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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

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List of acronyms and abbreviations

ADB	Asian Development Bank
CFSR	Climate Forecast System from NCEP
DEDE	Department of Alternative Energy and Efficiency, Silpakorn University, Bangkok, Thailand
DEPP	Department of Energy Policy and Planning of the Lao MEM
DHI	diffuse horizontal irradiance
DNI	direct normal irradiance
DTU	Danish Technical University
EDL	Électricité du Laos
GHI	global horizontal irradiance
GIS	geographic information system
IREP	Institute of Renewable Energy Promotion of the Lao MEM
Energy Alternatives Study	Energy Alternatives Study for the Lao PDR—Smart Infrastructure for the Mekong Program
Lao PDR	Lao People's Democratic Republic
LCOE	levelized cost of electricity (or energy)
LHV	lower heating value
MEM	Lao Ministry of Energy and Mines
MERRA	Modern-Era Retrospective Analysis for Research Applications from NASA
MONRE	Lao Ministry of Natural Resources and Environment
NASA	U.S. National Aeronautics and Space Administration
NCEP	U.S. National Centers for Environmental Prediction
NREL	U.S. Department of Energy's National Renewable Energy Laboratory
PV	photovoltaic
QC	quality control
RE	renewable energy
ReEDS	Regional Energy Deployment System from NREL
SIM	Smart Infrastructure for the Mekong
TMY	typical meteorological year
U.S.	United States
USAID	United States Agency for International Development

Executive summary

In an effort to address concerns such as energy security, reliability, affordability, and other objectives, the Government of the Lao People's Democratic Republic (Lao PDR) is seeking to advance its expertise and experience in energy system analysis and planning to explore energy alternatives. Assessing the potential and alternatives for deploying energy technology options is often an early step—and, in most cases, an ongoing process—in planning for the development of the energy sector as a whole. Reliable and robust data are crucial to conducting these types of planning-related analyses in a transparent manner that builds confidence among power sector stakeholders and encourages investment in future energy project development and infrastructure opportunities.

The Lao PDR is home to abundant energy resources, although the country's current fuel mix is based on relatively few of these resources—approximately 62.1% of existing electricity generation is hydropower-based, 37.5% is coal-based, and the remainder is biomass-based (MEM 2016). Power sector decision makers are increasingly interested in understanding the potential role of energy resources beyond hydropower in the future of their nation's electricity system. To this end, the Lao Ministry of Energy and Mines (MEM) is working to improve its tools, data, and analytic capacity to inform energy planning to 2030. This includes building capacity within MEM to analyze the opportunities for, and the impacts of, future energy system investment alternatives that could diversify its electricity generation mix and help ensure energy security and economic growth. To contribute to these efforts, the objective of this report is to support MEM in assessing the availability and quality of energy resource data that will serve as a foundational input to technical potential, economic potential, and other planning-related analyses of Lao PDR's domestic energy technologies.

The current report represents the first output of the Energy Alternatives Study for the Lao PDR (Energy Alternatives Study), a collaboration between MEM and the United States Agency for International Development under the auspices of the Smart Infrastructure for the Mekong (SIM) program.[1] The Energy Alternatives Study includes five tasks that build upon each other to meet the goals of the project as shown in FIGURE ES-1.

This report summarizes the availability, quality, and accessibility of data that serve as key inputs to energy planning activities for the power sector. The purpose of this data assessment is two-fold:

1. To facilitate the informed use of existing data by highlighting applications for these data as they relate to priority energy planning analyses
2. To inform future investments in energy data collection and management by identifying significant data gaps and providing guidance on how to fill these gaps.

[1] 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.

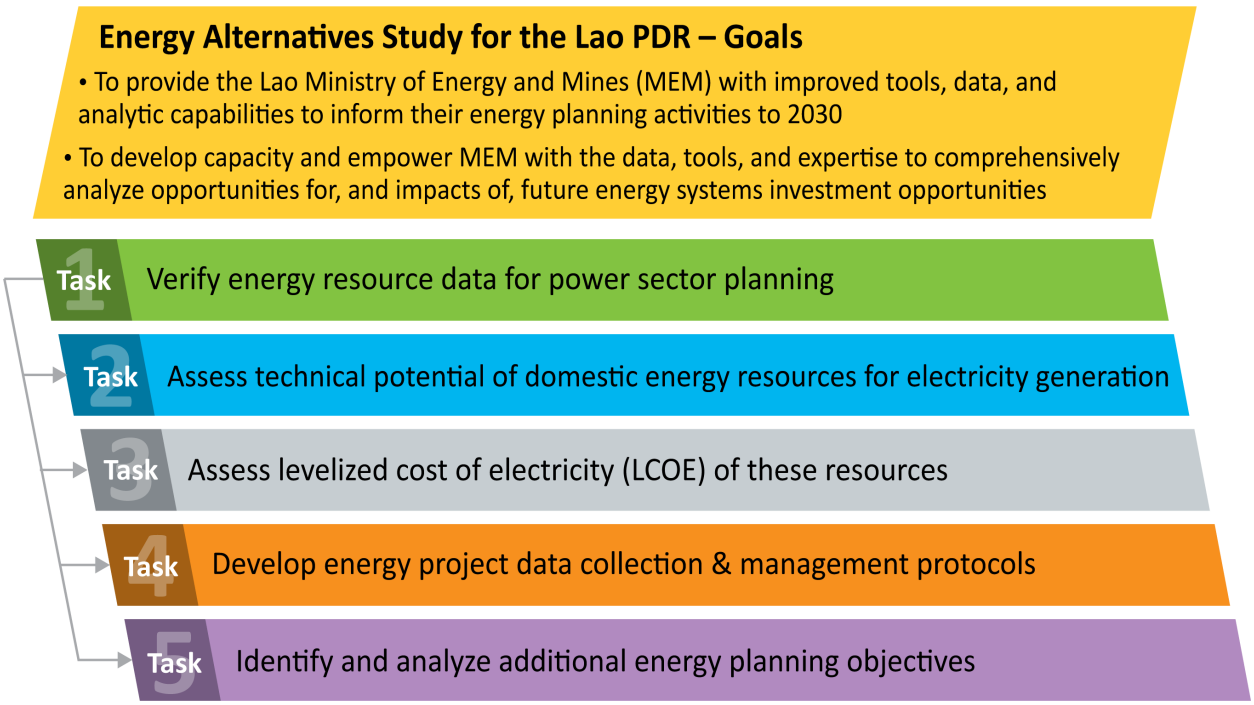

FIGURE ES-1. GOALS AND TASKS OF THE ENERGY ALTERNATIVES STUDY FOR THE LAO PEOPLE'S DEMOCRATIC REPUBLIC

The data identified in this assessment will inform the Energy Alternatives Study as well as future energy planning and energy alternative evaluation activities conducted by decision makers in Lao PDR. In addition, the data identified and gathered in this data assessment have been used to the extent possible to update the Renewable Energy Data Explorer (RE Data Explorer) datasets for Lao PDR.[2] RE Data Explorer is a no-cost, web-based application to facilitate RE decision making, investment, and deployment through a dynamic, online analytical tool. Users can visually explore spatial datasets for renewable energy (RE) resources, and related geographic information system (GIS) datasets as well as complete technical potential analyses for a set of the RE resources. The RE Data Explorer functionality for Lao PDR will be expanded as additional data and information are gathered (see Section 6 for details on the RE Data Explorer application).

TABLE ES-1 summarizes the data assessment for the priority energy planning analyses considered in this work. These analyses are:

- Technical potential of energy resources—the achievable energy capacity and generation of a particular technology, given resource potential, system performance, topographic limitations, and environmental and land use constraints
- Levelized cost of electricity—an economic assessment of the net present value of a unit cost of electricity—for example, US$/kWh—that can be used to compare different electricity generation technologies on a consistent basis.

The data assessment presents the datasets identified through a comprehensive data gathering activity conducted in partnership with MEM. This assessment is not intended to be a definitive assessment of

[2] Find additional information on the RE Explorer website at re-explorer.org.

energy resource data for the Lao PDR, as the existence and availability of data are dynamic issues and additional datasets may be identified in future work.

The energy resource data identified for Lao PDR is sufficient for the energy planning analyses included in this assessment; however, higher-resolution data for solar, wind, and biomass resources will become increasingly important in the medium and long term to increase the accuracy of these analyses and to support subsequent as well as related analyses. In addition, non-exploited hydropower resources data were not identified in this assessment, but would be necessary for any comprehensive technical potential analysis.

In addition to energy resource data, complementary data on environmental, land use, infrastructure, and other relevant features are available to conduct spatial analyses that support the identification of siting considerations that will impact the development of energy resources. However, many of the publicly available datasets describing these features are produced by either regional or global organizations and therefore may not reflect the most up-to-date and relevant information for the Lao PDR. Agencies within the government of the Lao PDR also maintain mostly nonpublic datasets that can inform analysis; however, some gaps appear to exist in these locally developed datasets. Specifically, recent, verified spatial data depicting the Lao transmission system were not available, but could support the calculation of the levelized cost of electricity. Also, detailed land use and development data and other data that can help in depicting areas of exclusion for energy development were not available, limiting the technical potential analysis.

TABLE ES-1. SUMMARY OF DATA-GAP ASSESSMENT

Datasets[1]	Gaps in existing data	Are sufficient data currently available for energy planning analyses?[2]	
		Technical Potential[3]	Levelized Cost of Electricity
Energy resource data			
Solar	Modeled hourly resolution solar irradiance data for multiple years or a typical meteorological year (TMY)	Yes	Yes
Wind	Modeled hourly resolution wind resource data for multiple years or a TMY	Yes	Yes
Hydro	Spatial data for estimation of non-exploited hydropower resources	No	Yes
Biomass	Finer resolution crop residue, forest residues, and biogas resource estimates	Yes[3]	Yes
Geothermal	No identified domestic resources; database and maps of resources	N/A	N/A
Coal	Database and maps of coal resources and reserves including existing and unexplored coal prospects	Yes[3]	Yes
Petroleum	No identified domestic petroleum, natural gas, or nuclear resources	N/A	N/A
Natural gas		N/A	N/A
Nuclear		N/A	N/A
Complementary data			
Power network	Spatial data depicting the transmission system (lines and substations, distribution network)	N/A	No
Ancillary meteorology	Modeled hourly ancillary meteorology datasets—for example, air temperature, air pressure, dew point	Yes	N/A
Environment	Detailed local land use and other data that help identify siting constraints for energy development—for example, protected areas or urban areas	No	N/A
Market and demand	Finer spatial and temporal resolution electricity consumption, import, and export data	N/A	N/A
Transportation	Local spatial data depicting roads, railroads, and riverports	Yes	N/A
Administrative and other	Updated public datasets for population and housing as well as special economic zones	Yes	N/A
Electricity generation costs	Cost and other data for wind and biomass technologies; data for mini-grid and stand-alone systems	N/A	Yes

Yes—Sufficient data for analysis No—Insufficient data for analysis N/A—Not applicable or required for analysis or no domestic energy resources

[1]Additional details can be found in the corresponding data assessment of Section 4.

[2]Refer to Section 3 for a description of the energy planning analyses listed here.

[3]Technical potential analysis does not apply to non-site-specific resources; instead, a site feasibility analysis for these is conducted (see Section 3).

Taking strategic actions in the short, medium, and long term could help MEM address the gaps identified in this assessment and provide for current and potential future data needs. Investing in foundational datasets will likely facilitate a wide range of useful analyses. In the short term, this may consist of procurement from a private data firm and/or efforts to increase data sharing between government ministries. Foundational datasets include both energy resources and complementary datasets that support both technical potential, levelized cost of electricity, and subsequent analyses. An internal validation of the results of this data assessment by MEM and a detailed mapping of data needs to local government ministries and organizations that produce them would support filling data gaps with local data and avoid the need to develop or procure additional data. MEM could also begin to build relationships with other government and non-government organizations that could share key complementary data—for example, a national meteorology institute.

In the medium term, MEM could take steps to ensure that they have the capacity to collect and maintain increasing amounts of data. This could consist of building in-house human capacity (e.g., spatial data and scientific computing experience) and infrastructure (e.g., computer hardware) to collect, maintain, share, and use data. Establishing a protocol and defining responsibilities for the collection and maintenance of spatial and related data would greatly aid MEM in future data collection and use.

Finally, in setting a strategy for the long term, MEM could consider developing the infrastructure and human resources to collect and maintain local, *best-in-class* energy resource data that are specific to Lao PDR. This may include developing a network of meteorological towers that allow for development and validation of RE resource data. This would allow MEM to be both a developer and consumer of the data required for analyses.

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1 Introduction

In an effort to address concerns such as energy security, reliability, affordability, and other objectives, the government of the Lao People's Democratic Republic (Lao PDR) is seeking to advance its expertise and experience in energy system analysis and planning to explore energy alternatives. Assessing the potential and alternatives for deploying energy technology options is often an early step—and, in most cases, an ongoing process—in planning for the development of the energy sector as a whole. Reliable and robust data are crucial to conducting these types of planning-related analyses in a transparent manner that builds confidence among power sector stakeholders and encourages investment in future energy project development and infrastructure opportunities.

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This report represents the first 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 (USAID) under the auspices of the Smart Infrastructure for the Mekong (SIM) program.[3] The Energy Alternatives Study includes five tasks that build upon each other to meet the goals of the project as shown in FIGURE 1.

This report summarizes the availability, quality, and accessibility of data that serve as key inputs to energy planning activities. The purpose of this data assessment is two-fold:

1. To facilitate the informed use of existing data within priority energy planning analyses
2. To inform future investments in data collection and management by identifying significant data gaps and providing guidance on how to fill these gaps.

[3] 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.

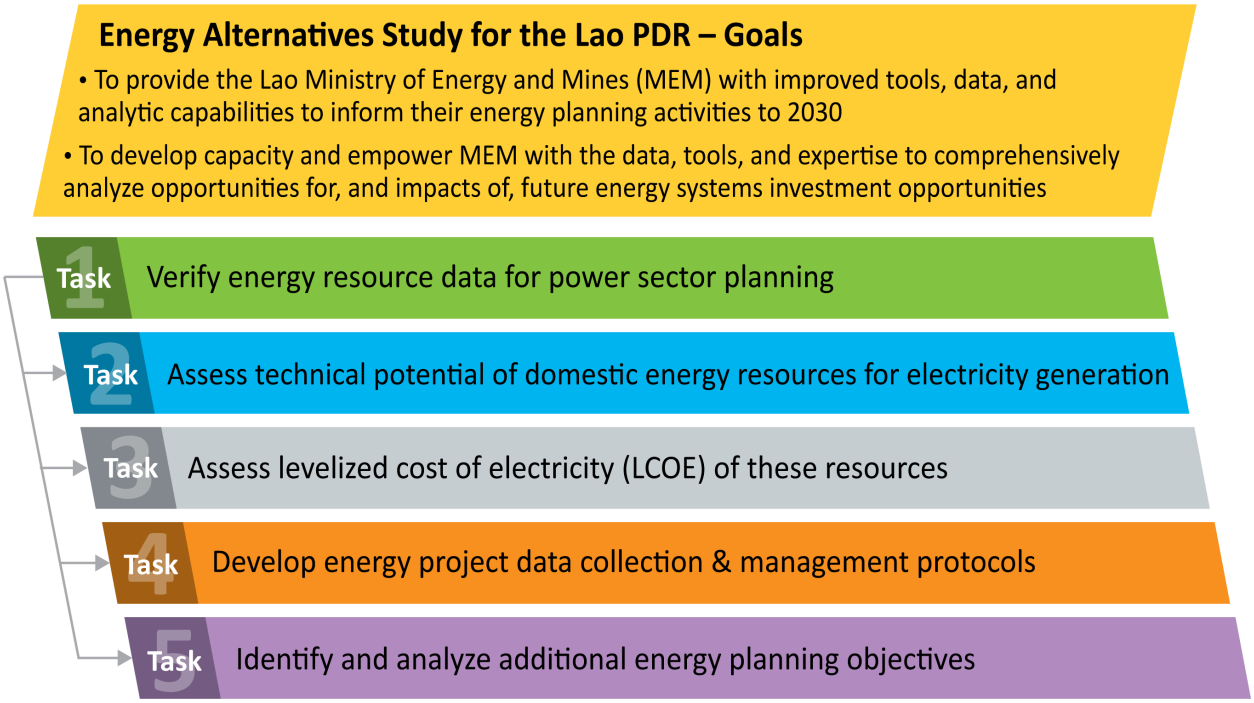

FIGURE 1. GOALS AND TASKS OF THE ENERGY ALTERNATIVES STUDY FOR THE LAO PEOPLE'S DEMOCRATIC REPUBLIC

The data identified in this assessment will inform the Energy Alternatives Study as well as future energy planning and energy alternative evaluation activities conducted by decision makers in Lao PDR. In addition, the data identified and gathered in this data assessment have been used to the extent possible to update the Renewable Energy Data Explorer (RE Data Explorer) datasets for Lao PDR.[4] RE Data Explorer is a no-cost, web-based application to facilitate RE decision making, investment, and deployment through a dynamic, online analytical tool. Users can visually explore spatial datasets for renewable energy (RE) resources, and related geographic information system (GIS) datasets as well as complete technical potential analyses for a set of the RE resources. The RE Data Explorer functionality for Lao PDR will be expanded as additional data and information are gathered (see Section 6 for details on the RE Data Explorer application).

