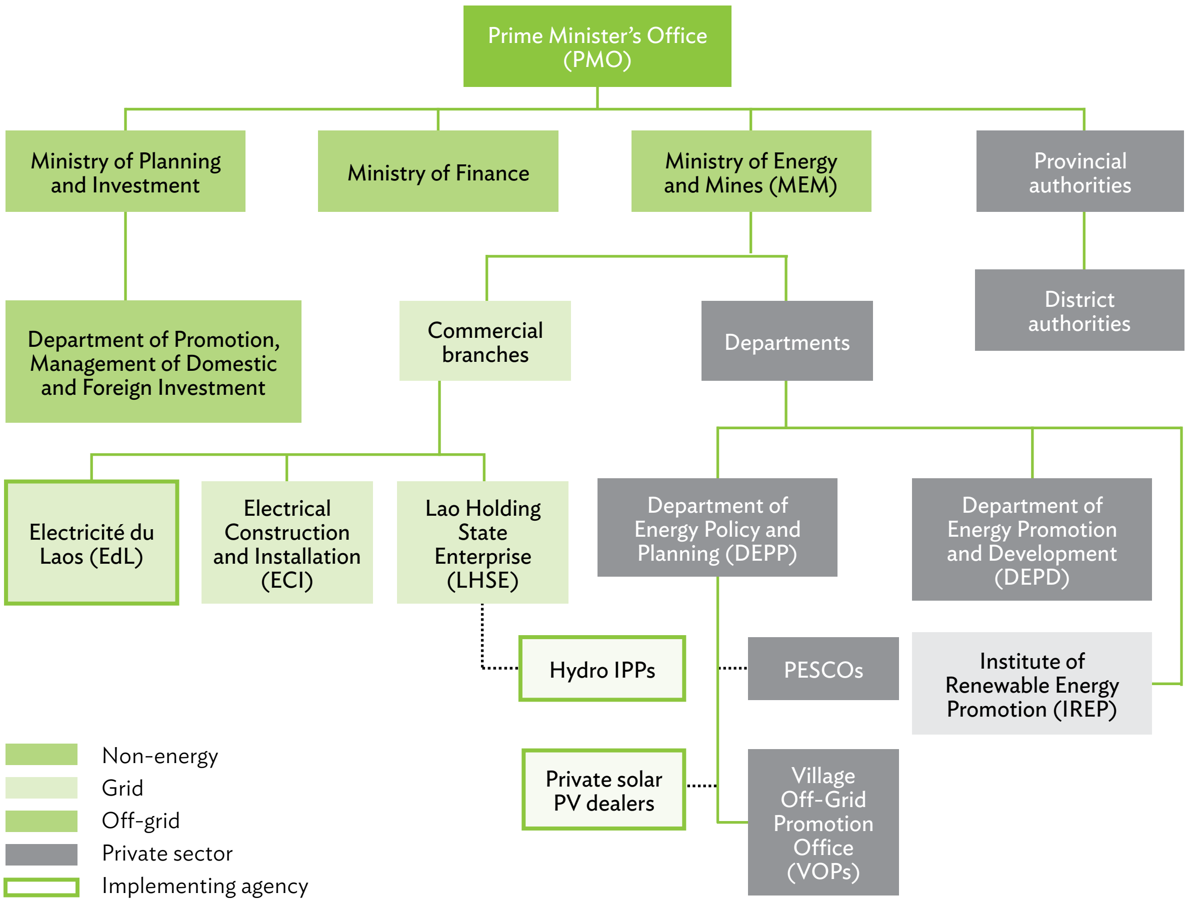
In addition, MEM is responsible for three state enterprises: (i) Electricité du Laos (EdL), a vertically integrated utility responsible for power generation, transmission, and distribution, as well as the management of electricity imports and exports; (ii) the Lao Holding State Enterprise, a special-purpose company holding the government's shares in export-oriented independent power projects; and (iii) the Electrical Construction and Installation Company, a construction contractor for EdL's distribution and transmission facilities. The Electricity Law (1997) provides the legal framework for private sector participation in generation through various modes of public–private partnerships.

EdL produces electrical power mainly through hydro-based generation and exports a part of it to Thailand. It operates four independent subregional grids, which are individually connected to Thailand's power grid. Large-scale independent power producers (IPPs) are mainly export dedicated but allocate 10% of their production for domestic use and are connected to EdL's network. Several medium-sized IPPs mainly serve the domestic market.

The Institute of Renewable Energy Promotion is the main agency responsible for the development and promotion of renewable energy. Its main functions are summarized in Box 5.1. In addition, the line ministries are expected to support renewable energy development and promotion, as summarized in Box 5.2.

[13] However, agreements with project developers and investors are signed by the Ministry of Planning and Investment.

Figure 5.1: **Energy Sector Institutional Framework: Lao PDR**



IPP = independent power producer, Lao PDR = Lao People's Democratic Republic, PESCO = Provincial Electricity Supply Company, PV = photovoltaic.

Source: Modified from World Bank (2012).

5.1.2 Renewable Energy and Rural Electrification Policy and Targets

In 2011, the government issued its Renewable Energy Development Strategy as a key component of the national socioeconomic development plan. Self-sufficiency, surplus production for export, and the participation of domestic and foreign investors in village-level projects are the main elements of the strategy. The focus is on small-power development for self-sufficiency and grid connection, biofuel production and marketing, and development of other clean energy sources.

The government supports renewable energy technologies by (i) providing financial incentives to investors in clean energies; and (ii) formulating and improving laws and regulations to facilitate renewable energy development.

Box 5.1: Functions of the Institute of Renewable Energy Promotion: Lao PDR

- Develop overall renewable energy policy and support the achievement of sustainable development goals,
- set objectives and goals based on resource potentials and develop a renewable energy database,
- carry out studies and demonstration projects on renewable energy technologies,
- formulate transparent market mechanisms and incentives to promote investment in renewable energy projects,
- promote capacity building for the development of renewable energy and strengthen the capacity of other government agencies,
- mainstream renewable energy in government policies and identify key issues for the public sector,
- raise awareness of the costs and benefits of renewable energy,
- facilitate compliance with the clean energy production targets of the Kyoto Protocol,
- expand subregional cooperation in renewable energy development and use,
- ensure fair access to the grid network for renewable energy projects,
- facilitate access to the revolving fund for renewable energy programs,
- encourage the development of renewable energy with the support of export credit agencies,
- seek solutions for improving the supply of electricity throughout the country,
- propose new financial mechanisms for renewable energy development,
- promote cooking and other domestic uses of renewable energy fuels,
- conduct feasibility studies on the development of alternative energies such as hydrogen, and
- monitor international research on renewable energy.

Lao PDR = Lao People's Democratic Republic.
Source: IREP (2011).

By 2025, the share of renewable energy sources in total energy consumption is projected to increase to 30%. In relative terms, this percentage share is more ambitious than those of Cambodia, Myanmar, Thailand, and Viet Nam. As shown in Table 5.1, mini-hydro projects and biofuels (biodiesel and bio-ethanol) are expected to be the main sources of renewable energy.

To meet these targets, the government has outlined the following plans for the short, medium, and long term:

- Short term (2010–2015): (i) develop framework laws, regulations, and guidelines for renewable energy projects; (ii) study development models; (iii) conduct market assessments and energy resource studies; (iv) advance rural energy planning; (v) develop model projects; (vi) facilitate capacity building and raise awareness of renewable energy technology; and (vii) support financing and marketing at both the national and local levels.

Box 5.2: Role of Line Ministries in Promoting Renewable Energy: Lao PDR

Ministry of Agriculture and Forestry, in collaboration with the Ministry of Natural Resources and Environment and provincial governments, carries out participatory land use planning and local land use zoning related to biomass crop production. Its provincial, district, and village cluster representatives promote biofuel development and provide extension services in cooperation with the Ministry of Energy and Mines (MEM).

Ministry of Natural Resources and Environment does research into the use of water resources and collaborates with the MEM in addressing concerns about the environmental and social impact of renewable energy development.

Ministry of Science and Technology conducts research into, and pilot-tests, renewable energy applications developed by other countries.

Ministry of Industry and Commerce facilitates the import of equipment and seeds related to the development of renewable energy, and supports the construction of gas stations for the distribution of biofuels.

Ministry of Public Works and Transportation promotes the use of alternative fuels in vehicles, public transportation systems, and freight and air transport.

Ministry of Finance determines appropriate tax and duty policies for renewable energy projects and helps raise funds for renewable energy development.

Central Bank of Lao PDR provides credit and low-interest loans for renewable energy projects.

Ministry of Planning and Investment formulates investment policies and incentives to attract and facilitate domestic and foreign investment in renewable energy projects.

Ministry of Culture and Tourism helps the public to understand better the government's energy efficiency and renewable energy development policies.

Ministry of Education and Sport encourages the development of the renewable energy curriculum and its integration into tertiary education.

Other sectors and provincial governments support the roles and responsibilities of these agencies.

Lao PDR = Lao People's Democratic Republic.
Source: IREP (2011).

- Medium term (2016–2020): (i) promote the renewable energy technology industry; (ii) formulate a clear midterm development plan; (iii) support the full development of biodiesel and bio-ethanol production from crops and the production of biogas from livestock manure; and (iv) increase competition and reduce dependence.
- Long term (2021–2025): (i) promote economically viable, renewable energy technologies; (ii) facilitate full competition; and (iii) promote Lao PDR as a biofuel exporter.

5.1.3 Incentive Framework

The government is currently reviewing its policy and regulatory frameworks for promoting the development and use of renewable energy by the private sector. At present, the

Table 5.1: **Renewable Energy Targets: Lao PDR**

Renewable Energy Types	Potential	Existing	2015		2020		2025	
	MW	MW	MW	ktoe	MW	ktoe	MW	ktoe
Electricity			140		243		728	416
Small hydropower	2,000	12	80	51	134	85	400	256
Solar	511	1	22	14	36		33	21
Wind	>40		6	4	12	23	73	47
Biomass	938		13	8	24	8	58	37
Biogas	313		10	6	19	16	51	33
Solid waste	216		9	6	17	12	36	23
Geothermal	59					11		
Biofuel	**ML**	**ML**	**ML**		**ML**		**ML**	
Ethanol	600		10	7	106	178	150	279
Biodiesel	1,200	0.01	15	13	205	239	300	383
Thermal Energy	**ktoe**	**ktoe**						
Biomass	227			23		29		113
Biogas	444			22		44		178
Solar	218			17		22		109
Total								
Energy demand (ktoe)				2,504		4,064		4,930
Renewable energy contribution				172		668		1,479
Proportion				7%		20%		30%

ktoe = kilotons of oil equivalent, Lao PDR = Lao People's Democratic Republic, ML = million liter, MW = megawatt.
Source: IREP (2011).

incentives available to renewable energy project developers are those included in the Law on the Promotion of Foreign Investment (2004):

- corporate income tax holidays of up to 7 years;
- exemption from import duties and taxes on raw materials and capital equipment;
- exemption from export duty on export products;
- 10% personal income tax for expatriate employees; and
- additional tax holidays and reduced tax rates for large projects with special concessions available by negotiation.

5.2 Solar Energy Resources Potential

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

Almost 40% of the Lao PDR's land area is unsuitable for large-scale solar PV installations because of the mountainous topography, particularly in the north. But the Lao PDR has medium solar resource potential, with GHI levels ranging between 1,200 and 1,800 kWh/m^2/yr. Most of the country has direct normal irradiation (DNI) ranging between 1,300 and 1,400 kWh/m^2/yr. Map 5.1 indicates the areas in Lao PDR that are potentially suitable for solar PV systems.

As shown in Table 5.2, Lao PDR's technical solar potential[14] is estimated to be 11.7 TWh/yr. The majority of this technical potential is in areas with GHI levels in the 1,500–1,800 kWh/m^2/yr range.

To assess the portion of technical potential that could be economically feasible, the estimated LCOE of solar power in the Lao PDR was compared with the current cost of other alternatives. Most solar power in the Lao PDR has an estimated LCOE of $0.18/kWh–$0.20/kWh. The import electricity tariff is $0.0617/kWh (ADB 2012); residential tariffs range from $0.034/kWh to $0.098/kWh, and commercial tariffs, from $0.4/kWh to $0.106/kWh. At these electricity rates, electrical power through solar PV is generally not a cost-effective option except for off-grid applications.

In summary, while much of the Lao PDR has suitable GHI intensities for solar PV generation, the mountainous topography, particularly in the north, limits the degree to which large-scale systems could be installed. The lack of grid systems connecting much of the rural population means that solar household systems are an option for those without other sources of electricity. Except for provisions under the Law on the Promotion of Foreign Investment (2004), support for solar power is lacking. According to the Lao Institute for Renewable Energy (LIRE), as of 2011, about 285 kWp of solar PV had been installed in pilot plants. About 20,000 solar home systems had also been installed (IREP 2011).

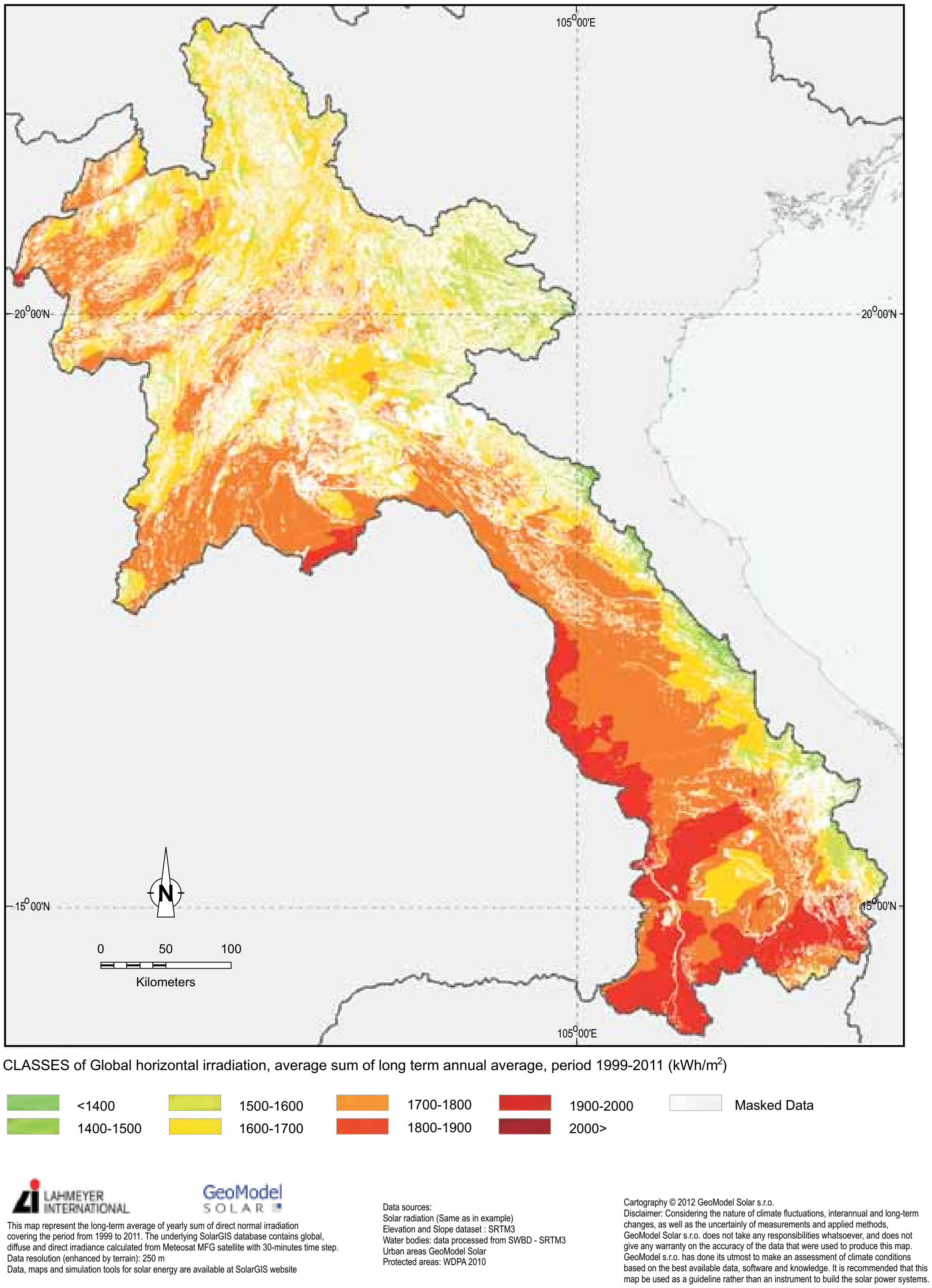
5.3. Wind Energy Resources Potential

As summarized in Section 3 and detailed in Annex 2, the potential for wind energy in the Lao PDR is dependent on the average wind speed, the land area suitable for wind turbine generator installations, the efficiency of these generators, and the load capacity of the grid system.

The Lao PDR has considerable wind resource potential, with 20% of the total land area having average wind speeds greater than 6 m/s, the minimum needed for modern wind turbines. As shown in Map 5.2 and Table 5.3, wind speeds average 6–7 m/s over about 38,787 km^2, 7–8 m/s over about 6,070 km^2, and more than 8 m/s over 700 km^2. The elevated parts of the country, especially the mountainous areas close to the border with Viet Nam, have the highest wind resource potential.

14 Based on the method described in Annex 1.

Map 5.1: **Areas Potentially Suitable for Solar Photovoltaic Development: Lao PDR**



Lao PDR = Lao People's Democratic Republic.
Source: GeoModel Solar; Lahmeyer International.

Table 5.2: **Technical Solar Energy Potential: Lao PDR**

Area (km^2)	**Potential Suitable Area** ('000 km^2)	**% of Total Area**	**Technical Potential**		**LCOE** ($/kWh)
			MWp	**MWh/yr**	
Unsuitable area	89.24	37.80	...	...	...
Less than 1,000	...	...	...	...	...
1,000–1,100	...	...	...	...	0.299
1,100–1,200	...	...	...	...	0.273
1,200–1,300	0.09	0.04	5.5	5,613	0.251
1,300–1,400	1.88	0.80	112.7	125,148	0.233
1,400–1,500	12.84	5.44	770.1	918,500	0.217
1,500–1,600	41.02	17.38	2,461.4	3,137,931	0.203
1,600–1,700	69.14	29.29	4,148.7	5,630,307	0.190
1,700–1,800	21.89	9.27	1,313.2	1,890,265	0.180
1,800–1,900	...	...	...	...	0.170
1,900–2,000	...	...	...	...	0.161
Over 2,000	...	...	...	...	0.157
Total			**8,812**	**11,707,764**	

... = data not available, km^2 = square kilometer, Lao PDR = Lao People's Democratic Republic, LCOE = levelized cost of electricity, MWh = megawatt-hour, MWp = megawatt-peak, yr = year.

Sources: GeoModel Solar; Lahmeyer International.

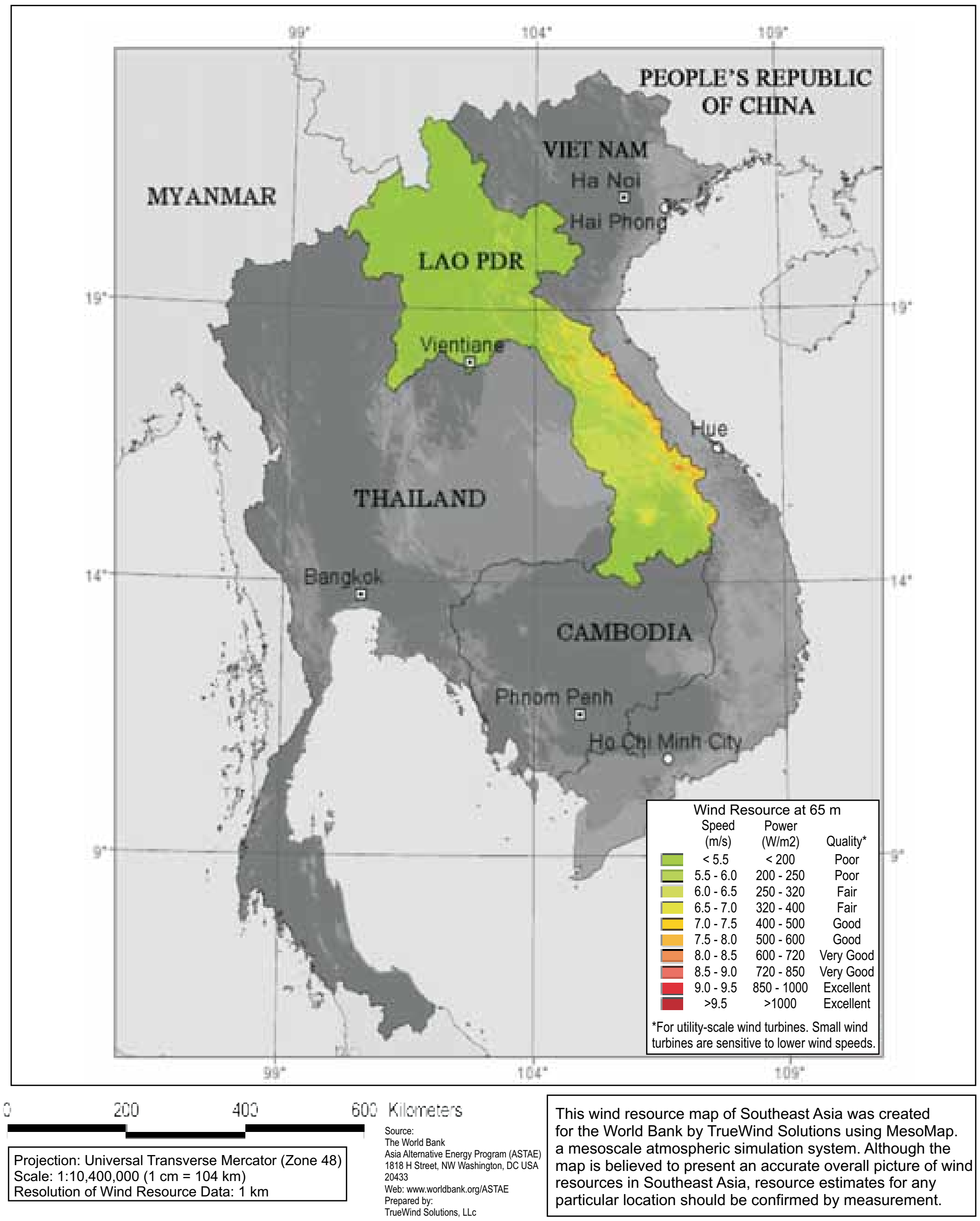
According to the estimates shown in Table 5.3, Lao PDR has a theoretical wind energy potential of 455 GW and a potential production capacity of about 1,112 TWh/yr. To get these estimates, the land area suitable for wind power result was multiplied by the average amount of wind power capacity that can be installed in a given area (assumed to be 10 MW/km^2).

However, the technical wind energy potential in the Lao PDR is much less, because of the limitations of the overall power generation and transmission grid systems. Daily, monthly, and seasonal variations in wind power would need to be balanced by alternative generation units. If balancing and stability considerations require limiting wind power input to 5% of overall power generation installed capacity, then the technical wind power potential would be less than 100 MW. If the wind power input could be increased to 20% of overall installed generation capacity, the technical potential could be about 380 MW.[15]

To assess the portion of technical potential that could be economically feasible, the estimated LCOE of wind power in the Lao PDR was compared with the current cost of other alternatives. Wind resource power in the Lao PDR has an estimated LCOE of $0.066/kWh–$0.114/kWh. The import electricity tariff is $0.0617/kWh (ADB 2012); residential tariffs range from $0.034/kWh to $0.098/kWh, and commercial tariffs, from $0.04/kWh to $0.106/kWh. At these electricity rates, electrical power through wind

[15] Section 3 and Annex 2 describe the methodology for calculating the theoretical and technical wind power capacity.

Map 5.2: **Wind Resources: Lao PDR**



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 5.3: **Theoretical Wind Energy Potential: Lao PDR**

Item	Average Wind Speed: 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)	Total
Area (km^2)	184,511	38,787	6,070	671	35	
Area (%)	80.2	16.9	2.6	0.3	0.0	
Theoretical potential (MW)		387,870	60,700	6,710	350	455,630
Indicative theoretical potential (TWh/yr)		911.49	176.03	23.49	1.33	1,112.34

km^2 = square kilometer, Lao PDR = Lao People's Democratic Republic, MW = megawatt, m/s = meter per second, TWh = terawatt-hour, yr = year.
Sources: World Bank (2001); Lahmeyer International.

energy could be a cost-effective option in grid-accessible areas with wind speeds above 7 m/s. The Institute for Renewable Energy reports that no wind generation capacity has yet been installed in the Lao PDR.

In summary, the Lao PDR has medium to high wind power potential and it could be competitive on a comparative cost basis. Large-scale use, however, would be severely constrained by the limitations of the overall power generation and transmission grid systems. If maintenance support could be assured, off-grid village-based wind turbine systems would appear to be a viable option. Renewable energy resources will account for 30% of the Lao PDR's overall installed energy capacity by 2025 if the government reaches its target. Wind power is expected to be a substantial component of renewable energy.

5.4. Biomass and Biofuel Energy Resources

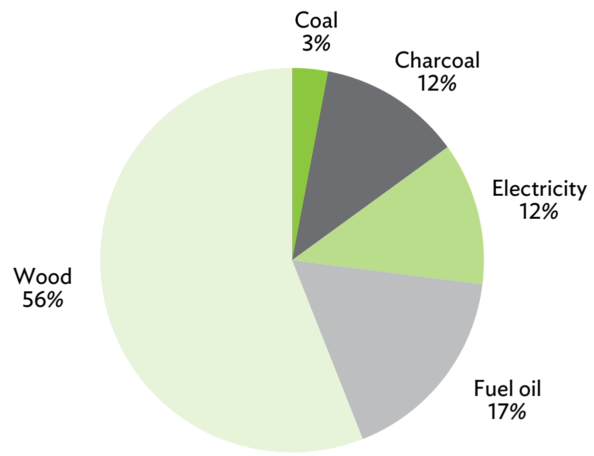
Biomass refers to organic matter that can be converted into energy through burning or conversion into fuels. It comprises forest and mill residues, agricultural crop residues and wastes, and animal manure. In the Lao PDR, wood and charcoal account for almost 70% of primary energy (Figure 5.2), thus contributing to extensive deforestation.

Biomass or biofuel is addressed here from two perspectives. The first is the use of agricultural residues for household cooking and heating and for commercial purposes to generate electricity. The second is the growth of selected crops as feedstocks for the production of biodiesel and bio-ethanol, which are blended with diesel and gasoline to reduce dependence on imported fuels.

5.4.1 Energy Potential from Agricultural Residues

The Lao PDR's agriculture sector is of vital importance and generates large amounts of residues. Some 80% of the Lao PDR's 6.3 million people depend on farming and natural resources for their livelihood. The sector accounts for about 40% of GDP, and while this share is in steep decline (because of the rapid growth of the hydropower and mining sectors),

Figure 5.2: **Primary Energy Sources, 2009: Lao PDR**



Lao PDR = Lao People's Democratic Republic.
Source: IREP (2011).

its employment share is relatively stable. Land ownership is almost universal, but holdings average only 1.6 ha. About 90% of agricultural land is devoted to rice production, which has doubled in output since 2000. Other major crops are maize, sugarcane, cassava, sweet potatoes, mung bean, soybean, and coffee. In recent years favorable export markets have engendered a rapid increase in maize production; sweet potato and cassava production has also increased rapidly because of the demand for starchy roots for ethanol production. Tree farming is another component of Lao PDR's agriculture sector, as is livestock raising, a source of feedstock (manure) for biogas production (discussed in Section 5.5).

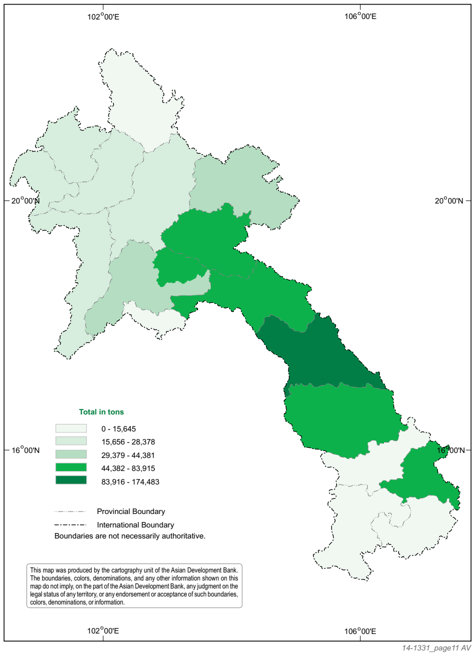
In considering the energy potential of agricultural residues, differences in production methods between lowland and upland areas of the country need to be taken into account. There are two main farming systems: the lowland rain-fed or irrigated farming systems along the Mekong floodplains and its tributaries, and the upland swidden agricultural system. A third but smaller system is the cultivation of horticultural crops and coffee in the Bolavens Plateau areas. Much of the land area is subject to severe erosion, especially where swidden farming is practiced.

Given the agricultural character of the country, the potential for biomass energy from rice, maize, sugarcane, and other agricultural residues is high. Residues generated in the field (primary residues) include paddy straw, sugarcane tops, maize stalks, and cassava stalks, while residues produced during processing (secondary residues) include rice husks, sugarcane bagasse, cassava stalks, and maize cobs. Secondary residues are usually available in large quantities at milling and processing sites. However, volumes of primary residues tend to be low because of the generally small size of farm holdings and residue collection difficulties.

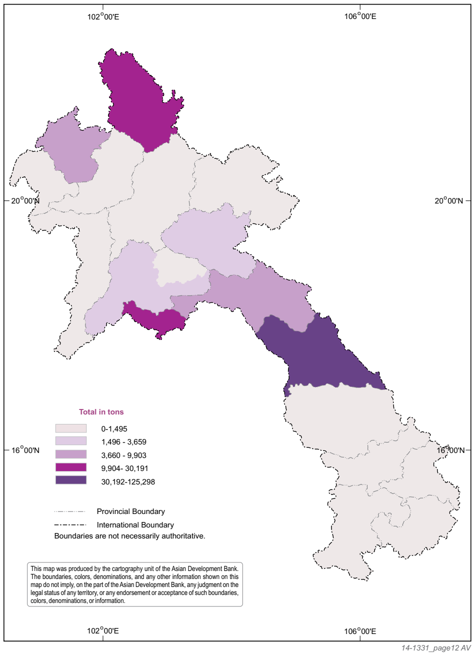
Map 5.3 shows the provincial distribution, in tons, of the main secondary crop residues.

Map 5.3: **Main Crop Residues: Lao PDR**

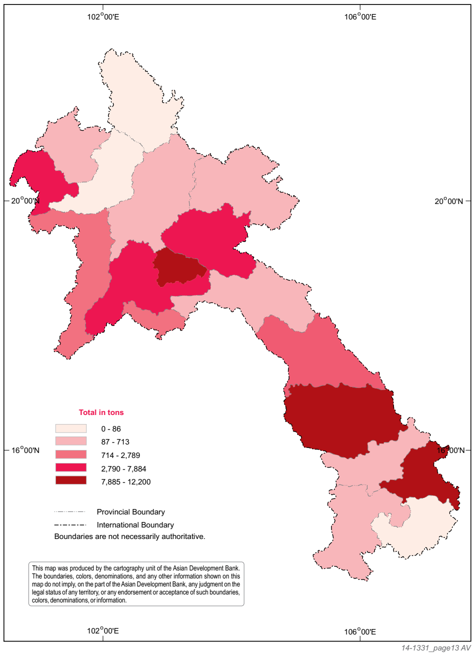
Rice Husk Production, 2010



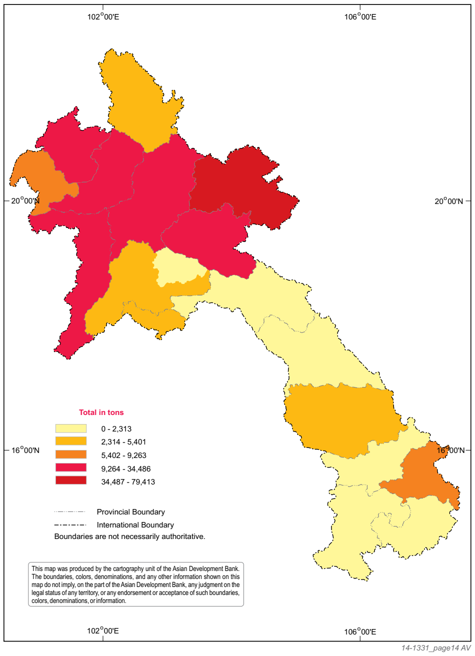
Sugar Cane Bagasse Production, 2010



Cassava Stalk Production, 2010



Maize Cob Production, 2010



Lao PDR = Lao People's Democratic Republic.
Source: Ministry of Agriculture and Forestry, Lao People's Democratic Republic.

Ministry of Agriculture and Forestry (MAF) data for 2010 were used in estimating the potential of biomass energy from agricultural residues (Table 5.4). The theoretical potential biomass energy from the combustion of rice husks, rice straw, maize cobs, cassava stalks, sugarcane bagasse, oil palm residues, and coconut residues was estimated to total 6,400 GWh. About 70% of this would be from rice residues and 15% from maize residues.

The crop residue production ratios (RPR) and other values considered in the calculation were drawn from studies done by B. Sajjakulnukit et al. (2005) and O. Akgün et al. (2011), as well as from data for Cambodia and Thailand.

Table 5.4: **Theoretical Biomass Energy Potential of Agricultural Residues: Lao PDR**

Biomass Residue	Total Yearly Biomass Production (10^3 tons)	Total Theoretical Energy Potential (10^6 GJ)	Total Theoretical Energy Potential (GWh)
Rice husks	767	9.86	2,740
Rice straw	1,013	6.12	1,700
Maize or corn cobs	255	3.66	1,017
Cassava stalks	64	0.44	123
Sugarcane tops and trash	247	1.66	462
Sugarcane bagasse	205	1.32	366

GJ = gigajoule, GWh = gigawatt-hour, Lao PDR = Lao People's Democratic Republic.
Source: MAF (2010); Author's calculations.

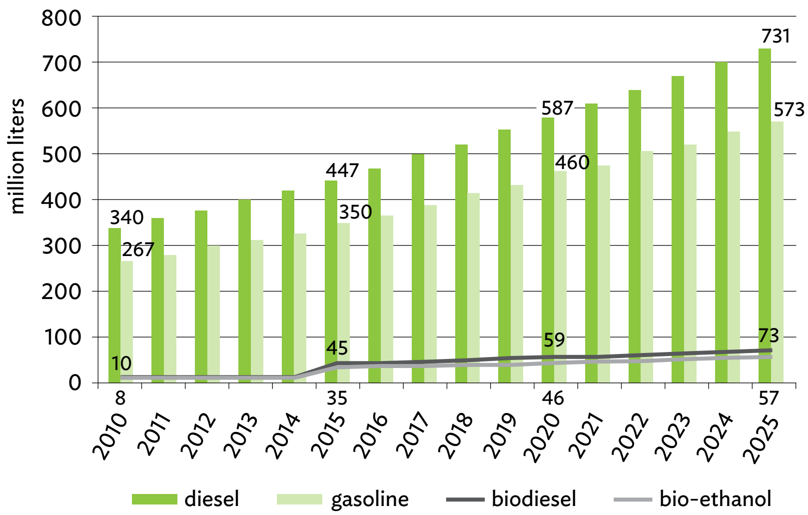
5.4.2 Biofuel Energy Potential of Biodiesel and Bio-Ethanol

To reduce its dependence on imports of petroleum products and to contribute to rural development, the government has been strongly promoting the production of biofuels. Designated energy crops provide oil as feedstock for biodiesel, and molasses and starch as feedstocks for bio-ethanol. The government has long-term plans for the further expansion of biofuel production, to include exports. Preference is being given to smallholder production, maintained under community land ownership and control. Incentives are given to domestic farmers and foreign investors, while ensuring proper monitoring to protect against negative environmental or socioeconomic effects.

