

GEOGRAPHIC INFORMATION SYSTEM-BASED DECISION SUPPORT SYSTEM FOR RENEWABLE ENERGY DEVELOPMENT AN INDONESIAN CASE STUDY

Bhuwneshwar Prasad Sah and Priyantha Wijayatunga

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Geographic Information System-Based Decision Support System for Renewable Energy Development: An Indonesian Case Study

Bhuwneshwar Prasad Sah and Priyantha Wijayatunga
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ABBREVIATIONS

ADB	-	Asian Development Bank
BIG	-	Badan Informasi Geospasial (Geospatial Information Agency) formerly Badan Koordinasi Survei dan Pemetaan Nasional (BAKOSURTANAL) or National Coordinating Agency for Surveys and Mapping
BPPT	-	Badan Pengkajian dan Penerapan Teknologi (Agency for the Assessment and Application of Technology)
BPS	-	Badan Pusat Statistik (Statistics Indonesia Agency)
DSS	-	decision support system
ESDM	-	Energi dan Sumber Daya Mineral (Ministry of Energy and Mineral Resources)
GDAS	-	Global Data Assimilation System
GIS	-	geographic information system
GRASS	-	Geographic Resources Analysis Support System
PLN	-	Perusahaan Listrik Negara (State Electricity Corporation)
WGS84	-	World Geodetic System 1984
WRI	-	World Resources Institute
UTM	-	Universal Transverse Mercator

WEIGHTS AND MEASURES

GW	-	gigawatt
GWh/year	-	gigawatt-hour per year
kW	-	kilowatt
kWh	-	kilowatt-hour
kWh/m ²	-	kilowatt-hour per square meter
MW	-	megawatt
MWh	-	megawatt-hour
MJ/kg	-	megajoules per kilogram

EXECUTIVE SUMMARY

In the Asia and Pacific region, recent estimates show that about 420 million people are still without access to electricity. There is an urgency to eliminate this access gap within a short period. At the same time, the cost of renewable energy deployment is exponentially coming down. This means there is a significant opportunity for expansion of clean energy development for the benefit of the populations in the Asia and Pacific region.

As a result, the international financing institutions' interest in the energy sector is no longer limited to assisting the countries to expand their centralized generation facilities but also to support distributed renewable energy development. In this regard, the contribution of geographic information system (GIS)-based decision support system (DSS) would be significant to ensure the right mix of renewable energy to meet the needs of the respective localities. The paper describes the use of such GIS-based DSS in developing a tool that quantifies the potential of five energy sources (solar, wind, biomass, hydropower, and geothermal) in a given geographical area, using Bali, Indonesia as a case study.

The open source GIS software QGIS, along with Geographic Resources Analysis Support System (GRASS), was used to process the data collected by a team composed mainly of staff from the Energi dan Sumber Daya Mineral, Government of Indonesia, World Resources Institute, and University of Tokyo. QGIS was used to manage incoming geospatial data via an interface similar to ArcGIS. Incorporating potential energy mix output, demographic and geographic data, and political boundaries with suitability criteria, a mapping tool is necessary to locate suitable installation sites of renewable energy harvesters, e.g., solar panels and wind turbines. Data processing is completed with QGIS, including installation of GRASS plugin, which is involved in raster processing. The spatial distribution of said resources was mapped using a GIS platform.

Consolidated data show that the range of technical potential in each *desa* (administrative village) in the eastern and western parts of Bali varies from 300 gigawatt-hours (GWh) per year to 12,000 GWh/year. In terms of total technical potential of solar energy, Buleleng and Klungkung districts alone can generate 59,000 GWh/year. Raw data shows Badung and Klungkung districts provide good source of wind energy. The overall technical potential of wind energy in the area was estimated to reach 33 GWh/year. It is estimated that Buleleng, Tabanan, and Gianyar districts can serve as a major biomass energy producer. A total of 329 megawatts (MW) from geothermal was recorded from different potential sites. Tabanan, Bangli, and Buleleng districts were identified as good sources of geothermal energy. Hydropower from 143 locations can offer up to 14.8 MW of capacity. The total estimated technical potential from all the renewable energy sources amounts to 115,372 GWh/year with solar energy contributing to 98% of the total energy yield. This shows that even if 5% of this technical potential can be developed, the projected energy requirement of 4,993 GWh/year in Bali by 2019 can be entirely met.

The focus of this DSS is entirely on estimating the technical potential of the resource mix from wind, solar, biomass, hydropower, and geothermal energy sources. Once the technical potential has been determined the factors such as financial viability, socioeconomic impacts and technological aspects need to be brought into the decision-making process.

I. INTRODUCTION

A. Overview of Renewable Energy

The Asian Development Bank (ADB) closely works with its developing member countries (DMCs) in the Asia and Pacific region to address the challenges of both energy security and climate change. With the growing concern of global warming and climate change, the call for utilization of renewable energy is growing in the region (ADB 2016a, 2016c). However, there is concern that variability in geographic distribution, dependency on climatic conditions, and uncertainty in supply make renewable energy less reliable. In simple terms, the sun is the main source of renewable energy, directly or indirectly. Solar photovoltaic cells directly capture energy from the sun, while wind turbines, hydropower, and bioenergy plants are indirect capturing mechanisms. Other sources of renewable energy are geothermal, which is heat coming from the earth's core; and ocean energy, where the sun contributes (EIA 2016).

Aside from climatic and geographic factors, challenges in harnessing renewable energy, and conflict in land allocation, there are also technological and socioeconomic issues that need to be addressed. Generation of electricity from burning fossil fuels such as oil, natural gas, and coal; and from nuclear sources (mostly in developed and few developing countries), is still dominant in producing electricity in most of the developed countries and some developing countries. However, tapping renewable energy is becoming a necessity for several reasons such as long-term cost certainty, energy security, growing price competitiveness, climate change issues related to fossil fuel, danger of accidents or hazards from nuclear power plants, requirement to decarbonize electricity generation, avoidance of unintended consequences of ever-increasing use of fossil fuels, etc.

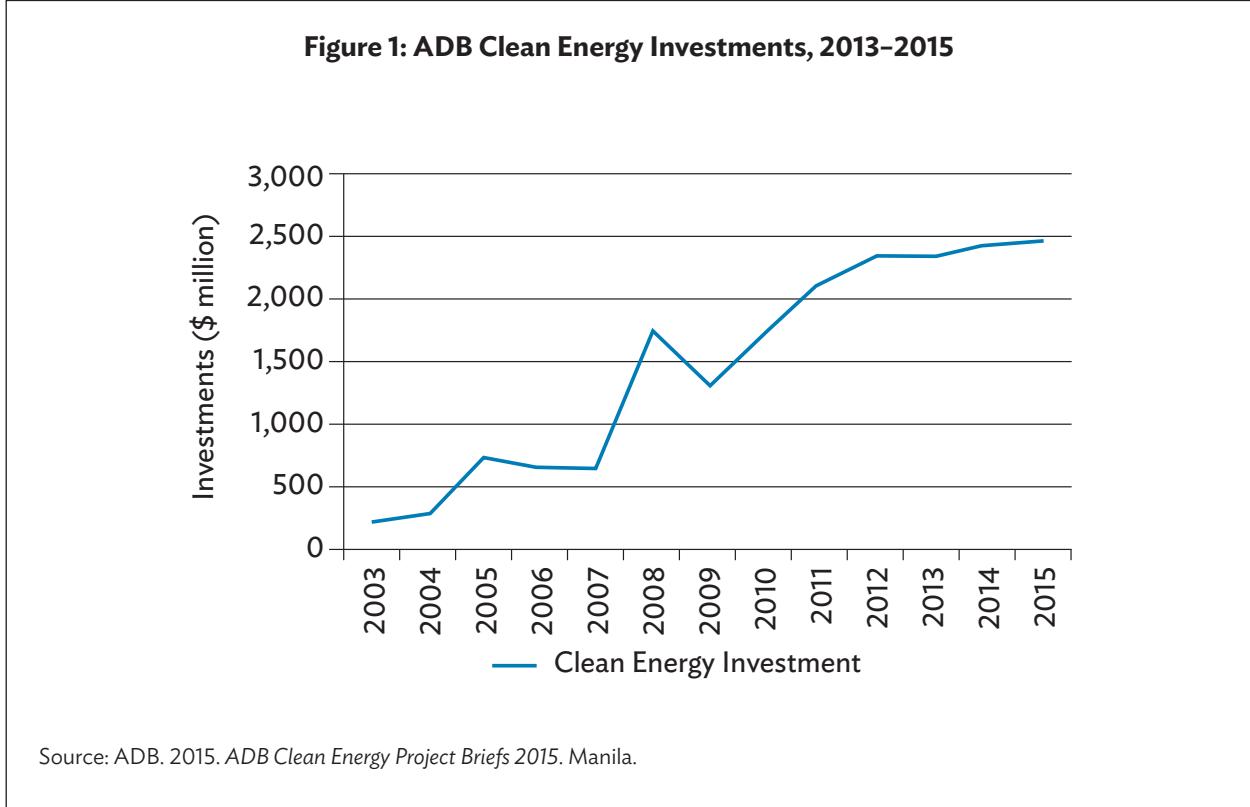
B. Prospective of Renewable Energy Development

In 2013, the total global supply of primary energy was 13,555 million tons of oil equivalent (Mtoe), of which 81% came from coal, oil, and natural gas. The share of renewable energy has been increasing over the years; however, it still is a mere 13.5%. As in the case of fossil fuels, the use of renewable energy as a primary source varies from direct consumption to electricity generation. The contribution of renewable energy including hydropower in electricity generation in energy terms was better at 21.2% of the total electricity generated. Since 1990, the supply of renewable energy has increased, with an average rate of 2.2% compared to fossil fuel, which was 1.9% (IEA 2015).

Recent estimates show that about 420 million people are still without access to electricity in the Asia and Pacific region. There is an urgency to eliminate this access gap within a short period. At the same time, the cost of renewable energy deployment is exponentially coming down. This means there is a significant opportunity for expansion of clean energy development for the benefit of the populations in this region.

ADB's energy sector program continues to be in line with its Energy Policy, 2009, which rests on three pillars: (i) clean energy development, (ii) increasing energy access, and (iii) improving governance in the energy sector. In supporting these pillars, the energy sector program is increasingly focused on adopting innovative technologies, financing mechanisms, and business models, and crafting conducive policy and regulatory frameworks, so that the DMCs can leapfrog in clean energy deployment. This means ADB's interest in the energy sector is no longer limited to assisting countries expand their centralized generation facilities, national transmission, and distribution networks, but also to support distributed electricity generation facilities either in the form of on-grid systems or off-grid systems.

With the Paris Agreement coming in to force and aggressive measures expected by countries to curb climate change, ADB’s thrust on clean energy development will be even stronger. ADB’s clean energy investments over the years have increased, and have been above \$2 billion since 2011 (Figure 1). In 2015, ADB investment in clean energy amounted to \$2.5 billion, which is almost 50% of its total energy sector investment. ADB has already committed to increasing this annually to \$3 billion by 2020. In order to achieve these targets and to support its DMCs in implementing their commitments to the Paris agreement, ADB needs to aggressively pursue all means available. In this regard, the contribution of GIS-based DSS for electrification would be significant to ensure the right mix of renewable energy to meet the needs of the respective localities.



C. Necessity for Renewable Energy and Geographic Information System-Based Decision Support System Tool

In Indonesia, the status of renewable energy use for electrification is encouraging; however, Indonesia’s neighbor, specifically Malaysia and the Philippines, are far ahead in renewable energy utilization (Table 1). The Philippines is tapping all sources of renewable energy to a considerable degree, while Malaysia is performing better in biomass and waste, hydropower, and solar. Figure 2 shows that the share of renewable energy is almost double in Malaysia and three times higher in the Philippines relative to Indonesia. Considering its larger land area and similar geophysical and environmental conditions, Indonesia could have done better. Combined shares of renewable energy from hydropower, biomass or waste, solar, wind, and geothermal sources translate to an installed electricity capacity in Indonesia of about 11.90% in 2015 (Figure 3).

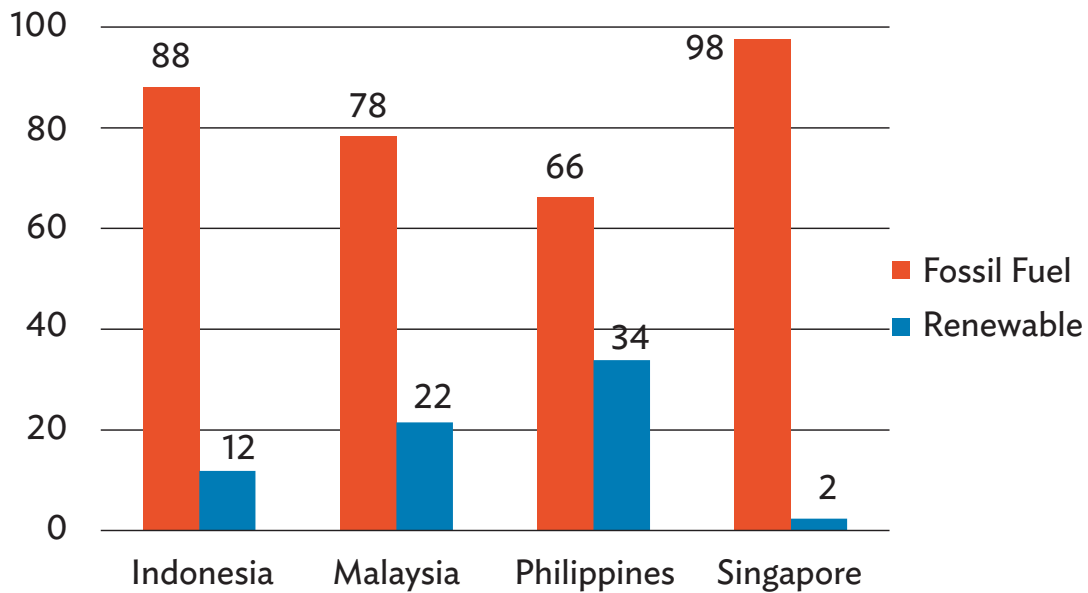
Table 1: Installed Electricity Capacity in Indonesia and Surrounding Countries, 2015

Country	Installed Electricity Capacity (MW)								
	Fossil Fuel					Renewable			
	Total	1-oil	2-gas	3-coal	4-hydro	5-bio	6-wind	7-solar	8-geo
Indonesia	56,210.59	8,904.77	14,040.70	26,580.00	5,231.00	36.00	1.12	12.00	1,405.00
Malaysia	32,566.77	1,432.49	15,436.97	8,690.00	5,496.83	1,346.83	1.15	162.50	0.00
Philippines	18,705.00	3,620.00	2,862.00	5,893.00	3,600.00	221.00	427.00	165.00	1,917.00
Singapore	13,238.60	2,974.50	9,950.30	0.00	0.00	256.80	0.00	57.00	0.00

1-oil = total electricity capacity oil (multifuel oil and gas included); 2-gas = total electricity capacity gas (multifuel oil and gas included); 3-coal = total electricity capacity coal, lignite (multifuel included); 4-hydro = installed hydroelectricity capacity; 5-bio = total electricity capacity biomass and waste; 6-wind = installed wind electricity capacity; 7-solar = installed electricity capacity from solar; 8-geo = installed geothermal electricity capacity; MW=megawatt.