A team from the United States (U.S.) Department of Energy's National Renewable Energy Laboratory (NREL) conducted this assessment in collaboration with MEM and other power sector stakeholders, drawing on lessons learned from experience conducting a wide range of energy planning analyses internationally. This work is not intended to be a definitive assessment of energy resource data for Lao PDR, as the existence and availability of data are dynamic issues, and additional datasets may exist and/or be under development to inform future work by MEM and other actors.[5]

[4] Find additional information on the RE Explorer website at re-explorer.org.

[5] This data assessment for the Lao PDR was also closely coordinated with a concurrent data assessment of the Lower Mekong, completed by NREL to support the USAID Clean Power Asia program, which works with Lower Mekong Countries and other Association of Southeast Asian Nations member states to bring greater quantities of RE into the region's electricity grid (Lopez et al. Forthcoming). While the Lower Mekong data assessment focuses specifically on data needs associated with planning for high levels of RE in the region, the data assessment for this Energy Alternatives Study includes considerations related to evaluating technical and economic potential of energy resources in the Lao PDR. The close coordination of these two efforts has enabled synergies in data collection and verification for overlapping energy planning analysis topics and has presented an opportunity to reinforce understanding of data needs and priorities with actors in the Lao PDR.

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

- Section 2 presents the approach taken for identifying and verifying energy resource data with MEM counterparts.
- Section 3 provides a brief summary of several priority energy planning analysis topics and the general data requirements associated with each of them.
- Section 4 consists of an assessment of the data availability for Lao PDR that would support the priority energy planning analyses and a summary of the priority data available and the gaps that remain.
- Section 5 presents potential approaches to identifying and acquiring necessary data to fill existing priority data gaps, along with strategies for working with imperfect data.
- Section 6 highlights the data identified and gathered in the RE Data Explorer and the Data Catalog and how these web applications support energy planning analyses.
- Section 7 summarizes the outputs of this activity, how these outputs will support energy planning analyses, and next steps in addressing data gaps and using data in the remaining Energy Alternatives Study tasks.

2 Data assessment approach

Energy planning analyses span a multitude of topics and can range in scope from the level of the individual natural gas power plant, wind turbine, or solar panel component to interactions across the electricity system, within power system and transmission system modeling activities. **The scope of any particular energy planning analysis drives its data requirements**. Thus, this data assessment is focused on three medium- to long-term power-system level analysis topics identified as priorities for Lao PDR in the context of the Energy Alternatives Study (and described further in Section 3):

- Estimation of the technical potential of energy resources (Energy Alternatives Study Task 2)
- Estimation of the economic potential of energy resources (Energy Alternatives Study Task 3)
- Analysis of additional objectives beyond least cost that could change the relative attractiveness of technologies and alternatives considered (Energy Alternatives Study Task 5).

This data assessment is resource and technology neutral; it includes both RE and non-RE resources of interest to the Lao PDR. This scope is intended to provide a comprehensive perspective on all domestically-available, commercialized generation technologies as Lao PDR actors conduct analyses and consider the relative merits and tradeoffs of different technologies. Energy resources that pertain to emerging technologies, such as enhanced geothermal—also known as engineered geothermal energy or hot dry rock energy—are beyond the scope of this analysis. The following energy resources are included in the assessment:

- Biomass
- Geothermal
- Hydropower
- Solar
- Wind
- Coal
- Natural gas
- Nuclear
- Petroleum

Guided by experts from MEM and other Lao agencies, NREL identified the best available datasets for use in each of the priority analyses listed above. These datasets include energy resource data as well as ancillary data that characterize geography, infrastructure, population distribution, and other factors that influence the development of RE resources.

NREL started the data identification process with an initial data search for publicly available data from international sources—for example, the World Bank, International Renewable Energy Agency, and other sources such as the Technical University of Denmark (DTU). NREL worked with the Technical Committee of the Energy Alternatives Study and Lao organization stakeholders to further refine and verify the outputs of this initial data sweep during the Workshop *Exploring and Analyzing Energy Resource Data* held together with MEM and USAID in the capital of Lao PDR, Vientiane, in April 2017 (Hayter et al. 2017).

Collecting and making sense of energy resource data and supporting ancillary data to inform decision making can be a complex task. The use of GIS for analysis and mapping for enhanced cognitive understanding can help decision makers make more informed decisions, because data feeds analysis and analysis informs decisions. The data assessment focused specifically on the availability of spatial data (GIS-based), which are particularly powerful, given the site-specific nature of many RE resources and the siting feasibility of resources not intrinsically tied to location. These include both non-RE—for example, coal and natural gas—and RE resources such as biomass. The key parameters for the identified datasets of interest included the:

Source	The organization(s) that produces, maintains, and/or disseminates the dataset
Spatial resolution	The finest resolution of the area covered by the dataset—for example, 1 km x 1 km grid cells, discrete sites
Geographic coverage	The administrative area that the dataset covers—for example, Lower Mekong subregion, Lao PDR, Vientiane
Temporal range	The total period of time that is observed in the data—for example, one year, multiple years, or a typical meteorological year (TMY)[6]
Temporal resolution	The time steps taken in the dataset—for example, annual, monthly, hourly
Vintage	The year in which the dataset was published
Format	The file type in which the dataset is available—for example, tabular, shape file
Accessibility	Any limitations on who may access this dataset, and/or if there is a cost associated with the dataset (publicly available, available for purchase, for official use only)
Language	The language(s) in which the data are available.

The data identified and gathered in this data-gap assessment were used to update the RE Data Explorer datasets for Lao PDR. RE Data Explorer allows users to visually explore spatial datasets for RE resources, non-RE resource deposits, and other base infrastructure. The application also enables users to visualize the energy resources and complete technical potential analyses for a set of the RE resources. As additional data and information are gathered, the RE Data Explorer functionality for Lao PDR will be expanded (see Section 6 for details on the RE Data Explorer application).

The outputs of this data verification process are presented in the data assessment (Section 4), and TABLE A-15 of Appendix A presents a list of the datasets identified in this data assessment. Additionally, Section 5 discusses approaches to addressing data gaps, and TABLE B-1 of Appendix B shows a summary of additional, potential, local sources of data identified by the Technical Committee of the Energy Alternatives Study.

[6] TMY data contain hourly or sub-hourly data that typify conditions at a specific location over a long period of time, such as 30 years. TMY datasets are not averages. TMY datasets are created by force-sampling values from the multi-year dataset for each period (for instance, in a monthly TMY dataset, January and March may be sampled from different years in the multi-year dataset). TMY is the preferred data type for technical potential analyses because it represents typical patterns (such as seasonality) over a long period, and help to smooth the impacts of unusual conditions such as drought or El Niño. Multiple years of data can also be used where TMY data are not available.

3 Priority energy planning analyses topics for Lao People's Democratic Republic

This section broadly introduces the priority energy planning analysis topics considered within the scope of the Energy Alternatives Study project to provide context to the data assessment (Section 4).

3.1 Resource potential

The development of a quantified understanding of energy resource potentials is a crucial preliminary energy planning analysis step. Energy resources—for example, solar, hydro, wind, coal, natural gas, etc.—are the primary input to the energy supply and demand balance. Demand for energy services provided by electricity—for example, lighting, cooling, water heating, etc.—is, for the most part, not dependent on the resources that supply this electricity; however, the different electricity generation technologies that supply this electricity are fundamentally tied to the availability of particular energy resources (Rogner et al. 2012). Therefore, any assessment of energy planning alternatives requires a detailed understanding of the energy resources available—including type and quantity, the location of these resources, and the technical and economic constraints that may impact their use. Not all physically available energy resources may be developable due to technical constraints to development in protected areas, certain terrain features, populated urban zones, water bodies, and other relevant constraints. Additionally, economic constraints may further limit these technically available resources to those that can be developed and provide for electricity generation at a cost below available project revenues. These considerations are important for identifying energy planning alternatives that are based on a technically and economically screened understanding of energy resource availability (Brown et al. 2016).

Any discussion of technical potential must start with the resource potential—i.e., the theoretical availability of various energy resources—as this is a foundational input to the subsequent analyses of technical potential and economic potential. The definition of resource potential and its relationship to the types of generation potential differs for RE and non-RE resources. Therefore, it is important to make a distinction between these definitions and clarify how they are addressed in the current assessment. FIGURE 2 presents the types of RE generation potential analyses and the relationship that resource potential has to these analyses as a foundational input. Technical potential and economic potential are discussed in detail in the sections that follow.

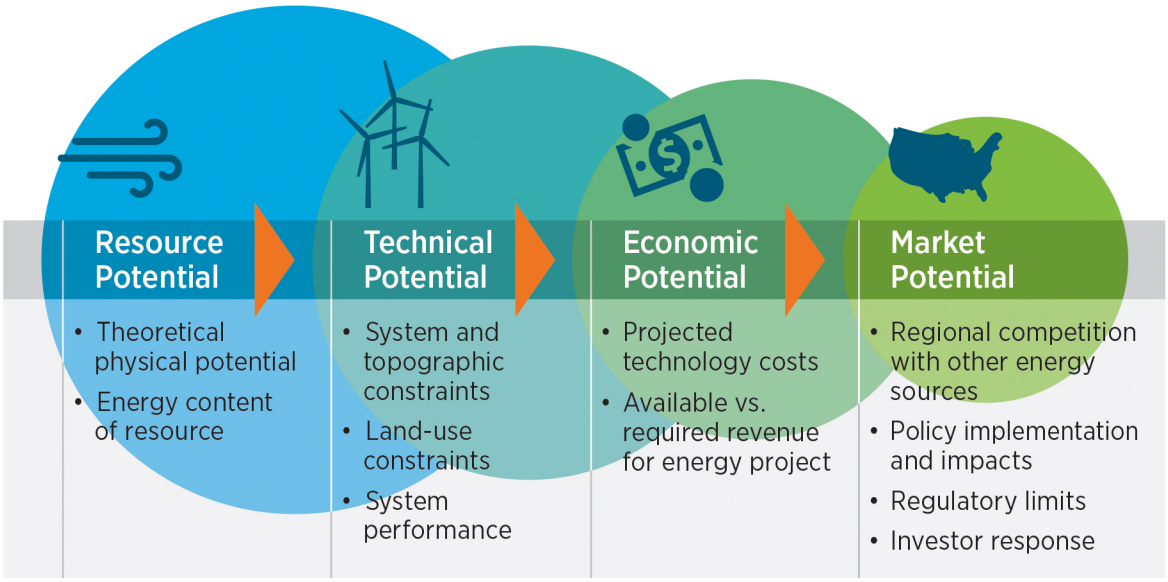

FIGURE 2. TYPES OF RENEWABLE GENERATION POTENTIAL

(Brown et al. 2016)

Nonrenewable resources differ from RE resources in many regards and care must be taken with any work that attempts to compare resources or the output of analyses that consider both RE and non-RE resources. Non-RE resources are often described through characterizations of resources and availability assessments that seem analogous to those of RE resources. Although these terms may be analogous to RE resources, the values that they describe should not be immediately considered quantitatively comparable (Rogner et al. 2012; Brown et al. 2016).[7]

In general, non-RE energy sources, specifically fossil fuels, are described in terms of resources, proven reserves, and production. FIGURE 3 shows the relationships and principles of these non-RE classifications. Non-RE "resources" is a term that refers to the total quantity of discovered and undiscovered primary energy 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 and the term is analogous to RE economic potential. The term "production" 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.

[7] Of note here is the fact that 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 (Btu, 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 resources available annually (TWh/year) (Brown et al. 2016).

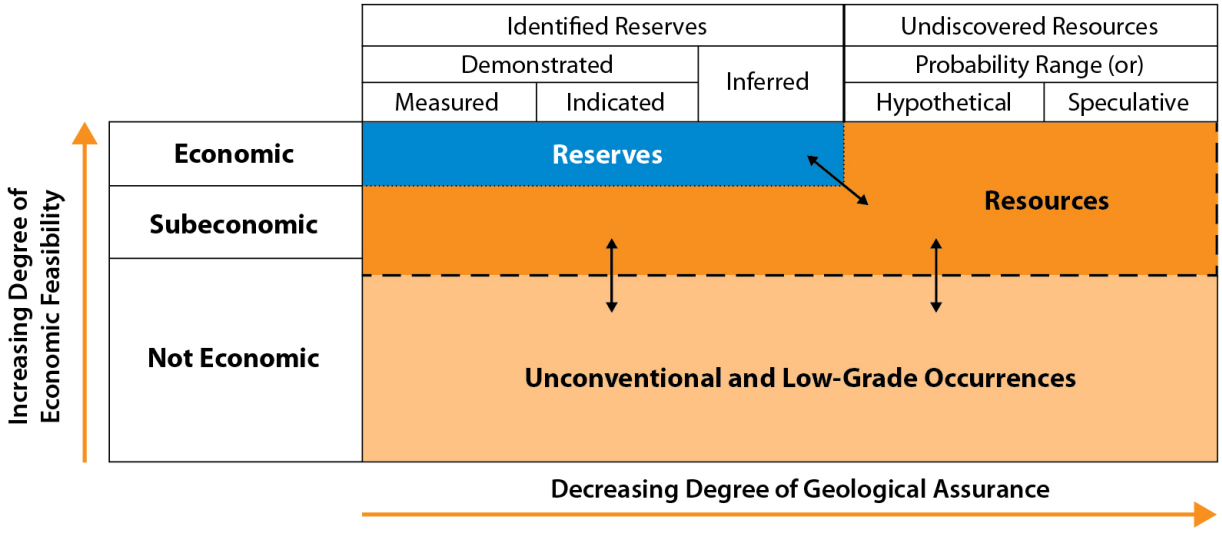

FIGURE 3. PRINCIPLES OF NONRENEWABLE RESOURCE CLASSIFICATION

Adapted from McKelvey (1967) and Rogner et al. (2012)

In addition to the classifications of RE and non-RE resources, these resources can be separated into site-specific and non-site-specific resources. The approaches to representing the resource potential for these site-specific and non-specific resources differ. Site-specific resources must be used for electricity generation at the site where they are available, i.e., solar, wind, geothermal, hydro, etc., and resource potentials can be represented visually as a layer of the total resources available where they would have to be used, pending further exclusion layers. Non-site-specific resources can be transported to the site where electricity is generated—for example, biomass, coal, natural gas, petroleum, etc. The resource potential layer represents where these resources are available and may be represented by the specific location of deposits. These resources may also be transported to a different site for electricity generation, however.

3.2 Technical potential

Technical potential represents the achievable energy capacity and generation of a particular technology given resource potential, system performance, topographic limitations, and environmental and land use constraints (FIGURE 2). Estimating the technical potential of various energy resources is an important planning tool because it establishes an upper-boundary estimate of energy resource development potential (Lopez et al. 2012).

The technical potential analyses discussed here build upon established methodologies for assessing the technical potential of RE resources and equivalent, comparable methodologies for non-RE resources where applicable. Verified existing estimates of non-RE resource potential can be used where available. Existing estimates of non-RE resource potential and non-site-specific resources—for example, biomass, coal, etc.—can be augmented by using geospatial analysis to identify where power plants could feasibly be sited.

3.2.1 Renewable energy resources

RE technical potential represents the achievable energy capacity and generation of a particular technology, given resource potential, system performance, topographic limitations, and environmental and land use constraints. Technical potential provides an upper boundary for RE deployment and serves as a fundamental input into many different types of RE analysis.

Technical potential for RE resources can be calculated through spatial analysis, a process that begins with filtering out the geographic areas that are technically infeasible to develop from a base layer of theoretical

RE resources. After the spatial analysis, a calculation of the generation potential of the remaining area is done using a generator model. RE technical potential data requirements—for site-specific and non-site-specific resources—include:

- Data depicting resource at a continuous surface and continuous spatial resolution, at hourly temporal resolution for RE generator modeling
- Solar: <10 km x 10 km nominal spatial resolution
- Wind: <2 km x 2 km nominal spatial resolution
- Protected areas
- Urbanized areas and/or population density
- Natural features
- Monuments and parks
- Terrain and terrain features—for example, elevation, slope, etc.
- Land use/land cover
- Other known exclusions, constraints, and stakeholder concerns.

Non-site-specific resources—i.e., biomass—can be augmented by using geospatial analysis to identify where power plants could feasibly be sited. The data requirements for site feasibility analyses are typically equivalent to those listed above.

3.2.2 Nonrenewable resources

Site feasibility can be used as a proxy analysis for non-RE resources, as there is no analogous technical potential analysis methodology for non-RE resources and the classification of resources, reserves, and production cannot be directly mapped to the terms used for RE resources. This allows for a spatial layer to be developed that represents the developable areas where power plants could potentially be sited. Additional analyses outside the scope of this work—for example, multicriteria analyses and optimization studies—could be employed to indicate the most attractive sites for development (Wu, Wang, and Strager 2011; Mays et al. 2012; Sultana and Kumar 2012; Silva, Alçada-Almeida, and Dias 2014; Rice et al. 2015).

A site feasibility of non-RE, non-site-specific resources begins with spatial layers of resources and reserves and the establishment of a set of exclusion layers and siting criteria specific to each resource type—for example, coal, natural gas, petroleum, nuclear, etc.—that are then used in a filtration process that produces composite suitability layers. These suitability layers may be visualized in maps that indicate the potential suitable sites for development of power plants for each technology type. The site suitability analyses data requirements include:

- Spatial resolution layers indicating the resources and reserves for each non-RE resource type—for example, coal, natural gas, petroleum, and nuclear
- Exclusion area data and layers equivalent to those listed above for RE resources
- Additional criteria indicating priority development areas and non-RE resources to develop
- Other criteria used in conjunction with the exclusion area data—for example, proximity to cooling water; proximity to urban areas, airports, protected areas, etc.; and proximity of coal mines that contain resources of a specific quality.

