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Renewable Energy Mini-Grids as the Least-Cost Energy Solution for the Electrification of Off-Grid Areas: A Case Study on Island Electrification in the Philippines

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Manila, 4. November 2014

Affidavit

I, **Elmar Elbling**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Renewable Energy Mini-Grids as the Least-Cost Energy Solution for the Electrification of Off-Grid Areas: A Case Study on Island Electrification in the Philippines", 100 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

The Philippines is an island archipelago where most of the inhabited islands currently enjoy only limited hours of electricity, generated by unsustainable, expensive and environmentally hazardous diesel powered plants. The core objective of this thesis is to prove that energizing islands in the Philippines through - renewable energy sources - will in the long run be more cost efficient than power generation through conventional diesel power plants. This thesis analyses current government policies and objectives in rural electrification in the Philippines; it also describes the legal framework and incentives available, and feasible business models that enable implementation of hybrid renewable energy mini-grids. The current electrification situation and key stakeholders, specifically in rural electrification and available renewable energy resources in the Philippines, are assessed and put into context with the goal of accelerated implemention of renewable energy mini-grids. An actual case study for the electrification of one specific remote island, using the energy modeling software HOMER, has been conducted. The two HOMER simulations, applying two different sets of future load assumptions, both prove that power generation through renewable energy lowers the cost of generation in the specific island. This thesis shall also contribute to wider implementation of renewable energy power generation systems in the Philippines through contributing to a thorough understanding of the government policies supporting rural electrification, presentation of feasible business models and the evidence that electrification through renewable energy is the least-cost electrification option available.

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List of Acronyms

ABEP: Accelerated Barangay Electrification Program

AC: Alternating Current

ADB: Asian Development Bank

BLEP: Barangay Line Enhancement Program

CAPEX: Capital Expenditure

CHP: Combined Heat and Power

CIF: Cost, Insurance and Freight

COE: Cost of Energy

DA: Department of Agriculture

DBP: Development Bank of the Philippines

DC: Direct Current

DENR: Department of Environment and Natural Resources

DOE: Department of Energy

DU: Distribution Utility

DYCM: dehydrated young coconut meat

E4ALL: Energy for All Initative

EMS: Energy Management System

EPIRA: The Electric Power Industry Reform Act of 2001

ERC: Energy Regulatory Commission

ER Program: Expanded Rural Electrification Program

FIT: Feed-In Tariff

FWAs: First Wave of Areas

GCV: Gross Calorific Value

HOMER: Hybrid Optimization Model For Electric Renewables

IEA: International Energy Agency

Kcal: kilocalorie

Kg: Kilogramm

kW: Kilowatt

kWh: Kilowatt-Hour

kWp: Kilowatt-Peak

LBP: Land Bank of the Philippines

LGU: Local Government Unit

LIDAR: LIght Detection And Ranging

MAF: Moisture and Ash Free Basis

MDGs: Millenium Development Goals

MEDP: Missionary Electrification Development Program

MMBFOE: Million Barrels Of Fuel Oil Equivalent

MJ: Megajoule

MW: Megawatt

NEA: National Electrification Administration

NGCP: National Grid Corporation of the Philippines

NRE: New and Renewable Energy

NREL: National Renewable Energy Laboratory

NPC: Net Present Cost

NPC-SPUG: National Power Corporation – Small Power Utilities Group

NPP: New Power Provider

NPV: Net Present Value

O&M: Operations and Maintenance

O&M&M: Operations, Maintenance and Management

PAG-ASA: Philippine Atmospheric Geophysical and Astronomical Services Administration

PHP: Philippine Peso

PIOU: Private Investor Owned Utility

PSA: Power Supply Agreement

PSALM Corp.: Power Sector Assets and Liabilities Management Corporation

PU: Private Utility

PV: Photovoltaic

RE: Renewable Energy

SAGR: Subsidized Acceptable Generation Rate

SEP: Sitio Electrification Plan

SHS: Solar Home System

SIIGs: Small Islands and Isolated Grids

SoC: State of Charge

SODAR: Sound Detection And Ranging

SE4ALL: Sustainable Energy for All

QTP: Qualified Third Party

UCME: Universal Charge for Missionary Electrification

UN-SPIDER: United Nations Platform for Space-based Information for Disaster Management and Emergency Response

Wp: Watt Peak

η: System Efficiency

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1. INTRODUCTION

Despite increasing efforts of governments, bilateral donors and multilateral development institutions to fight energy poverty, there are still around 1.3 billion people worldwide without access to electricity and around 2.6 billion without access to modern cooking facilities.[1] Around 615 million lacking access to electricity live in Asia and the Pacific[2]. Especially affected by the lack of energy access are people living in remote, rural areas that are not connected to the main transmission grid. There are multiple reasons why the transmission grid does not reach those areas, be it the difficult geographic terrain or populations who live dispersed which makes it either physically impossible or economically unviable to extend the grid.

Electrification of the so called off-grid areas is slowly picking up. In the Philippines, for example, many of those off-grid areas are in remote islands that enjoy only limited hours of electricity per day, generated by diesel generators. The implications of lack of electricity are manifold: on the one hand limited availability of power hampers the social and economic development of those areas, as lack of electricity prevents the usage of appliances for productive uses and other income generating activities; on the other hand electricity generation through fossil fuel based generation facilities contributes to increased greenhouse gas emissions and climate change. Access to electricity entails multiple other benefits for the poor apart from the positive socio-economic implications through increased business activity. Electricity access can enhance the personal life of each individual as e.g. substitution of polluting kerosene lamps mitigates the problem of indoor air pollution and the related health risks, electric lighting available during night hours enables school children to study after dawn, and improved electricity services allow for better access to information through electricity for appliances like TV and radio.

Lack of access to modern energy affects the social and economic development of the energy deprived local communities. However, it is also seen as a market opportunity for the private sector to tap into and fill in the energy access gap. According to the International Finance Corporation around $37 billion are spent every year on kerosene used for lighting and biomass for cooking. Ninety (90) percent of (poor) people spend substantial amounts for kerosene, candles and disposable batteries to meet their lighting needs which would allow them to avail access to modern energy services and appliances instead.[3] Although

[1] International Energy Agency, About energy poverty, http://www.iea.org/topics/energypoverty/
[2] International Energy Agency, World Energy Outlook 2013 Factsheet, 2013, http://www.worldenergyoutlook.org/media/weowebsite/factsheets/WEO2013_Factsheets.pdf
[3] International Finance Corporation: From Gap to Opportunity: Business Models for Scaling Up Energy Access (2012), p. 12

affordability has always been cited as a major barrier for the poor to accessing modern energy, those numbers indicate that the funds would be available to pay for modern energy services. Modern energy services in off-grid areas are usually provided through solar lanterns and individual solar home systems (SHS), however, renewable energy-powered mini-grids are also considered as environment friendly alternative to replace traditional fossil fuel for rural electrification.

The graph below depicts the so called energy ladder. It shows various energy access options comparing them in terms of efficiency, health risk and cost. The ladder starts with traditional fuels and systems for cooking and lighting, further up solar lanterns and household SHS to graduate to off-grid (mini-grid) systems and ultimately the connection to the transmission grid.

In climbing up to the next step of the ladder, there is gradual improvement in the quality of the energy service moving away from ineffecient, expensive energy sources that are potentially hazardous to health, like wood and kerosene, to more efficient and cleaner sources of energy. Moving up the ladder would not only translate into having available cheaper, more efficient and cleaner energy sources but would also result in the availability of sufficient energy for higher electricity loads to enable income generating activities.

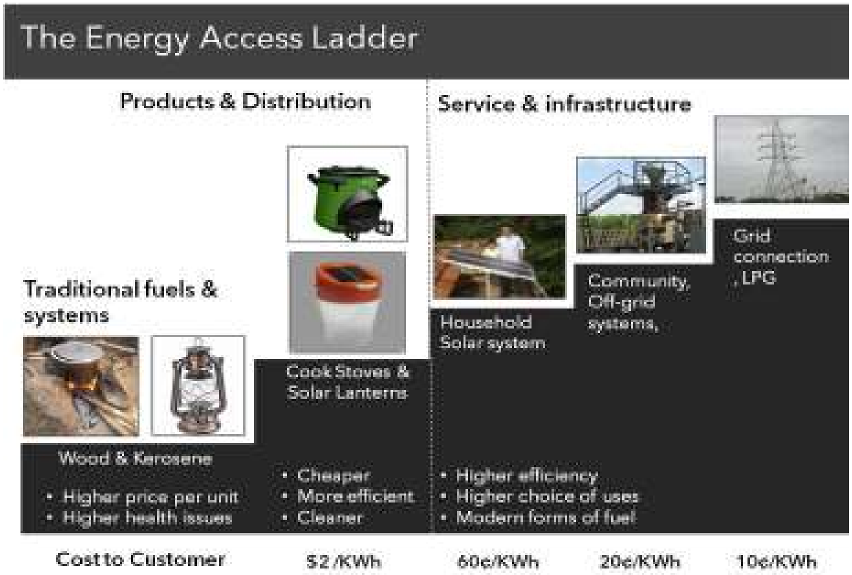

Figure 1: The Energy Access Ladder, Acumen[4]

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http://www.ifc.org/wps/wcm/connect/ca9c22004b5d0f098d82cfbbd578891b/EnergyAccessReport.pdf?MOD=AJPERES

[3] Figure 1: The Energy Access Ladder, Acumen, Acumen Blog: Plug and Play, Energy Access at the BOP, http://acumen.org/blog/plug-and-play-energy-access-at-the-bop/

Grid connection as the cheapest source of power is in many cases not an option for remote and off-grid areas, therefore mini-grid systems prove to be a viable alternative. In contrast to individual applications like solar lanterns and solar home systems they are more complex to implement but allow for more efficient power production and generate sufficient electricity to support income generating activities.