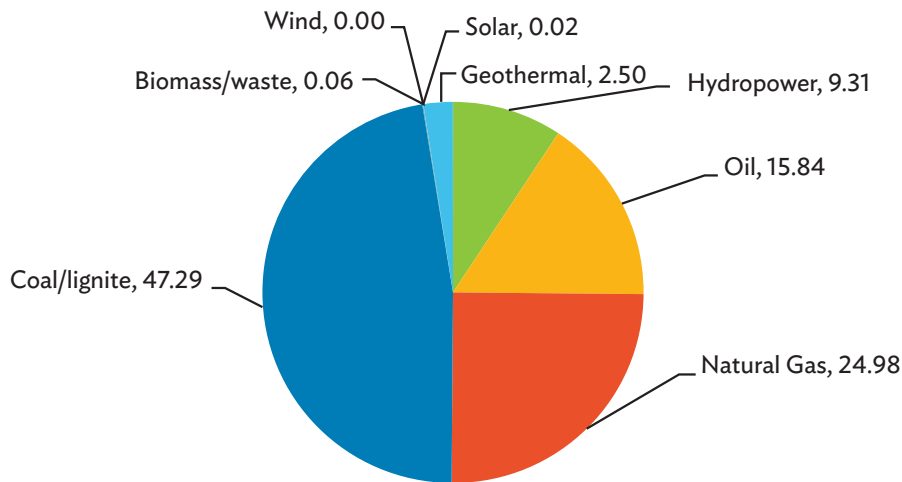
Source: Enerdata. <http://globaldata.enerdata.net/> (accessed 10 August 2016).

Figure 2: Share of Energy Source in Installed Electricity Capacity in Indonesia and Neighboring Countries, 2015 (%)



Source: Enerdata. <http://globaldata.enerdata.net/> (accessed 10 August 2016).

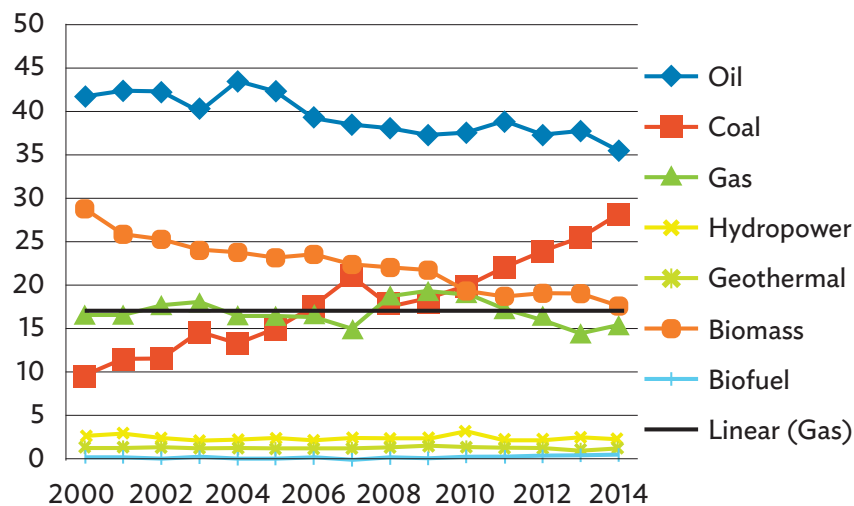
Figure 3: Proportional Share of Energy Source in Installed Electricity Capacity in Indonesia, 2015 (%)



Source: Enerdata. <http://globaldata.enerdata.net/> (accessed 10 August 2016).

Figure 4 shows the trend of primary energy consumption in Indonesia during the last 15 years. The share of oil in fossil fuel usage is declining and is being substituted by coal in a constantly increasing trend. Among the renewable sources, most of them show no change, except a declining trend in biomass. Most of the people in Indonesia and neighboring countries use biomass-based products for household energy consumption such as cooking and heating. The availability of electricity as a substitute contributes to this declining trend.

Figure 4: Trend of Proportional Share of Primary Energy Consumption in Indonesia (%)



Source: Energi dan Sumber Daya Mineral. 2015. *Handbook of Energy and Economic Statistics of Indonesia*. Jakarta.

Trends and practices show that much of the utilization of renewable energy is for electricity generation. Renewable energy will decarbonize electricity generation and will significantly reduce carbon dioxide (CO₂) emission. There has been recent, strong public support along with various government initiatives such as feed-in-tariffs, energy policy reforms, prioritization of mini and micro grid system of isolated and low demand areas, investment in research and development, and technology innovation for renewable energy. Fortunately, Indonesia is blessed with an abundance of renewable energy resources. However, their feasibility in terms of technical aspects and economic prospects should be assessed.

The Government of Indonesia is targeting to increase the share of renewable energy to 23% of all energy generated and distributed by 2025. In response to the Government of Indonesia and neighboring countries demand, there is appetite among developers, investors, and researchers to develop viable solutions to tap renewable energy from both the technical and economic aspects to fulfill the ever-increasing demand for electricity (ADB 2015, 2016a; EIA 2015).

As noted, the availability and amount of renewable energy on hand depend on the geographic and climatic conditions of a given area. It is therefore important in the development and utilization of renewable energy sources to quantify and map their spatial distribution (Lopez et al. 2012). In this working paper, the potential, both theoretical and technical, of five energy sources, namely, solar, wind, biomass, hydro, and geothermal are estimated.¹ Accordingly, a GIS-based decision support system (DSS) tool is devised that can be applied in similar geographic regions using the result of Bali, Indonesia as a test case.²

Manual processing of energy sources requires mastery in spreadsheet and GIS application. The DSS tool will aid in automating difficult tasks of processing each energy source and quantifying the total technical potential energy combination. The DSS also incorporates a suitability function that will analyze suitable locations for the installation of solar panels and wind turbines based on certain criteria.

II. MATERIALS USED

Several geospatial and demographic data of Bali were collected. For this study, the team; Energi dan Sumber Daya Mineral, government staff, World Resources Institute (WRI) experts, and a member from the University of Tokyo; gathered bulk data and materials to support the system. Open source GIS software known as QGIS was utilized along with Geographic Resources Analysis Support System (GRASS) as a raster processing tool to manage bulk data.

A. Topographic, Political Boundaries, and Demographic Data

The base topographic data includes land cover, digital terrain models, road, river networks collected from Badan Informasi Geospasial (BIG) or Geospatial Information Agency as shown in Table 2. The data also covers political boundaries, i.e., province, district, and *desa*. A *desa* is the smallest administrative unit for which population and other statistical data are available. The number of households connected to the grid was obtained for each *desa* from the Perusahaan Listrik Negara (PLN) or State Electricity Corporation. All the data were checked and integrated into the GIS database after editing.

¹ Estimated theoretical potential of wind, geothermal, hydropower, and solar energy data were obtained from ESDM. Theoretical and technical potential of biomass energy was estimated from data from the Center for Energy Resources Development Technology and Badan Pengkajian dan Penerapan Teknologi (Agency for the Assessment and Application of Technology).

² A short version of this paper was presented at the Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid, 19–21 April 2016.

Table 2: Topographic, Political Boundaries, and Demographic Data

Layer	Description	Type	Source	Projection
Bali_Land_Cover	Land cover	Polygon	BIG, 2013	Geographic coordinate system WGS84
Bali_Road	Road	Line	-do-	-do-
Provincial_Boundary	Provincial boundary	Polygon	-do-	-do-
Province_Capital	Province capital	Point	-do-	-do-
Bali_District_Boundary	District boundary	Polygon	-do-	-do-
Bali_District_Capital	District capital	Point	-do-	-do-
Bali_SubDistrict_Boundary	Subdistrict boundary	Polygon	-do-	-do-
Bali_SubDistrict_Capital	Subdistrict capital	Point	-do-	-do-
Bali_Desa_Boundary	<i>Desa</i> boundary	Polygon	BPS	-do-
Bali_Desa_Town	<i>Desa</i> town	Point	BIG	-do-
Bali_PLN_Transmission_20kV	Transmission 20 kV	Line	PLN	UTM 50S coordinate system WGS84
dem_bali10m	DEM at 10 m	Raster	BIG, 2013	-do-
Bali_River	River	Line	-do-	-do-

BIG = Badan Informasi Geospasial; -BPS = Badan Pusat Statistik; do = same as above; kV = kilovolt; PLN = Perusahaan Listrik Negara; DEM = digital elevation model; m = meter; WGS84 = World Geodetic System 1984; UTM = Universal Transverse Mercator.

Sources: Research and Development Center for Electricity and New-Renewable Energy Technology, ESDM; Castlerock Consulting, Indonesia; World Resources Institute (for land use); University of Tokyo (for solar and wind data – used for validation).

B. Energy Source Data

The Energi dan Sumber Daya Mineral (ESDM), or Ministry of Energy and Mineral Resources, has identified five sources of renewable energy in Bali. These are solar, wind, hydropower, geothermal, and biomass. Data for the first four energy sources were obtained from ESDM.

For solar and wind energy, ESDM used one-degree Global Data Assimilation System (GDAS) data from the National Oceanic and Atmospheric Administration and National Center for Environmental Prediction, and utilized the Atmospheric General Circulation Model (AGCM20) developed by the Meteorological Research Institute of Japan for interpolation, followed by further downscaling to a 5-kilometer (km) resolution. Technical assistance was provided by the National Research Center of the Bandung Institute of Technology, Indonesia. By utilizing 1:25,000 scale topographic datasets, and with input from the Department of Public Works, Indonesia, ESDM estimated the run-of-river hydropower potential from potential-head of the delineated basins. Data for the geothermal energy technical potential for Bali was extracted from ESDM's geological agency estimation dataset generated from across the country.

For biomass energy, computerized tabular data on agricultural, plantation and forest production, and biomass residuals were integrated with *desa* political boundary data. Typographical errors in the names of *desas* were corrected based on the names and identification numbers of corresponding *desas* in the *desa* boundary layer. The source, type of layer, and projection is shown in Table 3.

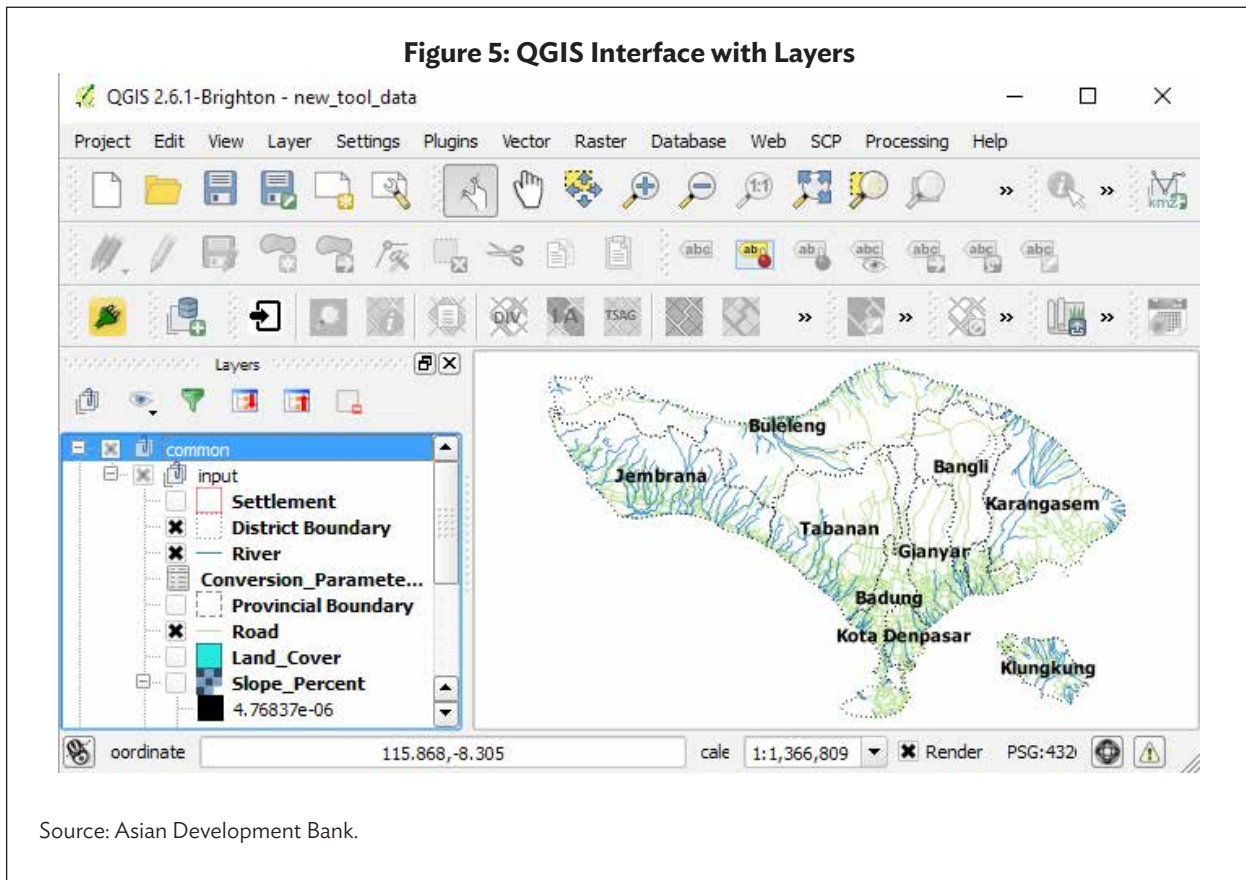
Table 3: Energy Source Data

Layer Name	Description	Type	Source	Projection
angin_bali	Wind	Polygon	ESDM, 2015	-do-
Surya_bali	Solar	Polygon	-do-	-do-
Point_kW_bali	Hydropower	Point	-do-	-do-
Bali_Desa_Biomassa	Biomass	Polygon	BPS, 2013	-do-

BPS = Badan Pusat Statistik, ESDM = Energi dan Sumber Daya Mineral, WGS84 = World Geodetic System 1984.
 Source: Asian Development Bank.

C. Software

Since its debut in 2002, QGIS has become popular because of its capabilities in managing geospatial data. Aside from being open source and free via General Public License, it is also multiplatform, supports numerous vector and image formats, and is programmable via a plugin.³ The familiar theme-based interface is similar to ArcGIS for Desktop, which is a commercial product of the Environmental Systems Research Institute. The interface of QGIS is shown in Figure 5.