3.3 Economic Potential

Economic potential is a measure of capacity and generation potential. It is defined as the subset of the available resource technical potential where the cost required to generate the electricity, which determines the minimum revenue requirements for development of the resource, is below the revenue available in terms of displaced energy and displaced capacity (FIGURE 2).

3.3.1 Levelized cost of electricity

The economic potential analysis in this work is a levelized cost of electricity (LCOE) calculation. The LCOE is an economic assessment of the net present value of a unit-cost of electricity—for example US$/kWh—that can be used to compare different electricity generation technologies on a consistent basis. With the LCOE for each resource type considered, the unit cost of electricity of each generation technology type can be compared. FIGURE 4 shows an example of LCOE for the electricity generation technologies for the United States from the Transparent Cost Database (OpenEI 2017).

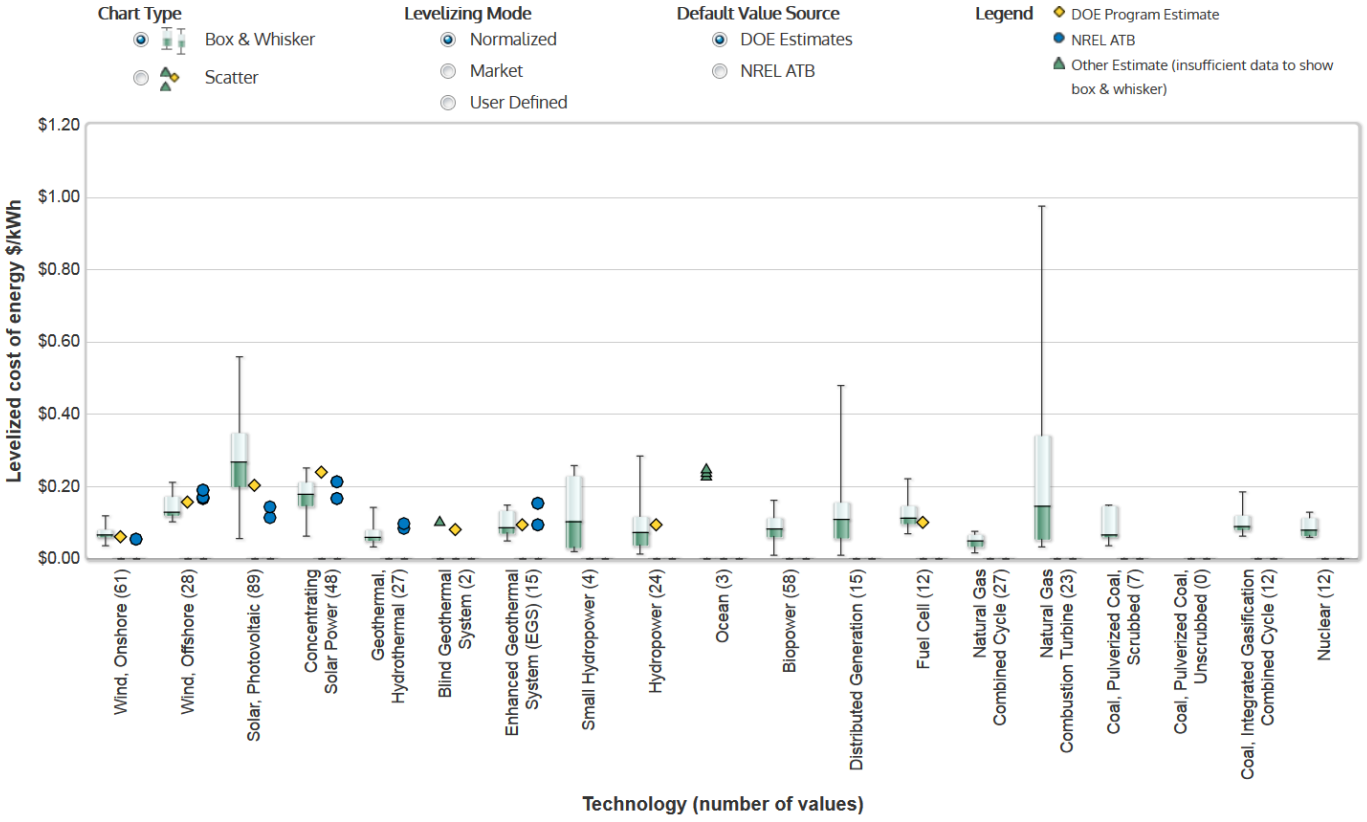

FIGURE 4. EXAMPLE OF LEVELIZED COST OF ENERGY (OR ELECTRICITY) FOR GENERATION TECHNOLOGIES IN THE UNITED STATES

Adapted from OPEN EI (2017)

This report concentrates on the data requirements for energy resource assessments and the subsequent tasks of the Energy Alternatives Study, including Task 3 on calculating LCOE. The methodology for calculating LCOE will be further described within Task 3 activities; however, the data requirements are discussed here.

The life cycle costs of the system and its components, the rate at which performance of technologies degrades, and the operation and maintenance requirements all affect the cost of electricity. The cost of electricity is also affected by project financing and incentives. The key datasets required, beyond the

technical potential, for each resource type—for example, wind, solar, biomass, geothermal, coal oil, natural gas, or nuclear—include:

- Investment cost by system size (US$ [or Laotian kip] and/or US$/W]
- Fixed operation and maintenance cost by generation system type (US$/kW)
- Variable operation and maintenance cost by generation system type (US/kWh)
- Fuel cost (US$/liter, US$/ton of biomass, $/MMBtu etc.)
- Capacity (or utilization or use) factor by generation system type (%)
- Annual electricity generation by type of generation system (MWh/year)
- Heat rate or efficiency of the power plant in converting fuel into electricity (% or Btu/kWh)
- System degradation rate (%/year).

Task 3 will estimate the LCOE for utility-scale generation technologies at the national level in Lao PDR; however, future initiatives may benefit from efforts to develop spatially referenced LCOEs. Examples of the development and use of spatially referenced LCOEs can be seen in Kline, Heimiller, and Cowlin (2008) and Brown et al. (2016).

Multiple factors beyond the direct costs of investment and operation and maintenance may also factor into the value framework for considering technology alternatives and therefore can be included in the LCOE estimation. These may include social, environmental, and economic factors such as population relocations, impact on fisheries, job creation, and/or others. These will be explored in detail within Task 5 of the Energy Alternatives Study.

4 Data assessment for Lao PDR

The data-gap assessment presented in this section focuses on the data that would support the priority energy planning analyses introduced in Section 3. The assessment is organized according to the appropriate data categories (Section 2). The section closes with a summary of the data available and the priority gaps that remain. Detailed data-gap assessment tables corresponding to each of the energy resources discussed in this section are included in Appendix A.

4.1 Energy resources

4.1.1 Solar

Highlights of data-gap assessment

Highest quality, freely available solar resource data available from the World Bank:

- Long-term annual average global horizontal irradiance
- Long-term annual average direct normal irradiance
- Long-term annual average optimal-tilt photovoltaic (PV) electricity output
- Fine spatial resolution of 1 km x 1 km.

Analysis applications of existing data

- Technical potential
- LCOE.

Recommendations to address data gaps

- Create or procure modeled, high temporal-resolution data, hourly solar irradiance for multiple years or a TMY with high spatial resolution (nominal 10 km x 10 km) to enable research into existing/future utility-scale PV systems—for example, 1-axis tracking, fixed-tilt, etc.; rooftop PV at various orientations and tilts; and additional energy planning analyses such as grid integration studies.

Solar resource, for application in RE analysis, is typically described as global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DHI). The highest quality publicly available solar resource dataset comes from the World Bank, which recently commissioned a long-term (covering the period of 2007 to 2015), global annual average dataset modeled by SolarGIS that includes GHI, DNI, and DHI.[8] The data are of high spatial resolution providing insights into spatial variability and impacts of terrain on beam irradiance. In addition, the solar resource dataset includes modeled fixed-tilt photovoltaic (PV) electricity output using optimal azimuth and tilt angles. The Ministry of Energy of Thailand's Department of Alternative Energy Development and Efficiency supported a solar resource assessment together with the Solar Energy Research Laboratory of Silpakorn University in Thailand for the Lao PDR that includes monthly and annual average irradiance. These data were developed with pyranometer stations (irradiance) established in five locations in Lao PDR and validation activities; however, these data are not publicly available (DEDE and MEM DEPP 2007; DEDE 2017).

The solar resource data for Lao PDR shown in TABLE A-2 includes GHI and DNI on the annual temporal resolution from the World Bank SolarGIS as well as monthly resolution datasets compiled by

[8] For additional information, see the Global Solar Atlas from the World Bank website at globalsolaratlas.info.

NREL. NREL provides a monthly temporal, 40 km x 40 km spatial resolution, irradiance dataset modeled with the plane-of-array tilted at latitude, a model assumption that results in near optimal irradiance for a fixed-tilt PV system. Annual PV Output, an estimate that describes the potential electric generation of fixed-tilt PV systems at optimum tilt and a spatial resolution of 1 km x 1 km, is available from the World Bank and SolarGIS. The PV Output data are useful for technical potential and LCOE analyses (see Section 3), but it does limit the analysis to the pre-modeled PV system, including assumptions made for the tracking, tilt, inverter ratio, losses, modules, etc.

Hourly resolution solar irradiance data for multiple years or a TMY would be ideal to also allow for modeling of different types of PV configurations—for example, 1-axis tracking and PV advances such as improved PV modules. In addition, hourly data would enable the creation of a distribution of PV potential based on likely rooftop orientations enabling distributed PV analysis and additional analyses such as grid integration studies. In addition to the Global Solar Atlas data, the Lao government maintains irradiance and meteorological stations that collect solar radiation and wind data, as described above. Although less useful for the priority analysis topics than the spatially-resolved datasets with national coverage described above, data from these stations can be used to validate future solar resource analyses for the Lao PDR.

4.1.2 Wind

Highlights of data-gap assessment

Highest quality, freely available wind resource available from the Danish Technical University (DTU):

- Long-term annual average wind speed at 50-, 80-, 200-meter hub heights
- Long-term annual average wind power density at 50-, 80-, 200-meter hub heights
- Fine spatial resolution of 1 km x 1 km.

Analysis applications of existing data

- Technical potential
- LCOE.

Recommendations to address data gaps

- Create or procure modeled high-resolution (hourly) wind resource data for multiple years or a TMY at multiple hub heights (80 m, 100 m, and 140 m) to enable research into existing and future wind turbine performance and cost and wind power plants; these data could also enable energy planning analyses such as grid integration studies.

Wind resource data for application in energy planning analyses are typically described as wind speed (alternatively wind power density) and wind direction at various hub heights—for example, wind speed modeled at 80 meters above the earth's surface. The highest quality publicly available dataset of wind resource for Lao PDR comes from the DTU through their Global Wind Atlas.[9] DTU's Global Wind Atlas provides long-term (sampled from the period of 1997 to 2016), annual, average wind speed and wind power density across the globe at 50-, 100-, and 200-meter hub heights using microscale modeling to capture local terrain effects on wind resource. DTU advises that their data have an application for

[9] For more information, see the DTU Global Wind Atlas website at globalwindatlas.com.

upscaling analysis (or evaluating higher hub-height opportunities) and energy integration modeling but should not be used for wind farm project siting.

Ideally, wind resource data would be at an hourly or subhourly temporal resolution, as these finer resolutions better capture the variability of the wind resource within time frames that are particularly relevant to power system operations. However, annual resolution wind speed and wind power density data are available from the DTU dataset for Lao PDR as shown in TABLE A-3. The DTU wind resource data can be used for the technical potential and LCOE analyses in Lao PDR due to the high spatial resolution and use of multiple years of data to create a long-term representative wind resource.

Although the annual average wind speed data can be used in these analyses with simplified assumptions, it is recommended that a high temporal resolution (i.e., hourly) wind resource data for multiple years or a TMY at multiple hub heights (80 m, 100 m, and 140 m) be obtained. Hourly wind resource enables researchers to model existing turbines, future turbines, and wind power plants or farms, and also supports additional energy planning analyses including grid integration studies.[10]

4.1.3 Hydropower

Highlights of data-gap assessment

- Although datasets representing the existing hydroelectric power plant locations were identified, no datasets were identified that detail the location of existing, non-exploited hydropower resources at the national level for Lao PDR.
- Publicly available hydropower assessment data, including hydropower plant status, capacity, and energy generation are available through Open Development Mekong.
- Restricted access hydrological data (including stream flow, watershed boundaries, soil characteristics, and others) are available from the Mekong River Commission.

Analysis applications of existing data

- Technical potential analysis is currently not feasible due to the absence of required data.
- LCOE calculations are feasible with existing, local data on investment and operation and maintenance costs.

Recommendations to address data gaps

- Develop, identify, or share comprehensive spatial data that allow the estimation of theoretical hydropower resources (non-exploited hydropower resources) for all of Lao PDR, not just the Mekong River Basin and its tributaries.

Unlike solar and wind energy resources, assessments of hydropower resources are limited in what can be assessed by global satellite observations. Suitability is dependent on multiple, site-level characteristics that include geology, environment, social, access, and other considerations. Verified resource and

[10] Grid integration studies (also referred to as power systems planning studies) consist of analyses of a set of scenarios and sensitivities that seek to inform stakeholders on the ability and needs of a power system to accommodate significant variable RE. For more information see the Greening the Grid website at http://www.greeningthegrid.org.

technical potential therefore require site-specific assessments of these characteristics in addition to raw natural resource data that may be obtained from satellite observations.

Datasets representing annual and seasonal non-exploited resources for hydropower development in Lao PDR were not identified in this work as shown in TABLE A-4. The data identified consisted of data initially compiled by International Rivers in 2014 from a variety of sources and made publicly available through Open Development Mekong (Open Development Mekong 2017). The dataset indicates the status—i.e., "operational," "under construction," "under study," and "potential"—of hydropower plants, as well as the estimated potential plant capacity and energy generated, where applicable. These data are also based on the installed and planned hydropower development report from MEM (2016). The Mekong River Commission maintains restricted-access regional hydrological data—including watershed boundaries and classification, stream flow, and soil classification—from monitoring stations on the Mekong River and its tributaries (MRC 2009). These data serve as a base for conducting a theoretical resource assessment for hydropower along the Mekong River in the Lao PDR. In addition to these datasets, consultations with MEM's Department of Energy Policy and Planning (DEPP) indicate that the DEPP collects and develops data on hydropower resources based on feasibility studies conducted at the provincial level, as well as pre-feasibility studies for large hydropower independent power producers. These data are not available publicly.

A technical potential analysis is currently not feasible due to the absence of required data for hydropower resources at the national level for Lao PDR. The Mekong River Commission and Open Development Mekong data could be useful as a foundation for national technical and economic potential analyses; however, additional data for hydropower resources outside of the Mekong River basin would be necessary. As an alternative to a technical potential analysis, a site feasibility screening analysis could be completed to identify locations where a hydropower plant could be located. This feasibility screening would then have to be supplemented by detailed analyses of sites to identify technical potential when the required datasets are available. The datasets required for LCOE calculation are discussed in Section 4.2.7.

The Lao PDR electricity system relies heavily on hydroelectric power plants to meet electricity demand in the country, as evidenced by the share of annual generation (MEM 2015a). For this reason, Lao PDR and actors in the country—including MEM and Électricité du Laos (EDL)—have gained significant experience in evaluating and developing domestic resources. These are estimated at 23,000 MW, of which 3,058 MW were developed as of 2014 (IES and MKE 2016; MEM 2016). It is assumed that spatial datasets that allow for estimation of non-exploited hydropower resources exist—in some form—and that MEM and EDL have developed significant experience in using these datasets for energy planning analyses.[11] The publicly available data represent the outputs of technical potential analyses, rather than the required data inputs to complete technical and economic potential analyses. Other, restricted data include the information needed to assess theoretical and technical potential; however, these data may only cover the Mekong River Basin. Technical potential, LCOE, and further energy planning analyses would be possible through the development, identification, and sharing of comprehensive spatial data that allow for the estimation of theoretical hydropower resources for all of Lao PDR, not just the Mekong River Basin and its tributaries.

[11] Confirmed by MEM and EDL members of the Technical Committee at the Workshop *Exploring and Analyzing Energy Resource Data*, April 5–6, 2017.

4.1.4 Biomass

Highlights of data-gap assessment

Freely available, partial biomass resource data at national and provincial level:

- Crop residues (rice husk, cane bagasse, cassava stock residue, and maize cob) by province
- Biogas potential estimates by province.

Analysis applications of existing data

- Technical potential
- LCOE

Recommendations to address data gaps

- Create or procure detailed crop residues data at the district, km^2, or on-site resolution level.
- Create or procure detailed forest residues data at the district, km^2, or on-site resolution level.
- Develop biogas resource estimates at finer resolutions than the provincial level.

Several assessments of biomass potential have been performed at the national and provincial level for Lao PDR (Akgün et al. 2011; Koumphonphakdi and Suntivarakorn 2014; ADB 2015). The ADB (2015) report is focused on residues from main crop production and provides the quantity and technical potential by feedstock, using data from the Lao Ministry of Agriculture and Forestry. The analyzed feedstocks include rice husk, sugar cane bagasse, cassava stock, and maize cob. The ADB also provides a detailed report on Lao PDR government plans for substantial development of biofuel, and includes estimated land requirements to meet government plans for biodiesel production. The ADB report as well as the study from Koumphonphakdi and Suntivarakorn (2014) provide estimates of biogas potential from animal manure (cattle, pig, chicken, and buffalo). In addition to estimates of crop residues, Akgün et al. (2011) provide estimates for forest residues, namely logging residues and primary and secondary mill residues.