A mini-grid provides centralized electricy generation at a local level using a village distribution network.[5] Mini-grids can be designed using different generation technologies or combining them, e.g. either powered by diesel generators, 100% renewable energy sources like sun, wind, hydro, biomass, etc. or combining the renewable energy sources with diesel generators creating a hybrid system.[6]

1.1. Motivation

The United Nations has declared 2012 the "Year of Sustainable Energy for All (SE4ALL)" recognizing that access to modern affordable energy services in developing countries is essential to reach the Millenium Development Goals[7] and sustainable development to reduce poverty.[8] The overarching goals of the SE4ALL Initative to be achieved by 2030 are: providing universal access to modern energy services; doubling the global rate of improvement in energy efficiency; and doubling the share of renewable energy in the global energy mix.[9]

The Asian Development Bank (ADB) launched its Energy for All Initative (E4ALL) in 2008 to adress the problem of energy poverty by increasing support to energy access projects and companies. Several programs under Energy for All support the development of mini-grids all over Asia including the Philippines. In June 2014 ADB was named the Regional Hub for the SE4ALL Initiative for the Asia and Pacific, reiterating its role in energy access but including also the areas of renewable energy and energy efficiency. ADB, especially through its

[5] Alliance for Rural Electrification: Hybrid Mini-Grids for Rural Electrification: Lessons Learned, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf

[6] GVEP International: Global Village Energy Partnership, Policy Briefing, (2011), http://www.gvepinternational.org/sites/default/files/policy_briefing_-_mini-grid_final.pdf

[7] Definition Millenium Development Goals (MDGs): In the year 2000 189 United Nations Member States adopted the Millenium Declaration to achieve 8 MDGs: 1) Eradicate extreme poverty and hunger, 2) Achieve universal primary education, 3) Promote gender equality and empower women, 4) Reduce child mortality, 5) Improve maternal health, 6) Combat HIV/AIDS, malaria, and other diseases, 7) Ensure environmental sustainability, 8) Develop a global partnership ofor development, http://data.worldbank.org/about/millennium-development-goals

[8] Sustainable Energy for All, Global Tracking Framework, p. 67, http://www.iea.org/publications/freepublications/publication/global_tracking_framework.pdf

[9] Sustainable Energy for All, About Us, http://www.sustainableenergyforall.org/about-us

Energy for All Initiative, is taking the lead to push the energy access agenda in the Asia and Pacific region by bringing together stakeholders from governments, the private sector and other key stakeholders to make universal access to energy happen by 2030.

1.2. Core Question and Objective

The key question to be answered in this thesis is whether the case can be made for renewable energy hybrid mini-grid systems as the least-cost option for the electrification of remote island grids in the Philippines as compared to conventional diesel mini-grids.

The core objective of the thesis is to prove that renewable hybrid mini-grids can compete with conventional diesel gensets for the electrification of off-grid, remote or isolated areas in the Philippines and to examine the various government policies, regulations and business models that will allow implementation of commercially viable hybrid mini-grid systems.

1.3. Citation of Main Literature

Documents published by government agencies like the Department of Energy, the National Electrification Administration and the Electricity Regulatory Commission as well as the respective laws, rules and regulations that govern rural electrification and renewable energy application in the Philippines have served as the primary source of information to analyze government policies and current laws. Especially The Electric Power Industry Reform Act of 2001, the National Electrification Administration Reform Act of 2013 and the Renewable Energy (RE) Act of 2008 have been elaborated on in detail. Those laws constitute a substantial part of the legal framework for rural electrification, defining the rules for generation and distribution of electricity in the Philippines; they also govern the current government subsidy system and the incentives available, especially if renewable energy sources are employed for generation of power.

Two publications by the Alliance for Rural Electrification called “Rural Electrification with Renewable Energy, Technologies, Quality Standards and Business Models” and “Hybrid Mini-Grids for Rural Electrification: Lessons Learned“ have served among others as basis to explain technical features and technologies used in rural electrification, specifically hybrid mini-grids.

HOMER (Hybrid Optimization Model For Electric Renewables), an energy modeling software has been used to come up with the least-cost electrification option for the island analyzed in the case study. The “Getting Started Guide For HOMER Legacy (Version 2.68)” published by the National Renewable Energy Laboratory has been essential in getting acquainted to the software and conducting the simulations. The HOMER wind and solar resource files provided by HOMER Energy are the basis for the simulations using the HOMER software.

1.4. Structure of Work

The thesis is broadly divided into two parts. Chapter one, two and three, forming the first part, give an introduction into the topic and a general overview about the Philippines, its electrification situation and the theoretical foundations on renewable energy sources and mini-grids. In the second part, consisting of chapter three and four, an actual case study on the least-cost electrification of an island in the Philippines is presented and the respective conclusions are presented in the last chapter.

Chapter two first gives a general country description of the Philippines in terms of location, population and economic situation followed by an analysis of the renewable energy resources available. Specific focus is put on hydro, solar, wind and biomass as those are resources potentially available for the least-cost electrification of the island described in the case study. This chapter also elaborates on the current electrification situation in the Philippines, specifically the situation in off-grid areas and remote islands, the legal framework for electricity generation and distribution and on the key stakeholders and government agencies in this field. Chapter two concludes with an overview of government policies and objectives with regard to off-grid electrification and business models for the implementation of power generation projects in general, and more specifically elaborates on the models feasible in the Philippines.

Chapter 3 describes in more detail specific renewable energy technologies focusing on solar, wind and biomass. Those renewable energy technologies form the basis for the HOMER simulations, to find the least-cost electrification solution for the island, as conducted in the case study in chapter 4. The concept of mini-grids, explaining the modalities and features of conventional diesel mini-grids in contrast to hybrid mini-grids, are discussed at the end of this chapter.

The actual case study on the least-cost electrification of an island is conducted in chapter four. First the island is described in terms of location, current electricity consumption and renewable energy resources available. In a further step the assumptions for the technical design and financial analysis are elaborated on in detail, specifically the cost assumptions for the different renewable energy technologies and resources available. After having defined the assumption of the load forecast, the simulation exercise is being conducted, using the

HOMER software. HOMER comes up with the optimal design for the hybrid mini-grid and hence the least-cost renewable energy electrification option for the island.

In the concluding chapter the result of the HOMER simulation exercise is being analysed and the least-cost electrification option put into context with the legal framework and electification policies in the country that should lead to a replication of renewable energy mini-grids on a large scale all over the Philippines.

1.5. Method and Approach for Calculation of Case Study

The least-cost renewable energy option for the electrification of the island and the design of the hybrid mini-grid is conducted using the HOMER software. HOMER, the micropower optimization model which is used to design hybrid renewable micro-grids, is a computer model that has originally been developed by the National Renewable Energy Laboratory (NREL). The optimization and sensitivity analysis conducted by the software takes into account different technology costs and energy resources available and allows to evaluate the economic and technical feasibility of different technology options.

HOMER simulates the operation of a system and calculates the system costs such as capital, replacement, operation, maintenance, fuel and interest. The program performs energy balance calculations for each hour in the year and compares the electric and thermal demand to the energy that can be supplied by the system, respectively calculates the flow of energy to and from each system component. It calculates also for each hour whether the generators should be operated and whether the batteries need to be charged or discharged.

As a result of the optimization procedure HOMER comes up with all possible system configurations sorted by the net present cost to allow comparison of the system design options and hence also defines the least-cost option. It gives detailed information about which components should be included in the system design and how many and what size of each component should be used. The program also enables the performance of sensitivity analysis by changing the sensitivity variables as inputs, e.g. simulation of system configurations for a range of different wind speeds or fuel prices. [10] [11] In chapter 4 the key parameters and assumptions used for the HOMER simulation and the results of the modeling exercise are elaborated on in detail. To gather specific information on the socio-economic

[10] Homer Energy, The Homer Software, http://www.homerenergy.com/software.html
[11] National Renewable Energy Laboratory, HOMER The Micropower Optimization Model, p. 4, Getting Started Guide For HOMER Legacy (Version 2.68), http://www.homerenergy.com/pdf/HOMERGettingStartedGuide.pdf

profile and the current electrification situation of the island, that serves for the case study, and the cost assumptions of renewable technologies, interviews with local experts were conducted.