The promotion of biodiesel and bio-ethanol production in the Lao PDR is target driven rather than based on the overall land area suitable for agriculture. Clearly, the production potential has to be limited by the agriculture–energy nexus and other considerations. Plantations of agricultural crops suitable for biodiesel and bio-ethanol production may displace traditional crops and grazing areas and disrupt farm livelihoods. Biofuel production needs to be planned according to sustainable and socially acceptable levels.

By 2025, the government expects to meet 10% of the Lao PDR's transport fuel needs with domestically produced biodiesel and bio-ethanol (Figure 5.3). Transportation fuel

Figure 5.3: **Transportation and Biofuel Demand Projections: Lao PDR**



Source: NSDTA (2011).

demand is projected to increase by 5% yearly, from 607 million liters in 2010 to more than 1,300 million liters by 2025. About 55% of this total (over 700 million liters) is likely to be for diesel fuel and 45% (almost 600 million liters) for gasoline. Given the 10% displacement target for both, this means that by 2025, the Lao PDR, should be producing about 70 million liters of biodiesel and 60 million liters of bio-ethanol.

In addition, the government expects the Lao PDR to export both biodiesel and bio-ethanol and has accordingly set the following production targets for 2025, to meet domestic consumption and export needs:

- 300 million liters of biodiesel; and
- 150 million liters of bio-ethanol.

The Decree on Biofuels Promotion and Development (2010) established the overall legal framework—the guidelines, measures, specific development goals, mechanisms, and institutional arrangements—for reaching these targets. Particularly important are the principles that govern biofuel businesses. Included here are the financial incentives for the cultivation of the needed crops, the processing of feedstocks, biofuel distribution and use, and biofuel R&D to enable the economically viable and sustainable development of the natural resource potential.

The decree defines biofuels as follows:

- Biofuels comprise biodiesel, bio-ethanol, bio-methanol, and other fuels produced from biomass to be used mainly for vehicles and for heating and electricity generation in accordance with national standards.

- Bio-ethanol is ethyl alcohol (C_2H_5OH) produced from agricultural plants and other biomass sources.
- Biodiesel refers to the biofuel produced from oily plants, animal fat, cooking oil residues, wastes, and other biomass processed into fuel certified by the government for use in diesel engines.

The government's Biofuels Action Plan specifies the feedstocks for biodiesel and bio-ethanol production based on detailed feasibility studies, impact assessments, and cost–benefit analyses of feedstock options, land availability, and socioeconomic implications. The recommended feedstock for biodiesel is *Jatropha curcas*, for bio-ethanol it is sugarcane, cassava, or maize. Other oil-bearing crops or other possible alternatives (e.g., cooking oil) could be considered for use as biodiesel feedstocks, and other sugar-producing or starchy plants, as bio-ethanol feedstocks, after more thorough research and assessment.

The government aims to demonstrating the use of 3%–10% ethanol–gasoline blends (E3 to E10) and 3%–10% biodiesel blends (B3 to B10) during the period 2010–2015, and making the use of such blends mandatory from 2015 onward. It has developed road maps with timelines and milestones for the necessary policy, legal, financial, market, and organizational interventions. These include:

- a nationwide extension network for technical assistance to small-scale producers (including research support, demonstration projects, and field testing of high yielding fuel crop varieties);
- financing services for small-scale biofuel and feedstock producers;
- a nationwide marketing network for biofuel feedstocks;
- partnerships with industry players for the processing, production, blending, and distribution of biofuels; and
- an information campaign to promote the use of biofuels.

MAF and MEM are responsible for implementing the Biofuels Action Plan. The provincial, district, and village cluster representatives of MAF are expected to promote biofuel development and to provide extension services in cooperation with MEM.

Biofuel production has been relatively slow to develop. While several public and private organizations have been involved in biofuel promotion and production, most companies have initially targeted the export market. For example, KOLAO Farm and Bio-energy Co., Ltd., the Lao PDR's biggest biodiesel producer, reportedly produced 100,000 liters of oil from 400 tons of Jatropha seeds in 2009. It exported some 40% of this to Indonesia and used the remaining 60% to promote its biodiesel activities in the Lao PDR. KOLAO is developing around 61,450 ha of land for Jatropha production and an overall target of 144,000 ha. By 2010, it was growing Jatropha on more than 26,000. With the incentives proposed under the government's biofuel decree, small-scale producers, as well as KOLAO, may now target the domestic market. As KOLAO is finding, however, profitability is low and the investment returns from biodiesel production appear uncertain.

5.4.3 The Agriculture–Biofuel Nexus

As biofuel production depends on the availability of appropriate feedstocks, the government has encouraged local farmers and private sector investors to grow Jatropha and oil palm for biodiesel production, and sugarcane and cassava for bio-ethanol production. Lao PDR has gained enough experience in village cluster development to facilitate large-scale crop production for industrial use. Individual farmers can also engage in crop production for biofuel use. The government has mandated the use of B10 and E10 in the transport sector, so it is assumed that biofuel producers will meet local demand first. Following is a review of the feedstock requirements.

Jatropha Curcas and Palm Oil as Feedstocks for Biodiesel Production

Research shows that *Jatropha curcas* is the best crop for biodiesel production in the Lao PDR (NEDO and LIRE 2008). As described in the Cambodia section of this report, the plant can grow in almost all types of soil, including poor and degraded land, contributes to erosion control, can survive the dry season as it does not need much water, and lives up to 50 years. Provided that there is sufficient land, Jatropha does not compete with food crop plantations. However, the plant is poisonous and cannot be eaten by humans or animals. Careful attention must therefore be paid to the location of Jatropha cultivation.

Regional and international studies have estimated widely different seed yields per hectare. The Rapid Strategic Environmental Assessment of the Renewable Energy Development Strategy, done by MEM (2010), reported relatively low Jatropha seed yields of 2 tons per hectare per year. Estimates of extraction ratios and seed oil yield are also needed. From field experience and stakeholder consultations, MEM and LIRE have determined that biodiesel production calculations should assume an average extraction ratio of 0.9 and a seed oil content factor of 0.35 per ton. Estimates of the amount of land needed to meet the biodiesel target through Jatropha cultivation (Table 5.5) are based on these assumptions.

Given the average yield of 2 tons of Jatropha seeds per hectare, about 114,000 ha of Jatropha plantations would be needed by 2025 to meet the target of replacing 10% of local diesel demand with biodiesel.[16]

Palm oil could also be a feedstock for biodiesel production. With yields of about 7 tons of fruits per hectare per year, some 3 tons of pericarp oil and 750 kg of seed kernel can be produced from 10 tons of fruit (SNV 2009). However, relatively large amounts of labor, fertilizer, and propagation material for planting are necessary, raising investment costs. Moreover, because oil palm trees require air with some salt content, they cannot be planted in most areas of the Lao PDR. Nonetheless, it may be possible to grow oil palm. The Institute of Renewable Energy Promotion is encouraging investors, including Lao Agro Tech Co. Ltd. of Thailand, to establish oil palm plantations. The land area required for a significant contribution to biodiesel production has not been quantified, however.

[16] O. Schönweger et al. (2012) reported that concessions for 25,179 ha of Jatropha have been granted. However, this does not mean that they have all been planted. Furthermore, small farm holdings or plantations operating without properly registered concessions are not included here.

Table 5.5: **Projected Land Requirements for Jatropha and Biodiesel Production: Lao PDR**

Item	2015	2020	2025
Projected diesel demand (million liters)	447.00	587.00	731.00
10% biodiesel requirement (million liters)	44.66	58.65	73.09
Conversion factor: crude oil to biodiesel	0.94	0.94	0.94
Required Jatropha crude oil (million liters)	47.52	62.40	77.76
Kg/liter density of crude oil	0.92	0.92	0.92
Required Jatropha crude oil (thousand tons)	43.71	57.40	71.54
Extraction ratio (technology)	0.90	0.90	0.90
Jatropha seed oil content	0.35	0.35	0.35
Jatropha seed requirement (thousand tons)	138.77	182.23	227.10
Average Jatropha seed yield (tons per hectare)	2.00	2.00	2.00
Land requirement (thousand hectares)	69.00	91.00	114.00

Lao PDR = Lao People's Democratic Republic.

Sources: Authors' calculations, MEM (2010), Vientiane Times (2012) (Information herein was derived from the study report: Rapid Strategic Environmental Assessment of the Renewable Energy Development Strategy. Ministry of Energy and Mines (MEM), Lao PDR, 2010. A Vientiane Times article of 1 March 2012 featuring a government statement on biofuels made reference to KOLAO's potential to produce 2 million liters of biodiesel. http://www.emergingfrontiers.com/2012/03/01/biofuels-a-growing-industry).

Sugarcane and Cassava as Feedstocks for Bio-ethanol Production

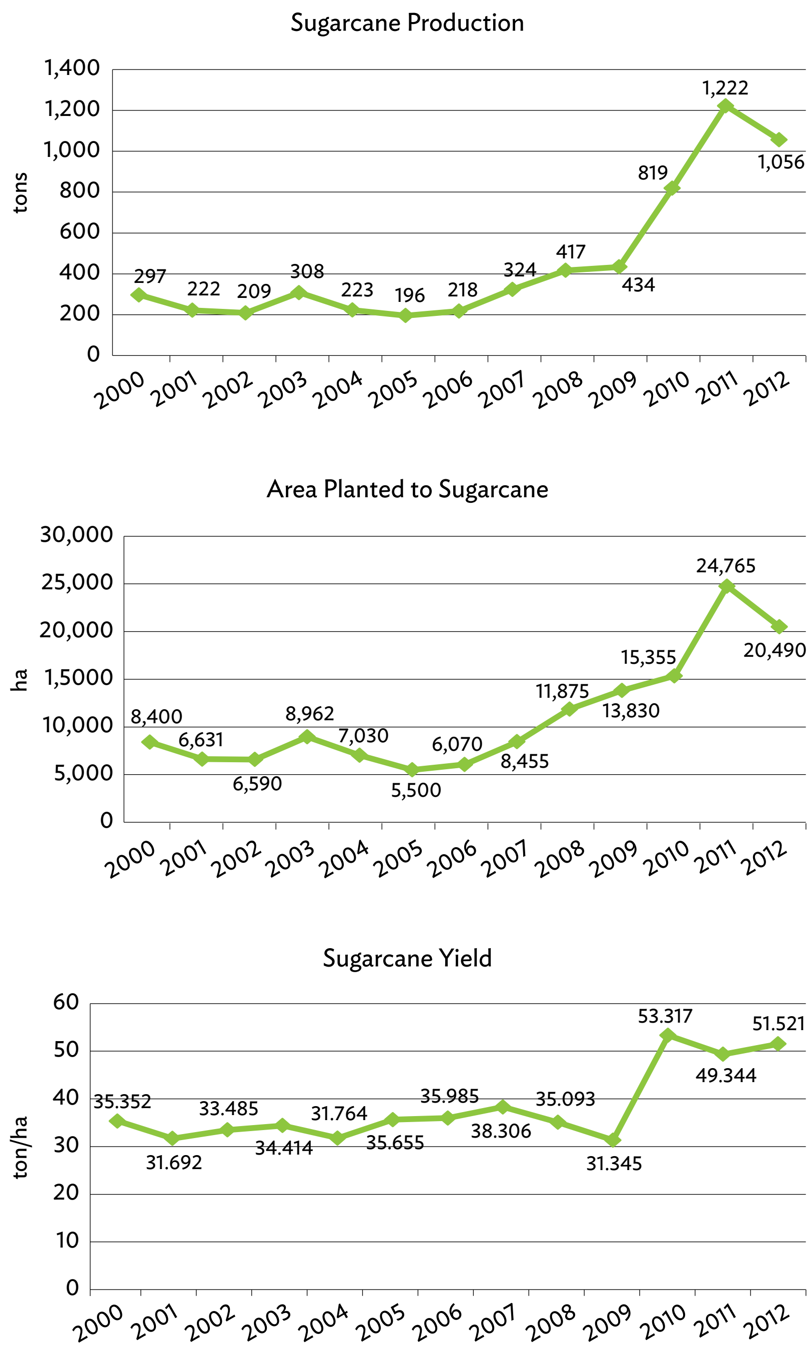
Bio-ethanol will be used as a partial substitute for gasoline. As in the case of biodiesel, the government has set a target for bio-ethanol production sufficient to displace, through blending, 10% of imported gasoline. Domestic use of bio-ethanol will be mandated after 2015, starting at E3 and gradually increasing to E10, the 10% displacement target. The main bio-ethanol feedstocks are expected to be sugarcane and cassava.

Sugarcane is cultivated on a large scale in the Lao PDR. The total land area planted to sugarcane in 2012 was estimated to be 20,000 ha (Figure 5.4). The average annual yield was between 32 and 36 tons per hectare in 2000–2009, then it increased rapidly to between 50 and 53 tons per hectare in 2010–2012. The sugarcane was processed mainly into sugar for local consumption and export. Biomass and saccharose (which can be processed into bio-ethanol) are the main products of sugarcane.

Sugarcane production in the Lao PDR has more than tripled in the past decade, as a result of an increase in the land area devoted to sugarcane and in yields per hectare. About 15 kg of sugarcane is needed to produce 1 liter of ethanol (LIRE 2009). For the commercial production of bio-ethanol, large-scale facilities must also be available.

As shown in Table 5.6, if sugarcane is the main feedstock for bio-ethanol production and if sugarcane yields continue to average 50 tons per hectare, meeting the government's bio-ethanol targets would require at least 10,500 ha in 2015, and almost 17,000 ha by

Figure 5.4: **Sugarcane Production: Lao PDR**



ha = hectare, Lao PDR = Lao People's Democratic Republic.
Source: FAO Statistics Database.

Table 5.6: **Sugarcane and Bio-Ethanol Target Requirements: Lao PDR**

Item	2015	2020	2025
Gasoline demand (million liters)	350.42	460.16	573.45
10% bio-ethanol requirement (million liters)	35.04	46.02	57.34
Conversion factor (kg sugarcane/liters ethanol)	15.00	15.00	15.00
Million kg of sugarcane	525.64	690.25	860.17
Average sugarcane yield (tons per hectare)	50.00	50.00	50.00
Land requirement (hectares)	10,513.00	13,805.00	17,203.00

kg = kilogram, Lao PDR = Lao People's Democratic Republic.
Source: Authors' calculations.

2025.[17] This plus the 14,000 ha now planted to sugarcane for sugar production would amount to some 31,000 ha, a significant amount of the Lao PDR's limited agriculture land.

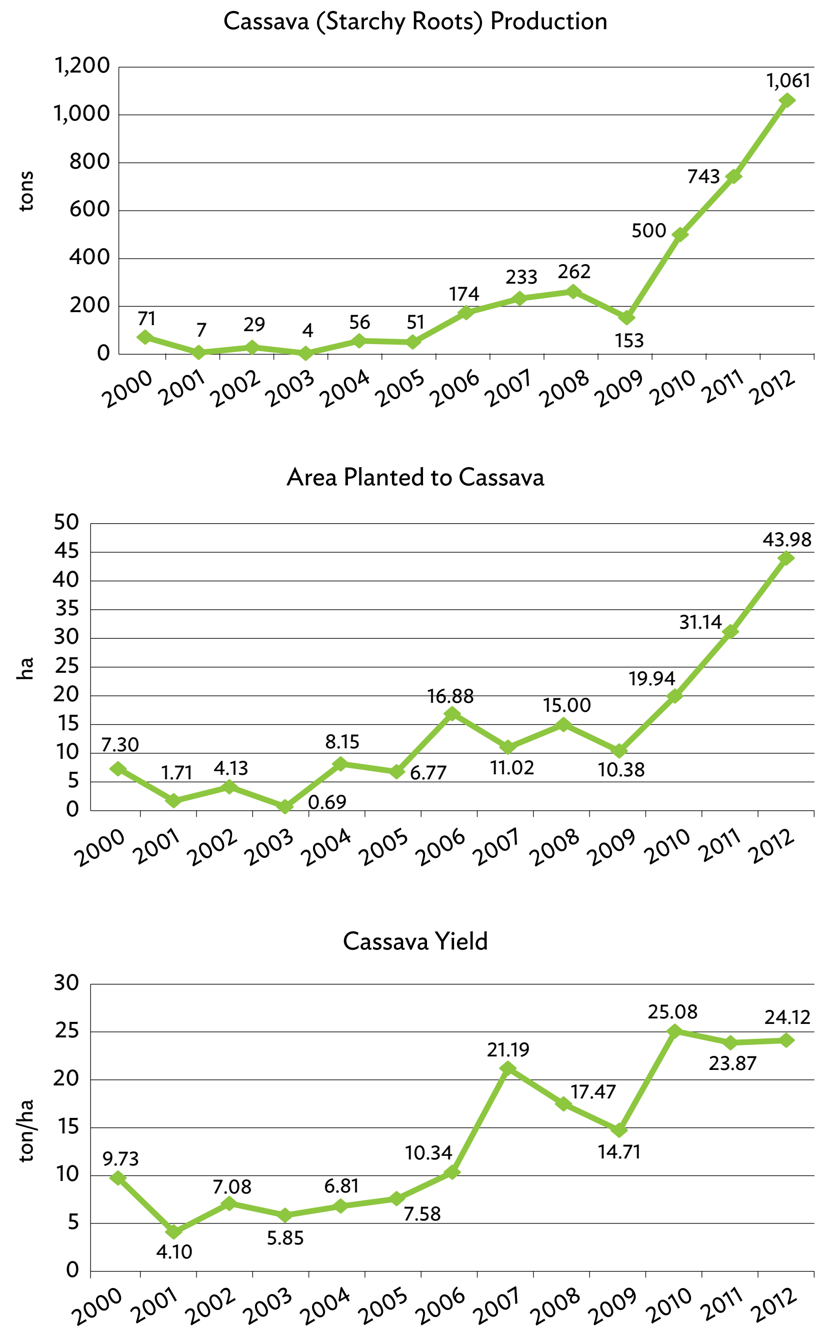
The land requirement could be sharply reduced if the Lao PDR were to match Thailand's yields, which now average about 70 tons per hectare and could go up to 80 tons per hectare by 2018, according to that country's plans. At these levels of output, the Lao PDR would need less than 15,000 ha of land to meet the 2025 bio-ethanol target.

Cassava is the other main bio-ethanol feedstock option; it is also a good substitute for rice and for grain in livestock feed. According to the UN Food and Agriculture Organization (FAO 2000), the Lao PDR has about 4.5 million ha of land suitable for cassava. Figure 5.5 shows a strong increase in cassava production particularly since 2008, mostly as a result of an increase in areas under cassava cultivation. Yields per hectare average about 15 tons; this is low compared with Thailand's 23 tons per hectare at present and expected 27 tons by 2018.

The Lao PDR's capacity to meet the government's mandate for bio-ethanol production will depend on the existing ethanol plant technologies and feedstock output. The total land area under cassava cultivation was 10,375 ha in 2009; by 2012, it had increased to about 43,975 ha. An expansion of this area for bio-ethanol production would reduce the amount of land that can be used to grow food. Measures taken to encourage the growing of cassava as feedstock for bio-ethanol must ensure to preserve agricultural land needed to meet the Lao PDRs food requirements.

[17] The sugarcane crop yield of 50 tons/ha is a very recent development based on UN data and not yet verified by MAF. Whether it will be sustainable is unknown. In a study done for LIRE, Gaillard, Robert, and Rietzler (2010) calculated the land requirements on the assumption that sugarcane yield would average 38 tons/ha. If this same assumption is used, the land required would be 13,800 ha in 2015 and 22,600 ha by 2025.

Figure 5.5: **Cassava Production: Lao PDR**



ha = hectare, Lao PDR = Lao People's Democratic Republic.

Note: Data for this figure come from the FAO Statistical Database. The values for the period up to 2006 are considerably lower than those obtained by the Ministry of Agriculture and Forestry (MAF) from the FAO Global Spatial Database of Agricultural Land Use Statistics (2001–2006). Current data (after 2006) were not available from the MAF for comparison.

Source: FAO Statistics Database.

The estimates of cassava production required to meet the government's bio-ethanol targets by 2025 are based on the following assumptions:[18]

- cassava yield of 21 tons per hectare; and
- bio-ethanol conversion factor of 180 liters of ethanol per ton of cassava.

Table 5.7 indicates that about 15,000 ha would be needed for cassava cultivation if the government were to rely solely on the crop to meet its bio-ethanol targets for 2025. Using new high-yielding cassava varieties in combination with good farming practices could considerably reduce the land requirements.

Table 5.7: **Projected Land Requirements for Cassava and Bio-Ethanol Production: Lao PDR**

Item	2015	2020	2025
Gasoline demand (million liters)	350.42	460.16	573.45
10% bio-ethanol requirement (million liters)	35.04	46.02	57.34
Conversion factor (liters ethanol/tons cassava)	180.00	180.00	180.00
Million tons of cassava	0.19	0.26	0.32
Average cassava yield (tons per hectare)	21.00	21.00	21.00
Land requirement (hectares)	9,270.00	12,174.00	15,171.00

Lao PDR = Lao People's Democratic Republic.
Source: Authors' calculations.

Currently, large-scale production of cassava in the Lao PDR is being undertaken by two companies, mainly for markets in the Republic of Korea and Thailand. Bio-ethanol production in the Lao PDR is still at a preliminary stage.

5.4.4. Impediments to the Development of Biofuel

Biofuel development in the Lao PDR has had to face a number of challenges, including:

- land concession and contract farming issues;
- low yields of Jatropha crops, leading to poor returns on investment;
- seasonality of the feedstock;
- lack of technical expertise among farmers and operators of biofuel production plants; and
- insufficient coordination among government agencies and with the private sector.

According to the Lao Institute for Renewable Energy (LIRE), investors from the People's Republic of China (PRC), France, Italy, Japan, the Republic of Korea, Thailand, and Viet Nam have established Jatropha plantations in the Lao PDR but with limited success. Many projects have been abandoned because of (i) improper business models,

18 The assumptions are drawn from a modeling study done for LIRE by Gaillard, Robert, and Rietzler (2010).

(ii) poor understanding of the local context, (iii) inexperience, or (iv) overly optimistic expectations (LIRE 2009).

In summary, biofuel production in the Lao PDR is still in the formulation or experimental stage. The government has set ambitious targets for biodiesel and bio-ethanol as 10% substitutes for diesel and gasoline. It has also issued detailed road maps for achieving these targets by 2025. Experience so far, however, has been disappointing, with projects failing to meet expectations. Also of concern is the agriculture–energy trade-off. Considerable land is required to meet the government's biofuel targets. Unless the returns from the production of biofuel feedstock can be better demonstrated, the Lao farming community may be reluctant to expand this form of agriculture. Land grants for foreign investors raise issues of land rights and displacement, including those related to grazing areas for livestock.[19] A serious impediment to biofuel production is the generally low productivity in the agriculture sector. Progress in raising agricultural productivity would be doubly beneficial—for the country's food and energy targets.

5.5 Biogas Energy Resources Potential

As part of its strategy for improving rural livelihoods, the government is promoting the use of biogas generated from animal (cow, buffalo, pig) manure as a household energy fuel.

Livestock is a traditional sector for farm households in the Lao PDR. About half of farm households raise buffalo for draught power, one-third raise cattle, and pigs and small ruminants (e.g., goats) are also common, especially in the highland and sloping areas. Cattle and buffalo are predominantly raised in the central region, while commercial pig and poultry operations are found near Vientiane and other centers. Livestock sales account for more than 50% of the cash income of households in the rural upland areas.

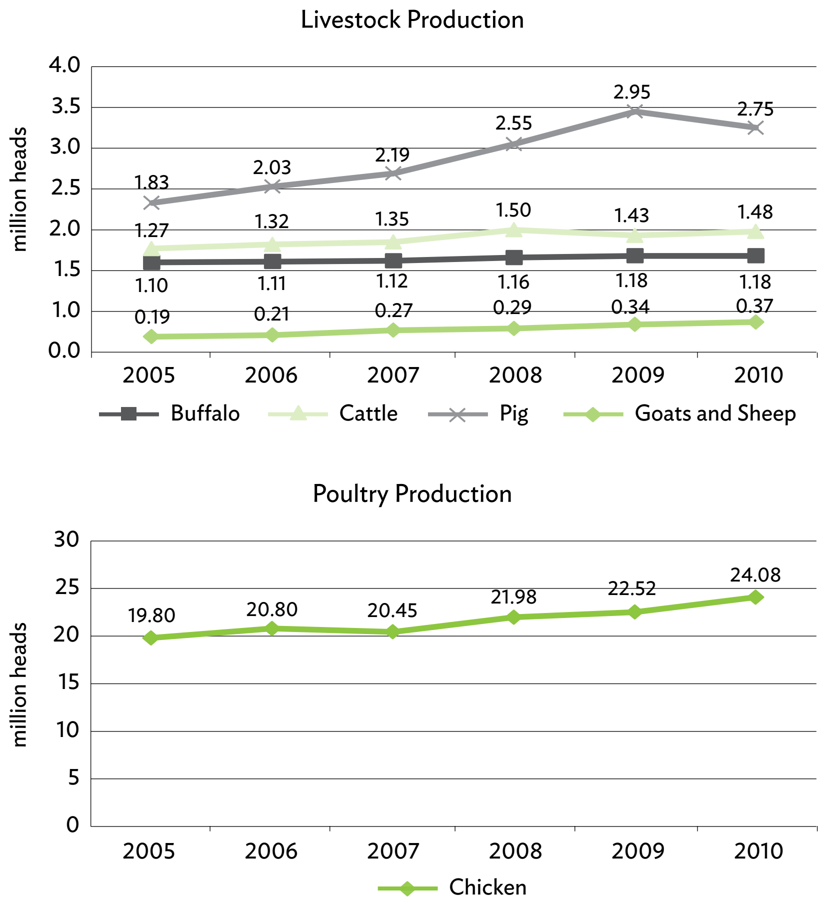
Livestock exports to Thailand and Viet Nam have been increasing, in line with the growing demand for more protein. However, while the Lao PDR's livestock population has increased, productivity, as defined by carcass weight, has remained well below Thailand's, because traditional livestock production has been weakened by a poor genetic base, lack of disease control, and the absence of a domestic animal feed industry.

The granting of land concessions to promote foreign direct investment also poses new challenges to rural communities, as it has reduced the areas for crop plantations and for livestock grazing. In addition, opportunities for off-farm cash income have reduced the pool of farm labor. These and other factors are hampering the growth of the livestock sector.

As animal manure is the primary feedstock for biogas, estimates of the Lao PDR's livestock and poultry populations are needed. Figure 5.6 indicates that the pig population has increased substantially since 2005, but the cattle and buffalo populations have increased

[19] Land leasing agreements for biofuel crop plantations allow for rental periods of up to 30 years, which can be extended on a case-by-case basis. Land leases for areas in excess of 10,000 hectares must be approved by the National Assembly. The agreements stipulate the obligations of the contracting parties and discuss specific issues such as compensation for losses.

Figure 5.6: **Livestock and Poultry Production: Lao PDR**



Lao PDR = Lao People's Democratic Republic.
Source: Ministry of Agriculture and Forestry.

relatively little. While poultry production has markedly expanded, poultry manure is generally a less useful feedstock for biogas since chickens are typically free ranging.

As indicated in Table 5.8, Lao PDR could produce some 5 million cubic meters of biogas per day, with pig manure accounting for three-quarters of this total. If harnessed, this would be a significant energy source for lighting and cooking in the rural areas.

However, collecting enough manure is difficult. As buffalo and cattle generally graze freely, manure recovery rates are quite low and households may not have enough supply to fuel biogas digesters. Pig manure is more concentrated, so there is considerable potential from this source.

Drawing on experience gained from previous biogas programs in the Lao PDR, Viet Nam, and elsewhere, SNV (2006) estimates that for sufficient manure collection and the proper

Table 5.8: **Theoretical Biogas Energy Potential: Lao PDR**

Livestock	2010 Production (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	1.183	8.00	9,464,000	16	1,514,240	0.250	378,560
Cattle	1.475	8.00	11,800,000	16	1,888,000	0.250	472,000
Pigs	2.752	2.00	5,504,000	17	935,680	4.200	3,929,856
Chicken	24.078	0.08	1,926,240	25	481,560	0.575	276,897
Total							**5,057,313**

kg = kilogram, Lao PDR = Lao People's Democratic Republic, m^3 = cubic meter.
Source: Authors' calculations.

Table 5.9: **Biodigester Volumes and Daily Feed Rates: Lao PDR**

Item	Digester Volume (m^3)			
	4	6	8	10
Daily dung[a] requirement (kg)	20–40	40–60	60–80	> 80
Daily gas production (m^3)	0.8–1.6	1.6–2.4	2.4–3.2	> 3.2

kg = kilogram, Lao PDR = Lao People's Democratic Republic, m^3 = cubic meter.
[a] Based on a hydraulic retention time of 40 days, type of manure.
Source: Author's calculations.

setup of household biogas plant systems, each farm household would need to stable three to nine cattle or buffalo during most of the day or night, or raise 7 to 30 mature pigs (SNV 2006). Biodigester design requirements are shown in Table 5.9.

Farmer household data on livestock holdings, together with estimates of mean biogas yields by type of livestock, provide the basis for calculating the Lao PDR's technical biogas energy potential– estimated to be about 1.4 million cubic meters daily, or about one-fourth of the theoretical potential (Table 5.10).

Biogas technology was first introduced in the Lao PDR in the 1980s by the MAF, with assistance from the FAO. Initiatives with various other agencies followed suit. In 2005, it was reported that 47 pilot family-size biogas units had been installed so far, 34 under the auspices of a Lao–PRC program, 11 under the Canada–Thailand Trilateral Environment Program, and 1 each under ADB and SNV programs. At the time of reporting in 2005, few of the units were operating. The poor results, according to the report, were due to the following:

- scarcity of feedstock because of the difficulty of collecting manure from free-range livestock;
- transaction and transportation costs, limiting the feasibility of drawing feedstock from large pig and poultry farms;
- poor understanding of how to manage and maintain the biodigester units;
- low awareness of the benefits of biogas technology to households; and
- lack of incentives to use biogas energy, given the energy alternatives that are relatively easy to obtain and use (e.g., firewood, charcoal).

Table 5.10: **Technical Biogas Energy Potential: Lao PDR**

Livestock	Total No. of Households	Ave. No. of Animals per Household	Daily Manure Production Factor (kg/animal)	Substrate Quantity (kg/day)	Dry Matter Factor (%)
Buffalo	123,728	6.8	8	6,839,603	16
Cows	156,152	6.8	8	8.494,669	16
Pigs	66,725	8.5	2	1,134,325	17
Total				**16,484.597**	

Livestock	Net Dry Matter Available (kg/day)	Mean Biogas Yield Factor (m^3/kg dry matter)	Daily Biogas Production (m^3/day)	Energy Content per Day (kWh/m^3)
Buffalo	1,094.337	0.25	273,584	1,641,505
Cows	1,359,147	0.25	339.787	2,038,721
Pigs	192.835	4.20	809,908	4,859,448
Total	**2,646,319**		**1,423,279**	**8,539,674**

kg = kilogram, kWh = kilowatt-hour, Lao PDR = Lao People's Democratic Republic, m^3 = cubic meter.

Note: Number of households based on 1998/99 census; total number includes only those with three or more livestock heads for buffalo and cattle, and above 10 heads for pigs.

Source: Authors' calculations.

In 2006, SNV together with the MAF launched the Biogas Pilot Program (BPP). The initial target of the program was 6,000 biogas systems by 2010. However, fewer than 2,000 were installed from 2007 to 2010. In 2011 and 2012, there were only about 450 installations each year. The low adoption rate is attributable to several factors in addition to the causes cited above:

- high up-front costs, despite the subsidy of up to 50%;
- difficulty in maintaining the necessary number of livestock;
- lack of access to financing and credit; and
- cultural barriers (e.g., having to stand rather than sit while cooking).

Despite the setbacks, the government is continuing with its plans to expand the installation of biogas systems to more than 10,000 households in five provinces. The World Bank has proposed supporting this endeavor with a small pilot project featuring alternative financing mechanisms.

In summary, the Lao PDR has considerable biogas potential, but harnessing this at the farm household level has been slow to develop. Firewood and charcoal are easier energy sources for rural households in mountainous areas, and avoid the installation costs of biodigesters, which farmers find difficult to finance. Still, biodigesters are a clean form of energy and their wider use would contribute to various environmental benefits, notably helping to reduce deforestation.

5.6 Summary of Renewable Energy Potential and Developments

The government target is that, by 2025, renewable energy resources will account for 30% of the Lao PDR's total energy consumption. Minihydropower projects are projected to account for about 60% of Lao PDR's renewable energy capacity. The other major contributors will be solar, wind, biofuel, and biogas.

Large-scale solar and wind systems are limited by gaps in the Lao grid network and by lack of connectivity for large portions of the rural population. This situation, though, means that solar and wind power for rural households and villages are options for those without other sources of electricity. The cost of electricity from solar power would be high, but wind power could be competitive on a comparative cost basis. According to the Lao Institute for Renewable Energy, as of 2011, about 285 kWp of solar PV had been installed in pilot plants. Additionally, about 20,000 small solar home systems had been installed. No wind power systems have been installed. Factors critical to harnessing solar and wind energy in the Lao PDR include extensions of the grid system, financial support, credit access, and regular proper maintenance and access to replacement parts.

The government has set ambitious targets for biodiesel and bio-ethanol, domestic production of which is targeted to substitute for diesel and gasoline consumption by 10% in each case by 2025. The government has detailed road maps for achieving these targets. The land requirements needed to meet these targets are considerable, potentially displacing food crops and grazing areas for cattle. This has already occurred to some extent, following land concessions to foreign investors. Safeguard provisions will need to be complied with to minimize dislocations and negative consequences for farm households. Biofuel projects in the Lao PDR have largely failed to meet expectations so far. Low crop yields for biofuel feedstock, notably Jatropha, sugarcane, and cassava, have contributed to poor investment returns. There is nonetheless considerable biofuel potential and the government has created the regulatory framework for biofuel production. Besides helping to reduce dependence on petroleum imports, such production could make the Lao PDR an exporter of biodiesel and bio-ethanol.

Biogas is potentially an important energy source for farm households in the Lao PDR. Most farm households have sufficient manure supply for biodigesters, but there is difficulty of collection; livestock are mostly free ranging. Early projects to introduce household biodigester systems ended subsequently with most biodigesters not operating. A project launched in 2006 targeting the installation of 6,000 biodigester rural household systems by 2012 was only partially successful, despite being well planned. Cultural, financial, and other factors impeded 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 are needed.