³ Open Source Geospatial Foundation. <https://www.qgis.org/en/site/about/>

III. DATA PREPARATION

Prior to data processing, the bulk of data coming from different sources must be organized. Ideally, these data should be thematically grouped in an intuitive manner. Since the data sources came from different government agencies, overlapping geospatial features must be checked and the projection should be standardized. The symbols that will be used should properly reflect the type of features present on the layer. Finally, all the customization made should be placed in one QGIS project file for easy retrieval.

A. Thematic Grouping

The groupings of all collected layers are topography, administrative, demography, and energy as described in Table 4.

Table 4: Thematic Group

Thematic Group	Layers
Topography	Road, River, Contour, Digital Elevation Model, Land Cover, Spot Elevation, Settlement, Forest
Administrative	Provincial, City, Municipality, Town, District, Subdistrict, Provincial capital, District capital, Town capital
Demography	Population, Number of HH, Number of HH connected to grid
Energy	Solar, Wind, Hydropower, Geothermal, Biomass

HH = household.

Source: Asian Development Bank.

B. Map Projection

Geospatial data from different sources will have different projections. A map projection is a representation of a part of the earth on a plane surface. Having different projections is problematic most especially in GRASS raster analysis, which does not allow layer processing to accommodate different coordinate systems. Different countries have their own local projection setting but in this project, it was standardized to Universal Transverse Mercator (UTM) coordinate system with World Geodetic System 1984 (WGS84) datum. Since UTM are equally divided into 60 segments called zones, all that is needed is to set the zones depending on the location.

For Bali as the study area, the map projection setting is WGS84 / UTM Zone 50S. The “S” denotes southern hemisphere.

C. Map Symbol

A map shows different layers, which are represented by different symbols or features such as road, river, and vegetation. Symbols should be relevant to what they represent to improve the appearance or readability of the map. Symbols of each energy source are presented in Figure 6.

Figure 6: Map Symbols for Energy (GWh/year)

Energy Source	Solar	Wind	Biomass	Hydropower	Geothermal
Map Symbol	<ul style="list-style-type: none"> □ NO DATA □ 0.00–500.00 □ 500.00–1,000.00 □ 1,000.00–2,000.00 □ 2,000.00–3,000.00 □ 3,000.00–4,000.00 □ 4,000.00–12,401.98 	<ul style="list-style-type: none"> □ NO DATA □ 0.00–0.10 □ 0.10–0.30 □ 0.30–0.50 □ 0.50–0.70 □ 0.70–0.90 □ 0.90–1.83 	<ul style="list-style-type: none"> □ NO DATA □ 0.00–1.00 □ 1.00–5.00 □ 5.00–10.00 □ 10.00–15.00 □ 15.00–20.00 □ 20.00–21.92 	<ul style="list-style-type: none"> ○ 0.05–1.00 ○ 1.00–2.00 ○ 2.00–3.00 ○ 3.00–4.00 ○ 4.00–5.00 ○ 5.00–5.28 	<ul style="list-style-type: none"> ○ 21.02 ○ 52.56 ○ 121.94 ○ 475.14

GWh = gigawatt-hour.

Source: Asian Development Bank.

IV. MAPPING POTENTIAL OF ENERGY SOURCES

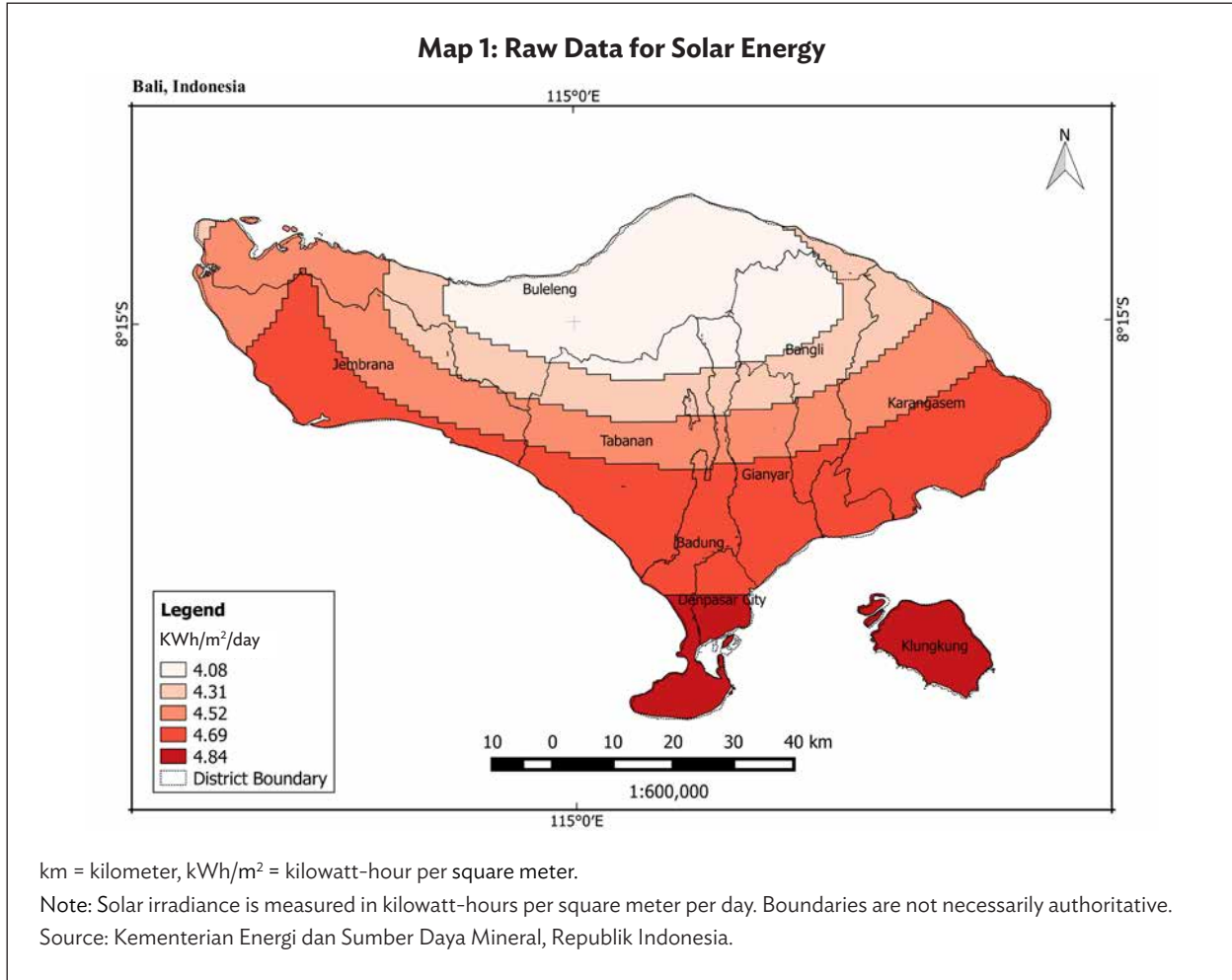
After identifying, grouping, and symbolizing the topographic data, administrative boundaries, demographic data, and energy source, the next step is to process each of them. Raw data from solar for example, only shows potential energy of the entire area based on one-degree GDAS data. The quantitative technical potential energy for each political boundary should be established in order to identify which *desa* generates highest solar energy. This is practically important because when needed, the system can quickly sort the data in prioritizing the ideal locations for the installation of solar power plants.

A. Solar Energy

Solar energy is measured by solar irradiance. It is the power per unit area produced by the sun in the form of electromagnetic radiation. The potential solar energy for Bali province was derived from one-degree GDAS data (MODIS Ancillary Data) from the National Center for Environmental Prediction of the National Oceanic and Atmospheric Administration. The raw solar layer is shown in Map 1.

Other source of solar datasets from the University of Tokyo, prepared from the 20-km resolution Atmospheric General Circulation Model (AGCM20) developed by the Meteorological Research Institute of Japan was analyzed as a reference. It was used for analysis and comparison with data from ESDM. It was decided however that ESDM data would be used in performing solar suitability analysis.

Since the solar irradiance unit is represented in a daily unit, it will be multiplied by the number of days in a year (365 constant) to get the potential solar energy per square meter per year. The output shows that the entire island of Bali has the potential source of solar energy that exceeds the 900 kilowatt-hours per square meter per year ($\text{kWh}/\text{m}^2/\text{year}$) requirement. In Europe, solar radiation should be at least 900 $\text{kWh}/\text{m}^2/\text{year}$ for a site to be considered suitable for a solar project (Castillo et al. 2016). The island of Bali has solar irradiance from 1,490 to 1,776 $\text{kWh}/\text{m}^2/\text{year}$, which is a clear indication that Bali has the potential for commercially viable solar energy projects.

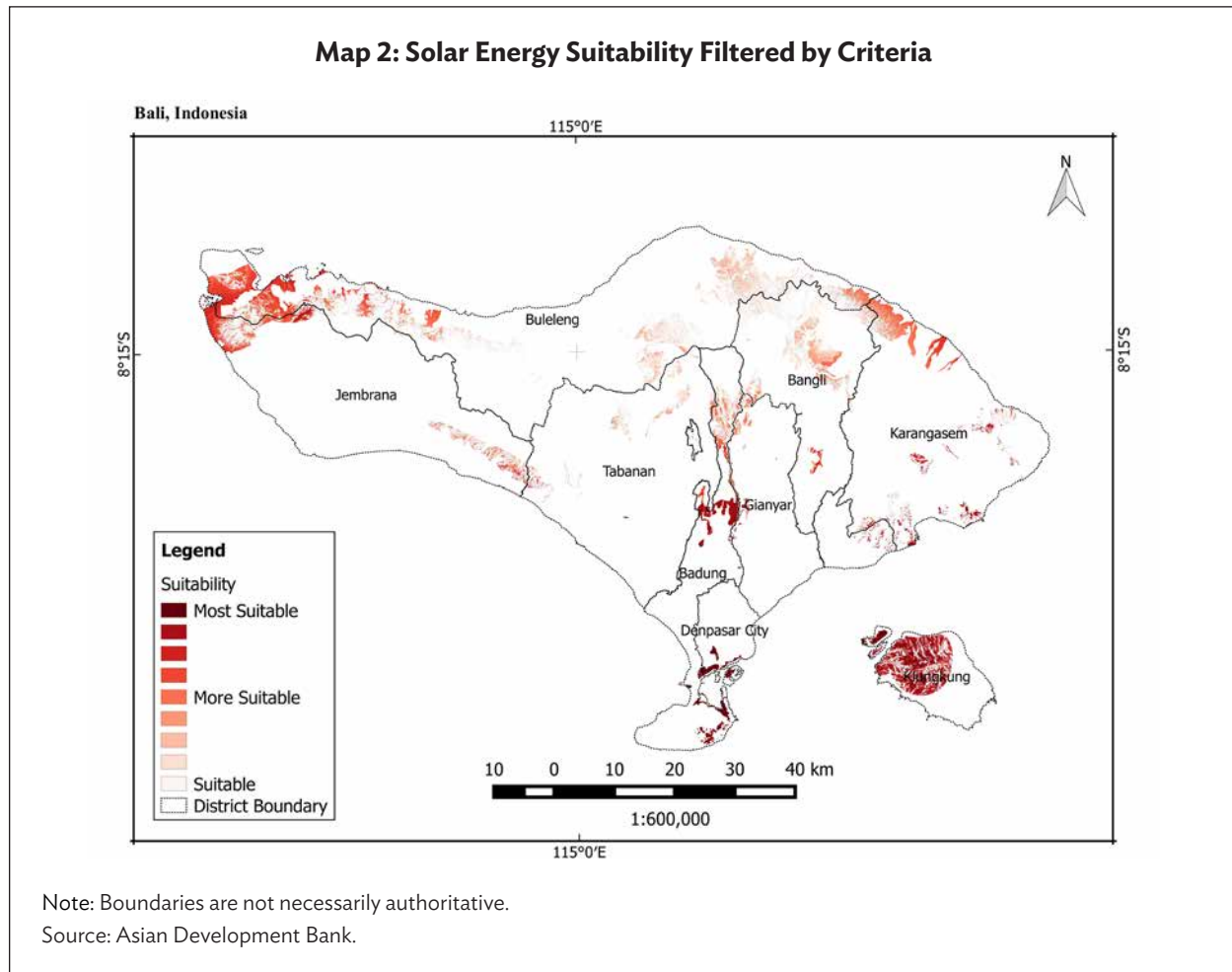


To be able to compute for the technical potential energy of the entire area, the first objective is to get the solar suitability based on some criteria (Drobne and Lisec 2009). Solar suitability is the process of selecting ideal locations for the installation of solar energy projects where the considerations are as follows:

- (i) irradiance should be greater than 900 kWh/m²/year;
- (ii) topography: slope $\leq 30\%$;
- (iii) accessibility: distance from the nearest road $\leq 5,000$ m;
- (iv) ineligible settlements;
- (v) eligible land cover types: herbs and grasses, open fields—bare land, savannas, and bushes and shrubs; and
- (vi) ineligible land cover types: lakes, buildings not used as homes, seasonal crops in wetland areas, seasonal crops in dry land areas, lowland forest, highland forest, mangrove forest, plantations, garden and plant mixes, salt or brackish water, rivers.

Map 2 shows the suitable area in Bali that passed the criteria. The districts of Klungkung, Buleleng, and Bangli exhibit suitable areas for the installation of solar power projects. These areas can either be herbs, grasses, open fields, bare land, savannahs, bushes, or shrubs, which are eligible land covers. Aside from road buffer and eligible slope value, the significant reduction in suitable area was caused by small coverage of eligible land covers. The settlements were considered ineligible as well.

The suitability of small energy access-type application is not that significant compared to a larger decentralized system. The size of the power plant can be used as part of the criteria to further enhance the system.