2. COUNTRY OVERVIEW PHILIPPINES

2.1. General Country Description

The Philippines is a large island group in Southeast Asia that consists of more than 7,100 islands and is located between the Philippine Sea and the South China Sea, east of Vietnam. It has a total land area of 300,000 sq.km and a coastline of more than 36,000 km.[12] With a population of around 98 million, it is the 12th largest country in the world in terms of population and very young with more than a third of the overall population being under 15 years old.[13] [14] [15]

The country is divided in three main geographic areas, Luzon, Visayas and Mindanao and consists of 80 provinces and 39 chartered cities, with Manila serving as the capital. Barangay, the Filipino term for village, is the smallest administrative division; sitios are territorial enclaves that form part of a barangay.[16]

With USD 272 billion in 2013 Philippines ranks 40 globally with regard to the Gross Domestic Product (GDP)[17] and 120 in terms of GDP per capita (USD 6,000).[18] The Philippine economic growth has been exceptional in the Asian region and with a 7.2% growth in GDP in 2013 well above the average of 4.7% recorded from 2008-2012. Growth forecast is also promising with a predicted rate of 6.4% for 2014 and 6.7% for 2015.[19]

The country lies within the Ring of Fire which is a region of subduction[20] zone volcanism surrounding the Pacific Ocean and is in general very vulnerable to natural disasters. Since 1968 twelve destructive earthquakes have been recorded in the Philippines with seismic activity observed in almost all regions of the country and a total of 22 historically active volcanoes. In 1991, Mount Pinatubo erupted in one of the most violent eruptions in the 20th

[12] The World Factbook https://www.cia.gov/library/publications/the-world-factbook/geos/rp.html
[13] The World Bank, Population (Total). http://data.worldbank.org/indicator/SP.POP.TOTL
[14] The World Factbook https://www.cia.gov/library/publications/the-world-factbook/geos/rp.html
[15] World Population Review, http://worldpopulationreview.com/countries/philippines-population/
[16] Wikipedia http://en.wikipedia.org/wiki/Barangay
[17] The World Bank, GDP ranking: 01-Jul-2014
[18] The globaleconomy.com, Purchasing Power Parity 2012, GDP per capita http://www.theglobaleconomy.com/rankings/GDP_per_capita_PPP/
[19] Asian Development Bank: Philippines, Economic, Economic Performance, http://www.adb.org/countries/philippines/economy
[20]Subduction: "The process of one tectonic plate sliding under another, resulting in tensions and faulting in the earth's crust, with earthquakes and volcanic eruptions", http://www.thefreedictionary.com/subduction

century devastating the surrounding areas and claiming up to 800 lives.[21] [22] The Philippines is prone to various climate and weather-related perils like typhoons, monsoons and the weather phenomenon El Niño-La Niña, greatly endangering its people.[23] On November 8, 2013 typhoon Hayan (local name Yolanda) struck in the Visayas region. Having been the most powerful storm to make landfall recorded in history, it caused more than 6,000 casualities and more than USD 900 million in estimated damages.[24] [25] [26]

Map 1: Map of the Philippines, Worldatlas[27]

2.2. Renewable Energy Resources Available

The renewable energy (RE) resources available in the Philippines range from hydro, wind, solar, biomass to geothermal and ocean resources. However, this chapter will focus mainly

[21] The Manila Observatory: Mapping Philippine Vulnerability to Environmental Disasters, Geophysical Risk Maps, http://vm.observatory.ph/geophys_maps.html
[22] About.com: Mount Pinatubo Eruption http://geography.about.com/od/globalproblemsandissues/a/pinatubo.htm
[23] The Manila Observatory: Mapping Philippine Vulnerability to Environmental Disasters, Climate- and Weather-Related Risk Maps
[24] Official Gazette, Typohoon Yolanda
[25] Official Gazette, Official List of Casualties: Typhoon Yolanda
[26] National Disaster Risk Reduction and Management Council
[27] Map 1: Map of the Philippines, Worldatlas, http://www.world-atlas.biz/philippines.htm

on hydropower (specifically micro-hydro)[28], wind, solar and biomass as those are resources applicable in the context of smaller scale rural and village electrification through mini-grids. The government of the Philippines wants to utilize the abundant RE resources available to decrease dependency on imported and polluting fuels and wants to increase its share in gross power generation. Conventional fuels like coal with 38.76% and natural gas with 26.93% (2012 figures) are the major contributors to gross power generation. RE resources are picking up with hydro constituting 21% and geothermal around 11% of total installed capacity. More details and current figures on installed capacity in RE and gross power generation from renewable energy wil be discussed in chapter 2.3. Electrification Situation.

2.2.1 Hydro

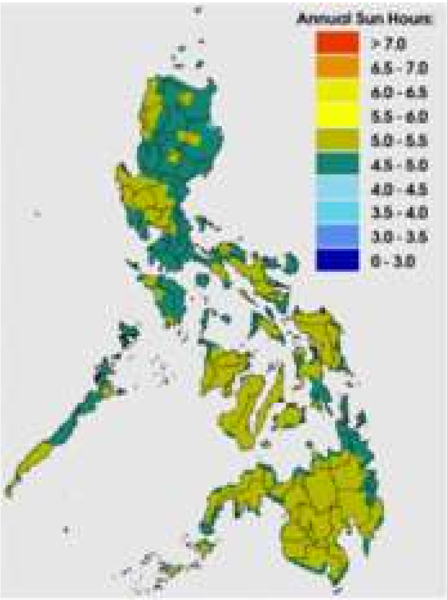
The Philippines sourced 14% of its overall power generation from hydropower. Hydro potential in the country is vast and a large amount of hydropower resources remain untapped. The potential of the country is estimated at 13,097 MW, of which 85% are considered as large and small hydros (11,223 MW), 14% (1,847 MW) are classified as mini-hydro while less than 1 percent (27 MW) are considered micro-hydros. The classification of hydro plants based on their capacities are as follows: (i) micro-hydro - 1 to 100 kW; (ii) mini-hydro - 101 kW to 10 MW; and (iii) large hydro - more than 10 MW.[29] The graph below illustrates locations for potential for micro-hydro power plant installations which is particularly interesting for the development of mini-grid systems.

Map 2: Map of the Philippines indicating micro-hydro potential, Department of Energy[30]

[28] Micro-hydro are those systems with capacities of 100 kW and below
[29] Department of Energy: Philippine Power Statistics, Hydropower, https://www.doe.gov.ph/renewable-energy-res/hydropower
[30] Map 2: Map of the Philippines indicating Micro-Hydro Potential, Department of Energy: Philippine Power Statistics, Micro-Hydro Potentials in the Philippines https://www.doe.gov.ph/renewable-energy-res/resource-maps/276-micro-hydro

2.2.2 Solar

Positioned close to the equator the average solar irradiation in the Philippines, based on sunshine duration, is 161.7 watts per square meter, ranging from 128 to 203 watts per square meter. The annual potential is estimated at 5.1 kilowatt-hour (kWh)/m^2/day. [31] [32] As of 2012, solar generated a total of 1,320 MWh which only constitutes around 0.002% of the total gross power generation of the country.[33] The graph below gives an overview of annual sun hours in the Philippines, also indicating the most favourable location for solar applications.



Map 3: Map of the Philippines indicating Solar Potential, Philippine Solar Power Adventure Inc. [34]

2.2.3. Wind

The Philippines shows promising potential for wind energy. The wind resources in the country depend mainly on latitude, elevation, and proximity to the coastline. According to a study conducted by the National Renewable Energy Laboratory (NREL) it is estimated that around 10,000km^2 of windy land areas with good-to-excellent wind resource potential are available in the Philippines. Based on the conservative estimate of about 7 MW per km^2 this area could support more than 70,000 MW of potential installed capacity. Using the moderate

[31] Department of Energy: Solar energy Potential Sites, https://www.doe.gov.ph/renewable-energy-res/resource-maps/278-solar\

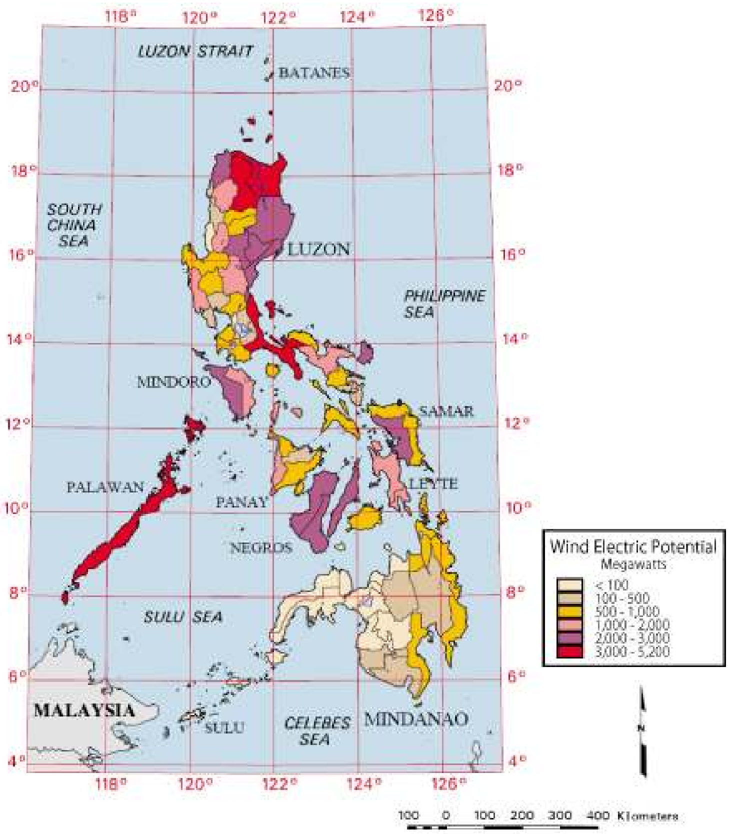
[32] Department of Energy: Micro-Hydro Potentials in the Philippines, Biomass, Solar, Wind and Ocean, https://www.doe.gov.ph/renewable-energy-res/biomass-solar-wind-and-ocean