6 Renewable Energy Developments and Potential in Myanmar

Myanmar is geographically the largest country in Southeast Asia, with a population of about 60 million.[20] The agriculture sector has been declining in relative importance and now accounts for just under 40% of gross domestic product (GDP), but it is still the source of employment for more than 60% of the labor force. Strong overall growth rates during the past decade,[21] led by the industrial sector (which includes energy and mining), per capita GDP remains one of the lowest in Southeast Asia, at about $715.

Although classified as a least-developed country, Myanmar has extensive natural resources in the form of hydropower, natural gas, precious gems, and timber. However, development was hampered in the late 1980s by the deep economic sanctions imposed by many countries, in response to Myanmar's suspension of democratic liberties. During this period, Myanmar lost much of its access to international investment and assistance, from ADB and the World Bank, among others. Consequently, the energy sector, including renewable energy sources, has lagged behind. Some two-thirds of Myanmar's primary energy supply is from biomass—firewood and charcoal—and rural areas for the most part lack electricity.

The government that took office in March 2011 has introduced sweeping political and economic reforms fundamental to development. The government is also drafting a new national development plan. The reforms, especially those concerning democratic representation, have led countries to lift or ease economic sanctions.

Investment in the energy sector, including the development of the country's renewable energy resources in partnership with the private sector, is expected to be an important driver of the economy.

6.1 Institutional and Policy Framework for Renewable Energy Initiatives

6.1.1 Institutional Framework

Several ministries have responsibilities for developing and promoting the use of renewable energy in Myanmar:

[20] This population estimate is approximate, in the absence of a recent census.

[21] Cyclone Nargis, however, devastated much of the country in 2008 and led to a sharp drop in GDP.

- The Ministry of Energy (MOE) is the overall focal point for energy policy, coordination and international cooperation. The ministry's main area of responsibility is the oil and gas sector.
- The Ministry of Electric Power (MOEP) is responsible for power generation, transmission, and distribution. The ministry combines two former ministries: the first was responsible for developing, operating, and maintaining all large hydropower and coal-fired thermal plants; the second, for developing and maintaining the transmission and distribution systems throughout the country, and for operating gas-fired thermal plants and minihydropower plants. The Hydropower Generation Enterprise (HPGE) and the Myanmar Electric Power Enterprise (MEPE) are the main power-generating companies. The Yangon City Electricity Supply Board (YESB) distributes power to consumers in Yangon, and the Electricity Supply Enterprise (ESE), to the rest of the country.
- The Ministry of Agriculture and Irrigation (MOAI) takes the lead in the development of biofuels, micro-hydropower (with installed capacity of up to 10 MW), bioenergy from agricultural residues, and biogas.
- The Ministry of Science and Technology (MOST) is responsible for the overall development and promotion of renewable energy, for off-grid rural electrification and other purposes.
- The Ministry of Environmental Conservation and Forestry (MOECAF) regulates the use of biomass from forest resources for energy purposes.

Table 6.1 summarizes the main components of the institutional framework.

To promote energy-related investment, the Electricity Law (1984) opened up generation projects to private sector participation. Public energy utilities form joint ventures with foreign companies, especially for hydropower projects and oil and gas development.

Table 6.1: **Energy Institutional Framework: Myanmar**

Area of Concern	Ministry
Oil and gas sector	Ministry of Energy
Electric power: hydropower Electric power: thermal, power transmission and distribution, mini-hydro	Ministry of Electric Power, combining two former ministries, which merged in 2012 Generation and distribution enterprises: HPGE, MEPE, YESB, ESE
Coal	Ministry of Mines
Biomass and firewood	Ministry of Agriculture and Irrigation Ministry of Environmental Conservation and Forestry
Energy efficiency	Ministry of Industry
Renewable energy development and promotion	Ministry of Science and Technology

ESE = Electricity Supply Enterprise, HPGE = Hydropower Generation Enterprise, MEPE = Myanmar Electric Power Enterprise, YESB = Yangon Electricity Supply Board.

Source: Ministry of Electric Power.

6.1.2 Renewable Energy and Rural Electrification Policy and Targets

The government is developing a comprehensive energy policy, in particular, to extend electrification to the rural population. It will include various forms of renewable energy and the use of diesel generators. Myanmar's energy policy framework has four main goals:

- Energy independence. Hydropower is the main source of energy and the government is continuously strengthening the country's electricity generation, transmission, and distribution systems. Private sector participation in the form of independent power producer (IPP) investments for local investors and build–operate–transfer (BOT) or joint ventures for foreign investors is encouraged.
- Wider use of new and renewable energy sources. To prevent deforestation, the government is emphasizing forest conservation, discouraging excessive use of fuelwood and charcoal, and promoting the substitution of transport fuels with compressed natural gas.
- Energy efficiency and conservation.
- Household use of alternative fuels. The government is advocating the production and use of biofuels—biodiesel and bio-ethanol.

Because of the fragmented institutional framework for energy sector management, Myanmar lacks a unified policy for promoting the development and use of its renewable energy resources. The government has not officially established renewable energy targets, although the Ministry of Electric Power aims to develop around 472 MW of installed capacity (about 15% of total generation capacity) from small hydropower generation plants by 2016. According to reports, the government also plans to use domestically produced biodiesel and bio-ethanol as substitutes for 10% of imported oil and gasoline by 2020.

6.1.3 Incentive Framework

At present, Myanmar has no specific renewable energy incentives but investors in can draw on the incentives provided in the new Foreign Investment Law (2012). These incentives include the following:

- 5-year income tax holiday for foreign investors;
- exemption from a tax on profits if the profits are maintained in a reserve fund and reinvested in Myanmar within 1 year;
- for exported goods, income tax relief of up to 50% of the profits;
- deductions for R&D expenses;
- right to carry forward a loss and offset it against profits for up to 3 consecutive years from the year the loss is sustained; and
- exemptions or relief from customs duties for the importation of machinery, equipment, instruments, machinery components, spare parts, and materials required for the enterprise.

The new law also assures investors that their investments will not be nationalized during the contract period, their permits will not be terminated without good reason, and their foreign currency can be repatriated in the same foreign currency.

6.2 Solar Energy Resources Potential

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

Myanmar has good solar resource potential, with 60% of the land area suitable for PV development, having Global Horizontal Irradiation (GHI) levels of between 1,600 and 2,000 kWh/m^2/yr, and average Direct Normal Irradiation (DNI) levels of about 1,400 kWh/m^2/yr. In Map 6.1, the areas in red indicate where the GHI levels are highest and solar PV development is therefore most suitable.

Because of Myanmar's mountainous terrain and protected areas, more than a third of the land area is unsuitable for solar PV installations. On the basis of installable capacity per unit of land area of 0.06 kWp/m^2 and other factors (see Annex 1), Myanmar's maximum technical solar power potential is estimated at 40 TWh/yr (Table 6.2).

To assess how much of this technical potential could be developed economically, the levelized cost of electricity (LCOE) produced by solar PV was compared with the current cost of other alternatives in Myanmar. Most of Myanmar's solar power has an estimated LCOE of $0.16/kWh–$0.19/kWh. Electricity tariffs range from $0.035/kWh to $0.075/kWh for grid-connected supply and from $0.10/kWh to $0.30/kWh for off-grid supply.[22] At these rates, electrical power from solar PV would be cost effective only in off-grid areas. But as most of the rural population has no access to the grid, solar power could be the only viable alternative. More research is needed to determine the LCOE for small-scale off-grid solar PV generation.

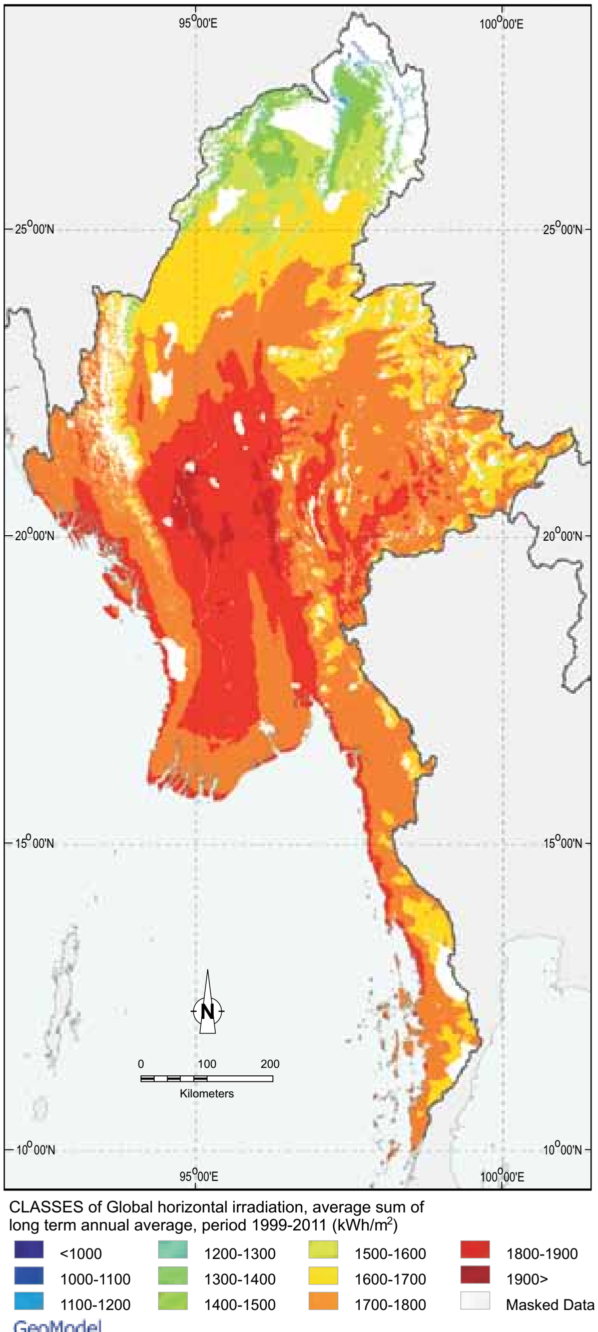
Solar energy in Myanmar is at an early developmental stage. No large-scale solar plants have yet been installed in the country, although several, according to reports, are being planned. Solar-powered battery-charging stations, solar lighting, solar home systems, and village minigrids with solar components have been installed to a limited extent but there are no data on their overall capacity.

The following pilot projects have been implemented:

- Solar Photovoltaic Battery Charging Community Enterprise, financed by the Energy Services and Income-Generating Opportunities for the Poor (ENSIGN), in collaboration with Yoma Bank and the Energy Planning Department of MOE;
- Demonstrative Research on a Photovoltaic Power Generation System in Myanmar, in cooperation with the New Energy and Industrial Technology Development Organization (NEDO) of Japan and the Department of Electric Power of MOEP; and

[22] 35 kyats (MK) per kilowatt-hour general use, MK75/kWh small bulk, MK100/kWh–MK300/kWh off-grid supply (ADB 2012).

Map 6.1: Areas Potentially Suitable for Solar Photovoltaic Development: Myanmar



This map represent the long-term average of yearly sum of direct normal irradiation covering the period from 1999 to 2011. The underlying SolarGIS database contains global, diffuse and direct irradiance calculated from Meteosat MFG satellite with 30-minutes time step.
Data resolution (enhanced by terrain): 250 m
Data, maps and simulation tools for solar energy are available at SolarGIS website

Data sources:
Solar radiation (Same as in example)
Elevation and Slope dataset : SRTM3
Water bodies: data processed from SWBD - SRTM3
Urban areas GeoModel Solar
Protected areas: WDPA 2010

Cartography © 2012 GeoModel Solar s.r.o.
Disclaimer: Considering the nature of climate fluctuations, interannual and long-term changes, as well as the uncertainly of measurements and applied methods, GeoModel Solar s.r.o. does not take any responsibilities whatsoever, and does not give any warranty on the accuracy of the data that were used to produce this map. GeoModel s.r.o. has done its utmost to make an assessment of climate conditions based on the best available data, software and knowledge. It is recommended that this map be used as a guideline rather than an instrument to build the solar power systems.

Sources: GeoModel Solar; Lahmeyer International.

Table 6.2: **Technical Solar Energy Potential: Myanmar**

Area (km²)	**Potential Suitable Area** ('000 km²)	**% of Total Area**	**Technical Potential**		**LCOE** ($/kWh)
			MWp	**MWh/yr**	
Unsuitable area	227.83	33.58	...	...	...
Less than 1,000	0.00	0.00	...	...	...
1,000–1,100	0.01	0.00	0.8	705	0.294
1,100–1,200	0.11	0.02	6.8	6,517	0.268
1,200–1,300	0.65	0.10	39.2	41,044	0.247
1,300–1,400	3.07	0.45	184.0	208,239	0.228
1,400–1,500	8.72	1.29	523.0	635,790	0.213
1,500–1,600	22.33	3.30	1,339.0	1,741,119	0.199
1,600–1,700	73.70	10.89	4,421.8	6,116,427	0.187
1,700–1,800	199.07	29.42	11,944.1	17,523,061	0.176
1,800–1,900	131.71	19.47	7,902.6	12,256,255	0.167
1,900–2,000	10.00	1.48	600.2	981,211	0.158
Over 2,000	...	...	...	...	0.154
Total			**26.962**	**39,510,368**	

... = 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.

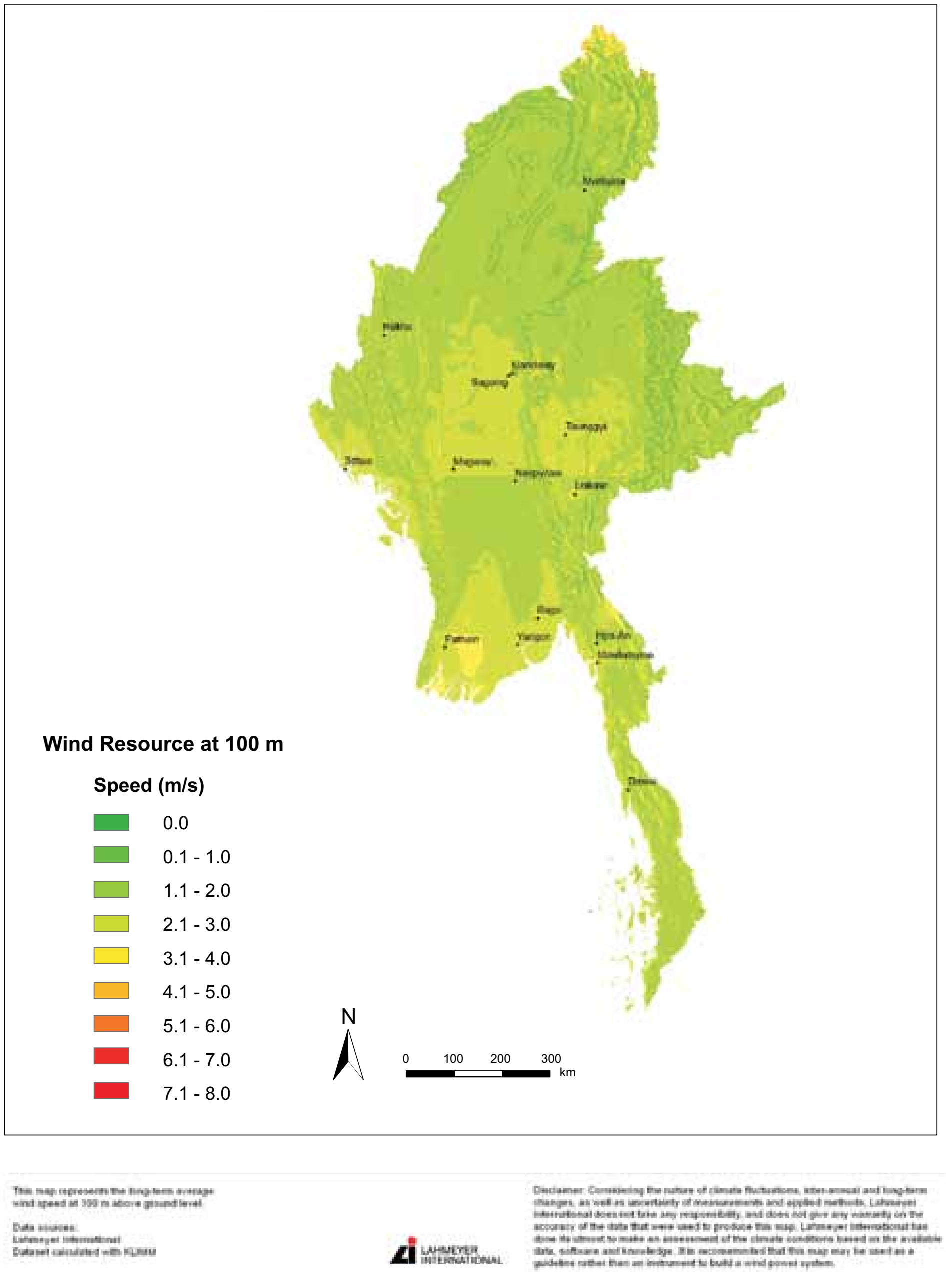
- Solar Power Village Electrification Scheme, with R&D work on solar equipment prototypes, supported by the Myanmar Scientific and Technological Research Department of MOST and the Department of Physics of Yangon Technological University.

MOST has begun providing off-grid electricity through solar systems to schools and institutes, and plans to install solar systems in technical schools throughout the country that have little or no access to the central grid.

6.3 Wind Energy Resources Potential

As summarized in Section 3 and detailed in Annex 2, the potential for wind energy in Myanmar is dependent on the average wind speed, the land area suitable for wind turbine generator installations, the efficiency of these generators, and the load capacity of the grid system. An average wind speed of at least 6 m/s is needed for modern wind turbines. As shown in Map 6.2, most of Myanmar has low average wind speeds (below 4 m/s). The areas with relatively high wind speeds are in the mountainous regions of the Chin and Shan states, the elevated central parts of Myanmar, and the coastal regions in the south and western parts of the country.

Map 6.2: **Wind Resources: Myanmar**



m = meter, m/s = meter per second.

Source: Lahmeyer International.

Table 6.3: **Theoretical Wind Potential in Myanmar**

Item	Average Wind Speed: 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)	Total
Area (km^2)	673,194	3,382	0	0	0	
Area (%)	99.95	0.05				
Theoretical potential (MW)		33,829				33,829
Indicative theoretical potential (TWh/yr)		79.5				79.5

km^2 = square kilometer, m/s = meter per second, MW = megawatt, TWh = terawatt-hour, yr = year.
Source: Lahmeyer International.

To estimate theoretical wind resource potential in Myanmar, the area of land (in km^2) with average wind speeds greater than 6 m/s was multiplied by the wind power installation density of 10 MW/km^2. As shown in Table 6.3, Myanmar has less than 3,400 km^2 with sufficient average wind speeds to make a wind project feasible. The theoretical installed wind capacity is about 33 GW and the theoretical generation potential could be in the order of 80 TWh/yr. Some previous studies estimate a much higher theoretical potential,[23] even though the MOEP acknowledges that Myanmar's wind speeds are low and irregular.

In addition to slow wind speeds, Myanmar's limited grid and system capacity is a critical factor hampering large-scale wind generation. The technical potential for wind energy development is therefore low—only about 86 MW if grid input is limited to 5% of total installed capacity, and 343 MW if grid input could be as high as 20%.

To assess what portion of this technical potential could be economically feasible, the estimated levelized cost of electricity (LCOE) of wind energy in Myanmar was compared with the current cost of other alternatives. Wind power in Myanmar has an estimated LCOE of $0.093/kWh–$0.114/kWh. Electricity tariffs in Myanmar range from $0.035/kWh to $0.075/kWh for grid-connected areas, and from $0.10/kWh to $0.30/kWh for off-grid areas. At these electricity rates, electricity from wind power would be cost effective only for off-grid applications. More R&D is needed to determine the LCOE for small-scale or off-grid wind power.[24] The LCOE can vary considerably, depending on local conditions.

Some wind turbines are operating in Myanmar, at the Technological University (Kyaukse), Shwetharlyoug and Dattaw mountains in Kyaukse Township, and the Government Technical High School (Ahmar) in the Ayeyarwady region. Two memorandums of understanding for

23 For instance, a study by Japan's NEDO (1997), the basis for a statement from the MOEP that was quoted in UNDP (2013).

24 A number of institutions, including the Department of Physics at Yangon University and MOEP's Department of Electric Power and Myanmar Electric Power Enterprise, have engaged in wind energy R&D, in cooperation with NEDO of Japan, which has built meteorological observation stations in central and lower Myanmar. NEDO has also supported the installation of wind and solar measuring equipment at several sites, to collect data and determine the feasibility of hybrid wind and solar power projects.

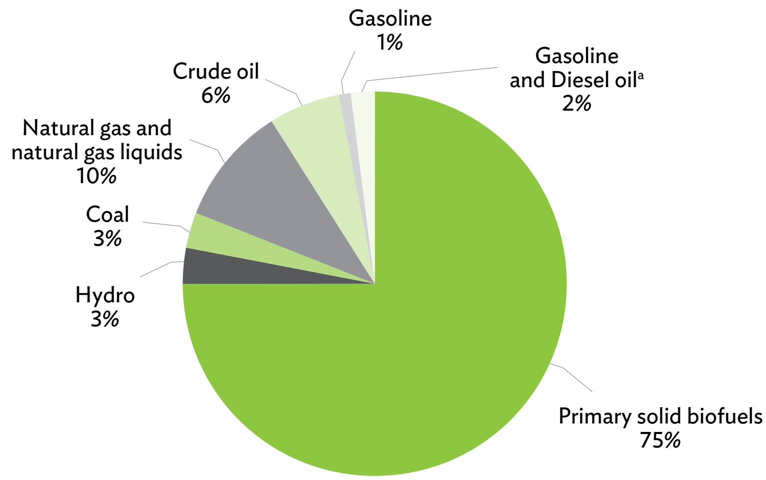
wind development projects were signed recently between Thai developers and the MOE, but the projects are still at the development stage.

6.4 Biomass and Biofuel Energy Resources

Biomass refers to organic matter that can be converted into energy either through burning or through conversion into fuels. It comprises forest and mill residues, agricultural crops and wastes, and animal manure. As shown in Figure 6.1, firewood and charcoal account for 75% of Myanmar's primary energy, contributing to deforestation and health problems (e.g., by increasing indoor air contamination with particulate matter through the use of biomass for cooking and heating). Figure 6.1 indicates that agricultural residues are an important energy source for rural households. The government is pursuing an energy policy that supports the wider use of renewable sources of energy, while addressing the environmental, health, and social issues associated with excessive household use of firewood and charcoal.

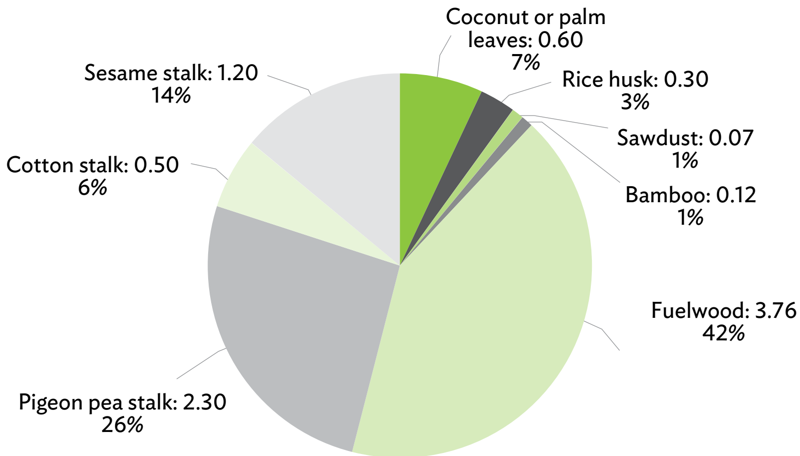
Biomass and biofuels are dealt with here from two perspectives. The first is the use of agricultural residues for household cooking and heating, and for commercial power generation. The second is the growth of selected crops as feedstock for the production of biodiesel and bio-ethanol, which are blended with diesel and gasoline to reduce dependence on imported fuels.

Figure 6.1: **Primary Energy Sources, 2010: Myanmar**



[a] Includes fuel oil, jet fuel, kerosene, jet fuel, kerosene, and other petroleum products.
Source: New Energy Architecture: Myanmar, Asian Development Bank (2013).

Figure 6.2: **Yearly Biomass Consumption of Each Rural Household: Myanmar**
(tons; percentage of household's biomass consumption total)



Source: MOAI (2011a).

6.4.1 Biomass Energy Potential of Agricultural Residues

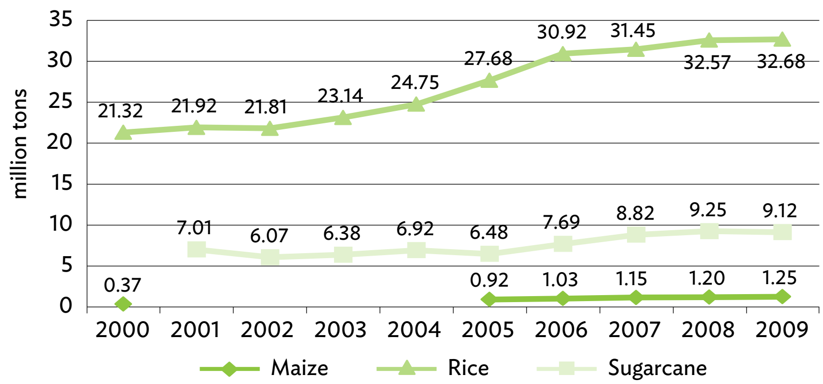
Myanmar's agriculture sector is traditional, with subsistence farming still widespread. Agriculture has been concentrated mainly in the delta and the extensive fertile alluvial plains of the Central Belt, which comprises the lower and middle basins of the Ayeyarwady River, and the lower reaches of the Chindwin River, Sittaung River, and Bago River basins. The Central Dry Zone has sandy soils with the lowest annual rainfall and the second-highest population density. The Coastal Region, with the smallest land area and the highest annual rainfall, is highly suitable for growing perennial crops, such as coconut, palm oil, and rubber. The mountainous region, which occupies the north, west, and east of the country, takes up almost half of the total land area and is characterized by dense forest.

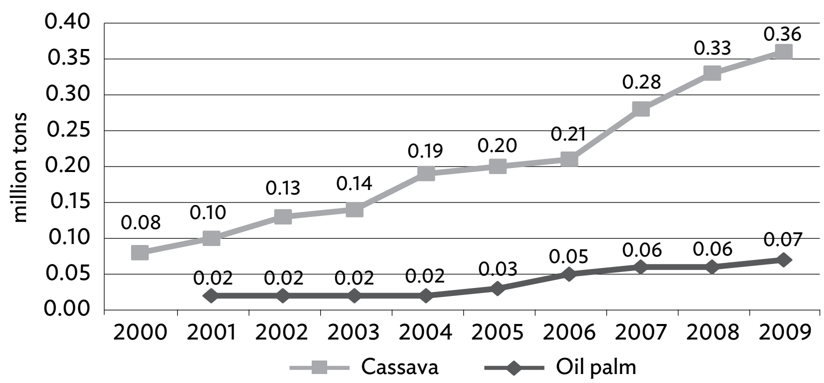
In 2010, there were 4.9 million farms cultivating an estimated 21 million ha. Sixty-four percent of the farm holdings are small (up to 5 ha) (USAID, 2013) and farmers are limited to tilling rights, unable to use land as collateral for loans for farm improvements (machinery, irrigation systems). Moreover, farm holdings are shrinking, as the tilling rights can be inherited but not sold. Productivity is low, reducing the potential for biomass energy production.

Despite these weaknesses, agricultural output has increased markedly since 2000. As shown in Figure 6.3, rice production has increased by 50% and cassava production has quadrupled.

The biomass energy potential of agricultural residues in Myanmar was estimated from MOAI data for 2009, together with other data noted below. Table 6.4 shows the total yearly

Figure 6.3: **Crop Production Trends, 2000–2009: Myanmar**
(million tons)





Source: MOAI (2011b).

tonnage of rice husks, rice straw, corn cob, cassava stalk, bagasse, sugarcane trash, and oil palm and coconut residues, together with their theoretical energy potential. The estimated total theoretical energy potential of these agricultural residues is almost 60,000 GWh, about 80% of this from rice residues. The residue production ratios (RPR) of the crops and other values shown in the calculation are drawn from studies done by B. Sajjakulnukit et al. (2005) and O. Akgün et al. (2011), as well as from regional data. Annex 3 outlines the methodology used in these calculations.

6.4.2 Biomass and Biofuel Energy Potential of Biodiesel and Bio-Ethanol

In light of Myanmar's large land mass and the dependence of 60% of the labor force on agriculture, there would appear to be considerable potential for the cultivation of crops suitable for use as biodiesel and bio-ethanol feedstock. While official targets await the finalization of the government's energy policy and national development strategy, it is reported that the government plans to substitute domestically produced biodiesel and

Table 6.4: **Theoretical Biomass Energy Potential of Agricultural Residues, 2009: Myanmar**

Biomass Residue	Total Yearly Biomass Production (10^3 tons)	Total Theoretical Energy Potential (10^6 GJ)	Total Theoretical Energy Potential (GWh)
Rice			
Rice husk[a]	8,170	104.90	29,163
Rice straw[*]	10,784	65.10	18,094
Sugarcane			
Sugarcane tops and trash[a]	2,754	18.50	5,145
Sugarcane bagasse[a]	2,280	14.60	4,073
Maize or corn cobs[a]	311	4.40	1,241
Cassava stalks[a]	31	0.20	60
Oil palm			
Oil palm frond[a]	179	1.40	398
Oil palm fiber[a]	10	0.16	45
Oil palm shell[a]	3	0.04	10
Oil palm EFB[a]	29	0.30	83

GJ = gigajoule, GWh = gigawatt-hour.

[a] Residues that are "theoretically" available for energy production.

Source: Authors' calculations.

bio-ethanol for 10% of imported oil and gasoline by 2020. MOE, MOAI, and MOST, among others, will need to coordinate closely among themselves to ensure that such targets are realistic and are not achieved at the expense of food security and the tilling rights of farmers.

The MOE has issued the following biofuel guidelines:

- Bio-ethanol (95% ethanol): produced from sugar and starch-based crops, such as sugarcane and cassava, to substitute for gasoline.
- Gasohol: anhydrous (at least 99.96%) ethyl alcohol mixed with gasoline at a specified, typically low-ethanol, blend ratio.
- Biodiesel: diesel fuel obtained from a nonedible oil plant (such as Jatropha) or an edible oilseed crop (such as oil palm, coconut, rapeseed, or soybean).

The government intends to substitute gasoline gradually with bio-ethanol to meet energy demand at the community level, and with gasohol (a blend of 15% anhydrous ethanol and 85% gasoline) at the national level. Diesel will also be substituted with a diesel blend of 5%–20% Jatropha oil at the community level and biodiesel at the national level (ADB 2012).

Myanmar has not yet developed a biofuel plan with clear targets and a road map for reaching them. Regulations are needed to avoid potential conflict with food security. Of particular interest is the cultivation of Jatropha for biodiesel production and sugarcane for bio-ethanol production.

Jatropha Cultivation

The Jatropha Plantation Project for Biodiesel Production was launched in 2005, with an initial target of 3.23 million ha of plantation. Under the scheme, entrepreneurs and local farmers were encouraged to grow Jatropha in large-scale plantations and community forests, and along roadsides. By September 2011, about 2 million ha had been planted with Jatropha. The project, however, encountered a number of problems.

On the technical side, there were issues concerning the low nutrient value of the soil, the lack of a promising seed variety and fertilizer, narrow spacing, unsystematic pruning, difficulty in disseminating the technology, and pest problems. Human resource capacity and postharvest technology, including processing and the marketing of the end product, were also inadequate. Most importantly, the project was not economically viable: the market price of biodiesel was not enough to cover the cost of the feedstock and processing.

The MOAI has identified steps that should be taken to strengthen Jatropha-based biodiesel production in Myanmar (ADB 2012):

- increase productivity through new improved varieties;
- expand cultivation in highly fertile areas of the country;
- improve management practices;
- improve postharvest technology and processing techniques;
- develop marketing systems and credit facilities;
- create better links between research and implementation;
- motivate smallholder producers;
- facilitate technology exchange with international organizations; and
- improve the information network.

Sugarcane Production

Sugarcane production in Myanmar has expanded considerably since export markets were established in 1998. Interest in bio-ethanol production based on sugarcane as a feedstock is reflected in the following developments:

- In 2000, the Myanmar Sugarcane Enterprise (now the Sugarcane Development Department) set up the first gasohol plant, with a capacity of 500 gallons of 99.5% ethanol per day. It was uneconomic at the time, as the cost of production was twice the government-controlled price of gasoline and there was no market for the factory's output. A sharp increase in the price of gasoline in August 2007 revived interest in the factory, which was transferred to private ownership.
- Since 2002, the Myanmar Chemical Engineers Group has built four ethanol plants with a total annual production capacity of 1.95 million gallons.
- In 2008, the Myanmar Economic Cooperation built two large bio-ethanol plants, with a combined capacity of 1.8 million gallons per year. In addition, Great Wall,

a private company, has built two ethanol plants, one based on sugarcane and the other on cassava.

Regulations concerning bio-ethanol production are needed to avoid potential conflict with food security.

6.4.3 Impediments to Biomass and Biofuel Development

Impediments to biofuel development in Myanmar include the following:

- Food security. The demand for food products (cereals and edible oils, sugar) and for animal feeds (coarse grains, broken rice) is increasing. Most current crops cannot be used for biofuel production.
- Investment. There is inadequate capital investment (by both government and the private sector) in the installation of biofuel plants, as well as in R&D for the various types of feedstock.
- Horizontal and vertical integration. The supply chain of the sector must be synchronized with the processing side. Commercial processing, marketing, and use has been slow to develop and could compromise the momentum gained on the supply side.

In summary, biofuel production in Myanmar is still at a preliminary stage, with discouraging experience so far. While Myanmar has the land resources for biofuel production, it lacks agricultural productivity and other basics for profitable returns. The considerable amount of land needed to meet a 10% substitution ratio of biodiesel for diesel fuel and bio-ethanol for gasoline raises questions about food security and tilling rights.

6.5 Biogas Energy Resources Potential

In this study, biogas potential is estimated on the basis of biodigester production from animal manure. Myanmar's livestock and poultry population is large, so the biogas energy potential could be considerable.

Livestock are a vital source of cash income for farmers, with cattle, buffalo, pigs, sheep, goats, chickens, and ducks being the most important livestock species. From 2005 to 2011, the agriculture sector grew at an annual rate of about 5%, while the livestock subsector grew by almost 9%. The amount of manure generated from livestock creates a waste problem, but it can also be an important source of clean energy in the form of biogas.