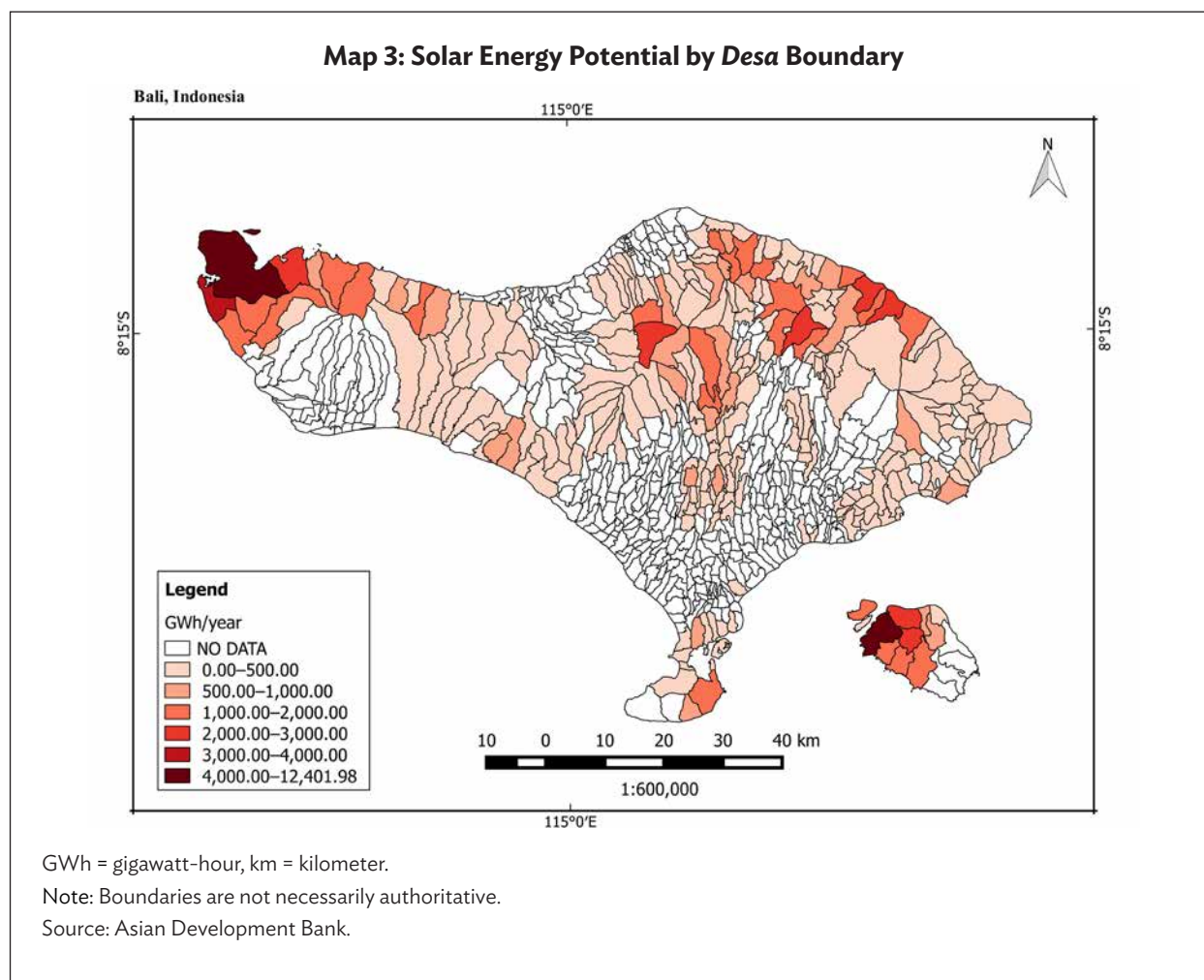
The suitable area was multiplied to annual potential solar energy per square meter. The product or annual solar energy of the entire area was intersected with the administrative boundary summarized by *desa*. The sum of the product of potential energy and the intersection area is the aggregate potential energy per *desa*. Applying the potential conversion parameters and formula given in Table 5, the technical potential solar energy has been estimated to be about 113,436 GWh/year as shown in Map 3.

Table 5: Potential Energy Conversion Parameters

Energy Source	Energy Generation		Plant Factor (efficiency) [B]	Operation (hours) [C]	Area [D]	Maintenance [E]	GWh/year
	Units	Value [A]					
Solar	kWh/m ²		0.16	NA		0.95	$([A]*[B]*[D]*[E]*365)/1,000,000$
Wind	kW		0.39	NA	NA	0.80	$([A]*[B]*[C]*[E]*365)/1,000,000$
Hydropower (mini and micro)	kW		0.70	24.00	NA	0.80	$([A]*[B]*[C]*[E]*365)/1,000,000$
Geothermal	kW		0.30	24.00	NA	0.80	$([A]*[B]*[C]*[E]*365)/1,000,000$
Biomass	kWh		0.30	NA	NA	0.80	$([A]*[B]*[E])/1,000,000$

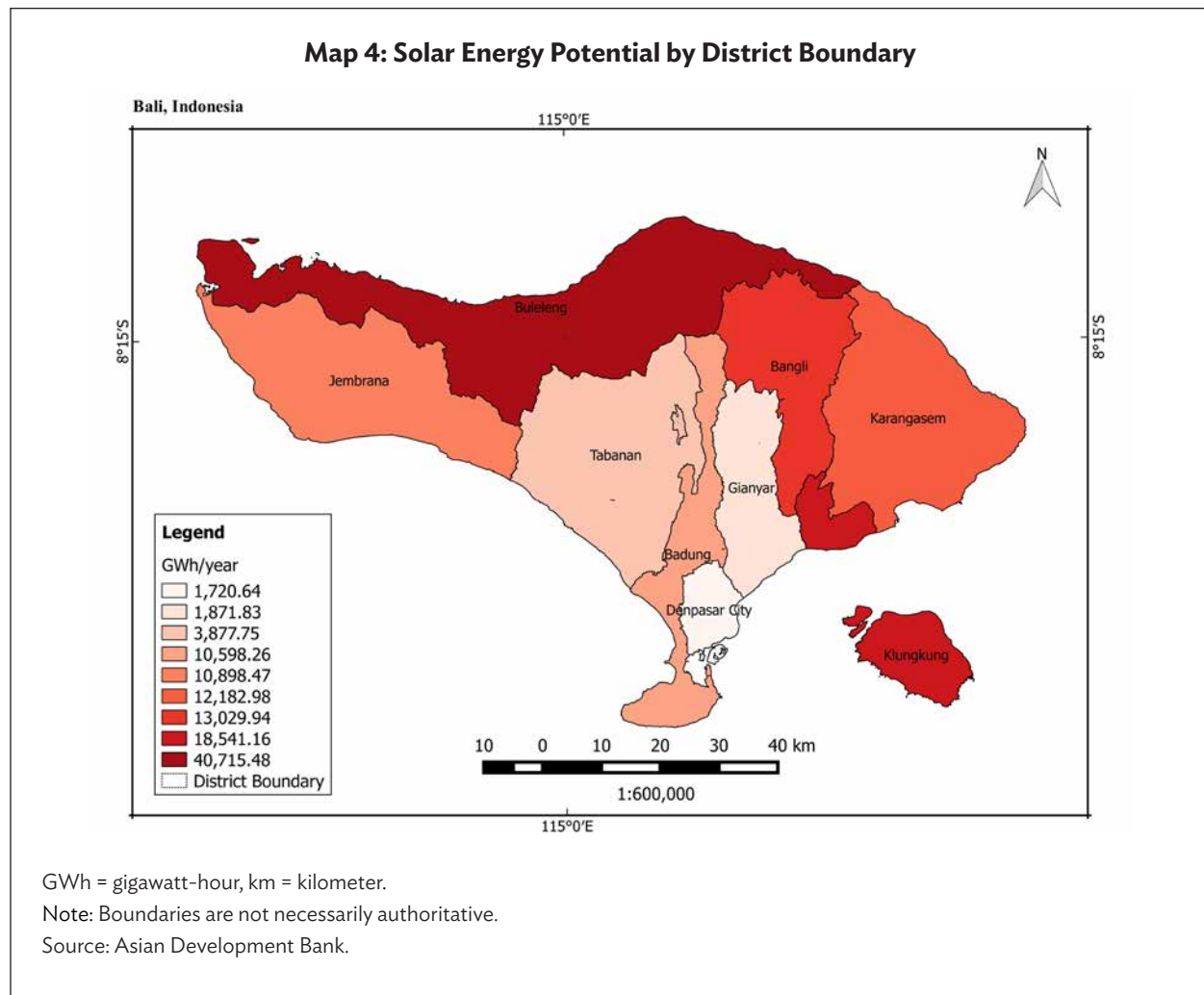
GWh/year = gigawatt-hour per year, kW = kilowatt, kWh/m² = kilowatt-hour per square meter.

Source: ADB estimates based on consultation meeting with Kementerian Energi dan Sumber Daya Mineral, Republik Indonesia.



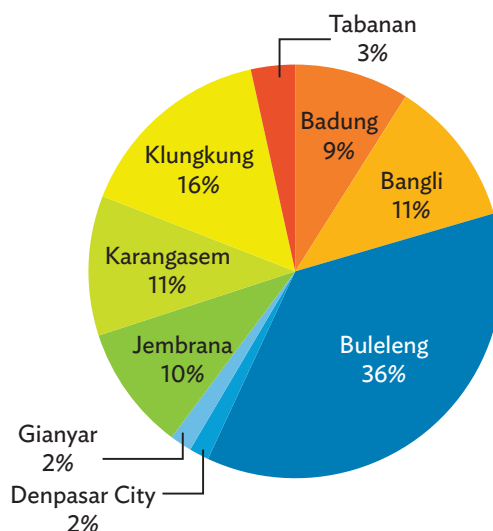
A *desa* boundary belongs to a bigger (district) administrative boundary. The summary values by district boundary as shown in Map 4 were calculated based on the sum of potential energy per *desa* belonging to particular district.

The district map of solar energy potential (Map 4) shows that Buleleng and Klungkung districts can generate around 59,000 GWh/year, or 52% of the entire solar energy potential of Bali as shown in Figure 7.



In urban areas like Denpasar, solar rooftops can offer huge potential, especially for industrial and commercial buildings with concrete roofs, such as warehouses, factories, schools, public buildings, etc. As long as there are classified structural data available, these criteria can be considered.

Presently, maps showing building foot print (> 1:1,000 scale) is not available. Also, data on building (roof) types are not available. Such data can be created using high-resolution earth observation satellite data coupled with sampled field surveys.

Figure 7: Solar Energy Potential by District Chart (GWh/year)

GWh = gigawatt-hour.

Source: Asian Development Bank.

B. Wind Energy

Wind data from ESDM covered the eastern, western, and southern parts of Bali. It was derived from one-degree GDAS data (MODIS Ancillary Data) from the National Center for Environmental Prediction of the National Oceanic and Atmospheric Administration. The average wind speed ranges from 3.65 to 5 meters per second (m/s) at 50 m height, confirming that there is modest wind energy potential available for power generation.

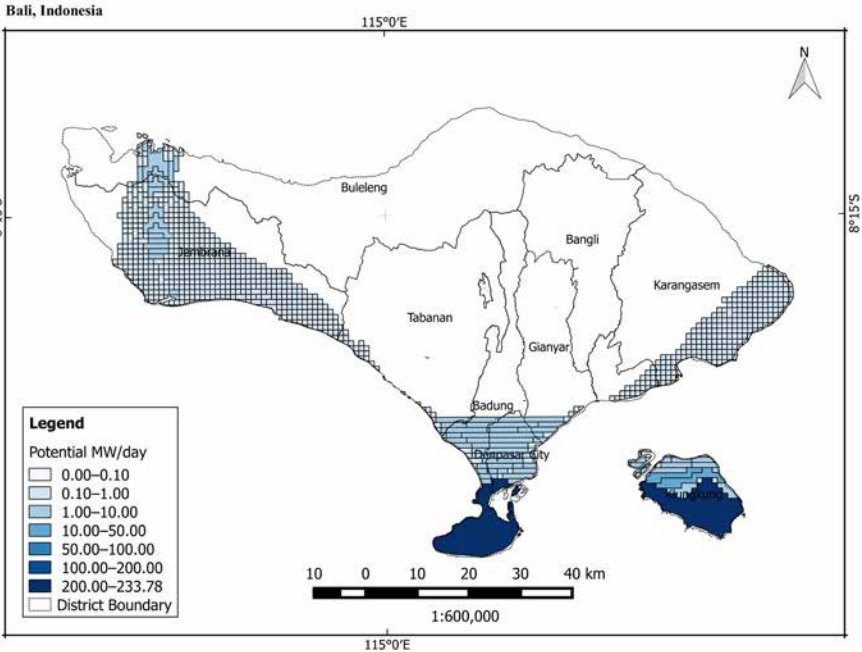
The raw potential wind energy is shown in Map 5. The districts of Klungkung and Badung show good potential since some *desa* in southern areas can generate potential electricity up to 233 MW daily.

To compute for the technical potential wind energy, wind data area needs to be filtered by some criteria:

- (i) wind speed annual average should be at least 3.65 m/s at 50 m;
- (ii) topography: slope $\leq 30\%$;
- (iii) accessibility: distance from the nearest road $\leq 5,000$ m;
- (iv) ineligible settlements; and
- (v) ineligible land cover types: lakes and rivers.

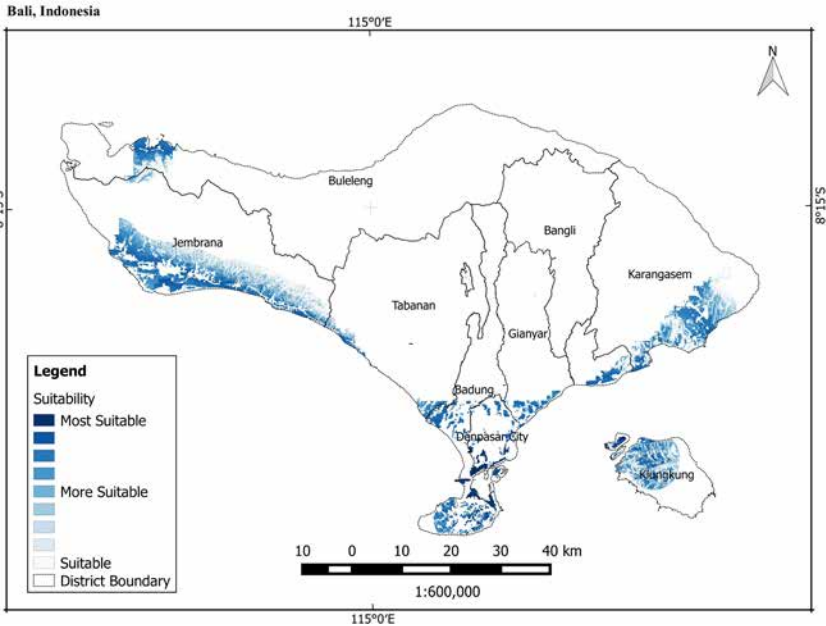
With all criteria filtered, the wind suitability output is shown on Map 6. The energy value not calculated but given by the ESDM as a part of the raw data attributes along with wind speed.

