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TASK 2 REPORT—A GIS-BASED TECHNICAL POTENTIAL ASSESSMENT OF DOMESTIC ENERGY RESOURCES FOR ELECTRICITY GENERATION

Energy Alternatives Study for the Lao People's Democratic Republic: Smart Infrastructure for the Mekong Program

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List of acronyms and abbreviations

CSP	concentrating solar power
EDL	Électricité du Laos
Energy Alternatives Study	Energy Alternatives Study for the Lao PDR – Smart Infrastructure for the Mekong Program
GIS	geographic information system
IPP	independent power producer
IRP	integrated resource planning
Lao PDR	Lao People's Democratic Republic
LCOE	levelized cost of electricity (or energy)
MEM	Lao Ministry of Energy and Mines
NREL	U.S. Department of Energy's National Renewable Energy Laboratory
PV	photovoltaic
RE	renewable energy
REZ	renewable energy zone
SIM	Smart Infrastructure for the Mekong
U.S.	United States
USAID	United States Agency for International Development
UXO	unexploded ordnance

Executive summary

The government of the Lao People's Democratic Republic (Lao PDR) has historically prioritized investment in the country's abundant hydropower resources to ensure a secure, reliable, and affordable supply of energy to support economic development. The country has benefited from this power for development; however, as a result, the energy sector is highly dependent on hydropower resources that contribute 62.1% of the electricity generation mix, with coal and biomass comprising 37.5% and 0.4% of this mix, respectively (MEM 2016). In order to diversify this portfolio, power sector decision makers are exploring the role that energy resources beyond hydropower could play in their country's future power system to inform energy planning through 2030.

The purpose of this report is to support the Lao Ministry of Energy and Mines (MEM) in assessing the technical potential of domestic energy resources for utility scale electricity generation in the Lao PDR. Specifically, this work provides assessments of technical potential, and associated maps of developable areas, for energy technologies of interest. This report details the methodology, assumptions, and datasets employed in this analysis to provide a transparent, replicable process for future analyses. The methodology and results presented are intended to be a fundamental input to subsequent decision making and energy planning-related analyses.

This report is the second output of the *Energy Alternatives Study for the Lao PDR* (Energy Alternatives Study), a collaboration led by MEM and the United States Agency for International Development under the auspices of the Smart Infrastructure for the Mekong program.[1] The Energy Alternatives Study is composed of five successive tasks that collectively support the project's goals as shown in FIGURE ES-1. This work is focused on *Task 2 – Assess technical potential of domestic energy resources for electricity generation*. The work was carried out by a team from the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) in collaboration with MEM and other Lao power sector stakeholders.

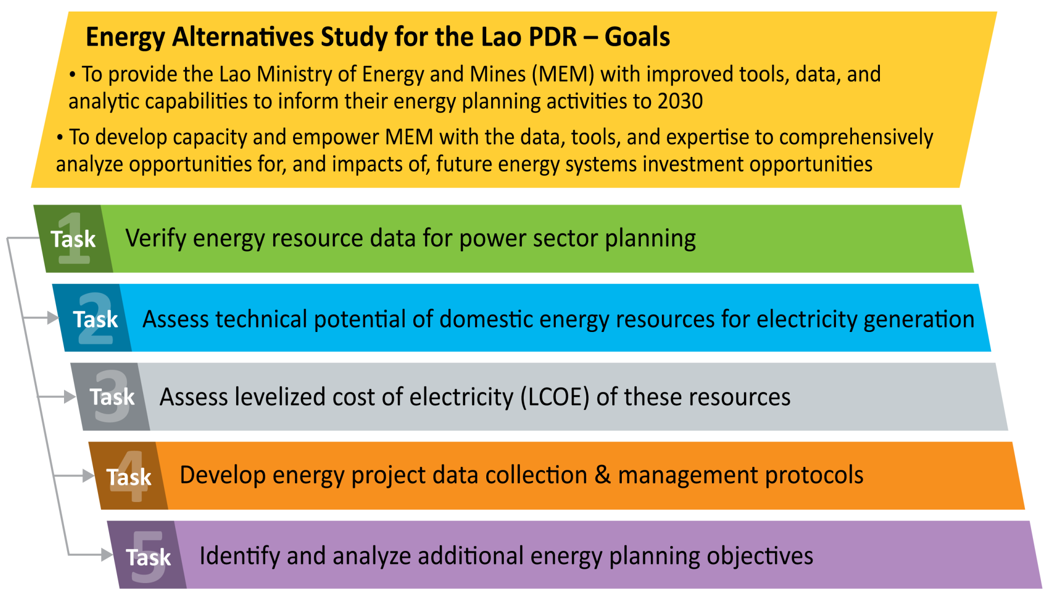

FIGURE ES-1. GOALS AND TASKS OF THE ENERGY ALTERNATIVES STUDY FOR THE LAO PDR
(Lee et al. 2018)

[1] The Smart Infrastructure for the Mekong program—a United States Government interagency program—provides assistance to support climate-smart, environmentally sound, and socially equitable infrastructure, clean energy development, and land and/or water resources use.

This work concentrates on domestic energy resources for utility-scale electricity generation and considers solar photovoltaic (PV), wind, biomass, and coal resources. This work does not consider potentially imported energy resources (e.g., natural gas) or domestic energy resources that are not present in sufficient quantity for utility-scale generation (e.g., geothermal resources). A technical potential assessment of hydropower resources is currently not feasible due to the absence of required data including site-level assessments of multiple characteristics (e.g., geology environment and access) as well as spatial data on estimated non-exploited hydropower resources (Lee et al. 2018). Previous studies estimated total hydropower resource potential to be between 23,000 and 26,000 MW, of which approximately 3,894 MW has been developed (IES and MKE 2016; MEM 2015b, 2011). MEM and Électricité du Laos have gained significant experience in the evaluation and development of hydropower resources and expect to develop close to 10,034 MW of additional capacity by 2025 (MEM 2017).

The technical potential assessment found an abundant renewable energy (RE) resource base in Lao PDR that includes solar, wind, and biomass. TABLE ES-1 summarizes the technical potential results in terms of generation (in GWh) for all RE-based electricity generation technologies considered, as well as capacity (in GW) and the suitable land area for development (in km^2) for solar PV and wind energy. The theoretical, upper-limit of potential with no development exclusions is presented as the *Base-Lao PDR* assessment. The technical potential results are shown for a series of scenarios with increasingly more selective development exclusions.

The total technical generation potential for utility-scale, fixed-tilt solar PV ranges from 731 to 8,997 TWh/year with a corresponding potential installed capacity of 516 to 6,678 GW. The technical potential for utility-scale wind turbines (100 m hub height) was assessed to range from 135 to 682 TWh/year with a corresponding installed capacity of 116 to 557 GW. The total technical potential for annual generation from utility-scale biomass feedstocks, including logging, primary mill, and secondary mill residues is less than those of wind and solar but still significant at 0.72 TWh/year.

TABLE ES-1 also shows the results of the site feasibility analysis conducted for coal power. Site feasibility is employed here as a proxy analysis for non-RE resources, given that there is not a methodology analogous to RE technical potential assessment and that non-RE resources such as coal can be transported to different sites for electricity generation. A GIS-based site feasibility analysis identifies the sites and total area (in km^2) where power plants could potentially be sited for non-RE, domestic energy resourced-based electricity generation. The installed capacity and the annual generation potential for coal power are not estimated. The site-feasibility analysis for coal generation shows that with the application of siting exclusions (e.g., protected areas and populated areas) and priority areas (e.g., proximity to coal deposits and waterbodies) the total land area that is feasible for siting of coal power generation drops from 45,957 to 1,685 km^2.

The technical potential for domestic energy resources for electricity generation assessed in this work may support Lao PDR in energy planning for 2030 and beyond. Direct comparison between technical potential and domestic electricity demands is not possible as technical potential does not consider the economic or market feasibility of these resources and it does not account for transmission and distribution system losses; however, a broad comparison is made here to highlight the magnitude of resources technically available. The technical potential for electricity generation for Lao PDR is significantly larger than total domestic consumption of 4,239 GWh/year in 2015 and the projected domestic electricity consumption for 2030 of 21,844 to 33,024 GWh/year. Additionally, this technical potential could be considered in offsetting electricity imports that reached approximately 2,049 GWh/year in 2015. This domestic technical potential may also provide opportunities to utilize existing and planned interconnections for the export of electricity to regional neighbors. With increased regional electricity demand and corresponding electricity supply requirements, this could position Lao PDR to be a net exporter of electricity following recent trends and stated policy goals.

TABLE ES-1. SUMMARY OF TECHNICAL POTENTIAL OF DOMESTIC ENERGY RESOURCES FOR LAO PDR

	Technical Potential		Suitable Area (km²)
	Generation (GWh/year)	Capacity (GW)	
Solar PV – Utility-scale, fixed-tilt			
Base-Lao PDR: No exclusions	11,139,178	8,277	229,878
Scenario 1 (S1): Relaxed exclusions (*excludes protected areas, waterbodies, and wetland areas*)	8,996,660	6,678	185,519
S2: S1 **+** Slope exclusion (*excludes areas with slope > 5%*)	2,304,415	1,619	44,958
S3: S2 **+** Agriculture and forest area exclusions	731,613	516	14,380
S4: S3 **+** Urban area exclusion	731,417	516	14,376
Wind power – Rural, utility-scale, 100 m hub height			
Base-Lao PDR: No exclusions	842,835	691	229,878
S1: Relaxed exclusions (*excludes protected areas, waterbodies, and wetland areas*)	682,161	557	185,519
S2: S1 **+** Slope exclusion (*excludes areas with slope > 20%*)	343,463	283	94,428
S3: S2 **+** Forest area exclusion	223,268	180	59,531
S4: S3 **+** Agriculture area exclusion	135,129	116	38,486
Biomass[1] – Multiple scales			
Logging residue – Utility-scale	376		
Primary and secondary mill residues – Utility-scale	344		
Biogas – Nonutility-scale	2.53		
Crop residues (rice husk & sugar cane bagasse) – Nonutility-scale	802		
Coal power site feasibility[2] – Utility-scale			
S1: All exclusions (*excludes areas with slope > 12%, areas < 5 km from an airport, contiguous areas < 1.2 km², protected areas, agricultural areas, waterbodies, wetland areas, urban areas, densely populated areas, and areas > 5 km from a road*)			45,957
S2: S1 **+** priority areas (*excludes areas > 32 km from coal deposits and areas > 32 km from water sources*)			1,685

1. A single, base analysis of annual generation is considered for each of the biomass resources with no exclusion-layers analysis due to the current data resolution and non-site-specific nature of biomass resources. Suitable area and installed capacity are not assessed.
2. A site feasibility analysis is conducted for coal power technology as a proxy to technical potential to identify land area where plants could be sited. The installed capacity and the annual generation potential are not estimated. The Base-Lao PDR assumes 100% of land area would be feasible.

The technical potential assessment presented in this work is not definitive. As land-use designations, protected areas, and other stakeholder concerns are in constant flux, estimates of technical potential and land availability should be verified and updated for use in future planning analyses. Additionally, the existence and availability of data are dynamic issues, and additional datasets may exist and/or be under development that would further inform future planning analyses.[2] Also, technical potential assessments

[2] The technical potential estimate here is based on the data assessment from Lee et al. (2018) completed within the Energy Alternatives Study and a data assessment of the Lower Mekong, completed by Lopez et al. (Forthcoming) in support of the USAID Clean Power Asia program. USAID Clean Power Asia works with Lower Mekong Countries and other Association of Southeast Asian Nations member states to scale-up RE in the region's power systems.

are sensitive to the performance characteristics of the technologies considered, and assessments will evolve together with the available technologies. The technical potential results presented here do not include considerations of the economic and market feasibility of the various energy resources. The technical potential may be used as an input to further assessments of the economic and market potential of energy resources of interest (Brown et al. 2016; Lopez et al. 2012).

Recommendations

A set of actions are identified for the short, medium, and long term that may enable MEM to apply the technical potential assessment results to support planning activities and improve upon them for future analyses.

Short-term actions

In the immediate-term, MEM can take steps to use these technical potential results to support ongoing energy planning and policy activities. MEM can use this improved understanding of solar PV and wind technical potential to identify initial areas of interest for possible RE auctions in Lao PDR. MEM could highlight areas with high-quality resources that warrant additional detailed analyses for future RE auctions. Additionally, MEM could act to set future (or realign existing) national (or subnational) RE targets based on this improved depiction of the technical potential for utility-scale solar, wind, and biomass energy resources in Lao PDR.

MEM can begin to disseminate the results of this technical potential assessment to local decision makers and stakeholders. Sharing this improved understanding of the technical potential of RE resources and site feasibility of coal power may support decision makers addressing current energy planning concerns in Lao PDR.

MEM can also take steps to verify, improve, and update the results and methodology employed here and address data gaps. The internal verification of assumptions, exclusions, methodology, and results would help to refine this and future analyses for the specific context of Lao PDR. Ensuring that the assumptions and exclusions reflect development constraints unique to Lao PDR would improve the accuracy of future technical potential assessments and aid MEM to learn the methodology used here and build in-house technical potential assessment capacity.

MEM could also work with qualified local institutions (such as the National University of Laos) or private firms to identify and/or create the required datasets to include these assumptions and exclusions in the analyses. The exclusion analysis employed in this work relied on proxy assumptions based on assessments conducted in the United States for utility-scale RE generation, in the absence of accepted values for Lao PDR. The highest priority data gaps to address for future technical potential assessments are those for which publicly accessible, default datasets are absent; however, even when default data exist, data from in-country sources are preferred if they are of high quality. The following steps may help to improve future assessments:[3]

- Create or procure detailed crop residues, forest residues, and biogas resource data at finer resolutions than the national or province level. Data at the district, per km^2, or on-site resolution would allow for a more in-depth and accurate analysis, which would be more in line with the wind and solar resources included in this work.
- Develop and share spatial datasets that allow for an estimation of the theoretical, non-exploited hydropower resources for all of Lao PDR.
- Develop, identify, or share verified spatial data depicting the Lao transmission system and interconnections with international neighbors. This complementary dataset would be beneficial for

[3] See Lopez et al. (Forthcoming) and Lee et al. (2018) for additional details on addressing these foundational dataset gaps.

the considerations of meeting domestic electricity demands and plans for electricity imports and exports. Spatial data on current and planned transmission system and international interconnections together with system characteristics and hourly data would support a more detailed analysis of how technical potential could be used to supply domestic demand and contribute to electricity import and export plans.

- Develop or share spatial land-use classification data. Agricultural and forested areas represented a significant exclusion for solar PV, wind, and coal power siting in this work. As there may be multiple types of agricultural and forested areas within Lao PDR, each with different development restrictions, a data layer depicting these land-use classifications may aid in refining the estimated suitable land area and technical potential for different technologies.

Medium-term actions

To ensure that the results of this assessment are valuable beyond the initial step completed here of identifying domestic resources, MEM may want to use the results of this assessment within medium-term planning activities. MEM may consider additional analysis of the role that these domestic resources (e.g., solar, wind, biomass) may play in meeting domestic demand and with electricity import and export strategies—considering existing and planned transmission systems and interconnections with regional neighbors.

MEM can build on their understanding of technical potential and their capability with these base assessments to conduct more sophisticated analyses. MEM could take steps to conduct an economic potential analysis for RE resources in Lao PDR. An economic potential assessment (beyond establishing levelized cost of electricity in Task 3 of the Energy Alternatives Study) would further refine the technical potential assessment identifying the resources for which the cost of generating electricity is lower than expected project revenues. An economic potential study would include an analysis of the energy resources together with a transmission infrastructure overlay allowing for quantification of the economic viability of siting technologies in certain locations (Brown et al. 2016). An economic-potential assessment would further inform RE target-setting activities, capacity expansion planning, and policy design.

As MEM continues to build capacity to inform energy planning, it may consider conducting a longer-term integrated resource planning (IRP) activity. An IRP would support MEM in developing a strategy to meet projected energy demands through a combination of supply- and demand-side actions that would also satisfy multiple objectives for resource use in Lao PDR. These objectives could include minimizing future power system costs, maximizing energy security, maximizing reliability, and maximizing access to energy services, among other objectives. The results of technical and economic potential assessments would be used in an IRP to depict the domestic RE resources available for electricity generation in Lao PDR. These resources could be considered together with other RE and non-RE resources and electricity imports as supply-side electricity generation options within an IRP activity.

With an improved understanding of the technical potential for large-scale wind and solar resources in Lao PDR, MEM could conduct integrated transmission expansion and RE generation development planning to potentially increase the share of RE resources in the power system. The Renewable Energy Zone (REZ) Transmission Planning Process would utilize the results of a technical potential assessment, such as the current work, to identify REZs that have high-quality RE resources with suitable topography, land-use designations, and demonstrated developer interest. The process would then study transmission expansion options to connect these REZs to the power system (Lee, Flores-Espino, and Hurlbut 2017).

In the medium term, MEM could consider working with other ministries and institutes in Lao PDR to harmonize land-use designation restrictions and energy development strategies. With economic and population growth in Lao PDR there will undoubtedly be increased, competing demand for use of land (e.g., forest, agricultural, and other designations). This study found that agricultural and forested area exclusions can significantly limit the suitable area for energy system development as well as the resulting technical potential. MEM can use the results of this and future technical-potential assessments to educate other decision makers and stakeholders on the role that land-use designations and development restrictions play in energy system planning and development and to work on land-use designation policies that would support energy system development alongside other development objectives in Lao PDR.

In the medium to long term, MEM could develop or procure higher temporal resolution RE resource data, with an emphasis on wind and solar, to improve technical and economic potential assessments and to facilitate more sophisticated activities such as integrated resource planning, REZ transmission planning, and grid integration studies. Currently, the best available data for wind and solar in Lao PDR provides long-term, annual, average wind speed and wind power densities. MEM could improve these data by creating or procuring high-resolution resource data for wind and solar (preferably hourly or subhourly) as these finer resolutions better capture the variability of resources within timeframes that are relevant to power system operations (Lee et al. 2018; Lopez et al. Forthcoming).

Long-term actions

In the long term, MEM can apply expertise and data to update and improve upon technical-potential analyses and use the results from these assessments in more sophisticated analyses that support energy policy objectives in Lao PDR. For example, as Lao PDR begins to significantly scale up RE electricity generation connected to the grid, MEM may consider a grid integration study to improve understanding of the technical, economic, and reliability constraints and options associated with achieving high levels of variable RE. These studies require high-resolution data including RE resource potential and energy demand data.

MEM may wish to consider periodic technical-potential assessment updates to ensure that they remain relevant to energy planning analyses. Periodic technical-potential assessment updates are possible and appropriate as resource and associated data quality improve, system characteristics change, exclusions are identified, and internal capacity to do these assessments increases (Lopez et al. 2012). As improved, higher-resolution data become available for energy resources of interest, this may improve the accuracy of the potential capacity, generation, and suitable land area. Improvements in RE technologies are consistently being made, and the assumptions about these technologies can significantly influence the results (e.g., capacity factor, power density). Additionally, the technologies of interest to decision makers may change, and additional assessments may be required. For example, this assessment was made for utility-scale, fixed-tilt solar PV and wind turbines with 100 m hub height; however, for the reasons described above, interest may grow for these and other systems—requiring an assessment that includes assumptions specific to these technologies.

This report is intended to inform decision makers and is structured as follows:

- **Section 1 provides an introduction to the Energy Alternatives Study and the Task 2** technical potential assessment of domestic energy resources for electricity generation.
- **Section 2 describes the methodology and assumptions** made for a geographic information system (GIS)-based technical potential assessment of Lao PDR.
- **Section 3 presents the resulting estimates of technical potential** for the energy resources of interest for Lao PDR and accompanying maps of developable areas.
- **Section 4 discusses how technical potential could support power sector strategies** of Lao PDR considering electricity demand and supply trends and imports and exports from regional neighbors.
- **Section 5 concludes with the key takeaways of the analysis for decision makers** as well as priority steps for continual future improvement of the assessments made in this work.

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1 Introduction

The conventional approach taken by the government of the Lao People's Democratic Republic (Lao PDR) to ensure a secure, reliable, and affordable supply of energy in support of economic development has been to prioritize hydropower investment. The country has benefited from this power for development; however, this has constrained the diversity of the country's current electricity generation mix to hydropower (62.1%) and more recent additions of coal-fired power (37.5%) and biomass power (0.4%) (MEM 2016). In order to diversify this portfolio and take advantage of other domestic energy resources, the power sector decision makers are exploring the potential role that energy resources beyond hydropower could play in their country's future power system.

As a central actor in this energy diversification transition, the Lao Ministry of Energy and Mines (MEM) is strengthening its capacities in energy system analysis and planning to explore energy alternatives to inform energy planning to 2030. This includes analyzing future energy system investment opportunities that would result in a diversification of the national electricity generation mix. The purpose of this report is to support MEM in assessing the technical potential of domestic energy resources under consideration in Lao PDR for utility-scale electricity generation. Specifically, this work provides assessments of technical potential, and the associated maps of developable areas, for energy technologies of interest to support subsequent planning analyses. The methodology, assumptions, and datasets employed for the technical-potential assessment are provided to ensure transparent, replicable results enabling decision makers to apply the approach in future assessments.

The Energy Alternatives Study for the Lao PDR (Energy Alternatives Study) is composed of five successive tasks that collectively support the project's goals as shown in FIGURE 1. This report is the second output of the Energy Alternatives Study, a collaboration led by MEM and the U.S. Agency for International Development (USAID) within the Smart Infrastructure for the Mekong (SIM) program.[4] The work was carried out by a team from U.S. Department of Energy's National Renewable Energy Laboratory (NREL) in collaboration with MEM and other Lao power sector stakeholders.

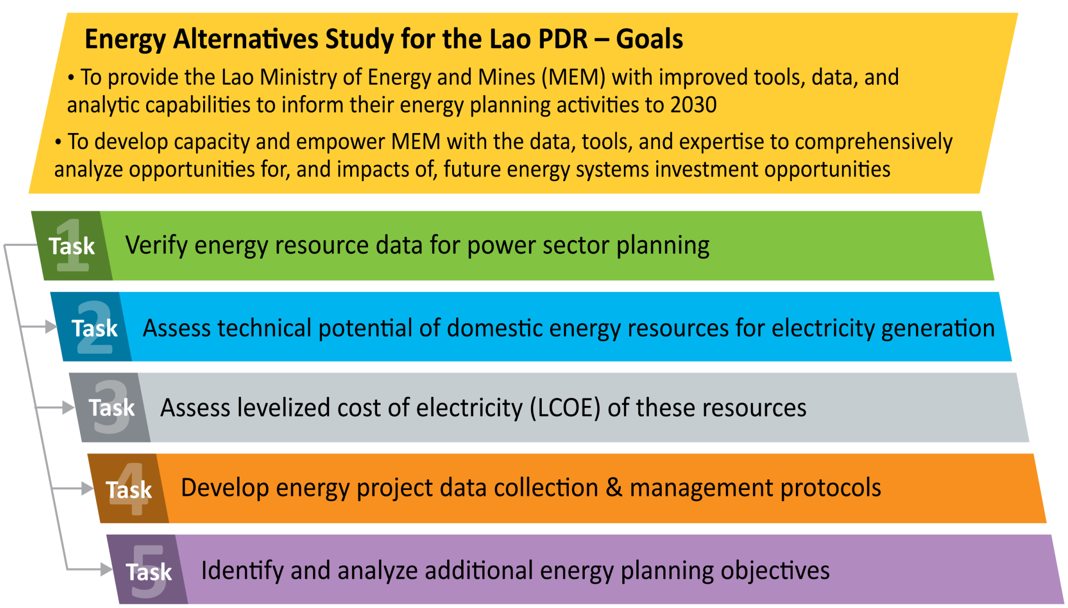

FIGURE 1. GOALS AND TASKS OF THE ENERGY ALTERNATIVES STUDY FOR THE LAO PEOPLE'S DEMOCRATIC REPUBLIC
(Lee et al. 2018)

[4] The SIM program—a United States Government Interagency program—provides assistance to support climate-smart, environmentally sound and socially equitable infrastructure, clean energy development, and land and/or water resources use.

The estimate of technical potential presented here is not definitive as the existence and availability of data are dynamic issues, and additional datasets may exist and/or be under development that would further inform future planning analyses conducted by MEM and other actors.[5] The technical potential calculation includes considerations of different exclusion layers, which allow for the identification of land areas where energy systems can be developed. As land-use designations, protected areas and other stakeholder concerns are in constant flux, any estimates made here would have to be verified and updated for use in future planning analyses. Additionally, the technical-potential estimates presented here are sensitive to the performance characteristics of the technologies considered and as such these estimates will evolve in parallel with the technologies available. The technical-potential results presented here may support energy planning analyses and RE target setting; however, the results do not include considerations of the economic and market feasibility of the resources. The technical potential may be used as an input to further assessments of the economic and market potential of energy resources of interest.

This work is intended to inform decision makers and is structured as follows:

- **Section 2 describes the methodology and assumptions** made for a geographic information system (GIS)-based technical potential assessment of Lao PDR.
- **Section 3 presents the resulting estimates of technical potential** for the energy resources of interest for Lao PDR and accompanying maps of developable areas.
- **Section 4 discusses how technical potential could support power sector strategies** of Lao PDR considering electricity demand and supply trends and imports and exports from regional neighbors.

  Section 5 concludes with the key takeaways of the analysis for decision makers as well as priority steps for continual future improvement of the estimates made in this work.

[5] The data used in this technical potential estimate is based on the data assessment from Lee et al. (2018) completed within the Energy Alternatives Study as well as the closely coordinated data assessment of the Lower Mekong, completed by Lopez et al. (Forthcoming) in support of the USAID Clean Power Asia program. Clean Power Asia works with Lower Mekong Countries and other Association of Southeast Asian Nations member states to scale-up RE in the region’s electricity grid.

2 Methodology – technical potential assessment

This section presents the methodology followed to assess the technical potential of RE resources and site feasibility of domestic, fossil-fuel-resource-based electricity generation. As energy resources (e.g., solar, wind, hydro, natural gas, and coal) are the primary input for electricity generation, any assessment of energy planning supply and demand requires an understanding of these resources—including type and quantity, the location of these resources, and the technical and economic constraints that may impact their utilization (Brown et al. 2016; Lopez et al. 2012).[6]

2.1 RE resource considerations

Resource potential is the theoretical amount of RE resource that is physically available across a given area of consideration—representing the theoretical upper bound of resource availability. It is a foundational input to the subsequent analyses of technical, economic, and market potential (FIGURE 2), which are all important for identifying energy planning alternatives that are based on actual, screened resource availability (Brown et al. 2016; Lopez et al. 2012).

Technical potential is a subset of the RE resource potential and represents the technically achievable energy capacity, electricity generation, and suitable land area for a particular RE-based electricity generator with assumed system performance and geographic development constraints. The technical potential is important for planning as it sets an upper-boundary estimate of energy resource development potential (Lopez et al. 2012). Estimation of technical potential for electricity generation begins with the energy resource potential. All of the energy resource potential may not be technically exploitable as a result of a number of constraints to development. These may include protected areas, certain terrain features, populated urban zones, water bodies, and other pertinent constraints.