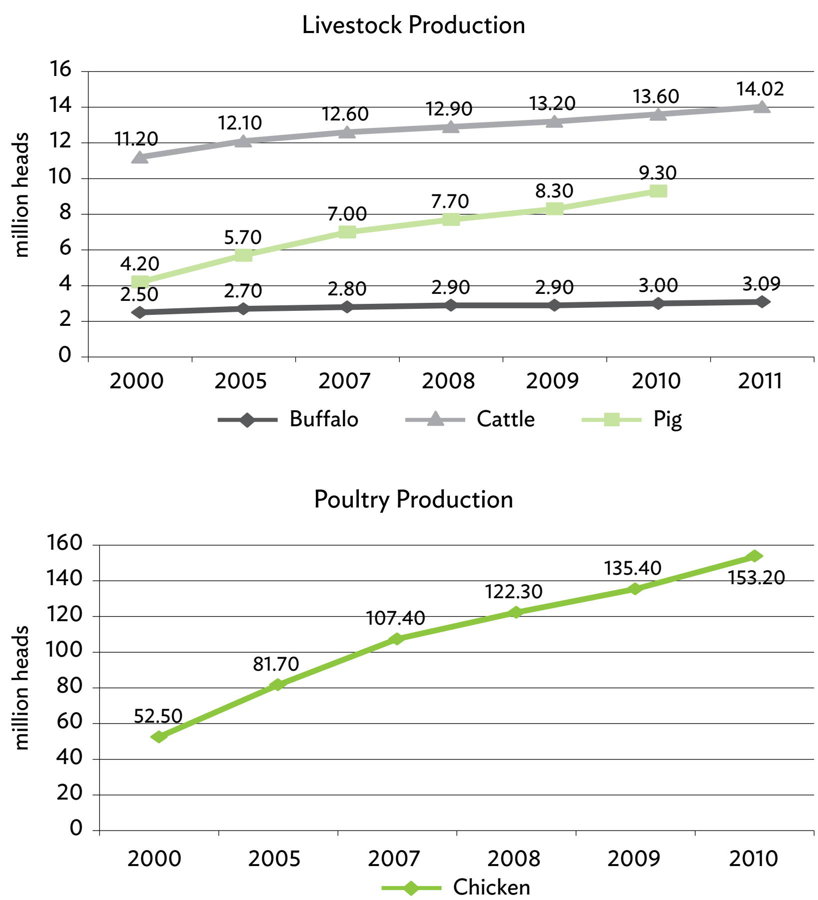
According to Ministry of Livestock and Fisheries, farm household herd sizes are typically small, averaging 5–6 cattle and buffalo, 4 pigs, and about 40 poultry. Cattle are mostly concentrated in the Mandalay, Sagaing, and Magway divisions in the central region. Cattle and buffalo are generally used for cultivation and provide local transportation. Milk production is also significant. Manure is used as fertilizer and traded locally or transported for use on high-value crops in other farms. Large-scale pig and poultry farms are a more ready source of manure.

Figure 6.4 presents population figures for the livestock and poultry subsectors from 2000 to 2012. The rapid growth rates in the livestock population numbers experienced since 2000, especially for pigs and poultry, underscore the potential for biogas production in Myanmar.

The theoretical energy potential for biogas production per day was calculated for each type of animal on the basis of the livestock numbers for 2010–2011 (Table 6.5). The calculation makes use of conversion factors established by scientific research into biogas yields from different animal manure substrates. The methodology for calculating the energy potential is presented in Annex 4.

As shown in the table, Myanmar could theoretically produce more than 20 million cubic meters of biogas daily. However, this figure greatly overstates the technical and economic potential. The technical potential is limited by the small numbers of livestock owned by farm households in Myanmar, on average, and by the reality that the livestock is largely free

Figure 6.4: **Livestock and Poultry Production: Myanmar**



Source: Ministry of Livestock and Fisheries, 2011; Livestock Breeding and Veterinary Department, for 2011–2012 data..

Table 6.5: **Theoretical Biogas Energy Potential: Myanmar**

Livestock	2010 Production[a] (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	3.09	8.00	24,720,000	16	3,955,200	0.250	988,800
Cattle	14.02	8.00	112,160,000	16	17,945,600	0.250	4,486,400
Pigs	9.30	2.00	18,600,000	17	3,162,000	4.200	13,280,400
Chicken	153.20	0.08	12,256,000	25	3,064,000	0.575	1,761,800
Total							**20,517,400**

kg = kilogram, m^3 = cubic meter.

[a] buffalo and cattle production figures are 2011/2012 statistics.

Source: Authors' calculation.

ranging, hence sufficient manure for the biodigesters is difficult to collect. Commercial-scale livestock production is little developed, except around Yangon and Mandalay. Other technical matters concern low animal weight and the percentage of dry matter content in the manure. The economic potential has been limited by the lack of competitiveness with conventional fuels.

The government has nonetheless been promoting the use of biogas since the 1980s. A total of 867 family-size, floating-type biogas digesters have been built in 134 townships and the gas produced was mainly used for cooking and lighting. The floating-drum digester was popular but became obsolete with the introduction of the fixed-dome digester in 2000. FAO and SNV estimated that about 1,200 biogas plants have been installed so far throughout Myanmar with assistance from various organizations. An estimated 80% of these are no longer in operation. Table 6.6 provides a summary account of Myanmar's experience with biogas production.

FAO and SNV (2012) noted that 20% of farm households with cattle and buffalo are able to collect at least 20 kg of fresh manure every day—the minimum amount required to run a biodigester. This means that some 600,000 household biodigesters could be installed in Myanmar and thereby contribute importantly to reducing energy shortages in the rural areas.

FAO and SNV (2012) also indicated the technical potential of community-based biogas plants. Of the 13,750 village groups in Myanmar, about half host a sufficient number of cattle and buffalo to supply a 50-cubic-meter biogas plant with 400 kg of fresh manure per day. More than 5,000 community-based biogas plants could be installed, greatly assisting the 80% of village groups that currently have no electricity supply.

In summary, there is good potential for biogas production in Myanmar and success in this field would generate significant income, environmental and health benefits, at both the household and community levels. Experience, however, suggests that careful planning and continued support is needed to improve biodigester adoption rates and sustainability of operation.

Table 6.6: **Installed Biogas Projects: Myanmar**

Institution/ Organization	Brief Description	Installation Date	No. of Plants Installed
GoRUM (Myanmar government)	Initial demonstration through the installation of floating-drum biogas plants; currently not in operation	1980–2000	867
Mangrove Service Network (MSN)	Demonstration plants installed in Delta under the Human Development Initiative; currently not operating	1996–2002	3
Economically Progressive Ecosystem Development (ECODEV)	One rectangular biogas plant was installed in the training center of ECODEV; currently not in operation	2000	1
Metta Development Corporation	In 2003, Metta organized a practical training course in biogas installation; 27 participants attended this course and installed one fixed-dome biogas plant (6 m^3) in the Metta training center in Myitkyina (Kachin State)	2003	1
Myanmar C. P. Livestock Co.	Medium-scale biogas plants (batch type) costing $12,500 have been installed; these convert biogas into electricity through a generator (25 kW) to power lamps, fans, and pumps. All systems are in operation.	2008	9
Myanmar Agricultural Produce Trading (MAPT) under the Ministry of Commerce	Low-cost community biogas plants made from liquid rubber–coated bamboo mats or plastic (tunnel type) costing $875 (excluding transmission) installed in South Shan State (52 units), Delta (2), Magway division (2), and Northern Rakhine State (10) to produce electricity using petrol engines (2 kW). Activities were cofinanced by Kanbawza Bank; cost-free for the villages. Currently the systems are not in operation.	2009–2011	66
Ar Yone Oo	Cement biogas plants premanufactured in Yangon (100 units) costing about $550 each. One demonstration unit has been installed outside Yangon.	2010–2011	1
FAO	Fiberglass biogas plants premanufactured in Yangon installed in Northern Rakhine State to produce electricity. Currently the operation rate is 60%.	2009–2011	75
MOST	In 10 different divisions and states, various fixed-dome plants ranging in size from 5 m^3 to 100 m^3 have been installed. Almost 90% of all systems with a size of 15 m^3 or more are used to produce electricity for villages, most of them in Mandalay division; 80% to 90% of the plants are reported to be in operation.	2002–2010	174
Total			**1,197**
	Projects still operating	**From 195 to 213**	

FAO = Food and Agriculture Organization of the United Nations, kW = kilowatt, m^3 = cubic meter, MOST = Ministry of Science and Technology.

Source: FAO and SNV (2012).

6.6 Summary of Renewable Energy Potential and Developments

Myanmar's solar energy resource potential is dependent on the intensity of solar irradiation, the land area suitable for photovoltaics (PV) development, and the efficiency of the solar energy systems. While 60% of Myanmar's land area has high solar irradiation levels (both GHI and DNI), a third of the country is unsuitable for PV development because of the mountainous terrain and protected areas. Moreover, the electricity transmission grid system and the robustness of the load capacity are limited, hampering input of solar power. No large-scale solar systems have been installed so far in Myanmar. The cost of electrical power from solar PV is generally much higher than that of other local grid connected options. However, solar PV would be cost effective for rural and off-grid applications. Solar-powered battery-charging stations, solar lighting, solar home systems and village solar minigrids have been installed in Myanmar, but there are no data on their overall capacity and extent.

Myanmar's wind energy potential is low, as most of the country has average wind speeds of less than 4 m/s, unsuitable for modern wind turbines. The relatively high-speed wind areas are in the mountainous regions of the Chin and Shan states, the elevated central parts of Myanmar, and the coastal regions in the south and western parts of the country, much of which is relatively inaccessible. In addition to low average wind speeds, Myanmar's grid system is limited, a critical factor hampering large-scale wind generation. As in the case of solar energy, the cost of wind energy in Myanmar is higher than prevailing tariffs for electricity for grid-connected areas—about $0.10/kWh, versus $0.03/kWh–$0.08/kWh. However, as electricity tariffs in off-grid areas are much higher (up to $0.30/kWh) wind power connected to minigrid systems in these areas could be competitive. More research is needed to determine the cost of small-scale or off-grid wind power. While a few wind turbines have been installed, there is no significant wind power generation in Myanmar. Recently, two memorandums of understanding were signed between Thai developers and the MOE regarding wind development projects, but these are still at the development stage.

Myanmar's biomass energy potential from agricultural residues is considerable, reflecting the importance of the agriculture sector. About 70% of the population is engaged in farming (ADB 2013), with 21 million ha under cultivation. Despite the small size of farm holdings and the fact that farmers are limited to tilling rights, agricultural output has increased markedly since 2000: rice production increased by 50% and cassava production quadrupled. The annual tonnage of rice husks, rice straw, corn cobs, cassava stalks, bagasse, sugarcane trash, and oil palm and coconut residues would be sufficient to generate almost 60,000 GWh. More than 90% of this would be from rice crop residues. The economic potential of agricultural residues is much less than the theoretical or technical potential, because of the difficulty of collection.

Myanmar's biofuel potential is high, again a reflection of the importance of the country's agriculture sector and its large land mass. As yet, however, the government has not specified biofuel targets and a road map for realizing them. Unofficially, it is expected that by 2020 domestically produced biodiesel and bio-ethanol will substitute for 10% of imported oil and gasoline. Jatropha is being promoted as a feedstock for biodiesel and sugarcane as a feedstock for bio-ethanol. But low yields from Jatropha crops have discouraged investment in biodiesel production; measures are needed to improve seed quality, the nutrient value of the soil, and technical knowledge for marketing and processing. The program promoting biodiesel production has not been viable economically. The market price of biodiesel has not been enough to cover the cost of the feedstock and processing. The tracts of land required to meet the 10% substitution ratio of biodiesel for diesel fuel and bio-ethanol for gasoline would be considerable, raising questions about food security and tilling rights.

Myanmar's biogas potential is also high, as most farms have sufficient manure from their livestock to run biodigesters, if collection difficulties can be overcome. FAO and SNV (2012) estimated that some 600,000 farm households are in this category. An estimated 5,000 village groups also have sufficient manure supplies for medium-scale biogas plants generating 50 cubic meters daily. Success in this field would generate significant income and environmental and health benefits, at both the household and community levels. Experience suggests that careful planning and continued support is needed to improve biodigester adoption rates and sustainability of operation. Over the past 2 decades, about 1,200 biogas plants have been installed throughout Myanmar, with assistance from various organizations, but an estimated 80% of these are no longer in operation.

7 Renewable Energy Developments and Potential in Thailand

Although the government has been intensely promoting alternative energy sources, 60% of Thailand's primary commercial energy is from imports, with imported oil accounting for 80% of domestic oil consumption. To reduce this dependence and Thailand's emissions of greenhouse gases, the national energy policy has the underlying objective of creating an 'Energy-Sufficiency Society'. At present, alternative energy accounts for only about 12% of Thailand's overall energy use. The government's target is to raise this to 25% by 2021.

7.1 Institutional and Policy Framework for Renewable Energy Initiatives

7.1.1 Institutional Framework

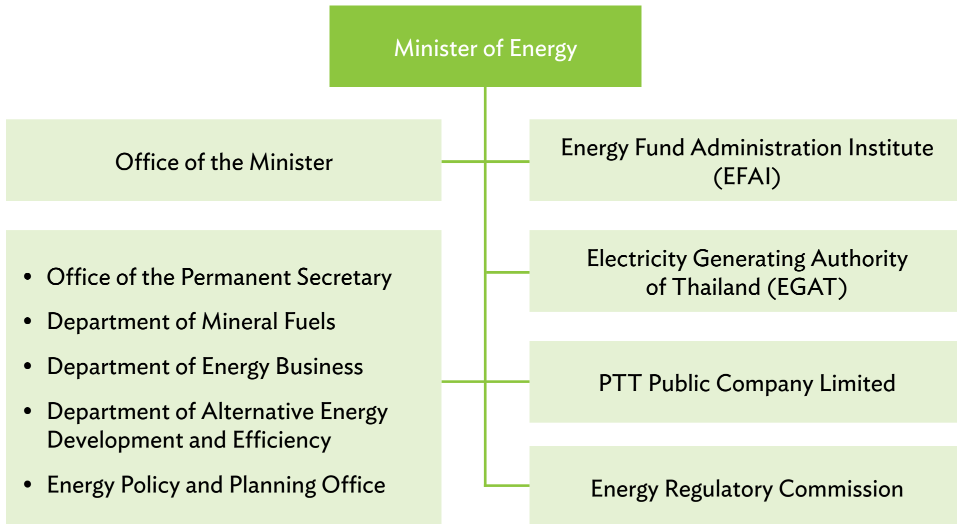
The Ministry of Energy (MOE) is responsible for energy policy, regulation, and development. As shown in Figure 7.1, the ministry has five departments and four state agencies. The Department of Alternative Energy Development and Efficiency (DEDE) is the main agency responsible for developing and promoting the use of renewable energies, while the Energy Policy and Planning Office addresses overall energy policy and planning needs, including those for renewable energy.

The four state agencies have key MOE responsibilities. The Electricity Generating Authority of Thailand (EGAT) integrates the generation and transmission functions. The Metropolitan Electricity Authority carries out the distribution and retail functions for the Bangkok Metropolitan Area, as well as for the provinces of Nonthaburi and Samutprakarn, and the Provincial Electricity Authority performs those functions for other provinces. The Energy Regulatory Commission is responsible for electricity and natural gas regulation.

The Thai government opened up the generation sector to private sector participation in 1992. Private sector generation is classified into independent power producers (IPPs) with installed power generation capacity of more than 90 MW, small power producers (SPPs) with generation capacity of 10–90 MW, and very small power producers (VSPPs) with generation capacity of less than 10 MW.

IPPs and SPPs are required to sell bulk power to EGAT, and VSPPs, to local distribution companies. Renewable energy power generation is open to all three categories of producers. MOE may also own power generation plants, especially in restricted or protected areas.

Figure 7.1: **Energy Sector Institutional Framework: Thailand**



Source: MOE.

7.1.2 Renewable Energy and Rural Electrification Policies and Targets

Under the government's Renewable Energy Development Plan, issued in 2008, renewable energy would account for 20% of Thailand's energy consumption by 2022. In 2012, this plan was replaced by the Alternative Energy Development Plan (AEDP), which raised the renewable energy target to 25% of total energy consumption by 2021. The AEDP had the overall objectives of (i) developing renewable energy to replace imported fossil fuels and strengthen Thailand's energy security, (ii) creating an integrated green community based on renewable energy, and (iii) supporting the country's renewable energy technology industry and making it competitive in international markets. The projected quadrupling of installed renewable energy capacity by 2021 would be achieved through significant increases in solar and wind power, a doubling of biomass energy, and a multifold increase in minihydropower (Table 7.1). In July 2013, the National Energy Policy Council (NEPC) revised the AEDP and set new targets for the use of solar, wind, biogas, biomass, biofuel, and other appropriate forms of renewable energy.

The DEDE is responsible for implementing the AEDP. Figure 7.2 summarizes the overall plan up to 2021.

Table 7.1: **Renewable Energy Targets: Thailand**
(MW)

Renewable Energy	Installed Capacity 2011	Installed Capacity 2013	AEDP Target, 2021
Solar	79	823.46	2,000
Wind	7	222.71	1,200
Biomass	1,790	2,320.78	3,630
Biogas	159	265.23	600
Mini- and micro-hydro	96	108.80	1,608
Municipal solid waste	26	47.78	160
Geothermal	...	...	1
Tidal wave	...	...	2
Hydrogen	...	...	...
Total	**2,157**	**3,788.00**	**9,201**

... = data not available, AEDP = Alternative Energy Development Plan, MW = megawatt.
Source: DEDE.

7.1.3 Incentive Framework

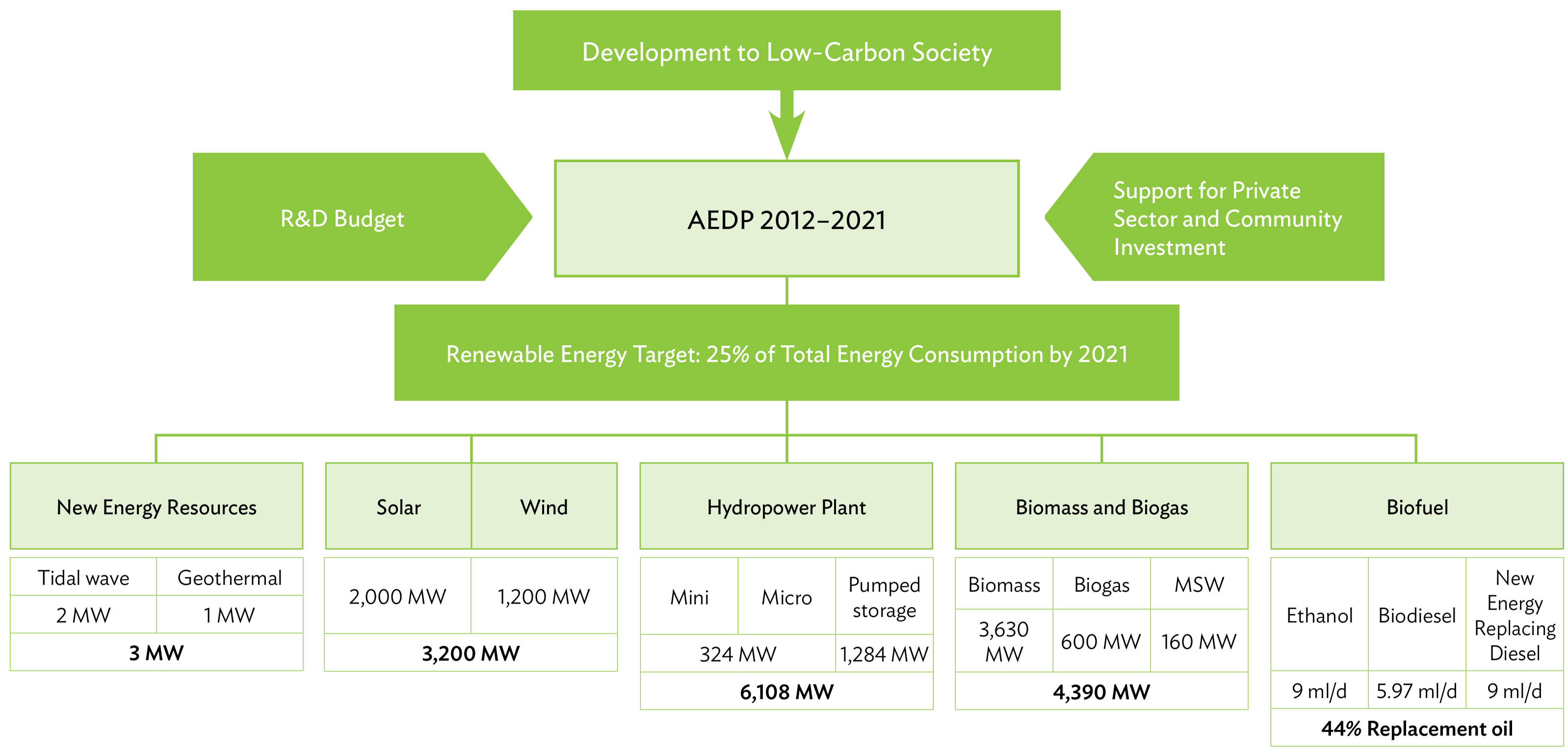
The main form of government regulatory support for renewable energy development in Thailand is the feed-in premium (a variant of the feed-in tariff), first applied in 2006. Renewable energy power companies receive a price premium over the purchase rate of state-owned utilities, based on avoided generation costs. Eligible technologies are biomass, biogas, municipal solid waste, wind, mini- and micro-hydropower, and solar. As shown in Table 7.2, the adder rates are differentiated according to technology, capacity, location, and use as diesel replacement.

A review of the solar PV policy by the NEPC in June 2010 resulted in a reduction in the adder rate from 8 baht (B) per kilowatt-hour to B6.5 /kWh because of oversubscription and reduction in PV cost.

Other mechanisms in support of renewable energy in Thailand are the following:

- Financial incentives in the form of grants and low-interest loans. MOE provides grants in support of biogas, municipal solid waste, and solar thermal projects, ranging from 20% to 100% of the capital investment but up to a maximum of B50 million per project. Grants are sourced from the Energy Conservation Fund, which also provides low-interest loans up to a maximum of B50 million and 7 years in support of small and medium-sized projects. Another financial mechanism is the Equity Fund, which allows renewable energy developers to opt for credit guarantees or government shareholder participation of up to a maximum of B50 million in either case.

Figure 7.2: **10-Year Alternative Energy Development Plan: Thailand**



ml/d = million liter per day, MSW = municipal solid waste, MW = megawatt, R&D = research and development.

Note: AEDP revised targets for 2013: solar = 3,000 MW, wind = 1,800 MW, mini- and micro-hydro = 324 MW, biomass = 4,800 MW, biogas = 3,600 MW, municipal solid waste = 400 MW, ethanol = 9 ml/d, biodiesel = 7.2 ml/d, new energy = 3 ml/d. (Source: Energy in Thailand: Facts and Figures 2013)

Source: MOE.

Table 7.2: **Renewable Energy Feed-in Premium: Thailand**

Renewable Energy Technology	Adder Rate (Baht/kWh) 2007	2010	Special Adder Rate for Diesel Replacement (Baht/kWh)	Special Adder Rate for Three Provinces in the South (Baht/kWh)	Duration (Years)
Biomass					
Installed capacity ≤ 1 MW	0.30	0.50	1.00	1.00	7
Installed capacity > 1 MW	0.30	0.30	1.00	1.00	7
Biogas					
Installed capacity ≤ 1 MW	0.30	0.50	1.00	1.00	7
Installed capacity > 1 MW	0.30	0.30	1.00	1.00	7
MSW					
Digester landfill	2.50	2.50	1.00	1.00	7
Thermal process	2.50	3.50	1.00	1.00	7
Wind					
Installed capacity ≤ 50 kW	3.50	4.50	1.50	1.50	10
Installed capacity > 50 kW	3.50	3.50	1.50	1.50	10
Mini- and micro-hydropower					
kW > Installed capacity < 200 kW	0.40	0.80	1.00	1.00	7
Installed capacity ≤ 50 kW	0.80	1.50	1.00	1.00	7
Solar					
All capacity sizes	8.00	6.50	1.50	1.50	10

kW = kilowatt, kWh = kilowatt-hour, MSW = municipal solid waste, MW = megawatt.
Source: AEDP.

- Fiscal incentives provided by the Board of Investments (BOI). Tax incentives for renewable energy projects include exemption from or reduction of import duties on machinery and essential materials, exemption from or reduction of income tax, and special corporate tax allowances. Tax incentives for private sector investors include income tax exemptions for 8 years for earnings from the manufacture of solar cells, the generation of renewable energy, the manufacture of energy-saving or renewable energy equipment and machinery, and the provision of consulting services to enable energy savings. For the next 5 years, the BOI grants a 50% reduction in the corporate income tax rate depending on the location and nature of the project.
- Other BOI incentives include exemption from restrictions on foreign equity in manufacturing or designated services and from land ownership restrictions, and guarantees and protections to mitigate risks for investors. BOI also provides information awareness services.

7.2 Solar Energy Resources Potential

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

Thailand has strong solar irradiation and resource potential. Its Global Horizontal Irradiation (GHI) ranges between 1,500 and 2,000 kWh/m^2 per year, and more than 70% of the country has GHI levels of at least 1,700 kWh/m^2. Direct Normal Irradiation (DNI) is also high: most of the country has DNI levels of 1,100–1,450 kWh/m^2 per year.

Thailand has about 380,000 km^2 that could be suitable for solar PV systems. The areas in deep red in Map 7.1 are those with the highest irradiation levels; areas in white, composing about 25% of the total land area, are water bodies, protected areas, or areas unsuitable for solar PV systems because of slope or elevation.

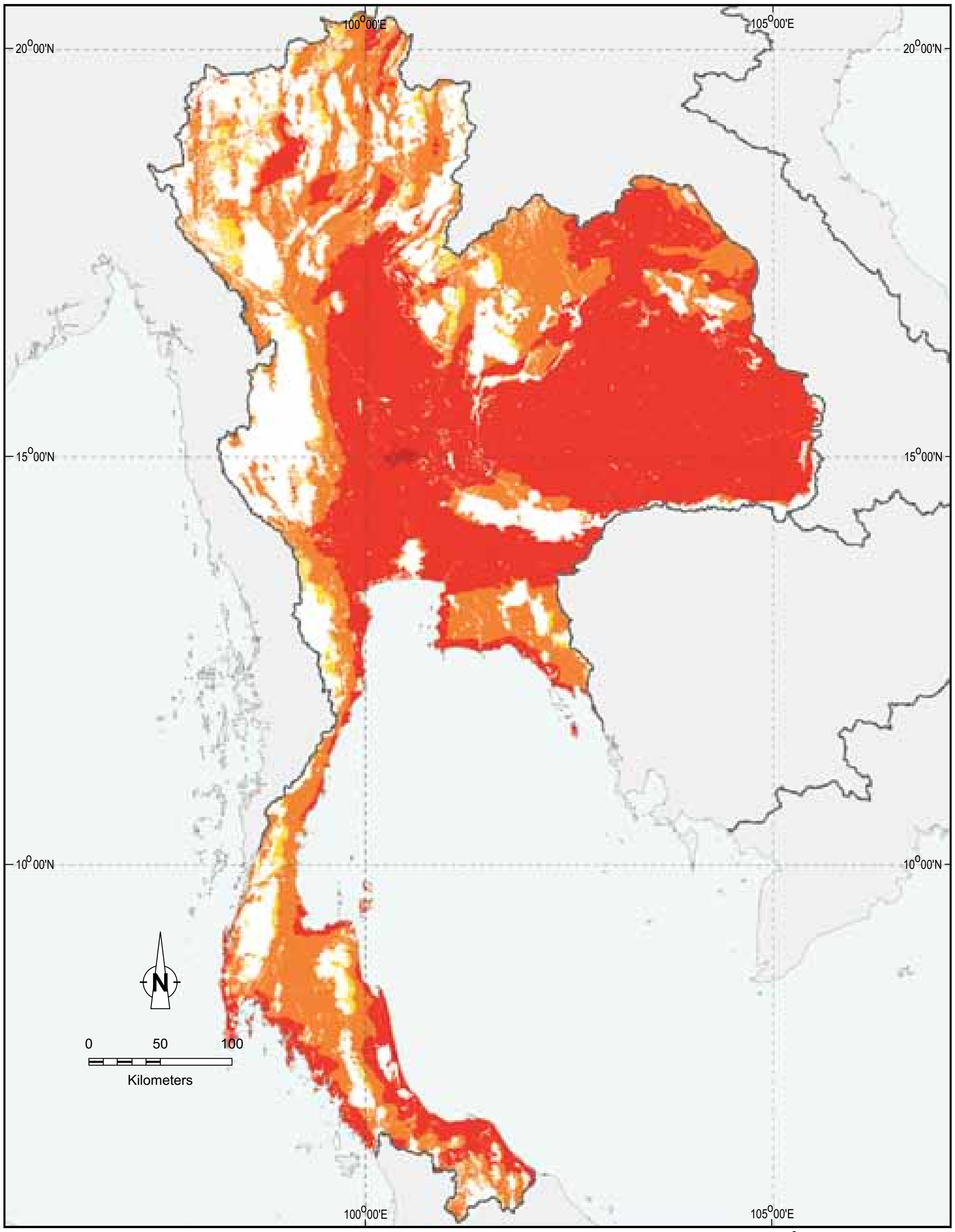
The technical solar potential was calculated as the product of total suitable land area in square meters (380,000 km^2) and the installable capacity of 0.06 kWp/m^2, which represents the average installed capacity per square meter, based on current technologies. As shown in Table 7.3, Thailand's maximum technical solar potential is about 33.4 TWh/yr, more than 90% of which is attributable to areas with the highest irradiation levels.

To assess the portion of technical potential that could be developed on an economic basis, the estimated levelized cost of electricity (LCOE) of solar power in Thailand was compared with the current cost of other alternatives. Most solar power in Thailand has an estimated LCOE of between $0.17/kWh and $0.18/kWh. Thailand's electricity import tariffs are about $0.05/kWh (ADB, 2012), and retail electricity rates range between $0.06/kWh and $0.13/kWh. At these electricity rates, electrical power through solar PV would be cost effective only for areas with higher electricity tariff rates, such as remote off-grid communities.

However, as noted earlier, the government provides generous support for renewable energy projects. In 2013, the government announced plans to promote the generation of 1,000 MW through solar PV projects, with feed-in tariff rates differentiated according to size and application (as shown in Table 7.4). Of the 1,000 MW of new solar power, 200 MW is designated for roof-mounted systems, and the remaining 800 MW, for community-based ground-mounted systems.

The development of solar power in Thailand dates from the early 1980s. By 2007, more than 1,000 solar units with a combined capacity of almost 3,000 kilowatts (kW) had been installed. These included battery systems for villages, power systems for schools, health stations, water pumps, and minigrid systems. However, sustainability was limited, with only half of the capacity still functioning by 2008. Installed solar power nonetheless continued to increase, tripling between 2008 and 2011 from an estimated 32 MW to 111 MW (CDKN, 2013). Installed capacity jumped to 635 MW in 2013, following the commissioning of

Map 7.1: **Areas Potentially Suitable for Solar Photovoltaic Development: Thailand**



CLASSES of Global horizontal irradiation, average sum of long term annual average, period 1999-2011 (kWh/m^2)

<1600 | 1600-1700 | 1700-1800 | 1800-1900 | 1900> | Masked Data

LAHMEYER INTERNATIONAL

GeoModel SOLAR

This map represent the long-term average of yearly sum of direct normal irradiation covering the period from 1999 to 2011. The underlying SolarGIS database contains global, diffuse and direct irradiance calculated from Meteosat MFG satellite with 30-minutes time step.
Data resolution (enhanced by terrain): 250 m
Data, maps and simulation tools for solar energy are available at SolarGIS website

Data sources:
Solar radiation (Same as in example)
Elevation and Slope dataset : SRTM3
Water bodies: data processed from SWBD - SRTM3
Urban areas GeoModel Solar
Protected areas: WDPA 2010

Cartography © 2012 GeoModel Solar s.r.o.
Disclaimer: Considering the nature of climate fluctuations, interannual and long-term changes, as well as the uncertainly of measurements and applied methods, GeoModel Solar s.r.o. does not take any responsibilities whatsoever, and does not give any warranty on the accuracy of the data that were used to produce this map. GeoModel s.r.o. has done its utmost to make an assessment of climate conditions based on the best available data, software and knowledge. It is recommended that this map be used as a guideline rather than an instrument to build the solar power systems.

Sources: GeoModel Solar; Lahmeyer International.

Table 7.3: Technical Solar Energy Potential: Thailand

Area (km^2)	Potential Suitable Area ('000 km^2)	% of Total Area	Technical Potential MWp	Technical Potential MWh/yr	LCOE ($/kWh)
Unsuitable area	133.08	25.94	...	...	...
Less than 1,000	...	...	...	...	...
1,000–1,100	...	...	...	...	0.302
1,100–1,200	...	...	...	...	0.276
1,200–1,300	...	...	...	...	0.254
1,300–1,400	...	...	...	...	0.235
1,400–1,500	...	...	...	...	0.219
1,500–1,600	0.23	0.05	14.0	17,556	0.204
1,600–1,700	11.21	2.18	672.6	900,566	0.192
1,700–1,800	138.10	26.91	8,286.0	11,766,235	0.181
1,800–1,900	229.60	44.75	13,776.3	20,680,272	0.171
1,900–2,000	0.87	0.17	52.0	82,358	0.163
Over 2,000	...	...	...	...	0.158
Total			**22,801**	**33,446,986**	

... = data not available, km^2 = square kilometer, kWh = kilowatt-hour, LCOE = levelized cost of electricity, MWh = megawatt-hour, MWp = megawatt-peak, yr = year.

Sources: GeoModel Solar; Lahmeyer International.

Table 7.4: Solar Photovoltaic Feed-in Tariff Rates: Thailand

Technology	Duration (years)	Feed-in Tariff Rate (Baht/kWh)
Roof-mounted systems 200 MW must be installed by the end of 2013		
Installed capacity < 10 kW	25	7.0
10 kW < installed capacity < 250 kW	25	6.6
250 kW < installed capacity < 1,000 kW	25	6.2
Community-owned ground-mounted systems 800 MW must be installed by the end of 2014		
1 MW per village	1–3	9.75
	4–10	6.5
	11–25	4.5

kW = kilowatt, kWh = kilowatt-hour, MW = megawatt.

Source: Energy Research Institute, Chulalongkorn University.

numerous large plants. The government's plans for an additional 1,000 MW of solar power will more than double this capacity.

In summary, solar power is firmly established in Thailand, with the support of a well-structured institutional framework and generous financial and fiscal incentives. The government's target of 2,000 MW of solar PV installation by 2021 appears achievable. Thailand's extensive and robust grid system enables the acceptance of commercial-scale grid-connected renewable energy.

7.3 Wind Energy Resources Potential

As outlined in Section 3 and Annex 2, the potential for wind energy in Thailand is dependent on the average wind speed, the land area suitable for wind turbine generator installations, the efficiency of these generators, and the load capacity of the grid system. An average wind speed of at least 6 m/s is needed for modern wind turbines.