Map 5: Wind Energy Potential (MW)



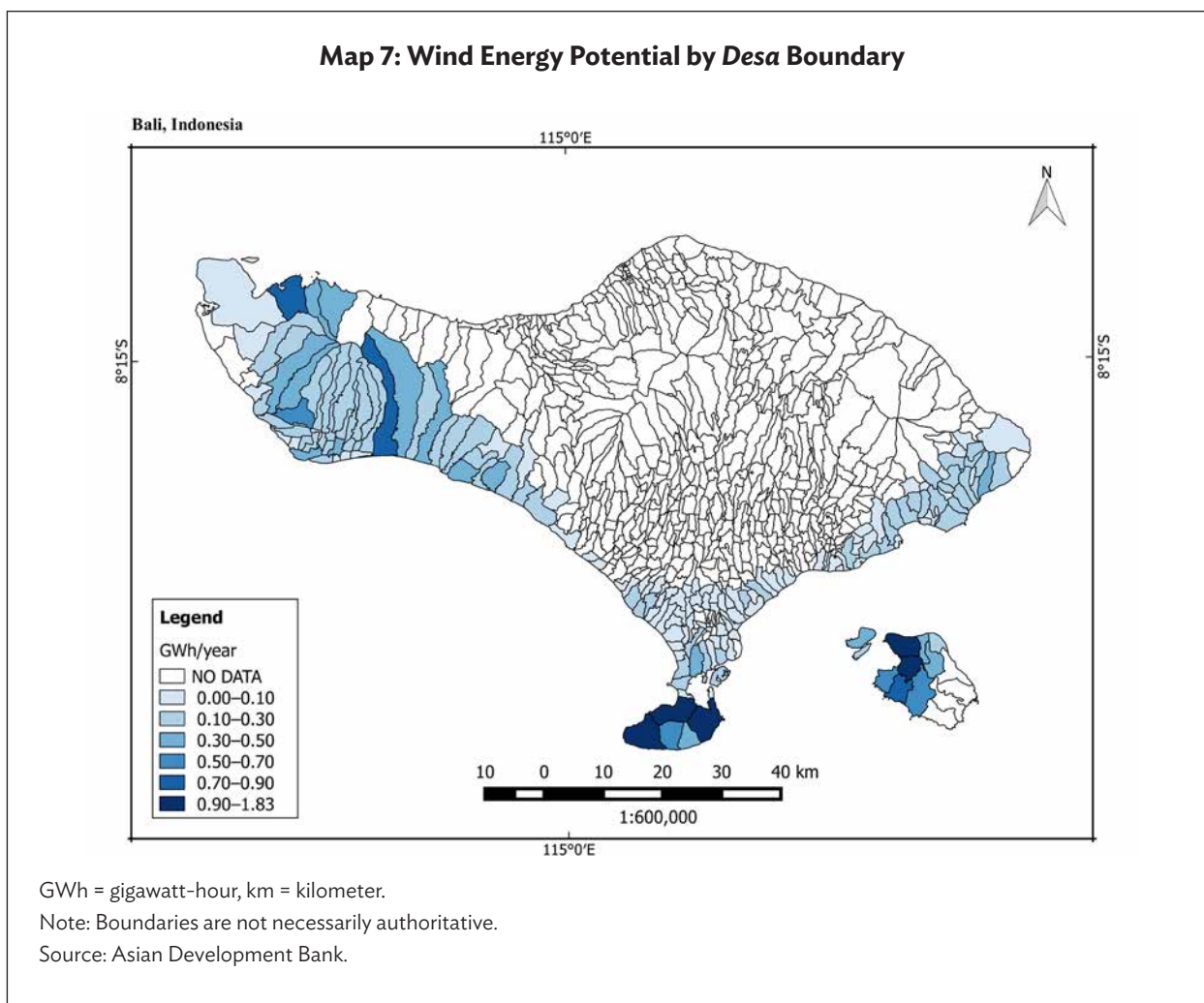
MW = megawatt, km = kilometer.
Note: Boundaries are not necessarily authoritative.
Source: Kementerian Energi dan Sumber Daya Mineral, Republik Indonesia .

Map 6: Wind Energy Suitability Filtered by Criteria



km = kilometer.
Note: Boundaries are not necessarily authoritative.
Source: Asian Development Bank.

The suitable wind area has been multiplied to wind energy per unit area to get potential energy per polygon then summarized by *desa*. Applying the potential conversion parameters and formula, given in Table 5, the technical potential wind energy is estimated to be about 33 GWh/year as shown in Map 7.



C. Biomass Energy

The sources of biomass and heating values of residual by-products from agriculture, plantation, and forest production groups are shown in Table 6.

Table 6: Biomass Group

Group	Plant
Agriculture	Rice, Maize, Sugarcane, Cassava, Peanuts
Plantation	Coconut, Candlenut, Coffee, Rubber wood
Forest Production	Wood waste of production forest, Acacia wood waste

Note: Data have been compiled in consultation with Kementerian Energi dan Sumber Daya Mineral, Center for Energy Resources Development Technology, and Badan Pengkajian dan Penerapan Teknologi, Republik Indonesia.

Source: Asian Development Bank.

Bali produces approximately 1,050,000 tons/year of biomass agricultural by-products. This is 95% of the total biomass energy source that the island can produce. Plantations generate 4% or approximately 37,500 tons/year, while the remainder comes from forest production.

Table 7 shows that burning biomass residuals generates heat energy, described as heating value in megajoules per kilogram (MJ/kg), with values dependent on their type and quality.

Table 7: Heating Value of Biomass Residuals

Biomass Types	By-product Residuals			Heating Value (MJ/kg)		
	1	2	3	1	2	3
Rice	Rice husk (t)	Straw (t)		14.50	15.70	
Maize	Cobs (t)	Husk (t)		17.00	19.66	
Sugarcane	Bagasse (t)	Hay top cane (t)	Blotong (t)	14.40	17.62	17.62
Coconut	Shell (t)	Fiber (t)		18.20	16.70	
Cocoa	Shell (t)			17.00		
Candlenut	Candlenut shell (t)			21.96		
Cassava	Stems and leaves (t)	Cassava peel (t)	Onggok (t)	18.42	18.42	18.42
Peanuts	Peanut shells (t)			19.20		
Coffee	Coffee hulls (t)			12.38		
Rubber wood	Total biomass waste (t)			14.98		
Forest	Wood waste of production forest (t)	Acacia wood waste (t)		18.84	18.84	

MJ = megajoules, MJ/kg = megajoules per kilogram, t = ton.

Note: 3.6 MJ is equivalent to 1 kWh of electric energy.

Sources: Center for Energy Resources Development Technology, Badan Pengkajian dan Penerapan Teknologi, Republik Indonesia.

The equivalent energy of the individual by-products of plants have each been calculated based on the heating value as shown in Table 7. Figure 8 shows an example calculation of potential energy from rice husk:

Figure 8: Calculation of Potential Energy from Rice Husk

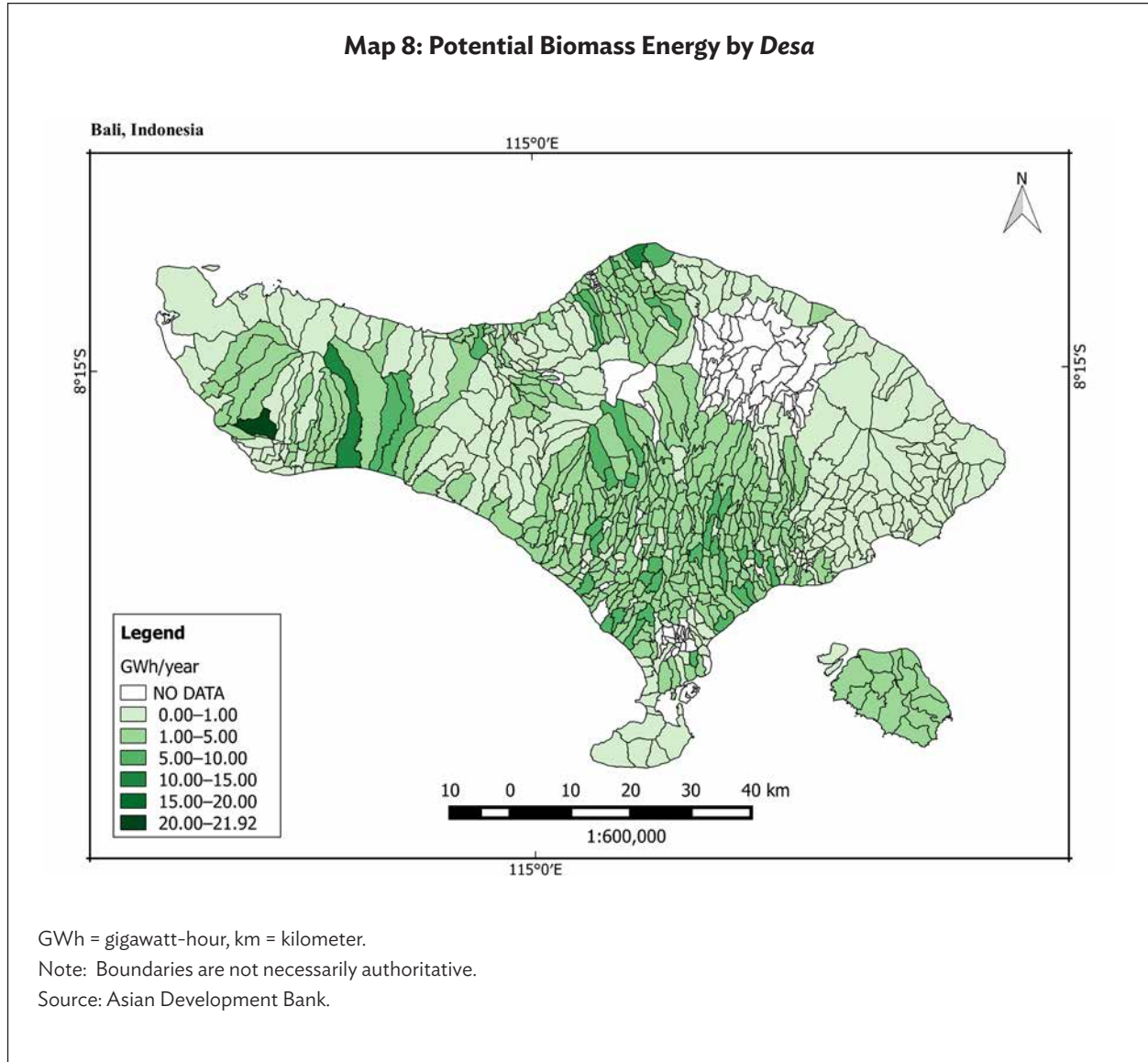
$$\begin{aligned} \text{Rice husk (kWh)} &= 40.07 \times 1,000 \times 14.5 / 3.6 \\ &= 161,393 \end{aligned}$$

where: 40.7 is rice husk in ton
 1,000 is conversion factor from ton to kilogram
 14.5 is heating value of rice husk
 3.6 is conversion factor from MJ/kg to kWh

kWh = kilowatt-hour, MJ/kg = Mega Joule per Kilogram.

Source: Asian Development Bank.

After the calculation of individual biomass energy, the total energy from agriculture, plantation, and production forest are summed up. The total area is calculated in order to get the density per unit area. Applying the potential conversion parameters and formula given in Table 5, the technical potential of biomass energy in GWh/ha/year is estimated per *desa* as shown in Map 8, and per district in Map 9.



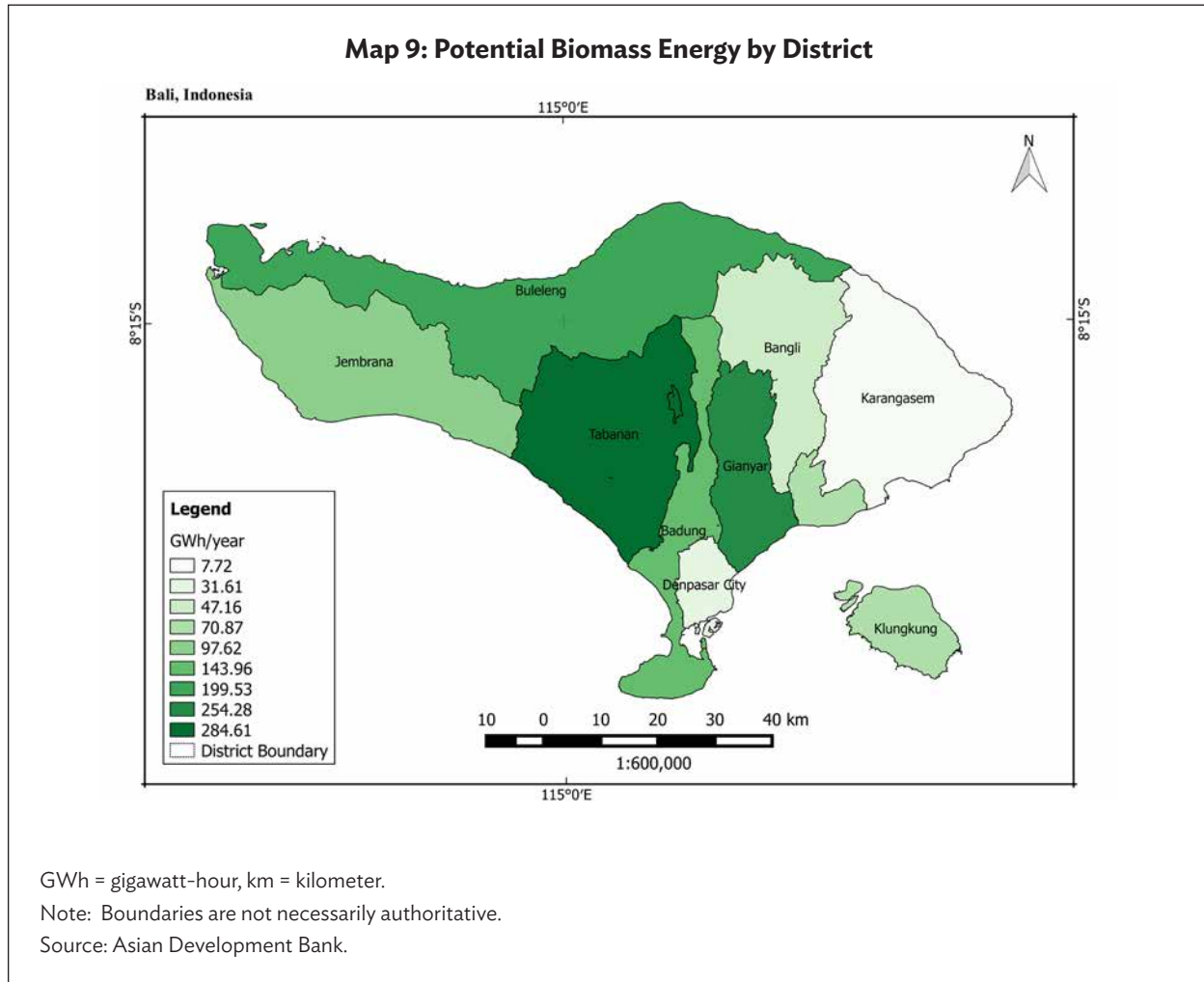
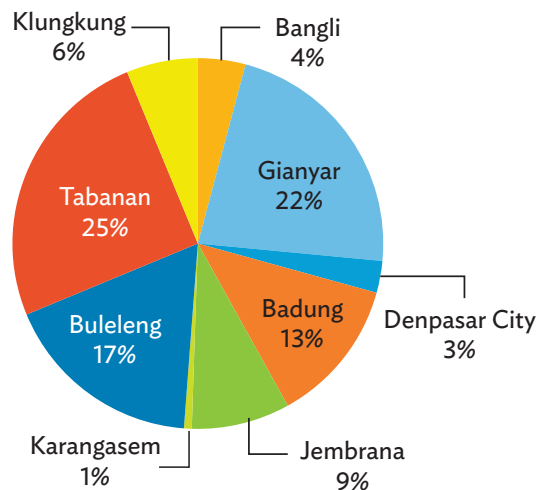


Figure 9 shows that the districts of *Tabanan*, *Gianyar*, and *Buleleng* can be major sources of potential biomass energy of up to 71% for the entirety of Bali. This potential mostly came from agricultural by-products (rice husk and straw, maize cobs and husk, sugarcane bagasse, hay top cane, and *blotong*, cassava stem/leaves, peel and *onggok*, and peanut shell) producing approximately 700,000 tons/year.