[33] Department of Energy: Philippine Power Statistics, Gross Power Generation by Plant Type https://www.doe.gov.ph/doe_files/pdf/02_Energy_Statistics/Power-Statistics-2012.pdf

[34] Map 3: Map of the Philippines indicating Solar Potential, Philippine Solar Power Adventure Inc., Why Solar Works in the Philippines, http://www.philsolarpoweradventure.com/engineering/why-solar-works-in-the-philippines/

wind resources assumption, the total land area would increase to more than 25,000km^2 supporting more than 170,000 MW of potential installed capacity.[35] According to the Philippine Atmospheric, Geophysical Astronomical Services Administration (PAG-ASA)[36] the country has a mean average of about 31 watts per square meter (W/m^2) of wind power density.[37]

As can be seen in the map below the best wind resources are located in the north and northeast areas while in the south and southwestern part of the country the wind resources are minimal.[38]



Map 4: Philippines Wind Electric Potential, Good-to Excellent Wind Energy Resource, National Renewable Energy Laboratory[39]

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[35] National Renewable Energy Laboratory, Executive Summary, http://www.nrel.gov/wind/pdfs/26129.pdf

[36] Definition PAGASA: The Philippine Atmospheric, Geophysical and Astronomical Services Administration is the Philippine national institution dedicated to provide flood and typhoon warnings, public weather forecasts and advisories, meteorological, astronomical, climatological, and other specialized information and services primarily for the protection of life and property and in support of economic, productivity and sustainable development, United Nations, UN-SPIDER, http://www.un-spider.org/links-and-resources/institutions/philippines-atmospheric-geophysical-and-astronomical-services-administration-pag

[37] Department of Energy: Micro-Hydro Potentials in the Philippines, Biomass, Solar, Wind and Ocean, https://www.doe.gov.ph/renewable-energy-res/biomass-solar-wind-and-ocean

[38] National Renewable Energy Laboratory, Executive Summary, http://www.nrel.gov/wind/pdfs/26129.pdf

Wind Power Classification

Class	Resource Potential		Wind Power Density (W/m2) @ 30m	Wind Speed (a) (m/s) @ 30m
	Utility	Rural		
1	Marginal	Moderate	100 – 200	4.4 – 5.6
2	Moderate	Good	200 – 300	5.6 – 6.4
3	Good	Excellent	300 – 400	6.4 – 7.0
4	Excellent	Excellent	400 – 600	7.0 – 8.0
5	Excellent	Excellent	600 – 800	8.0 – 8.8
6	Excellent	Excellent	800 – 1200	8.8 – 10.1

Table 1: Wind Energy Resource Atlas Of The Philippines, Philippines Wind Electric Potential, Good-to Excellent Wind Energy Resource, National Renewable Energy Laboratory[40]

2.2.4. Biomass

There is substantial potential for electricity production through biomass, especially through the use of residues from the agricultural sector. According to the Department of Agriculture's (DA) and the Department of Environment and Natural Resources (DENR) estimates the country's agricultural sector could potentially produce up to 323.1 million barrels of fuel oil equivalent (MMBFOE) in 2012.[41] For the purpose of this thesis, the following biomass resources will be elaborated on in more detail: rice husk, coconut residues, sugar mill bagasse and other energy crops. Livestock manure which is also a potential feedstock for biogas production will not be dealt with in detail as in general availability of this type of feedstock on islands and hence use for island electrification is limited, the resource is also quite site specific.

Biomass technologies currently in use span from the use of bagasse as boiler fuel for cogeneration, rice/coconut husks dryers for crop drying, biomass gasifiers for mechanical and electrical applications, fuelwood and agriwastes for oven, kiln, furnace and cookstoves for cooking and heating purposes.[42]

[39] Map 4: Philippines Wind Electric Potential, Good-to Excellent Wind Energy Resource, National Renewable Energy Laboratory, http://www.nrel.gov/wind/pdfs/26129.pdf
[40] Table 1: Wind Energy Resource Atlas Of The Philippines, Philippines Wind Electric Potential, Good-to Excellent Wind Energy Resource, National Renewable Energy Laboratory, http://www.nrel.gov/wind/pdfs/26129.pdf
[41] Department of Energy: Micro-Hydro Potentials in the Philippines, Biomass, Solar, Wind and Ocean, https://www.doe.gov.ph/renewable-energy-res/biomass-solar-wind-and-ocean
[42] Ibid

2.2.4.1. Rice Husk

Rice is the main agricultural product in the Philippines with an average yearly production of 17.72 metric tons between 2011 and 2013. About 3.54 tons (around 20%) is rice husk which is a by product from rice production. [43] Milling is an essential stage of post-production of rice. In the milling process the husk and the bran layers are removed and an edible, white rice kernel is produced. [44]

Rice husk is still considered waste and disposal is seen as a problem by many rice mills. The use of rice husk as fuel still is limited, despite the many positive features. Rice husk has high calorific value (more than 3,000 kcal/kg) and is a renewable carbon-neutral free energy source. It is usually free and concentrated at mills which facilitates further processing. While the benefits of rice husk for power generation are enormous, some negative characteristics have to be noted. Rice husk, if used as fuel, is difficult to ignite and burn with open flame. Its ash content is ranging high, between 17% and 26%, and the low melting point of ash can potentially entail the problem of stench and clogging during firing. Rice husk is very abrasive which could wear off the equipment quickly.[45] [46]

Picture 1: Rice Husk, Daily Tech[47]

[43] Militar Jeriel G., Affiliated Renewable Energy Center Central Philippine University (CPU-AREC), The Energetic Utilization of Rice Husk in Rice Mills in the Philippines, http://www.giz.de/fachexpertise/downloads/2014-en-militar-pep-infoveranstaltung-biogas-biomasse-philippinen-thailand.pdf
[44] Rice Knowledge Bank, Your information source for rice farming, http://www.knowledgebank.irri.org/step-by-step-production/postharvest/milling
[45] Militar Jeriel G., Affiliated Renewable Energy Center Central Philippine University (CPU-AREC), The Energetic Utilization of Rice Husk in Rice Mills in the Philippines, http://www.giz.de/fachexpertise/downloads/2014-en-militar-pep-infoveranstaltung-biogas-biomasse-philippinen-thailand.pdf
[46] CLEANTECH Global, Rice Husk, http://www.dpcleantech.com/biomasslab/example-analysis/rice-husk
[47] Picture 1: Rice Husk, Daily Tech, South Korean Researchers Turn Rice Husk into Silicon Battery Anodes, http://www.dailytech.com/South+Korean+Researchers+Turn+Rice+Husks+Into+Silicon+Battery+Anodes/article31979.htm

2.2.4.2. Coconut Residues

With half a billion, the Philippines has the largest number of coconut trees globally. The Philippines is the top producer of coconut charcoal in the world with a total of 19,500,000 tonnes produced annually. [48] [49] Coconut is planted on 3,55 million hectares (2013), which is 26% of total agricultural land; around 15.344 billion nuts are produced per year on average, i.e. 43 nuts per tree per year on average.[50] Major coconut wastes include coconut shell (12%) and coconut husks (35%).[51]

Map 5: Philippine Coconut Residue Resource Potential, Department of Energy[52]

Coconut in general is either used as food or for non-food purposes. The coconut meat is the part mostly used for food, while other parts like coconut water is used as food or used to produce food. Major coconut products are cocnut meat products like coconut oil, dessicated

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[48] Baconguis Santiago R., Abandoned Biomass Resource Statistics in the Philippines, Ecosystems Research and Development Bureau http://www.nscb.gov.ph/ncs/10thNCS/papers/invited%20papers/ips-20/ips20-03.pdf

[49] Zues Resources - Philippines Coconut Charcoal, http://zuesresources.com/about.php

[50] Philippine Coconut Authority, Coconut Statistics, www.pca.da.gov.ph/cocostat.php

[51] Baconguis Santiago R., Abandoned Biomass Resource Statistics in the Philippines, Ecosystems Research and Development Bureau http://www.nscb.gov.ph/ncs/10thNCS/papers/invited%20papers/ips-20/ips20-03.pdf Research and Development