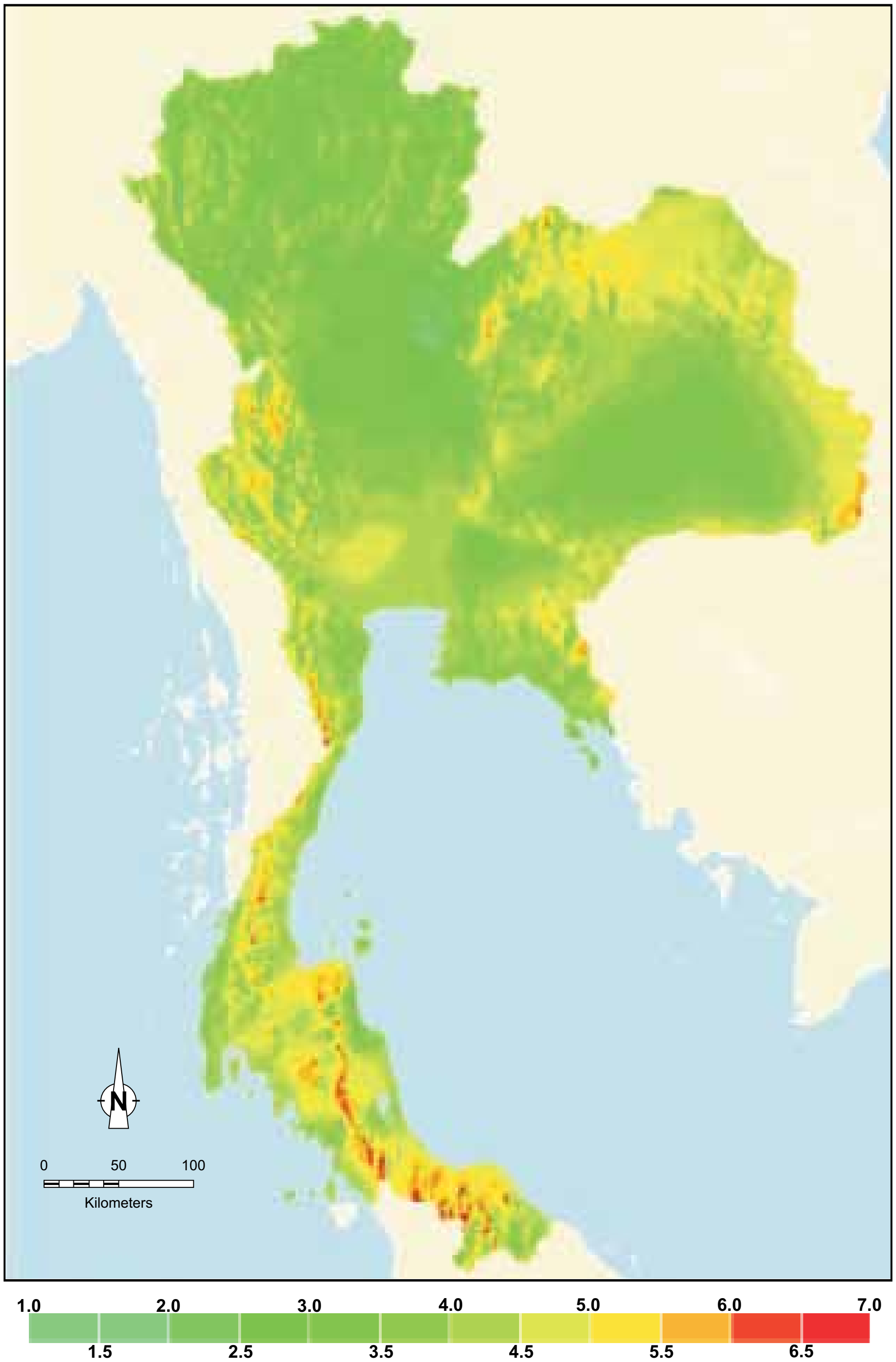
Section 3 indicated that Thailand accounts for most of the GMS potential for wind energy. This is largely because of its extensive grid and generation system, which facilitates transporting wind energy on a commercial scale. As also noted in Section 3, differences in wind-speed data measurements and mapping methodology warrant caution in making intercountry comparisons and reference to country shares of total wind energy in the GMS. Most of Thailand, in fact, experiences light winds. In 2010, DEDE/MOE did a study on the wind resource potential of Thailand based on 15 years of atmospheric data. According to the study, most of the country has average wind speeds of less than 6 m/s, except for mountainous areas in the south and the northeast of the country and in the western part of the central region, which have the minimum required wind speeds of 6–7 m/s (Map 7.2).

Table 7.5 indicates a theoretical wind energy potential of slightly more than 380 GW for Thailand, assuming 38,000 km^2 of suitable land area with sufficient wind speeds and an installation density of 10 MW/km^2.

The technical potential is much less than this, because of the extensive protected areas, the difficulty of installing wind turbines in mountainous or remote areas, and the need for a grid system nearby. Given Thailand's robust generation capacity and grid network, the system is likely to have a wind power load capacity closer to 20% (compared with 5% for less robust systems). DEDE has estimated the overall technical potential of wind power capacity at 1,600 MW. Under the Renewable Energy Development Plan, around 1,200–1,300 MW of wind power capacity was to be developed by 2022. The AEDP raised the target to 2,000 MW by 2021.

To assess the portion of technical potential that could be developed on an economic basis, the estimated levelized cost of electricity (LCOE) of wind power in Thailand was compared with the current cost of other alternatives. Most wind power in the country has an estimated LCOE of $0.076/kWh–$0.114/kWh. Thailand imposes $0.05/kWh in tariffs on imports of electricity (ADB 2012) and charges retail electricity rates ranging between $0.06/kWh and $0.13/kWh. At these electricity rates, grid-accessible areas with wind speeds of 6–7 m/s or higher could be considered cost competitive.

Map 7.2: **Wind Resources: Thailand**
(m/s)



m/s= meter per second.
Source: DEDE (2010).

Table 7.5: **Theoretical Wind Energy Potential: Thailand**

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 (km^2)	477,157	37,337	748	13	0	
Area (%)	92.6	7.2	0.2	0.0	0.0	
Theoretical potential (MW)		373,370	7,480	130	0	380,980
Indicative theoretical potential (TWh/yr)		877.42	21.69	0.46	...	899.57

... = data not available, km^2 = square kilometer, m/s = meter per second, MW = megawatt, TWh = terawatt-hour, yr = year.
Sources: World Bank (2001); DEDE (2010); Lahmeyer International.

Despite Thailand's relatively weak wind resources, there has been significant development of wind power. A total of 7.28 MW of wind power had been installed by 2012, and in 2013, wind power generation amounted to 222.71 MWh (DEDE, 2014). EGAT has supported the development of wind power in Thailand with several pilot projects including:

- a 250 kW project commissioned in 2008;
- a 1.5 MW demonstration plant commissioned in 2009; and
- a 1.5 MW gearless wind turbine pilot plant commissioned in 2011.

EGAT is planning two additional projects totaling 21 MW.

Before 2012, wind parks tended to be small scale, such as the 200 kW King's Wind Farm, using low-speed 10 kW turbines. More recently, several larger grid-connected wind projects have been commissioned:

- the 104 MW West Huay Bong 2 wind farm in Nakhon Ratchasima Province, commissioned in 2012;
- the 104 MW West Huay Bong 3 wind farm in Nakhon Ratchasima Province, commissioned in 2013;
- the 8 MW Thappana wind plant, commissioned in 2013; and
- 60 MW Khao Kho wind farm project in Phetchabun Province, now under construction.

Other wind projects amounting to an estimated 1,400 MW are in various stages of development.

In summary, despite light wind speeds in most of the country, Thailand is actively developing wind energy and could surpass its target of 1,200 MW of wind power by 2021. The adder tariff system and other incentives have been effective in promoting wind energy development.

7.4 Biomass and Biofuel Energy Resources

Biomass refers to organic matter that can be transformed into energy through burning or through conversion into a gas or oil, which can then be used as fuel. This discussion centers on the energy potential of agricultural residues and of biofuel production from crop feedstock. According to the DEDE, discussions of biomass potential in Thailand exclude conventional biomass.

7.4.1 Biomass Energy Potential of Agricultural Residues

Agricultural residues continue to be an important source of energy in rural areas. Although the agriculture sector accounts for little more than 10% of GDP, nearly 40% of Thailand's population (67 million in 2012) is dependent on the sector for their livelihood. There are almost 6 million farm households, averaging about 3.5 ha per household. Some 20% of farmers are commercial professionals and have large landholdings (2004). In terms of land use, 28% of the land is cultivated for crops like rice, maize, and cassava; 7% is cultivated for permanent crops such as citrus, coffee, and rubber; and 65% is nonarable or classified as pastures, forests, built-up areas, etc.[25] Oil palm output has doubled since 2000 and sugarcane and cassava output has also increased significantly (Figure 7.3). As discussed later, these are the main feedstocks for the domestic production of biofuels in Thailand.

Crop harvesting and processing in Thailand produces large amounts of residues. As shown in Figure 7.4, fuelwood is declining in relative importance but still accounts for 60% of the biomass total. Paddy husk and sugarcane bagasse are of increasing importance. Some residues have been used as energy sources for the agricultural processing sector through cogeneration (steam and electricity) systems.

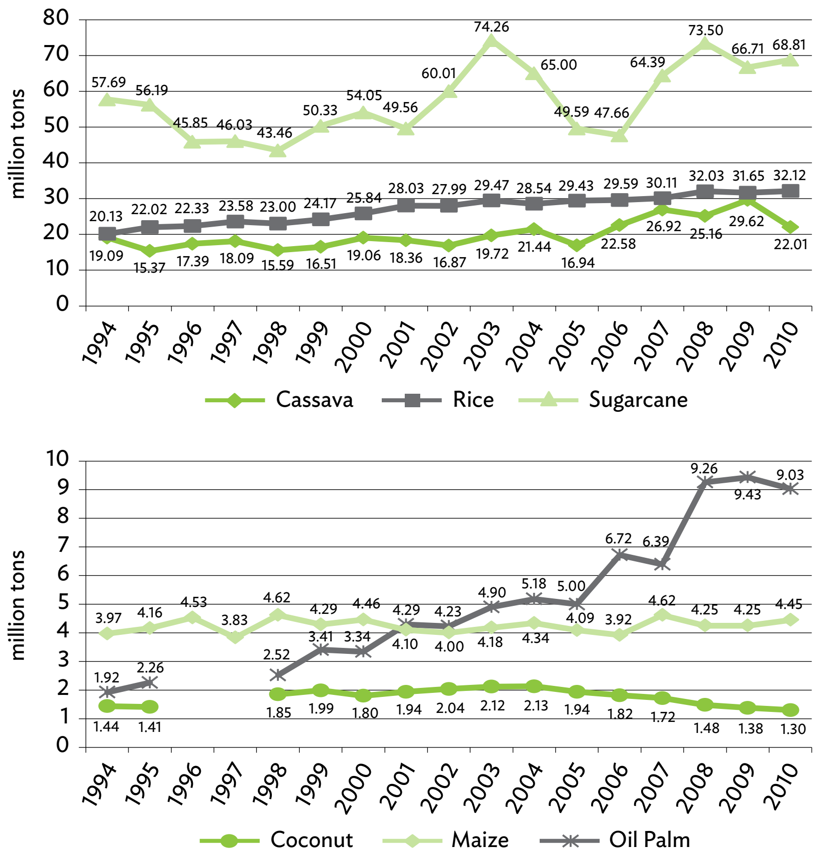
In 2010, DEDE published official data on biomass residues from major agricultural crops, including provincial data for rice, sugarcane, cassava, and oil palm residues (Map 7.3). The geographic distribution of these residues is distinct: crop residues are concentrated in the central part of Thailand, and oil palm residues, in the southern provinces.

As described in Annex 3, determining the theoretical potential of biomass energy from Thailand's agricultural residues involves calculating the residue to product ratios (RPRs) for each of the main crops and the energy values for the residues. These ratios and values are based on research results for Thailand and other GMS countries. To illustrate, the RPR for rice husk is estimated to be 0.27 and the energy or heating value is about 13 megajoules (MJ) per kilogram; for cassava, the RPR is only 0.09 but the heating value is 17. The theoretical annual biomass energy potential of agricultural residues in Thailand is estimated to be over 200,000 GWh (Table 7.6). Rice, sugarcane, and oil palm account for 85% of this potential.

Understandably, the technical and economic potential of agricultural residues is much less than the theoretical potential, partly because of the difficulty of residue collection.

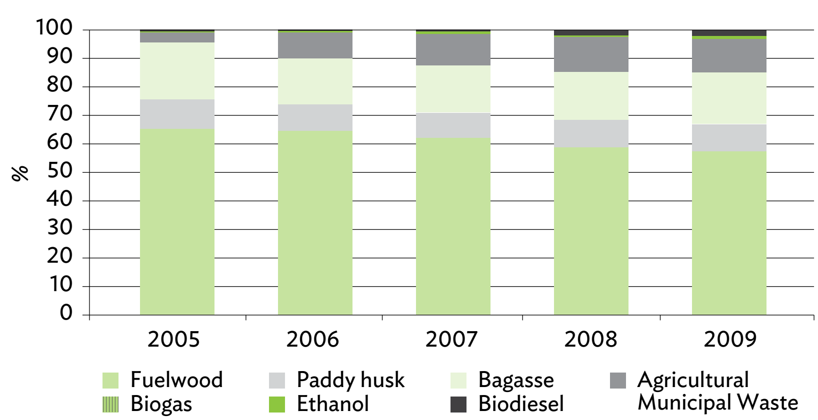
[25] Central Intelligence Agency (CIA), US. 2012. World Fact Book.

Figure 7.3: **Crop Production Trends: Thailand**
(million tons)



Source: FAO.

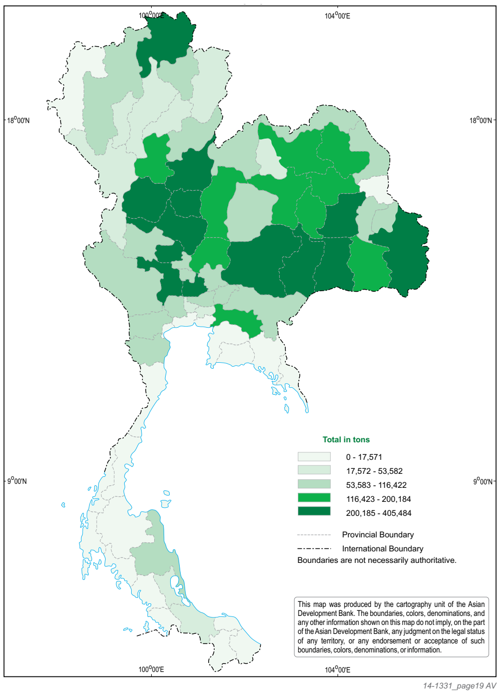
Figure 7.4: **Biomass Primary Energy Sources: Thailand**



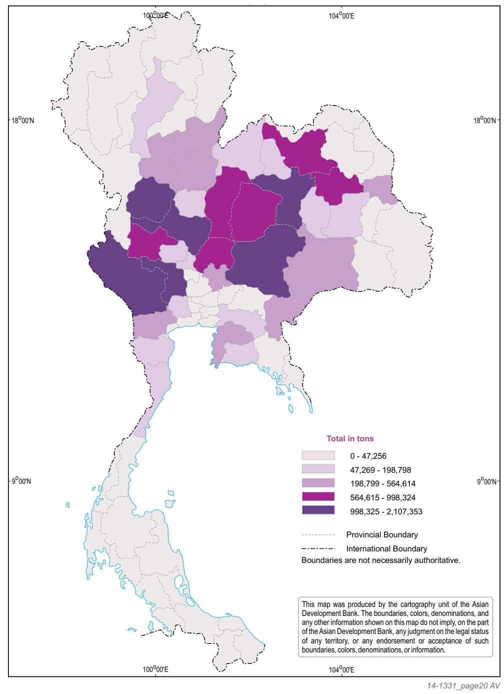
Source: DEDE.

Map 7.3: Main Crop Residues: Thailand

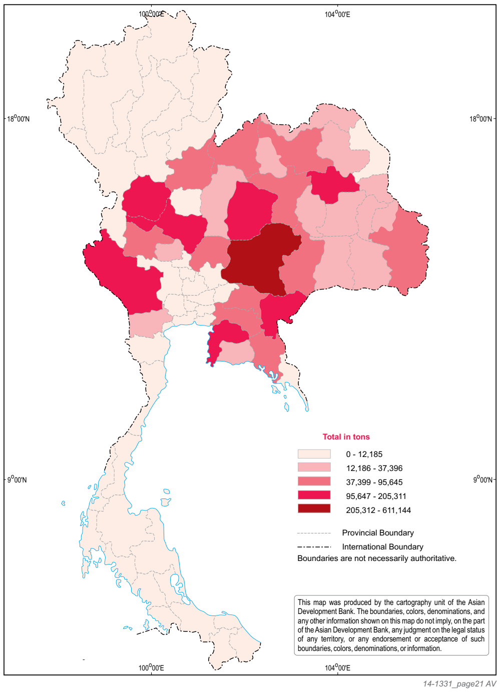
Rice Husk Production, 2010



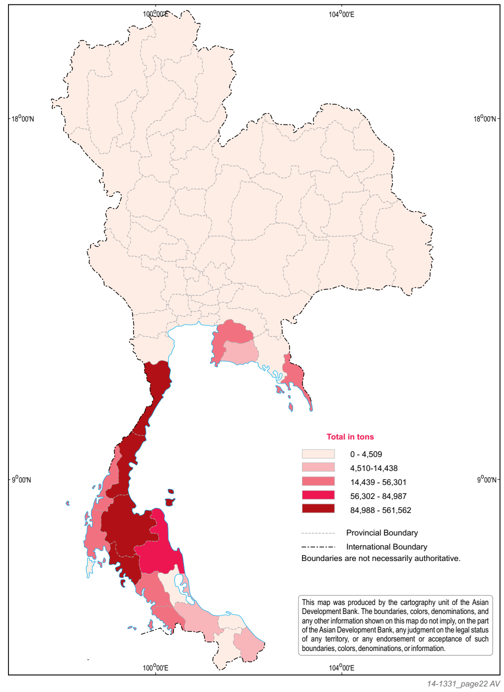
Sugarcane Bagasse Production, 2010



Cassava Stalk Production, 2010



Oil Palm Empty Fruit Bunch Production, 2010



Source: Office of Agricultural Economics, Thailand.

Table 7.6: **Theoretical Biomass Energy Potential of Agricultural Residues: Thailand**

Biomass Residue	Total Theoretical Energy Potential (10^6 GJ)	Total Theoretical Energy Potential (GWh)
Rice		
Rice husks	94.9	26,366
Rice straw	86.7	24,085
Maize or corn cobs	15.9	4,440
Cassava stalks	13.3	3,720
Sugarcane		
Sugarcane tops and trash	139.1	38,638
Sugarcane bagasse	110.1	30,584
Oil palm		
Oil palm frond	187.4	52,068
Oil palm fiber	21.3	5,923
Oil palm shell	4.7	1,306
Oil palm fruit bunch	39.0	10,839
Coconut		
Coconut shell	2.7	752
Coconut husk	6.1	1,697
Coconut frond	4.1	1,143

GJ = gigajoule, GWh = gigawatt-hour.
Source: Authors' calculation.

7.4.2 Biofuel Energy Potential of Biodiesel and Bio-ethanol

In 2012, Thailand's transport sector accounted for 35.8% of total final energy consumption, primarily in the form of petroleum products. The government is now strongly encouraging the increased use of biofuels, as underscored by the AEDP targets. The share of biofuels in Thailand's alternative energy mix is therefore expected to increase considerably in the future. These targets will, in turn, affect Thailand's future agricultural outlook, as they imply additional use of the country's natural resources.

Domestic production of bio-ethanol for transport purposes started in 2004. Since then, the number of bio-ethanol refineries has grown steadily. With AEDP-related incentives, new market players will be encouraged, increasing production further. While molasses that is a by-product of sugar manufacturing is now the main feedstock for bio-ethanol production, new entrants are expected to use cassava as feedstock.

Biodiesel production started in 2006 and its use quickly increased to 1.23 million liters per day (MLPD) (730 million liters per year [MLPY]) in 2008, and 1.725 MLPD in 2011 (Department of Energy Business, MOE; Kumar et al. 2013). As palm oil is the primary feedstock for biodiesel production, large-scale refineries are concentrated in the southern part of Thailand. There are also a few large palm oil plantations near the Bangkok Metropolitan Area.

Thailand is endeavoring to develop alternative sources for biofuel production. Second-generation ethanol production and other ways of using ethanol for blending with diesel oil are being researched. R&D is also being done on the use of algae, Jatropha, and other possible feedstocks for biodiesel production. The action plan (2012–2016) for research into new fuels for future diesel substitution is a collaborative effort between MOE and the Ministry of Science and Technology.

Since Thailand's biofuel policy and targets for biodiesel are distinct from those for bio-ethanol, these biofuels are discussed separately in the following subsections.

Biodiesel Targets and Production

Palm oil is the main feedstock for biodiesel production in Thailand, as endorsed by the government in its Biodiesel Development and Promotion Strategy (2005). Compared with other potential feedstocks (e.g., *Jatropha curcas*, peanut, sesame, and castor bean oil), palm oil has the highest biodiesel yield potential in liters per hectare. Its production and marketing costs are also lower than those of other feedstocks.

The AEDP targets 7.2 million liters per day (~2,628 million liters per year—MLPY) consumption of biodiesel by 2021, up from 2.8 MLPD in 2012. Total palm consumption, including domestic consumption, biofuel production, and national stock, is expected to require more than a million hectares of oil palm, compared with 626,330 ha currently. Another supply-side requirement is improved yield per hectare, notably in terms of oil seed extraction rates, which have fallen markedly since 2000. On the demand side, the government aims to balance biodiesel production with the domestic demand for palm oil, especially for cooking oil. Under the AEDP, B10 to B20 (10% to 20% biodiesel) diesel substitutes will be pilot-tested in fleet trucks and fishing boats. The government has been trying to increase the biodiesel blend ratio in diesel fuel and, according to the DEDE, expects to be able to use 10% of the biodiesel blends by 2021.

Bio-ethanol

The AEDP targets an increase in bio-ethanol use, to 9 MLPD by 2021 (~3,285 MLPY). Currently, there are some 20 gasohol production plants with a combined capacity of 4.8 MLPD, and three more plants are being built. However, actual bio-ethanol production in 2011 was only 1.61 MLPD[26] (domestic consumption 1.28 MLPD, exports of 0.38 MLPD). This could be attributed to the government's decision to reverse its planned policy of mandating compulsory use of ethanol–gasoline blending, resulting in a fairly stable ethanol consumption

[26] Bio-ethanol production for 2012 and 2013 1.4 million liter per day (ml/d) and 2.6 ml/d.

level (1.39 MLPD in 2012). According to the DEDE, achieving the AEDP ethanol targets will depend greatly on government policies and incentives, including the following:

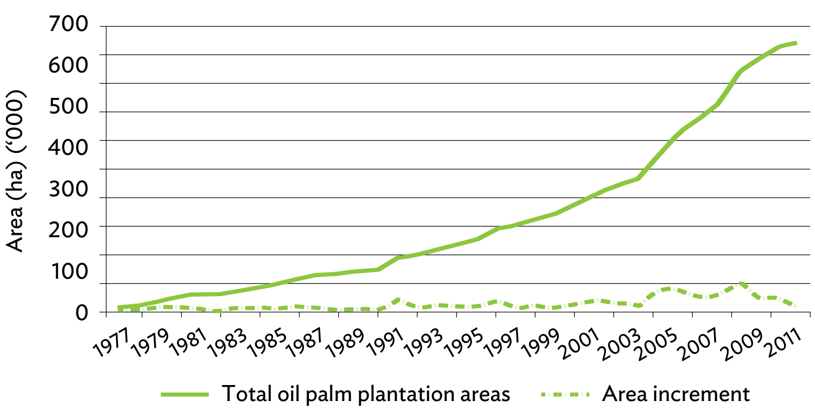
- On the supply side, the government expects to improve yields of existing feedstock, to more than 94 tons per hectare for sugarcane and 31 tons per hectare for cassava by 2021. Output per year would be about 105 million tons of sugarcane and 35 million tons of cassava.
- On the demand side, the following measures are being taken or will be taken:
  - Thailand stopped selling 91-octane (regular) gasoline in October 2012.
  - The government provides a subsidy of 1.05 baht per liter (April 2014) for E20 gasohol (20% ethanol and 80% gasoline), making E20 less expensive than 95 octane gasohol.
  - The government has gradually liberalized ethanol regulations and provides budgetary support to increase ethanol demand.
  - Recent support measures include a reduced excise tax on flexible-fuel vehicles (FFVs) of 8% for vehicles using E10 gasohol, and 3% for those using E20.
  - Future measures (2016), according to the DEDE, are likely to include a reduced excise tax of 5% for FFVs using E20 gasohol.

As indicated earlier, the DEDE/MOE is responsible for establishing compulsory and voluntary programs for renewable energy and for implementing the AEDP 2012–2021 program for biofuels.

7.4.3 The Agriculture–Biofuel Nexus

As shown in Figure 7.5, the number of hectares planted to oil palm has more than doubled since 2000, to nearly 700,000 ha.

Figure 7.5: **Area Planted to Oil Palm: Thailand**



ha = hectare.
Source: DEDE.

Table 7.7: **Land Requirement for Palm Oil as Biodiesel Feedstock: Thailand**

Item	2012	2013	2014	2015	2016	2017	2018	2021
Anticipated biodiesel demand (million liters)	1,146	1,208	1,248	1,288	1,329	1,369	1,413	2,628
Conversion factor, crude palm oil to biodiesel	0.936	0.936	0.936	0.936	0.936	0.936	0.936	0.936
Required crude palm oil (million liters)	1,224	1,291	1,333	1,376	1,420	1,463	1,510	2,808
Density of crude palm oil (kg/liter)	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Required crude palm oil (million tons)	1.09	1.15	1.19	1.22	1.26	1.30	1.3	2.50
Current extraction rate (tons CPO per ton FFB)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Production yield (tons FFB per hectare)	16	16	16	16	16	16	16	16
Land requirement (million hectares)	0.62	0.65	0.67	0.69	0.72	0.74	0.76	1.42

kg = kilogram.

Note: DEDE expects extraction rates to improve yearly, to 0.185 by 2021, resulting in a production yield of 23.53 (tons FFB per hectare) and therefore a significantly reduced land requirement of 0.57 million ha.

Sources: Office of Agricultural Economics, Ministry of Agriculture and Cooperatives; MOE.

Table 7.7 shows the land requirements for oil palm as the main feedstock for biodiesel production. Meeting the target of 2,628 million liters of biodiesel by 2021 will require about 1.4 million ha of oil palm plantation, double the amount of land currently devoted to oil palm as a feedstock for biodiesel.

The AEDP target for bio-ethanol would similarly require a very substantial increase in sugarcane and cassava cultivation. Tables 7.8 and 7.9 show the increase in land needed for sufficient feedstock to meet the bio-ethanol target of 3,275,000 millions of liters a year by 2021. Table 7.8 is based on the assumption that sugarcane/molasses is the feedstock for 20% of bio-ethanol production; Table 7.9, on the assumption that cassava provides 80% of the feedstock.

A total of 1.1 million ha of land (the combined land requirements shown in Tables 7.8 and 7.9) will be needed to meet the bio-ethanol production target by 2021. Cassava may be a better feedstock, as its cultivation appears to require much less land. Including marginal lands in feedstock production would increase the land requirements because of lower crop yields.

Table 7.8: **Land Requirement for Sugarcane as Bio-Ethanol Feedstock: Thailand**

Item	2012	2013	2014	2015	2018	2021
Ethanol required from molasses (million liters per year)	447.30	438.00	514.80	591.30	591.40	657.00
Conversion factor (liters ethanol per ton molasses)	250	250	250	250	250	250
Molasses used (million tons)	1.79	1.75	2.06	2.37	2.37	2.63
Molasses-to-sugarcane ratio (kg molasses per ton sugarcane)	46	46	46	46	46	46
Sugarcane production (million tons)	38.90	38.09	44.77	51.42	51.43	57.13
Production rate used (tons sugarcane per hectare)	94	94	94	94	94	94
Land requirement (hectares)	413,784	405,180	476,226	546,994	547,086	607,771

kg = kilogram.

Source: Authors' calculations.

Table 7.9: **Land Requirement for Cassava as Bio-Ethanol Feedstock: Thailand**

Item	2012	2013	2014	2015	2018	2021
Ethanol required from cassava (million liters per year)	830.70	1,022.00	1,201.20	1,379.70	2,365.60	2,628.00
Conversion factor (liters ethanol per ton cassava)	180	180	180	180	180	180
Cassava requirement (million tons)	4.62	5.68	6.67	7.67	13.14	14.60
Average cassava yield (tons per hectare)	31	31	31	31	31	31
Land requirement (hectares)	**148,871**	**183,154**	**215,269**	**247,258**	**423,943**	**470,968**

Source: Authors' calculations.

7.4.4 Impediments to Biomass and Biofuel Development

Since biofuels are largely based on food crops, their development raises issues of food security and concerns with respect to farm communities. Sugar and cassava products in Thailand have traditionally been exported to international food markets, while palm oil largely meets the domestic demand for cooking oil. An increase in the feedstock requirements of local biofuel processing plants could significantly affect exports and local food supplies. When biodiesel use was introduced in 2007, Thailand quickly experienced a shortage of palm oil in local markets and the price of cooking oil spiked.[27]

Increased agricultural productivity of key feedstock crops is essential to meeting the AEDP biofuel targets. As most Thai farmers are smallholders with poor access to information and modern farming practices, the government should strengthen its extension services, information dissemination, financial, and other support services.

Coordination among government agencies and ministries responsible for development of biofuels could also be strengthened. In particular, it would be beneficial if the DEDE had the capacity to regularly assess and monitor progress in meeting the AEDP targets and to work with the NEPC to ensure appropriate biofuel policies.

7.5 Biogas Energy Resource Development in Thailand

Biogas energy now accounts for 4% of Thailand's renewable energy mix.[28] This accomplishment reflects a long period of research, pilot projects, and adoption of new technologies.

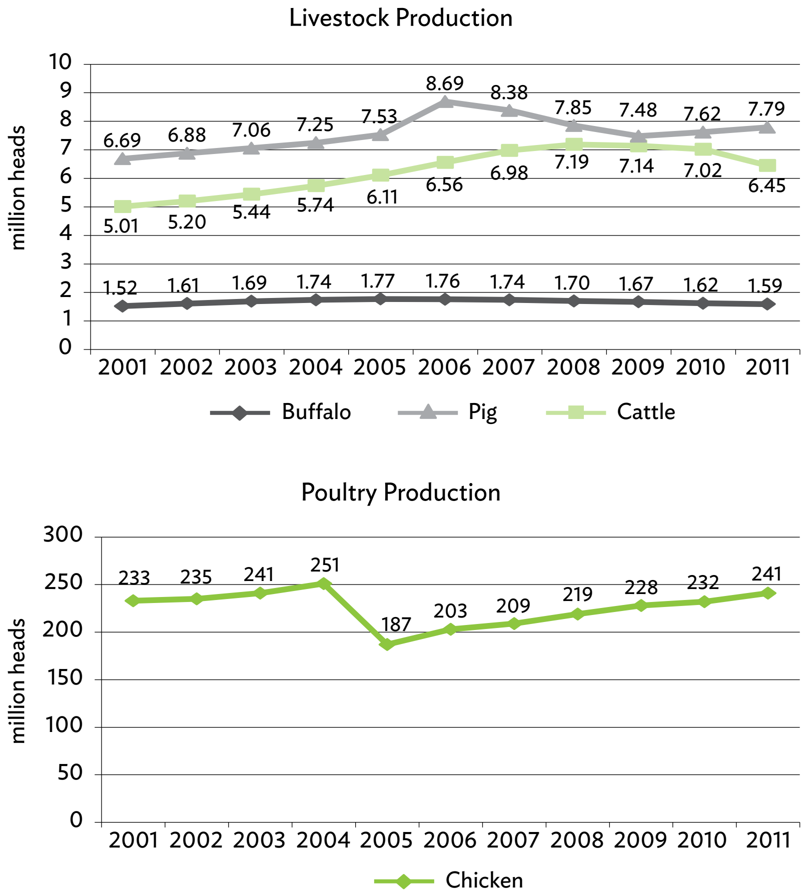
Biogas technology using a floating-drum system was first introduced in Thailand in the 1950s. The oil crises in the 1970s and 1980s prompted the government to provide biogas programs for rural energy. The programs were also designed as a health measure to reduce indoor air pollution from wood-burning cooking stoves. In 1988, the Thai-German Biogas Project was started and a Biogas Advisory Unit (now known as the Biogas Technology Center) was established to provide advice on biogas technology to small and medium-sized livestock farms throughout Thailand. While biogas is primarily designed to help meet the energy needs of farming communities, it is also promoted as a means of addressing the negative environmental impact of animal waste. The main sources of feedstock for biogas in Thailand are agro-industrial wastes, municipal solid wastes, and farm animal wastes, primarily from cows, cattle, buffalo, and pigs. The focus here is on biogas produced from animal waste.

Thailand's livestock population has steadily increased since 2000; as shown in Figure 7.6, the cattle population has increased by 30% and the pig population by 15%.

27 Oil palm supply exhibits a cyclic pattern of incurring surpluses for possible export after the harvest season, followed by the need for small imports to satisfy the demand from cooking oil processing plants before the next harvest. This cyclic pattern was changed fundamentally with the introduction of biodiesel, which increased domestic demand for biofuel feedstock and reduced exports (ADB 2009).

28 As reported by the King Mongkut's University of Technology Thonburi, Chaiprasert, 2011.

Figure 7.6: **Livestock Population, 2001–2011: Thailand**



Source: Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, 2011.

Traditionally, livestock was held on a small-scale basis, with free-range cattle and buffalo, and pigs and chickens kept in the backyards of farm households. Now, however, many livestock farms are organized on a large-scale industrial basis, especially with regard to pigs and poultry. The poultry industry, in particular, has successfully transformed itself into a leading export sector.

7.5.1 Biogas Energy Potential

Thailand's livestock population figures provide the feedstock for very substantial biogas energy resources. Table 7.10 indicates a theoretical energy potential of almost 19,000 million kWh per year. As explained in Annex 4, this estimate is based on daily manure waste for cattle, pigs, and chickens, together with the recoverable fraction and biogas yields from the volatile solids.

Table 7.10: **Theoretical Biogas Energy Potential: Thailand**

Livestock	2011 Production (million heads)	Daily Manure Production Factor (kg/animal)	Substrate Quantity (kg/day)	Dry Matter Factor (%)	Total Dry Matter Available (kg/day)
Cattle	6.447	5.00	32,235,000	17.44	5,621,784
Pig	7.786	0.50	3,893,000	35.22	1,371,115
Chicken	240.712	0.03	7,221,360	33.99	2,454,540

Livestock	Mean Biogas Yield Factor (m^3/kg dry matter)	Yearly Biogas Production (million m^3/yr)	Energy Content	
			million kWh	TJ
Cattle	0.250	513	3,078	11,081
Pig	4.200	2,102	12,612	45,401
Chicken	0.575	515	3,091	11,127
		3,130	**18,780**	**67,609**

kg = kilogram, m^3 = cubic meter, TJ = terajoule, yr = year.
Source: Authors' calculations.