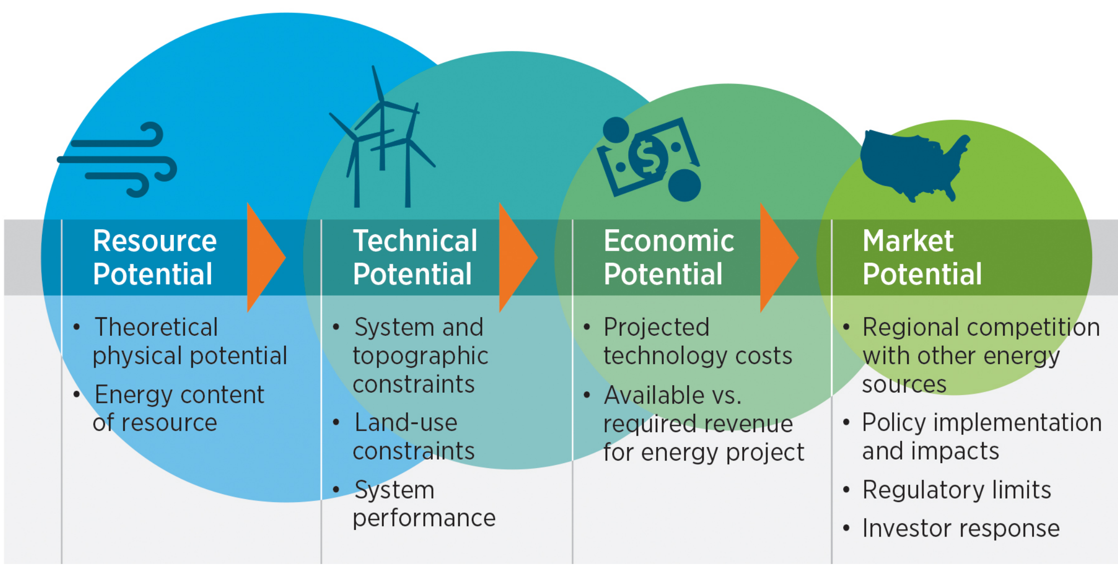

FIGURE 2. TYPES OF RENEWABLE GENERATION POTENTIAL

(BROWN ET AL. 2016)

As development may be technically possible but expensive and economically unattractive in many areas, the exclusion layers often include a set of hybrid layers that identifies technically developable areas with some overlap into economically viable areas. As an example, resources in agricultural areas may be attractive for development but could cause food security issues that would negate the benefits of RE

[6] For additional descriptions on renewable electricity generation potential and technical potential see Lopez et al. (Forthcoming), Lee et al. (2018), Brown et al. (2016), and Lopez et al. (2012).

development. As another example, mountainous areas with high slope may also appear to be technically developable, but the high cost for transporting materials into remote locations and constructing platforms to handle the high slope may cause these areas to be less favorable than locations with less resource potential but lower development costs.

2.2 Non-RE and additional resource considerations

Non-RE resources and RE resources are fundamentally different in many regards, and care should be taken within any analysis that proposes to compare these resource types or the output of analyses that consider both resource types. As described in Brown et al. (2016), the terms and definitions used for resource and generation potential for RE and non-RE resources may appear analogous; however, these terms and definitions are not immediately transferable and the results may not be quantitatively comparable. It is, therefore, important to detail how RE and non-RE resources are addressed in the current work and the Energy Alternatives Study (Lee et al. 2018). [7]

Additionally, energy resources may be classified as either site-specific or non-site-specific. Site-specific indicates that electricity generation must occur at the site where the resource is available as in the case of solar, wind, and geothermal. Non-site-specific means that the resource can be transported to the site where electricity is generated as in the case of biomass, coal, natural gas, and petroleum. The location of site-specific resource potential is generally represented as a layer of the total resources available where they would have to be utilized. Non-site-specific resources are typically represented by identifying the location of the resources or deposits, for example the location of a coal mine.

This technical-potential assessment is completed for site-specific and non-site-specific RE resources of interest. For non-RE resources a preliminary analysis is conducted to identify where power plants could feasibly be sited given a number of constraints. The methodologies followed for these analyses and the assumptions made for the resources considered are described in the sections that follow.

2.3 Approach to technical potential assessment

2.3.1 RE resources

The total $\mathit{Technical\ Potential\ Capacity}$ for electricity generation (MW) is essentially the product of two factors, as shown in Equation 1. The annual $\mathit{Technical\ Potential\ Generation}$ for electricity generation (in MWh/year) is calculated with the addition of two additional factors as shown in Equation 2. The GIS-based, technical potential assessment identifies the land area (in km^2) that is available for RE development, the installed capacity (in MW), and the annual electric generation (in MWh/year) for variable RE resources and technologies of interest. This GIS-based approach to assessing the technical potential is also detailed following Equation 3.

$$\mathit{Technical\ Potential\ Capacity} = \mathit{Land\ Area} \times \mathit{Power\ Density}$$

EQUATION 1.

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[7] Non-RE resources are finite and are depleted with extraction and transformation. These non-RE resources are reported in terms of the total primary energy available in resources or reserves (BTUs, barrels of oil, tons of coal, or million cubic feet of natural gas). This differs significantly from RE resources, which are not depleted with use and are typically reported in terms of annual available resources (TWh/year) (Brown et al. 2016). In general, non-RE resources, specifically fossil fuels, are described in terms of proven reserves and production. “Non-RE resources” is a term that refers to the total quantity of discovered and undiscovered primary energy that is contained in the Earth’s crust that is currently subeconomic for extraction and production. The term “reserves” refers to identified deposits that are considered economic for production—analogous with RE economic potential. The term “production” then describes the non-RE products that are developed from these reserves. The discussion of non-RE resources focuses on those included in the scope of this assessment (Rogner et al. 2012).

$$\text{Technical Potential Generation} = \text{Land Area} \times \text{Power Density} \times \text{Capacity Factor} \times \text{Operating Hours}$$

EQUATION 2.

The available *Land Area* (in km^2) represents the total, technically developable area for the generation technology of interest within the boundary area of analysis. This is determined through an exclusions layer analysis, which systematically filters out areas where energy resources are technically undevelopable.

The *Power Density* (in MW/km^2) represents the maximum amount of electric power that a generator can produce (nameplate capacity) for a unit area of land, produced under specific assumptions for each technology. For example, the power densities of an illustrative solar PV system (36 MW/km^2) and a wind power system (3 MW/km^2) differ—implying that more area for wind installation is required to install equivalent capacities of wind and solar. However, actual generation (in GWh) is highly dependent on additional technology considerations and energy resource availability.

The *Capacity Factor* (%) is the ratio of the estimated annual system generation and its nameplate output. This factor is specific to the technology and the potential resources of the location in which it operates. Capacity factor is determined as the ratio of the annual generation (MWh) to the nameplate capacity (MW) and annual operating hours as shown in Equation 3.

$$\text{Capacity Factor} = \text{Annual Generation} / (\text{Nameplate Capacity} \times \text{Annual operating hours})$$

EQUATION 3.

The *Operating Hours* (hours) are an estimation of the total annual hours of operation and are generally assumed to be 8,760 hours annually.

As this work follows a GIS-based approach for technical-potential assessment, the analysis is conducted within a GIS application, such as QGIS or ArcGIS, utilizing multiple data layers as shown in FIGURE 3. The main steps of this process are detailed below to provide a transparent and repeatable methodology that actors in Lao PDR can follow in future analyses.

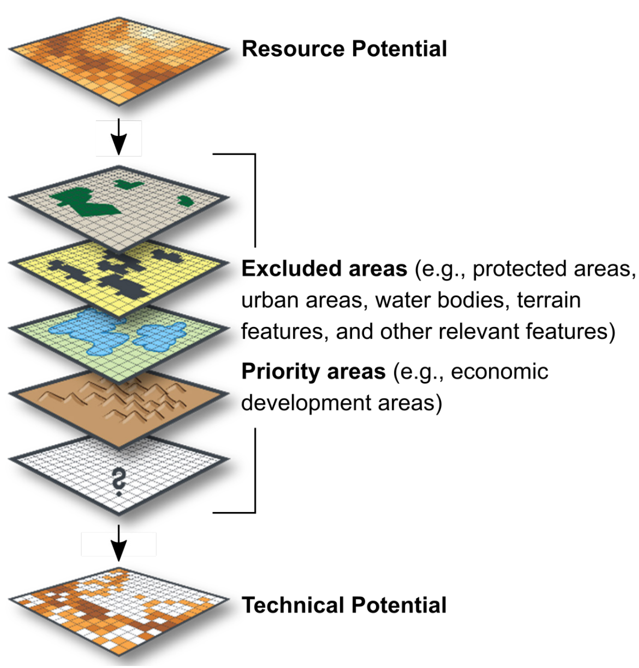

FIGURE 3. GIS-BASED TECHNICAL POTENTIAL ASSESSMENT APPROACH

ADAPTED FROM LOPEZ (2016)

Step 1. Assess the RE resource potential. This step results in a spatial layer that represents the resource potential for the RE resource under consideration—e.g., solar, wind, biomass. High-resolution, modeled annual average solar and wind resource data are available on the RE Data Explorer, a web-based application that provides spatial data and analysis capabilities for Lao PDR and other regions. [8] The data currently available on RE Data Explorer can be augmented as higher resolution data and data for other resources of interest become available (Lee et al. 2018).

Step 2. Determine capacity factors. This step applies technology-specific considerations of annual generation potential, nameplate capacity, and annual operating hours to the resource potential to calculate a spatial layer of capacity factors for the RE-based electricity generation technology. The steps that follow assist in focusing on areas with the greatest technical potential for development of new solar, wind, biomass, or other electricity generating systems.

Step 3. Conduct exclusions layer analysis. This step identifies the available land area that is technically developable through an exclusion analysis. This is conducted through a layer-stacking process—in a GIS application—to systematically filter out land areas that are not technically developable from a base layer of generation potential. The result is a layer depicting the area (and corresponding capacity factors) that remain technically developable.

Multiple technical constraints to development are considered in this step. Topographic constraints refer to a ground slope that would not support development of specific system types, for example solar PV development may be constrained to land with less than a 5% incline. Area constraints refer to the size of a land parcel (or contiguous area) that would be required to site a system, for example a utility-scale, fixed-tilt PV system of 1 MW may require 0.027 km^2 to be considered feasible. Land-use constraints may consist of water or wetland areas, agricultural areas, forested areas, or urban areas where development of a specific technology is unfeasible. Protected area constraints include development on nationally protected lands and areas of critical environmental or biodiversity concern. Additional layer constraints are highly context-specific and may include culturally or spiritually significant areas or sites that may be contaminated by unexploded ordnances (UXO), for example.

As technical potential is highly sensitive to the exclusions to and priorities of development, scenario analyses are considered best practice. A scenario analysis allows for an assessment of the technical potentials that may result from different possible combinations of exclusions and priorities for each technology considered.

Step 4. Apply power densities. This step applies the power density assumptions for the considered technology to the map of developable areas and capacity factors resulting from the exclusions layer analysis. The identification and use of an appropriate technology for the technical potential assessment is important, as technical potential is also sensitive to the power density and other technology specific considerations such as capacity factors. For example, specific wind turbines are chosen based on average annual wind speeds. For Lao PDR, where wind speed is generally low, a large turbine with a long rotor diameter is better for capturing low wind speeds. Technical potential assessment does not capture additional costs that may be incurred from selecting large turbines, but further economic potential analysis may help describe how higher capital costs and a greater levelized

[8] High-resolution, modeled annual average solar and wind resource data can be viewed on RE Data Explorer (re-explorer.org) from the Global Solar Atlas from the World Bank (globalsolaratlas.info) and the Global Wind Atlas from the Danish Technical University (globalwindatlas.com), respectively.

cost of electricity (LCOE) may mean a larger turbine can generate more electricity in lower wind speeds, but comes with higher costs.

Step 5. Calculate the technical potential. This final step identifies the resulting land area, potential installed capacity, and the annual electric generation for each technology considered. The results are obtained in both numeric—e.g., total values for the country or regions of interest—and spatial formats—e.g., maps depicting the location and estimates of technical potential for the country or regions of interest. For a scenario analysis this would consist of a range of results from the scenarios considered.

The assumptions for each RE technologies considered in this assessment are presented in Section 2.4.

The province administrative boundaries of Lao PDR are shown in Appendix A. The spelling of province names used in this work follow the convention of MEM (2015b).

2.3.2 Non-RE resources

Site feasibility is employed here as a proxy analysis for non-RE resources, given that there is not a methodology analogous to RE technical potential assessment. A GIS-based site feasibility analysis identifies the areas where power plants could potentially be sited for non-RE, domestic energy resource-based electricity generation. Existing estimates of non-RE, domestic resource potentials identified in Lee et al. (2018) are used as inputs for this analysis. The analysis begins with spatial layers depicting the location of resources and reserves. A set of exclusion layers and siting criteria (e.g., proximity to cooling water and urban areas, airports, and protected areas), and priority development data layers (e.g., proximity to coal deposits that contain resources of a specific quality), which are specific to each resource type (e.g., coal, natural gas, petroleum, and nuclear), are then applied in a successive process that produces composite suitability layers. These feasibility layers, similar to technical potential, consist of a hybrid of feasibility considerations (e.g., contiguous area) and exclusions that include economic considerations (e.g., proximity to coal mines or roads).

The data requirements for site feasibility analyses typically correspond to those described in Section 2.3.1 for available land area. The specific exclusions and proximity assumptions applied are detailed in Section 2.4.

This is a preliminary site-feasibility analysis that should to be augmented in the future by multiple criteria or optimization studies as well as more detailed project-level studies—outside of the scope of the current work—to indicate the most attractive, feasible sites (Mays et al. 2012; Sultana and Kumar 2012; Rice et al. 2015).

2.4 Technology-specific assumptions

This work concentrates on utility-scale systems for electricity generation that represent mature technologies in the region. Distribution level rooftop solar photovoltaics (PV) and small-scale wind generation are not considered within the scope of this work. Concentrating solar power (CSP)—defined as utility-scale electricity generation from the collection of solar heat energy in a central location— is not considered to be a mature technology in the region and is outside the scope of the work. Considerations for CSP typically require solar energy resource potentials of 5 kWh/m^2/day or greater; however, direct normal irradiance in Lao PDR peaks at roughly 4 kWh/m^2/day (Lopez et al. 2012).[9] Hydropower technical-potential assessment requires site-level assessments of multiple characteristics (e.g., geology environment, and access) as well as spatial data on estimated non-exploited hydropower resources,

[9] Future technology improvements may lead to increased performances that could affect the threshold assumed here. Also, higher-resolution local datasets developed in the future may provide additional information on areas that meet this threshold.

neither of which were available for this work. Additionally, it is assumed that MEM and EDL have experience in evaluating and developing domestic hydropower resources (Lee et al. 2018).

The assumed exclusions and constraints for this technical potential assessment are based on proxy U.S. data for technical potential of utility-scale RE generation where applicable due to an absence of accepted values for Lao PDR and regional proxy values. The Technical Committee of the Energy Alternatives Study reviewed these assumptions and were invited to provide feedback on the initial assumptions—including the exclusion and priority layers used—and results (see Appendix C). The assumptions were modified to reflect feedback from the Technical Committee of the Energy Alternatives Study where possible. Not all of the exclusion and priority layers could be included in this analysis due to a lack of available data. As these data become available, the Technical Committee of the Energy Alternatives Study can follow the methodology detailed above to repeat and update the technical-potential assessment considering additional, improved datasets for the technologies of interest.[10]

The sections that follow detail the energy resource datasets used and the assumptions made for each of the technologies considered. Additional details on the complementary data and assumptions are included in Appendix D.

2.4.1 Utility-scale solar PV (urban and rural)

Utility-scale solar PV consists of PV deployed inside of both urban and rural areas and connected to the transmission system. The technical potential for urban and rural areas was not calculated separately because of the relatively small footprint represented by urban areas and their low density, which may allow for PV installations near load centers. Solar resource data for Lao PDR were obtained from the Global Solar Atlas, owned by the World Bank Group and provided by SolarGIS (World Bank 2017). A fixed-tilt PV system is assumed in this work with a power density of 36 MW per km^2 (see Section 2.3.1) (Ong et al. 2013). Capacity factors for Lao PDR were determined by the ratio of the PV output over the modeled installed capacity (in kWh/kW/day) with the use of spatial data. The capacity factors for the solar PV system configuration used in this technical potential assessment are shown in FIGURE 4. These site-specific capacity factors, as detailed in 2.3.1, are the ratio of the estimated annual system generation and the maximum potential generation if operated at nameplate capacity for the same time period. The capacity factors are specific to the technology and the potential resources at the location in which they operate.

[10]As described in Lee et al. (2018) energy resource and complementary datasets as well as the barriers to and priorities for energy development are dynamic and may change as new information becomes available and policies are indorsed.

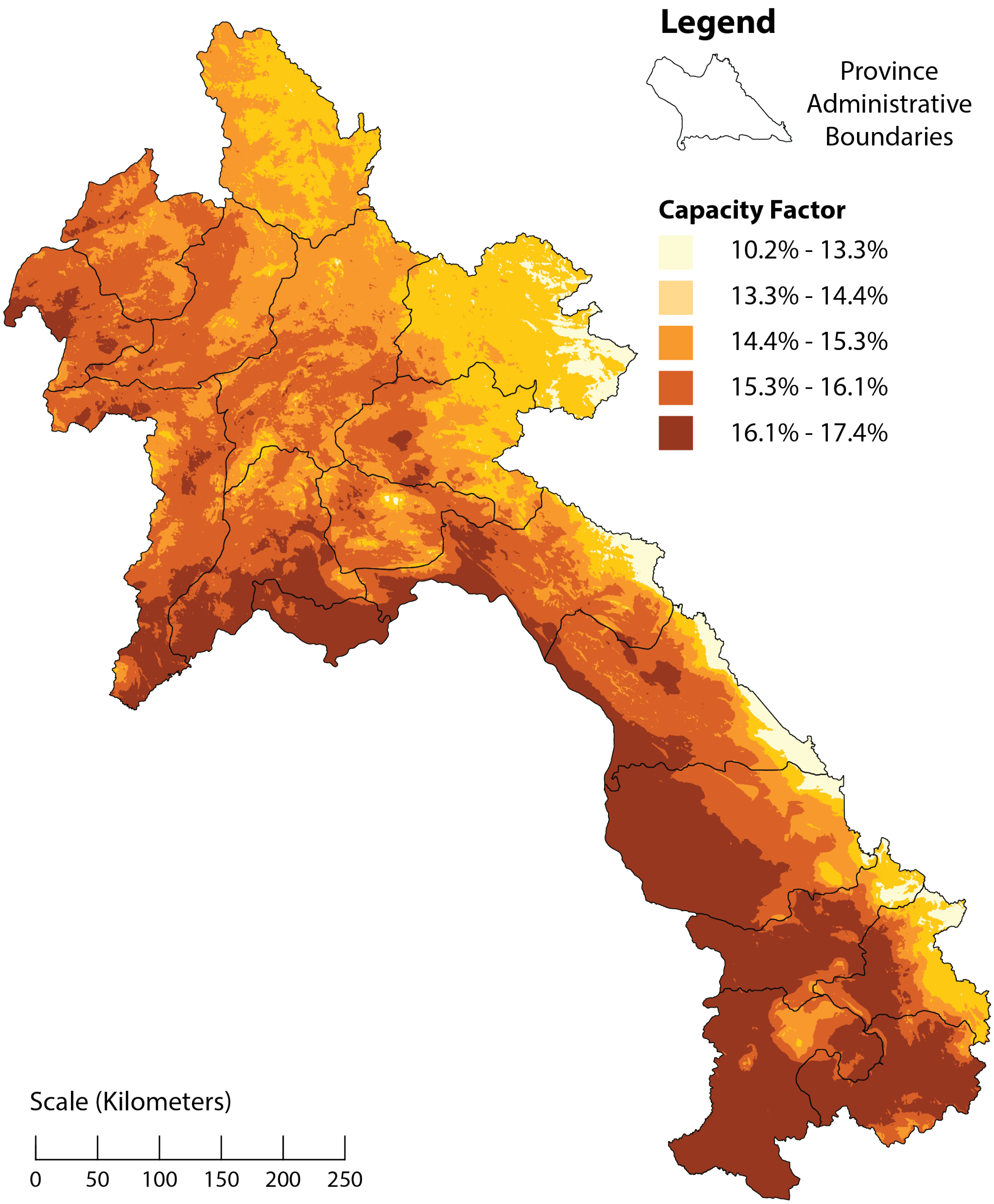

FIGURE 4. MAP - CAPACITY FACTORS FOR REPRESENTATIVE SOLAR PV SYSTEM IN LAO PDR

Building upon a base estimate of technical potential, this work considers a set of scenarios that represents progressively restrictive exclusions as shown in TABLE 1. The technical potential for utility-scale PV begins with a base estimate with no exclusions for the entire country (Solar PV Base-Lao PDR). Two additional base scenarios are then considered that constrain development potential to only within areas that are forested (Solar PV Base-Forest), and only within areas that are possibly contaminated by UXO (Solar PV Base-OXU). Solar PV Base-Forest and Solar PV Base-UXO scenarios provide an estimate of the potential generation that may not be available if related development exclusions were applied (e.g., no development in areas contaminated by UXO). Next, the potential within a set of four different scenarios is estimated through the application of a set of increasingly restrictive exclusion layers. Scenarios 2 through 4 exclude land areas that have slopes greater than or equal to 5%. All scenarios exclude protected areas, waterbodies, and wetland areas. Scenarios 3 and 4 further exclude both forested and agricultural areas. Scenario 4 is the most restrictive scenario restricting development within urban areas in addition to the constraints considered in scenarios 1 through 3.

A contiguous area exclusion for solar PV has not been applied in this work due to the restrictions in the resolution of the current land-cover and land-use data layers. In the United States (U.S.), where there is an abundance of high-resolution data depicting different land uses, and an abundance of potential land available for development, the contiguous area filter ensures that only the land areas with the highest potential value are focused on for additional analysis. In Lao PDR, the various mountainous regions and less-available spatial data mean a contiguous area filter would unnecessarily restrict analysis of potentially useful plots of land. Instead, it was assumed that project developers can assess the minimum contiguous land area at a later stage. This allows for the opportunity to explore different system sizes.[11]

TABLE 1. UTILITY-SCALE SOLAR PHOTOVOLTAICS (PV) – EXCLUSIONS (GREEN) FOR TECHNICAL POTENTIAL ASSESSMENT

Exclusions	Base			Scenarios			
	Lao PDR No exclusions	**Forest** Development constrained to only within forested areas	**UXO** Development constrained to only areas with UXO	**1** Relaxed exclusions	**2** Scenario 1 + slope exclusion	**3** Scenario 2 + agriculture & forest exclusions	**4** Scenario 3 + urban exclusion
Slope							
Greater than 5%							
Land cover and use							
Protected areas							
Water & wetland areas							
Agricultural areas							
Forested areas							
Urban areas							
Priority areas							
Forested areas							
Unexploded Ordnances							

2.4.2 *Utility-scale wind power (rural)*

Utility-scale wind power consists of wind resources located in rural areas (outside of urban areas). Wind resource data for Lao PDR were obtained from the Global Wind Atlas from the Danish Technical

[11]The land area required for a utility-scale, fixed-tilt PV system is highly dependent on the technology; however, 27,000 m^2 allows for a 1-MW system, roughly. Constraints such as this are often applied in larger countries such as the US, where a contiguous area exclusion would not eliminate a significant portion of available land area. (Lopez et al. 2012).

University (DTU 2017). Capacity factors were modeled using wind speeds at a 100 m hub height with assumed 15% losses (wind farm wiring, transformer, and other losses) and 98% availability. The Weibull probability distribution is used for wind speed distributions assuming a K=2 following Mone et al. (2017). A power density of 3 MW/km^2 is assumed for the turbine technology (Brown et al. 2016). The Asian Development Bank (2015) used a minimum cutoff of 6 m/s for wind resources with the assumption that speeds below this threshold were not sufficient for modern wind turbines. Minimum and maximum wind-speed cutoffs were not used in the current work; instead the turbine configuration was selected to best utilize the available wind resources of Lao PDR (Mone et al. 2017). The power curve in FIGURE 5 shows how the electric power output varies at different wind speeds for the representative wind turbine configuration modeled in this technical potential assessment. The cut-in speed, where the turbine starts to generate electricity, is approximately 2 m/s for this configuration. The power curve shows that wind speeds below approximately 2 m/s are insufficient for electricity generation, suggesting that there is insufficient torque on the turbine blades to cause them to rotate and drive the generator. The power output rises from this cut-in speed up to a rated power output of around 1.2 MW, which represents the maximum output, with a corresponding wind speed of approximately 13 m/s. The maximum power output of the modeled turbine is 2 MW; however, due to the assumed losses and availability the modeled turbine is seen to reach a rated power output of about 1.2 m/s. Turbine power outputs then fall as wind speeds begin to pass the rated-power-output wind speed (13 m/s). Average wind speeds in Lao PDR do not typically pass this rated-power-output wind speed, and no maximum cutoff wind speed was used for this turbine.

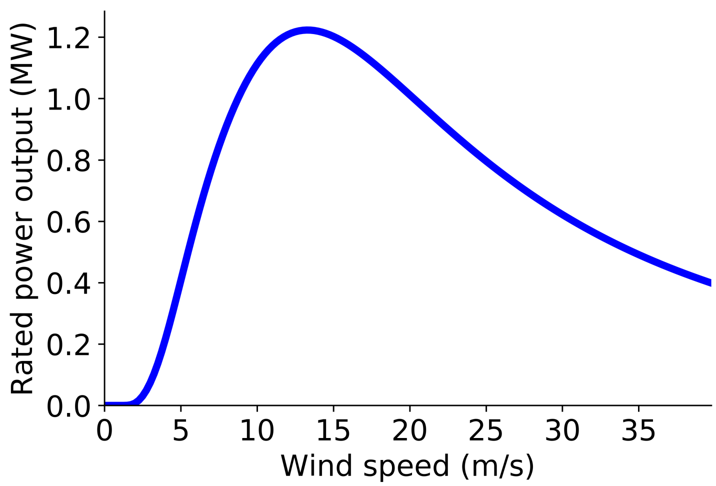

FIGURE 5. POWER CURVE FOR REPRESENTATIVE WIND TURBINE IN LAO PDR

The modeled capacity factors for the wind turbine configuration used in this technical potential are shown in FIGURE 6. As described in 2.3.1, the capacity factor is the ratio of the estimated annual system generation and the maximum potential generation if operated at nameplate capacity for the same period of time. Capacity factors are specific to the technology and the potential resources at the location in which they operate.