[52] Map 5: Philippine Coconut Residue Resource Potential, Department of Energy, Energy Resources, https://www.doe.gov.ph/renewable-energy-res/resource-maps/275-cocnut-residues/1762-resource-maps-coconut-residues

coconut and dehydrated young coconut meat (DYCM), coconut milk products like coconut cream, powdered coconut milk and tuba (coconut wine), coconut syrup/honey and coconut sugar, etc.[53]

Coconut Shell

Coconut shell is most widely and importantly used for production of coconut charcoal.[54] The activated carbon is used in air purification systems such as cooker hoods, air conditioning, industrial gas purification systems and gas masks. Coconut shell can also be used for the production of bio-gas (producer gas) through gasification. The producer gas can be burned as a fuel in a boiler or in internal combustion gas engines for electricity generation or combined heat and power (CHP).[55]

Picture 2: Coconut Shell, Ajit Vadakayil, blogspot[56]

2.2.4.3. Sugar Mill Bagasse

Sugarcane is a promising agricultural sources of biomass energy due to its high energy-to-volume ratio and resistance to cyclonic winds, drought, pests and diseases. However its availability is limited geographically to tropical and sub-tropical regions. According to the

[53] Department of Agriculture, Mindanao Rural Development Program 2, www.damrdp.net/eLearning/Coconut/lessons/module02/m02l01.htm
[54] Baconguis Santiago R., Abandoned Biomass Resource Statistics in the Philippines, Ecosystems Research and Development Bureau http://www.nscb.gov.ph/ncs/10thNCS/papers/invited%20papers/ips-20/ips20-03.pdf
[55] Dhurai1 K. R., International Journal of Energy Engineering, An Experimental Study on Biomass Gasifier for Burner System, p. 36
[56] Picture 2: Coconut Shell, Ajit Vadakayil, blogspot, Ayurveda and activated coconut shell charcoal http://ajitvadakayil.blogspot.com/2012/06/ayurveda-and-activated-coconut-shell.html

International Sugar Organization (ISO), "Sugarcane is a highly efficient converter of solar energy, and has the highest energy-to-volume ratio among energy crops. Indeed, it gives the highest annual yield among all biomass of all species. Roughly, 1 ton of Sugarcane biomass – based on Bagasse, foliage and ethanol output – has an energy content of equivalent to one barrel of crude oil". It is therefore considered one of nature's most effective storage devices for solar energy and as energy crop could play a significant role in energy production.[57] Bagasse is the byproduct from milling. It is the cane fiber remaining after the crushing of sugar cane before its transformation into sugar.[58] It has been traditionally used by sugar mills to generate steam and electricity for internal electricity demand. A ton of sugarcane processed in a mill produces around 190 kg of Bagasse.[59]

Picture 3: Bagasse, Indiamart[60]

2.2.4.4. Energy Crops

There is a variety of energy crops and grass species suitable to be planted in the Philippines like napier grass, ipil-ipil, sweet sorghum, etc. Napier or elephant grass is the most popular improved pasture species in the Philippines as it is robust and tall reaching a height of two to five meters when mature. It is long lived, can survive for more than three years, is drought resistant and can produce the feedstock rapidly. It grows best under warm conditions like in

[57] BioEnergy Consult, Biomass Resources from Sugar Industry, http://www.bioenergyconsult.com/tag/sugarcane/
[58] Enertime, Biomass Co-Generation, http://www.enertime.com/en/references/biomass-co-generation
[59] BioEnergy Consult, Biomass Resources from Sugar Industry, http://www.bioenergyconsult.com/tag/sugarcane/
[60] Picture 3: Sugar Cane Bagasse, Indiamart, http://dir.indiamart.com/impcat/sugarcane-bagasse.htm

the Philippines, is also drought resistant and very productive with yields up to 30 tonnes/ ha.[61] [62]

Picture 4: Napier Grass[63]

The grass can be harvested between five and eight times a year in tropical regions and if used for biogas, napier grass as feedstock can produce around 7,000 - 17,000m^3/ha.[64] The produced biogas can be used for the generation of electricity, cooking gas, and bio-gas for vehicles.[65]

[61] Wellington Z. Rosacia, Rhodora M. Rimando, et al, Environmental Requirement and Management of some Important Forage Species in the Philippines, http://erdb.denr.gov.ph/publications/rise/r_v19n1_3.pdf

[62] Mendoza T.C., University of the Philippines at Los Baños, Renewable Biomass Fuel As "Green Power" Alternative for Sugarcane Milling in the Philippines, http://www.reap-canada.com/online_library/IntDev/id_eco_sugarcane/29-3%20Renewable%20Biomass.pdf

[63] Picture 4: Napier Grass, http://www.pinterest.com/pin/17944098490749747/

[64] Asia Biomass Energy Cooperation Promotion Office, Promoting Napier Grass / Biogas Power Generation in Thailand, http://www.asiabiomass.jp/english/topics/1405_02.html

[65] Ministry of Energy, Department of Alternative Energy Development and Efficiency, Napier Grass, http://weben.dede.go.th/webmax/content/napier-grass

2.3. Electrification Situation

According to the International Energy Agency the Philippines has an electrification rate of 83%, with access to electricity being unevenly distributed between urban and rural areas. While 94% of the urban population has access to electricity, only around 73% of rural Philippines is electrified. That results in around 28 million people without access to electricity.[66] On a municipal/-city level as well on a barangay[67] level the country is around 100% energized.[68]

The government entities in charge of the power sector in off-grid areas in the Philippines are the Department of Energy (DOE), National Electrification Administration (NEA), Energy Regulatory Commission (ERC), National Power Corporation – Small Power Utilities Group (NPC-SPUG) and Power Sector Assets and Liabilities Management Corporation (PSALM Corp.).[69] Responsibilities and tasks of those government entities will be elaborated on in detail in this chaper.

Particulars	Potential	Accomplishment as of		Percentage		Inc/(Dec)	
		March 31, 2014	Dec. 31, 2013	March 31, 2014	Dec. 31, 2013	Number	%
Municipalities	1,475	1,475	1,475	100%	100%	-	-
Barangays	36,063	36,052	36,052	99.97%	99.97%	-	-
Sitios/Puroks	103,489	85,797	83,994	82.90%	81.16%	1,803	2.15%
Connections	12,858,700	10,288,658	10,152,834	80.01%	78.96%	135,824	1.05%

Table 2: Status of Energization Philippines, 1st quarter 2014, National Electrification Administration[70]

[66] International Energy Agency: World Energy Outlook 2012
[67] Barangays, which are under the administrative supervision of cities and municipalities, are the lowest level of political unit of government in the Philippines and can sometimes be subdivided into sitios in rural areas: http://en.wikipedia.org/wiki/Administrative_divisions_of_the_Philippines
[68] National Electrification Administration, Status of Energization, http://www.nea.gov.ph/status-of-energization/category/71-2014-month
[69] Department of Energy, Department Circular No. 2013-07- 12 Rules and Regulations to Implement Republic Act No. 10531, https://www.doe.gov.ph/doe_files/pdf/announcements/NEA_IRR_Circular_Form.pdf
[70] Table 2: Status of Energization Philippines, 1st quarter 2014, National Electrification Administration, Compliance Report on Performance of ECs 1st Quarter 2014

2.3.1. Generation and Distribution

2.3.1.1. Installed Capacity in MW

In the year 2012 a total of 17,025 MW of installed capacity was recorded in the Philippines with the major part of the installed capacity or 33% being based on coal (5,568 MW) followed by hydro at 21% (3,521 MW) and oil at 18% (3,074 MW). Other new and renewable energy (NRE) sources such as wind, solar and biomass only account for 0.9% of total installed capacity or 153 MW. However, the statistics prove that in relative terms the proportion of other NRE sources has risen by impressive 31% from 2011 to 2012 (Table 3: Installed Capacity in MW).[71]

Installed Capacity in MW				
	2011	2012	Change in % 2011-2012	Total capacity share in % - 2012
Oil based	2,994	3,074	2.67	18.06
Hydro	3,491	3,521	0.86	20.68
Geothermal	1,783	1,848	3.65	10.85
Coal	4,917	5,568	13.24	32.70
New Renewables	**117**	**153**	**30.77**	**0.90**
Natural Gas	2,861	2,862	0.03	16.81
TOTAL CAPACITY	**16,162**	**17,025**	**5.34**	**100**

Table 3: Installed Capacity in MW, Department of Energy[72]

[71] Department of Energy: Philippine Power Statistics, Installed Generation Capacity in MW https://www.doe.gov.ph/doe_files/pdf/02_Energy_Statistics/Power-Statistics-2012.pdf

[72] Table 3: Installed Capacity in MW, Installed Generation Capacity in MW Department of Energy, Philippine Power Statistics, https://www.doe.gov.ph/doe_files/pdf/02_Energy_Statistics/Power-Statistics-2012.pdf

2.3.1.2. Gross Power Generation by Plant Type in MWh

As shown in table 3 depicted above new and renewable energy sources like wind, solar and biomass constitute a negligible portion of total installed capacity and gross power generation in the Philippines. In 2012 only 0.25% of power was generated through biomass plants, 0.10% by wind power plants, and less than 0.01% by solar plants.