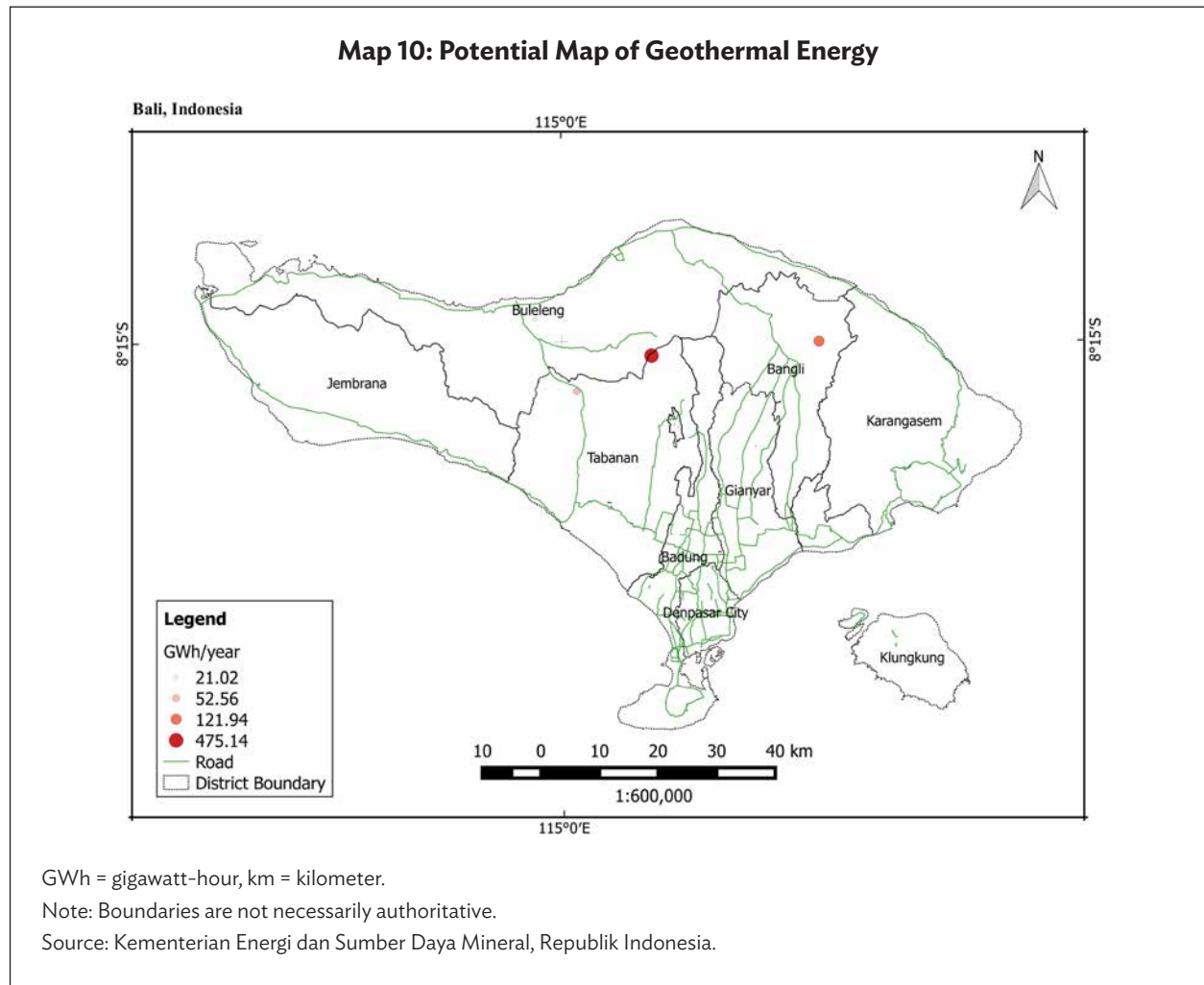
Figure 9: Potential Biomass Energy by District Chart

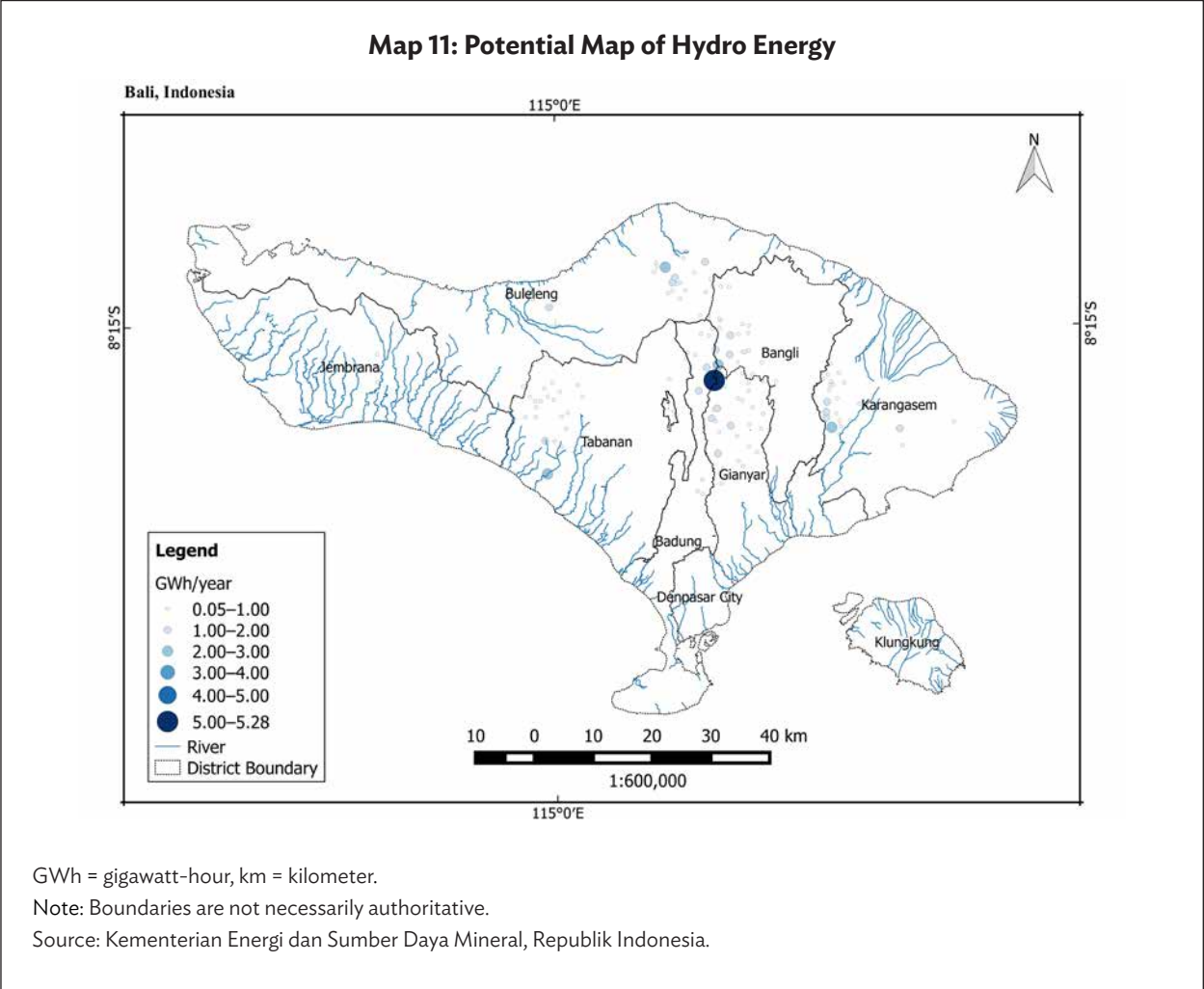


Source: Asian Development Bank.

D. Hydropower and Geothermal Energy

ESDM point data show the location distribution of hydropower (mini/micro) and geothermal potential and the value of potential energy for each. Five sites were identified which had total geothermal potential of 329 MW (ranging from 10 to 226 MW each) as shown in Map 10. Out of nine districts in Bali, only three (*Tabanan, Bangli, and Buleleng*) have geothermal energy source. Identified for potential hydropower were 143 more sites, with potential energies ranging from 0.1 MW to 1.075 MW as shown in Map 11. The total energy from these potential sites is 14.8 MW. The technical potential for hydropower and geothermal energy was computed using conversion parameters and formula shown in Table 5.



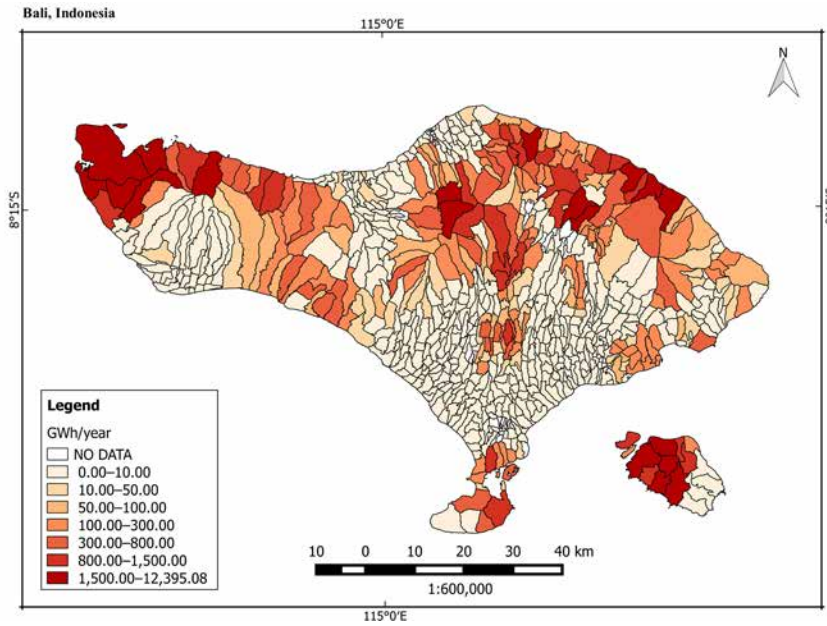


V. POTENTIAL ENERGY MIX ESTIMATION

The energy mix summarizes the potential of the five energy sources. The easiest way to assess which energy source has a better potential for a particular geographic location is to combine all the resources. Associating this mix with demographic information primarily with population, future energy requirements, number of household connected to Perusahaan Listrik Negara (PLN), non-PLN, and household without electricity can aid in determining which administrative boundary will benefit most from renewable energy.

The map shown in Map 12 illustrates that the eastern and western parts of Bali have the potential energy mix by *desa* level. The map shows that these areas can contribute from 300 GWh/year to 12,000 GWh/year. Map 13 shows that summarizing by district; Buleleng and Klungkung can contribute potential energy up to 59,500 GWh/year.

Map 12: Potential Energy Mix by Desa

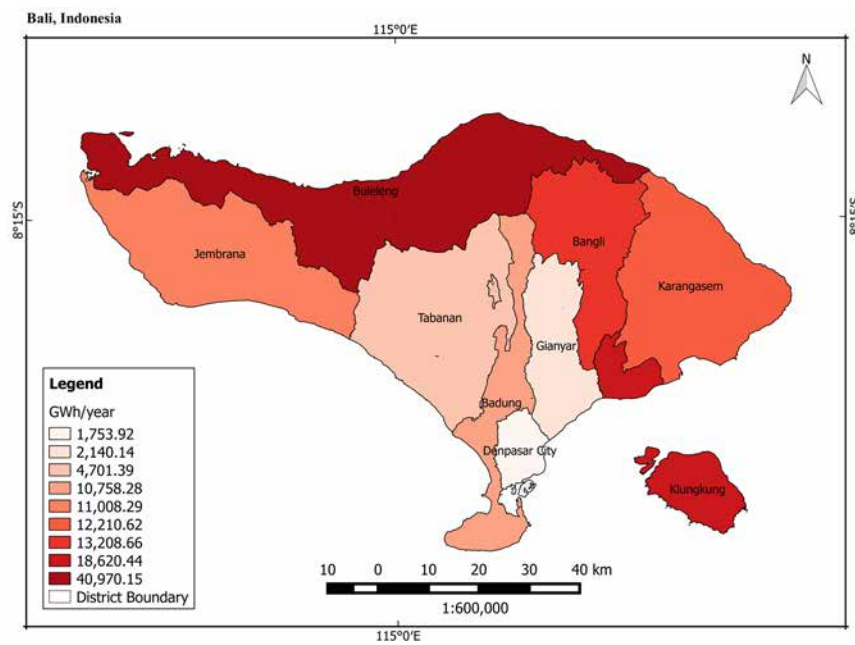


GWh = gigawatt-hour, km = kilometer.

Note: Boundaries are not necessarily authoritative.

Source: Asian Development Bank.