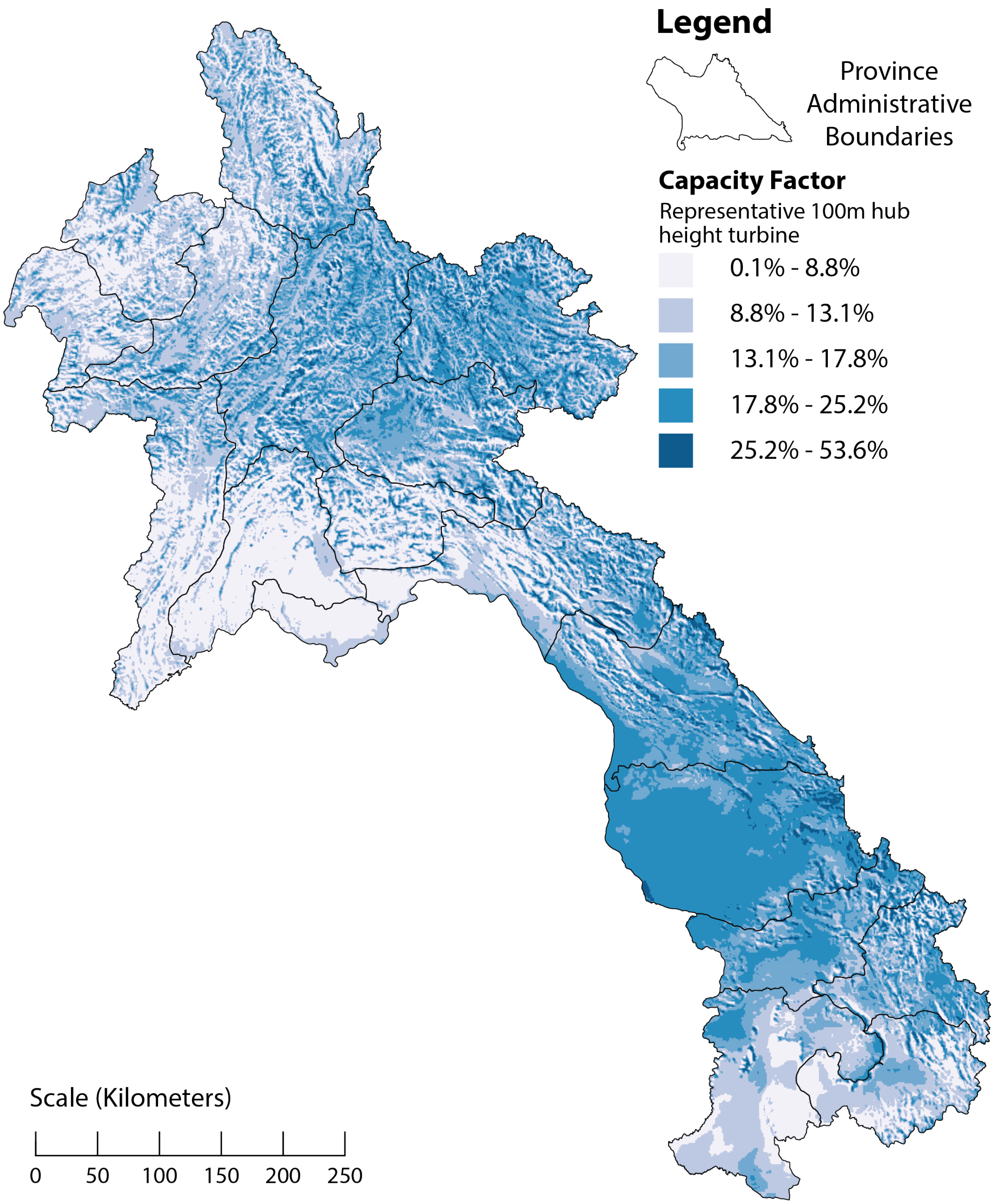

FIGURE 6. MAP – CAPACITY FACTORS FOR REPRESENTATIVE WIND TURBINE IN LAO PDR

The considerations for the base estimates of technical potential and a set of progressively restrictive scenarios are shown in TABLE 2. A base estimate of technical potential is made for the country prior to applying exclusions or priorities (Wind Base-Lao PDR). Two additional base scenarios are then considered that constrain development potential to only within agricultural areas (Wind Base-Agricultural), and only within areas potentially contaminated by UXO (Wind Base-UXO). Wind Base-Agricultural and Wind Base-UXO scenarios provide an idea of the potential generation that may not be available if related development exclusions were applied (e.g., no development in agricultural areas). The four scenarios included in this technical potential assessment are based on increasingly restrictive exclusions. Scenario 1 is the least restrictive with land use exclusions for protected areas, water covered areas, and wetland areas. Scenarios 2 through 4 exclude land areas with slope greater than 20%. Scenarios 3 and 4 exclude all forested area. Scenario 4 is the most restrictive scenario and excludes agricultural areas.

TABLE 2. UTILITY-SCALE WIND POWER – EXCLUSIONS (GREEN) FOR TECHNICAL POTENTIAL ASSESSMENT

Exclusions	Base			Scenarios			
	Lao PDR No exclusions or constraints	**Agriculture** Development constrained to only within agricultural areas	**UXO** Development constrained to only areas with UXO	**1** Relaxed exclusions	**2** Scenario 1 + slope exclusion	**3** Scenario 2 + forest exclusion	**4** Scenario 3 + agriculture exclusion
Slope							
Greater than 20%							
Land-cover and use							
Protected areas							
Water & wetland areas							
Forested areas							
Agricultural areas							
Priority areas							
Agricultural areas							
Unexploded Ordnances							

2.4.3 Biomass power technology

This study provides an assessment of the technical potential for biogas, logging residues, primary and secondary mill residues, and crop residue (rice husk and sugarcane bagasse). In general, logging residues, primary mill residues, and secondary mill residues are used in large-scale (e.g., utility-scale generation) and middle-scale (e.g., minigrid) electricity generation applications due to the high energy density of these materials. Biogas and crop residues are predominately used in middle-scale and distributed-scale (e.g., stand-alone, distributed systems) applications. Previous work assessing the theoretical potential for Lao PDR included additional crop residues (e.g., rice straw, sugar cane tops and trash, cassava stalk, and maize cob); however, these feedstocks are not typically collected for electricity generation due to their diffuse nature and low energy density (ADB 2015). Therefore, these additional crop residues are not assessed in this work. A more attractive use of these resources (and any other crop residues) may be for the production of pellets to be used for heating and cooking.

The potential annual biogas production at the province level was obtained from Koumphonphakdi and Suntivarakorn (2014). The conversion factors of 4.70 MWh/tonne CH4 and 666.6 x 10-6 tonne CH4/m3 were used to estimate technical potential (Lopez et al. 2012; IPCC 1996).[12] This study obtained the annual logging residue as well as primary and secondary mill residue production from Akgün et al. (2011). To

[12] The unit metric tonne (tonne) refers to 1,000 kg or 2,205 lbs.

calculate technical potential of these three biomass resources the conversion factors of 1.1 MWh/bone dry tonne (BDT) and 2.65 BDT/m3 were used (Lopez et al. 2012; Global Wood 2017). Rice husk and sugarcane bagasse production data are derived from ADB (2015). For rice husk, a 10% moisture content was assumed with a conversion factor of 0.538 kWh/kg (Das and Hoque 2014). A 50% moisture content was assumed for sugarcane bagasse with a conversion factor of 4.2 kWh/kg (MacKay 2009).

Depending on data availability, the technical potential for biomass resources is assessed on an annual basis at either country level (logging residue, primary mill residues, and secondary mill residues) or at the provincial level (biogas and select crop residues). Biogas technical potential was assessed at the province level following a similar approach with annual stock productions and conversion factors. A single, base analysis is considered for the biomass and biogas technical-potential assessments with no exclusions or additional scenarios due to the current data resolution and lack of site-specific data.

2.4.4 Coal power technology

A site feasibility analysis is conducted for coal power technology as a proxy analysis to a technical potential assessment to identify areas where coal-fired power plants could potentially be sited (see Section 2.3.2). Estimates place coal resources between 500-600 million tons and reserves at approximately 700-900 million tons (Lee et al. 2018). The coal resources and reserves detailed in Marutani (2006) were used for the locations of coal deposits in Lao PDR.[13] A minimum plant-siting footprint of 1.2 km^2 is assumed based on industry guidelines for an advanced coal-fired power plant (Mays et al. 2012); however, beyond this footprint, no additional technology specific assumptions are made in this technology neutral analysis.[14] The analysis does not estimate the installed capacities (in MW) or the annual generation potential (in GWh/year) for coal-fired power plants in the country as this requires detailed datasets on coal deposits that are not available in addition to assumptions on coal power technologies of interest that are outside of the scope of this work.

The considerations for the site feasibility analysis are shown in TABLE 3. The base site feasibility (Coal Base-Lao PDR) identifies the locations of deposits and assumes no exclusions for development. Scenarios 1 and 2 exclude land area with slope greater than 12%, contiguous areas of less than 1.2 km^2, protected areas, agricultural areas, water-covered areas, wetland areas, urban areas, and densely populated areas from development. Both scenarios assume that development of a coal power plant within 5 km of an airport is not feasible. Scenario 2 further limits development to within priority areas that are less than 32 km of a coal deposit to facilitate transport of energy resources, less than 5 km from roads, and less than 32 km from a cooling water source (Mays et al. 2012; Rice et al. 2015).

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[13] This coal deposit data is available for visualization and download on the RE Data Explorer. See Appendix C and Lee et al. (2018) for additional description.

[14] A lenient minimum footprint size is used for the Lao PDR in this preliminary analysis. For example, the concession area for the Hongsa Mine Mouth Power Plant was 76.4 km^2 for a 1,878 MW plant, which also included access to a water reservoir and a lignite deposit (Power Technology 2017).

TABLE 3. COAL POWER PLANTS – EXCLUSIONS (GREEN) FOR SITE-FEASIBILITY ANALYSIS

Exclusions	Base	Scenarios	
	Lao PDR Coal deposit locations with no exclusions	**1** All exclusions	**2** Scenario 2 + Priority areas for development
Slope			
Greater than 12%			
Contiguous area			
Less than 1.2 km^2			
Proximity			
Less than 5 km from airport			
Land-type(s)			
Protected areas			
Agricultural areas			
Water and wetland areas			
Urban areas			
Densely Populated areas[1]			
Priority areas			
Greater than 5 km from road			
Less than 32 km from coal deposit			
Less than 32 km from water source			

1. Densely populated areas have greater than 200 people / km^2

3 Results – technical potential assessment

This section presents a summary of the results for the technical potential assessment (or site feasibility analysis) for each of the electricity generation technologies considered together with a map and a table depicting the total country-level and province-level technical potentials. These results follow from the application of the technical potential assessment described in Section 2.3 and the specific considerations for each energy resource type detailed in Section 2.4.

3.1 Utility-scale solar PV (urban and rural)

The resource potential—represented here as the technical potential with no development exclusions—for utility-scale solar PV in Lao PDR is 11,139,178 GWh/year as shown for the Base-Lao PDR assessment in TABLE 4. An assessment of the technical potentials that would be bounded only inside of forest area or within area potentially contaminated by UXO is 4,953,049 and 3,436,712 GWh/year for the Base-Forest and Base-UXO assessments, respectively. These Base-Forest and Base-UXO assessments provide an idea of the potential generation that may not be available if related development exclusions were applied (e.g., no development in forested areas). A set of four scenarios was considered for the technical potential that include progressively restrictive exclusions as shown in TABLE 4. The total technical potential for Lao PDR ranges from 8,996,660 to 731,417 GWh/year for the least restrictive and most restrictive development exclusions, respectively.

The technical potential for the Base-Lao PDR, Scenario 1, and Scenario 3 assessments are shown in FIGURE 7, FIGURE 8, and FIGURE 9, respectively. The country- and province-level technical potentials for the Base-Lao PDR, Scenario 1, and Scenario 3 are presented in TABLE 5, TABLE 6 and TABLE 7, respectively. Results for the remaining solar PV assessments are in Appendix B. The average capacity factors are also presented for each assessment at the national level and the average for each province.

The Base-Lao PDR assessment found a total technical potential of 8,277 GW in Lao PDR with no exclusions. In FIGURE 7 the most attractive resources are seen to be located in Vientiane and in the southern provinces of Attapeu, Champachack, Saravane, and Savannakhet. The Vientiane Prefecture (near the capital) also has an attractive capacity factor for solar PV. The Base-Forest and Base-UXO assessments show the overlap that exists between solar resources and forested areas and areas potentially contaminated with UXO. A large share of Lao PDR is forested and the Base-Forest assessment finds a significant share of solar resources located within forested areas (3,712 GW total technical-potential capacity). Similarly, the Base-UXO assessment found a substantial overlap of solar resources with land area potentially contaminated by UXO (2,550 GW total technical-potential capacity). MEM may have to consider land-use policies as well as associated costs when considering solar development in potentially forested areas and those with UXO, respectively.

Scenario 1 considers limited exclusions for development (i.e., excludes protected areas, waterbodies, and wetland areas) and is seen to remove approximately 19% of the suitable land area, potential capacity, and potential generation from the Base-Lao PDR assessment. As seen in FIGURE 8, the attractive resources near Vientiane and along the southwestern border for the country have not been excluded.

Scenario 2 excludes areas with slope greater than 5%, resulting in a significant exclusion of land area with an approximate 80% reduction in available land area, potential capacity, and potential generation from the Base-Lao PDR assessment. Of the land exclusions considered for solar PV development, the slope exclusion has the most significant effect on technical-potential assessments. The results from Scenario 2 highlight the mountainous terrain that Lao PDR must consider when developing solar (or any other) energy resources. The resources in mountainous provinces in the north of the country are significantly reduced with this exclusion. The suitable area and technical potential in Phongsaly province, for example in the north, are seen to drop from 1,351 km^2 to 263km^2 and from 696,929 GWh/year to 12,044 GWh/year, respectively. Less-mountainous regions such as Champachack province in the south are not affected as significantly by this exclusion. To develop resources in these mountainous areas at slopes above 5% Lao PDR would have to consider potentially higher development costs for access and preparation of terrain with high slopes in addition to potentially decreased generation due to solar shading.

The addition of agricultural and forested area exclusions in Scenario 3 further limits the available land area and the technical potential to approximately 14,380 km^2 and 731,613 GWh, respectively. This represents an approximate 94% reduction from the Base-Lao PDR assessment. Agriculture and forest land exclusions in Scenario 3 further decreased the technical potential for the country. There is high competition for use of these lands, and any energy policy or planning activities from MEM must take this into consideration for current and possible future land-use policies and work with other stakeholders in the country for energy development.

The exclusion of urban areas with Scenario 4 is seen in TABLE 4 to have minimal effect on the total technical potential for the country, and the suitable area and technical potential do not change significantly from Scenario 3. Table B-4 shows that the southern provinces of Champachack, Savannakhet, Khammuane, and Saravane may have the most robust solar technical potential taking into account the exclusions listed and so represent the provinces with the most suitable areas for development and technical potential for generation.

TABLE 4. SUMMARY OF SOLAR PV TECHNICAL POTENTIAL FOR LAO PDR

Solar PV	Potential Suitable Area (km^2) (*% change from the Base-Lao PDR*)	Technical Potential	
		Capacity (GW) (*% change from the Base-Lao PDR*)	Generation (GWh/year) (*% change from the Base-Lao PDR*)
Base-Lao PDR (*no exclusions*)	229,878	8,277	11,139,178
Base-Forest (*development constrained to forested areas*)	103,086	3,712	4,953,049
Base-UXO (*development constrained to areas with UXO*)	70,878	2,550	3,436,712
Scenario 1 (S1): Relaxed exclusions (*excludes protected areas, waterbodies, and wetland areas*)	185,519 (*19%*)	6,678 (*19%*)	8,996,660 (*19%*)
Scenario 2: S1 **+** Slope exclusion (*excludes areas with slope greater than 5%*)	44,958 (*80%*)	1,619 (*80%*)	2,304,415 (*79%*)
Scenario 3: S2 **+** Agriculture and forest area exclusions	14,380 (*94%*)	516 (*94%*)	731,613 (*93%*)
Scenario 4: S3 **+** Urban area exclusion	14,376 (*94%*)	516 (*94%*)	731,417 (*93%*)

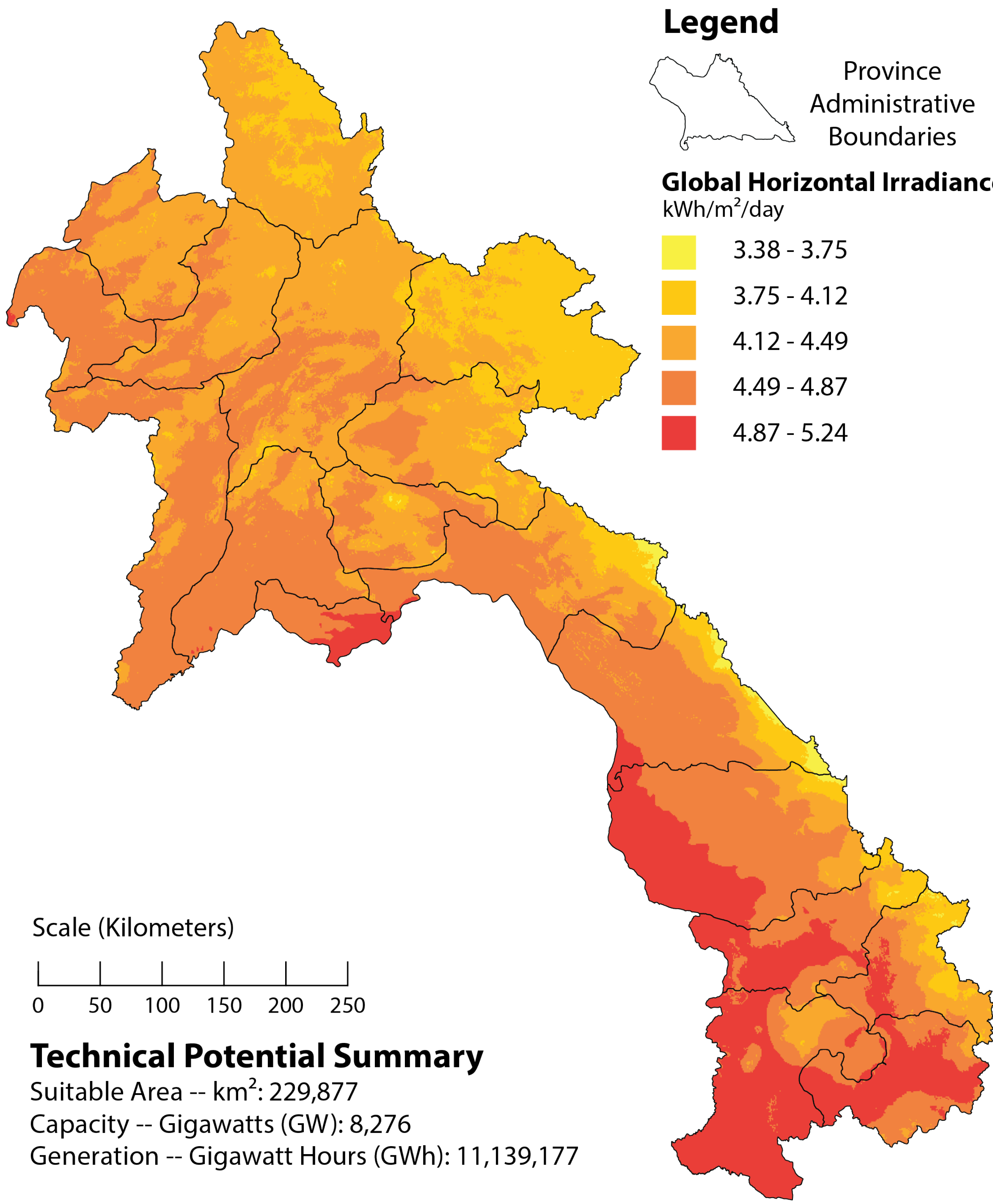

FIGURE 7. MAP – SOLAR PV TECHNICAL POTENTIAL: BASE-LAO PDR WITH NO EXCLUSIONS

TABLE 5. SOLAR PV TECHNICAL POTENTIAL: BASE-LAO PDR WITH NO EXCLUSIONS

Solar PV Base-Lao PDR	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**229,878**	**8,277**	**11,139,178**	**15.37**
Province[15]				
Attapeu	9,508	342	491,859	16.40
Bokeo	6,859	247	341,577	15.79
Borikhamxay	15,819	569	761,233	15.26
Champachack	14,909	537	773,813	16.46
Huaphanh	17,299	623	754,410	13.83
Khammuane	16,545	596	795,928	15.25
Luangnamtha	9,793	353	475,810	15.41
Luangprabang	19,964	719	952,308	15.13
Oudomxay	11,771	424	568,151	15.30
Phongsaly	15,351	553	696,929	14.40
Saravane	10,173	366	511,074	15.93
Savannakhet	21,421	771	1,073,033	15.88
Sekong	8,355	301	395,162	15.00
Vientiane Prefecture	3,621	130	187,633	16.43
Vientiane	12,521	451	623,046	15.78
Xayabury	15,607	562	772,844	15.70
Xaysomboune	7,734	278	372,944	15.29
Xiengkhuang	12,628	455	591,424	14.85

[15] The province administrative boundaries of Lao PDR are shown in Appendix A. The spelling of all provinces of Lao PDR in this work follow the convention used in MEM (2015b).

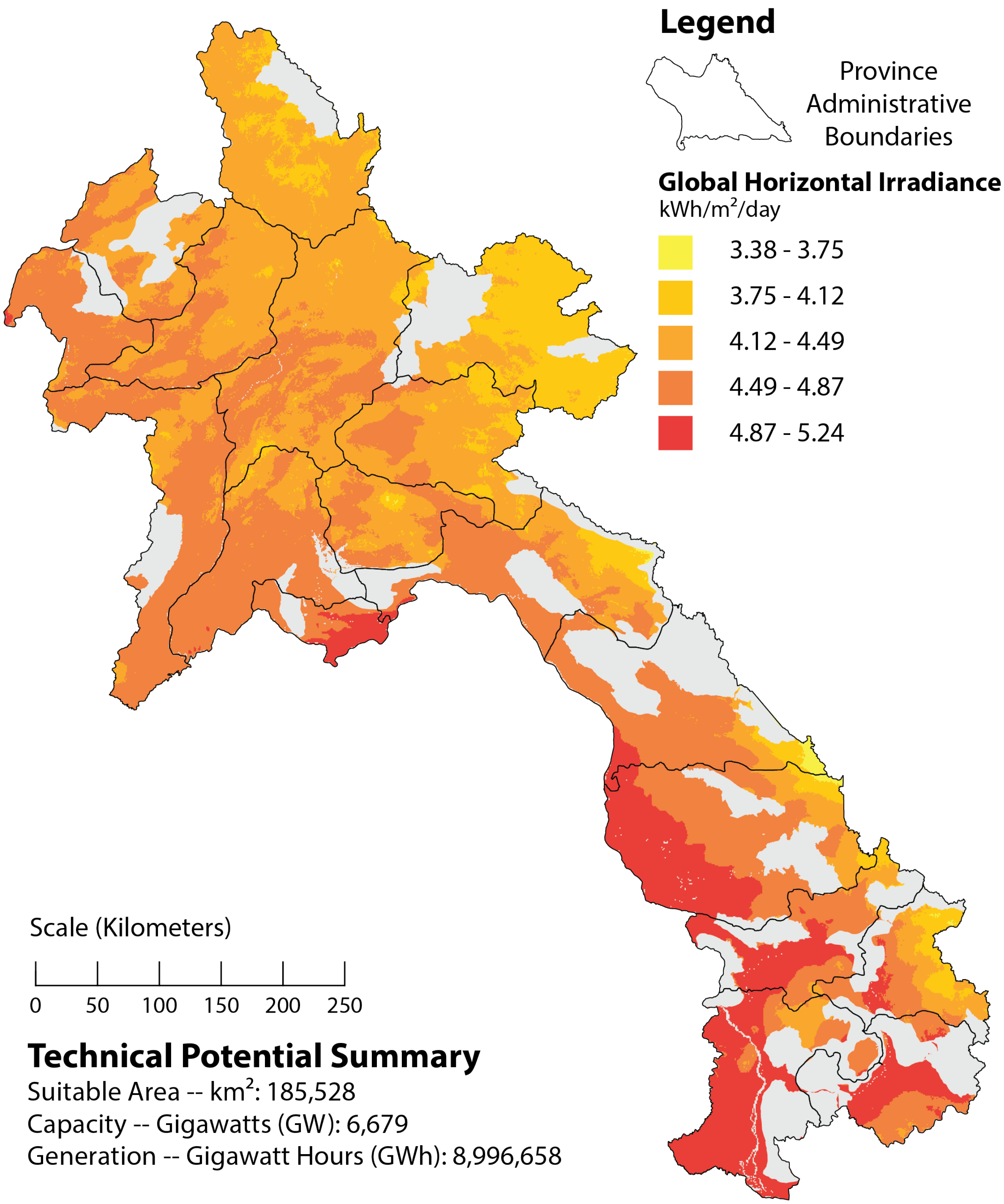

FIGURE 8. MAP – SOLAR PV TECHNICAL POTENTIAL: SCENARIO 1 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, AND WETLAND AREAS

TABLE 6. SOLAR TECHNICAL POTENTIAL: SCENARIO 1 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, AND WETLAND AREAS

Solar PV Scenario 1	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**185,519**	**6,678**	**8,996,660**	**15.38**
Province				
Attapeu	4,907	177	254,150	16.42
Bokeo	5,936	214	295,844	15.80
Borikhamxay	11,365	409	550,382	15.36
Champachack	9,919	357	516,625	16.52
Huaphanh	13,036	469	565,788	13.76
Khammuane	9,621	346	471,891	15.55
Luangnamtha	7,087	255	345,828	15.47
Luangprabang	19,513	702	930,745	15.13
Oudomxay	11,748	423	567,034	15.30
Phongsaly	13,502	486	615,130	14.45
Saravane	7,039	253	357,662	16.11
Savannakhet	17,828	642	896,638	15.95
Sekong	6,231	224	293,041	14.91
Vientiane Prefecture	2,917	105	151,720	16.50
Vientiane	11,502	414	572,802	15.79
Xayabury	13,738	495	681,595	15.73
Xaysomboune	7,477	269	360,562	15.29
Xiengkhuang	12,153	438	569,223	14.85

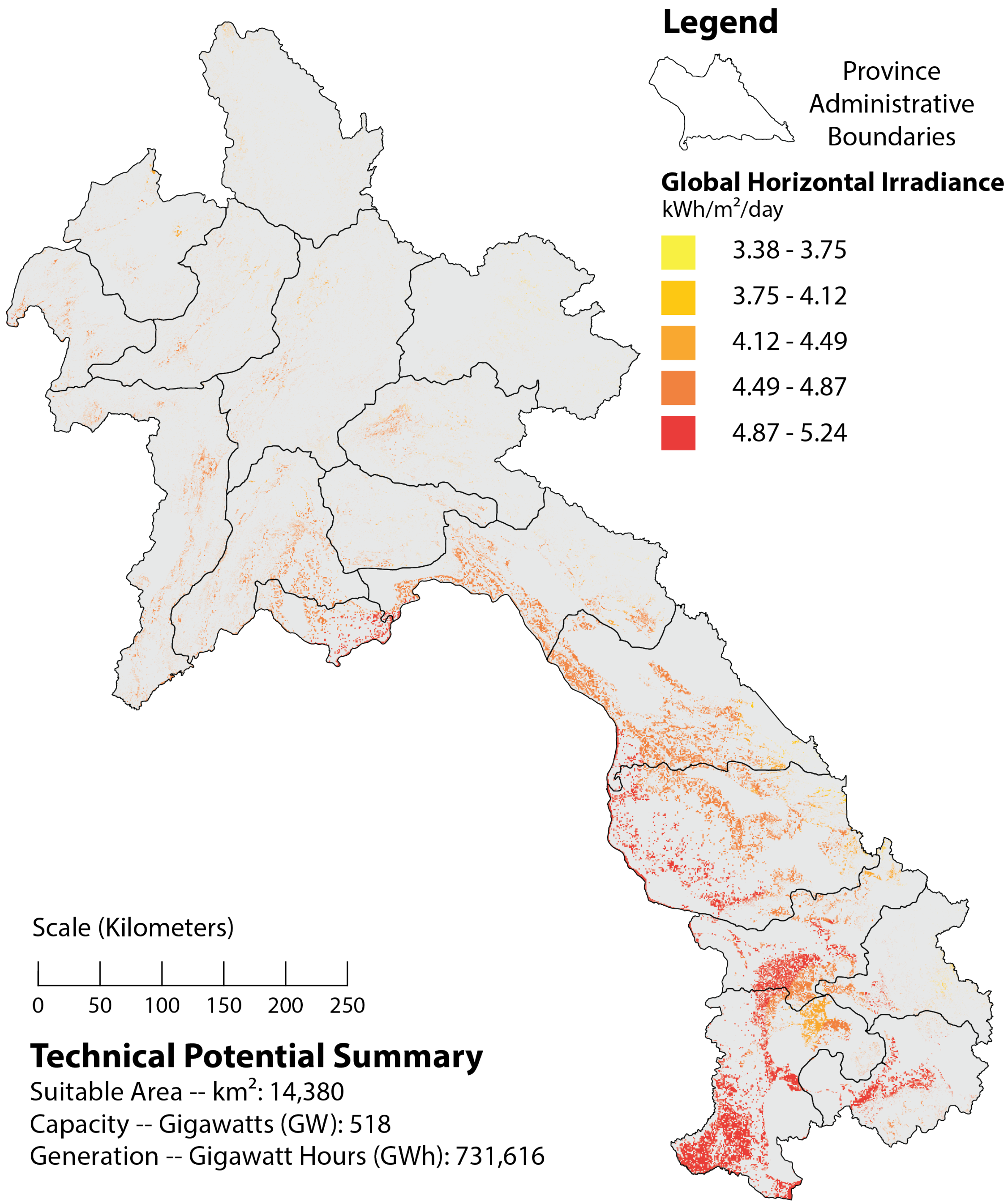

FIGURE 9. MAP – SOLAR PV TECHNICAL POTENTIAL: SCENARIO 3 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AREAS WITH SLOPE > 5%, AGRICULTURAL AREAS, AND FORESTED AREAS

TABLE 7. SOLAR PV TECHNICAL POTENTIAL: SCENARIO 3 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AREAS WITH SLOPE > 5%, AGRICULTURAL AREAS, AND FORESTED AREAS

Solar PV Scenario 3	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**14,380**	**516**	**731,613**	**16.13**
Province				
Attapeu	615	22	32,638	16.83
Bokeo	179	6	9,020	16.01
Borikhamxay	1,064	38	53,833	16.05
Champachack	3,214	116	167,947	16.57
Huaphanh	130	5	5,694	13.87
Khammuane	1,988	72	99,926	15.94
Luangnamtha	117	4	5,672	15.44
Luangprabang	284	10	13,666	15.24
Oudomxay	199	7	9,659	15.42
Phongsaly	147	5	6,726	14.56
Saravane	1,501	54	77,228	16.32
Savannakhet	2,617	94	132,492	16.05
Sekong	282	10	13,852	15.55
Vientiane Prefecture	470	17	24,505	16.53
Vientiane	660	24	33,392	16.05
Xayabury	511	18	25,796	16.00
Xaysomboune	141	5	6,927	15.57
Xiengkhuang	261	9	12,640	15.35

3.2 Utility-scale wind power (rural)

The technical potential for utility-scale wind in Lao PDR with no exclusions to development is 842,835 GWh/year as depicted in the Base-Lao PDR results in TABLE 8. An assessment of the technical potential for wind resources within agricultural and also within areas potentially contaminated by UXO are 92,416 GWh/year and 298,605 GWh/year for the Base-Agriculture and Base-UXO assessments, respectively. These base assessments give an estimate of the generation potential from wind that may be excluded if development exclusions for these areas were applied (for example, limited or no development on areas contaminated by UXO). The total technical potential for utility-scale wind ranges from 682,161 to 135,129 GWh/year for the least restrictive and most restrictive development exclusions, respectively.