Province resolution data for crop residues and biogas resources are estimated on an annual basis as shown in TABLE A-5. These data are sufficient for conducting a technical potential analysis and for the calculation of LCOE.

Future technical potential and other energy planning analyses—for example, site feasibility studies—would be facilitated by the development or procurement of detailed biomass resource data at the district, km^2, or on-site resolution level.

4.1.5 Geothermal

Highlights of data-gap assessment

Surface manifestations do exist; however, these resources are small in size, have water temperatures below 70ºC, and are mainly used as hot spring tourist sites. A total of 59 MW of potential resource capacity has been identified.

Analysis applications of existing data

- Not considered as domestic energy resources for the technical potential and LCOE analyses

Recommendations to address data gaps

- Collect and analyze water samples (geothermometry) from all sites and catalogue existing geologic studies.
- Create a database and maps that detail the name and locations of known hot springs and other geothermal anomalies.
- Encourage universities to perform field mapping and geologic analysis of these areas to create a base of knowledge.
- Encourage or require organizations undertaking petroleum resource exploration to maintain and share survey data on temperature and formation of wells to help build geologic maps.

Geothermal energy resources in Lao PDR are predominantly unsuitable for electricity generation as the water temperatures do not rise above 70ºC and the resources are small in size (Tien Hung et al. 2015). Resources are typically used as hot springs sites for tourists due to lower temperatures (MEM 2011). Previous studies identified a total of 59 MW of potential resource capacity (IES and MKE 2016; MEM 2011).

Geothermal resources will not be considered in this work as domestic energy resources for the technical potential and LCOE analyses; however, the datasets that would be required for these analyses comprise borehole temperature observations (temperature at depth), geothermal heat flow, thermal conductivity, surface features (wells and springs), and hydrothermal areas, and are shown in TABLE A-6.

Approaches to harnessing potential geothermal energy resources are continually advancing. It would be in the interest of Lao PDR to be prepared to take advantage of technical advances by collecting and analyzing water samples (geothermometry) from all potential sites and cataloguing existing geologic studies. This would permit the creation of a database and maps that detail the names and locations of known hot springs and other geothermal anomalies. MEM could consider encouraging universities to perform the field mapping and geologic analysis of these areas to create a base of knowledge. MEM could also encourage or require organizations undertaking petroleum resource exploration to maintain and share survey data on temperature and formation of wells to help build geologic maps.

4.1.6 Coal

Highlights of data-gap assessment

Coal resources are estimated at approximately 500-600 million tons and reserves at approximately 700-900 million tons; however, a significant number of possible coal deposits remain unexplored.[12] Deposits are predominantly composed of lignite with small amounts of anthracite supplies. Mid-grade lignite reserves in the country are considered to be suitable for use in electricity generation.

Analysis applications of existing data

- Siting feasibility analysis for power plants
- LCOE.

Recommendations to address data gaps

- Create an updated database and maps that detail coal resources and reserves that include existing and planned mines as well as currently unexplored coal prospects
- Include attributes that characterize deposits in the spatial data that support energy planning analyses.

Previous studies have characterized and identified the location of Lao coal deposits. The Lao Department of Geology and Mines, which is responsible for inventory and mapping of mineral commodity deposits, has produced two geologic maps that cover the entire country (1:1,500,00 and 1:1,000,000 scales) together with the United Nations Economic and Social Commission for Asia and the Pacific in 1990 and the British Geological Survey in 1991. The process of digitalizing these began in 2003 (Marutani 2006).

These studies have estimated coal resources at approximately 500-600 million tons and reserves at approximately 700-900 million tons; however, a significant number of possible coal deposits remain unexplored (Marutani 2006). The largest identified share of reserves is located in the Hongsa deposit in the northern Lao Xayaboury province. The coal deposits in Lao PDR are reported to be predominantly lignite with an energy content of 8-10 MJ/kg. There are also small anthracite deposits. Less significant bituminous and anthracite coals have also been identified. Mid-grade lignite reserves in the country are considered to be suitable for use in electricity generation (IES and MKE 2016; Pillai 2014; ADB 2010; Vongsay 2013).

The coal resources and reserves (tons) in Lao PDR are currently in tabular form and available from third-party sources without complete coverage for the country (Marutani 2006). The dataset identified for coal includes the location of specific coal resources and reserves (shown in TABLE A-7) and is sufficient for a site feasibility analysis—conducted in place of the technical potential—as well as LCOE analysis.

The creation of an updated database and map detailing coal resources and reserves that includes currently unexplored coal prospects would support energy planning analyses and a comprehensive power plant siting feasibility analysis (see Section 3.2.2). The database and map would be improved by detailed classifications of the deposit rank—i.e., lignite, sub-bituminous, high-volatile, bituminous, low-volatile, or anthracite coal; estimated calorific value or lower heating value (LHV) (MJ/kg); moisture content;

[12] The natural units of tons of coal are the standard for accounting for coal resources and reserves; however, the energy content varies widely between different categories of coal—for example, lignite, bituminous, and anthracite—as well as specific resource deposits in different regions (Rogner et al. 2012).

deposit depth; and the content of harmful substances such as sulfur (softer coals typically have higher sulfur contents (Rogner et al. 2012).[13]

FIGURE 5 depicts the relationship between the deposit rank and these characteristics. Deposit ranks such as anthracite and bituminous resources are seen to have higher potential LHV as well as lower levels of moisture content than typical lignite and sub-bituminous deposits.

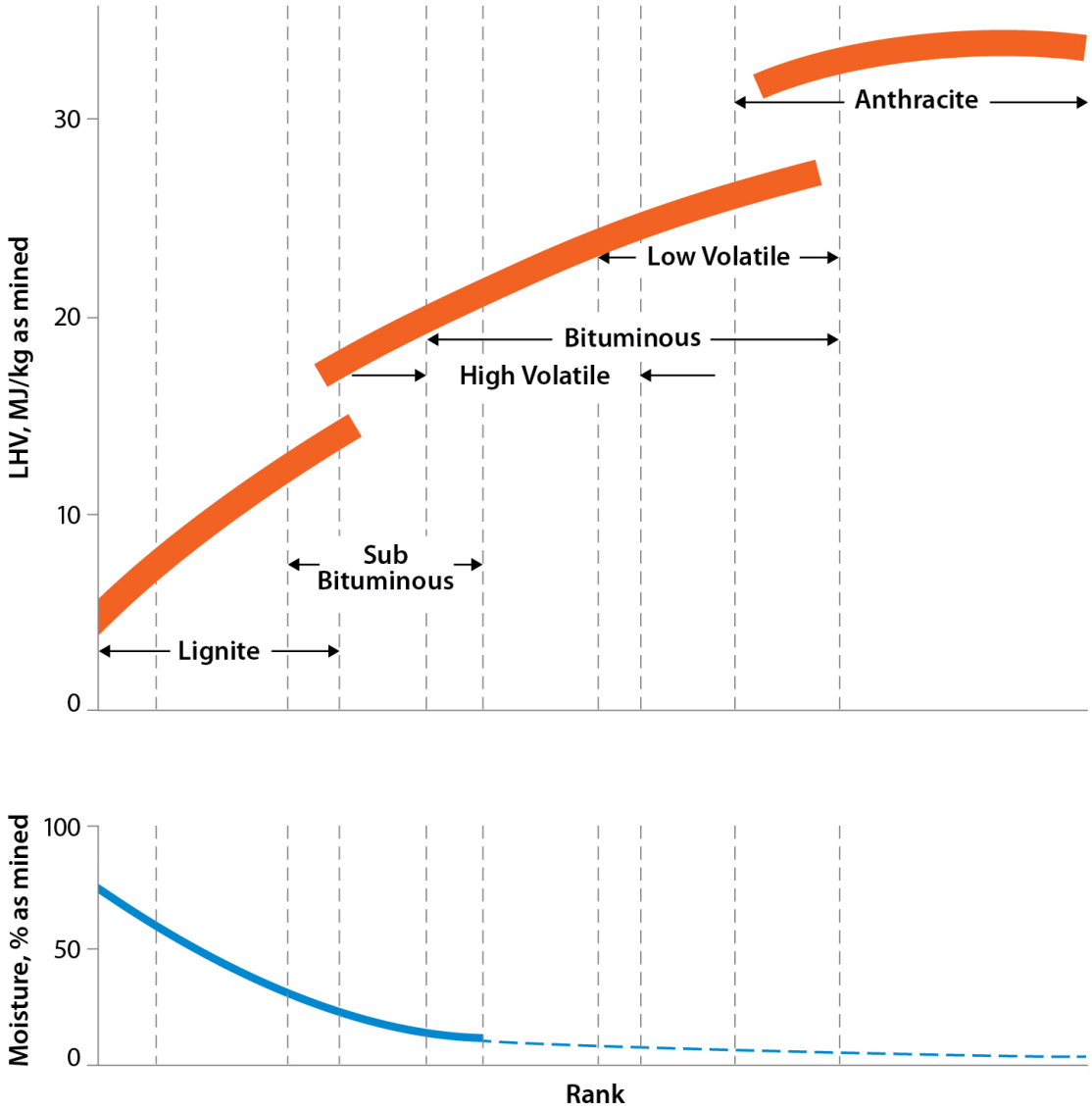

FIGURE 5. CALORIFIC VALUE AND MOISTURE CONTENT OF VARIOUS COAL RANKS

Adapted from Couch (1988) and Rogner et al. (2012)[14]

[13] The calorific value is typically expressed as the LHV. This is a common measure for thermal electricity generation technologies and is defined as the energy in the form of heat (J) released by the complete combustion of a unit of fuel (kg) when the water produced is assumed to remain as a vapor and the heat is not recovered (IEA 2017).
[14] Volatility describes the coal burn rate. Coals with high volatility ignite easily; however, they have lower energy content per unit volume than lower volatility coals (Couch 1988; Rogner et al. 2012).

4.1.7 Petroleum and natural gas

Highlights of data-gap assessment

No estimates of domestic oil or natural gas resources were identified. Sources have indicated that Lao PDR does not have proven domestic petroleum or natural gas reserves.

Analysis applications of existing data

- Not considered as a domestic energy resource for the technical potential analysis
- LCOE analysis will consider imported resources.

Recommendations to address data gaps

- Create an updated database and map that details potential petroleum resources and reserves, including currently unexplored prospects.

No estimates of domestic oil or natural gas resources were found in a review of available literature, and sources have indicated that Lao PDR has no proven domestic oil or natural gas reserves (ADB 2010; MEM 2011; Pillai 2014). Activity ceased in 1997 when petroleum companies from the United Kingdom and United States that had been working under exploration concessions from 1989 to 1996 felt the effects of the Asian financial crisis. Petroleum and natural gas exploration and possible production activities reportedly resumed in 2009, when the government awarded a production-sharing contract to a British oil company. The award of this contract was based on indications of possible natural gas resources in the Champassak and Savannakhet provinces. So far, however, no proven reserves have been identified in this region (ADB 2010; Pillai 2014).

Petroleum and natural gas resources will not be considered as domestic resources in the technical potential and LCOE analyses. Studies that depict spatially referenced resources and reserves in Lao PDR were not found in the literature review; however, this is to be expected as resources and proven reserves are typically owned or controlled by agreements with private or national companies that typically have vested interest in resources and reserves they have explored and measured (Brown et al. 2016). The non-RE resources data-gap assessments are consolidated in TABLE A-7.

Technologies allowing for the extraction and use of petroleum and natural gas have developed significantly in recent years. To ensure that the data available in Lao PDR allow for the consideration of these technologies in planning analyses, decision makers may consider creating an updated database and map that details potential petroleum resources and reserves, including currently unexplored prospects (refer to Section 3.2.2).

4.1.8 Nuclear

Highlights of data-gap assessment

There is no indication of domestic nuclear resources—for example, uranium—for electricity generation in Lao PDR.

Analysis applications of existing data

- Not considered as a domestic energy resource for the technical potential analysis
- LCOE analysis will consider imported resources.

Recommendations to address data gaps

- Create an updated database and map that details potential nuclear resources, including currently unexplored prospects.

Previous Lao PDR energy sector studies have not indicated the existence of any domestic nuclear resources—for example, uranium—for electricity generation (Marutani 2006; ADB 2010; Pillai 2014). Studies have reported the existence of uranium resources in neighboring Vietnam, however (Maunsell and Lahmeyer 2004).

Nuclear resources will not be considered as domestic resources in the technical potential and LCOE analyses.

The government of Lao PDR has expressed interest in considering potential future nuclear energy development in the country. Given confirmation of specific environmental and safety assurances, decision makers may consider creating an updated database and map that details potential nuclear resources, including currently unexplored prospects (refer to Section 3.2.2) (Vongsay 2013; Kouphokham 2013).

4.2 Complementary data for analyses

4.2.1 Power network

Highlights of data-gap assessment

- Current and planned location data for transmission lines and substations are maintained by MEM. Hourly load data at various spatial resolutions and some information on the characteristics of generators and transmission network elements are also recorded by MEM and EDL. MEM's power network data, while not public, is likely sufficient to support several energy planning analyses.
- Publicly available, unverified data on transmission lines and substations is available from multiple sources.

Analysis applications of existing data

- Site feasibility for power plants
- LCOE.

Recommendations to address data gaps

- Consider making a limited set of transmission data—for example, high voltage transmission lines and substations—publicly available to support energy planning analyses for audiences such as private sector developers or investors.

Publicly accessible data on the location and capacity of transmission system lines and substations in Lao PDR are available from the World Bank (2005a, 2005b) and Open Street Maps. Although the Open Street Maps dataset contains a considerable number of digitized lines, it lacks attributes such as the type of transmission line and the nominal voltage. Additionally, there are no studies on the completeness and accuracy of the transmission system components currently available on Open Street Maps. The World Bank data are based on a digitized map of transmission lines from the year 2005 and is not appropriate for applications requiring high accuracy. Due to the data vintage of the World Bank (2005a) dataset, the completeness and accuracy of the data would need to be studied prior to its use in energy planning analyses. The MEM maintains data on the locations of existing and planned transmission lines and substations, the latest version of which covers the 2016–2025 planning period. MEM, EDL, and EDL-Generation also collect hourly load data at various spatial resolutions and some information on the characteristics of generators and transmission network elements, although the scope of the latter data is not clear.

Publicly available data detailing the installed capacity of coal, diesel, hydropower, and natural gas generators are available in tabular format (MEM 2017). Unverified spatial data from the World Bank and Open Street Maps depicting the transmission lines and substations exist online. Data detailing the transmission and distribution system losses and current tariffs are available from MEM. The power network data from MEM are shown in TABLE A-8, and—although these data are not public—they are likely sufficient to conduct economic potential analyses such as LCOE. These transmission system data from MEM or EDL, however, would have to be made available in a GIS format that includes spatial data on the location of transmission system lines and substations and additional attributes such as transmission line type and nominal voltages. These transmission system and generator data are not necessary to evaluate technical potential analyses, however.

MEM and EDL should consider making a limited set of transmission data—for example, high voltage transmission lines and substations—publicly available to support energy planning analyses that may be conducted by external actors and private sector developers or investors.

4.2.2 Ancillary meteorology

Highlights of data-gap assessment

Data are available from the U.S. National Aeronautics and Space Administration (NASA) Surface meteorology and Solar Energy website; however, it is spatially coarse and contains daily averages.

Analysis applications of existing data

- Technical potential
- Site feasibility for power plants.

Recommendations to address data gaps

- Obtain hourly ancillary meteorology datasets from free sources such as the U.S. National Centers for Environmental Prediction (NCEP), Climate Forecast System (CFSR), or the NASA Modern-Era Retrospective Analysis for Research Applications (MERRA).

Ancillary meteorological data as discussed in this document refers to data useful in RE generator modeling. For example, to model solar PV, solar irradiance is required. It is also important, however, to include local ground temperature to capture its effects on module performance. Likewise, air pressure at hub height can have an impact on the performance of a wind turbine. Typically, these data are acquired from reanalysis (an approach for creating climate monitoring data) datasets, which are available globally.

The ancillary meteorological data identified for Lao PDR are presented in TABLE A-9. Hourly or subhourly resolution data are available from NASA for air temperature, atmospheric pressure, ground wind direction, ground wind speed, dew point, and relative humidity. Annual resolution data are available for heating and cooling degree days and relative earth skin temperature. These datasets are good for gaining a general understanding of the spatial distribution of the natural phenomena and supporting technical potential analyses.

To take full advantage of the energy planning analysis data for technical potential and economic analyses, obtaining hourly reanalysis data available through MERRA from NASA as well as the CFSR from NCEP is recommended.[15]

[15] For more information, see the NASA MERRA website: gmao.gsfc.nasa.gov/reanalysis/MERRA/ and the NCEP CFSR website at cfs.ncep.noaa.gov/cfsr/.