Map 13: Potential Energy Mix by District

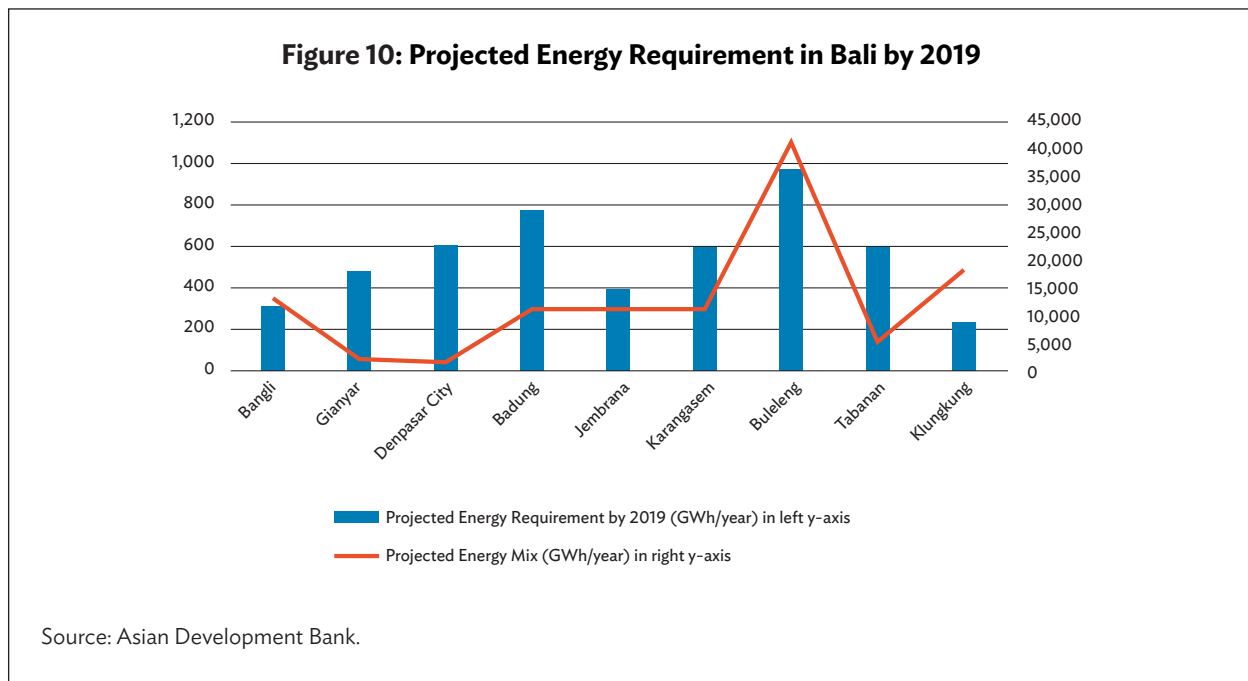


GWh = gigawatt-hour, km = kilometer.

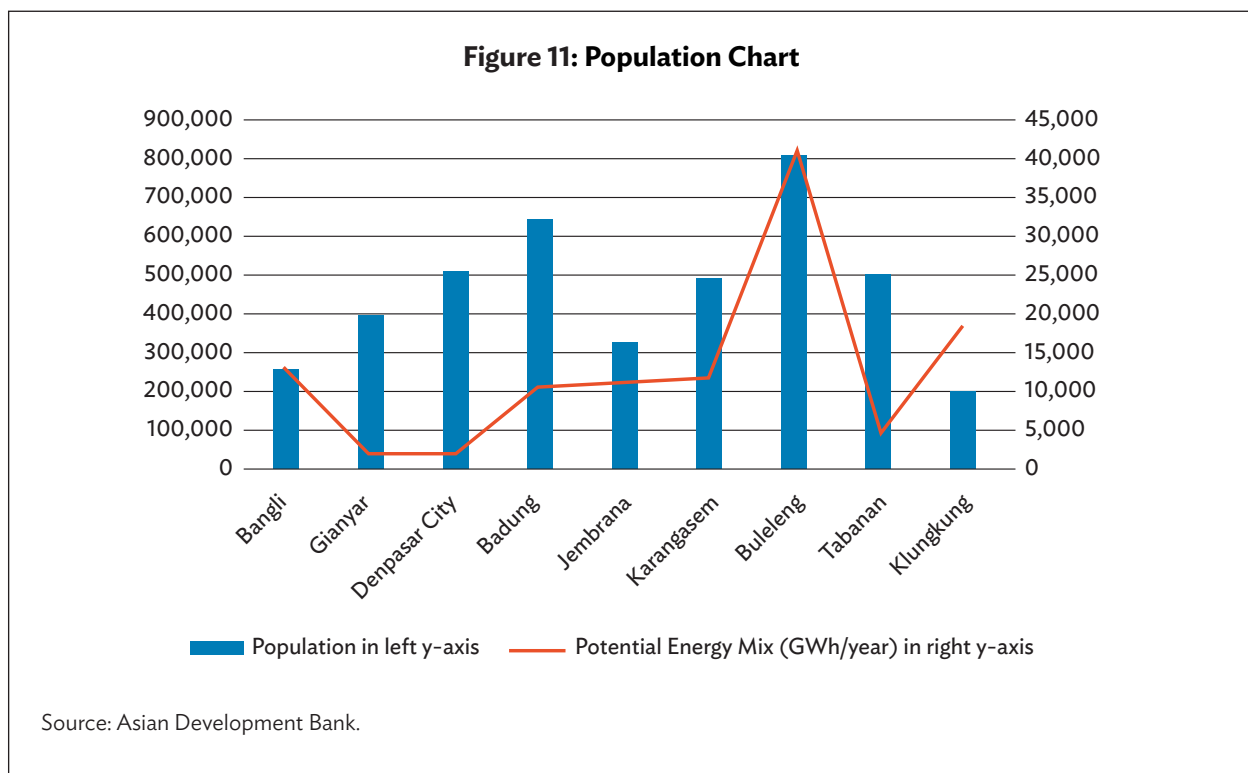
Note: Boundaries are not necessarily authoritative.

Source: Asian Development Bank.

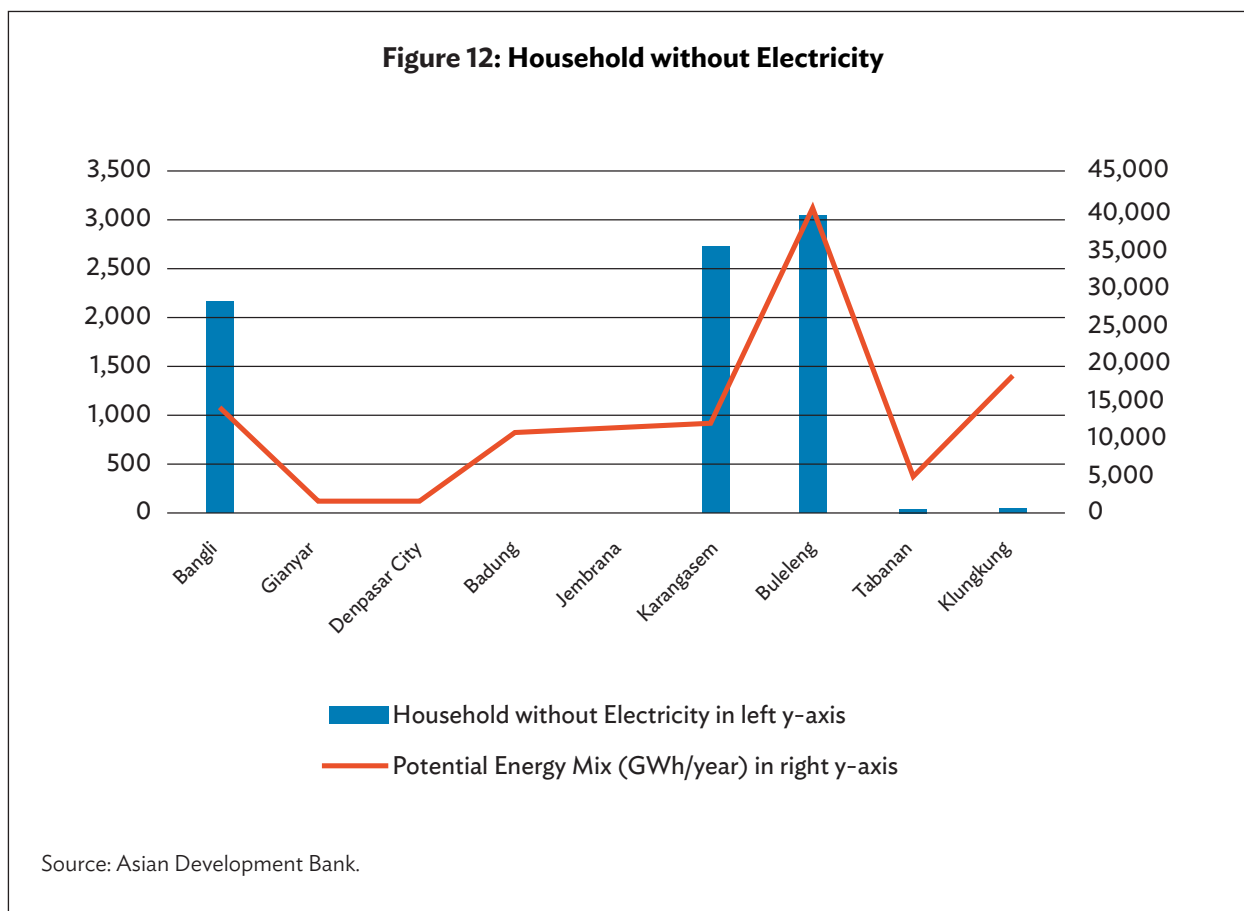
Figure 10 shows that the potential energy mix (115,371.9 GWh/year) in Bali is more than enough to meet the projected energy requirement by 2019 (4,992.73 GWh/year).



The population in Bali, Indonesia is based on household family size of 3.91 (national average) multiplied by the total number of households. Figure 11 shows the comparison in population and potential energy mix. In *Buleleng* district, the population is about 811,075.



According to Figure 12, the districts of *Buleleng*, *Karangasem*, and *Bangli* in Bali have 8,046 households without electricity. The potential energy mix is promising most specially in *Buleleng*. Once harnessed, the renewable energy mix can generate up to 40,969 GWh/year.



The total theoretical potential from solar and wind energy is approximately 1,397,370 GWh/year (1,397,279 GWh/year of solar potential and 91 GWh/year of wind potential). These results came from the product of potential energy and potential conversion parameters given in Table 5 but none of the suitability criteria were considered. The technical potential of solar and wind combined is 113,470 GWh/year as presented in Table 8. The energy mix from all five sources shows that the total technical potential in Bali is 115,371.9 GWh/year (Table 8).

The summary of computed technical potential of renewable energy sources in Bali (Table 8) shows that there is sufficient renewable energy potential, specifically solar energy, that can be tapped to meet electricity demand of 4,993 GWh/year by 2019 and even beyond that time. However, without proper policy and market intervention, it would be difficult to harness this potential. The estimated quantified energy mix, along with spatial distribution at *desa* level can be effectively used for different sizes and types of energy generation planning, specifically for small rooftop or backyard solar or hybrid photovoltaic and mini and micro grids. In this context, a geo-enabled DSS may assist decision makers in selecting the appropriate technologies.

Table 8: Projected Energy Demand and Technical Potential of Renewable Energy in Bali

District	Number of Households	Population	Demand, 2019 (GWh/year)	Technical Potential Renewable Energy (GWh/year)					
				Biomass	Solar	Wind	Hydropower	Geothermal	Total
Bangli	66,144	258,623	310.35	47.16	13,029.94	0	9.62	121.94	13,208.66
Gianyar	102,957	402,562	483.07	254.28	1,871.83	0.62	13.41	0	2,140.14
Denpasar City	131,193	512,965	615.56	31.61	1,720.64	1.68	0	0	1,753.92
Badung	165,781	648,204	777.84	143.96	10,598.26	5.53	10.53	0	10,758.28
Jembrana	84,541	330,555	396.67	97.62	10,898.47	10.43	1.77	0	11,008.29
Karangasem	127,129	497,074	596.49	7.72	12,182.98	4.63	15.29	0	12,210.62
Buleleng	207,436	811,075	973.29	199.53	40,715.48	1.59	11.50	42.05	40,970.15
Tabanan	128,802	503,616	604.34	284.61	3,877.75	0.83	10.50	527.70	4,701.39
Klungkung	50,111	195,934	235.12	70.87	18,541.16	8.41	0	0	18,620.44
Total	1,064,094	4,160,608	4,993	1,137.36	113,436.5	33.72	72.62	691.69	115,371.9

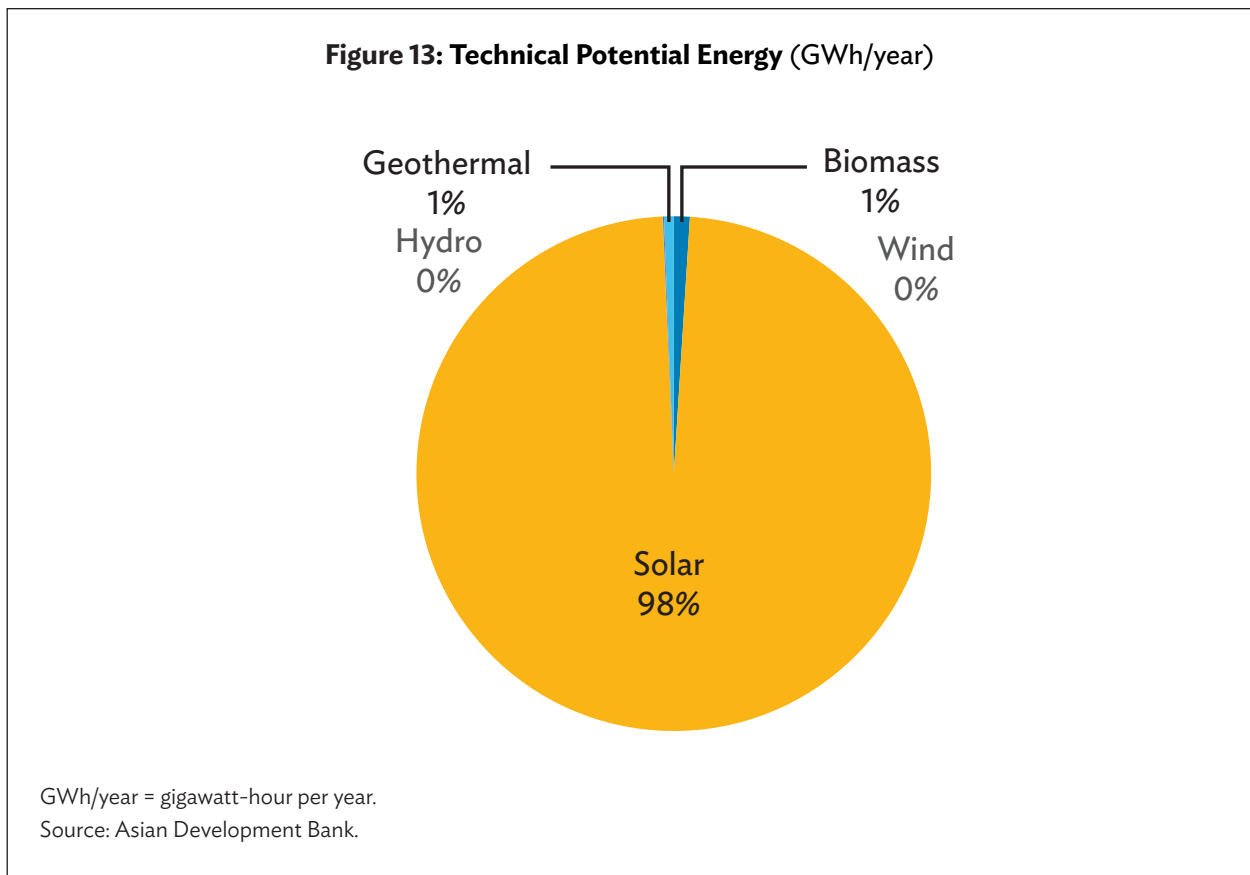
GWh/yr = gigawatt-hour per year.