The technical potential for the Base-Lao-PDR, Scenario 1, and Scenario 3 assessments are shown in FIGURE 10, FIGURE 11, and FIGURE 12, respectively. The country- and province-level technical potentials for the Base-Lao-PDR, Scenario 1, and Scenario 3 assessments are also detailed in TABLE 9, TABLE 10, and

TABLE 11, respectively. Results for additional wind assessments are in Appendix B. The average capacity factors are also presented for each assessment at the national level and the average for each province.

The Base-Lao PDR assessment found a total, wind technical-potential capacity of 691 GW in Lao PDR with no exclusions. Provinces including Savannakhet and Khammuane in the south as well as Huaphanh in the northeast are seen in TABLE 5 to have the most attractive wind energy resources. The Base-Agriculture assessment found that a limited amount of the total technical-potential capacity (66 GW) is located in agricultural areas, signifying a small overlap of resources on these land areas. The Base-UXO assessment shows an overlap between wind energy resources and areas potentially contaminated with UXO. As discussed, with solar resource development MEM may have to address the associated costs with developing in areas with UXO.

Wind Scenario 1 excludes development on protected areas, waterbodies, and wetland areas and does not represent a significant decrease in technical potential or suitable land area from the Base-Lao PDR assessment. These exclusions reduced the total suitable area for development, technical potential capacity, and technical potential generation by approximately 19% from the Base-Lao PDR. As seen in FIGURE 11, the suitable land areas and technical potentials in the southern province of Savannakhet, which was attractive in the Base-Lao PDR assessment, is not significantly impacted by this exclusion dropping from 113,198 GW to 94,986 GW; however, the technical potential of the northern province of Huaphanh has a more significant reduction from 77,928 GW to 58,135 GW.

The addition of the exclusion of areas with a slope greater than 20% in Scenario 2 results in an approximate 59% reduction of suitable land area and technical potential. This exclusion, similar to the exclusion for solar development, emphasizes the mountainous terrain that planners and wind developers must consider in Lao PDR. Development in areas with potentially larger slopes would likely incur higher development costs for access and preparation of terrain with high slopes or be technically unfeasible.

With the addition of an exclusion for forested areas, Scenario 3 significantly reduces the total suitable area for wind development and the technical potential by 74% from the Base-Lao PDR assessment. Scenario 3 highlights Savannakhet as an interesting province for development as it maintains a technical potential for generation of 63,309 GWh, representing approximately 28% of the total generation potential of Scenario 3 (223,268 GWh as shown in TABLE 11).

Scenario 4, which adds an agricultural area exclusion, making it the most exclusive scenario, results in a further decrease of suitable area for development, technical-potential capacity, and potential generation with a reduction to 38,486 km^2, 116 GW, and 135,129 GWh/year, respectively. This is an approximate 83% reduction of area and technical potential from the Base-Lao PDR assessment. In this scenario, the technical potential for generation of Savannakhet province drops to 20,716 GWh/year or approximately 15% of the total generation potential for the scenario (135,130 GWh/year in TABLE B-8). Attractive wind resources are dispersed throughout Lao PDR, and some of the most robust provinces for wind resources considering the exclusions in the most-exclusive Scenario 4 and the resulting technical-potential generation (see TABLE B-8), include the southern provinces of Savannakhet (20,716 GWh/year), Khammuane (12,761GWh/year), and Champachack (12,126 GWh/year) as well as the northern provinces of Luangprabang (11,700 GWh/year) and Xiengkhuang (8,633 GWh/year).

TABLE 8. SUMMARY OF WIND TECHNICAL POTENTIAL FOR LAO PDR

Wind	Potential Suitable Area (km²) (*% change from the Base-Lao PDR*)	Technical Potential	
		Capacity (GW) (*% change from the Base-Lao PDR*)	Generation (GWh/year) (*% change from the Base-Lao PDR*)
Base-Lao PDR (*No exclusions*)	229,878	691	842,835
Base-Agriculture (*development constrained to agricultural areas*)	22,337	66	92,416
Base-UXO (*development constrained to areas with UXO*)	70,878	213	298,605
Scenario 1 (S1): Relaxed exclusions (*excludes protected areas, waterbodies, and wetland areas*)	185,519 (*19%*)	557 (*19%*)	682,161 (*19%*)
Scenario 2: S1 **+** Slope exclusion (*excludes areas with slope greater than 20%*)	94,428 (*59%*)	283 (*59%*)	343,463 (*59%*)
Scenario 3: S2 **+** forest area exclusion	59,531 (*74%*)	180 (*74%*)	223,268 (*74%*)
Scenario 4: S3 **+** agriculture area exclusion	38,486 (*83%*)	116 (*83%*)	135,129 (*84%*)

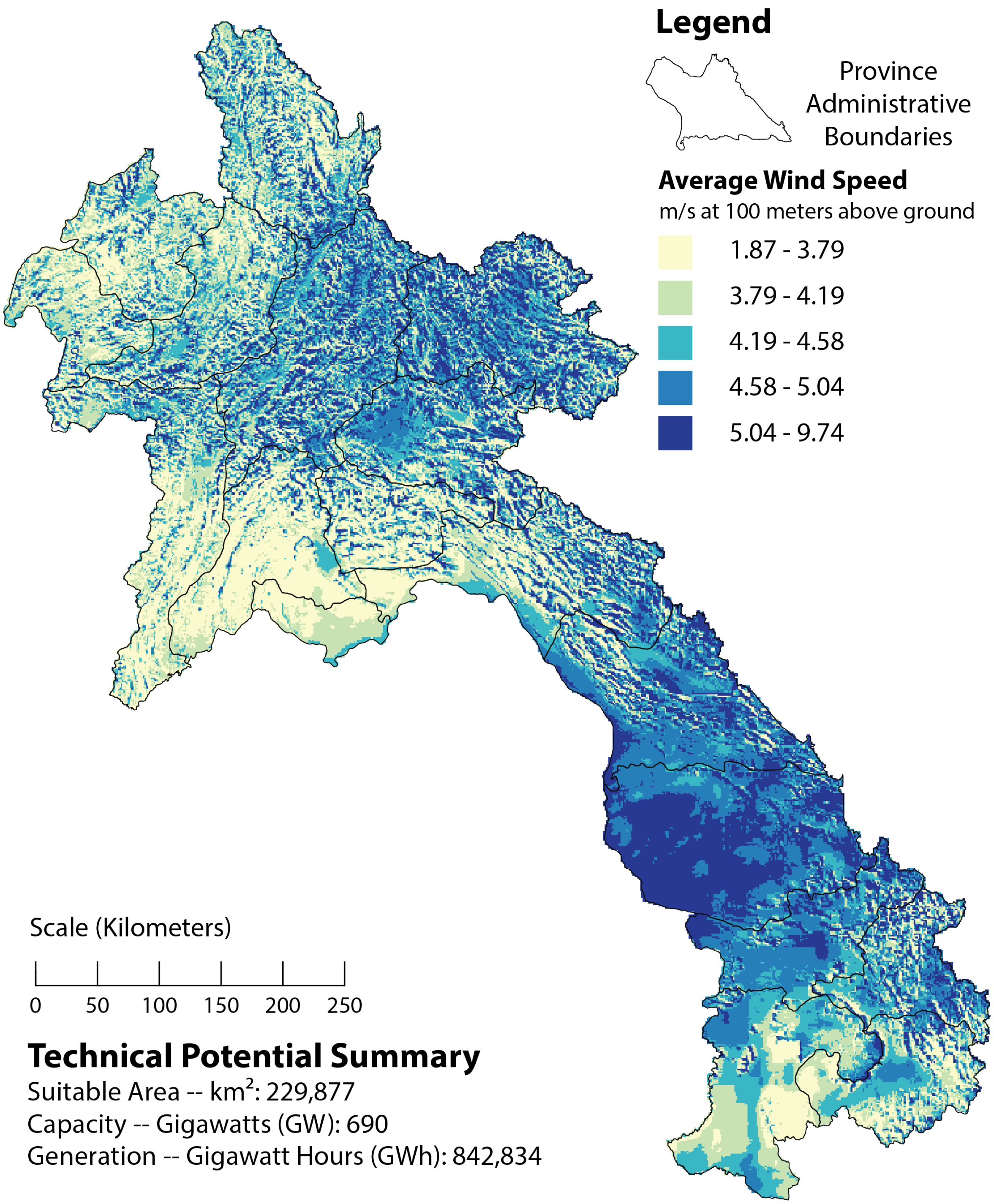

FIGURE 10. MAP – WIND TECHNICAL POTENTIAL: BASE-LAO PDR WITH NO EXCLUSIONS

TABLE 9. WIND TECHNICAL POTENTIAL: BASE-LAO PDR WITH NO EXCLUSIONS

Wind Base-Lao PDR	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**229,878**	**691**	**842,835**	**14.80**
Province				
Attapeu	9,508	29	29,316	11.73
Bokeo	6,859	21	18,206	10.10
Borikhamxay	15,819	47	54,603	13.13
Champachack	14,909	45	45,858	11.70
Huaphanh	17,299	52	77,928	17.14
Khammuane	16,545	50	75,802	17.43
Luangnamtha	9,793	29	27,197	10.57
Luangprabang	19,964	60	83,146	15.85
Oudomxay	11,771	35	37,882	12.25
Phongsaly	15,351	46	50,211	12.45
Saravane	10,173	31	46,591	17.43
Savannakhet	21,421	64	113,198	20.11
Sekong	8,355	25	34,392	15.66
Vientiane Prefecture	3,621	11	7,872	8.27
Vientiane	12,521	38	27,373	8.32
Xayabury	15,607	47	41,630	10.15
Xaysomboune	7,734	23	21,027	10.35
Xiengkhuang	12,628	38	50,603	15.25

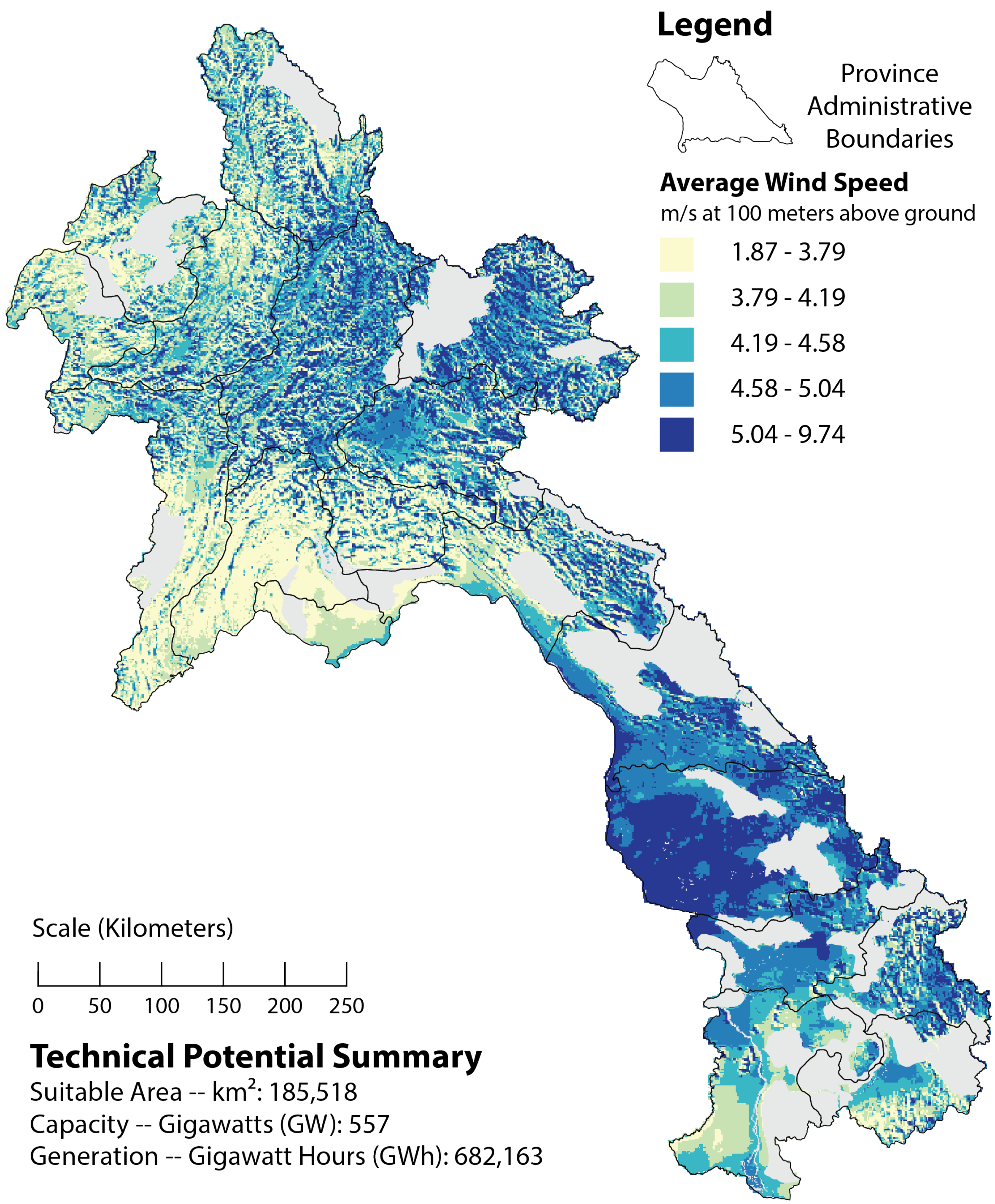

FIGURE 11. MAP – WIND TECHNICAL POTENTIAL: SCENARIO 1 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, AND WETLAND AREAS

TABLE 10. WIND TECHNICAL POTENTIAL: SCENARIO 1 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, AND WETLAND AREAS

Wind Scenario 1	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**185,519**	**557**	**682,161**	**14.95**
Province				
Attapeu	4,907	15	15,740	12.21
Bokeo	5,936	18	16,224	10.40
Borikhamxay	11,365	34	39,547	13.24
Champachack	9,919	30	32,755	12.57
Huaphanh	13,036	39	58,135	16.97
Khammuane	9,621	29	44,925	17.77
Luangnamtha	7,087	21	20,157	10.82
Luangprabang	19,513	59	81,060	15.81
Oudomxay	11,748	35	37,825	12.25
Phongsaly	13,502	41	44,856	12.64
Saravane	7,039	21	32,226	17.42
Savannakhet	17,828	53	94,986	20.27
Sekong	6,231	19	25,887	15.81
Vientiane Prefecture	2,917	9	6,423	8.38
Vientiane	11,502	35	24,972	8.26
Xayabury	13,738	41	37,372	10.35
Xaysomboune	7,477	22	20,450	10.41
Xiengkhuang	12,153	36	48,621	15.22

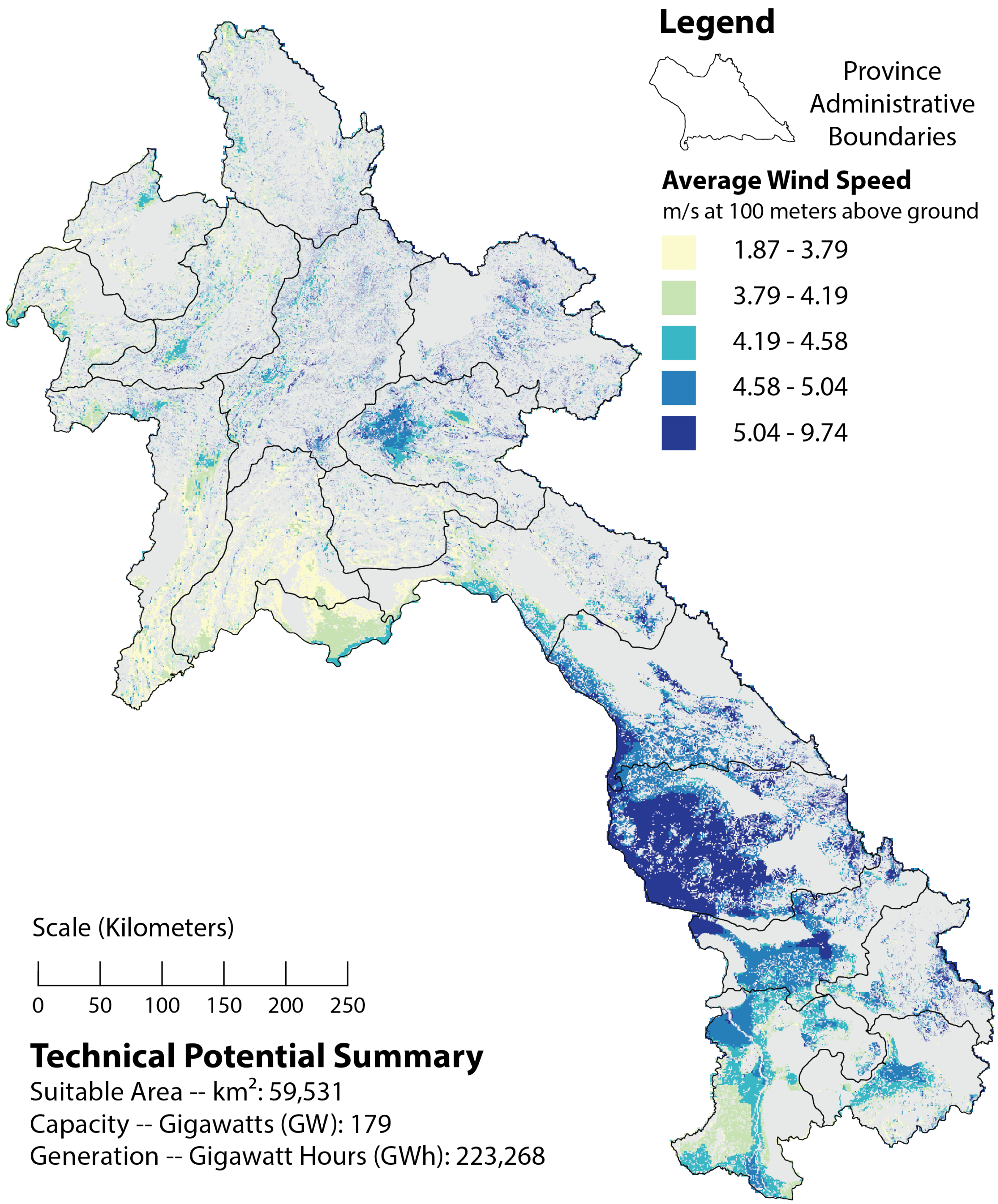

FIGURE 12. MAP – WIND TECHNICAL POTENTIAL: SCENARIO 3 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AREAS WITH SLOPE > 20%, AND FORESTED AREAS

TABLE 11. WIND TECHNICAL POTENTIAL: SCENARIO 3 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AREAS WITH SLOPE > 20%, AND FORESTED AREAS

Wind Scenario 3	Potential Suitable Area (km²)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**59,531**	**180**	**223,268**	**16.13**
Province				
Attapeu	1,910	6	6,579	16.83
Bokeo	1,518	5	3,891	16.01
Borikhamxay	3,067	9	9,548	16.05
Champachack	6,652	20	22,701	16.57
Huaphanh	1,760	5	7,665	13.87
Khammuane	4,155	12	19,223	15.94
Luangnamtha	1,275	4	3,400	15.44
Luangprabang	3,136	9	12,248	15.24
Oudomxay	2,194	7	6,669	15.42
Phongsaly	1,988	6	6,131	14.56
Saravane	4,184	13	19,131	16.32
Savannakhet	11,570	35	63,309	16.05
Sekong	1,271	4	5,258	15.57
Vientiane Prefecture	2,272	7	5,198	16.53
Vientiane	4,029	12	7,705	15.55
Xayabury	4,389	13	10,499	16.05
Xaysomboune	1,270	4	2,812	16.00
Xiengkhuang	2,891	9	11,301	15.35

3.3 Biomass power technology

The technical potential for utility- and nonutility-scale biomass and biogas power generation in Lao PDR is estimated at about 1,525 GWh/year as shown in TABLE 12.

Biomass resources are only assessed at the national level due to data availability, as detailed in Section 2.4. The total technical potential for utility-scale generation from logging, primary mill, and secondary mill residues is estimated at 720 GWh/year. The technical potential for select crop residues (rice husk and sugar cane bagasse) is estimated at about 801.63 GWh/year (nonutility-scale as discussed in Section 2.4.3).

Biogas generation can be considered for minigrid or distributed systems in Lao PDR. The technical potential for biogas (nonutility-scale) power generation is estimated at about 2.53 GWh/year. This nonutility-scale potential is shown in FIGURE 13 at the province level and detailed in TABLE 13. At the province level the northern provinces of Huaphanh, Luangnamtha, and Xayabury as well as the southern provinces of Savannakhet, Saravane, and Champachack have the most attractive annual potential biogas productions and technical potential for nonutility-scale electricity generation.

TABLE 12. SUMMARY OF BIOMASS AND BIOGAS TECHNICAL POTENTIAL FOR LAO PDR

Biomass and Biogas Base-Lao PDR	Technical Potential
	Generation (GWh/year)
Lao PDR (Total)	1,525
Resources – Multiple Scales	
Logging residue – Utility-scale	376
Primary mill residue – Utility-scale	254
Secondary mill residue – Nonutility-scale	90
Biogas – Nonutility-scale	3
Rice husk – Nonutility-scale	371
Sugar cane bagasse – Nonutility-scale	431

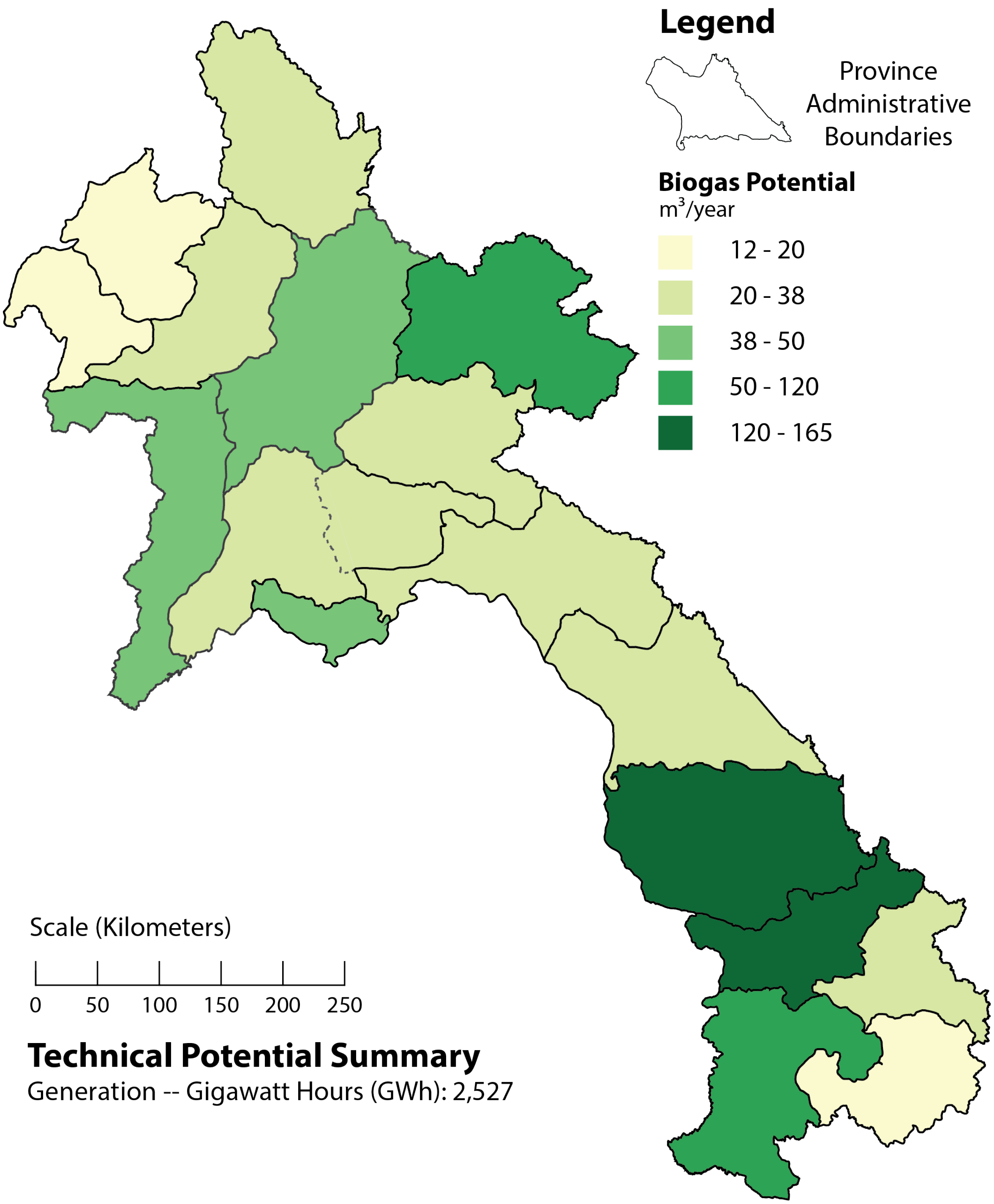

FIGURE 13. MAP – BIOGAS NONUTILITY-SCALE TECHNICAL POTENTIAL FOR LAO PDR

(XAISOMBOUN PROVINCE IS REPRESENTED AS PART OF VIENTIANE PROVINCE AND SEPARATED WITH A DASHED LINE AS XAISOMBOUN IS NOT REPRESENTED IN THE DATA SOURCE. PRIOR TO CREATION IN A 2013 RESTRUCTURING OF ADMINISTRATIVE BORDERS, THE LAND AREA OF XAISOMBOUN WAS MOSTLY WITHIN VIENTIANE PROVINCE.)