4.2.3 Environment

Highlights of data-gap assessment

Good coverage of spatial data from diverse regional and global entities:

- Protected areas—Protected Plant (national parks and protected areas)
- Land use and farms at the national, provincial, and district level—Lao Decide Info[16]
- Land use—U.S. Geologic Survey (USGS) Global Land Cover
- Contaminated lands—National Regulatory Authority for Unexploded Ordnances
- Drought events from Lao Decide Info
- General climate data—Greater Mekong Subregion Information Portal

Analysis applications of existing data

- Technical potential
- Site feasibility for power plants

Recommendations to address data gaps

- Identify, develop, and share local environmental datasets that may address more nuanced land use and development policies, which would ultimately impact the available supply of RE.
- Work with local stakeholders and experts to identify priority exclusionary locations for RE and non-RE development

"Environmental data" is a broad category that is important for many different types of energy planning analysis including technical potential and economic potential—including LCOE—analyses. These data include protected areas, contaminated lands, and land use datasets that are fundamental to understanding the types of geographic areas that should be included in and excluded from technical potential calculations.

The data existing for Lao PDR shown in TABLE A-10 primarily comes from several regional and global efforts to create various assortments of geospatial environmental data. For example, Protected Planet[17] tracks protected lands and national parks and the USGS creates global land cover data. The Lao National Regulatory Authority for Unexploded Ordnances has developed a geospatial layer depicting bombing campaign data in Lao PDR. These areas are considered to be contaminated lands for this work. In addition to these datasets, geospatial data on rivers, lakes, groundwater, and topography are also available (UXO LAO 2013). Stakeholder consultations with Lao organizations indicate that Lao government agencies collect a variety of relevant data, including on national biodiversity areas (Department of Forestry Management within the Ministry of Forestry), land use (National Agriculture and Forestry Research Institute), protected areas (Ministry of Forestry), and fisheries (Ministry of Forestry). These datasets are not public and must be formally requested from the appropriate ministry for use.

[16] Lao Decide Info is an online platform of the Lao PDR government that presents spatial data from the social, economic, environmental, and agricultural sectors to support informed planning and decision making. For more information, see the Lao Decide website at decide.la.

[17] Protected Planet is an online interface with the World Database on Protected Areas. Find more information at www.protectedplanet.net.

In addition to these datasets, geospatial data on rivers and lakes are available from the USGS Shuttle Radar Topography Mission dataset. Groundwater data cited by a United Nations Educational, Scientific and Cultural Organization (UNESCO) report are available from the Department of Statistics and the Center for Development and Environment within the Lao Ministry of Natural Resources and Environment (KIGAM, CCOP Technical Secretariat, and UNESCO Bangkok Office 2015). Additionally, topography is available from the RE Data Explorer based on data from the Consortium for Spatial Information of the Consultative Group for International Agricultural Research digital elevation model.

The environmental data publicly available for Lao PDR are sufficient to conduct basic technical potential analyses. As the technical potential analysis serves as an input to economic analysis, the data available are also applicable to economic analyses; however, it is not necessary for estimation of LCOE. Lao PDR has great coverage from global and regional data portals, but lacks strictly local datasets that may address more nuanced land use and development policies that would ultimately impact the available supply of RE. These would detail for example, unprotected lands and water resources that are critical habitats for species, regions for agriculture, or fresh water fisheries where development may be not be ideal. Such datasets are generally acquired through local stakeholder engagement and can play a critical role in designing analysis scenarios for renewable futures.

4.2.4 Market and demand

Highlights of data-gap assessment

Good coverage exists for all of the market and demand datasets required for the LCOE in this work. These data are locally sourced from MEM and available publicly through annual "Electricity Statistical Yearbooks" (MEM 2015a).

Analysis applications of existing data

- Complementary energy planning analyses.

Recommendations to address data gaps

- Develop and share finer-resolution data—for example, monthly or hourly—of electricity consumption as well as imports and exports. This may also include spatial resolution for certain datasets.
- Consider developing a digital, continually updated, public database of electricity sector market and demand data.

"Market and demand data" is a wide-ranging category that consists of electricity sector features that are important for many different types of energy planning analysis. The data in this category are not necessary for technical potential analyses or calculation of LCOE. These electricity sector features of interest are not necessary spatially referenced data and include electricity consumption (GWh) and demand (MW), electricity generation (GWh), imported and exported electricity (GWh), electricity costs for end users (monetary units/kWh), and the cost of imported and exported electricity (monetary units/GWh).

The data identified for Lao PDR (shown in TABLE A-11) have coverage for all of the electricity sector demand and market features described above. These data are sufficient for the complementary energy planning analyses in the scope of this work. The datasets available from MEM all have annual resolution and are shared in annual "Electricity Statistical Yearbooks" from MEM (MEM 2015a).

Future energy planning analyses would benefit from higher resolution—for example, monthly or hourly—datasets for electricity consumption and imports and exports. If these finer resolution data—in terms of time steps or spatial resolution—existed for the remaining features identified above, this would also support energy planning analyses such as spatial energy demand projections. MEM may also consider developing a digital, continually updated, public database, as the vintage of data identified was 2015.

4.2.5 Transportation

Highlights of data-gap assessment

Spatial data representing roads, railroads, and airports are available at the national level from local and international sources; however, the most recent detailed data are not publicly available. Unfortunately, the completeness and accuracy of the public data are unknown and thus require validation.

Analysis applications of existing data

- Site feasibility for power plants.

Recommendations to address data gaps

- Consider making a limited set of recent transportation spatial data—for example, roads, railroads, and riverports—publicly available to support energy planning analyses that may be conducted by external actors and private sector developers or investors.
- Validate the completeness of public data available from Open Street Maps.

Transportation systems play an integral role in the installation, operation, and maintenance of all RE and non-RE systems, and spatial transportation data are used in analyses to better understand the economic costs of pursuing certain types of RE projects.

In Lao PDR, the most recent official publicly available roads data are from 1999 and were created by Lao National Geographic Department—the country's official surveying and mapping authority. Alternatively, road, railroad, and airport location data are also publicly available through the Open Street Map project, but the completeness and accuracy of these data have not been verified. The transportation data-gap assessment is shown in TABLE A-12.

Transportation system data are not necessary for technical potential analyses; however, these data are typically used in site feasibility analyses for power plants (see Section 3.2.2). MEM and the Lao National Geographic Department could consider making a limited set of recent transportation spatial data—for example, roads, railroads, and riverports—publicly available to support energy planning analyses that may be conducted by external actors and private sector developers or investors. Alternatively—or in the meantime—Lao actors should consider validating the completeness of public data available from Open Street Maps.

4.2.6 Administrative and other categories

Highlights of data-gap assessment

A rich set of local and international data exists for administrative and other related categories for Lao PDR to support the priority energy planning analyses. Population density can serve as proxy dataset for load and is important for understanding potential development exclusions. Lao PDR also has a rich statistical database of land use and farms at the national, provincial, and district level hosted by Lao Decide Info.

Analysis applications of existing data

- Technical potential
- Site feasibility of power plants.

Recommendations to address data gaps

- Consider updating and consolidating publicly available data to support energy planning analyses that may be conducted by external actors and private sector developers or investors.

Administrative and other categories represent a broad dataset that includes administrative boundaries, land ownership, and electrification rates, among other considerations. Administrative boundaries are critical for characterizing, summarizing, and presenting analytical results within Lao PDR. They provide a means by which policy makers and researchers can understand the relative differences in RE potential throughout the country.

Lao PDR has a rich database from which to draw the "other" category, as shown in the data-gap assessment for Lao PDR in TABLE A-13. The location of cities, villages, and other built areas as well as administrative boundaries—for example, national, state, etc.—are available from local and international sources. The available population density data can serve as a "proxy" dataset for load and is also important for understanding potential development exclusion layers (for technical potential) or for understanding populations at risk of natural hazard events. Proxy datasets represent indirect information that can be used as a substitute or to infer details about another desired dataset. Lao PDR also has a detailed statistical database of land use and farms at the national, provincial, and district level hosted by Lao Decide Info. Special economic zones, which may be of interest to developers, are available from international sources. Spatially referenced population and housing census data from 2005 have been hosted on Lao Decide Info. Finally, Lao PDR also has spatial data on poverty created by a World Bank study that can be useful in complementary analyses such as electrification studies.

All these datasets have usefulness and are sufficient for the technical and economic—including LCOE—analyses of priorities for this work as well as other energy planning analyses.

Lao actors could consider updating and consolidating publicly available data to support energy planning analyses that may be conducted by external actors and private sector developers or investors. Stakeholders identified several local datasets of interest, including official administrative boundaries (from the National Geographic Department), restricted military areas (from the Ministry of National Defense), economic zones (from the Ministry of Planning and Investment) and village electrification (from the MEM). These datasets are not public and a formal request to the appropriate ministry is required for use.

4.2.7 Electricity generation costs

Highlights of data-gap assessment

Sufficient in-country coverage is available for investment costs, operation and maintenance costs, capacity factors, and annual electricity generation (GWh) for hydropower and thermal generation—i.e., coal, petroleum, and natural gas. Regional study data exist for solar and hydropower investment costs, operation and maintenance costs, and capacity factors. There is a lack of cost and capacity factor data for wind and biomass technologies, and system degradation rates are unavailable beyond limited availability from regional studies. Partial data for capacity (MW) expansion plans are available from in-country sources.

Analysis application of existing data

- LCOE.

Recommendations to address data gaps

- Update and consolidate public data for LCOE calculations for all technologies—including wind, biomass, and geothermal technologies.
- Collect and consolidate public data for LCOE calculations for mini-grid and stand-alone system generation to allow for analyses of generation technologies at these scales.
- Identify additional priority consideration for cost and benefit analyses—for example, fisheries, population relocation, revenue loss, infrastructure costs, etc.—that may improve LCOE rankings.

Electricity generation costs is not a data category—unlike the preceding dataset categories discussed—but instead an economic analysis that requires a specific collection of datasets. This collection of data is assessed here to identify the data necessary for the subsequent Energy Alternatives Study tasks 3 and 5 (LCOE and the identification of additional energy planning alternatives). Calculation of LCOE requires a broad set of data that includes investment costs, operation and maintenance costs (fixed and variable), average annual generation (GWh), capacity factors, and system degradation rates specific to each of the electricity generation technologies considered. LCOE may also require data for additional cost and benefit considerations—for example, fisheries, population relocation, revenue loss, infrastructure costs, etc. These data are in addition to the complementary datasets and the technical potential analyses previously described.

Lao PDR has coverage of the investment costs, operation and maintenance costs, and capacity factors for hydropower and thermal generation (coal, petroleum, and natural gas) from in-country sources (TABLE A-14). Solar and hydropower investment costs, operation and maintenance costs, and capacity factors are also available from regional studies; however, these works present average values for Lao PDR. There is a lack of cost and capacity factor data for wind and biomass technologies. Local datasets for system degradation rates are unavailable beyond those found in regional studies for solar, hydropower, and petroleum-based generation technologies (MRC 2009; ACE 2016). Local data on annual electricity generation by type of generation system are partially available from the year 2015 (MEM 2015a); however, these data only represent hydropower and biomass technologies, which account for the dominant share of utility-scale electricity generation. Information about the locations and capacity (MW) of planned electricity generation system expansion is limited. Planned expansion of hydropower capacity is available but not spatially referenced. Datasets describing capacity expansion for other energy

resources are lacking. Partial data are available on planned expansion of independent power producers from MEM (2015b) and data for system hydropower expansion are available from MEM (2016).

Updating and consolidating publicly available data for additional technologies—for example, wind, biomass, and geothermal technologies may support energy planning analyses. These datasets may aid in-country energy planning as well as that conducted by external actors and private sector developers or investors. Electricity generation cost considerations for this work only included utility-scale datasets and do not include mini-grid or stand-alone systems. The collection and consolidation of publicly available data for these other system types by Lao actors may support external actors and private sector developers or investors. The LCOE analysis and ranking of technology options may also be improved by the identification of additional priorities for energy planning in Lao PDR and inclusion of these priorities in the calculation of LCOE.

4.3 Summary of data-gap assessment

Currently, the highest priority data gaps are those for which sufficient data are not available for the priority analyses of the Energy Alternatives Study. These high priority data gaps are necessary to assess technical potential and conduct technology site feasibility assessments and LCOE assessments for Lao PDR. Specifically, these include:

1. Spatial datasets for unexploited hydropower energy resources[18]
2. Spatial data depicting the transmission system (lines and substations)
3. Detailed land use and development data and priority exclusion layers.

TABLE 1 is a summary of the data-gap assessment for the energy planning analyses presented in the preceding sections. This summary indicates whether the data available for each dataset category are sufficient for the applicable analysis, as well as priority needs that could be considered by actors to improve currently available data. The priority needs are recommendations that would improve the available datasets and, in turn, the outputs of energy planning analyses. These priority needs are not necessarily required for the current Energy Alternatives Study, but rather indicate where steps could be taken to improve the datasets identified in this study.

The data assessment covers a broad range of data categories, each with substantial data requirements for the priority energy planning analyses. Not all of the data presented in this data assessment conducted for the Energy Alternatives Study may be available or currently exist; however, this assessment is meant to provide a comprehensive list of relevant data for actors. In considering this data-gap assessment summary, actors may need to prioritize these needs due to time, budget, and other constraints.

[18] In the absence of data for a technical potential analysis, feasible sites for hydropower plants will be identified (refer to Section 3.2).

TABLE 1. SUMMARY OF DATA-GAP ASSESSMENT

Datasets[1]	Gaps in existing data	Are sufficient data currently available for energy planning analyses?[2]	
		Technical potential[3]	Levelized cost of electricity
Energy resource data			
Solar	Modeled hourly resolution solar irradiance data for multiple years or a TMY	Yes	Yes
Wind	Modeled hourly resolution wind resource data for multiple years or a TMY	Yes	Yes
Hydro	Spatial data for estimation of nonexploited hydropower resources	No	Yes
Biomass	Finer resolution crop residue, forest residues, and biogas resource estimates	Yes[3]	Yes
Geothermal	No identified domestic resources. Database and maps of resources	N/A	N/A
Coal	Database and maps of coal resources and reserves including existing and unexplored coal prospects	Yes[3]	Yes
Petroleum	No identified domestic petroleum, natural gas, or nuclear resources	N/A	N/A
Natural gas		N/A	N/A
Nuclear		N/A	N/A
Complementary data			
Power network	Spatial data depicting the transmission system (lines and substations, distribution network)	N/A	No
Ancillary meteorology	Modeled hourly ancillary meteorology datasets—for example, air temperature, air pressure, dew point	Yes	N/A
Environment	Detailed local land use and other data that help identify siting constraints for energy development—for example, protected areas or urban areas	No	N/A
Market and demand	Finer spatial and temporal resolution electricity consumption, import, and export data	N/A	N/A
Transportation	Local, spatial data depicting roads, railroads, and riverports	Yes	N/A
Administrative and other	Updated public datasets for population and housing as well as special economic zones	Yes	N/A
Electricity generation costs	Cost and other data for wind and biomass technologies; data for mini-grid and stand-alone systems	N/A	Yes

Yes—Sufficient data for analysis No—Insufficient data for analysis N/A—Not applicable or required for analysis or no domestic energy resources

[1]Additional details can be found in the corresponding data assessment of Section 4.

[2]Refer to Section 3 for a description of the energy planning analyses listed here.

[3]Technical potential analysis does not apply to non-site-specific resources; instead a site-feasibility analysis for these is conducted (see Section 3).

5 Addressing data gaps

Reliable, robust, and validated data are critical for informed planning, policy development, and investment in the energy sector. As the Energy Alternatives Study seeks to expand on the resources—i.e., data and tools—available to decision makers in the assessment of power generation alternatives, access to these data by a diverse set of actors will be a key requirement to ensure the quality and consistency of inputs informing program design, modeling, policy analysis, and investment in domestic energy options. Decision makers will therefore need to address data gaps—which will inevitably exist—to ensure confidence in the results of any energy planning analyses.

There are different levels of data gaps, specifically, gaps in data that cannot be overcome as the data simply do not exist and gaps that are a result of "imperfections" or limitations within existing datasets and their intended applications. It should be noted that imperfections and limitations of data are common even in the most data-rich environments, and should not be seen as a hard barrier to good analysis and modeling. Developing statistical methods to overcome imperfections is also common, and—although there generally is no "perfect" method for any given data issue—there are guiding principles. For example, what are the relationships or patterns in the data that can be leveraged, what assumptions are being made with the application of certain methods, and how can one quantify and present confidence in results to an audience?

5.1 Prioritization of data needs

The data-gap assessment in Section 4 presents a comprehensive list of data requirements for the energy planning analyses of concern for the Energy Alternatives Study. Not all of the data in this list will be readily available and Lao actors may need to prioritize the data needs for analysis.

The highest priority data are those for which publicly accessible "default" datasets are not available or do not have coverage for Lao PDR. Default datasets are publicly available data developed mostly from modeled data at the international or regional scale. These datasets may support several energy planning analyses of interest; however, they do not represent locally modeled, measured and validated data and therefore are generally limited to early-stage analyses such as resource and technical potential assessments. An example of a publicly available default dataset with Lao PDR coverage is the high-quality resource dataset—i.e., GHI, DNI, and DHI—from the World Bank, which commissioned a long-term, global annual average dataset modeled by SolarGIS (Section 4.1.1).

The medium priority data consist of complementary datasets that present electricity sector-specific data—i.e., energy market and demand (Section 4.2.4), LCOE (Section 4.2.7), and national development goals and concerns (Energy Alternatives Study Task 5)—that may not be available or that may not represent the most recent available data.

The lower priority data are those for which a default dataset exists; however, even in these cases local data are preferred if they are higher quality—for example, more recent, higher resolution than a default or proxy dataset.