While the theoretical biogas potential is substantial, a number of factors point to a much more conservative technical potential:

- Animal waste collection is difficult and costly. Animal farms, mostly small scale, are distributed throughout the country and many lack manure-collection systems. Cows and cattle tend to free range, making collection of manure costly in time and labor.
- Only layer chicken farms are suited to biogas technology. Chicken manure from broiler farms contains rice husks, which cannot be processed in biogas digesters.
- Improved waste management practices have lowered the biogas potential. Moreover, animal manure may be sold as fertilizer or other uses, reducing the feedstock for biogas.

These factors were taken into account in calculating Thailand's technical biogas potential (Table 7.11). In particular, the calculation includes a collectibility factor for the different animal wastes, as estimated by DEDE. The collectibility factor (recoverable fraction) is expressed as a percentage of the total waste produced. The biogas yields of volatile solids were derived through DEDE tests and field investigations. Thailand's technical biogas energy potential is about 2,500 million kWh, or 13% of the theoretical potential. Cattle waste accounts for 58% of the technical potential, pig waste for 15%, and chicken waste for 27%. Pig farming is becoming the main focus of attention for expanding biogas production in Thailand. Pig farms are increasingly large-scale, modern operations, accounting for more than 50% of the overall pig population.

Table 7.11: **Technical Biogas Energy Potential: Thailand**

Livestock	2011 Production (million heads)	Daily Manure Production Factor (kg/animal)	Recoverable Fraction (%)	Substrate Quantity (kg/year)	Volatile Solids (VS) Factor (%)
Cattle	6.447	5.00	0.5	5,882,887,500	13.37
Pig	7.786	0.50	0.8	1,136,756,000	24.84
Chicken	240.712	0.03	0.8	2,108,637,120	22.34

Livestock	Biogas Yield from VS Factor (m^3/kg VS)	Yearly Biogas Production (million m^3/yr)	Energy Content	
			million kWh	TJ
Cattle	0.307	241	1,449	5,216
Pig	0.217	61	368	1,324
Chicken	0.242	114	684	2,462
		417	**2,500**	**9,002**

kg = kilogram, m^3 = cubic meter, MJ = megajoule, TJ = terajoule.
Note: 1 m^3 biogas = 6 kWh; 1 kWh = 6 MJ.
Source: DEDE.

While Thailand has been generally successful in adopting biogas technology on a national scale, production levels are still far short of the AEDP target. In 2012, installed biogas capacity was only about 138 MW; the target for 2021 is 600 MW. To help accelerate biogas production, the government provides two principal forms of support:

- subsidy of up to 33% of the total investment, on a case-by-case basis; and
- tariff adder, a higher rate for the sale of electricity from biogas systems to the national grid.

In addition, there are significant tax concessions favoring renewable energy projects, including biogas projects. The Energy Policy and Planning Office (EPPO) has mobilized the Energy Conservation Fund to promote biogas systems in Thailand. Table 7.12 summarizes EPPO's biogas promotions for pig farms:

The direct subsidy to farmers during phase 1 of the EPPO project helped establish community and private sector confidence in the biogas sector, and to overcome resistance to footing the upfront costs of biogas systems. One of Thailand's first commercially funded biogas projects, Sanguan Wongse Industries, was undertaken in 2003 with the support of equity financing from international investors under a build–own–operate–transfer (BOOT) model. Since the start of commercial operation, the project has become nearly energy self-sufficient and has had an annual internal rate of return of 15%–17%. Drawing from this and other examples, most medium- to large-scale pig farms have implemented biogas systems or are in the process of installing such systems.

Table 7.12: **Energy Policy and Biogas Promotions for Pig Farms: Thailand**

Item	Phase 1	Phase 2	Phase 3	Phase 4[b]	Total
Period	1995–1998	1997–2003	2002–20010	2008–2013	
Subsidy budget ($)	640,041	2,894,942	24,373,708		27,908,692
Technical data					
Technology	UASB	UASB	UASB	Channel Digester–Junior and Fixed Dome for small pig farms	
Digester volume (m^3)	10,000	46,000	280,000		336,000
Number of swine farms (with biodigesters)	6	14	Section 1: 215 medium-size farms (150,000 m^3 biodigesters) Section 2: 34 large-scale farms (130,000 m^3 biodigesters)	240,000 livestock units: Section 1: medium and large-size (2 million pigs) Section 2: small size (<60 LSU) (400,000 pigs)	
Energy data					
Biogas production (million m^3/yr)	1.6	10.0	76[a]		11.6
Electricity production (GWh/yr)	1.63	12.50	88.92[a]		14.13
LPG (million kg/yr)	0.10	0.25	1.05[a]		0.35
Fuel oil (million liters/yr)	...	0.27	251[a]		0.27

... = data not available, GWh = gigawatt-hour, kg = kilogram, LPG = liquefied petroleum gas, m^3 = cubic meter, yr = year, UASB = upflow anaerobic sludge blanket.

Notes:

[a] Forecast data, by the end of 2009.

[b] Additional information from Chiang Mai University.

Source: Chiang Mai University research; Methane to Markets, 2009.

Phase 4 (2008–2013) of the EPPO project targets over 1,700 waste sites, including animal waste. With this ongoing initiative, biogas production is expected to increase by 350% to 600 MW by 2021.

7.6 Summary of Renewable Energy Potentials and Developments

Thailand is heavily dependent on imported energy sources (notably oil, gas, and electricity). To reduce this dependence and the country's greenhouse gas emissions, the national energy policy has the underlying objective of establishing an "Energy-Sufficiency Society" and promoting "Green Growth." At present, alternative energy sources (solar, wind, biofuel, biogas, and minihydropower) account for only 12% of Thailand's overall energy use, and the government is targeting an increase 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 over the period up to 2021 is expected to derive from dramatic advances in solar and wind power, a doubling in biomass energy, and a multifold increase in minihydropower. The main support for renewable energies in Thailand is the feed-in tariff premium, differentiated according to technology, capacity, and location. Other mechanisms in support of investment in renewable energy in Thailand are financial incentives in the form of grants and low-interest loans, and fiscal incentives in the form of exemption from import duties, and personal income tax and corporate income tax provisions.

Thailand has strong irradiation levels and hence excellent solar power potential. While little of the technical potential has so far been developed, solar PV systems are increasingly evident throughout Thailand. The government's target of nearly 2,000 MW of solar PV installation by 2021 appears achievable; if the target is reached, solar PV would account for 20% of Thailand installed renewable energy. The development of solar power is supported by a well-structured institutional framework and financial and fiscal incentives. These forms of support continue to be needed, as the cost per kW/h of solar power is $0.5–$0.10 more than the tariff rate for on-grid electricity. For off-grid applications, solar PV is increasingly competitive; in some cases, it is the only viable option. In 2013, the government announced plans to promote the implementation of 1,000 MW in solar PV projects, again subsidized by favorable feed-in tariff rates differentiated by size and application. Of the 1,000 MW of new solar power, 200 MW is to be generated from roof-mounted systems, while the remaining 800 MW is to be generated from community-based ground-mounted systems.

Thailand's wind resources are relatively modest, with average wind speeds of less than 6 m/s in most of the country. There has nonetheless been significant development of wind power: in 2013, wind power generation amounted to 222.71 MWh. Until recently, wind parks tended to be small scale, but several larger grid-connected wind projects have been commissioned. The favorable adder tariff system and other incentives have been effective in promoting wind energy. Thailand's well-established grid and robust load systems are also critical factors in facilitating expansion of wind power.

To help reduce Thailand's dependence on imported transportation fuels and lower greenhouse gas emissions, the government is strongly encouraging the increased production and use of biofuels. Under the AEDP, domestic biodiesel production is expected to reach 2,628 million liters by 2021, and bio-ethanol production, 3,275,000 million liters. This would entail more than a doubling of domestic biodiesel production and more than a sixfold increase in bio-ethanol production. The share of biofuel in Thailand's alternative energy mix is expected to increase considerably. The land needed to meet these targets will be extensive. It is estimated that 1.4 million ha will need to be planted to oil palm as feedstock for biodiesel, and 1.1 million ha will need to be planted to sugarcane and cassava as feedstock for bio-ethanol. The amount of land under cultivation for biofuel feedstock, would more than double, raising concerns about food security and the implications for farm communities.

Biogas energy now accounts for 4% of Thailand's renewable energy mix. While Thailand has been generally successful in adopting biogas technology on a national scale, output levels are still far short of the AEDP target. In 2012, installed biogas capacity was only about 138 MW; the target for 2021 is 600 MW. To help accelerate biogas production, the government provides subsidies of up to 33% of the total investment in biodigester installation. It also offers 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 pig manure is now used in biodigesters. The government is promoting ever-wider use of biodigesters, with apparent success. For small farms, however, the problem of collecting sufficient manure as feedstock, together with the up-front investment cost, continues to discourage adoption of the technology. Firewood and agricultural residues are still the primary energy sources in much of rural Thailand.

8 Renewable Energy Developments and Potential in Viet Nam

Viet Nam has experienced rapid economic growth over the past 2 decades, resulting in sharply increased demand for electricity, transportation fuels, and energy, generally for industrial, commercial, and residential use. If rapid economic growth continues, it is expected that Viet Nam's energy needs will triple by 2020. The main sources of energy for sustaining rapid economic growth are petroleum, coal, natural gas, and hydropower. As in the case of other GMS countries, rural households still rely mainly on solid fuels, especially firewood and coal, for heating, lighting, and cooking.

Renewable or alternative energy sources are at a preliminary stage of development. Viet Nam's renewable energy policy and targets have been integrated into its current National Plan for Power Development 2011–2020. The plan targets an increase in the share of renewable power generation, from 3.5% in 2010 to 4.5% by 2020, and possibly to 6% by 2030.

8.1 Institutional and Policy Framework for Renewable Energy Initiatives

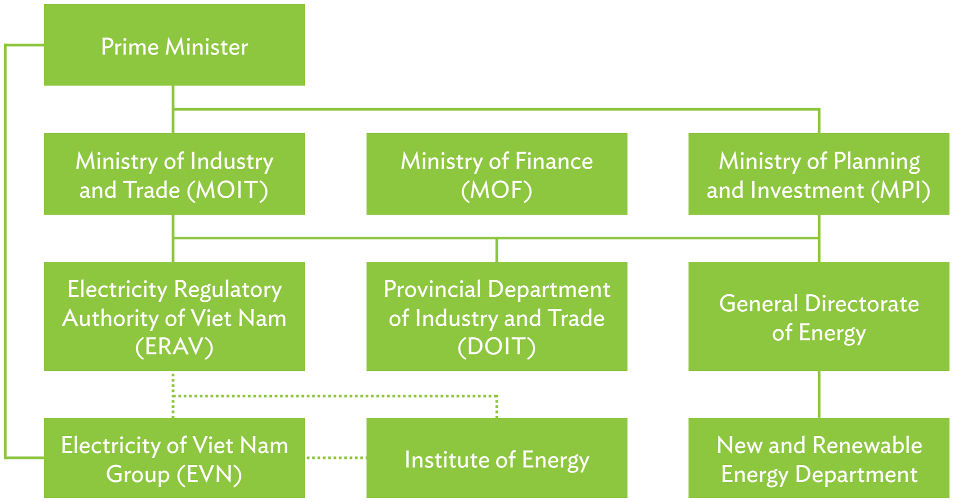
8.1.1 Institutional Framework

The Office of the Prime Minister has overall responsibility for policies, regulations, strategies, and plans concerning the development of renewable energy. In turn, three ministries are involved in formulating or implementing renewable energy policies:

- The Ministry of Industry and Trade (MOIT) is responsible for the design of energy policies and national energy plans. MOIT is also responsible for the management of coal, oil, gas, electricity, nuclear energy, and renewable energy.
- The Ministry of Planning and Investment coordinates and allocates funds for energy proposals submitted by line ministries and agencies.
- The Ministry of Finance (MOF) formulates energy sector taxation and tariff policies.

For all three agencies, decisions are subject to approval by the Prime Minister's Office. The institutional framework is shown in Figure 8.1.

Figure 8.1: **Energy Sector Institutional Framework: Viet Nam**



Source: IISD (2013).

In addition, a number of national and local government agencies have responsibilities relevant to renewable energy development:

- The Electricity Regulatory Authority of Vietnam (ERAV) is responsible for power market establishment and supervision, power planning, tariff regulation, and licensing.
- The General Energy Department under the Ministry of Industry and Trade (MOIT) is responsible for overall energy sector policy and planning.
- The provincial Departments of Industry and Trade (DOIT) are responsible for implementing state management directives with respect to the energy sector, including directives for renewable energy, at the provincial level.
- Electricity of Viet Nam (EVN) is a state-owned utility responsible for developing and managing electricity production, transmission, and distribution.
- The Institute of Energy undertakes and prepares energy sector plans, strategies, and policies.

Viet Nam's energy sector is in transition from a single-buyer market model to a competitive retail market system. The generation segment has been opened up to build–operate–transfer (BOT) and independent power producer (IPPs) projects. The distribution sector has also been opened up to private distributors, particularly those in rural areas not covered by EVN's distribution network.

8.1.2 Renewable Energy and Rural Electrification Policy and Targets

Viet Nam's renewable energy policy and targets are included in the National Plan for Power Development 2011–2020 (Power Development Plan VI). The main objective is to promote efficient use of energy resources and to ensure energy security at a reasonable price. More specifically, the plan is aimed at (i) providing adequate electricity for domestic demand; (ii) prioritizing the development of renewable energy sources for electricity production; (iii) reducing electricity intensity and improving energy efficiency; and (iv) accelerating electrification in rural and mountainous areas.

The plan targets an increase in the share of renewable energy in total power generation, from 3.5% in 2010 to 5% by 2020 and 6% by 2030. The capacity target for each renewable energy type is shown in Table 8.1. Most of the increase in installed capacity is expected to be in wind and biomass energy.

Table 8.1: **Renewable Energy Targets: Viet Nam**

	Installed Capacity (MW)	
Renewable Energy	**2020 Target**	**2030 Vision**
Wind	1,000	6,200
Biomass	500	2,000
Hydropower		
Conventional	17,400	17,400
Storage	1,800	5,700
Total	**20,700**	**31,300**

MW = megawatt.
Source: National Power Development Plan VI.

8.1.3 Incentive Framework

In 2012, the Ministry of Finance (MOF) introduced a feed-in tariff for wind power generation of $0.078/kWh. This amount combines a fixed purchase price of $0.068/kWh and a $0.01/kWh subsidy financed from the state budget through the Environment Protection Fund. The subsidy can be adjusted by a decision of the Prime Minister.

As the agency responsible for the purchase of electricity from wind power developers, EVN is also eligible for a price subsidy from the government. EVN, on the other hand, is required to report the following data to the Electricity Regulatory Authority of Viet Nam: (i) general information on wind farms with signed power purchase agreements for the following year (including the name of the wind farm, investor, installed capacity, output, and location, and the contract's value, date, and number); (ii) amount of electricity purchased from the wind farm in the previous year; (iii) expected output to be contracted with the wind farm operator in the current year and subsequent years; and (iv) the expected total amount subsidized.

While the feed-in tariff for wind power generation was specified, the reference price for projects generated from other renewable energy resources with installed capacity of less than 30 MW is based on EVN's avoided cost. The avoided cost is defined as the production cost per kilowatt-hour of the most expensive power-generating unit in the national power grid. The current avoided cost rate is $0.05 per kWh.

Viet Nam's Investment Law also provides support for renewable energy projects, both for domestic and foreign investors. The corporate tax incentives are summarized in Table 8.2. In addition to the sectors and areas shown in the table, the government has established more than 250 special industrial zones and 20 economic zones with special incentives. The category "Encouraged and Special Encouraged" investments includes renewable energy investments.

Table 8.2: **Investment Law Tax Incentives: Viet Nam**

Item	Corporate Income Tax (CIT) Rate	Availability of CIT Incentives (years)	CIT Exemption Holiday (years)	50% Reduction of CIT (consecutive years after tax exemption period)
Encouraged sectors	20	10	2	3
Encouraged areas	20	10	2	6
Encouraged sectors in encouraged areas	15	12	3	7
Special encouraged industries and special encouraged areas	10	15	4	9

Note: Encouraged and special encouraged sectors cover (i) production of renewable energies, high-activities; (ii) high-tech, modern technologies, ecological and environmental protection, and research and development; (iii) labor-intensive industries; and (iv) forestry, agriculture, fishery, and animal husbandry. These sectors include areas related to renewable energy development.

Encouraged areas include geographic areas entitled to investment incentives located in regions with poor socioeconomic development, industrial parks, export-processing zones, zones producing high-tech equipment, and economic zones.

Source: Viet Nam National Power Development Plan VI.

Fiscal incentives for renewable energy projects include the following:

- Preferential corporate tax rates;
- Exemption from import tax on equipment and materials; and
- Accelerated depreciation rates.

Another incentive is export credits for renewable energy projects, covering up to 70% of the construction cost. The credit is for 12 years, benchmarked to government bond interest rates. Renewable energy projects that comply with the Clean Development Mechanism of the Kyoto Protocol are entitled to additional support measures, such as land rent exemptions.

8.2 Solar Energy Resources Potential

As noted for Cambodia, the Lao PDR, Myanmar, and Thailand, and as outlined in Annex 1, a country's solar energy resource potential is largely dependent on the degree of solar irradiation, the estimated land area suitable for photovoltaics (PV) development, and the efficiency of the solar energy systems. The potential for solar energy can be assessed in theoretical, technical, and economic terms.

Viet Nam has medium solar irradiation and resource potential. Its Global Horizontal Irradiation (GHI) levels are between 1,200 and 2,000 kWh/m^2, widely distributed across the entire range. About one-third of the land area is unsuitable for PV development, primarily because of Viet Nam's mountainous terrain. Of the land area suitable for PV development, only one-third has GHI levels higher than 1,700 kWh/m^2/yr. Direct Normal Irradiation (DNI) levels range from less than 400 to 1,500 kWh/m^2/yr.

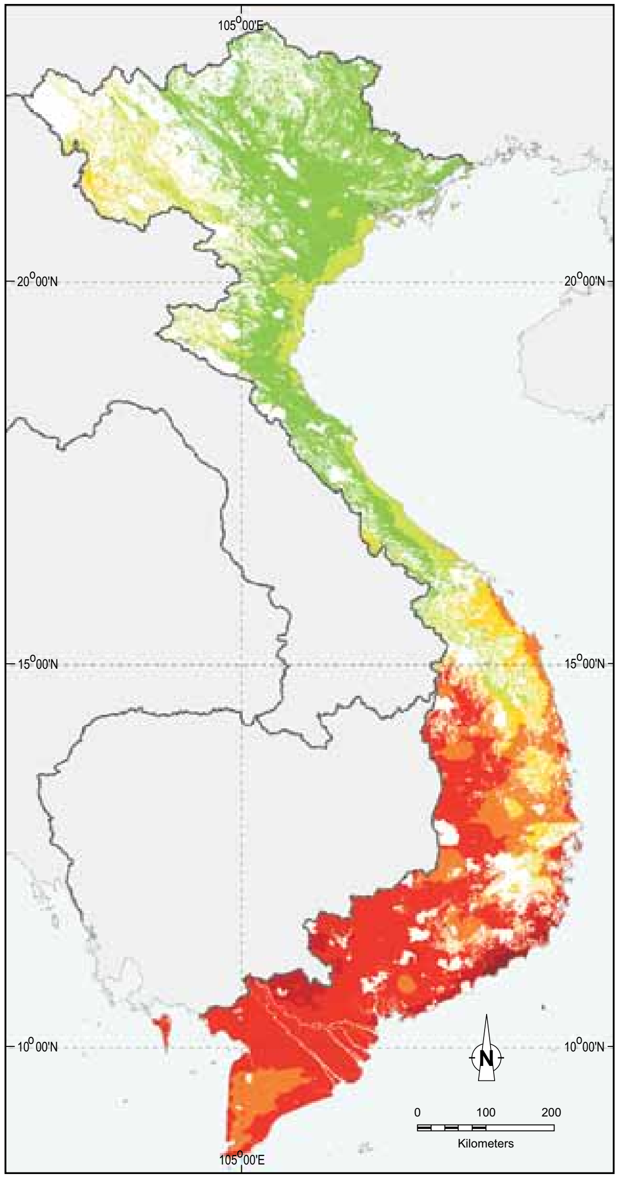
Viet Nam has about 220,000 km^2 that could be suitable for solar PV systems. The areas shown in deep red in Map 8.1 indicate areas with the highest irradiation levels; areas shown in white are water bodies, protected areas, or areas unsuitable because of slope or elevation. The map shows considerable differences in irradiation intensities between the northern and southern portions of the country.

The technical solar potential was calculated as the product of the total suitable land area in square meters (220,000 km^2) and the installable capacity of 0.06 kWp/m^2, which represents the average installed capacity per area based on current technologies. As shown in Table 8.3, Viet Nam's technical solar potential is about 18 TWh/yr, with more than 60% of this attributable to areas with the highest irradiation levels, which are in the southern half of the country.

To assess the portion of technical potential that could be economically feasible, the estimated levelized cost of electricity (LCOE) of solar power in Viet Nam was compared with the current cost of other alternatives. Most solar power in Viet Nam has an estimated LCOE between $0.17/kWh and $0.22/kWh. Electricity import tariffs in Viet Nam are $0.05/kWh and electricity tariffs range from $0.03/kWh to $0.16/kWh. At these electricity rates, electrical power through solar PV is not a cost-effective option except under special situations, for example, off-grid applications. However, solar projects should be evaluated on a case-by-case basis. Comparisons with the cost of other alternatives need to be area specific, as solar power may be competitive in many parts of Viet Nam simply because the alternative (e.g., diesel-powered generators) is even more costly. The various incentives provided by the government for investment in solar energy are also an important consideration.

While little of Viet Nam's solar potential has so far been harnessed, residential and small-scale rural installations are numerous. An estimated 4,000 families have installed solar home systems. Rural electrification programs since 1990 have included PV systems, but a survey is needed to determine their current status. Estimates of total installed solar

Map 8.1: **Areas Potentially Suitable for Solar Photovoltaic Development: Viet Nam**



CLASSES of Global horizontal irradiation, average sum of long term annual average, period 1999-2011 (kWh/m²)

<1300	1500-1600	1800-1900	Masked Data
1300-1400	1600-1700	1900-2000	
1400-1500	1700-1800	2000>	

LAHMEYER INTERNATIONAL

GeoModel SOLAR

This map represent the long-term average of yearly sum of direct normal irradiation covering the period from 1999 to 2011. The underlying SolarGIS database contains global, diffuse and direct irradiance calculated from Meteosat MFG satellite with 30-minutes time step.
Data resolution (enhanced by terrain): 250 m
Data, maps and simulation tools for solar energy are available at SolarGIS website

Data sources:
Solar radiation (Same as in example)
Elevation and Slope dataset : SRTM3
Water bodies: data processed from SWBD - SRTM3
Urban areas GeoModel Solar
Protected areas: WDPA 2010

Cartography © 2012 GeoModel Solar s.r.o.
Disclaimer: Considering the nature of climate fluctuations, interannual and long-term changes, as well as the uncertainly of measurements and applied methods, GeoModel Solar s.r.o. does not take any responsibilities whatsoever, and does not give any warranty on the accuracy of the data that were used to produce this map. GeoModel s.r.o. has done its utmost to make an assessment of climate conditions based on the best available data, software and knowledge. It is recommended that this map be used as a guideline rather than an instrument to build the solar power systems.

Sources: GeoModel Solar; Lahmeyer International.

Table 8.3: **Technical Solar Energy Potential: Viet Nam**

Area (km²)	**Potential Suitable Area** ('000 km²)	**% of Total Area**	**Technical Potential**		**LCOE** ($/kWh)
			MWp	**MWh/yr**	
Unsuitable area	109.10	32.94	...	...	...
Less than 1,000	...	...	...	...	...
1,000–1,100	...	...	...	...	0.301
1,100–1,200	...	...	...	...	0.275
1,200–1,300	0.04	0.01	2.5	2,586	0.253
1,300–1,400	5.23	1.58	314.1	345,836	0.234
1,400–1,500	69.92	21.11	4,195.3	4,961,641	0.218
1,500–1,600	25.48	7.69	1,529.0	1,933,035	0.204
1,600–1,700	11.37	3.43	682.4	918,346	0.192
1,700–1,800	28.26	8.53	1,695.6	2,420,234	0.181
1,800–1,900	72.61	21.92	4,356.5	6,573,592	0.171
1,900–2,000	8.19	2.47	491.1	781,158	0.162
Over 2,000	0.99	0.30	59.6	97,259	0.158
Total			**13,326**	**18,033,687**	

... = data not available, km^2 = square kilometer, kWh = kilowatt-hour, LCOE = levelized cost of electricity, MWh = megawatt-hour, MWp = megawatt-peak, yr = year.

Sources: GeoModel Solar; Lahmeyer International.

capacity vary from 1.5 MW to 4 MW. A number of small-scale grid-connected PV plants have recently been developed, including:

- 212 kW Big C Supermarket in Di An;
- 200 kW Intel factory in Saigon High-Tech Park; and
- 100 kW power project near Ho Chi Minh City.

In summary, Viet Nam has medium solar power potential, predominately in the southern half of the country. Little of this potential has been harnessed so far. Somewhat surprisingly, the government's renewable energy resource targets omit reference to solar power.

8.3 Wind Energy Resources

Wind energy is expected to gain increasing importance in Viet Nam, from less than 50 MW currently to 1,000 MW by 2020 and to 6,200 MW by 2030. If these targets are realized, by 2030 wind power would account for 20% of total renewable energy capacity in Viet Nam. As outlined earlier, the government has introduced a wide range of financial support for wind energy, including a highly favorable feed-in tariff.

8.3.1 Wind Energy Resource Potential

As outlined in Annex 2, the potential for wind energy in Viet Nam is dependent on the average wind speed, the land area suitable for wind turbine generator installations, the efficiency of these generators, and the load capacity of the grid system. An average wind speed of at least 6 m/s is needed for modern wind turbines to be effective.

Viet Nam has moderate wind resource potential, with wind speeds of 6–7 m/s over about 2,435 km^2, 7–8 m/s over about 220 km^2, and greater than 8 m/s over 20 km^2. As shown in Map 8.2, the best wind resource potential is along the coastal areas in the south central region and the mountainous regions of central Viet Nam.

Table 8.4 shows the theoretical wind resource potential, clustered by classes of average wind speed. Viet Nam's theoretical wind potential is estimated to be about 26,763 MW, assuming 2,676 km^2 of suitable land area with sufficient wind speeds (> 6 m/s) and an installation density of 10 MW/km^2 (the average installation capacity per km^2). Land area considered unsuitable for wind power production (i.e., areas with slopes exceeding 20%, protected parks and nature preserve, wetlands, urban areas, watercourses and water bodies) are excluded from the land areas shown in Table 8.4.[29]

As with most countries, Viet Nam's technical wind potential is much less than the theoretical potential, largely because of system constraints. If wind energy generation were to be limited to 5% of the system capacity, Viet Nam's technical wind potential would be about 760 MW. But if the wind energy generation capacity could be raised to 20% of total generation capacity, the technical potential would be over 3,000 MW. The technical potential will increase as the grid and total generation capacity are developed further.

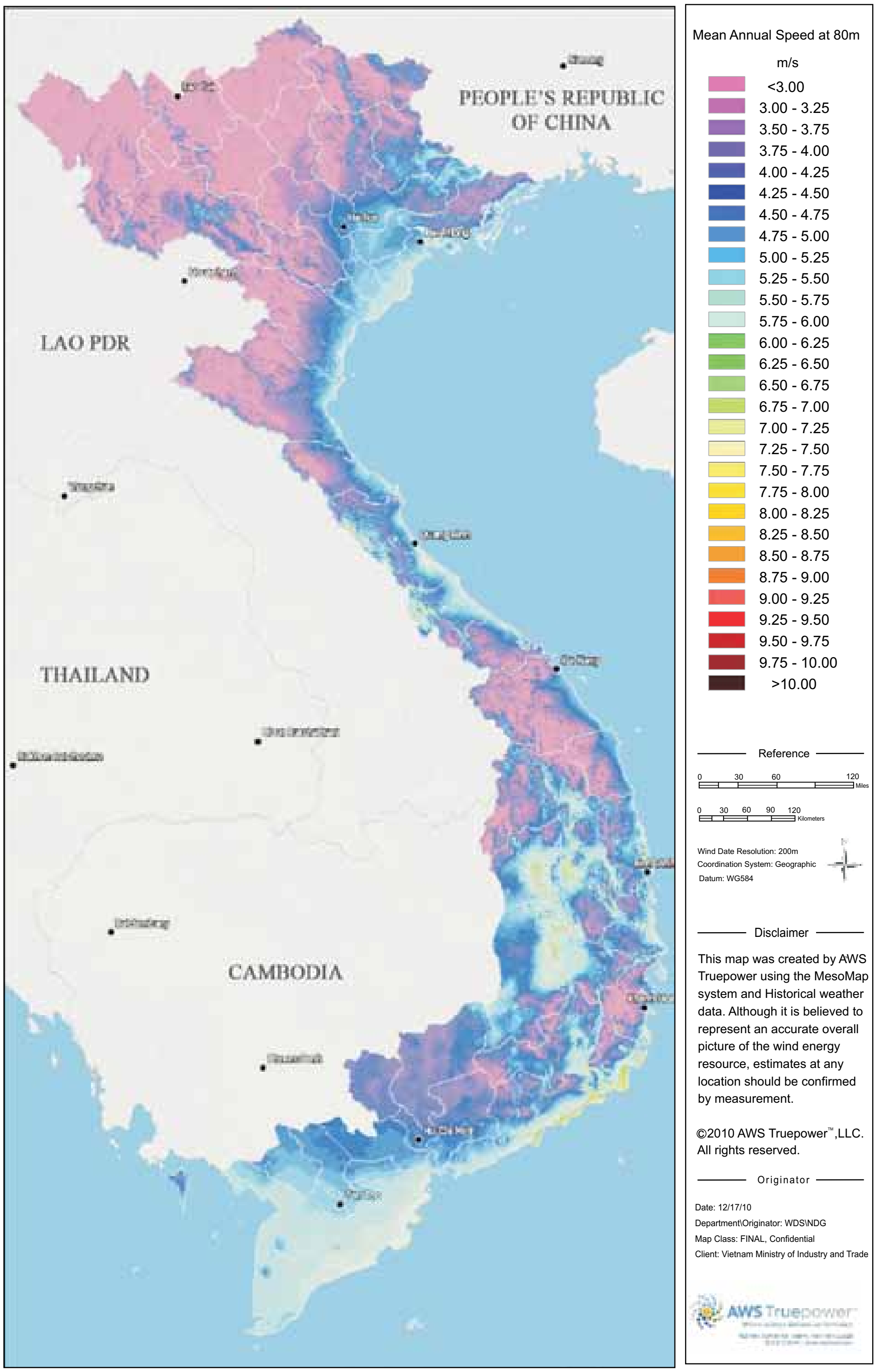
To assess the portion of technical potential that could be developed on an economic basis, the estimated levelized cost of electricity (LCOE) from wind power in Viet Nam was compared with the current cost of other alternatives. Most of the wind resource has an estimated LCOE ranging from $0.093/kWh to $0.114/kWh. Electricity import tariffs are $0.051/kWh and electricity tariffs range from $0.03/kWh to $0.158/kWh. At these electricity rates, grid-accessible areas with average wind speeds classified as relatively high or high (more than 7 m/s) could be considered potentially economically suitable for wind projects.

As shown in Table 8.1, the power development plan has set a target of 1,000 MW of wind by 2020 and 6,200 MW by 2030. The latter is termed a "vision." It will be important to reconcile this vision with Viet Nam's maximum technical potential for wind power, which, in view of the limit of 20% of the current installed capacity, is about half the target level.

It would appear that the various financial and other incentives in support of wind power, notably the favorable feed-in tariff rate, are proving effective in promoting this form of renewable energy. 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

[29] Note: In this case, excluding unsuitable areas meant using a methodological approach slightly different from that used in the analysis for the other countries. Comparison of the wind resource analysis results for the various countries is therefore of limited interest.

Map 8.2: **Wind Resources: Viet Nam**



Source: AWS Truepower 2011, Wind Resource Atlas of Viet Nam. (At 80m, AWS Truepower, LLC 2011, Albany, Wind Resource Atlas of Vietnam, https://www.esmap.org/sites/esmap.org/files/MOIT_Vietnam_Wind_Atlas_Report_18Mar2011.pdf)

Table 8.4: **Theoretical Wind Energy Potential: Viet Nam**

Item	Average Wind Speed: 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)	Total
Area (km^2)	40,473	2,435	220	20	1	
Area (%)	19.3	1.2	0.1	0.01	0	
Theoretical potential (MW)	404,732	24,351	2,202	200	10	26,763
Indicative theoretical potential (TWh/yr)		57.22	6.39	0.70	0.04	64.35

km^2 = square kilometer, m/s = meter per second, MW = megawatt, TWh = terawatt-hour, yr = year.
Sources: AWS Truepower (2011); Lahmeyer International.

1,000 residential wind turbines (> 0.5 kW) have been installed in Viet Nam since 2000. Eleven grid and 6 hybrid wind systems have also been installed in several places, including offshore islands.

Since 2010, the following commercial wind projects have been commissioned:

- 66 MW in Binh Thuan Province: 30 MW in Tuy Phong in 2010 and 2011, 6 MW in Phu Quy in 2013, and 30 MW in Phu Lac 1 (ongoing); and
- 98 MW in Vinh Trach Dong, Bac Lieu Province: 16 MW in 2013 and 82 MW (ongoing).

In summary, Viet Nam has moderate wind power potential, and government incentives, together with the need to develop new sources of energy, have prompted investment in wind power plants. Continuing advances in wind technology and the declining cost of electricity generation by wind power have meant that this energy source offers a competitive alternative or supplement to local conventional generation options. Also, the continual upgrading of Viet Nam's grid and overall generation capacity will enable more grid-connected wind power generation.

8.4 Biomass and Biofuel Energy Resources

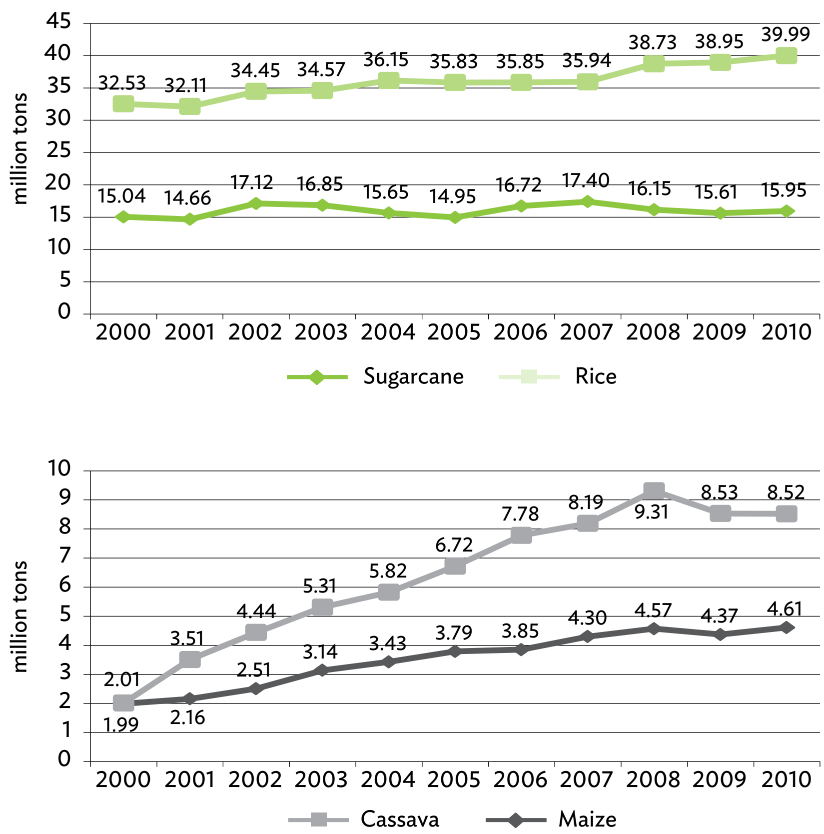
Viet Nam has considerable potential for domestically produced biodiesel and bio-ethanol, which would reduce its dependence on fossil fuels and imported petroleum products. Apart from foreign exchange and greenhouse-gas considerations, biofuel substitutes would help in phasing out firewood and charcoal as primary energy sources and reducing deforestation. However, the agriculture–energy nexus is a concern. Large-scale plantations for biofuel feedstock will inevitably have implications for food supplies and farming communities. The challenge will be to minimize the trade-offs by facilitating the production of clean fuels and the reduction of greenhouse-gas emissions while creating new farming opportunities.