TABLE 13. BIOGAS TECHNICAL POTENTIAL FOR LAO PDR

Biogas – Nonutility-scale Base-Lao PDR	Technical Potential Generation (MWh/year)
Lao PDR (Total)	**2,527**
Province	
Attapeu	41
Bokeo	57
Borikhamxay	72
Champachack	222
Huaphanh	153
Khammuane	91
Luangnamtha	58
Luangprabang	148
Oudomxay	107
Phongsaly	105
Saravane	511
Savannakhet	387
Sekong	84
Vientiane Prefecture	134
Vientiane and Xaysomboune[1]	104
Xayabury	138
Xiengkhuang	116

1. Xaisomboun Province is represented as part of Vientiane Province as Xaisomboun is not represented in the data source. Prior to creation in a 2013 restructuring of administrative borders, the land area of Xaisomboun was mostly within Vientiane Province.

3.4 Coal power technology

The total feasible area for siting coal power plants at the country level, shown in TABLE 14, ranges from 45,957 to 1,685 km^2 for the least restrictive and most restrictive development exclusions, respectively. The addition of the priority areas (proximity to coal deposits and waterbodies) significantly reduces the area that may be feasible for siting coal power technologies. This is also seen at the province level where certain provinces do not have land area that is considered feasible given these development restrictions. The Vientiane Capital and Prefecture provinces are seen to have the largest total feasible land area in Scenario 2. The land area considered feasible for siting coal power generation in Lao PDR for Scenario 1 and Scenario 2 is shown in FIGURE 14 and FIGURE 15, respectively.

The coal power site-feasibility Base-Lao PDR assessment removes all exclusions for coal development and assumes no restrictions to coal development in the country. As this is an unlikely scenario anywhere in the world with regards to coal development, two scenarios are considered.

Scenario 1 excludes areas with slope greater than 12%, areas less than 5 km from an airport, contiguous areas less than 1.2 km^2, protected areas, agricultural areas, waterbodies, wetland areas, urban areas, densely populated areas, and areas greater than 5 km from a road, as detailed in Section 2.4.4. With these exclusions the suitable land area for siting coal power is significantly reduced (80%) from the total area in the Base-Lao PDR assessment. The suitable area is concentrated in the southern provinces of Savannakhet, Champachack, Khammuane, Saravane, Borikhamxay, and Attapeu; however, other provinces including Vientiane and Vientiane Prefecture (the latter containing the capital and most urban area), also have suitable land area for development.

Scenario 2 adds to the exclusions of Scenario 1 by prioritizing development in areas less than 32 km from coal deposits and areas less than 32 km from water sources. These additional priorities significantly reduce the total suitable land area to just 1,685 km^2. This is a 99% reduction from the Base-Lao PDR assessment. With these restrictions, provinces including Champachack, Khammuane, Borikhamxay, and Attapeu that had suitable area in Scenario 1 no longer have suitable land area for coal development. The province of Vientiane remains of interest with the exclusions and priorities of Scenario 2 with 1,084 km^2 of suitable area. Additionally, Vientiane prefecture also remains of interest in this scenario due to the 284 km^2 of suitable land that is close to the country's capital and most urban area, Vientiane.

TABLE 14. SUMMARY OF COAL POWER SITE FEASIBILITY FOR LAO PDR

Coal power site feasibility	Potential Suitable Area (km^2)		
	Base-Lao PDR	Scenario 1 – All exclusions[1] (*% change from the Base-Lao PDR*)	Scenario 2 – Addition of priority areas[2] (*% change from the Base-Lao PDR*)
Lao PDR (Total)	**229,878**	**45,957** (*80%*)	**1,685** (*99%*)
Province			
Attapeu	Not applicable[3]	3,779	-
Bokeo		523	2
Borikhamxay		3,740	-
Champachack		8,469	-
Huaphanh		290	-
Khammuane		6,200	-
Luangnamtha		346	52
Luangprabang		539	-
Oudomxay		682	62
Phongsaly		293	1
Saravane		4,461	74
Savannakhet		8,981	63
Sekong		1,339	-
Vientiane Prefecture		1,266	284
Vientiane		2,473	1,084
Xayabury		1,758	38
Xaysomboune		462	16
Xiengkhuang		356	9

1. Excludes areas with slope > 12%, areas < 5 km from an airport, contiguous areas < 1.2 km^2, protected areas, agricultural areas, waterbodies, wetland areas, urban areas, densely populated areas, and areas > 5 km from a road – see Section 2.4

2. Excludes areas with slope > 12%, areas < 5 km from an airport, contiguous areas < 1.2 km^2, protected areas, agricultural areas, waterbodies, wetland areas, urban areas, densely populated areas, areas > 5 km from a road, areas > 32 km from coal deposits, and areas > 32 km from water sources – see Section 2.4

3. Results for the Base- Lao PDR are the entire land area of Lao PDR and are considered not applicable here. The total land area of Lao PDR is 229,878 km^2. This area was used to estimate the percentage change from the Base-Lao PDR suitable land area.

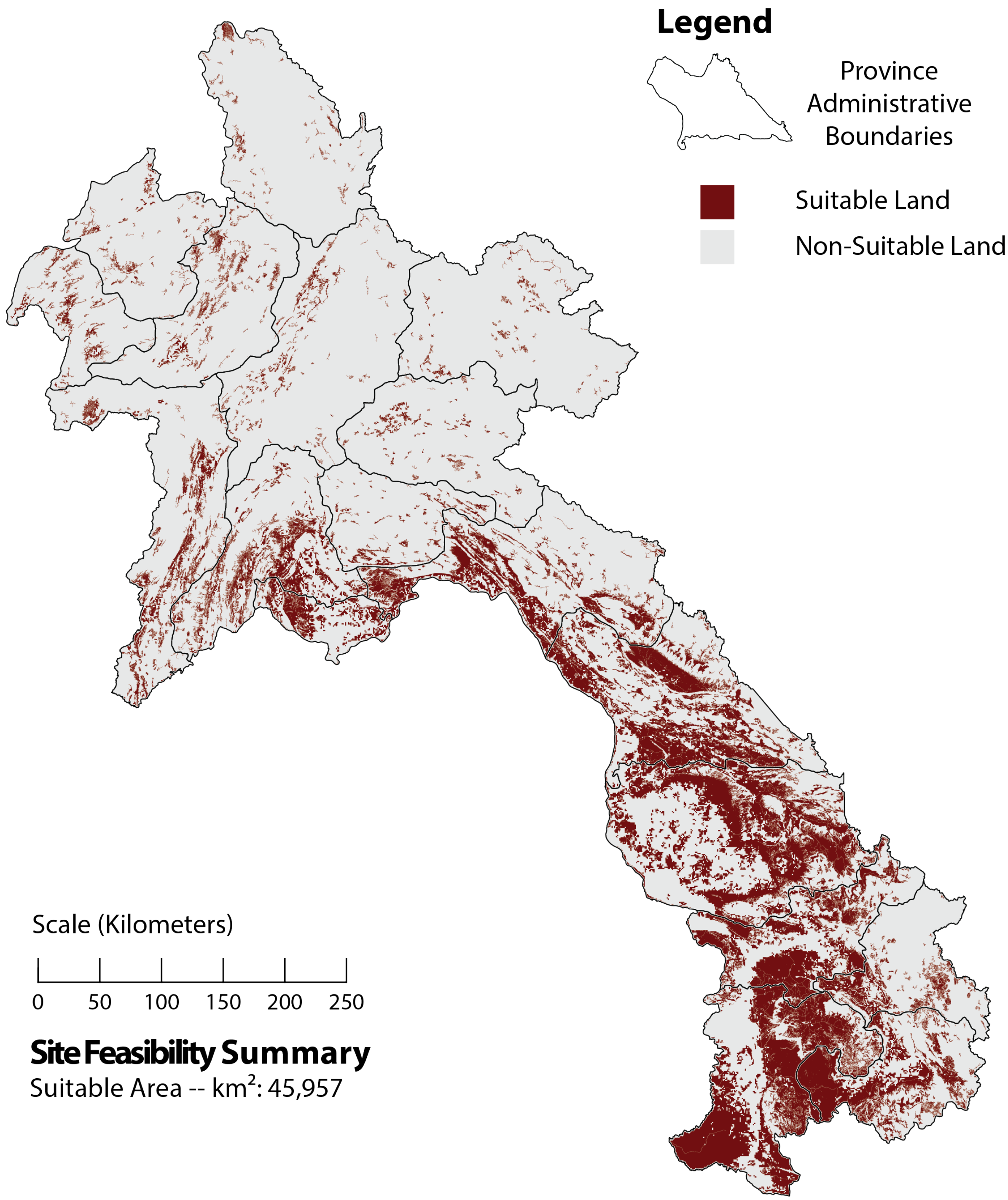

FIGURE 14. MAP – COAL POWER SITE FEASIBILITY FOR LAO PDR: SCENARIO 1 WITH EXCLUSIONS FOR AREAS WITH SLOPE > 12%, AREAS < 5 KM FROM AN AIRPORT, CONTIGUOUS AREAS < 1.2 KM^2, PROTECTED AREAS, AGRICULTURAL AREAS, WATERBODIES, WETLAND AREAS, URBAN AREAS, DENSELY POPULATED AREAS, AND AREAS > 5 KM FROM A ROAD

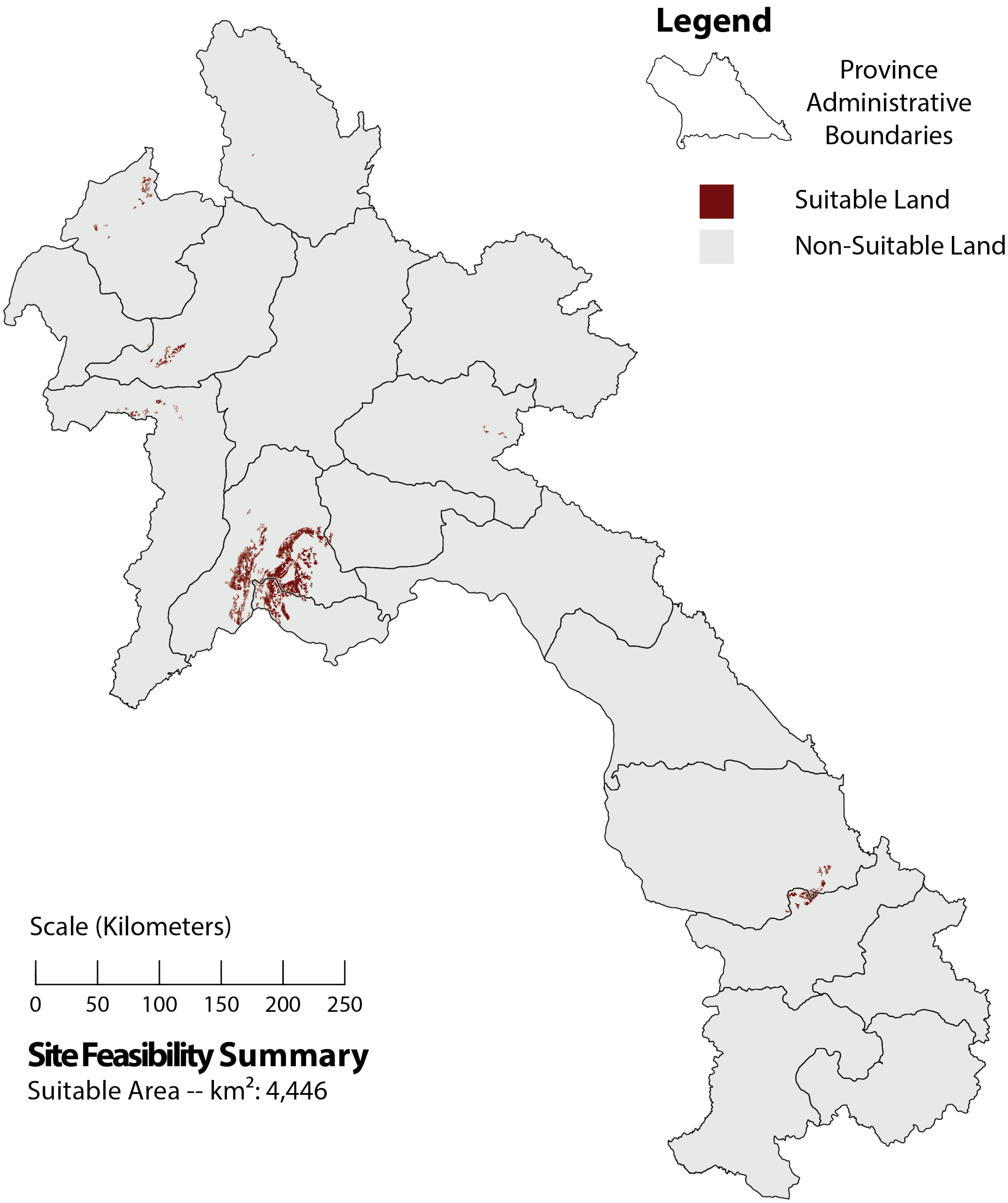

FIGURE 15. MAP – COAL POWER SITE FEASIBILITY FOR LAO PDR: SCENARIO 2 WITH EXCLUSIONS FOR AREAS WITH SLOPE > 12%, AREAS < 5 KM FROM AN AIRPORT, CONTIGUOUS AREAS < 1.2 KM^2, PROTECTED AREAS, AGRICULTURAL AREAS, WATERBODIES, WETLAND AREAS, URBAN AREAS, DENSELY POPULATED AREAS, AREAS > 5 KM FROM A ROAD, AREAS > 32 KM FROM COAL DEPOSITS, AND AREAS > 32 KM FROM WATER SOURCES

4 Discussion

With a growing economy and a population with increasing electricity access, electricity demands in the Greater Mekong Subregion (Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam) are forecast to grow significantly through 2030 (ACE 2017; EIA 2017; IES and MKE 2016; MEM 2015a). To meet increased demands, decision makers in the region will have to explore options for domestic, imported, and exported energy resources for electricity generation. For Lao PDR these options will have to help to ensure energy security, sustain socio-economic development, and enhance environmental and social sustainability (IREP 2016).

This section discusses how the domestic technical potential identified in this work could support future electricity strategies for Lao PDR. The domestic technical potential results are discussed in relation to recent trends in domestic electricity demand, domestic supply, and electricity imports and exports.

4.1 Domestic electricity demand and supply

Electricity demand

Demand for electricity in Lao PDR has grown over the last decade from under 1,000 GWh in the early 1990s to a total domestic electricity consumption of 4,239 GWh in 2015 (FIGURE 16) with a peak demand of 760 MW. Since 2006, annual electricity consumption growth rates have been consistently above 5%. The capital, Vientiane, and surrounding area represent approximately 37% of the total national consumption; however, demand in other regions of the country has increased together with electricity access rates—91% of households now have access to electricity (MEM 2015b).

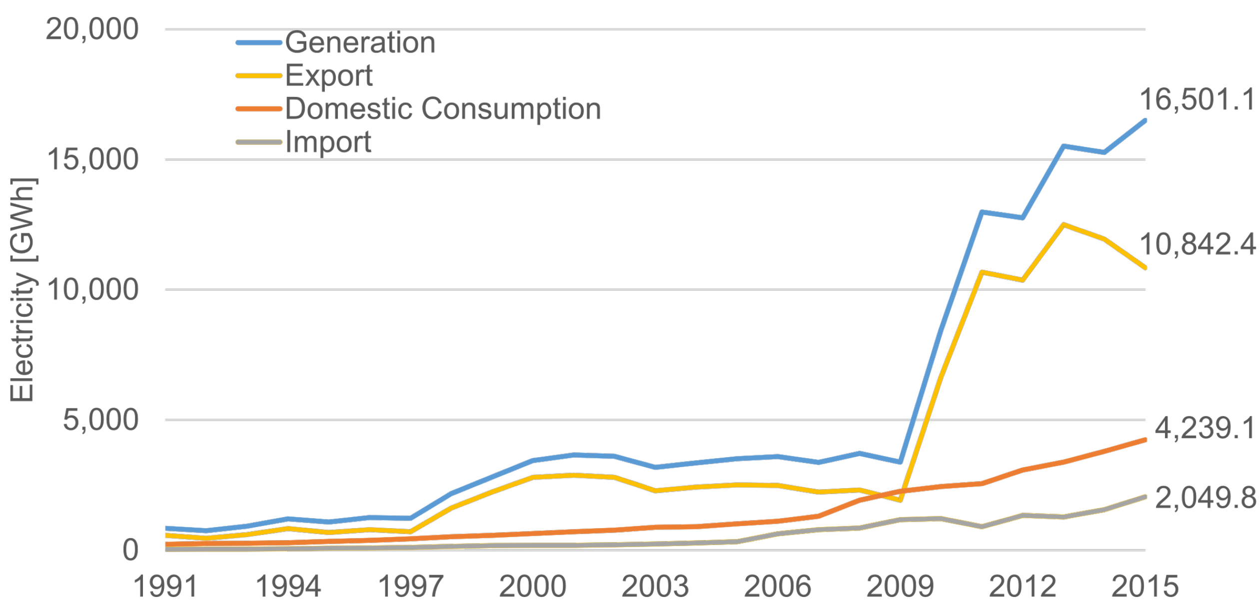

FIGURE 16. ELECTRICITY GENERATION, CONSUMPTION, EXPORT AND IMPORT IN LAO PDR FOR 1991 TO 2015

ADAPTED FROM MEM (2015B)

With increased economic development and growing access to electricity, rising electricity consumption patterns in Lao PDR are projected to continue. MEM projects domestic electricity consumption for 2030 to reach a level between 21,844 GWh and 33,024 GWh for low- and high-growth scenarios, respectively, which correspond to GDP growth forecasts.[16] These low- and high-growth scenarios correspond to peak demand levels between 4,312 MW/year and 6,358 MW/year, respectively (MEM 2015a). FIGURE 17 shows the low, medium, and high domestic electricity consumption projections to 2030.

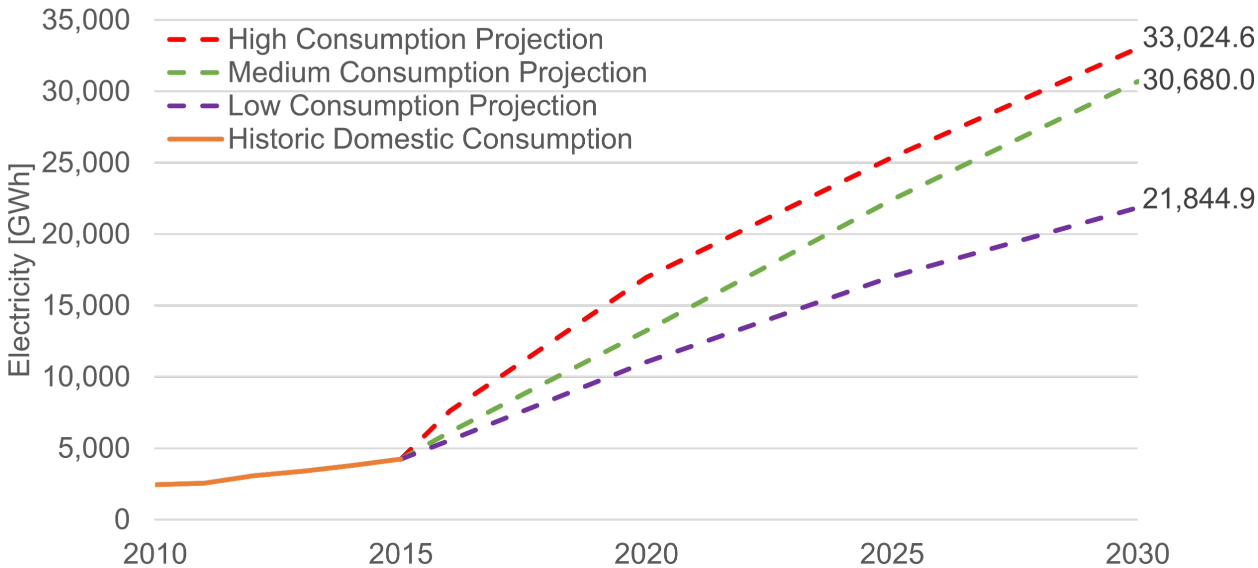

FIGURE 17. PROJECTED DOMESTIC ELECTRICITY CONSUMPTION FOR LAO PDR 2015–2030 (WITHOUT TRANSMISSION AND DISTRIBUTION LOSSES)

ADAPTED FROM MEM (2015A)

Electricity supply

Domestic electricity generation in Lao PDR has increased since 1991, from 834 GWh/year to over 16,500 GWh/year in 2015, as part of efforts to meet domestic demand and export electricity for regional demand. From FIGURE 16 it is evident that increased generation after 1997 aligns with rises seen in domestic electricity consumption as well as electricity exports.

Total installed electricity generation capacity in 2015 was 5,813 MW according to MEM (2015b). The majority of this capacity is hydro (3,894 MW) and coal-fired (1,878 MW) power, and a smaller share comprises biomass gasification with sugarcane (39.70 MW) and solar PV home systems (0.812 MW).[17] The state-owned generation company, EDL, owns approximately 10.72% of total generation assets (623.39 MW), and independent power producers (IPPs) own the remaining majority, or 89.28% of installed capacity (5,189.88 MW) (MEM 2015b).

As shown in FIGURE 16, not all domestic generation contributes to meeting domestic demand as a share of this generation was developed as dedicated projects to export electricity (IES and MKE 2016). Recent imbalances in domestic supply and demand (FIGURE 16) may be a result of export commitments for EDL and IPP generation that export significant shares of their generation to regional neighbors.

To meet forecasted domestic electricity demand growth discussed above, Lao PDR will have to increase installed capacity or potentially increase electricity imports from neighboring countries. MEM (2015a) has expressed a need to reach 19,124 MW of total domestic installed capacity by 2030 to meet both projected domestic demand and export requirements. This will require an additional 13,311 MW of installed capacity to be added to the current capacity during the period 2016–2030.[18] MEM anticipates that the total installed capacity in 2030 will be composed of predominantly hydro (run-of-river and large

[16] The low, medium and high scenarios are based upon different GDP growth rates of 6.5%, 7%, and 7.5%, respectively, and additional assumptions about demand growth for different regions in the country (MEM 2015a).
[17] Solar PV home systems are standalone or minigrid systems and do not have access to the grid.
[18] This is the difference between 19,124 MW in 2030 and 5,813 MW in 2015.

hydro) and thermal (coal) generation. Approximately 90% of the installed capacity in 2030 will be provided by IPPs and the remainder by EDL (MEM 2015a).

The share of the total domestic electricity supply provided by domestic IPPs or imported has consistently grown in recent years as seen in FIGURE 18. In 2015, electricity imports totaled 2,049.8 GWh or 41% of the total domestic supply, while electricity supplied by IPPs totaled 1,513.7 GWh or 31% of the domestic supply (MEM 2015b).

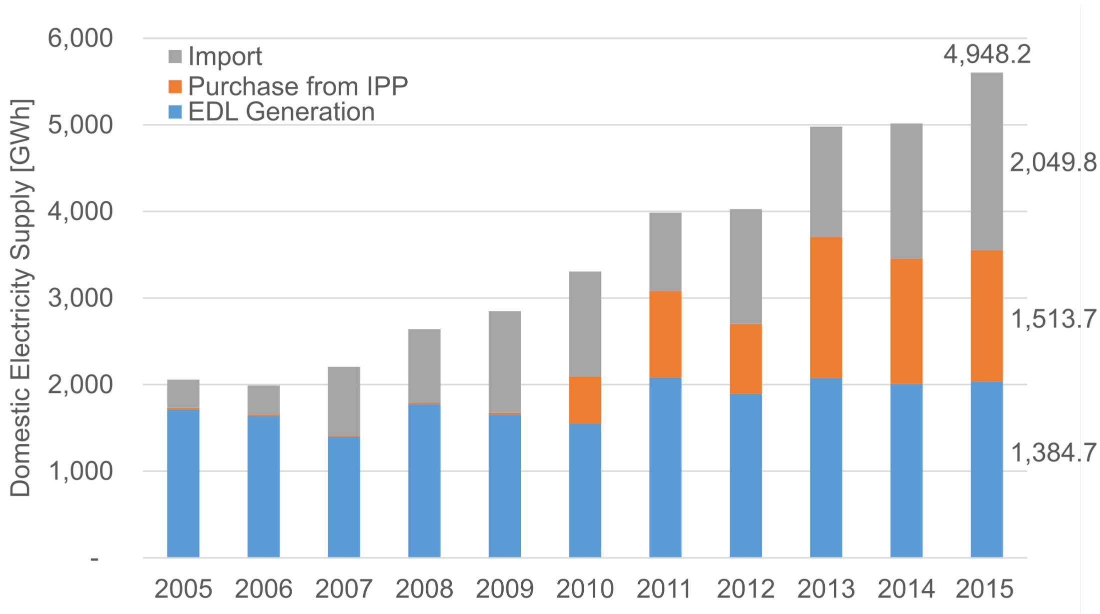

FIGURE 18. TOTAL DOMESTIC ELECTRICITY SUPPLY FOR LAO PDR FROM 2005–2015

ADAPTED FROM MEM (2015B)

Lao PDR has interconnections with neighboring Cambodia, China, Thailand, and Vietnam (EDL 2015), allowing for the import and export of electricity. Specific import agreements have been signed with China, Vietnam, and Thailand; however, Thailand, was the source of the dominant share of imported electricity through existing interconnections in 2015 with 1,748 GWh of imported electricity as depicted in FIGURE 19. A majority of electricity imports in Lao PDR, supply demand in the Lao capital and surrounding areas; however, imports also serve the southern provinces of Khammuane and Savannakhet (MEM 2015b).

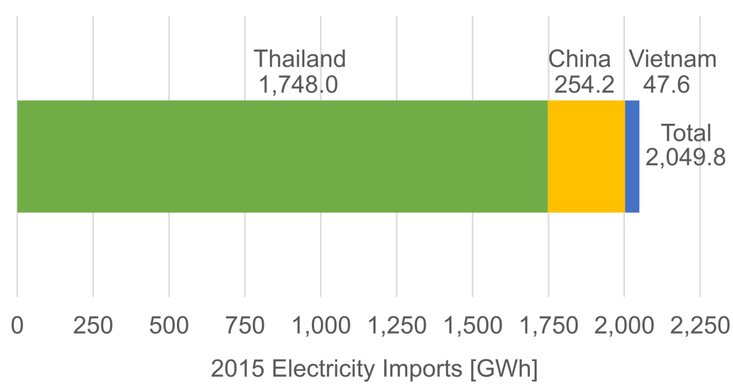

FIGURE 19. ELECTRICITY IMPORTS BY COUNTRY OF ORIGIN FOR LAO PDR IN 2015

ADAPTED FROM MEM (2015B)

Regional electricity demand and supply

The countries of the Greater Mekong Subregion have undergone significant economic growth in the past few decades that is forecast to continue through the year 2030 and beyond. Increased energy and electricity consumption across the region have followed this economic growth. TABLE 15 presents the 2014 installed capacity of countries that border Lao PDR, electricity consumption and peak demand, and projected 2030 electricity consumption levels. Regional neighbors such as Cambodia, Myanmar (Burma), and Vietnam expect to see electricity consumption increases by 2030 of two to roughly six times 2014 levels. China, specifically the southern region of China that borders Lao PDR, also expects significant increases in electricity demand over the same period.