5.2 Data collection strategies

The datasets discussed in this work may come from a variety of government agencies and local organizations. Specific knowledge of the institutions in Lao PDR will aid in directing in-country actors to the best local sources of existing data. Appendix B presents a list of potential in-country sources identified for existing data gaps during the April 2017 Workshop: *Exploring and Analyzing Energy Resource Data* (Hayter et al. 2017). General examples of organizations that may house data include:

- Government agencies (non-specific names)

- Ministry of Energy, Renewable Energy, or Power
- National Energy information Agency or Energy Commission
- Ministry of the Environment
- Ministry of Natural Resources
- National Meteorology Institute
- Ministry of Agriculture and Forestry
- Ministry of Planning or Development.

- Electricity utilities and/or transmission system operators
- Energy regulators
- Universities or other research institutions
- Nongovernmental organizations
- Development banks or donors.

5.3 Data development and procurement

In the case that data are not available publicly, they may need to be developed by an institution or procured from a private source.

The development of data has different levels of involvement and required expertise that are highly dependent upon the data to be created and the intended applications. For example, the Lao Bureau of Statistics may be in a position to create a database of housing stocks that would have wide applications, from distributed generation evaluation to energy efficiency estimations. This database could be developed using local sources and surveys. On the other hand, creating a modeled hourly solar resource dataset requires detailed knowledge of atmospheric science and radiative transfer methods as well as access to satellite images. In such cases, without an institution that has existing expertise or a desire to build expertise for resource research, it might be more efficient and desirable to procure the data from a private firm.

Many private firms exist that are capable of creating such data with a high degree of accuracy. The key in these situations is to ensure that the data procured can be shared across government institutions so that all may have access for various analysis applications. The data procured also typically come with accompanying high-resolution ancillary meteorological data.

In general, spatially referenced—i.e., geospatial—datasets are preferred. These datasets associate geographic locations with the data of interest. Publicly available geospatial datasets can be incorporated into the RE Data Explorer for visualization and analysis. Data in any of the following file formats could be used for a geospatial analysis:

- ESRI Shapefiles[19]
- MapInfo TAB files[20]
- Any tabular file including CSV and TSV
- JSON and GEOJSON
- XML
- GML
- KML
- WMS (Web Map Services) and WFS (Web Feature Services)—for visualization purposes only.

[19] For more information on ESRI, see their website at esri.com.
[20] For more information on MapInfo, refer to their website at mapinfo.com.

6 Renewable Energy Data Explorer and data catalog

The RE Data Explorer is a no-cost, web-based application to facilitate RE decision making, investment, and deployment through a dynamic, online analytical tool.[21] Users can visually explore spatial datasets for RE resources—and non-RE resource deposits—and other base infrastructure. The RE Data Explorer wraps complex spatial analysis techniques into an easy-to-use interface targeted at non-specialists. RE Data Explorer is the primary platform for visualizing and distributing publicly-available GIS data for the Energy Alternatives Study.

Energy resource data, complementary data, and barriers to and priorities for energy development are dynamic and may change as new information becomes available or policies are enacted. The RE Data Explorer provides a platform for updating and analyzing energy resource and complementary data and comparing different scenarios in a dynamic way. The tool allows the visualization of energy development barriers and priorities relative to the availability of energy resources. The tool is also able to provide a quantitative estimate of resource and technical potentials—for wind and solar currently—based on certain user-specified constraints. This type of analysis can also be conducted by analysts with other GIS tools.

The RE Data Explorer Data Catalog is a metadata repository developed to support research and discovery of the RE resource and GIS data that power the RE Data Explorer application.[22] It is also a place for researchers to contribute data in support of the RE Explorer project. As a metadata repository, the Data Catalog does not necessarily store any datasets. Instead, similar to a library card catalog system, the Data Catalog:

1. Enables a person to find a dataset based on certain identifiers—for example, author, title, keyword, date of publication
2. Shows what datasets are available and enables co-locating based on author, subject, geographic coverage, etc.
3. Assists in the choice of an appropriate dataset by providing information on evaluating objectives— for example, resolution, licensing restrictions.

The data identified and gathered in this data-gap assessment went into updating the RE Data Explorer datasets for Lao PDR. This enables users to visualize the non-RE and RE resources and complete technical potential analyses for a set of the RE resources; however, the RE Data Explorer functionality for Lao PDR will be expanded as additional data and information are gathered—for example, data for roads or hydro resources and information on additional exclusions areas or priorities—and these resources are included in the RE Data Explorer Data Catalog.

6.1 Treatment of public versus nonpublic datasets

The development of datasets can entail a great deal of effort and contain data that are highly sensitive for many reasons including security or proprietary concerns. For this reason not all datasets are publicly available and are restricted to use by specific decision makers. This effort seeks to understand the availability of data that can inform decision-making related to energy planning regardless of whether those data are publicly available. RE Data Explorer and the Data Catalog include controls for publicly and nonpublicly available datasets.

RE Data Explorer allows the management of datasets that can be shared publicly. Visualization and download can be enabled for distributable public datasets; however, other datasets can be limited to visualization—disabling download capabilities. The Data Catalog is a metadata repository for both public and nonpublic data and indicates the data source and any access restrictions.

[21] Find additional information on the RE Explorer website at re-explorer.org.
[22] The RE Data Explorer Data Catalog is available at data.re-explorer.org

7 Conclusions

This report summarizes the availability, quality, and accessibility of data that serve as key inputs to theoretical potential analyses and other analyses that inform other priority energy planning activities that will support energy planning to 2030 in Lao PDR. Reliable and robust data will be vital inputs to energy planning analyses as the Lao PDR explores opportunities for, and the impacts of, future energy system investment alternatives. By diversifying its electricity generation mix, the Lao PDR will be helping to ensure energy security and economic growth.

The domestic energy resource data as well as complementary datasets identified and validated in this work—summarized in TABLE 1—will aid decision makers in building an understanding of the potential role that these abundant resources can play in the future of their nation's power system. These datasets will serve as a foundational input to technical and economic analyses of energy technologies as well as other energy planning analyses.

Additionally, the assessment of data gaps and the guidance provided to fill these gaps (see Section 4 and the summary in TABLE 1) will help decision makers, energy planners, and investors prioritize future investments in data collection and development (see Section 5). These efforts will facilitate analyses that are based on robust and reliable datasets that build confidence among power sector stakeholders and encourage investment in future energy project development and infrastructure opportunities.

A key finding of this assessment is that sufficient data are available to conduct the priority energy planning analyses discussed in this assessment—i.e., technical potential and LCOE. However, these analyses could be greatly improved if the data gaps detailed in Section 4 are addressed. Improving upon existing data and filling data gaps will also support longer-term energy planning considerations such as grid integration studies to scale up variable RE generation.

Data collection can be a daunting, and, in some cases, an expensive task. A key theme that emerges in this assessment is that many datasets overlap analysis topics. For example, resource data are used in both technical potential analysis and estimation of LCOE. Also, certain analysis results feed into other analyses as inputs—for example, economic potential usually requires technical potential as an input. The acquisition and development of data will enable a variety of energy planning activities, some of which are of immediate concern, and others that may emerge in the future as the energy sector of the Lao PDR evolves.

7.1 Recommendations

Taking strategic actions in the short, medium, and long term will enable MEM to address the gaps identified in this assessment and provide for current and potential future data needs.

Short-term actions

Addressing gaps in foundational datasets will support technical potential, LCOE, and subsequent analyses. This may begin with an internal validation of the results of this data assessment and a mapping of data needs to local government ministries and organizations that may house these data. MEM could also begin to build relationships with government organizations that may have and be able to share key complementary data.

- Investing in the development of foundational datasets that will enable a wide range of useful analyses. These include both energy resources and complementary datasets that support technical potential analyses and the calculation of LCOE.
- The highest priority gaps are those for which publicly accessible "default" datasets are not available for Lao PDR. The order in which these are addressed would align with planning objectives, but would

include (1) the sharing of spatial data for unexploited hydropower energy resources, (2) the sharing of spatial data depicting the transmission system (lines and substations), and (3) the identification of detailed land use and development data and priority exclusion layers for Lao PDR.

- The medium priority data gaps consist of complementary datasets that present electricity sector-specific data—i.e., energy market and demand, electricity generation costs of various technologies, and national development goals and concerns (Energy Alternatives Study Task 5). These data may not be available or may not represent the most recent available data.
- The lower priority data are those for which a default dataset exists; however, even in these cases local data are preferred if they are higher quality—for example, more recent, higher (temporal or spatial) resolution than a default or proxy dataset. These would include (1) modeled, high spatial resolution (nominal 10 km x 10 km) hourly solar irradiance data; (2) modeled, hourly resolution wind resources at 80 m, 100 m, and 140 m hub heights; (3) finer resolution (e.g., district-level) crop and forest residues and biogas resources; (4) database and maps of geothermal sites; and (5) database and maps of coal resources and reserves.
- An internal validation of the results of this data assessment by MEM and a detailed mapping of data needs to local government ministries and organizations that produce them would support filling data gaps with local data and avoid the need to develop or procure additional data. An initial mapping conducted with the Energy Alternatives Study Technical Committee is shown in Appendix B.
- Identifying Lao government organizations and universities that have complementary spatial datasets—for example, a national meteorology institute—and developing partnerships with these organizations would provide access to valuable local datasets and minimize the burden for in-house data development and storage for MEM.
- As the data to fill these gaps may not exist in Lao PDR, in the short term it could be beneficial to procure high-resolution data from private firms and/or commission the development of these data from regional research organizations, such as the Solar Energy Research Laboratory at Silpakorn University in Thailand (see Section 4.1.1). These data would likely also include high-resolution ancillary meteorological data. Any procured data should be of sufficient quality to support a range of current (and future) energy planning analyses and be shareable across government institutions, allowing access for various analysis applications.

Medium-term actions

In the medium term, MEM could shift from acquiring priority datasets to ensuring that they have the capacity to collect and maintain these data.

- Developing in-house human capacity—for example, spatial data and scientific computing experience—and infrastructure resources—for example, computer hardware—to collect, maintain, share, and use these data could be beneficial for MEM. Establishing a protocol and defining responsibilities for the collection and maintenance of spatial and related data would greatly aid MEM in future data collection and use. A demand for data beyond foundational datasets will likely come as MEM analyzes opportunities for future energy systems investments.
- Considering additional data requirements for energy planning analyses that take into account high levels of RE penetration—for example, RE zones transmission planning, grid integration studies, etc.—as well as energy system resiliency and risk will help MEM to evaluate and compare future energy system development and infrastructure opportunities.

Long-term actions

In the long term, MEM could consider developing the infrastructure and human resources to collect and maintain local, best-in-class RE resource datasets that are specific to Lao PDR. This would allow MEM to be both a developer and consumer of the data it requires for analyses.

Expanding and developing an in-country network of irradiance stations and meteorological towers would allow the validation of existing publicly available or privately procured energy resource datasets. These stations and validation activities would also aid in the creation of local datasets that represent best-in-class resolution and accuracy and would likely build confidence among industry stakeholders.

Remaining energy alternatives study tasks

The remaining tasks in the Energy Alternatives Study will employ the data identified and verified in this data-gap assessment and use the spatial data contained in RE Data Explorer to inform energy planning in Lao PDR. Applications such as RE Data Explorer—updated with the data identified in the Energy Alternatives Study—enable the informed use of existing data in conducting priority energy planning analyses. MEM should consider sharing additional local datasets that may be available to enhance the data available on RE Data Explorer as well as to support the subsequent tasks of the Energy Alternatives Study.

The RE Data Explorer Data Catalog, which serves as a central metadata repository, supports the research and discovery enabled by energy resource and GIS data. Researchers can contribute data to the Data Catalog in support of the RE Explorer project. These contributions promote informed energy planning analyses and decision making in Lao PDR. As examples, the data and tools available in RE Data Explorer can advance activities such as setting RE targets and developing study areas for energy planning analyses that make the diversification of the energy sector possible.

References

ACE. 2016. "Levelized Cost of Electricity of Selected Renewable Technologies in the ASEAN Member States." Jakarta: Association of Southeast Asian Nations (ASEAN) Center for Energy (ACE). www.aseanenergy.org/resources/publications/asean-resp-levelised-cost-of-electricity-of-selected-renewable-technologies-in-the-asean-member-states/.

ADB. 2010. "Sector Assistance Program Evaluation for the Energy Sector in Lao PDR." SAP: LAO 2010-42. Manila: Asian Development Bank (ADB). https://www.adb.org/sites/default/files/evaluation-document/35381/files/in259-10-0.pdf.

———. 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.

Couch, Gordon R. 1988. "Lignite Resources and Characteristics." International Energy Agency Coal Research (IEACR)/13. London: IEACR.

DEDE. 2017. "Solar Energy Potentials in Laos." Ministry of Energy of Thailand—Department of Alternative Energy Development and Efficiency (DEDE). http://weben.dede.go.th/webmax/content/solar-energy-potentials-laos.

DEDE and MEM DEPP. 2007. "Assessment of Solar Energy Potentials for Lao PDR." Bangkok: Ministry of Energy of Thailand—Department of Alternative Energy Development and Efficiency (DEDE), Department of Energy Policy and Planning (DEPP) of the Lao Ministry of Energy and Mines (MEM) (previously the Department of Electricity), and the Solar Energy Research Laboratory at Silpakorn University, Thailand.

Hayter, Sheila, Jessica Katz, Anthony Lopez, and Nathan Lee. 2017. "Workshop Report: Exploring and Analyzing Energy Resource Data." Energy Alternatives Study for the Lao PDR Smart Infrastructure for the Mekong (SIM) Program. Golden, CO: National Renewable Energy Laboratory (NREL).

IEA. 2017. "Lower Heating Value." *IEA Glossary*. Paris: International Energy Agency (IEA). https://www.iea.org/about/glossary/l/#tabs-2.

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.

KIGAM, CCOP Technical Secretariat, and UNESCO Bangkok Office. 2015. "Current Status and Issues of Groundwater in the Mekong River Basin." Bangkok: Korea Institute of Geoscience and Mineral Resources (KIGAM), Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP) Technical Secretariat, and UNESCO Bangkok Office. http://unesdoc.unesco.org/images/0024/002436/243616E.pdf.

Kline, David, Donna Heimiller, and Shannon Cowlin. 2008. "GIS Method for Developing Wind Supply Curves." NREL/TP-670-43053. Golden, CO: National Renewable Energy Laboratory (NREL). www.nrel.gov/docs/fy08osti/43053.pdf.

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.

Kouphokham, Khamso. 2013. "Chapter 10: Lao PDR Country Report." In *Analysis on Energy Saving Potential in East Asia*, edited by Shigeru Kimura. Vol. ERIA Research Project Report 2012–19. Jakarta Pusat, Indonesia: Economic Research Institute for ASEAN and East Asia (ERIA). www.eria.org/publications/research_project_reports/FY2012-No.19.html.

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.

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.

Maunsell and Lahmeyer. 2004. "Power System Development Plan for Lao PDR: Final Report, Volume A: Main Report." Auckland: World Bank. http://siteresources.worldbank.org/INTLAOPRD/491761-1094074854903/20252472/PSDP%20Main%20Report.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.

McKelvey, Vincent E. 1967. "Mineral Resource Estimates and Public Policy." *American Scientist*, 60: 32-40.

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

———. 2015a. “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.

———. 2015b. “Independent Power Producers Hydropower Projects: Memorandum of Understanding.” Vientiane: Lao PDR Ministry of Energy and Mines (MEM). www.poweringprogress.org/new/power-projects/plan.

———. 2016. “Hydropower Development Updated July 2016.” Data on installed and planned generation capacity. Report available in Lao. Vientiane: Lao PDR Ministry of Energy and Mines (MEM). http://laoenergy.la/download_free.php.

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

MRC. 2009. “Hydropower Sector Review for the Joint Basin Planning Process.” Vientiane: Mekong River Commission (MRC). www.mrcmekong.org/assets/Other-Documents/BDP/BDP2-Regional-Hydropower-Sector-Review-5-Mar-09.pdf.

Open Development Mekong. 2017. “Greater Mekong Subregion Hydropower Dams.” Data. Open Development Mekong. 2017. https://opendevelopmentmekong.net/dataset/?id=greater-mekong-subregion-hydropower-dams.

OpenEI. 2017. “Transparent Cost Database.” Open Energy Information (OpenEI). 2017. http://en.openei.org/wiki/Transparent_Cost_Database.

Pillai, G.M. 2014. “Lao PDR National Sustainable Energy Strategy Report on Enabling Environment and Technology Innovation Ecosystem for Affordable Sustainable Energy Options.” New Delhi: Asian and Pacific Centre for Transfer of Technology (APCTT) of the Economic and Social Commission for Asia and the Pacific (UNESCAP).

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.

Silva, Sandra, Luis Alçada-Almeida, and Luis C. Dias. 2014. “Biogas Plants Site Selection Integrating Multicriteria Decision Aid Methods and GIS Techniques: A Case Study in a Portuguese Region.” *Biomass and Bioenergy* 71:58–68. https://doi.org/10.1016/j.biombioe.2014.10.025.

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.

Tien Hung, Nguyen, Nguyen Thi Lan Anh, Nguyen Thi Vuong, Nguyen Thuy Linh, and Prain Fridviksson. 2015. "Overview of Geothermal Resources in North Part of Laos." In *Proceedings World Geothermal Congress 2015, 19-25 April*. Melbourne, Australia.

UXO LAO. 2013. "Lao National Unexploded Ordnance Programme (UXO LAO)." National Committee for Rural Development and Poverty Eradication. 2013. www.uxolao.org.

Vongsay, Akhomdeeth. 2013. "Energy Sector Development in Lao PDR." presented at the Institute of Energy Economics, Japan (IEEJ): Energy policy training course, Tokyo.