Biomass refers to organic matter that can be converted into energy through burning or conversion into a gas or oil, which can then be used as fuel. The focus here is on agricultural residues and agricultural crops for conversion into biofuels.

8.4.1 Biomass Energy Potential of Agricultural Residues

Agricultural residues are an important source of energy in the rural areas. Although the agricultural sector accounts for little more than 20% of GDP, nearly 60% of Viet Nam's workforce remains engaged in agriculture. A total area of about 11 million ha is under cultivation. Farms are typically small, averaging about 1 ha. Rice production occupies three quarters of Viet Nam's total cultivated area. Other important crops are maize, cassava, sugarcane, coffee, and rubber. As shown in Figure 8.2, cassava production since 2000 has quadrupled, maize production has doubled, and rice production has increased by 25%. Sugarcane production, however, has shown little increase.

Figure 8.2: **Crop Production Trends, 2000–2010: Viet Nam**
(million tons)



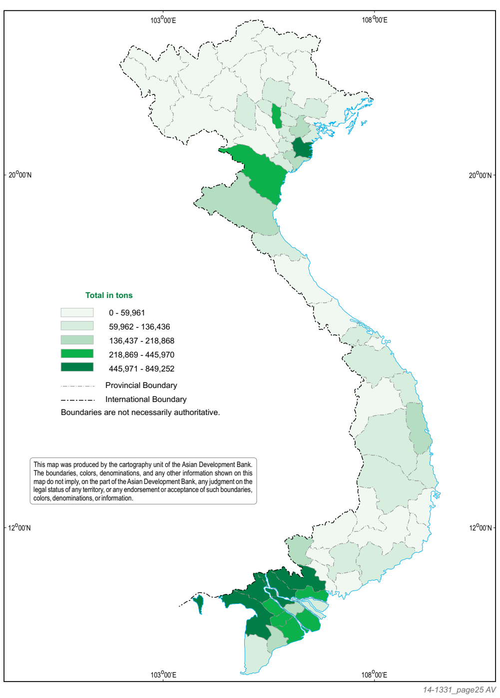
Source: Government Statistics Office (2010).

While of declining importance as Viet Nam modernizes and industrializes, biomass still accounts for more than 45% of total energy sources (IEA, 2006). The main resources for biomass energy are rice husks, other agriculture waste, wood, and animal manure. Most of the biomass energy is used in rural areas as home energy (firewood and straw for cooking and heating). Biomass energy for industrial use is still limited, but there is considerable potential for this, given the amount of crop residues generated. Secondary residues are usually available in large quantities at milling and processing sites. Primary residues tend to be of low volume because of the small size of farm holdings and the difficulty of collection.

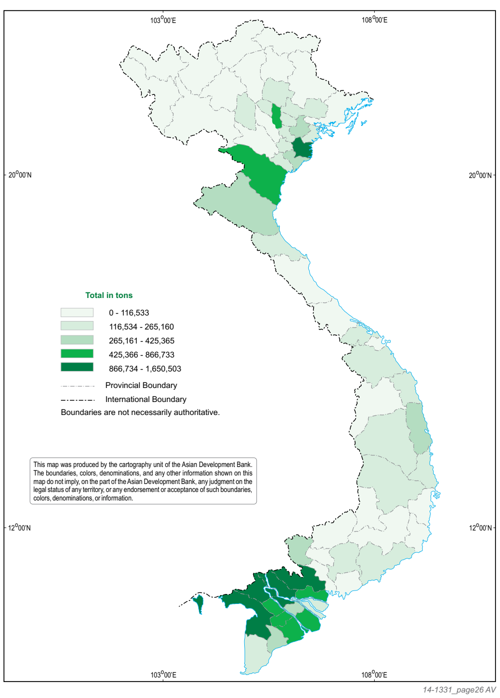
On the basis of published residue-product-ratio (RPR) values from S. Papong et al. (2004), B. Sajjakulnukit et al. (2005), and O. Akgün et al. (2011), biomass residues by province were calculated for rice, maize, cassava, and sugarcane, as shown in Map 8.3. The province-by-province distribution indicates where the biomass potential from agricultural residues is greatest. Clearly, the Red River Delta and the Mekong River Delta are Viet Nam's agricultural centers.

Map 8.3: **Main Crop Residues: Viet Nam**

Rice Husk Production, 2010



Rice Straw Production, 2010



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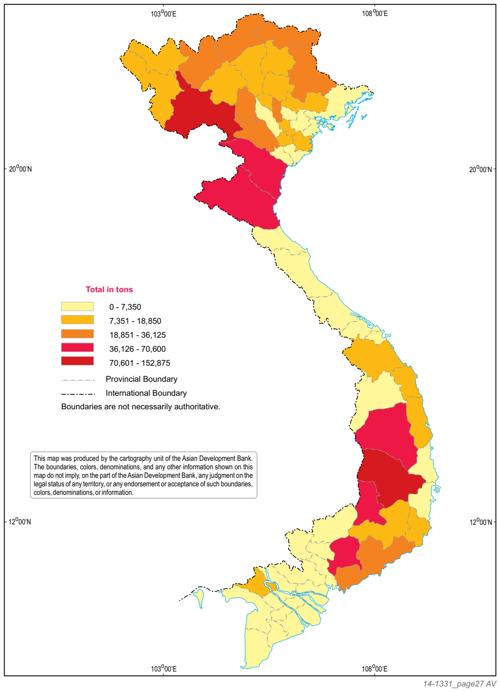
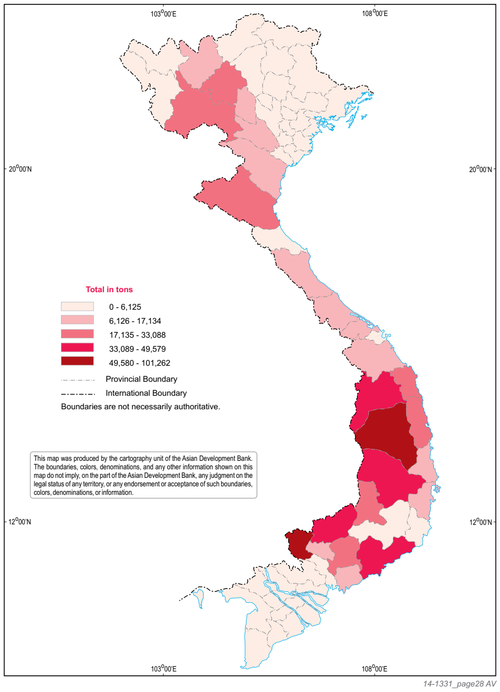
Map 8.3: **Main Crop Residues: Viet Nam** *(cont.)*

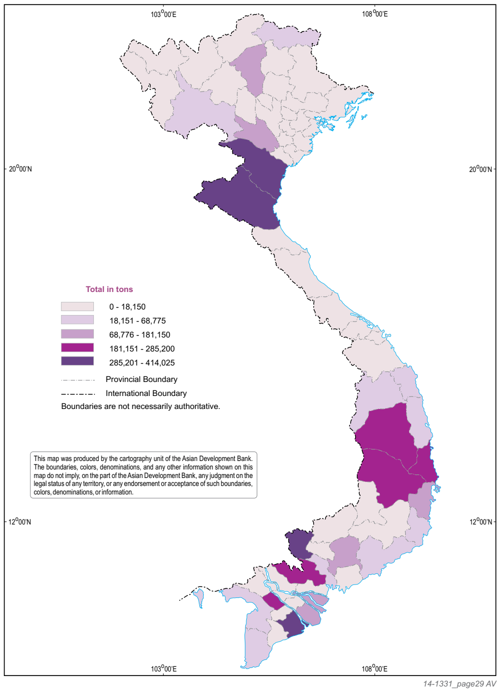
Maize Cob Production, 2010



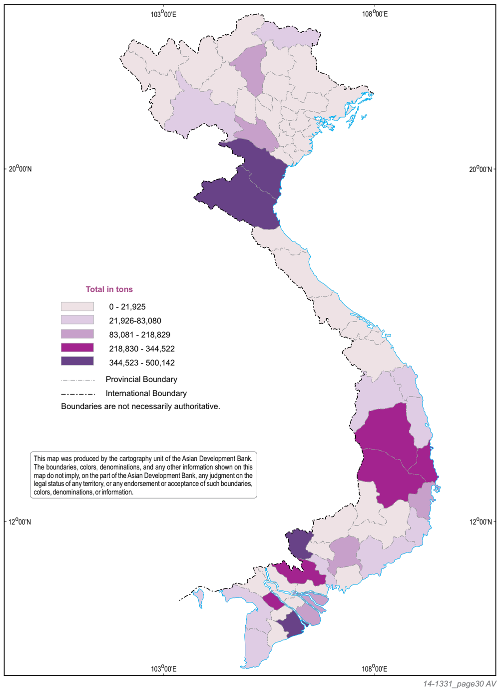
Cassava Stalk Production, 2010



Sugarcane Bagasse Production, 2010



Sugarcane Top Production, 2010



Source: General Statistics Office, Viet Nam.

Crop yields in 2010 indicate that the annual theoretical potential of biomass energy from the combustion of rice husks, rice straw, corn cobs, cassava stalk, bagasse, and sugarcane trash is about 84,875 GWh. The technical level is much less than this, because of the difficulty of collection of the residues and their inclusion in the grid network. But the fact that biomass continues to be the primary energy source for Viet Nam attests to its usefulness.

Table 8.5: **Theoretical Biomass Energy Potential of Agricultural Residues: Viet Nam**

Biomass Residue	Total Yearly Biomass Production (10^3 tons)	Total Theoretical Energy Potential (10^6 GJ)	Total Theoretical Energy Potential (GWh)
Rice husks	9,197	118.1	32,830
Rice straw	17,875	107.9	29,897
Maize or corn cobs	1,151	16.5	4,591
Cassava stalks	750	5.1	1,440
Sugarcane tops and trash	4,816	32.3	8,996
Sugarcane bagasse	3,987	25.6	7,121

GJ = gigajoule, GWh = gigawatt-hour.

Source: Authors' calculations.

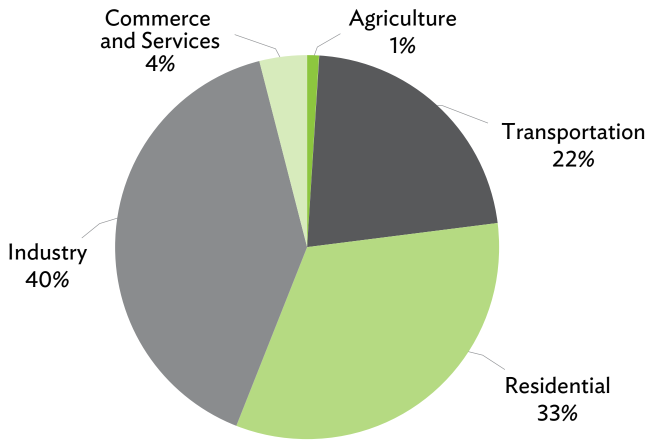
8.4.2 Biomass and Biofuel Energy Potential of Biodiesel and Bio-Ethanol

Industrialization and urbanization are rapidly changing energy use in Viet Nam. Data for 2010 indicate that the industrial sector was the main energy consumer, followed by the residential, transport, commercial, and agriculture sectors (Figure 8.3).

As background for determining Viet Nam's biofuel potential, it is noteworthy that imported refined petroleum products make up 70% of Viet Nam's consumption of transportation fuels. Further, car and motorcycle numbers are rapidly increasing; in 2002–2009, the number of cars increased from 670,000 to 1,000,000, and motorcycles, from 18.5 million to 20 million. During this same period, gasoline and diesel fuel consumption doubled. As shown in Table 8.6, the government expects gasoline consumption, as well as diesel consumption, to more than double again by 2025.

In response to the soaring demand for fossil fuels, and the threat of greenhouse-gas emissions and climate change it poses, the government is committed to developing green and low-carbon energy. This commitment is embodied in a number of key energy policies and decisions, notably the National Energy Development Strategy (NEDS) up to 2020 and Vision up to 2050. As stated in the NEDS, Viet Nam is endowed with many forms of renewable energy resources (mini-hydro, wind, solar, biogas, and biomass). These resources can be developed to meet rapidly increasing energy demand as well as to protect

Figure 8.3: **Final Energy Consumption, by Sector, 2010: Viet Nam**



Source: ILSD (2013).

Table 8.6: **Fossil Fuel Demand Forecast: Viet Nam**
(million tons)

Product	2010	2015	2020	2025
Gasoline	5	6	9	13
Diesel	9	12	17	24

Source: Ministry of Industry and Trade (2010).

the environment. As noted earlier, the government has targeted an increase in the share of renewable energy, from 3% of total commercial energy in 2010 to 5% by 2020 and 11% by 2050.

An important component of the NEDS is the Scheme on Development of Biofuels up to 2015 with a Vision up to 2025, which was also passed in 2007. Its overall objective is "to develop biofuels, a new and renewable energy, for use as an alternative to partially replace conventional fossil fuels, contributing to assuring energy security and environmental protection." Table 8.7 summarizes the scheme.

In 2009, MOIT invited various institutions and enterprises to submit research proposals on biofuels. Grants amounting to VND43,376 million (~$2 million in current prices) were allocated in support of 22 research projects and 5 pilot production projects from 2009 to 2011 (AFD 2012). Investment, both public and private, in biofuel R&D, including studies on industrial-scale production, has intensified.

Biofuel began to be sold commercially in 2010 but demand has been low. The government has attributed this to lack of information about E5 (or E10), causing retailers to be reluctant

Table 8.7: **Summary of Biofuel Development Scheme: Viet Nam**

Item	Up to 2010	2010–2015	Vision up to 2025
Legal framework	• Formulation of legal systems to promote industrial-scale production and use of biofuels • Campaign to raise public awareness of biofuels • Development of road map for use of biofuels to partially replace fossil fuels		
Technology	• R&D toward mastery of technologies for biofuel production, from biomass generation and blending, to increasing conversion efficiency	• Mastery of the production of materials and additives for biofuel production	
Human resources	• Ready for initial implementation	• Technical staff with in-depth knowledge and skills in major areas related to biofuel production • Technicians with general skills, ready for biofuel production	
Feedstock preparation	• Planning and development of raw material areas • Mastery of production of high-yield plant seeding	• Development of raw material areas now being planned • Large-scale production of high-yield plants	
Expected output	• Pilot models for biofuel production and use • Annual capacity: 100,000 tons E5 and 50,000 tons B5 (equivalent to 0.4% of the country's projected oil and gasoline demand)	• Wide use of biofuels to replace fossil fuels • Scaling up of production and distribution network • By 2015: 250,000 tons of ethanol and vegetable oil output (blendable to 5 million tons of E5 and B5)	• Biofuel technology at world state-of-the-art level • Up to 1.8 million tons of of ethanol and vegetable oil output

Source: MOIT (2007); AFD (2012).

to invest in new storage and pumps for bio-ethanol. The private sector, on the other hand, attributes the slow response to the government's lack of a preferential policy for investment in biofuel production. Unlike other GMS countries, Viet Nam does not have explicit subsidies or support for biofuel projects. Moreover, loan interest rates for investments in ethanol plants remain high (at 18%–20% per year), undermining investment returns. Low demand for E5 has caused several processing factories to close or scale down operations.

It is anticipated that once biofuel use becomes compulsory in December 2014 for motor vehicles in seven cities and provinces,[30] biofuel consumption will start to increase and farmers will no longer be left with unsold cassava or other crops as feedstock for ethanol or biodiesel production. MOIT has estimated that by 2015 Viet Nam will need almost 7 billion liters of biofuels, climbing to 8.3 billion by 2020. Various government agencies are responsible for implementing Viet Nam's Biofuel Development Scheme:

- The Ministry of Industry and Trade (MOIT) is the main agency responsible for the overall implementation of the scheme.
- The Ministry of Finance (MOF) and the MOIT manage the use of the state budget in the implementation of the scheme.
  - The MOIT oversees a task force developing standards and technical regulations for the production, storage, distribution, and use of biofuels.
  - The Ministry of Science and Technology is responsible for the technical regulation of biofuels nationwide.
  - The Directorate for Standards, Metrology and Quality is responsible for the guidelines for compliance with biofuel certification standards.

8.4.3 The Agriculture–Biofuel Nexus

Conditions in Viet Nam highly favor biofuel production. There is a wide range of feedstock options, including rice and maize residues, cassava, sweet potato, and sugarcane for bio-ethanol, and oil-bearing crops such as Jatropha, soybeans, coconut, sunflower, and sesame for biodiesel. The government's highest priority, however, is national food security. Considering the limited land area available for food crops, Petrovietnam,[31] the state enterprise at the forefront of biofuel development, is relying on cassava as the main feedstock for bio-ethanol production. For biodiesel production, *Jatropha curcas* has been identified as the highest-oil-yielding crop. It is not considered a threat to food security, as plantation has been located primarily on bare, hilly, or degraded land. The agricultural land implications of cassava and Jatropha cultivation for biofuel production are discussed in the following subsections.

Biodiesel from Jatropha

The assumptions used in calculating Viet Nam's land requirements for producing biodiesel from Jatropha draw from international studies[32] and Mekong-area expertise. Jatropha seeds contain up to 35% of nonedible oil, which has similar energy content to diesel oil and, thus, can be substituted directly in most types of diesel engine. ADB reported that

[30] Ha Noi, Ho Chi Minh City, Haiphong, Danang, Can Tho, Quang Ngai, and Ba Ria-Vung Tau.

[31] Wholly owned by the Vietnamese central government, Petrovietnam is responsible for all oil and gas resources in the country and has become the country's largest oil producer and second-largest power producer.

[32] J. 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 of 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, and between 7 and 8 tons of seeds per hectare per year, yielding about 2 tons of biodiesel per hectare, in fertile soil and hot temperatures.

trial plantings of Jatropha in Viet Nam yielded 5 tons per hectare of seeds. This is more than double Lao PDR's level of 2 tons per hectare. The land area of Jatropha cultivation required to meet Viet Nam's demand for biodiesel demand is therefore projected on the basis of two scenarios—one at 5 tons per hectare and the other at 2 per hectare. Again drawing from international studies and Mekong experience, an extraction ratio of 0.9 and a seed oil content factor of 0.35 per ton of Jatropha seeds was used in the calculations. The results are presented in Table 8.8.

Table 8.8: **Land Requirement for Jatropha as Biodiesel Feedstock: Viet Nam**

Item	Description	2010	2015	2025
Targets	Required Jatropha crude oil (thousand tons)	2.50	150.00	1,200.00
	Extraction ratio (technology)	0.9	0.9	0.9
	Jatropha seed oil content	0.35	0.35	0.35
	Jatropha seed requirement (thousand tons)	7.94	476.19	3,809.52
Scenario 1	Average Jatropha seed yield (tons per hectare)	5.00	5.00	5.00
	Land requirement (thousand hectares)	2	95	762
Scenario 2	Average Jatropha seed yield (tons per hectare)	2	2	2
	Land requirement (thousand hectares)	4	238	1,905

Source: Authors' calculations.

On the assumption that Jatropha seed yields average 3.5 tons per hectare, about 1 million ha of Jatropha cultivation would be needed to meet Viet Nam's projected biodiesel target for 2025. Less land would be required if yields could be raised to 5 tons per hectare but more agricultural area would be needed if marginal land is used.

Bio-ethanol from Cassava

Cassava is an important crop in many provinces with competing uses—human consumption, animal feed, and other uses. Cassava is also an important export commodity, with Viet Nam the second-largest exporter after Thailand.

Cassava crop yields in Viet Nam increased between 2000 and 2010, from 8.4 tons per hectare to 17.2 tons per hectare (MOIT figures). Yields are expected to continue to increase because of the introduction of new sustainable cultivation techniques and high-yielding varieties. Average yields in Thailand are considerably higher and demonstrate the progress possible, as does recent MOIT research. The Ministry of Agriculture and Rural Development (MARD) aims to increase cassava yields to 20 tons per hectare from 2011 to 2015, and to 24 tons per hectare by 2025.

These yield projections are reflected in the calculation of the land requirements for cassava as the primary bio-ethanol feedstock in meeting Viet Nam's ethanol production targets for 2025 (Table 8.9). At yields of 20 tons per hectare, a total of 211,238 ha would be needed. If yields are raised to 24 tons per hectare, the total land area required drops to 176,032 ha. More agricultural area would be required if marginal land is used.

Table 8.9: **Land Requirement for Cassava as Bio-Ethanol Feedstock: Viet Nam**

Item	Description	2010	2015	2025
Targets	Bio-ethanol requirement from cassava (thousand tons)	5.00	100.00	600.00
	Ethanol density (kg/liter)	0.789	0.789	0.789
	Bio-ethanol requirement (thousand liters)	6,337.14	126,742.71	760,456.27
	Conversion factor (liters ethanol/tons cassava)	180.00	180.00	180.00
	Tons of cassava	35,206.31	704,126.18	4,224,757.08
Scenario 1	Average cassava yield (tons per hectare)	20.00	20.00	20.00
	Land requirement (hectares)	1,760	35,206	211,238
Scenario 2	Higher productivity level (tons per hectare)	24.00	24.00	24.00
	Land requirement (hectares)	1,467	29,339	176,032

kg = kilogram.
Source: Authors' calculations.

Combining the biodiesel and bio-ethanol targets for 2025, approximately 1.2 million hectares of agricultural land would be required for the cultivation of Jatropha and cassava as biofuel feedstocks.

8.4.4 Impediments to Biomass and Biofuel Development

Viet Nam's biofuel sector faces several challenges:

- Human resource deficiency. There is a lack of skilled workers and technical experts in the field, as well as limited capability to undertake biofuel-related R&D.
- Systemic problems in production. Aging or obsolete technologies cause systemic problems in production, resulting in high energy consumption, low output rates, and high production costs for processing plants.
- Need for dedicated lands for the production of biomass feedstocks for first generation biofuels. Because of existing agriculture land use policies intended to maintain sufficient forest cover and competing uses of land for food versus biofuel, the amount of land available for biomass production is limited.
- Lack of clarity regarding use of crops. The biofuel scheme does not clearly address the issue of food security versus the use of crops as feedstocks for biofuel production. More R&D is needed to resolve the agriculture–biofuel nexus.
- Weak legal framework and investment incentives. The legal framework and investment incentives need to be strengthened further to attract more private sector interest and participation in biofuel production and distribution.

In summary, Viet Nam has good potential for biofuel production. However, current production levels are marginal and demand is low, reflecting lack of information and distribution networks, and delays in mandatory use. Also, while there is government support for biofuel projects under the investment law and tax framework, Viet Nam, unlike other GMS countries, does not offer subsidies or specific support to investors or distributors. The government's top priority is food security and this has greatly influenced the setting of biofuel targets and the granting of land concessions for feedstock cultivation. Meeting even the government's conservative biodiesel and bio-ethanol targets for 2025 would require about 1 million hectares of Jatropha cultivation and 200,000 ha of cassava cultivation. Bio-ethanol production would appear to be more advantageous for Viet Nam, as the land implications are much less than those for biodiesel production.

8.5 Biogas Energy Resources

Livestock (mainly swine, cattle, buffalo, sheep, goats) and poultry account for about 20% of the agricultural GDP in Viet Nam. The manure generated from livestock and poultry populations creates a significant waste problem but is also an important source of biogas, a relatively clean fuel.

8.5.1 Biomass and Biogas Energy Potential

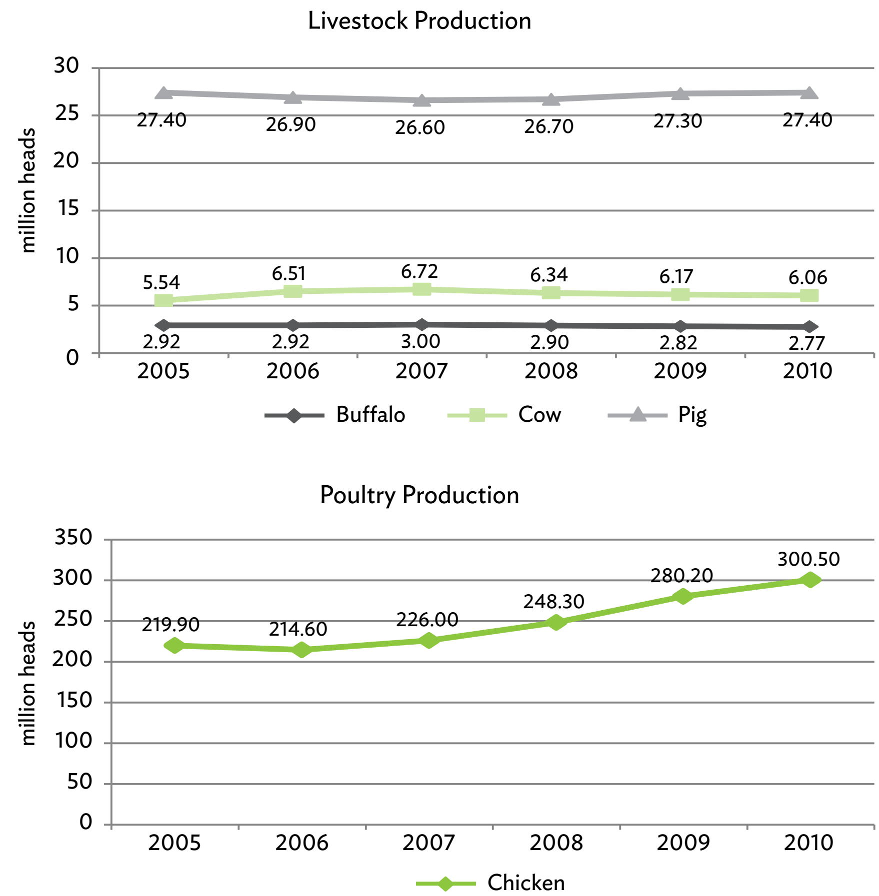
Livestock and poultry in Viet Nam are distributed among industrial and households farms. In 2010, there were about 23,000 industrial farms and 8.5 million household farms. Two-thirds of the farms were in the north. Figure 8.4 indicates the livestock and poultry trends from 2005 to 2010. The positive growth rates experienced in the pig, cow, and poultry levels show the potential for biogas production. The government is projecting a yearly increase of 7.5% in the cow population up to 2020, 2.4% in the pig population, and 1.8% in the chicken population.

The theoretical daily biogas production potential for Viet Nam has been calculated on the basis of animal population levels in 2010. As described in Annex 4, the calculation makes use of conversion factors established by scientific research in estimating potential biogas yields from different animal manure substrates. Given these conversion factors, about 45 million m^3 of biogas could be produced daily. This theoretical output, however, is not translatable into actual biogas production for the following reasons:

- Technical. Daily manure production of animals depends on their weight, and the amount of biogas produced per kilo of animal waste depends on the dry matter content, which may vary from one place to another.
- Socioeconomic. Most livestock and poultry are raised on smallholder farms (about 65% for pigs, 70% for poultry, and 90% for buffalo and cows) and not on centralized farms. This raises the practical issue of volume and collectibility of animal manure.

The technical potential for scale biogas production in Viet Nam is based on the assumption that only 35% of the animal waste produced from pigs, 30% from poultry, and 10% from ruminants can be used as substrate. Again, given the 2010 animal population levels, the technical potential for biogas production is shown in Table 8.10 to be about 15 million m^3/day, or about 324 terajoules per day. This indicates a significant market potential for large-scale farms, and a significant energy source for farm households.

Figure 8.4: **Livestock and Poultry Population Trends: Viet Nam**



Source: Government Statistics Office (2010).

According to the Viet Nam Institute of Energy Science, a farm with 10 pigs would be able to support a biogas system providing enough gas for cooking and lighting for a 4–5 person household. Larger-scale farms with 10 to 20 pigs could have a biogas system able to run a 1.5 kW electricity generator. An independent assessment has identified a potential market of 4.4 million rural households, or almost 20% of all households in Viet Nam, that could use biogas digesters (ADB 2012). The willingness to pay for digesters is categorized as medium to high, but lack of capital is identified as a barrier for most households.

The Ministry of Agriculture and Rural Development (MARD) has initiated programs to promote use of biodigesters. It partnered with the Netherlands Development Organization (SNV) in 2003, and more recently with ADB, in implementing a major biogas program. The program has targeted the construction of 168,000 biogas systems. Under the program, MARD promotes fixed-dome biogas systems designed and developed in Viet Nam, ranging from 4 m^3 to 50 m^3 in size. The larger ones are used for semicommercial scale

Table 8.10: **Technical Potential of Biogas Production, 2010: Viet Nam**

Livestock	Substrate Quantity (kg/day)	Availability Factor (%)	Net Substrate Available (kg/day)	Dry Matter Factor (%)	Net DM Available (kg/day)
Buffalo	22,160,000	10	2,216,000	16	354,560
Cow	48,480,000	10	4,848,000	16	775,680
Pig	54,740,000	35	19,159,000	17	3,257,030
Chicken	24,040,000	30	7,212,000	25	1,803,000
			33,435,000		**6,190,270**

Livestock	Mean Biogas Yield Factor (m^3/kg DM)	Daily Biogas Production (m^3/day)	Energy Content per Day[a] (kWh/day)	Energy Content per Day[b] (GJ/day)
Buffalo	0.250	88,640	531,840	1,914.62
Cow	0.250	193,920	1,163,520	4,188.67
Pig	4.200	13,679,526	82,077,156	295,477.76
Chicken	0.575	1,036,725	6,220,350	22,393.26
		14,998,811	**89,992,866**	**323,974.32**

DM = dry matter, GJ = gigajoule, kg = kilogram, kWh = kilowatt hour, m^3 = cubic meter.

[a] Based on 1 m^3 biogas = 6 kWh/m^3.

[b] Based on 1 kWh = 3.6 MJ.

Source: Authors' calculations.

piggeries and poultry farms. The smaller plants, for individual families, require dung from a minimum of six pigs or two cows. By the end of 2011, the biogas program had supported the construction of 114,000 household biodigesters, mostly using pig dung as feedstock. Aside from demonstrating that household biogas has the potential for large-scale rollout, the program has demonstrated that Viet Nam's waste problem can be a source of clean energy.

In summary, Viet Nam has considerable biogas potential and has started to exploit it. Sustainability will depend on proper regular maintenance, access to spare parts, and continued government support, especially for the farm household systems.

8.6 Summary of Renewable Energy Potentials and Developments

In summary, Viet Nam has moderate solar and wind power potential and relatively strong biofuel and biogas potential. But relatively little of Viet Nam's renewable energy has been developed. The government's renewable energy plans appear to be focused primarily on wind energy and biofuel production. Biogas is also being widely promoted. The government's renewable energy targets up to 2020 and 2030 are modest and seemingly achievable, especially with regard to wind energy.

Continuing advances in wind technology and the declining cost of electricity generation by wind power have meant that this energy source offers a competitive alternative or supplement to local conventional generation options. Also, the continual upgrading of Viet Nam's grid and overall generation capacity will enable more grid-connected wind power.

The government's renewable energy targets omit reference to solar power. Only one-third of Viet Nam's land area is suitable for PV development and only one-third of this has high solar irradiation. Further, solar energy continues to be costly and hence its development is largely restricted to off-grid areas.

Biofuel production raises concerns about food security, as up to 1 million hectares 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, on the other hand, offers a win–win outcome, both as a clean fuel and as a response to the waste problem. The government has been promoting biodigesters for industry and household use.

9 Conclusions: The Collective Renewable Energy Potential and Need for Regional Development

Several imperatives are driving development of renewable energy. First and foremost is the global need to reduce greenhouse gas emissions, the primary sources of which are the nonsustainable use of fossil fuels for industry and transportation. Rapid economic growth in the Greater Mekong Region has meant rapid growth in the demand for energy, especially for industry and transportation. While progress in energy efficiency and conservation has helped slow carbon and other greenhouse gas emissions, the sheer scale of rapid growth has been the overwhelming factor. A credible alternative to fossil fuels is critical. The world may be close to a tipping point in climate change, beyond which the consequences are expected to be disastrous. The five countries of the Greater Mekong Subregion (GMS) reviewed in this study—Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam—are a fraction of the global problem, but every fraction counts. The governments of the five countries are well aware of the global crisis and their responsibility to help contain the problem.

A second imperative driving the development of renewable energy is the need for developing countries to reduce their vulnerability arising from heavy reliance on imported energy, especially fossil fuels. Even Viet Nam, which is a net exporter of oil, is dependent on imports of refined petroleum products (gasoline and diesel) because of its limited refinery capacity. Myanmar is in a similar situation. The Lao PDR has yet to identify oil reserves, and Cambodia's off-shore reserves are largely serving as an export opportunity. Thailand's economy is the largest among the five countries and heavily dependent on imported energy, the transportation sector accounts for 35% of final energy demand in the country and transportation fuels are mostly imported. In addition to vulnerability to supply disruptions, heavy reliance on imported oil and gasoline carries with it costly foreign exchange requirements.

A third imperative driving the development of renewable energy is the need for inclusive growth. Industrialization and urbanization are transforming the five GMS countries, especially Thailand and Viet Nam. But even though Thailand has now reached upper-middle-income status, areas of the country continue to experience widespread poverty or low incomes on the edge of poverty; the same is true of Viet Nam, and, even more so, of Cambodia, the Lao PDR, and Myanmar. Income disparities throughout the GMS have widened sharply and many rural communities continue to lack electricity and other basic amenities. Energy is essential: without it, agricultural productivity and rural enterprise are hampered and education is limited to daylight hours and without the advantages of internet access.

Renewable energy alternatives in the form of solar, wind, biofuels, and biogas address these imperatives, not as a solution but as a nonetheless important step in the right direction for sustainable and inclusive growth. Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam have potential in each of these forms of renewable energy, to varying degrees. Solar energy in Thailand is gaining prominence and Viet Nam is nurturing a fledgling wind power presence. All five countries have promoted biofuel and biogas production—some successfully, others with insufficient public sector direction, technical leadership, and maintenance support.