Electricity generation requirements, which include transmission and distribution losses, in the Greater Mekong Subregion (including Lao PDR) are forecast to grow to 1,688,919 GWh/year by 2030 with installed capacity requirements reaching 351,993 MW (IEA 2015; IES and MKE 2016). The electricity consumption in China is forecast to grow to between 6,409,000 and 7,245,000 GWh/year by 2025, and the consumption in the southern grid region of China, which borders Lao PDR, is forecast to grow to a level between 1,076,000 and 1,217,000 GWh/year in the same period (Lin, Liu, and Kahrl 2016).

TABLE 15. ELECTRICITY DEMAND AND SUPPLY OF COUNTRIES THAT BORDER LAO PDR FOR 2014 AND 2030

	2014 Installed Capacity (MW)	2014 Peak Demand (MW)	2014 Electricity Consumption (GWh)	2030 Projected Electricity Consumption (GWh)
Cambodia	1,511	687	4,150	8,950
China	1,286,000	825,500	5,632,100	6,409,000 – 7,245,000
Southern Region Grid[1]	-	*136,100*	*949.8*	*1,076,000 – 1,217,000*
Myanmar (Burma)	4,583	2,235	9,570	56,715
Thailand	34,668	26,942	168,200	291,519
Vietnam	33,052	22,100	142,250	615,205

Sources: IES and MKE (2016), Lin et al. (2016), Maweni and Bisbey (2016), Ministry of Energy of Thailand (2015), NEMC (2015), and EDC (2014)

1. The southern region grid includes the Yunnan Province of China that borders Lao PDR and its regional neighbors.

The majority of Lao PDR's current electricity exports are destined for Thailand and provided through dedicated generation and interconnection projects (IES and MKE 2016). Electricity exports in 2015 reached 10,842.4 GWh, which was composed of 10,187 GWh from IPPs and a smaller contribution of 655.4 GWh from EDL. Thailand was the sole destination for exported electricity generation from IPPs. EDL exports are largely sent to Thailand (637.2 GWh) with a small share also going to Cambodia (18.2 GWh).

Countries in the region plan to meet a portion of growing electricity demands through imported electricity. Thailand, as an example, anticipates that imported hydropower electricity will meet 10%-15% and 15%-20% of electricity generation supply requirements in 2026 and 2036, respectively (Ministry of Energy of Thailand 2015). Lao PDR plans to provide a share of regional electricity demands though exports and has memoranda for power export to neighbors to reach a total of 29,000 MW by 2020. This power export consists of 2,000 MW destined for Cambodia (first stage), 12,000 MW to Yunnan Province of China (under discussion), 3,000 MW to Myanmar (Burma), 9,000 MW to Thailand, and 3,000 MW to Vietnam. Committed bilateral interconnection lines would include five 500-kV ties to Thailand's grid and two 500-kV lines connecting to Vietnam's grid (IREP 2016).

4.2 The role of domestic technical potential in energy demand and supply strategies

The technical potential for domestic energy resources for electricity generation assessed in this work may support Lao PDR in addressing a number of energy supply-and-demand strategy concerns as they plan for 2030 and beyond. Although not a direct comparison, TABLE 16 shows that the technical potential generation is significantly larger than the projected domestic electricity consumption for 2030 (21,844 to 33,024 GWh/year) (MEM 2015a). The maximum consumption projection for 2030 represents approximately 5% and 24% of the most restrictive technical potential generation assessments presented in this work for solar and wind respectively. A portion of this technical potential could contribute to meeting these domestic demands—following assessments of the economic and market potential in Lao PDR.

TABLE 16. PROJECTED TOTAL ELECTRICITY CONSUMPTION FOR 2030 AND TECHNICAL POTENTIAL GENERATION RESULTS FOR LAO PDR

Projected total annual domestic electricity consumption for 2030[1] (TWh/year)	Technical potential annual generation by technology[2] (TWh/year)
21.84 to 33.02	731 to 8,997 (*Solar PV*) 135 to 682 (*Wind*) 720 (*Biomass*)

1. Projected total domestic consumption for low and high growth scenarios from MEM (2015a)
2. The maximum values here correspond to the results of the least restrictive scenarios for utility-scale solar, wind, and biomass (i.e., logging, primary mill, and secondary mill residues) generation technologies. The minimum values correspond to the results of the most restrictive scenarios for these technologies.

If domestic electricity demand follows recent forecasts, decision makers will have to explore alternative plans to meet demand through a mix of domestic electricity generation from EDL and IPPs in addition to imported electricity from regional neighbors. MEM (2015a) anticipates for the majority of installed capacity in 2030 to consist of hydro- and coal-power generation; however, recent national targets for installed electricity generation capacity in 2025 aim to reach 33 MW of solar PV, 73 MW of wind, 58 MW of biomass, 51 MW of biogas, and 2,000 MW of small hydropower (IREP 2016). The technical potential of installed capacities for the most restrictive solar and wind scenarios assessed in this work are approximately 516 GW and 116 GW, respectively, which would be more than adequate to meet these RE targets, as shown in TABLE 17. To meet targets, only 0.0064% of the solar and 0.0635% of the wind technical potential would have to be developed.[19] Additionally, the GIS-based results depicting suitable land area for development may help to identify where these resources can be accessed. The technical potential results reported here—in addition to the transparent methodology—may also inform future analyses and decisions to realign RE targets with an improved depiction of resources, technical potential, and suitable land area for development.

[19] Additional economic and market-potential analyses would be necessary refine the technical potential results (see Section 2). This work only completes a simple volumetric assessment of the share that the target represents in the total technical potential assessed.

TABLE 17. NATIONAL INSTALLED CAPACITY TARGETS FOR 2025 AND TECHNICAL POTENTIAL RESULTS FOR LAO PDR

	2025 National Targets[1] (GW)	Technical Potential Capacity results[2] (GW)
Solar PV	0.033	516 to 6,678
Wind	0.073	116 to 557
Biomass[3]	0.058	*0.938*
Biogas[3]	0.051	*0.313*
Small hydropower[4]	0.080	*2.0*

1. Targets from IREP (2016)
2. For the least restrictive and most restrictive development exclusions, respectively, for solar PV and wind
3. Biomass and biogas technical potential capacity (GW) was not assessed in this work. Biomass and biogas technical potential capacity from IREP (2016)
4. Hydropower technical-potential capacity (GW) was not assessed in this work. Small hydropower target and technical potential capacity from IREP (2016)

The electricity imported to meet domestic demands in Lao PDR has increased recently to approximately 2,049 GWh/year in 2015 (FIGURE 16). As assessed in this report, the gross technical potential from RE resources would be adequate to meet recent demands for imported electricity. Even as additional constraints from economic and market potential analyses are applied, it is likely that RE resources would be sufficient to meet a portion of these demands given additional constraints from economic and market potential analyses. Lao PDR could consider offsetting the large portion of total imports that is destined for the Vientiane Capital (Section 4.1) with domestic solar and wind generation. The Vientiane and Vientiane Prefecture provinces are seen to have relatively attractive solar resources with approximately 33,392 GWh/year and 24,505 GWh/year, respectively, in generation potentials (see Solar Scenario 3 results in Section 3.2). Neighboring Luangprabang Province also has an estimated 12,248 GWh/year of wind power generation potential in addition to the potential generation of Vientiane and Vientiane Prefecture provinces of 7,705 GWh/year and 5,198 GWh/year, respectively (Wind Scenario 3 in Section 3.2). Also, imports serving the southern provinces of Khammuane and Savannakhet could be offset by the relatively excellent wind and solar resources in these provinces. Khammuane and Savannakhet have wind generation potentials of 19,223 GWh/year and 63,309 GWh/year, respectively (Wind Scenario 3 in Section 3.2). The solar PV generation potentials of Khammuane and Savannakhet are 99,926 GWh/year and 132,492 GWh/year, respectively (Solar Scenario 3). As a portion of electricity imports may be required to meet generation shortfalls as well as demand in areas without sufficient transmission system connections, further analysis would be required to assess the economic and market potential of these resources.

Increasing regional electricity consumption and the corresponding electricity supply requirements may provide opportunities to take advantage of existing and planned interconnections for the export of electricity generated in Lao PDR. Electricity exports from Lao PDR have increased significantly in recent years and represented approximately 66% of total domestic electricity generation in 2015 (see FIGURE 16). The government of Lao PDR has also expressed its intentions to increase electricity exports to regional neighbors to become the “battery” of Southeast Asia (Sager 2016). The technical potential identified in this work could provide a valuable contribution to power development plans as Lao PDR explores alternative pathways to meet both domestic demand and electricity export aspirations. Lao PDR has attractive solar PV technical potential along the border with Thailand (a major electricity export destination) in the provinces of the Vientiane Capital, Borikhamxay, Khammuane, and Savannakhet. Also, the southern provinces of Attapeu and Champachack that border Thailand, Cambodia, and Vietnam have relatively large solar PV technical potentials of 32,638 GWh/year and 167,947 GWh/year, respectively (Solar Scenario 3 in Section 3.1). The technical potential for wind power is significant in the provinces of Khammuane and Savannakhet, which border both Thailand and Vietnam, as described above in relation to the potential to offset imports.

Lao PDR may also explore potential coal power development with the site-feasibility analysis results from this work to meet domestic electricity demands, offset imports, and potentially export electricity. This would require additional detailed studies to assess the capacity and generation and also assess the availability of coal resources and reserves that could be utilized. It is important to point out that the total potential suitable area for coal power development is between 1,685 and 45,957 km^2 (see Section 3.4), significantly less than the potential area available for wind and solar projects. In the most stringent of exclusions scenarios this feasible area for coal development is concentrated around the provinces of the Vientiane Capital and Vientiane Prefecture, which may further influence the development of these systems. Also, Lee et al. (2018) observed that the majority of the domestic coal deposits are lignite with small quantities of anthracite. Mid-grade lignite reserves may be suitable for electricity generation; however, lignite is typically less attractive than anthracite for generation due to its lower calorific value (lower heating value [MJ/kg]) and higher moisture content.

In summary, the technical potential for domestic RE-based electricity generation assessed in this work may support efforts to achieve or surpass Lao RE targets, meet domestic electricity demands, potentially offset electricity imports, and support aspirations for increased electricity exports to regional neighbors. Next steps may consist of detailed economic and market-potential assessments of how domestic resources could provide for domestic demands, offset current imports, and support electricity export plans. Additional datasets would be valuable for these assessments:

- Hourly load data from the grid operator in Lao PDR would allow for an analysis of how seasonal and daily RE resource availability patterns align with domestic and export-related demands and how generators could potentially play a role in meeting power system demand considering ramping needs.
- Verified spatial data depicting the Lao transmission system and interconnections with international neighbors were not available for this work. This complementary dataset would be beneficial for the considerations of meeting domestic electricity demands and plans for electricity imports and exports. Spatial data on current and planned transmission systems and international interconnections together with system characteristics (e.g., minimum and maximum power flow ratings) and hourly data (e.g., historic electricity imports and exports by interconnection) would support a more detailed analysis of how the technical potential identified here could be delivered to domestic demand and how it could contribute to potential electricity export plans.
- In addition to the transmission system datasets, additional data on dedicated generation for electricity exports and existing and planned connections to the domestic transmission system would support an analysis of the role that this domestic technical potential could plan in supplying domestic demand in addition to exports to regional neighbors.

5 Conclusions

The technical-potential assessment for each of the technologies considered for Lao PDR is summarized in terms of potential generation, installed capacity, and suitable land area for development in TABLE 18. The theoretical, upper limit of potential with exclusions is presented in the Base-Lao PDR assessments. The technical-potential scenarios represent increasingly more restrictive exclusions. The potential for utility-scale solar ranges from 731–8,997 TWh/year with a corresponding potential installed capacity of 516–6,678 GW. The technical potential for utility-scale wind was assessed to range from 135–682 TWh/year with a corresponding installed capacity of 116–557 GW. The total technical potential for annual generation from utility-scale biomass feedstocks, including logging, primary mill, and secondary mill residues, is less than those of wind and solar but still significant at 0.72 TWh/year.

TABLE 18 also summarizes the potential, feasible land area for development of coal power in Lao PDR. The site-feasibility analysis for coal generation shows that with the application of siting exclusions and priority areas the total feasible land area drops from 45,957 to 1,685 km^2.

As these estimates are for the technical potential of solar, wind, and biomass resources, they do not represent economic or market potentials and, as detailed in Lopez et al. (2012), do not reflect:

- Allocation of available land among technologies—the assessment for each technology was done in isolation; however, land is typically assumed to be available for a mix of technologies
- Alignment of technical potential with existing and planned transmission systems, which are necessary to connect generation to load
- The location or magnitude of existing and forecasted domestic electricity loads as well as the locations or magnitudes of electricity imports and exports
- The cost related to the development of the generation technologies considered at any suitable location
- Agreement of the generation potential identified with national energy policy objectives or requirements such as reliability, time-of-productions of electricity, energy security, impact on economic development, or environmental impact
- Conformity of the results with energy policies, existing or planned, that could set RE development targets.

Despite these limitations to the technical potential, the assessment identified solar, wind, and biomass resources that could support the development of energy supply and demand strategy for 2030. This technical potential could contribute to achieving or surpassing Lao RE targets; meeting domestic electricity demands; and realizing regional electricity export ambitions.

Although direct comparison between technical potential and domestic electricity demands is not possible, the technical potential for annual generation in Lao PDR is significantly larger than projected domestic electricity consumption for 2030 of 21,844–33,024 GWh/year. Additionally, this technical potential could be considered in offsetting electricity imports that reached approximately 2,049 GWh/year in 2015.

This domestic technical potential may also provide opportunities to utilize existing and planned interconnections for the export of electricity to regional neighbors. With increased regional electricity demand and corresponding electricity supply requirements this could position Lao PDR to be a net exporter of electricity following recent trends and stated policy goals.

TABLE 18. SUMMARY OF TECHNICAL POTENTIAL OF DOMESTIC ENERGY RESOURCES FOR LAO PDR

	Technical Potential		Suitable Area (km^2)
	Generation (GWh/year)	Capacity (GW)	
Solar photovoltaic (PV) – Utility-scale, fixed-tilt			
Base-Lao PDR: No exclusions	11,139,178	8,277	229,878
Scenario 1 (S1): Relaxed exclusions (*excludes protected areas, waterbodies, and wetland areas*)	8,996,660	6,678	185,519
S2: S1 **+** Slope exclusion (*excludes areas with slope > 5%*)	2,304,415	1,619	44,958
S3: S2 **+** Agriculture & forest area exclusions	731,613	516	14,380
S4: S3 **+** Urban area exclusion	731,417	516	14,376
Wind power – Rural, Utility-scale, 100 m hub height			
Base-Lao PDR: No exclusions	842,835	691	229,878
S1: Relaxed exclusions (*excludes protected areas, waterbodies, and wetland areas*)	682,161	557	185,519
S2: S1 **+** Slope exclusion (*excludes areas with slope > 20%*)	343,463	283	94,428
S3: S2 **+** Forest area exclusion	223,268	180	59,531
S4: S3 **+** Agriculture area exclusion	135,129	116	38,486
Biomass[1] – Multiple scales			
Logging residue – Utility-scale	376		
Primary and secondary mill residues – Utility-scale	344		
Biogas – Nonutility-scale	2.53		
Crop residues (rice husk & sugar cane bagasse) – Nonutility-scale	802		
Coal power site feasibility[2] – Utility-scale			
S1: All exclusions (*excludes areas with slope > 12%, areas < 5 km from an airport, contiguous areas < 1.2 km^2, protected areas, agricultural areas, waterbodies, wetland areas, urban areas, densely populated areas, and areas > 5 km from a road*)			45,957
S2: S1 **+** priority areas (*excludes areas > 32 km from coal deposits and areas > 32 km from water sources*)			1,685

1. A single, base analysis of annual generation is considered for each of the biomass resources with no exclusion layers analysis due to the current data resolution and non-site-specific nature of biomass resources. Suitable area and installed capacity are not assessed.
2. A site feasibility analysis is conducted for coal power technology as a proxy to technical potential to identify land area where plants could be sited. The installed capacity and the annual generation potential are not estimated. The Base-Lao PDR assumes 100% of land area would be feasible.

5.1 Recommendations

A set of actions are identified for the short, medium, and long term that may enable MEM to apply the technical potential assessment results to support planning activities and improve upon them for future analyses.

Short-term actions

In the immediate term, MEM can take steps to use these technical potential results to support ongoing energy planning and policy activities. MEM can use this improved understanding of solar PV and wind technical potential to identify initial areas of interest for possible RE auctions in Lao PDR. MEM could highlight areas with high-quality resources that warrant additional detailed analyses for future RE auctions. Additionally, MEM could act to set future (or realign existing) national (or subnational) RE targets based on this improved depiction of the technical potential for utility-scale solar, wind, and biomass energy resources in Lao PDR.

In the short term, MEM can begin to disseminate the results of this technical-potential assessment to local decision makers and stakeholders. Sharing this improved understanding of the technical potential of RE resources and site feasibility of coal power may support decision makers addressing current energy planning concerns in Lao PDR.

In the short term, MEM can also take steps to verify, improve, and update the results and methodology employed here and address data gaps. The internal verification of assumptions, exclusions, methodology, and results would help to refine this and future analyses for the specific context of Lao PDR. Ensuring that the assumptions and exclusions reflect development constraints unique to Lao PDR would improve the accuracy of future technical potential assessments. This internal verification will also aid MEM to learn the methodology used here and build in-house technical-potential assessment capacity. Following the methodology in this work, MEM could improve the accuracy of the results by identifying (1) the additional context-specific assumptions to include for each technology considered and (2) the applicable development exclusions and accompanying data layers to complete an exclusion analysis. This capacity to assess domestic technical potential would aid in setting future RE targets and provide valuable inputs to more sophisticated work such as economic potential assessments, grid integration studies, or integrated resource planning work in the medium to long term.

MEM could also work with qualified local institutions (such as the National University of Laos) or private firms to identify and/or create the required datasets to include these assumptions and exclusions in the analyses. The exclusion analysis employed in this work relied on proxy assumptions based on assessments conducted in the U.S. for utility-scale RE generation in the absence of accepted values for Lao PDR. The highest priority data gaps to address for future technical potential assessments are those for which publicly accessible, default datasets are absent; however, even when default data exist, data from in-country sources are preferred if they are of high quality. The following steps may help to improve future assessments:[20]

- Create or procure detailed crop residues, forest residues, and biogas resource data at finer resolutions than the national or province level. Data at the district, per-km^2, or on-site resolution would allow for a more in-depth and accurate analysis, which would be more in line with the wind and solar resources included in this work.
- Develop and share spatial datasets that allow for an estimation of the theoretical, non-exploited hydropower resources for all of Lao PDR
- Develop, identify, or share verified spatial data depicting the Lao transmission system and interconnections with international neighbors. This complementary dataset would be beneficial for the considerations of meeting domestic electricity demands and plans for electricity imports and exports. Spatial data on current and planned transmission system and international interconnections, together with system characteristics and hourly data, would support a more detailed analysis of how technical potential could be used to supply domestic demand and contribute to electricity import and export plans.
- Develop or share spatial land-use classification data. Agricultural and forested areas represent a significant exclusion for solar PV, wind, and coal power siting in this work. As there may be multiple types of agricultural and forested areas within Lao PDR, each with different development restrictions,

[20] Refer to Lopez et al. (Forthcoming) and Lee et al. (2018) for additional details on addressing these foundational dataset gaps.

a data layer depicting these land-use classifications may aid in refining the estimated suitable land area and technical potential for different technologies.

Medium-term actions

To ensure that the results of this assessment are valuable beyond the initial step completed here of identifying domestic resources, MEM may want to use the results of this assessment within medium-term planning activities. MEM may consider additional analysis of the role that these domestic resources (e.g., solar, wind, biomass) may play in meeting domestic demand and with electricity import and export strategies—considering existing and planned transmission systems and interconnections with regional neighbors.

In the medium term, MEM can build on their understanding of technical potential and their expertise to conduct these base assessments to conduct more sophisticated analyses. MEM could take steps to conduct an economic potential analysis for RE resources in Lao PDR. An economic potential assessment (beyond establishing LCOE in Task 3 of the Energy Alternatives Study) would further refine the technical potential assessment identifying the resources for which the cost of generating electricity is lower than expected project revenues. An economic potential study would include an analysis of the energy resources together with a transmission infrastructure overlay allowing for quantification of the economic viability of siting technologies in certain locations (Brown et al. 2016). An economic potential assessment would further inform RE target-setting activities, capacity expansion planning, and policy design.

As MEM continues to build capacity to inform energy planning, MEM may consider conducting a longer-term integrated resource planning (IRP) activity. An IRP would support MEM in developing a strategy to meet projected energy demands through a combination of supply- and demand-side actions that would also satisfy multiple objectives for resource use in Lao PDR. These objectives could include minimizing future power system costs, maximizing energy security, maximizing reliability, and maximizing access to energy services among other objectives. The results of technical and economic potential assessments would be used in an IRP to depict the domestic RE resources available for electricity generation in Lao PDR. These resources could be considered together with other RE and non-RE resources and electricity imports as supply side electricity generation options within an IRP activity.

With an improved understanding of the technical potential for large-scale wind and solar resources in Lao PDR, MEM could conduct integrated transmission expansion and RE generation development planning to potentially increase the share of RE resources in the power system. The Renewable Energy Zone (REZ) Transmission Planning Process would utilize the results of a technical potential assessment, such as the current work, to identify REZs that have high-quality RE resources with suitable topography and land-use designations and demonstrated developer interest. The process would then study transmission expansion options to connect these REZs to the power system (Lee, Flores-Espino, and Hurlbut 2017).

In the medium term, MEM may wish to work with other ministries and institutes in Lao PDR to harmonize land-use designation restrictions and energy development strategies. With economic and population growth in Lao PDR there will undoubtedly be increased, competing demand for use of land (e.g., forest, agricultural, and other designations). This study found that agricultural and forested area exclusions can significantly limit the suitable area for energy system development as well as the resulting technical potential. MEM can use the results of this and future technical potential assessments to educate other decision makers and stakeholders on the role played by land-use designations and development restrictions in energy system planning. MEM may also help to work on land-use designation policies that would support energy system expansion alongside other development objectives in Lao PDR.

Also, in the medium to long term, MEM could develop or procure higher temporal resolution RE resource data, with an emphasis on wind and solar, to improve technical and economic potential assessments and to facilitate more sophisticated activities such as integrated resource planning, REZ transmission planning, and grid integration studies. Currently, the best available data for wind and solar in Lao PDR provide long-term, annual, average wind speed and wind power densities. MEM could improve these data by creating or procuring high-resolution resource data for wind and solar (preferably hourly or sub-hourly) as these finer resolutions better capture the variability of resources within timeframes that are relevant to power system operations (Lee et al. 2018; Lopez et al. Forthcoming).

Long-term actions

In the long term, MEM can apply expertise and data to update and improve upon technical potential analyses and use the results from these assessments in more sophisticated analyses that support energy policy objectives in Lao PDR. For example, as Lao PDR begins to significantly scale up RE electricity generation connected to the grid, MEM may consider a grid integration study to improve understanding of the technical, economic, and reliability constraints and options associated with achieving high levels of variable RE. These studies require high-resolution data including RE resource potential and energy demand data.

MEM should consider periodic technical-potential assessment updates to ensure that they remain relevant to energy planning analyses. Periodic technical-potential assessment updates are possible and appropriate as resource and associated data quality improve, system characteristics change, exclusions are identified, and internal capacity to do these assessments increases (Lopez et al. 2012). As improved, higher resolution data become available for energy resources of interest, this may improve the accuracy of the potential capacity, generation, and suitable land area. Improvements in RE technologies are consistently being made, and the assumptions about these technologies can significantly influence the results (e.g., capacity factor and power density). Additionally, the technologies of interest to decision makers may change and additional assessments may be required. For example, this assessment was made for utility-scale, fixed-tilt solar PV and wind turbines with 100 m hub height; however, for the reasons described above, interest may grow in these and other systems—requiring an assessment that includes assumptions specific to these technologies.

References

ACE. 2017. "The 5th ASEAN Energy Outlook." Jakarta: Association of Southeast Asian Nations (ASEAN) Center for Energy (ACE). http://www.aseanenergy.org/resources/the-5th-asean-energy-outlook/.

ADB. 2015. "Renewable Energy Developments and Potential in the Greater Mekong Subregion." Manila: Asian Development Bank (ADB). http://hdl.handle.net/11540/5054.

Akgün, Orkide, Mika Korkeakoski, Suvisanna Mustonen, and Jyrki Luukkanen. 2011. "Theoretical Bioenergy Potential in Cambodia and Laos." In *World Renewable Energy Congress 8-13 May, 2011*. Linköping, Sweden. www.ep.liu.se/ecp/057/vol1/045/ecp57vol1_045.pdf.

Brown, Austin, Philipp Beiter, Donna Heimiller, Carolyn Davidson, Paul Denholm, Jennifer Melius, Anthony Lopez, Dylan Hettinger, David Mulcahy, and Gian Porro. 2016. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results." NREL/TP-6A20-64503. Golden, CO: National Renewable Energy Laboratory (NREL). www.nrel.gov/docs/fy15osti/64503.pdf.

Das, Barun Kumar, and S. M. Najmul Hoque. 2014. "Assessment of the Potential of Biomass Gasification for Electricity Generation in Bangladesh." *Journal of Renewable Energy* 2014: 10.

DTU. 2017. "Global Wind Atlas." Danish Technical University (DTU), Department of Wind Energy. 2017. http://www.globalwindatlas.com/.

EDC. 2014. "Sustainable Development of Energy and Electricity Policy in Cambodia - Electricite Du Cambodge (EDC)." presented at the Institute of Energy Economics, Japan (IEEJ), Tokyo. https://eneken.ieej.or.jp/data/5586.pdf.

EDL. 2015. "Annual Report 2015." Vientiane: Électricité du Laos (EDL). http://www.edl.com.la/ckfinder/userfiles/files/Annual%20report/Annual%20Report%202015%20Okay%20.pdf.

EIA. 2017. "International Energy Outlook 2017." Washington, D.C.: Energy Information Agency (EIA). www.eia.gov/ieo.

Global Wood. 2017. "Wood Weights & Measures." 2017. http://www.globalwood.org/tech/tech_wood_weights.htm.

IEA. 2015. "Southeast Asia Energy Outlook: 2015." Paris: International Energy Agency (IEA). http://www.iea.org/publications/freepublications/publication/WEO2015_SouthEastAsia.pdf.

IES and MKE. 2016. "Alternatives for Power Generation in the Greater Mekong Subregion." Sydney: Intelligent Energy Systems Pty Ltd (IES) and Mekong Economics (MKE). http://awsassets.panda.org/downloads/regional.pdf.

IPCC. 1996. “Volume 3: Reference Manual - Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories:” Hayama, Japan: Intergovernmental Panel on Climate Change (IPCC). http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.html.

IREP. 2016. “Renewable Energy Data in Lao PDR: Institute of Renewable Energy Promotion (IREP), Lao Ministry of Energy and Mines (MEM).” presented at the East and Southeast Asia Renewable Energy Statistic Training Workshop: December 12-14, 2016, Bangkok.

Koumphonphakdi, Dethanou, and Ratchaphon Suntivarakorn. 2014. “Energy Potential of Biogas Production from Animal Manure in the Lao People’s Democratic Republic.” *Greater Mekong Subregion Academic and Research Network International Journal*, 8: 35-40. http://gmsarnjournal.com/home/wp-content/uploads/2015/08/vol8no2-1.pdf.