World Bank. 2005a. "People's Democratic Republic of Lao - Rural Electrification (Phase 1 -APL) Project." Washington, DC: World Bank. http://documents.worldbank.org/curated/en/730991468047754522/Peoples-Democratic-Republic-of-Lao-Rural-Electrification-Phase-1-APL-Project.

———. 2005b. "People's Democratic Republic of Lao - Rural Electrification (Phase 1 -APL) Project: Laos Electricity Transmission Network Dataset." Washington, DC: World Bank, Hosted on EnergyData.Info. https://energydata.info/dataset/laos-electricity-transmission-network-2005/resource/3039f96d-1979-4dc7-be64-f62f297e1d8a.

Wu, Jinzhuo, Jingxin Wang, and Michael P. Strager. 2011. "A Two-Stage GIS-Based Suitability Model for Siting Biomass-to-Biofuel Plants and Its Application in West Virginia, USA." *International Journal of Forest Engineering* 22 (2):28–38. https://doi.org/10.1080/14942119.2011.10702608.

Appendix A – Data-gap assessment tables

Each energy resource assessment includes a data-gap assessment table that details the desired datasets and respective levels of resolution. Each unique dataset is identified as shown in TABLE A-1. The layer ID indicates a specific dataset identified for Lao PDR as listed in the data collection table presented in TABLE A-1. The layer ID indicates the *source* for the specified dataset, the *vintage*—or year published—of the dataset, and a *quality flag* if issues exist such as spatial coverage, missing data, etc. The layer ID refers to the complete data list in TABLE A-15, presented at the end of Appendix A.

TABLE A-1. DATA-GAP ASSESSMENT TABLE KEY

Unique Identified Dataset	Color Key
-	Not applicable
Layer ID-Source-Vintage-(quality control (QC) flag: QC or None)	Exists and is in RE Data Explorer
Layer ID-Source-Vintage-(QC flag: QC or None)	Exists but is not in RE Data Explorer
	Does not exist or not identified

TABLE A-2. SOLAR RESOURCE DATA-GAP ASSESSMENT—LAO PDR

		Annual	Monthly	Hourly or Subhourly
Solar	GHI	104-World Bank-2016 [also 64]	64-NREL-QC	
	DNI	103-World Bank-2016 [also 63]	63-NREL-QC	
	DHI			
	Latitude Tilt	63-NREL-QC		
	PV Output	105-World Bank-2016		
	Typical Meteorological Year (TMY) Data			
	Spectral Data			
	Ground Measurements			

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-3. ONSHORE WIND RESOURCE DATA-GAP ASSESSMENT—LAO PDR

		Annual			Hourly or Subhourly		
		30–49 meter hub height	50–79 meter hub height	80 meter or greater hub height	30–49 meter hub height	50–79 meter hub height	80 meter or greater hub height
Wind	Wind Speed		145-DTU-2016	146-DTU-2016 [also 128]			
	Wind Direction						
	Wind Power Class and/or Power Density		145-DTU-2016	146-DTU-2016 [also 129]			
	Ground Measurements						

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-4. HYDROPOWER RESOURCE DATA-GAP ASSESSMENT—LAO PDR

		Annual	Seasonal
Hydropower	Large Hydropower Technical Potential—Not exploited		
	Small Hydropower Technical Potential—Not exploited		

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-5. BIOMASS RESOURCE DATA-GAP ASSESSMENT—LAO PDR

		Province/District	Country
		Annual	
Biomass	Logging Residues		224-Akgün et al. (2011)-2011
	Primary Mill Residues		224-Akgün et al. (2011)-2011
	Secondary Mill Residues		224-Akgün et al. (2011)-2011
	Biogas	225-Koumphonphakdi and Suntivarakorn-2014	223-ADB-2010 [also 225]
	Crop Residue	133-ADB-2010 [also 134, 135, 136]	133-ADB-2010 [also 134, 135, 136, 224]

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-6. GEOTHERMAL RESOURCE DATA-GAP ASSESSMENT—LAO PDR

		Spatial Data
Geothermal	Temperature at Depth	
	Geothermal Heat Flow	
	Thermal Conductivity	
	Borehole Temperature Observations (Temperature at Depth)	
	Surface Feature - Wells and Springs	
	Hydrothermal Areas	

Refer to data-gap assessment table key of TABLE A-1.

TABLE A-7. NONRENEWABLE ENERGY RESOURCES DATA-GAP ASSESSMENT—LAO PDR

		Province	District	Site Specific[1]
Non-renewable Resources	Coal Resources—potential, proven, or other (ktoe or barrels)			114-World Bank-2006-QC
	Petroleum Resources—potential, proven, or other (ktoe or barrels)			
	Natural Gas Resources—potential, proven, or other (ktoe, billion cubic meters [bcm] or other)			
	Nuclear Resources—potential, proven, or other			

[1]Spatial location of the site of the non-RE resource deposit

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-8. POWER NETWORK DATA-GAP ASSESSMENT—LAO PDR

		Spatial Data	Tabular Data
Power Network	Biofuel Plants		
	Bio-Refineries		
	Coal Plants		220-Lao MEM-2017-QC
	Diesel or Bunker Plants		220-Lao MEM-2017-QC
	Geothermal Plants		
	Hydropower Plants (large)	121-OpenDevelopmentMekong-2014 [also 217, 218, 54, 226]	121-OpenDevelopmentMekong-2014 [also 217, 218, 54, 226]
	Hydropower Plants (small)	121-OpenDevelopmentMekong-2014 [also 217, 218, 54]	121-OpenDevelopmentMekong-2014 [also 217, 218, 54]
	Natural Gas Plants		220-Lao MEM-2017-QC
	Multiple	54-NREL-QC	
	Solar farms		
	Wind Farms		
	Transmission Lines	85-OSM-2016-QC [also 226]	
	Substations	85-OSM-2016-QC [also 226]	
	Transmission Losses (%)		219-Lao MEM-2015 [also 115]
	Electric Tariffs		219-Lao MEM-2015 [also 115]
	Distribution Losses (%)		219-Lao MEM-2015 [also 115]

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-9. ANCILLARY METEOROLOGICAL DATA-GAP ASSESSMENT—LAO PDR

		Annual	Monthly	Hourly or Subhourly
Ancillary Meteorological	Air Temperature	89-NREL		95-NASA-Current
	Atmospheric Pressure	90-NREL		96-NASA-Current
	Cooling Degree Days	91-NREL		
	Heating Degree Days	93-NREL		
	Wind Direction (ground)			99-NASA-Current
	Wind Speed (ground)			98-NASA-Current
	Dew Point			100-NASA-Current
	Earth Skin Temperature	92-NREL		
	Relative Humidity	94-NREL		97-NASA-Current

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-10. ENVIRONMENTAL DATA-GAP ASSESSMENT—LAO PDR

		Spatial Data
Environmental	Rivers	119-NASA [also 108]
	Lakes	119-NASA
	Ground Water	128-UNESCO [also 129]
	Wastewater	
	Digital Elevation Model and/or Topography	51-CGIAR
	Protected Lands	53-NREL-2015
	National Parks	53-NREL-2015
	Contaminated Lands	122-National Regulatory Authority-QC
	Land Use and Land Cover	198-USGS-2010 [also 52, 110]
	Fauna Critical Habitat	
	Flora Critical Habitat	
	Flood Plain/Hazard	
	Landslide Frequency	
	Fire Frequency	
	Earthquake Frequency	
	Drought Events	87-Decide Laos-QC
	Tsunami Frequency	-
	Climate Data	111-Greater Mekong Subregion Information Portal-QC
	Volcanoes	-
	Climate Scenarios (precipitation, temperature, etc.)	88-NREL-2016

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-11. MARKET AND DEMAND DATA-GAP ASSESSMENT—LAO PDR

		Annual	Monthly	Hourly
Market & Demand	Commercial Electricity Price ($/kWh)	219-Lao MEM-2015 [also 116]	-	-
	Industrial Electricity Price ($/kWh)	219-Lao MEM-2015 [also 116]	-	-
	Residential Electricity Price ($/kWh)	219-Lao Mem-2015 [also 116]	-	-
	Peak Demand (MW)	219-Lao MEM-2015 [also 116]		
	Electricity Consumption (GWh)	219-Lao MEM-2015 [also 116]		
	Electricity Generation (GWh)	219-Lao MEM-2015 [also 116]		
	Domestic Electricity Wholesale Price ($/MWh)	216-Lao MEM-2016		
	Electricity Imports by Origin (GWh)	219-Lao MEM-2015 [also 116]		
	Imported Electricity Price by Origin ($/kWh)	219-Lao MEM-2015 [also 116]		
	Electricity Exports by Destination (GWh)	219-Lao MEM-2015 [also 116]		
	Exported Electricity Price by Destination ($/kWh)	219-Lao MEM-2015 [also 116]		

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-12. TRANSPORTATION DATA-GAP ASSESSMENT—LAO PDR

		Spatial Data
Transportation	Fueling Stations (by fuel type)	
	Vehicle Density (by type)	
	Railroads	58-NREL-2017-QC
	Roads (by type)	106-National Geographic Department-1999-QC [also 59]
	Airports	125-Natural Earth-2012 [also 126]
	Seaports	-
	Riverports	
	Biodiesel Plants	
	Ethanol Plants	

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-13. ADMINISTRATIVE AND OTHER CATEGORIES DATA-GAP ASSESSMENT—LAO PDR

		Spatial Data
Admin / Other	**Cities**	124-Natural Earth-2003
	Villages and/or Tribal Areas	109-National Geographic Department-QC
	Population Density	120-NASA-2016
	Administrative Boundaries (states, provinces, etc.)	56-NREL-2015 [also 57]
	Land Ownership	
	Built-Areas	107-National Geographic Department-1999-QC[also 204]
	Land Price	
	Statistics	86-Lao PDR Population and Housing Census--QC
	Poverty	123-World Bank-2015
	Other	-
	Electrification	219-Lao PDR MEM-2015[also 115]
	Economic and/or Special Zones	60-NREL-2012[also 61]

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-14. LEVELIZED COST OF ELECTRICITY (LCOE) DATA-GAP ASSESSMENT—LAO PDR

		Wind	Solar	Hydropower	Biomass	Geothermal	Coal	Oil	Natural Gas	Nuclear
Levelized Cost of Electricity (LCOE)*	Electricity Generation System Size and Cost by Type ($ [or kip] and/or $/W)		206-ACE-2014	220-Lao MEM-2017-QC [also 206]			220-Lao MEM-2017-QC	220-Lao MEM-2017-QC [also 213]	220-Lao MEM-2017-QC	
	Fixed Operation and Maintenance Cost by Generation System Type ($/kW or kip/kWh)		206-ACE-2014	220-Lao MEM-2017-QC [also 206]			220-Lao MEM-2017-QC	220-Lao MEM-2017-QC [also 213]	220-Lao MEM-2017-QC	
	Variable Operation and Maintenance Cost by Generation System Type (i.e., fuel cost) ($/liter, $/ton of biomass, etc. or kip/liter or kip/ton of biomass etc.)			220-Lao MEM-2017-QC			220-Lao MEM-2017-QC	220-Lao MEM-2017-QC	220-Lao MEM-2017-QC	
	Electricity Generation Annually by Type of Generation System (kWh/year)			219-Lao PDR MEM-2015 [also 220, 115]	219-Lao PDR MEM-2015 [also 220, 115]		220-Lao MEM-2017-QC	220-Lao MEM-2017-QC	220-Lao MEM-2017-QC	
	Capacity/Utilization Factor by Generation System Type (%)		206-ACE-2014	220-Lao MEM-2017-QC [also 206]			220-Lao MEM-2017-QC [also 206]	220-Lao MEM-2017-QC [also 213]	220-Lao MEM-2017-QC [also 206]	
	System Degradation Rate									
	Planned Electricity Generation System Expansion Locations			218-Lao PDR MEM-2017-QC[also 211, 212]						
	Technical Potential	223-ADB-2010	223-ADB-2010	223-ADB-2010	223-ADB-2010	223-ADB-2010				
	Other Considerations To Be Determined (fisheries, relocation, revenue loss, infrastructure costs, etc.)	-	-	208-Ziv et al.-2012-QC[also 209, 210, 215]	-	-	-	-	-	-

*Includes liquid based fuels

Refer to data-gap assessment table key in TABLE A-1.

TABLE A-15. SUMMARY OF DATA IDENTIFIED—LAO PDR

ID	Region	Layer Name	Category 1	Source Organization	Spatial Resolution	Temporal Resolution	Data Vintage	Data Format	Resource Link	Access Restrictions	Availability
51	Laos	Elevation	Environmental	CGIAR	90x90m	2000	2008	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/?aL=Xp3gcq%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Open	Free and publicly available
52	Laos	Land Use	Environmental	ESA	300x300m	2005	2005	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/?aL=9mlD02%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Open	Free and publicly available
53	Laos	Protected Areas	Environmental	Protected Planet	null	2015	2015	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/#/?aL=Vqadhx%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Open	Free and publicly available
54	Laos	Power Plants	Grid	CARMA	null	2009	2009	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/#/?aL=wRUAPE%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Open	Free and publicly available
56	Laos	Province Bnd	Administrative	Global Administrative Areas Database	null	2015	null	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/#/?aL=KAMbdi%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Open	Free and publicly available
57	Laos	County Bnd	Administrative	Global Administrative Areas Database	null	2015	null	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/#/?aL=tAL8PG%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Open	Free and publicly available
58	Laos	Railroads	Administrative	OpenStreetMap	null	2017	null	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/#/?aL=9JAKuv%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Open	Free and publicly available
59	Laos	Roads	Administrative	OpenStreetMap	null	2017	null	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/#/?aL=X-Fp4H%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Open	Free and publicly available
60	Laos	Economic Corridors	Economy	Environment Operations Center (Greater Mekong Subregion)	null	null	null	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/#/?aL=kqFX_o%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Creative Commons Attribution 4.0	Free and publicly available
61	Laos	Special Economic Zones	Administrative	Environment Operations Center (Greater Mekong Subregion)	null	null	null	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/#/?aL=bDmS-C%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Creative Commons Attribution 4.0	Free and publicly available
63	Laos	Direct Solar	Solar	NREL	40x40km	null	null	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/#/?aL=7LuVDL%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Open	Free and publicly available
64	Laos	Global Solar	Solar	NREL	40x40km	null	null	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/#/?aL=uIiP5q%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.2482467%2C103.257851&zL=5	Open	Free and publicly available
85	Lower Mekong	Power Infrastructure	Grid	OpenStreetMap	Unknown	2016	Unknown	Unknown	http://wiki.openstreetmap.org/wiki/Planet.osm	Open	Free and publicly available
86	Laos	Village-Level Statistics	Administrative	Lao Bureau of Statistics	Village	2005	2005	Vector	http://www.decide.la/en/downloads	Open	Free and publicly available

ID	Region	Layer Name	Category 1	Source Organization	Spatial Resolution	Temporal Resolution	Data Vintage	Data Format	Resource Link	Access Restrictions	Availability
87	Laos	Floods, Droughts, Landslides Occurred	Environmental	Lao Ministry of Agriculture and Forestry	Village	2010-2011	2011	Vector	http://www.decide.la/en/downloads	Open	Free and publicly available
88	Eastern Hemisphere	Climate Change Scenarios	Environmental	UCAR	1.4x1.4 degrees	1998-2100	2016	Unknown	https://gisclimatechange.ucar.edu/user/register	Open	Free and publicly available
89	Global	Air Temperature	Environmental	NASA - ASDC	1x1 degree	1983 - 2005	Unknown	Unknown	https://eosweb.larc.nasa.gov/sse/	Open	Free and publicly available
90	Global	Atmospheric Pressure	Environmental	NASA - ASDC	1x1 degree	1983 - 2005	Unknown	Unknown	https://eosweb.larc.nasa.gov/sse/	Open	Free and publicly available
91	Global	Cooling Degree Days	Environmental	NASA - ASDC	1x1 degree	1983 - 2005	Unknown	Unknown	https://eosweb.larc.nasa.gov/sse/	Open	Free and publicly available
92	Global	Earth Skin Temperature	Environmental	NASA - ASDC	1x1 degree	1983 - 2005	Unknown	Unknown	https://eosweb.larc.nasa.gov/sse/	Open	Free and publicly available
93	Global	Heating Degree Days	Environmental	NASA - ASDC	1x1 degree	1983 - 2005	Unknown	Unknown	https://eosweb.larc.nasa.gov/sse/	Open	Free and publicly available
94	Global	Relative Humidity	Environmental	NASA - ASDC	1x1 degree	1983 - 2005	Unknown	Unknown	https://eosweb.larc.nasa.gov/sse/	Open	Free and publicly available
95	Global	Air Temperature	Environmental	NASA - GES DISC	40x40km	1979-2017	2017	HDF	https://disc.sci.gsfc.nasa.gov/mdisc/	Open	Free and publicly available
96	Global	Air Pressure	Environmental	NASA - GES DISC	40x40km	1979-2017	2017	HDF	https://disc.sci.gsfc.nasa.gov/mdisc/	Open	Free and publicly available
97	Global	Relative Humidity	Environmental	NASA - GES DISC	40x40km	1979-2017	2017	HDF	https://disc.sci.gsfc.nasa.gov/mdisc/	Open	Free and publicly available
98	Global	Wind Speed	Environmental	NASA - GES DISC	40x40km	1979-2017	2017	HDF	https://disc.sci.gsfc.nasa.gov/mdisc/	Open	Free and publicly available
99	Global	Wind Direction	Environmental	NASA - GES DISC	40x40km	1979-2017	2017	HDF	https://disc.sci.gsfc.nasa.gov/mdisc/	Open	Free and publicly available
100	Global	Dew Point	Environmental	NASA - GES DISC	40x40km	1979-2017	2017	HDF	https://disc.sci.gsfc.nasa.gov/mdisc/	Open	Free and publicly available
103	Global	Direct Normal Irradiance	Energy Resource	World Bank - SOLARGIS	1x1km	Unknown	Unknown	Unknown	http://globalsolaratlas.info	Open	For purchase (contact author)
104	Global	Global Horizontal Irradiance	Energy Resource	World Bank - SOLARGIS	1x1km	Unknown	Unknown	Unknown	http://globalsolaratlas.info	Open	For purchase (contact author)
105	Global	PV Electricity Output	Energy Resource	World Bank - SOLARGIS	1x1km	Unknown	Unknown	Unknown	http://globalsolaratlas.info	Open	For purchase (contact author)
106	Laos	Roads	Administrative	National Geographic Department	Unknown	1999	2003	Vector	http://www.ngd.la/?p=346&lang=en	Open	Free and publicly available
107	Laos	Built-Up Areas	Administrative	National Geographic Department	Unknown	1999	2003	Vector	http://www.ngd.la/?p=343&lang=en	Open	Free and publicly available
109	Laos	Villages Points	Administrative	National Geographic Department	Unknown	2008	2008	Vector	http://www.ngd.la/?p=332&lang=en	Open	Free and publicly available