Gross Power Generation by Plant Type in MWh				
	2011	2012	Change in % 2011-2012	2012 Total capacity share in % - 2012
Coal	25,342,176	28,264,867	11.53	38.76
Oil-based	3,397,599	4,254,015	25.21	5.83
Combined Cycle	123,556	227,354	84.01	0.31
Diesel	2,762,331	3,332,081	20.63	4.57
Gas Turbine	0	0	0.00	0.00
Oil	511,712	694,580	35.74	0.95
Natural Gas	20,591,323	19,641,527	-4.61	26.93
Geothermal	9,942,330	10,249,990	3.09	14.06
Hydro	9,697,532	10,252,134	5.72	14.06
Wind	**88,204**	**75,339**	**-14.59**	**0.10**
Solar	**1,212**	**1,320**	**8.91**	**0.00**
Biomass	**115,274**	**182,819**	**58.60**	**0.25**
TOTAL GENERATION	**69,175,650**	**72,922,011**	**5.42**	**100**

Table 4: Gross Power Generation by Plant Type, Department of Energy[73]

2.3.1.3. Gross Power Generation by Ownership in MWh

The power plants in the Philippines are owned by three distinct groups: the private independent power producers (IPPs), NPC-owned IPPs and NPC/NPC-SPUG. The private IPPs provide 79% of the total power production in the Philippines, while NPC-owned IPPs provide around 13%. The rest is covered by NPC and NPC-SPUG through small islands and isolated grids. NPC-SPUG, which has the obligation to provide electricity in small islands and isolated grids, only accounts for 0,64% of total power production. As can be seen from

[73] Table 4: Gross Power Generation by Plant Type, Department of Energy, Philippine Power Statistics, https://www.doe.gov.ph/doe_files/pdf/02_Energy_Statistics/Power-Statistics-2012.pdf

the table below, power generation by NPC-SPUG has decreased by 14% between 2011 and 2012 which is most likely due to the privatization of NPC-SPUG's power plants.[74]

Gross Power Generation by Ownership in MWh				
	2011	2012	Change in % 2011-2012	2012 Total capacity share in % - 2012
NPC	5,141,747	5,241,101	1.93	7.19
NPC-SPUG	542,874	466,129	-14.14	0.64
NPC-IPP	9,535,783	9,874,848	3.56	13.54
Non-NPC	53,955,245	57,339,934	6.27	78.63
TOTAL GENERATION	**69,175,650**	**72,922,011**	**5.42**	**100**

NPC includes generation from power plants owned by NPC
NPC-SPUG includes generation from power plants owned by NPC and operating in off-grid areas
NPC-IPP includes generation of IPP's with contract to NPC
Non-NPC includes generation of IPPs to customers (e.g private DU's, EC's) other than NPC

Table 5: Gross Power Generation by Ownership in MWh, Department of Energy[75]

Table 6 shows the installed capacity for 2012 by ownership. Non-NPC power providers amount for the highest contribution of 12,784 MW. Non-NPC pover providers would include independent power producers (IPPs) like private investor owned utilities (PIOUs), local government units (LGUs), and electric cooperatives.

2012 Installed Capacity by Ownership in MW	
NPC	1,356
NPC - IPP	2,885
Non-NPC	12,784
TOTAL	**17,025**

Table 6: 2012 Installed Capacity by Ownership in MW, Department of Energy[76]

2.3.1.4. Distribution of Power

Electricity distribution in the Philippines is done by distribution utilities (DUs) that distribute electricity to end-users. Distribution utilities refer to private corporations, electric cooperatives (ECs), government-owned utilities or local government owned utilities (LGUs) which have an

[74] Gross Power Generation by Ownership in MWh, Department of Energy, Philippine Power Statistics, https://www.doe.gov.ph/doe_files/pdf/02_Energy_Statistics/Power-Statistics-2012.pdf
[75] Table 5: Gross Power Generation by Ownership in MWh, Department of Energy, Philippine Power Statistics, https://www.doe.gov.ph/doe_files/pdf/02_Energy_Statistics/Power-Statistics-2012.pdf
[76] Table 6: 2012 Installed Capacity by Ownership in MW, Department of Energy, https://www.doe.gov.ph/doe_files/pdf/01_Energy_Situationer/2012-Power-Plants-Ownership.pdf

exclusive franchise area to operate a distribution system.[77] According to a study published by University of the Philippines - College of Business Administration, as of 2006, 144 DUs are active in the Philippines of which 16 are private investor owned utilities (PIOUs), 8 are local government units (LGUs) and 119[78] customer-owned electric cooperatives (ECs).[79] Out of the 119 ECs around 40[80] operate in islands and off-grid areas. The majority of ECs are under the supervison of the National Electrification Administration, while four opted to register under the supervision of the Cooperative Development Authority (CDA).[81]

According to the Electricity Power Industry Reform Act of 2001 (EPIRA), the Distribution Utilities (DUs) have the obligation to provide services within their franchise areas, including unviable areas as part of its social obligation. In the event DUs are not able to electrify all barangays, the remaining unelectrified areas shall be opened to other DUs or qualified third parties.[82] [83]

2.3.2. Legal Framework

The Electric Power Industry Reform Act of 2001, the Renewable Energy (RE) Act of 2008 and the National Electrification Administration Reform Act of 2013 are the major laws dealing with policy and electrification of the country. This section will elaborate on the respective agencies and policies for electrification and more specifically describe the legal framework and regulations applicable in the off-grid space.

2.3.2.1. Electric Power Industry Reform Act of 2001 (EPIRA)

Along with the Renewable Energy (RE) Act of 2008, EPIRA is the major law that governs the power industry in the Philippines including off-grid renewable energy development. EPIRA basically set the stage for reforms in the Philippine power sector, specifically mandating the privatization of the sector and deregulation of the industry.[84] The broad objectives of the

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[77] Energy Regulatory Commission: Distribution Sector: http://www.erc.gov.ph/Distribution/Distribution
[78] National Electrification Administration, About us, http://www.nea.gov.ph/about-us/10-continue-from-about-us
[79] . Valderrama Helena Agnes S, Carlos C. Bautista, College of Business Administration, University of Philippines, “Efficiency Analysis of Electric Cooperatives in the Philippines”, September 2009
[80] National Power Corporation Small Power Utilities Group, SPUG OPERATIONS as of December 2012, http://www.spug.ph/about.asp
[81] Cooperative Development Authority: Statistics as of December 31, 2014, http://www.cda.gov.ph/index.php/resources/updates/statistics/264-statistics-as-of-december-31-2013
[82] Department of Energy, Expanded Rural Electrification, https://www.doe.gov.ph/power-and-electrification/expanded-rural-electrification
[83] Electricity Power Reform Act of 2001: Section 23, http://www.neda.gov.ph/wp-content/uploads/2013/12/R.A.-9136.pdf
[84] Asian Development Bank: Technical Assistance Consultant Report - Republic of the Philippines, Rural Community based Renewable Energy Development in Mindanao (TA-7781-PHI), p. 9, 13

government are (i) to ensure the quality, reliability, security and affordability of the electric power supply (ii) to ensure transparent and reasonable prices of electricity (iii) to enhance the flow of private capital and broaden the ownership base of the power generation, transmission and distributions sectors (iv) to promote the utilization of indigenous and new and renewable energy resources in power generation in order to reduce dependance on imported energy and (v) to provide for transparent privatization of the assets and liabilities of the National Power Corporation (NPC).[85]

The National Power Corporation through its Small Powers Utilties Group is responsible for missionary electrification and therefore in charge of provision of power generation and its associated power delivery systems in areas that are not connected to the grid. Missionary electrification is funded by the revenues from sales in the missionary areas as well as from the Universal Charge for Missionary Electrification (UCME), a subsidy, that is collected from all electricity end-consumers.[86] The UCME, which is regulated and set by the Energy Regulatory Commission, serves to cover the cost differential between the sales revenues on the one hand and operating and capital expense for expansion, rehabilitation and facilities for new areas that are developed based on the DOE's approved Missionary Electrification Development Plan (MEDP), on the other hand.[87] [88]

Large amounts of subsidy need to be allocated by the government for SPUG operations as they cannot appropriately charge the end-users with the true cost of generation.[89] Reason for the high generation costs include the logistical difficulties and high cost of providing fuel in the dispersed geographical locations of SPUG plants.[90]

DUs have an exclusive franchise to operate a distribution system, with the obligation to provide distribution service to all end-users within its franchise area. In remote and unviable villages that the franchised utility is unable to serve, EPIRA provides for the opening-up of these areas to Qualified Third Parties (QTP) to generate and distribute power.[91] [92] QTPs are

[85] Rules and Regulations to Implement Republic Act No. 9136, entitled "Electric Power Industry Reform Act of 2001", http://www.lawphil.net/statutes/repacts/ra2001/ra_9136irr_2001.pdf
[86] Electricity Power Reform Act of 2001, Section 70
[87] Rules and Regulations to implement Republic Act No. 9136, entitled "Electric Power Industry Reform Act of 2001", http://www.lawphil.net/statutes/repacts/ra2001/ra_9136irr_2001.pdf
[88] National Power Corporation-Small Powers Utilities Group , Universal Charge for Missionary Electrification, http://www.spug.ph/ucme_background.asp
[89] National Power Corporation-Small Powers Utilities Group, Historical Background, http://www.spug.ph/history.asp
[90] Ibid
[91] Electricity Power Reform Act of 2001, Chapter 1, SEC. 4 Definition of Term, http://www.neda.gov.ph/wp-content/uploads/2013/12/R.A.-9136.pdf
[92] Ibid

entitled to build, own, generate and distribute power in remote, “missionary areas“.[93] Once every year the Department of Energy issues a list of remote and unviable areas that cannot be served by a distribution utility and which shall be opened for qualified third parties. Such an entity could be an NGO, a private sector company, EC subsidiary or another entity that meets the qualification criteria set by DOE and ERC.[94] The criteria may include financial, technical, environmental, and other performance indicators, but preference is given to those which utilize least-cost new and renewable energy resources to provide electricity.