Lee, Nathan, Francisco Flores-Espino, and David Hurlbut. 2017. “Renewable Energy Zone (REZ) Transmission Planning Process: A Guidebook for Practitioners.” Technical Report. Golden, CO: National Renewable Energy Laboratory (NREL). www.nrel.gov/docs/fy17osti/69043.pdf.

Lee, Nathan, Anthony Lopez, Jessica Katz, Ricardo Oliveira, and Sheila Hayter. 2018. “Task 1 Report - Assessment of Data Availability to Inform Energy Planning Analyses: Energy Alternatives Study for the Lao People’s Democratic Republic: Smart Infrastructure for the Mekong Program.” Technical Report TP-7A40-70334. Golden, CO: National Renewable Energy Laboratory (NREL). https://www.nrel.gov/docs/fy18osti/70334.pdf.

Lin, Jiang, Xu Liu, and Fredrich Kahrl. 2016. “Excess Capacity in China’s Power Systems: A Regional Analysis.” Technical Report LBNL-1006638. Lawrence Berkeley National Laboratory. https://china.lbl.gov/sites/all/files/lbnl1006638.pdf.

Lopez, Anthony. 2016. “High-Level Overview of Data Needs for RE Analysis.” Presentation NREL/PR-6A20-67835. Golden, CO: National Renewable Energy Laboratory (NREL). http://www.nrel.gov/docs/fy17osti/67835.pdf.

Lopez, Anthony, Jessica Katz, Nathan Lee, and Ricardo Oliveira. Forthcoming. “Planning for a High Renewable Energy Future in the Lower Mekong: Assessment of Data Availability and Gaps to Inform Analysis and Action.” Golden, CO: National Renewable Energy Laboratory (NREL).

Lopez, Anthony, Billy Robers, Donna Heimiller, Nate Blair, and Gian Porro. 2012. “U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis.” Technical Report NREL/TP-6A20-51946. Golden, CO: National Renewable Energy Laboratory (NREL). www.nrel.gov/docs/fy12osti/51946.pdf.

MacKay, David JC. 2009. *Sustainable Energy — without the Hot Air: Errata*. Version 3.5.2. Cambridge, England: UIT Cambridge Lt. http://www.inference.org.uk/sustainable/book/errata/bioenergy.html.

Marutani, Masaharu. 2006. “Sector Plan for Sustainable Development of the Mining Sector in the Lao PDR: Final Report for Economic Geology.” Washington, DC: World Bank.

Maweni, Joel, and Jyoti Bisbey. 2016. “A Financial Recovery Plan for Vietnam Electricity (EVN): With Implications for Vietnam’s Power Sector.” Washington, D.C.: World Bank.

http://documents.worldbank.org/curated/en/971901468196178656/pdf/104097-REVISED-PUBLIC-ASTAE-Vietnam-Electricity-EVN-Optimized.pdf.

Mays, Gary T., Randy J. Belles, Brandon R. Blevins, Stanton W. Hadley, Thomas J. Harrison, Warren C. Jochem, Bradley S. Neish, Olufemi A. Omitaomu, and Amy N. Rose. 2012. "Application of Spatial Data Modeling and Geographical Information Systems (GIS) for Identification of Potential Siting Options for Various Electrical Generation Sources." ORNL/TM-2011/157/R1. Oak Ridge: Oak Ridge National Laboratory (ORNL). http://info.ornl.gov/sites/publications/files/Pub30613.pdf.

MEM. 2011. "Renewable Energy Development Strategy in the Lao PDR." Vientiane: Lao Ministry of Energy and Mines (MEM).

———. 2015a. "Demand Forecast 2016-2030: Main Report." Vientiane: Lao Ministry of Energy and Mines (MEM).

———. 2015b. "Electricity Statistics Yearbook 2015 of Lao PDR." Vientiane: Lao PDR Ministry of Energy and Mines (MEM). http://www.laoenergy.la/download_file.php?id_ph=143.

———. 2017. "Existing and Planned Hydropower Projects." Lao Ministry of Energy and Mines.

Ministry of Energy of Thailand. 2015. "Thailand Power Development Plan: 2015-2036." Bangkok: Energy Policy and Planning Office of the Ministry of Energy of Thailand.

Mone, Christopher, Maureen Hand, Mark Bolinger, Joseph Rand, Donna Heimiller, and Jonathan Ho. 2017. "2015 Cost of Wind Energy Review." Technical Report NREL/TP-6A20-66861. Golden, CO: National Renewable Energy Laboratory (NREL). http://www.nrel.gov/docs/fy17osti/66861.pdf.

NEMC. 2015. "Myanmar Energy Master Plan." Naypyidaw: The Government of the Republic of the Union of Myanmar National Energy Management Committee. http://www.burmalibrary.org/docs22/2015-12-Myanmar_Energy_Master_Plan-spdf-red.pdf.

Ong, Sean, Clinton Campbell, Paul Denholm, Robert Margolis, and Garvin Heath. 2013. "Land-Use Requirements for Solar Power Plants in the United States." Golden, CO: National Renewable Energy Laboratory (NREL). http://www.nrel.gov/docs/fy13osti/56290.pdf.

Power Technology. 2017. "Power Technology." Hongsa Mine Mouth Power Project, Laos. 2017. https://www.sisgeo.com/projects/geographical-areas/asia-and-oceania-projects/item/nam-louk-dam-hongsa-mine-mouth-power-project.html.

Rice, Jennie S., Timothy E. Seiple, Nino Zuljevic, Laurel C. Schmidt, Scott L. Morris, Chunlian Jin, Michaeal C.W. Kintner-Meyer, and Chris Vernon. 2015. "The Climate-Energy-Water-Land Nexus: A New Geospatial Model to Explore Regional Scale Power Plant Siting under Climate Change." Unpublished Work. Richland: Pacific Northwest National Laboratory (PNNL).

Rogner, Hans-Holger, Roberto F. Aguilera, Christina Archer, Ruggero Bertani, S. C. Bhattacharya, Maurice B. Dusseault, Luc Gagnon, et al. 2012. "Chapter 7 - Energy Resources and Potentials." In *Global Energy Assessment - Toward a Sustainable Future*, 423–512. Cambridge University

Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria. www.globalenergyassessment.org.

Sager, Jalel. 2016. “A Better Battery: Policy for Flexible Energy Futures in Laos.” presented at the Presentation to the Ministry of Energy and Mines, Lao Ministry of Energy and Mines, May 24, 2016.

Sultana, Arifa, and Amit Kumar. 2012. “Optimal Siting and Size of Bioenergy Facilities Using Geographic Information System.” *Applied Energy* 94 (June): 192–201. https://doi.org/10.1016/j.apenergy.2012.01.052.

World Bank. 2017. “Global Solar Atlas.” Global Solar Atlas. 2017. http://globalsolaratlas.info/.

Appendix A—Map of province administrative boundaries of Lao PDR

Figure A-1 shows the province administrative boundaries of Lao PDR used in this work. The spelling of province names used in this work follow the convention of MEM (2015b).

FIGURE A-1. MAP – PROVINCE ADMINISTRATIVE BOUNDARIES OF LAO PDR

Appendix B—Additional results of the technical potential assessment

This appendix presents additional maps and data from the technical potential results Section 3.

Utility-scale Solar PV

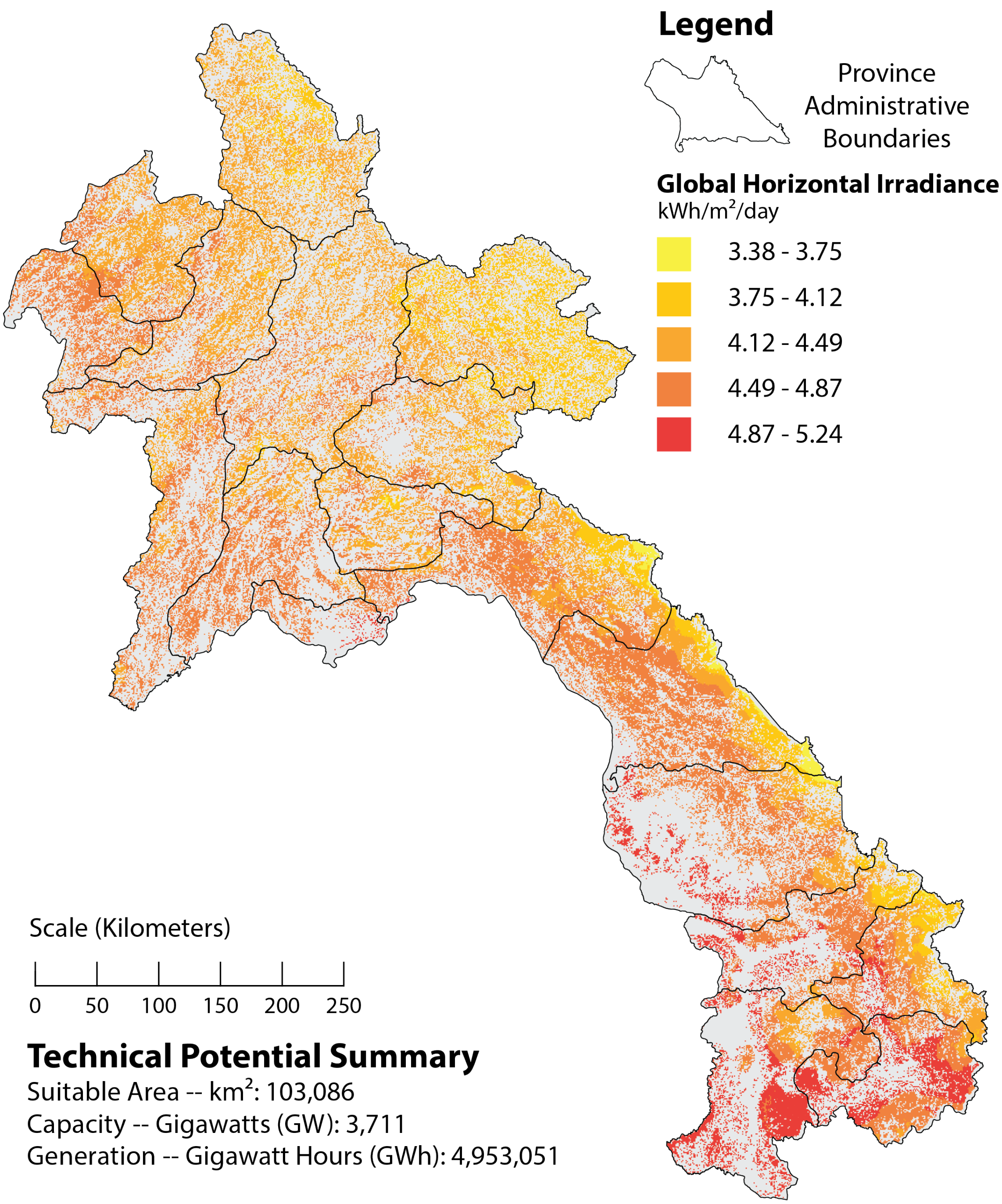

FIGURE B-1. MAP – SOLAR PV TECHNICAL POTENTIAL: BASE-FOREST WITH DEVELOPMENT CONSTRAINED TO FORESTED AREAS

TABLE B-1. SOLAR TECHNICAL POTENTIAL: PV BASE-FOREST WITH DEVELOPMENT CONSTRAINED TO FORESTED AREAS

Solar Base-Forest	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**103,086**	**3,712**	**4,953,049**	**15.24**
Province				
Attapeu	5,478	197	281,590	16.30
Bokeo	3,218	116	159,698	15.74
Borikhamxay	9,510	342	454,785	15.16
Champachack	6,262	225	321,269	16.27
Huaphanh	8,209	296	358,684	13.86
Khammuane	10,101	364	482,100	15.13
Luangnamtha	5,259	189	255,313	15.39
Luangprabang	7,123	256	338,247	15.06
Oudomxay	5,070	183	243,974	15.26
Phongsaly	6,334	228	287,491	14.39
Saravane	4,349	157	214,598	15.65
Savannakhet	7,463	269	364,761	15.50
Sekong	5,211	188	245,885	14.96
Vientiane Prefecture	851	31	43,807	16.31
Vientiane	4,759	171	236,087	15.73
Xayabury	5,569	200	274,019	15.60
Xaysomboune	3,131	113	149,653	15.16
Xiengkhuang	5,189	187	241,088	14.73

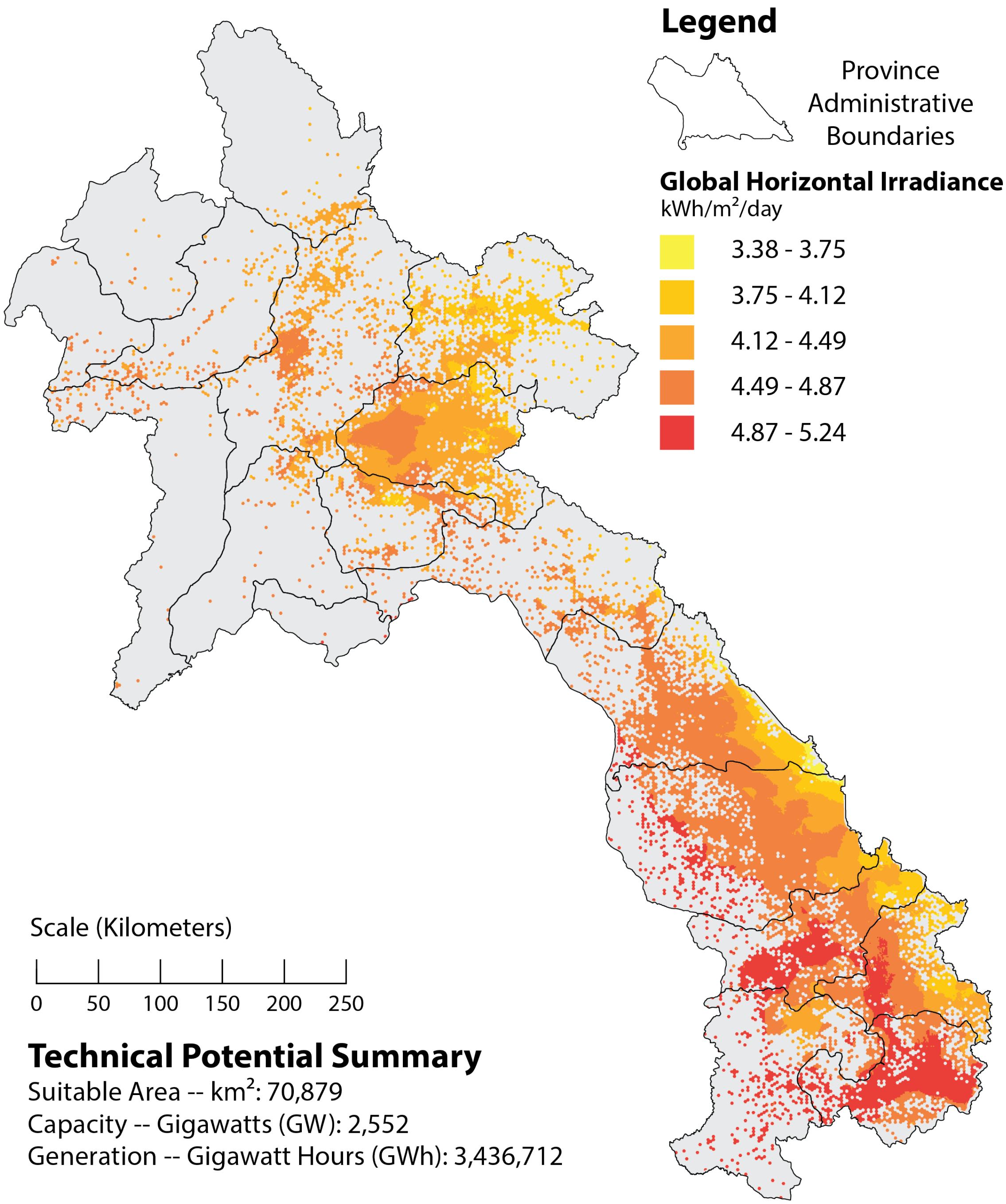

FIGURE B-2. MAP – SOLAR PV TECHNICAL POTENTIAL: BASE-UXO WITH DEVELOPMENT CONSTRAINED TO AREAS WITH UXO

TABLE B-2. SOLAR PV TECHNICAL POTENTIAL: BASE-UXO WITH DEVELOPMENT CONSTRAINED TO AREAS WITH UXO

Solar Base-UXO	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**70,878**	**2,550**	**3,436,712**	**15.38**
Province				
Attapeu	5,944	214	309,358	16.50
Bokeo	184	7	9,043	15.57
Borikhamxay	2,694	97	131,797	15.51
Champachack	3,478	125	176,706	16.11
Huaphanh	4,958	178	219,367	14.03
Khammuane	9,007	324	432,849	15.24
Luangnamtha	88	3	4,287	15.41
Luangprabang	4,327	156	206,937	15.16
Oudomxay	881	32	42,609	15.33
Phongsaly	601	22	27,500	14.51
Saravane	6,813	245	338,875	15.77
Savannakhet	13,048	470	638,340	15.51
Sekong	6,152	221	295,582	15.24
Vientiane Prefecture	41	1	2,138	16.34
Vientiane	648	23	31,263	15.30
Xayabury	506	18	24,911	15.62
Xaysomboune	2,301	83	110,701	15.26
Xiengkhuang	9,207	331	434,449	14.96

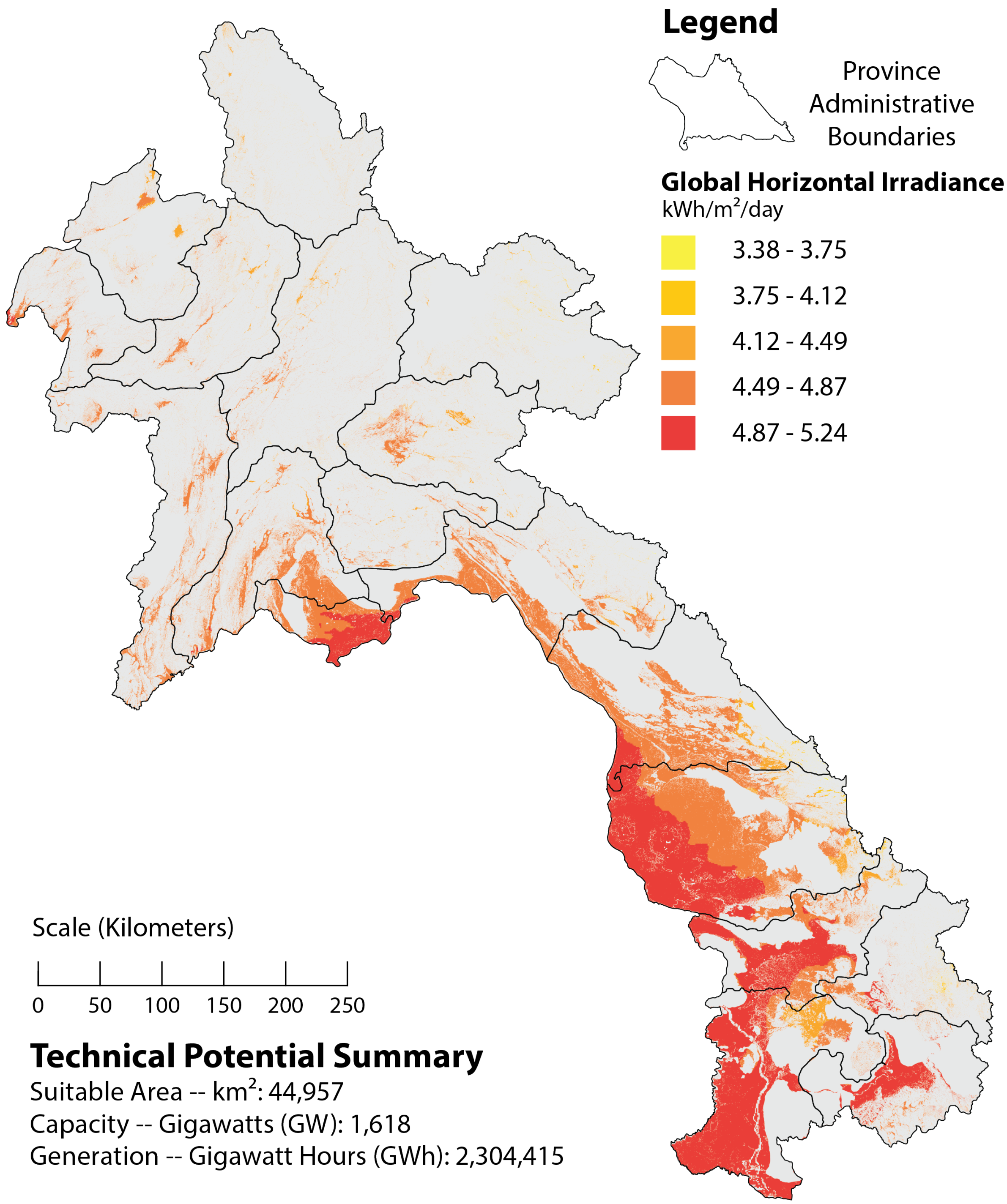

FIGURE B-3. MAP – SOLAR PV TECHNICAL POTENTIAL: SCENARIO 2 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AND AREAS WITH SLOPE > 5%

TABLE B-3. SOLAR PV TECHNICAL POTENTIAL: SCENARIO 2 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AND AREAS WITH SLOPE > 5%

Solar Scenario 2	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**44,958**	**1,619**	**2,304,415**	**16.25**
Province				
Attapeu	1,710	62	90,959	16.87
Bokeo	492	18	25,005	16.11
Borikhamxay	2,861	103	144,969	16.07
Champachack	7,856	283	411,936	16.63
Huaphanh	273	10	11,930	13.86
Khammuane	5,139	185	258,723	15.96
Luangnamtha	389	14	18,967	15.46
Luangprabang	533	19	25,643	15.24
Oudomxay	488	18	23,802	15.47
Phongsaly	263	9	12,044	14.54
Saravane	4,214	152	218,544	16.44
Savannakhet	12,923	465	664,705	16.31
Sekong	607	22	29,878	15.60
Vientiane Prefecture	2,416	87	125,993	16.54
Vientiane	2,424	87	123,321	16.13
Xayabury	1,288	46	65,151	16.05
Xaysomboune	308	11	15,090	15.55
Xiengkhuang	774	28	37,755	15.47

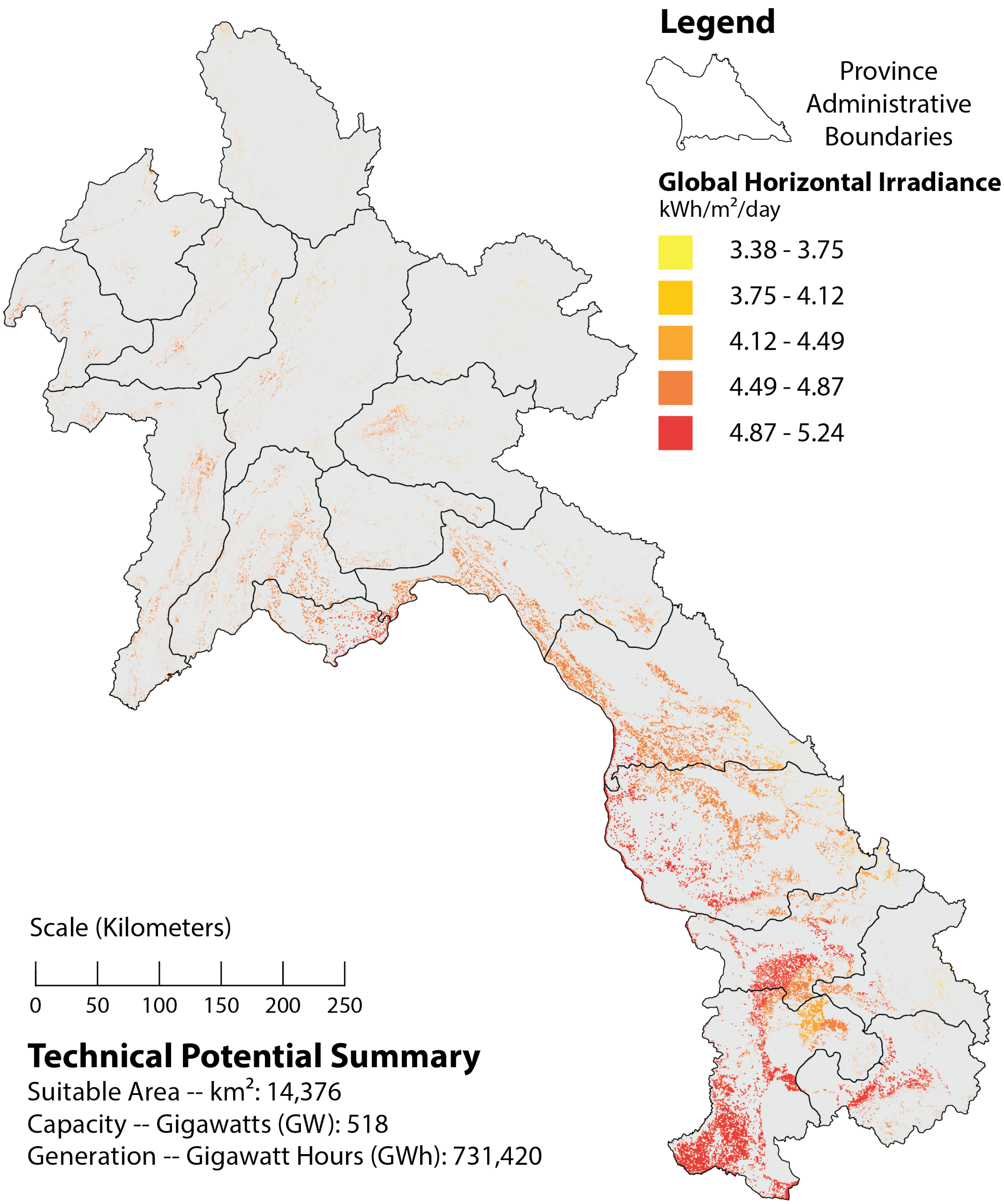

FIGURE B-4. MAP – SOLAR PV TECHNICAL POTENTIAL: SCENARIO 4 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AREAS WITH SLOPE > 5%, AGRICULTURAL AREAS, FORESTED AREAS, AND URBAN AREAS

TABLE B-4. SOLAR PV TECHNICAL POTENTIAL: SCENARIO 4 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AREAS WITH SLOPE > 5%, AGRICULTURAL AREAS, FORESTED AREAS, AND URBAN AREAS

Solar Scenario 4	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**14,376**	**516**	**731,417**	**16.13**
Province				
Attapeu	615	22	32,638	16.83
Bokeo	179	6	9,020	16.01
Borikhamxay	1,064	38	53,833	16.05
Champachack	3,214	116	167,947	16.57
Huaphanh	130	5	5,694	13.87
Khammuane	1,988	72	99,926	15.94
Luangnamtha	117	4	5,672	15.44
Luangprabang	284	10	13,666	15.24
Oudomxay	199	7	9,659	15.42
Phongsaly	147	5	6,726	14.56
Saravane	1,501	54	77,228	16.32
Savannakhet	2,617	94	132,492	16.05
Sekong	282	10	13,852	15.55
Vientiane Prefecture	466	17	24,309	16.53
Vientiane	660	24	33,392	16.05
Xayabury	511	18	25,796	16.00
Xaysomboune	141	5	6,927	15.57
Xiengkhuang	261	9	12,640	15.35