Generally, the potential for renewable energy in the five countries has only begun to be tapped. Thailand is the most advanced of the five countries, reflecting its higher income status and hence greater ability to invest in renewable energy initiatives. Indeed, the limited technical and financial resource capability of the public and private sectors, especially of individual households, is a major impediment to development and use of renewable energies in GMS countries. Renewable energies in the form of solar, wind, biofuel, and biogas continue to be costly compared with grid power—where it is available. Where grid power is not available, as is commonly the case for rural households, some form of renewable energy must be introduced or expanded upon. Firewood and charcoal are still the primary energy sources for rural communities throughout the GMS, providing an inexpensive form of energy but with negative environmental and gender impact (for instance, women are tasked with gathering firewood).

Renewable energy is a public good whose benefits (including reduced greenhouse-gas emissions) are not fully captured by the investor or user, leading to underinvestment or underuse relative to the socially optimal level. There is a strong rationale for public sector support for the development of renewable energies, including support for research and pilot projects. There is also a strong rationale for subsidy support, especially for off-grid areas where solar, wind, or biogas may be the only alternative. Support for biofuel is more complex, as its development inevitably gives rise to food security and land-use concerns. Moreover, questions surround the degree to which biofuels are a green form of energy. Still, reducing a country's vulnerability to external oil supply shocks is another manifestation of a public good that therefore justifies public sector support.

While renewable energy is an increasingly vital public good, however, the tools needed for its rapid development are lacking. Most obvious is the gap in knowledge. Basic data simply are not available. This report has had to draw on wind maps that are 13 years old, with the result that they provide little guidance for actual project development. This report has outlined the factors that determine the potential for solar, wind, biofuel, and biogas energy, but insufficient information is available concerning these factors. To illustrate, Viet Nam is developing its wind resources but the robustness of its grid and load system will determine the degree to which the resulting wind energy can be used as input to the grid. This is technical information that should be shared with private sector investors to mobilize their financial participation in wind power.

The public also needs to be fully informed about the urgency of developing and using renewable energies. Despite global realization that economic growth and individual household behavior cannot be a continuum of the past, country-level responses—including those of the GMS countries—have been slow to change. Mandated use of biofuels is an obvious way of drawing attention to renewable energy, but there have been missteps in this regard because of insufficient transparency of the regulations and marketing of the product. Also, controversy has surrounded the granting of land concessions to domestic and foreign developers of biofuel feedstocks. Perhaps the main deficiency is lack of technical knowledge and maintenance backup. Early biogas programs in Cambodia and Lao PDR have a poor legacy, slowing adoption rates for new more efficient biodigesters.

GMS countries share the need to accelerate the development of their renewable energy potential. Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam each have renewable energy targets up to 2020 and beyond. The targets range widely, from 6% to 20% of total energy supply, and even higher than this over the longer term. In some cases, these targets understate what is possible and likely; in other cases, the targets may be difficult to achieve. Knowledge sharing among the GMS countries could prove very helpful in charting the course ahead.

Regional economic cooperation with regard to energy supply, management, and use promotes the identification of the most cost-efficient and effective way of meeting energy security in an environment-friendly manner. Some GMS countries 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 help advance the development and use of green energy throughout the region. Given the urgency of the climate change issue, GMS countries need to take bold action to dramatically elevate the role of renewable energies and to phase down reliance on fossil fuels. The transition will be costly, especially as solar energy is still more costly than traditional energy sources (hydro, coal, and oil) and large-scale wind energy is dependent on the upgrading of grid and load systems. And the transition may be controversial, as greatly increased biofuel production would inevitably challenge agricultural land-use practices. Only increased biogas production offers a clear win–win outcome. Nonetheless, renewable energy and clean fuels are now mandatory.

GMS countries need a shared vision for renewable energy and a shared strategy for achieving this vision. Just as GMS countries have made groundbreaking progress over the past 20 years in regional cooperation and integration, now they must make similar progress in the transition to the development and use of renewable energy. But the time frame has to be greatly compressed. Each country needs to commit to the transition, not just in communiqués, but in terms of budgetary allocations, financial incentives, and mandated use. The donor community needs to realign its support to help accelerate the development and use of renewable energy in the GMS. The goal should be to make the GMS a model of what can be done in response to the threat of climate change, and the call for sustainable and inclusive growth.

ADB is working closely with the GMS governments to invest in renewable energy, and in energy efficiency. ADB is also working closely with the private sector, endeavoring to leverage scarce financial resources to gain maximum renewable energy and energy efficiency results. Public–private partnerships combining public and private interests are a model of cooperation essential to achieving what is possible and needed. As a knowledge bank, ADB is helping to inform key ministries and business and community leaders about international best practices and expertise concerning renewable energy and energy efficiency. As a highly operational bank backed by substantial technical and investment resources, ADB is helping developing member countries to achieve their renewable energy and energy efficiency targets.

This report on renewable energy developments and potential in GMS countries provides a foundation for optimism, for the potential is considerable and increasingly initiatives are under way to develop the potential. ADB encourages the GMS countries to accelerate the tempo and is commit to helping to mobilize the expertise and financial resources required. ADB's support of renewable energy in GMS countries will be inclusive, ensuring that the benefits embrace the poor and that the private sector is fully engaged in the investment opportunities. ADB will also twin its support for renewable energy with support for energy efficiency.

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Annex 1
Calculating Solar Energy Resources in the Greater Mekong Subregion

The estimation of the technical potential of solar energy in the Greater Mekong Subregion (GMS) involved the following steps:

1. The total land area in m^2 suitable for photovoltaic (PV) installations was determined, excluding the following:

- areas with slope of over 10 degrees;
- elevation areas higher than 1,500 meters above sea level (high mountain areas);
- inland water areas with extent larger than 0.1 km^2;
- urban areas with more than 100,000 inhabitants;
- protected areas because of their natural, ecological and/or cultural values.

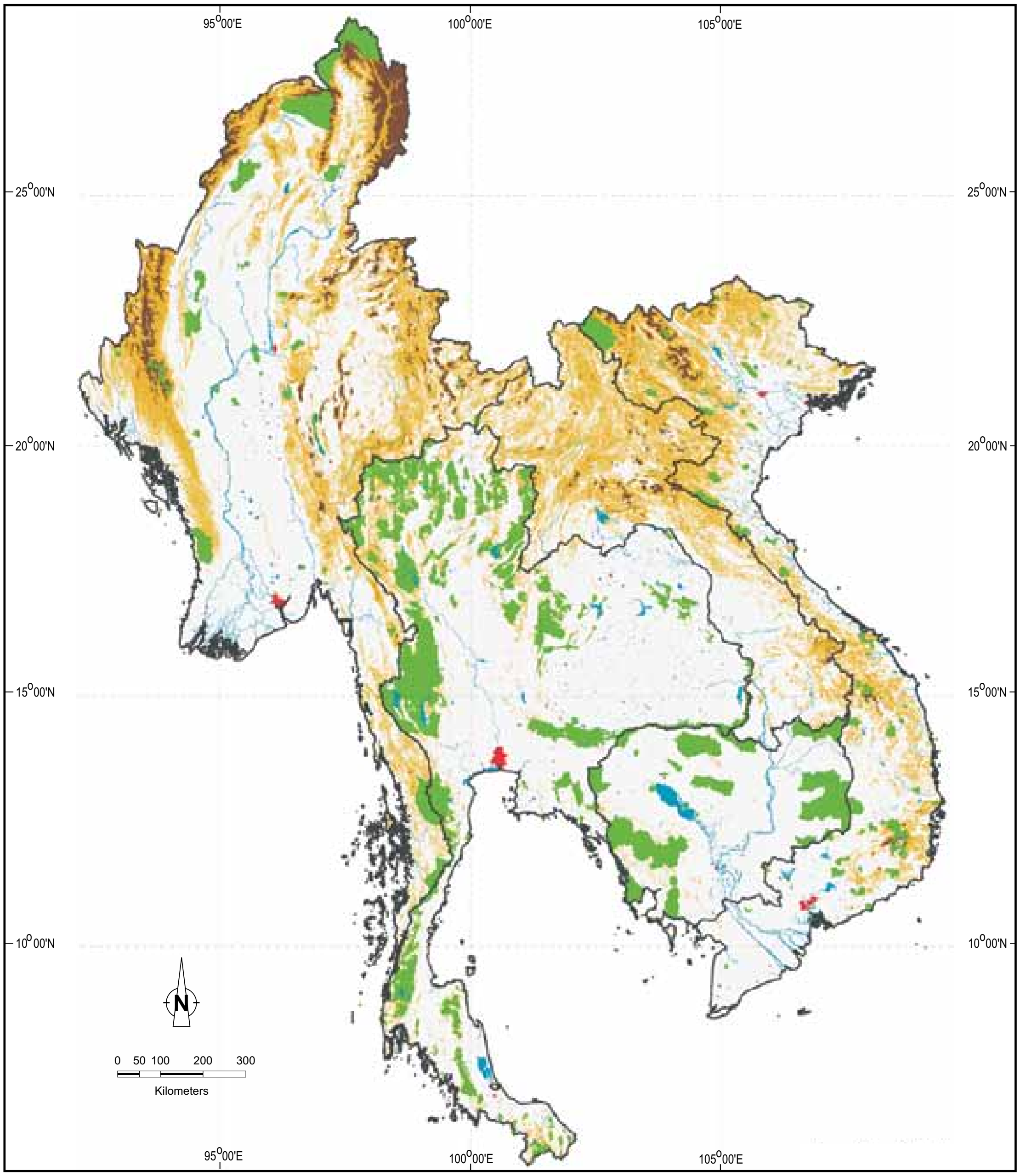
Map A.1.1 provides a general overview of excluded areas.

2. Land areas suitable for solar PV installation were then combined with their respective solar irradiation levels, as shown in Table A.1.1. The irradiation levels are based on GeoModel Solar s.r.o data sets, covering the period from 1999 to 2012. The data sets provide the long-term yearly average of the sum of Global Horizontal Irradiation (GHI). This value includes both DNI and Diffuse Horizontal Irradiation (DIF) and is of particular interest to photovoltaic installations. The table indicates almost 1.3 million km^2 suitable for solar PV, of which about 85% has solar irradiation levels of 1,600 kWh/m^2 or more.

3. The technical potential installation of solar PV for each country and irradiation range was calculated as the product of suitable land area (in m^2) multiplied by the installable capacity of 0.06 kWp/m^2. The conversion factor of 0.06 kWp/m^2 represents the amount of PV installable capacity per square meter possible with current solar technology. Table A.1.2 indicates that the installed technical potential of solar PV in the five countries could be almost 80,000 MWp, with Myanmar and Thailand accounting for 60% of this potential.

4. To estimate the potential technical production, first the GHI Tilt Gain from the installation of solar systems at the optimum inclination angle was calculated for each country and GHI range. As the GHI values are categorized be ranges of 100 $kWh/m^2/yr$, the mid-point of each range was used. The GHI Tilt Gain values are used as the GHI basis for calculating net generation per installed capacity. The GHI tilt gain range from 12% for Cambodia to 21% for Myanmar. The Technical Potential per country and irradiation level, in kWh/year, is calculated as the GHI Tilt Gain [kWh/m^2] (Table A.1.3) multiplied

Map A1.1: Greater Mekong Subregion Areas Unsuited for Solar Photovoltaic



EXCLUSION MASK composed of

- Urban areas (cities over 100 000 inhab.)
- Water Bodies (area over 1 ha)
- Slope (areas over 10 degrees)
- High elevetion (areas over 1500 m a.s.l)
- Protected areas (UICN categories I to V, excluding category VI)

Source: GeoModel Solar s.r.o. (2013).

Table A.1.1: **Land Area Suitable for Solar Photovoltaic**
(% of area)

	Cambodia	Lao PDR	Myanmar	Thailand	Viet Nam	Total
Unsuitable area	25.7	37.8	33.6	25.9	32.9	31.2
Less than 1,000	...	...	0.0001	...	...	...
1,000–1,100	...	...	0.0020	...	...	...
1,100–1,200	...	...	0.0167	...	...	0.0059
1,200–1,300	...	0.0385	0.0965	...	0.0128	0.0410
1,300–1,400	...	0.7956	0.4532	...	1.5805	0.5247
1,400–1,500	...	5.4366	1.2884	...	21.1114	4.6960
1,500–1,600	0.0017	17.3751	3.3006	0.0453	7.6943	4.5718
1,600–1,700	0.4693	29.2862	10.8922	2.1849	3.4339	8.5745
1,700–1,800	7.3119	9.2704	29.4220	26.9149	8.5326	20.7649
1,800–1,900	52.8610	...	19.4664	44.7485	21.9226	27.2866
1,900–2,000	13.6580	...	1.4785	0.1691	2.4715	2.244
Over 2,000	...	...	...	...	0.3000	0.0510
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

	Cambodia	Lao PDR	Myanmar	Thailand	Viet Nam	Total
Area ('000 km^2)	181.1	236.1	676.6	513.1	331.2	1,938.1
Unsuitable area	46.5	89.2	227.2	133.1	109.1	605.4
Less than 1,000	...	...	0.00	...	...	...
1,000–1,100	...	...	0.01	...	...	...
1,100–1,200	...	...	0.11	...	...	0.11
1,200–1,300	...	0.09	0.65	...	0.04	0.79
1,300–1,400	...	1.88	3.07	...	5.23	10.17
1,400–1,500	...	12.84	8.72	...	69.92	91.01
1,500–1,600	0.00	41.02	22.33	0.23	25.48	88.61
1,600–1,700	0.85	69.14	73.70	11.21	11.37	166.18
1,700–1,800	13.24	21.89	199.07	138.10	28.26	402.44
1,800–1,900	95.73	...	131.71	229.60	72.61	528.84
1,900–2,000	24.73	...	10.00	0.87	8.19	43.50
Over 2,000	...	...	...	...	0.99	0.99
Total	**134.6**	**146.9**	**449.4**	**380.0**	**222.1**	**1,332.7**

Lao PDR = Lao People's Democratic Republic.
Sources: GeoModel Solar; Lahmeyer International.

Table A.1.2: **Technical Potential of Installed Solar Power in the Greater Mekong Subregion**
(MWp)

	Cambodia	Lao PDR	Myanmar	Thailand	Viet Nam	Total
Less than 1,000	...	...	0	...	...	...
1,000–1,100	...	...	1	...	...	...
1,100–1,200	...	...	7	...	...	7
1,200–1,300	...	5	39	...	3	48
1,300–1,400	...	113	184	...	314	610
1,400–1,500	...	770	523	...	4,195	5,461
1,500–1,600	0	2,461	1,340	14	1,529	5,316
1,600–1,700	51	4,149	4,422	673	682	9,971
1,700–1,800	795	1,313	11,944	8,286	1,696	24,147
1,800–1,900	5,744	...	7,903	13,776	4,356	31,730
1,900–2,000	1,484	...	600	52	491	2,610
Over 2,000	...	...	...	...	60	59
Total	**8,074**	**8,812**	**26,962**	**22,801**	**13,326**	**79,959**

... = data not available, Lao PDR = Lao People's Democratic Republic, MWp = megawatt-peak.
Sources: GeoModel Solar; Lahmeyer International.

Table A.1.3: **Technical Production Potential Solar Photovoltaic in the Greater Mekong Subregion**
(MWh/yr)

	Cambodia	Lao PDR	Myanmar	Thailand	Viet Nam	Total
Less than 1,000	...	...	...	...	...	...
1,000–1,100	...	...	705	...	...	705
1,100–1,200	...	...	6,517	...	...	6,517
1,200–1,300	...	5,613	41,044	...	2,586	49,243
1,300–1,400	...	125,148	208,239	...	345,836	679,223
1,400–1,500	...	918,500	635,790	...	4,961,641	6,515,930
1,500–1,600	234	3,137,931	1,741,119	17,556	1,933,035	6,829,876
1,600–1,700	67,224	5,630,307	6,116,427	900,566	918,346	13,632,870
1,700–1,800	1,110,844	1,890,265	17,523,061	11,766,235	2,420,234	34,710,638
1,800–1,900	8,489,649	...	12,256,255	20,680,272	6,573,592	47,999,768
1,900–2,000	2,312,096	...	981,211	82,358	781,158	4,156,823
Over 2,000	...	...	...	...	97,259	97,259
Total	**11,980,046**	**11,707,764**	**39,510,368**	**33,446,986**	**18,033,687**	**114,678,852**
GWh/yr	**11,980**	**11,708**	**39,510**	**33,447**	**18,034**	**114,679**

... = data not available, GWh = gigawatt-hour, Lao PDR = Lao People's Democratic Republic, MWh = megawatt-hour, yr = year.
Source: GeoModel Solar, Lahmeyer International.

by the potential kWp installed (Table A.1.2) and by a system performance ratio on 78%. Table A.1.3 shows the technical solar PV production potential.

5. To evaluate the economic potential of solar power in the GMS, the levelized cost of electricity (LCOE) was estimated for each country and each irradiation level. The LCOE was derived by dividing the present value of the project costs (investment and operational costs but excluding financing costs) by the present value of the quantity of power generation. The LCOE represents the energy generation cost over the project life cycle.

Mathematically, the LCOE is described as follows:

$$\text{LCOE} = \frac{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+i)^t}}$$

where:

C_t represents the project costs incurred in year t;
E_t represents the power generation in year t;
i represents the economic discount rate;
n represents the number of years in the period under consideration.

6. Assumptions made to calculate the LCOE include a discount rate of 8%, a system useful life of 20 years, a system performance ratio of 78%, investment costs of \$2,145/kWp and operating costs of \$31.2/kWp/yr. These general assumptions are based on grid-connected, multi-megawatt scale PV plants being installed. Table A.1.4 indicates the estimated LCOE by country and irradiation level. Clearly, the LCOE for solar power varies considerably, dropping markedly with higher irradiation levels. Results for smaller or off-grid systems could differ significantly. Further, costs can vary considerably by site.

Table A.1.4: **Estimated Levelized Cost of Electricity by Solar Power**
($/kWh)

	Cambodia	Lao PDR	Myanmar	Thailand	Viet Nam	Average
1,000–1,100	0.308	0.299	0.294	0.303	0.302	0.301
1,100–1,200	0.281	0.273	0.268	0.277	0.276	0.275
1,200–1,300	0.259	0.251	0.247	0.255	0.254	0.253
1,300–1,400	0.240	0.233	0.228	0.236	0.235	0.234
1,400–1,500	0.223	0.217	0.213	0.220	0.219	0.218
1,500–1,600	0.209	0.203	0.199	0.206	0.204	0.204
1,600–1,700	0.196	0.190	0.187	0.193	0.192	0.192
1,700–1,800	0.185	0.180	0.176	0.182	0.181	0.181
1,800–1,900	0.175	0.170	0.167	0.172	0.171	0.171
1,900–2,000	0.166	0.161	0.158	0.163	0.163	0.162
Over 2,000	0.162	0.157	0.154	0.159	0.158	0.158

kWh = kilowatt-hour, Lao PDR = Lao People's Democratic Republic.
Sources: GeoModel Solar; Lahmeyer International.

Annex 2
Calculating Wind Energy Resources in the Greater Mekong Subregion

Calculation of wind energy resources in the Greater Mekong Subregion (GMS) was hampered by the lack of current data on wind speeds and other factors critical to estimating the potential. Due to measurement complexities, Lahmeyer International GmbH (the consulting firm) cannot warranty the accuracy of the data used to compile wind maps for the five GMS countries. Lahmeyer International recommends that the assessment—which is based on secondary research – be used as a general guideline rather than as a basis for investment in wind power systems. Potentially exploitable wind power can only be estimated on the basis of site specific analysis, including most importantly local wind measurements.

Estimation of the technical potential of wind power in the GMS involved the following steps:

1. Determination of average wind speeds. Measurement of wind speeds, the direction over time and their consistency, preferably over a period of at least 1 year, is the fundamental first step in calculating wind power potential. The most extensive publicly available study of the wind resource in the GMS is the Wind Energy Resource Atlas,[1] produced by the World Bank's Asia Sustainable and Alternative Energy (ASTAE) program in 2001. It provides estimates of the average wind speed in Cambodia, the Lao PDR, Thailand, and Viet Nam, but does not cover Myanmar. In the preparation of the atlas, an atmospheric simulation system was used. Wind resource potential was calculated by estimating the average wind speed and wind power density over a specific land area, expressed in megawatt per square kilometer (MW/km^2). This estimation is a theoretical potential, as it does not consider the suitability or availability of land nor the technical restrictions which impede exploitation. Other, more recent studies were incorporated where available. Again, Lahmeyer International cautioned that about the need for more current and site specific data.

2. Determination of wind turbine generator installation density. While the Wind Energy Resource Atlas of Southeast Asia assumed a wind turbine generator (WTG) installation density of 4 MW/km^2, modern wind energy conversion technologies can now reach WTG density of 10 MW/km^2.

[1] Wind resource data resolution is 1,000 m. This wind resource map was created for the World Bank by TrueWind Solutions using MesoMap, a mesoscale atmospheric simulation system. (Source: World Bank "Wind Energy Resource Atlas" http://go.worldbank.org/Z94R7D9VV0; accessed 31.8.2013)

3. Basic methodology. The theoretical wind capacity was calculated as the product of the available land area (in km^2) multiplied by the WTG installation capacity of 10 MW/km^2 multiplied by the annual energy yield midpoint in MWh/MW installed.

4. Determination of suitable land area. The total land of each country was classified according to the annual average wind speed. Only land areas with adequate wind speeds were included in the calculation. With modern wind turbines, the minimum wind speed needed is at least 6 m/s. Land areas with average wind speeds less than this were excluded.

5. Clustering land areas by average wind speed. As shown in Table A.2.1, wind energy potential is directly related to wind speeds. The wind generation potential in areas with high wind speeds can be 40% higher than the same installed capacity in medium wind speed areas.

Table A.2.1: **Estimated Annual Generation by Wind Speed Class**

Item	Wind Speed			
	Medium (6–7 m/s)	Relatively High (7–8 m/s)	High (8–9 m/s)	Very High (> 9 m/s)
Annual energy yield [MWh/MW installed]	2,100–2,600	2,600–3,200	3,200–3,800	3,800
Annual energy yield mid-point [MWh/MW installed]	2,350	2,900	3,500	3,800

m/s = meter per second, MW = megawatt, MWh = megawatt-hour.
Source: Lahmeyer International.

6. Calculation of the theoretical potential of wind power. The theoretical potential is simply the total land area with sufficient wind speed (> 6 m/s) multiplied by the WTG installation density of 10 MW/km^2. The theoretical potential does not take into consideration land use and limitations due to slope, protected areas, etc.

7. Calculation of the technical potential of wind power. Large land areas are excluded, reflecting rugged terrain, protected areas, nature preserves, forested areas, military grounds, and other uses. If the suitable land area were the only consideration, the technical potential would be the suitable land area (in km^2) times 10 MW/km^2. This product, however, is subject to the grid factor. Since wind power is intermittent, there has to be a strong backup. Thus, the ability of the grid network to accept injection of intermittent wind energy while maintaining stability is critical. In the absence of detailed information about the supply side (generation) and demand side (loads and load curves) in each of the countries, alternative assumptions were made: the grid can accept between 5% as the lower estimate and 20% as the upper limit. The technical potential of wind power was therefore determined as the product of suitable land area (in km^2) times 10 MW/km^2 multiplied by 0.05 and by 0.20 to define the lower and upper range.

8. Calculation of the economic potential of wind power. The economically feasible potential was determined based on the cost of wind power generation relative to the cost

of other alternatives. The levelized cost of electricity (LCOE) was estimated for each wind category level.

9. Calculation of the LCOE. The LCOE was derived by dividing the present value of the project costs (investment and operational costs but excluding financing costs) by the present value of the quantity of power generation. This represents the energy generation cost over the project life cycle.

Mathematically, the LCOE is described as follows:

$$\text{LCOE} = \frac{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+i)^t}}$$

where:

C_t represents the project costs incurred in year t;
E_t represents the power generation in year t;
i represents the economic discount rate;
n represents the number of years in the period under consideration.

10. Assumptions underlying LCOE estimation. The LCOE are calculated on the basis of the following assumptions: a discount rate of 8%; investment costs of $2,000/kW; operating costs from $17/MWh for low wind speed situations to $12/MWh for high wind situations; and a useful system lifespan of 20 years. The operating cost assumptions are based on a 2 MW WTG with 90 m rotor diameter. The specific operations and maintenance (O&M) costs are based on the per MWh costs of a 30 MW wind park.

11. Calculation of the LCOE under different wind speeds. Table A.2.2 indicates the costs of wind power under different wind speeds. When compared to current grid connected electricity rates, wind power is cost competitive in Cambodia at all calculated wind speeds and could be cost competitive in the other countries at wind speeds over 7 m/s.

Table A.2.2: **Cost of Wind Power in the Greater Mekong Subregion under Varying Wind Speeds**

Average Wind Speed	Medium (6–7 m/s)	Relatively High (7–8 m/s)	High (8–9 m/s)	Very High (> 9 m/s)
Annual energy yield range [MWh/MW installed]	2,100–2,600	2,600–3,200	3,200–3,800	> 3,800
Annual O&M costs [$/MWh]	17–15	15–13	13–12	< 12
Estimated LCOE ($/kWh)	0.114–0.093	0.093–0.077	0.077–0.066	< 0.066

kWh = kilowatt hour, LCOE = levelized cost of electricity, m/s = meter per second, MW = megawatt, MWh = megawatt-hour, O&M = operation and maintenance.

Source: Lahmeyer International.

12. Country comparisons. This is not recommended, as the data are not consistent. In the case of Viet Nam, the 2011 Wind Atlas data were used rather than the 2001 World Bank report used for the other GMS countries. In particular, Viet Nam's wind power potential is based on a narrower definition of suitable land, hence indicating it with relatively low wind power potential. This may simply be more realistic than an understatement.

Annex 3

Calculating Biomass Energy Resources in the Greater Mekong Subregion

Agricultural residues and other forms of biomass are increasingly seen as a favorable renewable energy source, especially in light of environmental concerns over fossil fuel consumption.

Published data of various institutions in GMS countries were used to calculate the potential energy from combustion of main crop residues such as rice husk, rice straw, corn cob, cassava stalk, bagasse, trash of sugarcane (as well as oil palm and coconut residues in the case of Thailand). The calculation was based on RPRs and other factors (Table A.3.1).

Table A.3.1: **Factors Used for Calculating the Energy Potential of Agricultural Residues**

	Residue-to-Product Ratio	Energy Use Factor	Surplus Availability Factor	Lower Heating Value (MJ/kg)
Rice husk	0.27	0.531	0.469	12.85
Rice straw	0.33	0.000	0.684	8.83
Maize /corn cob	0.25	0.193	0.670	16.63
Sugarcane tops and trashes	0.302	0.000	0.986	6.82
Sugarcane bagasse	0.25	0.793	0.207	6.43
Cassava stalks	0.088	0.000	0.407	16.99

Residue-to-product ratio (RPR)—Biomass fuels are available as by-products of rice milling and other agricultural crop production. The by-products or residues generated were calculated using an estimate for yield of crop residues, known as the Residue-to-Product. Country-specific RPRs were drawn from studies conducted in Southeast Asia, notably those by S. Papong et al. (2004), B. Sajjakulnukit et al. (2005), and O. Akgün et al. (2011), as well as from data for Thailand and Lao PDR. Where country-specific data were not available, such as for Cambodia, derived RPR values were applied.

Energy use factor—is the fraction of residue presently being used as fuel.

Surplus availability factor—the ratio of surplus (presently wasted) amount to the amount of residue generated.

Lower heating value (LHV)—Lower heating value is the useful net calorific value of a fuel defined as the amount of heat released by combusting a specified quantity.

In 2010, Thailand's Department of Alternative Energy Development and Efficiency (DEDE) published official data on biomass residues from major agricultural crops. The RPR values were thus derived and compared with reference values obtained from other sources (Table A.3.2). Where inconsistencies were noted between the derived and reference RPR values, RPR values from reference studies were used for calculating the biomass energy potential from Thailand crops (Table A.3.3).

Crop residues may also be used as fodder for animals (e.g., straw, stalks, leaves) or used for downstream processing (e.g., production of straw mattresses, rice husk ash). This "residue availability" factor is therefore taken into account in the calculation of the theoretical energy potential, adopting the formula presented by Bhattacharya et al. (2005).

Table A.3.2: **Comparative Residue-Product Ratios for Thailand's Main Crops**

Biomass Residues	RPR (derived)	RPR (reference)
Rice husks	0.23	0.230
Rice straw	1.19	0.447
Maize STL	0.89	...
Maize cob	0.19	0.250
Cassava stalks	0.12	0.088
Cassava roots	0.09	...
Sugarcane tops	0.20	0.302
Sugarcane bagasse	0.30	0.250
Oil palm frond	0.27	2.604
Oil palm fiber	0.15	0.147
Oil palm shell	0.13	0.049
Oil palm fruit bunch	0.22	0.250 / 0.428
Coconut shell	0.25	0.16
Coconut husk	0.56	0.362
Coconut frond	0.56	0.225

... = data not available, RPR = Residue–Product Ratios.

Notes:
1. RPR derived—based on actual biomass residues figures from the Office of Agricultural Economics, Thailand and published in the DEDE Annual Report 2010
2. RPR official—taken from various journal publications from studies conducted by the DEDE, Asian Institute of Technology (AIT), National Science Technology Development Agency (NSTDA) and Thailand Environment Institute (TEI) researchers.

Table A.3.3: **Parameters Used for Calculating the Energy Potential of Agricultural Residues in Thailand**

	Residue-to-Product Ratio	Energy Use Factor	Surplus Availability Factor	Lower Heating Value (MJ/kg)
Rice husk	0.230	0.531	0.469	12.85
Rice straw	0.447	0.000	0.684	8.83
Maize/corn cob	0.250	0.193	0.670	16.63
Cassava stalks	0.088	0.000	0.407	16.99
Sugarcane tops and trashes	0.302	0.000	0.986	6.82
Sugarcane bagasse	0.250	0.793	0.207	6.43
Oil palm frond	2.604	0.000	1.000	7.97
Oil palm fiber	0.147	0.858	0.134	16.19
Oil palm shell	0.049	0.588	0.037	17.00
Oil palm EFB	0.250	0.030	0.584	16.44
Coconut shell	0.160	0.413	0.378	16.48
Coconut husk	0.362	0.289	0.595	14.71
Coconut frond	0.225	0.159	0.809	14.55

Formulas employed

$$Tons\ Generated_{residue} = Tons\ Annual\ Production_{crop} \times RPR$$

$$Energy\ Potential_{residues} = Tons\ Generated_{residue} \times (SAF + EUF) \times LHV_{residue}$$

Data and calculations were compiled on a province-by-province basis for Cambodia, the Lao PDR, Myanmar, Thailand and Viet Nam, in each case showing the theoretical energy potential for their main agricultural residues. The data is available upon request. The aggregate results are shown in the country chapters of this report.

Biofuel potential in the GMS is target driven, rather than being determined by the total amount of agricultural land. Food security is the first priority of GMS countries hence biofuel production has to be limited. The individual country chapters indicated their respective biofuel targets and the amount of land required in order to produce the necessary feedstock, which varies considerably depending on agricultural productivity and the type of feedstock.

Annex 4
Calculating Biogas Energy Resources in the Greater Mekong Subregion

Biogas is a mixture of gases, notably methane (55%–65%) and other gases (CO_2, 35%–45%, H_2S 0%–3%, N_2 0%–3%, and H_2 0%–01%) (UNESCAP 2007). To produce biogas, organic waste materials or feedstocks are stored in specially constructed air-tight containers (commonly known as biogas digesters). The feedstocks used for biogas production include animal dung, which is the focus of this study. Anaerobic microorganisms break down the dung and release biogas in the process. The biogas can be burned as a fuel, for cooking or for lighting purposes, and the nutrient-rich slurry which is left can be used as organic compost.

The energy content directly depends on the methane content. One cubic meter of methane has an energy content of 10 kWh calorific energy. Therefore, one m^3 biogas which has roughly 60% methane has an energy content in the range of 6 kWh/m^3 or a typical calorific value of 21–24 MJ/m^3 (Bond and Templeton, 2011). When converted into electricity in a biogas powered electric generator, about 2.2 kWh of usable electricity is generated, which is equivalent to 1 liter alcohol, 0.8 liter petrol, 0.6 liter crude oil or 1.4 kg coal (SNV 2011).

In general, methane yield depends on many factors which relate to the substrate, the pre-treatment or conditions of the substrate and the digestion process. The quantity of biogas and methane produced mainly depends on the composition of the substrate. In practice it is often not possible to calculate the methane yield as the composition is not known and the degradation is not complete. Various studies, therefore, serve as reference for purposes of this paper Table A.4.1 shows the typical animal manure substrates used in biogas production and corresponding biogas yield calculations for most GMS countries. In the case of Thailand where in-house researches have been conducted by various national institutes, the factors used are presented in Table A.4.2.

Clearly there are considerable differences between the two tables, underscoring the need for improved data collection concerning the potential of renewable energies in the GMS.

Table A.4.1: Biogas Production from Selected Substrates for Cambodia, Lao PDR, Myanmar, and Viet Nam

Substrate	Daily production (kg/animal)	% DM	Biogas yield (m^3/kg DM)	Biogas yield (m^3/animal/day)[a]
Pig manure	2	17	3.6–4.8	1.43
Cow manure	8	16	0.2–0.3	0.32
Chicken manure	0.08	25	0.35–0.8	0.01

DM = dry matter, kg = kilogram, Lao PDR = Lao People's Democratic Republic, m^3 = cubic meter.

[a] Based on mean biogas yield (m^3/kg DM).

Source: Bond and Templeton, 2011.

Table A.4.2: Biogas Production from Selected Substrates for Thailand

Substrate	Daily production (kg/animal)	% DM	Biogas yield (m^3/kg DM)	Biogas yield (m^3/animal/day)[a]
Pig manure	0.5	17.44	3.6–4.8	1.43
Cow manure	5	35.22	0.2–0.3	0.32
Chicken manure	0.03	33.99	0.35–0.8	0.01

DM = dry matter, kg = kilogram, m^3 = cubic meter.

[a] Based on mean biogas yield (m^3/kg DM).

Sources: Bond and Templeton, 2011; daily production factors (kg/animal) and %DM were derived from Prasertsan, S. (TRF, Thailand) and Sajjakunukit, B. (DEDE, Thailand), 2006.

Renewable Energy Developments and Potential in the Greater Mekong Subregion

This report was produced under the technical assistance project Promoting Renewable Energy, Clean Fuels, and Energy Efficiency in the Greater Mekong Subregion (TA 7679). It focused on renewable energy developments and potential in five countries in the Greater Mekong Subregion (GMS): Cambodia, the Lao People's Democratic Republic, Myanmar, Thailand, and Viet Nam. It assessed the potential of solar, wind, biomass, and biogas as sources of renewable energy. Technical considerations include the degree and intensity of solar irradiation, average wind speeds, backup capacity of grid systems, availability and quality of agricultural land for biofuel crops, and animal manure concentrations for biogas digester systems. Most GMS governments have established plans for reaching these targets and have implemented policy, regulatory, and program measures to boost solar, wind, biomass, and biogas forms of renewable energy. Incentives for private sector investment in renewable energy are increasingly emphasized.

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