ID	Region	Layer Name	Category 1	Source Organization	Spatial Resolution	Temporal Resolution	Data Vintage	Data Format	Resource Link	Access Restrictions	Availability
110	Laos	Land Use	Environmental	National Geographic Department	Unknown	1999	2003	Vector	http://www.ngd.la/?p=324&lang=en	Open	Free and publicly available
111	Lower Mekong	Climate Data	Environmental	Greater Mekong Subregion Information Portal	Unknown	2050	2014	Unknown	http://portal.gms-eoc.org/maps?cmbIndicatorMapType=data&cmbIndicatorTheme=9&cmbIndicatorMap=30	Open	Free and publicly available
114	Laos	Coal Deposits	Coal	World Bank	null	2006	2006	data_map_vector	https://maps.nrel.gov/gst-lower-mekong/?aL=FKLg5m%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=14.26438308756265%2C103.24951171875&zL=5	Open	Free and publicly available
115	Laos	Electricity Statistics	Grid	Lao MEM	null	2014	2014	Print	http://laoenergy.la/admin/upload_free/cb0bfaff9558d1d767476cca252b287d99a6f6ba49782ee1c73dd8c79848e14a3a32481e1c7efdd80bd4b3547b03d806Electricity.pdf	Open	Free and publicly available
116	Laos	Electricity Tariffs	Grid	Lao MEM	null	2012	2012	Print	http://open_jicareport.jica.go.jp/pdf/12087904_01.pdf	Open	Free and publicly available
119	Global	Lakes and Rivers	Environmental	USGS - SRTM	Unknown	Unknown	Unknown	Unknown	https://lta.cr.usgs.gov/srtm_water_body_dataset	Open	Free and publicly available
120	Global	Population Density	Administrative	Socioeconomic Data and Applications Center (sedac)	1x1km	2015	2016	Unknown	http://sedac.ciesin.columbia.edu/data/collection/gpw-v3	Open	Free and publicly available
121	Lower Mekong	Dams	Hydropower	OpenDevelopmentMekong	Site Specific	2014	2014	Unknown	https://opendevelopmentmekong.net/dataset/?id=greater-mekong-subregion-hydropower-dams	Open	Free and publicly available
122	Laos	Unexploded Ordinances	Administrative	National Regulatory Authority for the UXO/Mine Action Sector in the Lao PDR	Village	1965-1975	Unknown	Unknown	http://www.nra.gov.la/bombinginformation.html	Open	Free but restricted (contact author)
123	Laos	Poverty	Poverty & Electrification	World Bank	Province	Unknown	2015	Print	http://documents.worldbank.org/curated/en/477381468415961977/Where-are-the-poor-Lao-PDR-2015-census-based-poverty-map-province-and-district-level-results	Open	Free and publicly available
124	Global	Urban Areas		Natural Earth	Site Specific	Unknown	2003	Unknown	http://www.naturalearthdata.com/downloads/10m-cultural-vectors	Open	Free and publicly available
125	Global	Airports		Natural Earth	Site Specific	Unknown	2012	Unknown	http://www.naturalearthdata.com/downloads/10m-cultural-vectors/airports	Open	Free and publicly available
126	Laos	Airports	Administrative	OpenDevelopmentMekong	Site Specific	Unknown	2014	Vector	https://laos.opendevelopmentmekong.net/dataset/?id=airports-of-laos	Open	Free and publicly available
128	Laos	Ground Water	Environmental	UNESCO and Lao MONRE	Unknown	2013-2014	2015	Print	http://unesdoc.unesco.org/images/0024/002436/243616E.pdf & http://www.monre.gov.la/en	Open	Free and publicly available
129	Lower Mekong	Ground Water	Environmental	Mekong River Commission	Unknown	1992	1992	Vector	http://www.arcgis.com/home/item.html?id=e17fec08485344c18d7980a093207550	Open	Free and publicly available
133	Laos	Rice Husk Production	Biomass	Lao PDR Ministry of Agriculture and Forestry	Province	Unknown	2010	Print	https://www.adb.org/sites/default/files/publication/161898/renewable-energy-developments-gms.pdf	Open	Free and publicly available
134	Laos	Sugarcane Crop Residues	Biomass	Lao PDR Ministry of Agriculture and Forestry	Province	Unknown	2010	Print	https://www.adb.org/sites/default/files/publication/161898/renewable-energy-developments-gms.pdf	Open	Free and publicly available

ID	Region	Layer Name	Category 1	Source Organization	Spatial Resolution	Temporal Resolution	Data Vintage	Data Format	Resource Link	Access Restrictions	Availability
135	Laos	Maize Cob Production	Biomass	Lao PDR Ministry of Agriculture and Forestry	Province	Unknown	2010	Print	https://www.adb.org/sites/default/files/publication/161898/renewable-energy-developments-gms.pdf	Open	Free and publicly available
136	Laos	Cassava Residues	Biomass	Lao PDR Ministry of Agriculture and Forestry	Province	Unknown	2010	Print	https://www.adb.org/sites/default/files/publication/161898/renewable-energy-developments-gms.pdf	Open	Free and publicly available
145	Global	Wind Speed	Energy Resource	DTU	1x1km	Unknown	Unknown	Raster	http://globalwindatlas.com/map.html	Open	Free and publicly available
146	Global	Wind Power Density	Energy Resource	DTU	1x1km	Unknown	Unknown	Raster	http://globalwindatlas.com/map.html	Open	Free and publicly available
198	Global	Land Use	Environmental	USGS - GLC	Unknown	Unknown	2010	Raster	https://landcover.usgs.gov/glc/	Open	Free and publicly available
204	Global	Built-Up Areas	Administrative	DLR	12x12m	2011-2014	2017	Vector	http://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-9628/16557_read-40454/	DLR License	Free but restricted (contact author)
206	Regional	LCOE Considerations		ASEAN Centre for Energy (ACE)	Country	2014	2014	Tabular	https://goo.gl/PbZDR1	Open	Free and publicly available
208	Lower Mekong	LCOE Considerations	Fisheries Loss	PNAS.org	N/A	2012	2012	Tabular	http://www.pnas.org/content/109/15/5609.full	Open	Free and publicly available
209	Lower Mekong	LCOE Considerations	Fisheries Loss	Portland State University	N/A	2011	2011	Tabular	http://web.pdx.edu/~kub/publicfiles/Mekong/LMB_Report_FullReport.pdf	Open	Free and publicly available
210	Lower Mekong	LCOE Considerations	Fisheries Loss	Mae Fah Luang University	N/A	2015	2015	Tabular	http://www.mfu.ac.th/nremc/gallery/Final%20Report%20on%20Mekong%20Hydropower%20Development.pdf	Open	Free and publicly available
213	Lower Mekong	LCOE Considerations		Mekong River Commission (MRC)	Country	2009	2009	Tabular	http://www.mrcmekong.org/assets/Other-Documents/BDP/BDP2-Regional-Hydropower-Sector-Review-5-Mar-09.pdf	Open	Free and publicly available
215	Lower Mekong	LCOE Considerations	Fisheries Loss	CGIAR	N/A	2012	2012	Report	https://cgspace.cgiar.org/handle/10568/34821	Open	Free and publicly available
217	Laos	Power Plants—Locations	Hydropower and Other	Lao MEM	Site Specific	2017	2017	Vector	Not Available	Shared with NREL	Restricted
218	Laos	Power Plants—Existing and Planned Development	Hydropower and Other	Lao MEM	Site Specific	2017	2017	Tabular	Not Available	Shared with NREL	Restricted
219	Laos	Electricity Statistics	Grid	Lao MEM	N/A	2015	2015	Report	Not Available	Shared with NREL	Free and publicly available
220	Laos	Power Plants	Hydropower and Other	Lao MEM	N/A	2017	2017	Tabular	Not Available	Shared with NREL	Restricted
223	Laos	Biogas Potential & LCOE	Energy Resource	ADB	Country	2010	2010	Report	http://hdl.handle.net/11540/5054	Open	Free and publicly available

ID	Region	Layer Name	Category 1	Source Organization	Spatial Resolution	Temporal Resolution	Data Vintage	Data Format	Resource Link	Access Restrictions	Availability
224	Lower Mekong	Biomass Potential	Energy Resource	(Akgün et al. 2011)	Country	2011	Complied 2006 & 2009	Journal article	http://www.ep.liu.se/ecp/057/vol1/045/ecp57vol1_045.pdf	Open	Free and publicly available
225	Laos	Biogas Potential	Energy Resource	(Koumphonphakdi and Suntivarakorn 2014)	Province	2014	Compiled 2010, 2011, 2012, 2013	Journal article	http://gmsarnjournal.com/home/wp-content/uploads/2015/08/vol8no2-1.pdf	Open	Free and publicly available
226	Laos	Power Infrastructure	Grid	World Bank	Country	2005	2005	Vector & JSON	http://documents.worldbank.org/curated/en/730991468047754522/Peoples-Democratic-Republic-of-Lao-Rural-Electrification-Phase-1-APL-Project https://energydata.info/dataset/laos-electricity-transmission-network-2005/resource/3039f96d-1979-4dc7-be64-f62f297e1d8a	Open	Free and publicly available
227	Lower Mekong	Hydrological Data	Hydropower and Other	Mekong River Commission	Regional	Unknown	Unknown	Unknown	http://www.mrcmekong.org/	Unknown	Restricted

Appendix B – Data-gap identification activity

The data-gap assessment presented below in TABLE B-1 details the outputs from the data-gap assessment verification and identification activity. This activity was led by the NREL team with input from the Technical Committee members—primarily from the MEM and EDL. Data gaps identified in this activity are shown in the table together with potential sources for these data and Technical Committee members that are responsible for collecting these data.

Data gaps that have been identified and resolved—through sharing of data from Lao or other sources identified—are highlighted in green. Data gaps that still need to be addressed are not highlighted.

TABLE B-1. DATA-GAP: ENERGY RESOURCE AND COMPLEMENTARY DATA—LAO PDR

Data Gap	Potential Source	Additional Comments
Coal Resources and Reserves • Type of deposit • Proven reserve vs. resource • Remaining questions: *How to count the coal reserve that is explored/used by private company as concession*?	Mining Department, MEM Geology Department, MEM	
Solar Data	Department of Alternative Energy and Efficiency (DEDE) Silpakorn University, Bangkok Thailand	Solar resource data study Shared as part of data collection activities.
Wind Data	Institute of Renewable Energy Promotion (IREP), MEM	A complete summary of measurements, data collection and reports from companies and may be done in about 18 months.
Biomass	IREP, MEM Ministry of Agriculture (MoA), Department of Planning	IREP will share a report for the Huaphanh Province biomass in tabular data. IREP will check for previous studies that could be helpful. MoA Dept. of Agriculture planning. Crop Statistics Yearbook 2015.
Hydro, large and small	MEM website—Data on Power Plants Planned and existing construction Locations of these plants Resources for Hydropower DEPP Electricity Generation Planning Division	These datasets are in Lao. MEM shared a pdf of data on existing power plants together with a spatial detailing their location. Additional datasets may exist.
Land Use Types	Department of Agriculture	
Protected Areas	Department of Mapping Ministry of Natural Resources and the Environment	Mainly elevation etc.

Data Gap	Potential Source	Additional Comments
National Biological Conservation Areas (NBCA)	Ministry of Public Works and Transportation—Department of Constructions	
	Ministry of Agriculture and Forestry	
Rivers and Lakes	Ministry of Natural Resources and the Environment	DEPP may have some data or contacts to reach out to.
	Mekong River Commission	
	Department of Mapping	
Fisheries	Ministry of Agriculture and Forest—Department of Fisheries and Livestock	
Ground Water	Ministry of Natural Resources and Environment, Department of Water Resources	
	Ministry of Public Works and Transportation	
	Ministry of Public Health	
Fauna Critical Habitat	Ministry of Agriculture and Forestry	
	Ministry of Natural Resources	
Flora Critical Habitat	Ministry of Agriculture and Forestry	
	Ministry of Natural Resources	
Floodplain/Hazard	Ministry of Natural Resources and Environment (MONRE), Department of Water Resources	
Landslide Frequency	MONRE, Department of Disaster Control and Climate Change	
Fire Frequency	MONRE, Department of Disaster Control and Climate Change	
	Ministry of Forest Managements and—Department of Forestry	
Earthquake Frequency	MONRE, Department of Meteorology	
Drought Events	MONRE, Department of Disaster Control and Climate Change	
Climate Data	MONRE, Department of Disaster Control and Climate Change	
Climate Scenarios	MONRE, Department of Disaster Control and Climate Change	
Major Roads	Ministry of Public Works and Transportation	
	Department of Mapping	
Railroads	Ministry of Public Works and Transportation	
	Department of Mapping	
Airports	Ministry of Public Works and Transportation	

Data Gap	Potential Source	Additional Comments
	Department of Mapping	
Riverports	Ministry of Public Works and Transportation Department of Mapping	Mostly for tourists and locals, but not for freight transport. There is some freight transport in northern Laos for China and Thailand.
Population Density	National Statistics Bureau Ministry of Planning and Investment	
Land Ownership	MONRE, Department of Natural Resources	
Land Prices	MONRE, Department of Land Development	Decree of MONRE—on website. *-Compensation Decree* *-provide compensation for land or provide new lands* *-Make a relocation committee for each project*
Census Data	Lao Statistics Bureau	We have 2005 data from Lao Decide.
Electrification	EDL may have Better Data. DEPP will inquire about data from EDL.	DEPP shared 2015 MEM Electricity Statistics Yearbook (most recent data in tabular form). Data from 2014 are also available online.
Economic and or Special Zones	Ministry of Planning and Investment—Investment Promotion Department	
Electricity Generation System Size (MW), Production (kWh, MWh), and Cost by Type ($ [or kip] or $/W)	DEPP, MEM has some data for hydro and coal and natural gas, oil? See spreadsheet	MEM shared dataset of costs and capacity factors for power plants in Laos.
Fixed Operation and Maintenance Cost by Generation System Type ($/kW or kip/kWh)	DEPP, MEM has some data for hydro and coal and natural gas, oil—see spreadsheet	MEM shared dataset of costs and capacity factors for power plants in Laos.
Variable Operation and Maintenance Cost by Generation System Type (i.e., fuel cost) ($/liter, $/ton of biomass, kip/liter or kip/ton of biomass etc.)	DEPP, MEM has some data for hydro and coal and natural gas, and oil—see spreadsheet	See previous O&M costs—this dataset is mixed with O&M costs for some power plants.
Electricity Generation Annually by Type of Generation System (kWh/year)	DEPP, MEM—see spreadsheet	2015 MEM Electricity Statistics Yearbook (tabular form). This can be compared with data in the costs datasets described in the preceding rows.
Transmission and Distribution Systems	Team has already spoken with MEM— DEPP—	Need to verify that these data are available—awaiting these data.

Data Gap	Potential Source	Additional Comments
	EDL—	
Power Plant Capacity (MW])	Shared in Excel file	MEM shared dataset. Installed capacity and additional data for power plants in Laos (Excel spreadsheet)
Planned Construction	In PDF file of hydro plants shared by MEM	MEM shared a pdf of data in English and a dataset that includes GIS coordinates of power plants. (also see Hydro, large and small)
Relocation and Cost	Decree of MONRE—could not locate on their website.	*-Compensation Decree* *See previous comment*
Wholesale Cost	Notice on pricing principles for independent power producers' domestic projects on MEM website.	MEM shared a pdf of the pricing principles notice. This pricing notice states the weighted levelized tariff for electricity sold to the EDL.
Electricity Tariff, Residential, Industry Services, etc.—each sector	MEM, DEPP 2014 report MEM They will share this. The person who has these values is not in.	MEM shared the 2015 MEM Electricity Statistics Yearbook (tabular form). This will be updated in 2018.
Electricity import and export cost	In 2014 Electricity Statistics Yearbook	MEM shared the 2015 MEM Electricity Statistics Yearbook. Assume independent power producers all export to Thailand unless otherwise specified.

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