Utility-scale wind power

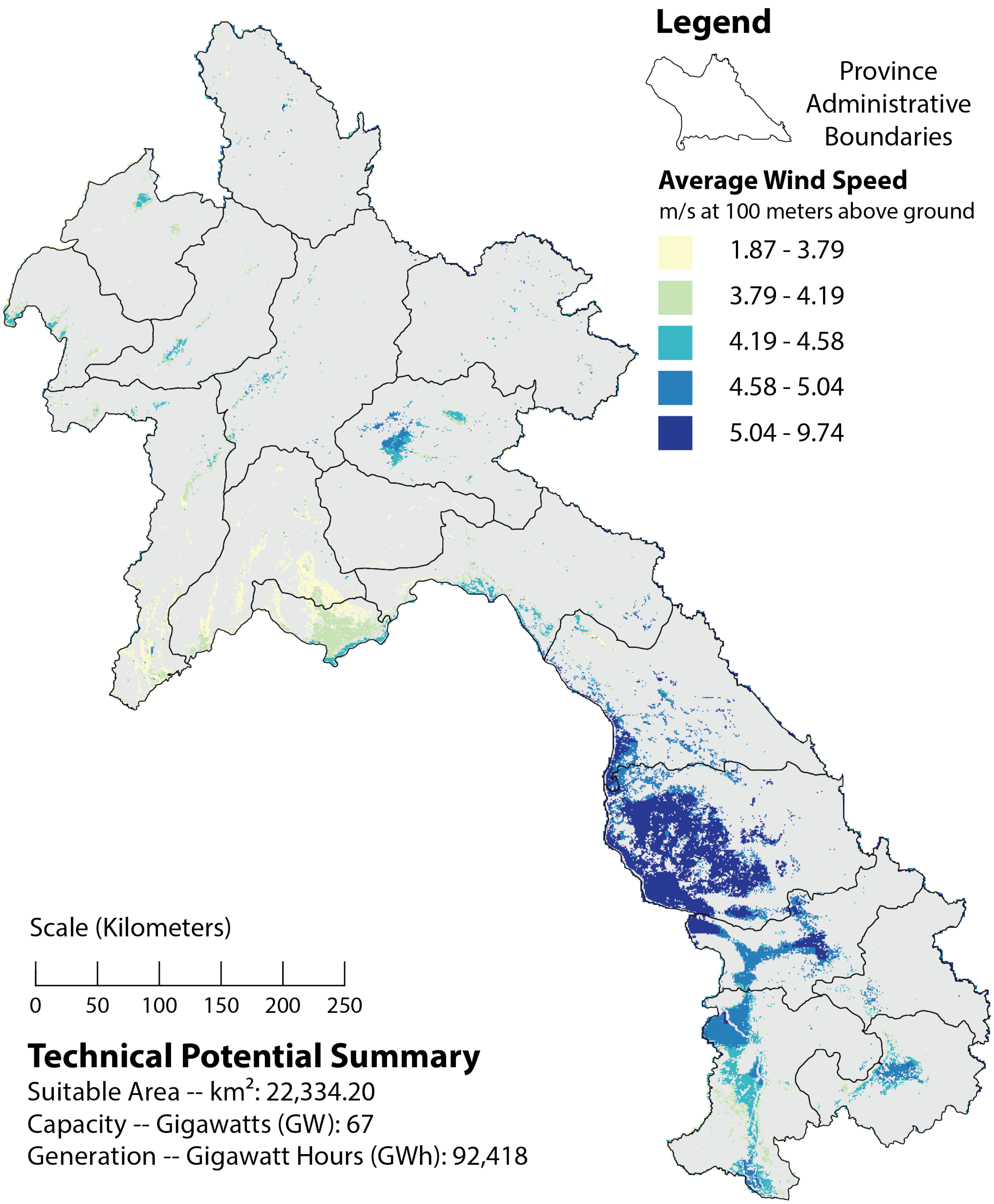

FIGURE B-5. MAP – WIND TECHNICAL POTENTIAL: BASE-AGRICULTURE WITH DEVELOPMENT CONSTRAINED TO AGRICULTURAL AREAS

TABLE B-5. WIND TECHNICAL POTENTIAL: BASE-AGRICULTURE WITH DEVELOPMENT CONSTRAINED TO AGRICULTURAL AREAS

Wind Base-Agriculture	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**22,337**	**66**	**92,416**	**15.70**
Province				
Attapeu	771	2	2,814	13.90
Bokeo	338	1	887	9.98
Borikhamxay	762	2	2,361	11.79
Champachack	2,955	9	11,033	14.21
Huaphanh	139	0	439	12.07
Khammuane	1,522	5	6,924	17.31
Luangnamtha	211	1	574	10.36
Luangprabang	213	1	698	12.45
Oudomxay	247	1	672	10.36
Phongsaly	123	0	345	10.72
Saravane	1,977	6	9,659	18.59
Savannakhet	7,730	23	43,464	21.40
Sekong	136	0	513	14.37
Vientiane Prefecture	1,663	5	3,848	8.81
Vientiane	1,454	4	2,684	7.02
Xayabury	1,222	4	2,516	7.84
Xaysomboune	96	0	149	5.92
Xiengkhuang	778	2	2,836	13.88

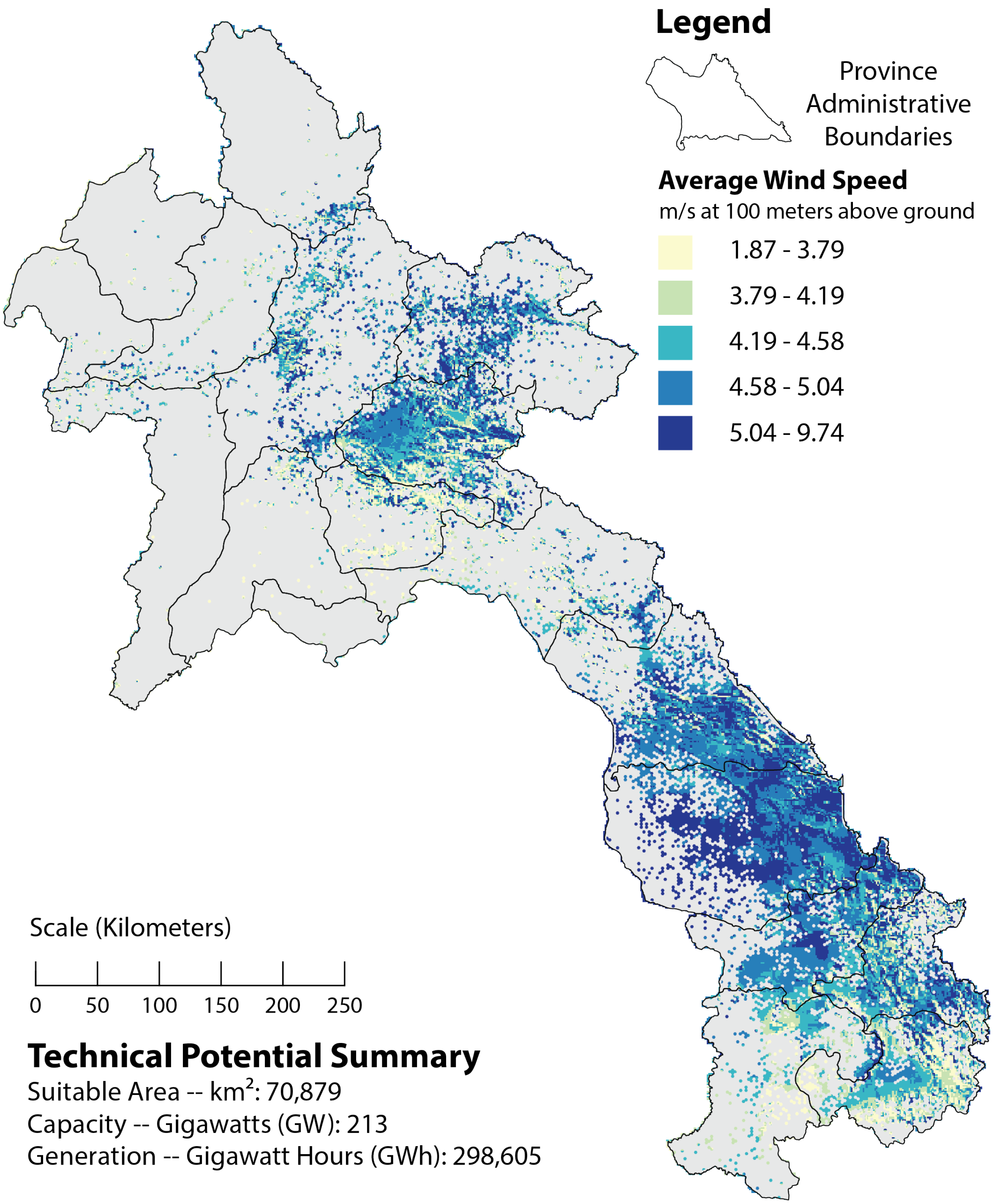

FIGURE B-6. MAP – WIND TECHNICAL POTENTIAL: BASE-UXO WITH DEVELOPMENT CONSTRAINED TO AREAS WITH UXO

TABLE B-6. WIND TECHNICAL POTENTIAL: BASE-UXO WITH DEVELOPMENT CONSTRAINED TO AREAS WITH UXO

Wind Base-UXO	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**70,878**	**213**	**298,605**	**15.96**
Province[21]				
Attapeu	5,944	18	18,692	11.97
Bokeo	184	1	501	10.36
Borikhamxay	2,694	8	9,613	13.58
Champachack	3,478	10	11,187	12.24
Huaphanh	4,958	15	22,601	17.35
Khammuane	9,007	27	41,907	17.70
Luangnamtha	88	0	237	10.23
Luangprabang	4,327	13	18,123	15.94
Oudomxay	881	3	3,028	13.08
Phongsaly	601	2	2,328	14.73
Saravane	6,813	20	30,885	17.25
Savannakhet	13,048	39	67,880	19.80
Sekong	6,152	18	24,821	15.35
Vientiane Prefecture	41	0	95	8.72
Vientiane	648	2	1,803	10.59
Xayabury	506	2	1,598	12.03
Xaysomboune	2,301	7	6,400	10.58
Xiengkhuang	9,207	28	36,906	15.25

[21] The province administrative boundaries of Lao PDR are shown in Appendix A. The spelling of all provinces of Lao PDR in this work follows the convention used in MEM (2015b).

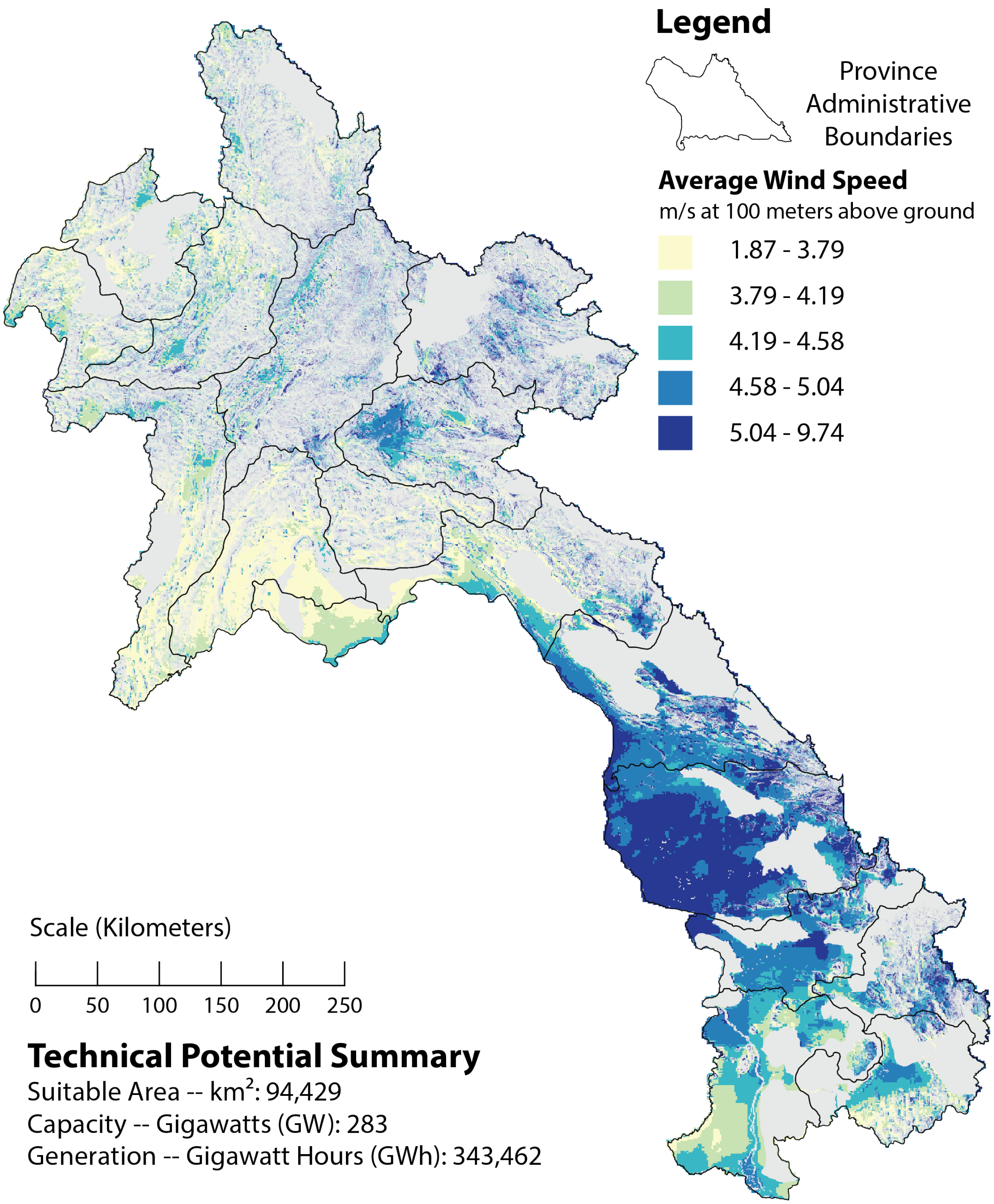

FIGURE B-7. MAP – WIND TECHNICAL POTENTIAL: SCENARIO 2 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AND AREAS WITH SLOPE > 20%

TABLE B-7. WIND TECHNICAL POTENTIAL: SCENARIO 2 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AND AREAS WITH SLOPE > 20%

Wind Scenario 2	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**94,428**	**283**	**343,463**	**13.76**
Province[22]				
Attapeu	3,528	11	11,182	12.06
Bokeo	2,596	8	6,511	9.54
Borikhamxay	6,015	18	18,527	11.72
Champachack	9,349	28	30,529	12.43
Huaphanh	3,379	10	14,606	16.45
Khammuane	7,586	23	34,782	17.45
Luangnamtha	2,574	8	6,619	9.79
Luangprabang	4,876	15	18,973	14.80
Oudomxay	4,025	12	11,909	11.26
Phongsaly	3,334	10	10,098	11.52
Saravane	6,052	18	27,100	17.04
Savannakhet	16,316	49	86,612	20.20
Sekong	2,811	8	11,554	15.64
Vientiane Prefecture	2,807	8	6,220	8.43
Vientiane	6,440	19	11,912	7.04
Xayabury	6,337	19	15,044	9.03
Xaysomboune	2,164	6	4,778	8.40
Xiengkhuang	4,239	13	16,507	14.82

[22] The province administrative boundaries of Lao PDR are shown in Appendix A. The spelling of all provinces of Lao PDR in this work follows the convention used in MEM (2015b).

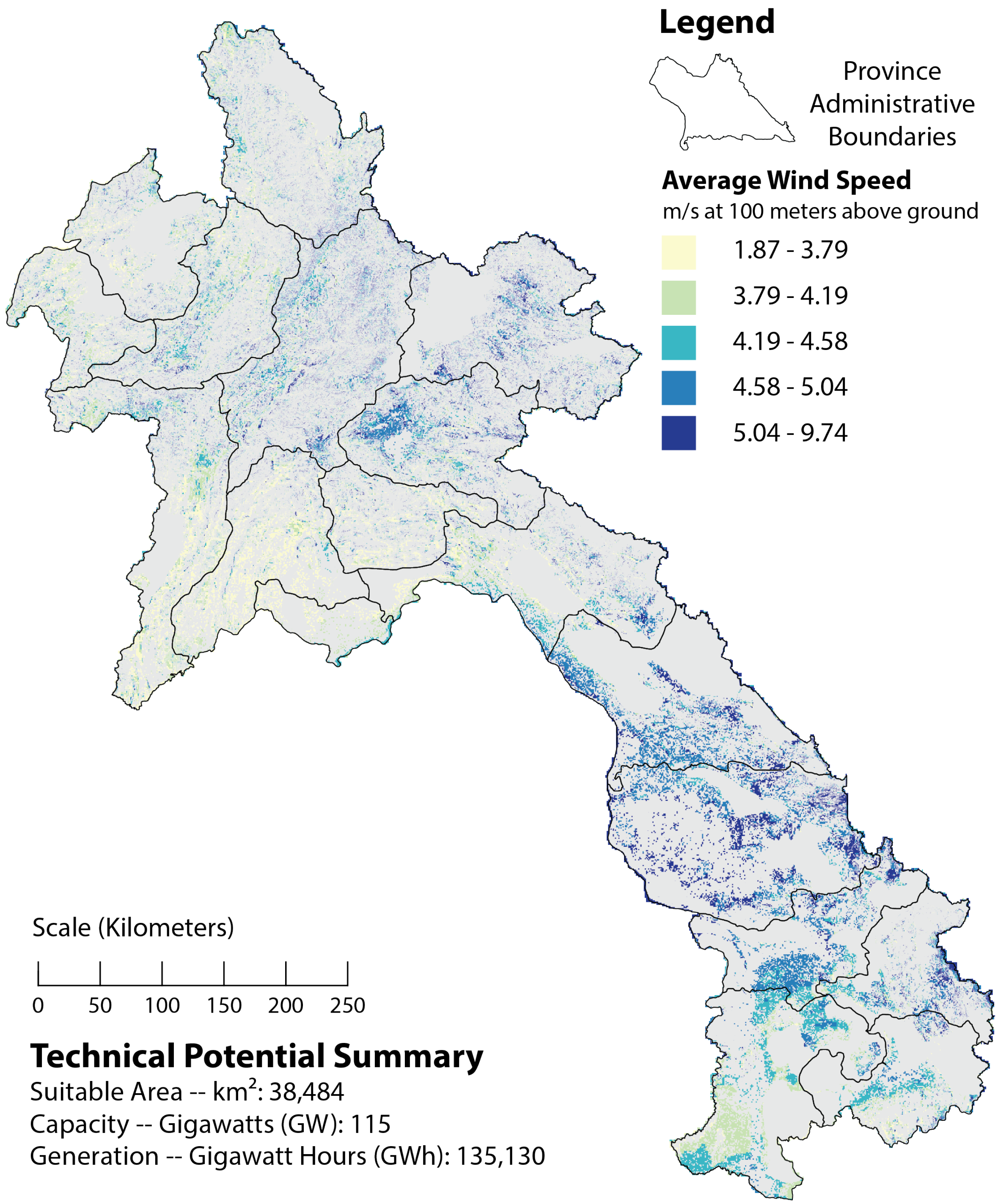

FIGURE B-8. MAP – WIND TECHNICAL POTENTIAL: SCENARIO 4 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AREAS WITH SLOPE > 20%, FORESTED AREAS, AND AGRICULTURAL AREAS

TABLE B-8. WIND TECHNICAL POTENTIAL: SCENARIO 4 WITH EXCLUSIONS FOR PROTECTED AREAS, WATERBODIES, WETLAND AREAS, AREAS WITH SLOPE > 20%, FORESTED AREAS, AND AGRICULTURAL AREAS

Wind Scenario 4	Potential Suitable Area (km^2)	Technical Potential		Capacity Factor (%)
		Capacity (GW)	Generation (GWh/year)	
Lao PDR (Total)	**38,486**	**116**	**135,129**	**13.25**
Province[23]				
Attapeu	1,290	4	4,254	12.55
Bokeo	1,204	4	3,056	9.66
Borikhamxay	2,323	7	7,249	11.87
Champachack	3,831	11	12,126	12.05
Huaphanh	1,678	5	7,408	16.79
Khammuane	2,787	8	12,761	17.42
Luangnamtha	1,079	3	2,863	10.10
Luangprabang	2,965	9	11,700	15.02
Oudomxay	1,981	6	6,076	11.67
Phongsaly	1,935	6	6,001	11.80
Saravane	2,284	7	9,852	16.42
Savannakhet	4,008	12	20,716	19.67
Sekong	1,175	4	4,889	15.84
Vientiane Prefecture	628	2	1,382	8.38
Vientiane	2,638	8	5,151	7.43
Xayabury	3,329	10	8,322	9.51
Xaysomboune	1,188	4	2,690	8.62
Xiengkhuang	2,163	6	8,633	15.19

[23] The province administrative boundaries of Lao PDR are shown in Appendix A. The spelling of all provinces of Lao PDR in this work follows the convention used in MEM (2015b).

Appendix C – Verifying spatial exclusions and priorities for Lao PDR

This appendix discusses the process taken to verify the spatial exclusions and priorities used for this GIS-based technical-potential assessment (see Section 2). This process was conducted with the Technical Committee of the Energy Alternatives Study and included (1) a discussion of the assumed exclusions and priorities for Lao PDR and initial results during the August 2017 Technical Potential and Levelized Cost of Energy Workshop and (2) a follow-up exercise on identifying spatial exclusions and priorities for energy development in Lao PDR.

As part of the August 2017 Technical Potential and Levelized Cost of Energy Workshop the technical potential assessment methodology was presented and discussed in detail with the Technical Committee of the Energy Alternatives Study. Following this discussion, the assumptions made for the technical-potential assessment for each technology considered were presented and discussed, together with preliminary results and accompanying maps. The feedback from these discussions was included in the current work. This feedback included further detailing of the technical-potential assessment methodology for a repeatable methodology that the Technical Committee could complete in the future. Also, the Technical Committee asked for consideration of areas potentially contaminated by UXO in the technical-potential assessment.

Following the workshop, the Technical Committee of the Energy Alternatives Study was invited to improve upon the preliminary results by identifying additional spatial exclusions and spatial priorities for energy development in Lao PDR. This feedback, while not received in time to provide input to the current work, could be used internally by the Technical Committee, together with the current work and datasets in future analyses to improve the technical-potential assessment for Lao PDR or to inform additional analyses.

Appendix D – Complementary dataset sources

This appendix lists the datasets and sources for datasets that complement the energy resource datasets identified in Section 2. These complementary datasets allow for the exclusion analysis conducted to assess the technical potential.

Category	Dataset	Description	Units	Source	Notes
Solar	Mean Annual Global Horizontal Irradiance	Long-term yearly average of daily totals of global horizontal irradiation (GHI) in kWh/m2, covering the period 1994/1999/2007 (depending on the region) to 2015. GHI is used as reference information for the assessment of flat-plate photovoltaic and solar heating technologies (e.g. hot water).	kWh/m2 /day	This data layer represents an output from the global solar model developed and owned by Solargis. It was commissioned by The World Bank with funding from the Energy Sector Management Assistance Program (ESMAP) under a global initiative on Renewable Energy Resource Mapping.	NREL cannot distribute these data but it can be downloaded from http://globalsolaratlas.info/
Solar	Capacity Factors	Capacity Factors providing annual average generation compared to nameplate capacity	%	Created from NREL processing of Global Horizontal Irradiance dataset	Can be created by users using the PVOUT dataset from the Global Solar Atlas http://globalsolaratlas.info/
Wind	Mean Annual Wind Speed	The DTU Global Wind Atlas project (GWA) has produced 250 m gridded data describing the predicted long-term wind climate over the globe. The data are in the form of wind speed frequency distributions for 12 direction sectors and frequency distributions for 12 direction sectors. These wind climate data are at 100 m above surface level. The post-processing includes aggregating the data into 1 km grid and projecting the data onto a single longitude latitude grid covering the world.	m/s	Data from DTU Wind Energy Global Wind Atlas, funded by Danish Energy Agency EUDP 11-II, Globalt Vind Atlas J.nr. 64011-0347	NREL cannot distribute this dataset but it can be downloaded from https://irena.masdar.ac.ae
Wind	Capacity Factors	Capacity Factors providing annual average generation compared to nameplate capacity	%	Created from NREL processing of Mean Annual Wind Speed dataset	Dataset can be created by users using the Mean Annual Wind Speed dataset from the Global Wind Atlas

Category	Dataset	Description	Units	Source	Notes
					http://globalwindatlas.com/
Admin	Country / Province Boundaries	Province- and Country-level administrative boundaries.	n/a	GADM	http://www.gadm.org/
Admin	Roads	Major Roads	n/a	OpenStreetMap Contributors	http://openstreetmap.org/
Admin	Population	Gridded Population of the World, Version 4 (GPWv4): Population Density Adjusted to Match 2015 Revision UN WPP Country Totals	people per km2	Center for International Earth Science Information Network - CIESIN - Columbia University	www.ciesin.org/data.html
Admin	UXO	A dataset depicting aerial bombing targets in Laos during the Vietnam War. These data do not depict the locations or probability of the existence of UXO but indicate the target of individual aerial bombing missions, which may be helpful in identifying land areas contaminated with UXO.	# of missions	Theater History of Operations (THOR) Data: Vietnam War — Digitized paper mission reports by location, mission data, and other attributes	Hosted on data.world: https://data.world/datamil/vietnam-war-thor-data. Also see the National Regulatory for UXO/Mine Action Sector in Lao PDR (UXO-NRA) for additional data and activities in Laos: http://www.nra.gov.la/bombinginformation.html
Admin	Protected Areas	Database of protected areas of IUCN categories I through VI, other protected areas and areas defined under international agreements.	n/a	World Database on Protected Areas Consortium, copyright World Conservation Union (IUCN) and UNEP-World Conservation Monitoring Centre (UNEP-WCMC)	NREL cannot distribute this dataset, but can be downloaded from https://www.protectedplanet.net/
Environmental	Land Use / Land Cover	GlobCover is an European Space Agency (ESA) initiative that began in 2005 in partnership with Joint Research Centre (JRC), European Environment Agency (EEA), Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Programme (UNEP), Global	n/a	GlobCover 2009	Categories aggregated into more generalized categories by NREL.

Category	Dataset	Description	Units	Source	Notes
		Observation of Forest and Land Cover Dynamics (GOFC-GOLD), and International Geosphere-Biosphere Programme (IGBP).			
Environmental	Slope	The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. The SRTM data are available as 3 arc second (approx. 90m resolution) DEMs.	%	CGIAR	Slope calculated using elevation DEM by NREL
Environmental	Rivers	River systems in the Greater Mekong Subregion	n/a	Asian Development Bank / Environment Operations Center (www.gms-eoc.org) based on UN FAO AGLW Hydrological Basins of Southeast Asia (www.fao.org/geonetwork)	Downloaded from https://opendevelopmentmekong.net/dataset/?id=greater-mekong-subregion-river s
Environmental	Coal Deposits	A dataset containing coal deposits in Lao PDR compiled by the World Bank for the "Sector Plan for Sustainable Development of the Mining Sector in the Lao PDR" and published in November of 2006. This dataset presents major known deposits based on information from the Lao Department of Geology and Mines, exploration reports, private-sector feasibility studies, and additional information shared by mining companies. The deposit values reported are for the total of reserves and resources in 1,000 tons. Detailed characteristics on each of the deposits can be found in the World Bank report. Reserves consist of identified deposits that are likely to be economically feasible. Resources consist of deposits that are undiscovered (hypothetical and speculative) as well as identified deposits that are not economically feasible. Reserves are therefore not a subset of resources following this definition from McKelvey (1967).	Ton	The World Bank	This data layer has been added to the RE Data Explorer for Lao PDR at http://re-explorer.org/

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