In order to provide electric services in an unviable area, ERC requires that the QTP enters into a contract with the distribution utility that waives to provide electricity in that unviable area. The QTP acquires the right to recover the cost of generation and distribution by availing the Universal Charge. In the areas covered by the QTP, ERC will set the rules for computation and determination of rates and tariffs to be applied. The subsidy shall be pay directly a portion of the cost of power used by the consumers.[95]

2.3.2.2. Renewable Energy (RE) Act of 2008

RE Act of 2008 stipulates that it is a policy of the State to (i) accelerate the exploration and development of renewable energy resources such as but not limited to biomass, solar, wind, hydro, geothermal and ocean energy sources, including hybrid systems, to achieve energy self-reliance and reduce the country's dependence on fossil fuels and thereby minimize the country's exposure to price fluctuations in the international markets, to (ii) increase the utilization of renewable energy and promote its efficient and cost-effective commercial application by providing fiscal and nonfiscal incentives, to (iii) encourage the development and utilization of renewable energy resources to prevent or reduce harmful emissions and to (vi) establish the necessary infrastructure and mechanism to carry out this mandate.[96]

The Act also introduces a Feed-In Tariff (FIT) system for electricity produced from wind, solar, ocean, run-of-river hydropower and biomass.[97] ERC in consultation with the National Renewable Energy Board (NREB) shall formulate and promulgate FIT rules which include (i) (a) priority connections to the grid for electricity generated from emerging renewable energy

[93] Asian Development Bank: Technical Assistance Consultant Report - Republic of the Philippines, Rural Community based Renewable Energy Development in Mindanao (TA-7781-PHI), p. 13
[94] Ibid
[95] Rules and Regulations to Implement Republic Act No. 9136, entitled “Electric Power Industry Reform Act of 2001”, http://www.lawphil.net/statutes/repacts/ra2001/ra_9136irr_2001.pdf
[96] Department of Energy, The Renewable Energy Act of 200 (RE Act), Section 2, https://www.doe.gov.ph/issuances/republic-act/627-ra-9513
[97] Department of Energy, The Renewable Energy Act of 200 (RE Act), Section 7, https://www.doe.gov.ph/issuances/republic-act/627-ra-9513

resources such as wind, solar, ocean, run-of-river hydropower and biomass power plants, (ii) the priority purchase and transmission of, and payment for, such electricity and (iii) the determination of fixed tariffs for electricity produced by renewable energy for a mandated number of years, which shall not be less than twelve years.[98] Net-metering is also being introduced by this act obliging distribution utilities to enter into net-metering agreements with qualified end-users who install RE systems.[99]

Section 12 of the RE Act specifically deals with off-grid renewable energy development obliging NPC-SPUG or qualified third parties serving off-grid areas to source a minimum percentage of its annual generation from available RE sources as determined by DOE.[100]

The law also provides incentives to promote the use or RE like (i) income tax holiday for seven years of commercial operations, (ii) duty-free Importation of RE machinery, equipment and materials, (iii) accelerated depreciation, (vi) zero VAT on purchase of local supply of goods, properties and services, for the development, construction and installation of its plant facilities and (v) cash incentives for RE developers for missionary electrification, i.e. cash generation-based incentive per kilowatt hour rate generated, equivalent to fifty percent (50%) of the universal charge for power needed to service missionary areas.[101] Those incentives are also available for RE developers of hybrid and cogeneration systems utilizing RE sources and conventional energy, but are only applicable for the equipment uilizing RE resources.[102]

Under the financial assistance program, government financial institutions like Development Bank of the Philippines (DBP), Land Bank of the Philippines (LBP), the Phil-Exim Bank and others should, to the extent possible, provide preferential financial packages for the development, utilization and commercialization of RE projects.[103]

It is not only the RE developers who benefit from the incentive schemes under this law. Communities/LGUs which are hosting energy plants are entitled to receive 80% of the share from royalty and/or from RE projects which can be used directly to subsidize the electricity consumption of end users in the RE host communities/LGUs; the scheme is available for those host communities/LGUs whose monthly consumption does not exceed 100 kWh.[104]

[98] Ibid
[99] Department of Energy, The Renewable Energy Act of 200 (RE Act), Section 10, https://www.doe.gov.ph/issuances/republic-act/627-ra-9513
[100] Department of Energy, The Renewable Energy Act of 200 (RE Act), Section 12
[101] Department of Energy, The Renewable Energy Act of 200 (RE Act), Section 15
[102] Department of Energy, The Renewable Energy Act of 200 (RE Act), Section 19
[103] Department of Energy, The Renewable Energy Act of 200 (RE Act), Section 29
[104] Department of Energy, The Renewable Energy Act of 200 (RE Act), Section 31

2.3.2.3. National Electrification Administration Reform Act of 2013

The National Electrification Administration Reform Act 2013 lays down the powers, functions and privileges of NEA and the regulates the supervisory and oversight functions of the NEA over the ECs. The act stipulates also the mandates, powers, functions and privileges of the ECs. Through the act electric cooperatives, which traditionally have been engaged only in distribution of electricity, have been empowered to also engage in power generation within their franchise areas. It also gives the ECs the right to acquire existing generation facilities which are privately or government owned or they can also participate in a bid on an existing NPC-SPUG generating facility to acquire and start generating electricity. In Rule VI (Total Electrification) NEA and the ECs are mandated to electrify all remaining unelectrified households.[105]

2.3.3. Key Stakeholders in Rural Electrification

Various government agencies are involved in the formulation and implementation of rural electrification in the Philippines. The Department of Energy (DOE), Energy Regulatory Commission (ERC), National Power Corporation – Small Power Utilities Group (NPC-SPUG) and the National Electrification Administration (NEA) are the main policy and regulatory agencies governing the Philippine power sector.

2.3.3.1. Department of Energy

The Department of Energy (DOE) is mandated by the Republic Act 7638 to prepare, oversee and supervise all programs, projects and activities of the Government related to energy exploration, development, utilization, distribution and conservation.[106] DOE approves - on a yearly basis - the Missionary Electrification Development Plan, which declares that unviable areas shall be opened to Qualified Third Parties (QTP). Details on the QTP scheme are being elaborated on in the section on the Electric Power Industry Reform Act of 2001 (EPIRA).

[105] Department of Energy (DOE), National Electrification Administration Refor Act of 2013, Department Circular No. DC 2013-07-0015, Rule III, The Electric Cooperatives, Rule VI Total Electrification, www.nea.gov.ph/ao39/ra-10531/
[106] Department of Energy, Mandate/Mission/Vision, https://www.doe.gov.ph/about-doe/what-we-do/mandate-mission-vision

2.3.3.2. National Electrification Administration

The National Electrification Administration (NEA) is a government-owned and controlled corporation with borrowing authority and corporate powers. Its major mandate is to achieve total rural electrification of the country on an area coverage basis, in the most effective and efficient manner by working with, overseeing and providing financial, institutional and technical services to Electric Cooperatives (ECs).[107] [108] ECs, which are distribution utilities have been given the national franchise to distribute electric power to all end-users in the country side.[109] ECs are small not-for-profit entities owned and controlled by locally elected boards and member consumers. Currently 119 ECs operate under the supervision of NEA, whereby 40 of those operate in islands and off-grid areas.[110]

2.3.3.3. Energy Regulatory Commission

The Energy Regulatory Commission (ERC) was established with the enactment of the Electric Power Industry Reform Act (EPIRA) of 2001. It is an independent regulatory body performing the combined quasi-judicial, quasi-legislative and administrative functions in the electric industry and has a two-fold mandate ensuring education and protection of consumers on the one hand and promotion of competitive operations in the electricity market on the other hand.[111] Consumers are protected in terms of quality and reliability and also with regard to reasonable pricing of electricity. Its powers and functions comprise among others the (i) determination and approval of retail rates that promote efficiency and non-discrimination (ii) setting lifeline rates for marginalized end-users (iii) review of power purchase contracts between the Independent Power Producers (IPPs) and NPC, including the distribution utilities (iv) determination, fixing and approval of a universal charge to be imposed on all electricity end-users.[112]