Source: Asian Development Bank.

Among five sources of energy, solar energy has the highest potential, contributing 98%; followed by biomass. The other four sources combined contribute only 2% as shown in Figure 13. Biomass has potential but it is difficult to collect; can add to pollution; and is usually used for heating, cooking, and livestock feed by the community. It can be assumed that around 25% is used by the community and the rest can be allotted for biomass energy.

Solar energy is the best source because it is freely available most especially in areas near the equator, which Bali is. It is nonpolluting, and the price of solar panels is becoming more affordable. However, it is important to recognize that large storage is needed if all the demand is met by solar energy, which is beyond the scope of this paper.

Although solar energy exhibits best potential, policy makers can easily arrive at a proper mix of solar and biomass.



VI. MAPPING TOOL FOR RENEWABLE ENERGY

Manual data processing of energy sources is a tedious task. It is prone to error and it requires mastery in data manipulation in spreadsheet and GIS application. The mapping tool for renewable energy alleviates the mentioned difficulties and all it requires is familiarity with how GIS application and plugins work. The tool is designed with flexibility so that it can be used in similar geographic regions of Asia and the Pacific.

The tool basically prepares each energy source by linking political boundary, applying a conversion parameter, calculating heating value of biomass data, and computation of potential energy. The tool also incorporates a suitability function for solar and wind energy. With suitability function, the tool will be able to analyze suitable locations for the installation of solar panels and wind turbines in consideration of certain criteria.

A. Software Requirement

1. QGIS

The software used in processing the data is QGIS. This free and open source GIS software can be downloaded from <https://www.qgis.org/en/site/forusers/download.html>. Different installers are available from the link for different operating systems (Windows, Linux, MacOS X, and Android) but select version 2.14 and above in order for plugins to run properly. It is important also to install Geographic Resources Analysis Support System (GRASS) plugin for QGIS. GRASS is a requirement in raster processing.

2. Plugin Development


The interface of a mapping tool for renewable energy will be in the form of a QGIS plugin. A plugin is a collection of customized functions developed from Python programming language built-in in QGIS. To install the plugin, copy the folder “.\MappingTool_RenewableEnergy” to “C:\Users\\.qgis2\python\plugins”.⁴ Open QGIS then in the “Plugins” menu, click “Manage and Install Plugins”. Search “Mapping Tool for Renewable Energy” and click the tick box to enable the tool as shown in Figure 14.

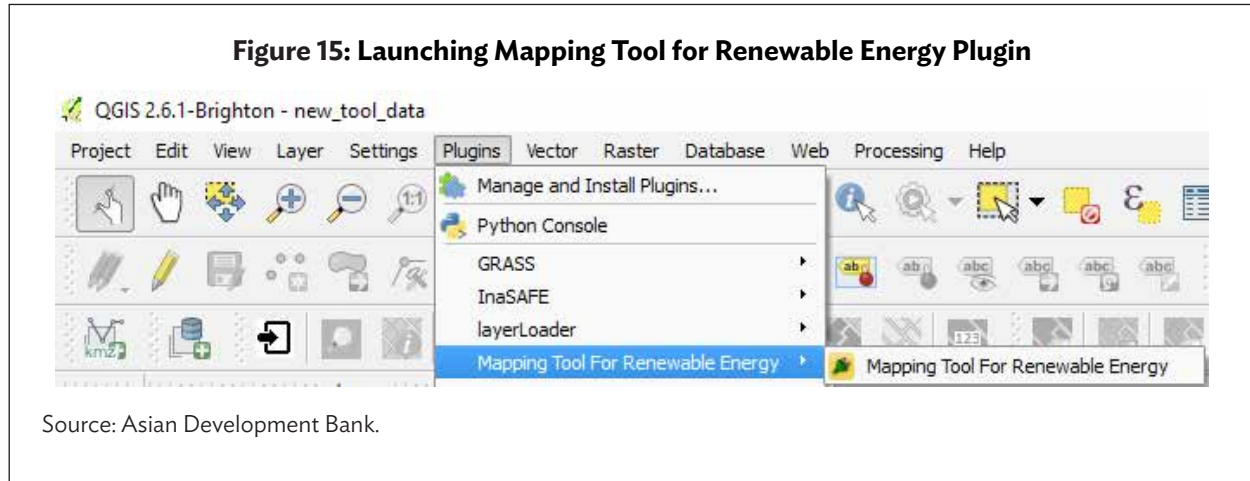
Figure 14: Installation of Mapping Tool for Renewable Energy Plugin



Source: Asian Development Bank.

⁴ The plugin tool is separate from the installation CD but is available upon request.

The tool interface can be opened by clicking the Mapping Tool for Renewable Energy button  that can be found in the QGIS toolbar. Alternatively, it can be accessed from the Plugins menu as shown in Figure 15.



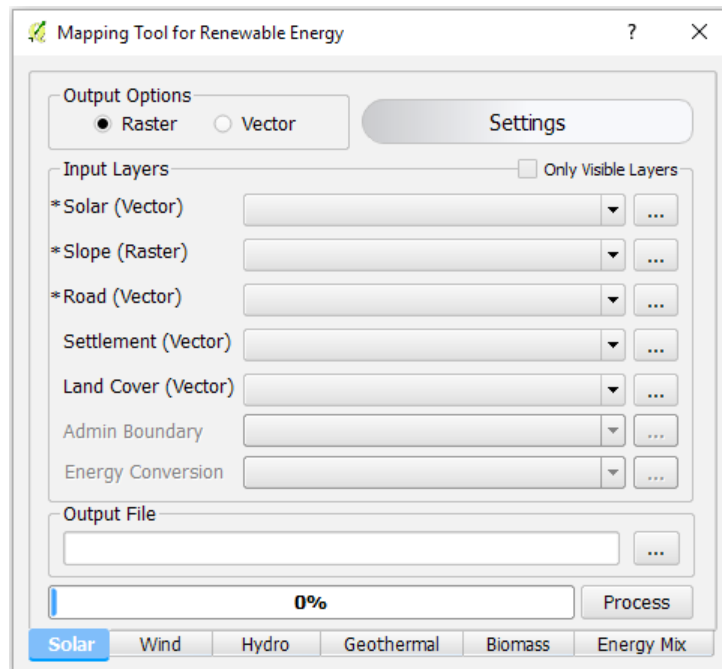
B. Interface

The main interface as shown in Figure 16 contains tabs where each energy source can be processed individually. The procedure involved can be found in the Manual of Mapping Tool for Renewable Energy.⁵

- (i) **Output options.** This option is available for solar and wind energy source. Raster output is for determining the suitable location for installation of solar panels or wind turbines. This option has five input parameters. Vector output requires additional administrative boundary to be able to summarize the energy potential per political boundary, in this case, per *desa*.
- (ii) **Only visible layers.** This option is for filtering the layers on the combo box. Checked means only visible layers will be listed on the control whereas all layers are hidden.
- (iii) **Input layers.** These are the required layers to be able to process the energy source. Layers such as Solar, Road, Settlement, Land Cover, and Admin Boundary are in vector format while Slope is in raster format.
- (iv) **Output file.** The user can set the path where to save the output by clicking the browse button and setting a file name.
- (v) **Process.** This is the button the user can press when all the input and output parameters have been completed.
- (vi) **Settings.** The settings interface is where to set conditions for the input and output parameters as shown in Figure 17. The condition setting can be found in Appendix 1 of the Manual of Mapping Tool for Renewable Energy.

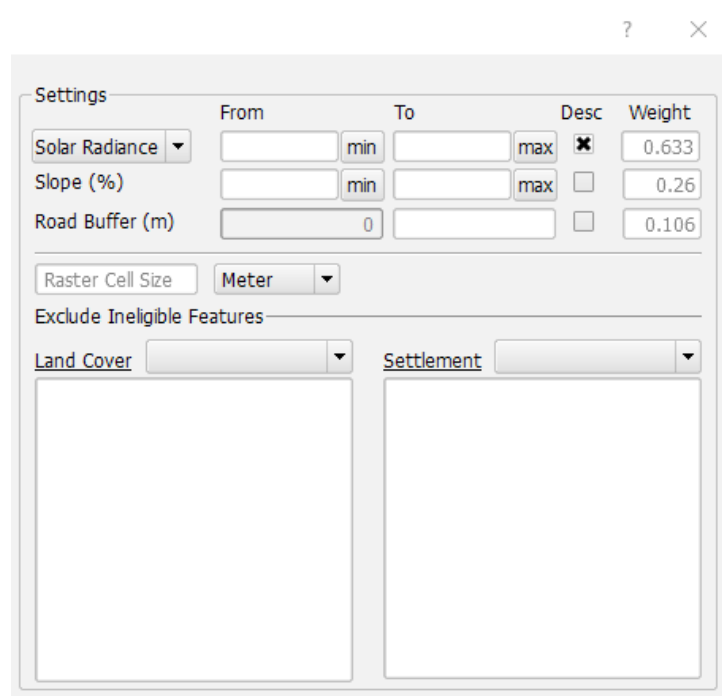
⁵ The manual is available upon request from Infrastructure Specialist (GIS), SDCC, Asian Development Bank.

Figure 16: Mapping Tool for Renewable Energy Interface



Source: Asian Development Bank.

Figure 17: Settings of Mapping Tool



Source: Asian Development Bank.

VII. LIMITATIONS OF CURRENT WORK AND FUTURE ENHANCEMENTS

The focus of the phase 1 decision support system (DSS) is on estimating the potential resource mix from wind, solar, biomass, hydropower, and geothermal renewable energy sources. It is the first phase of a multiphase effort. The key limitations of phase 1 are described below, after which further work required for addressing these limitations is described.

- (i) The current study does not assess the financial viability of the renewable energy sources and is only limited to estimating the gross energy potential in each geographical unit based on energy density of the resource and the land mass available for exploiting the resource. As an example, the highest wind energy resource is in the northwest region of Nusa Penida and southern region of Bali island (see Map 7), where the average annual wind speed is 5 m/s at a height of 50 m above ground level. Although the wind speed numbers were converted into wind energy density and then to GWh per year, these conversions did not take into account the financial viability of the wind project at the locations. As a rule of thumb, commercial utility-scale wind projects are financially feasible in locations where the annual average wind speed is higher than 6.5 m/s at hub height. Although it is a crude rule-of-thumb, the fact that the highest resource location has a wind speed (after extrapolation to hub height) that is below the threshold wind speed suggests that there are no financially feasible wind projects in Bali. Note the crude rule-of-thumb does not account for feed-in tariff, subsidies, and other factors. In planning future work, a more rigorous financial feasibility analysis should be performed for all the renewable sources of interest, which would extend the current work to a more comprehensive DSS that assesses financial viability.
- (ii) Solar photovoltaic rooftop potential was not determined in urban and industrial areas. This potential is likely to be substantial and financially feasible given the rapid drop in cost. With minimal or no incentives, such distributed power generation may be cheaper than the diesel-based power generation alternative. In addition, solar photovoltaic rooftops promise to significantly increase self-sufficiency of power among consumers, which is a big motivator. In the next phase, data related to rooftop solar photovoltaic potential will be obtained, processed, and integrated with the DSS and its financial viability model.
- (iii) Ground-mounted solar potential was determined based on suitability criteria illustrated in Map 2. It filtered out a large fraction of land area in the main island of Bali, which suggests that the criteria were too restrictive. Based on experience, almost all villages and small towns would have sufficient land available for solar parks to meet the energy demand of the community. Therefore, in the next phase, the criteria for site selection will be revisited.
- (iv) Biomass potential was determined without considering in-house consumption, amount required for year-round energy production, economies of scale in terms of size of power plant, cost of collection, and financial viability. In the next phase, a more comprehensive model will be developed in the DSS that incorporates all the parameters (in addition to resource availability) that are required for determining financial viability.
- (v) All the resource assessments were conducted with data from ESDM. It should be pointed out that the ESDM dataset does not match datasets from other sources. As an example, the wind dataset of ESP3 (<http://indonesia.windprospecting.com/>) is different from ESDM. It is therefore necessary to compare the accuracy of different data sources and present results based on more than one source of data in order to indicate the amount of resource uncertainty.

As is evident from the above, financial feasibility of power generation depends on a variety of factors like amount of resource (this is the only aspect that is covered in this report); quality of resource; financial parameters (feed-in tariff, other incentives, interest rates, expected equity rate of return and others); economies of scale (solar photovoltaic is not as sensitive as wind to project size) and other factors like infrastructure (roads, transmission, and others). An important next step in the project is to create a consolidated decision support model that incorporates some of the most important, if not all, factors that determine the financial viability of the renewable energy sources.

VIII. CONCLUSION

The technical potential of energy mix (115,371.9 GWh/year) in Bali, Indonesia is substantially higher than its projected energy requirement by 2019 (4,992.73 GWh/year). The spatial distribution of said resources was mapped using a GIS platform. The result can contribute to the diversification of power generation, and policy formulation for future analyses and utilization of renewable energy.

A GIS-based decision support system tool has been devised that can be used for most of the geographic area in the region. Using the results of Bali as a test case, the working paper envisions presenting a tool that can be utilized for similar geographic regions.

The focus of this decision support system is on estimating the potential resource mix from wind, solar, biomass, hydropower, and geothermal renewable energy sources. The tool can be enhanced by incorporating financial viability, socioeconomic, and technological aspects to make it a complete package for policy and decision makers.

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Geographic Information System-Based Decision Support System for Renewable Energy Development

An Indonesian Case Study

The Asia and Pacific region is blessed with abundant renewable energy resources. Ironically, 420 million of its people still have no access to electricity, which makes tapping renewable energy an urgent necessity. The geographic information system (GIS)-based Decision Support System is a tool designed to help quantify renewable energy sources in a geographical area. Using Bali, Indonesia as case study, the tool estimates the technical potential and creates the right mix of renewable energy (solar, wind, biomass, hydropower, and geothermal) to meet Bali's specific energy needs. Find out more about this GIS-based system and its potential as a practical tool to support the region's rapid deployment of renewable energy technologies.

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Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