2.3.3.4. National Power Corporation-Small Powers Utilities Group

The National Power Corporation through its Small Power Utilities Group (NPC-SPUG) performs the missionary electrification function, being therefore responsible for generation and its associated power delivery systems in areas that are not connected to the

[107] National Electrification Administration, About us, http://www.nea.gov.ph/about-us
[108] Presidential Decree No. 269 (PD269), Office of the President of the Philippines, 1973
[109] Republic Act No. 9136: Electric power Industry Reform Act of 2001
[110] Asian Development Bank: Technical Assistance Consultant Report - Republic of the Philippines, Rural Community based Renewable Energy Development in Mindanao (TA-7781-PHI), p. 3
[111] Energy Regulatory Commission: Brief History of Energy Regulation, http://www.erc.gov.ph/Pages/history
[112] Energy Regulatory Commission: Our Mission, http://www.erc.gov.ph/Pages/Mandates-and-Functions

transmission system, especially non-electrified island/isolated villages.[113] As the power provider of last resort, it serves areas that are not serviced by DUs and other QTPs.[114] SPUG operations are heavily subsidized as the true cost of generation is much higher than the rate that can be charged to the end-user in those rural areas.[115] According to the law NPC-SPUG is mandated to privatize its power generation facilities and associated power delivery systems. NPC may generate and sell electricity from its existing generating assets but is not allowed to incur any new obligations to purchase power through bilateral contracts with generation companies or other suppliers.[116]

SPUG has been providing electric service to 770,862 households in 231 areas nationwide through the operation of 116 land-based diesel power plants, 9 power barges, 17 mini-grids, 154 micro grids, 1 grid-connected wind plant and 1 mini-hydro plant. It is also providing electricity services to 5,129 households in remote areas using solar photovoltaic systems.[117]

2.3.3.5. Power Sector Assets & Liabilities Management Corporation

Power Sector Assets and Liabilities Management Corporation (PSALM Corp.), which has been in existence since 2001, is in charge of taking ownership, managing, privatizing and disposing of generation and other assets of the National Power Corporation, including transmission assets. One of its functions is to conduct due diligence on its assets to determine the readiness for privatization. PSALM is also responsible for the collection of the Universal Charge (UC) that is collected from all electric consumers and used to finance the missionary electrification activities of the government.[118]

2.3.4. Off-Grid Electrification Policies

As rural electrification is one of the top priorities of the government to alleviate poverty, in 1999 the Accelerated Barangay Electrification Program (ABEP) was launched with the DOE,

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[113] Electric Power Industry Reform Act of 2001, Section 70
[114] National Power Corporation, Missionary Electrification, http://www.napocor.gov.ph/index.php/spug
[115] National Power Corporation-Small Powers Utilities Group, Historical Background, http://www.spug.ph/history.asp
[116] Rules and Regulations to implement Republic Act No. 9136, entitled “Electric Power Industry Reform Act of 2001”, Rule 13. Missionary Electrification http://www.lawphil.net/statutes/repacts/ra2001/ra_9136irr_2001.pdf
[117] National Power Corporation, Missionary Electrification, http://www.napocor.gov.ph/index.php/spug
[118] Imageinet International Inc., 2.5 Private Sector Assets and Liabilities Management Corporation (PSALM) http://www.imaginet.com.ph/25-private-sector-assets-and-liabilities-management-corporation-psalm

NEA and NPC-SPUG, partnering up to increase access to electricity in the un-electrified areas.[119]

In 2003 the Expanded Rural Electrification Program (ER Program) was established to focus not only on electrification of barangays but more specifically also on sitios and households, with the goal of achieving 100% barangay electrification by 2008 and 90% household electrification by 2017.[120] The graph below depicts the anticipated electrification rate to reach 90% household electrification until 2017.

Figure 2: Total Electrification Philippines, National Electrification Administration[121]

To implement the Sitio Electrification Plan (SEP) in 2011 a yearly allocation, amounting to at least PHP 2 billion (appr. USD 45,926,130)[122] provided by the government to achieve full electrification of all sitios until 2015, has been approved by the government.[123] In the graph below the expected yearly increase of the electrification rate is described reaching 100% by 2015. In addition the Barangay Line Enhancement Program (BLEP) was put in place. In

[119] Department of Energy, Expanded Rural Electrification, https://www.doe.gov.ph/power-and-electrification/expanded-rural-electrification
[120] Department of Energy, https://www.doe.gov.ph/power-and-electrification/expanded-rural-electrification
[121] Figure 2: Total Electrification Philippines, National Electrification Administration, Status of Energization, Compliance Report on Performance of ECs 1st Quarter 2014, http://www.nea.gov.ph/compliance-report-on-performance-of-ecs-1st-qtr-2014
[122] FX-Rate September 6, 2014: 1 PHP = USD 0.023
[123] National Electrification Administration, Sitio Electrification gets PNoy nod, http://www.nea.gov.ph/news/155-sitio-electrification-gets-pnoy-nod

2013, PHP 3.8 billion (appr. USD 87,259,650)[124] was allocated for electrification of sitios under the SEP of which around PHP 1 billion (appr. USD 22,963,070)[125] was earmarked for the Barangay Line Enhancement Program. Those barangays, previously energized through new and renewable energy sources such as individual solar systems and solar lanterns, will be connected to the grid.[126]

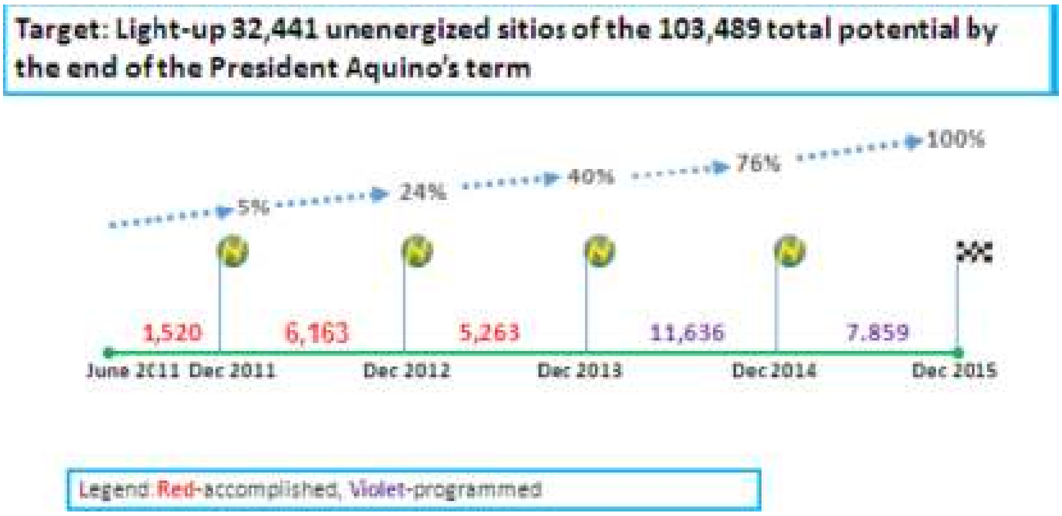

Figure 3: Roadmap Sitio Electrification Program, National Electrification Administration[127]

The graph below depicts the amount of subsidy granted by the national government from 1992 to 2013 clearly showing the stark increase in the overall expense for electrification between 2011 and 2013. Overall twice as much subsidy has been granted compared to the 18 years before.

[124] FX-Rate September 6, 2014: 1 PHP = USD 0.023
[125] Ibid
[126] National Electrification Administration, NEA lends Php2.68B to power coops, http://www.nea.gov.ph/news/266-nea-lends-php268b-to-power-coops
[127] Figure 3: Roadmap Sitio Electrification Program, National Electrification Administration, Status of Energization, Compliance Report on Performance of ECs 1st Quarter 2014, http://www.nea.gov.ph/compliance-report-on-performance-of-ecs-1st-qtr-2014

Figure 4: Electrification Subsidy Received from National Government, National Electrification Administration[128]

2.3.5. Business Models for Electrification in Off-Grid Areas

Ownership is one of the main criteria to differentiate business models in rural electrification. According to this typology different models are available with the Community-Based Electrification Model, Private Sector-based Electrification Model, Utility-based Model and Hybrid Business Models as the most prominent ones. For the implementation of electrification projects in off-grid areas in the Philippines those models will be elaborated on in more detail, specifically taking into account the legal framework and sub-models developed in the Philippines.

2.3.5.1. Community-Based Electrification Model

Community based mini-grid systems are mostly implemented in isolated areas were a system can not be run commercially viable and therefore does not attract investment of the private sector or public utilities. In this model the community becomes the owner of the system and is responsible for its operation, mainenance, tariff collection and management of services. What makes this model unique is that the owners and managers in a cooperative or community-based organization are also the consumers which gives them the pressure to provide reliable and quality service. One of the challenges that come with the model is that the local communities usually lack the technical and financial expertise to design, install and maintain a system in order to develop a sustainable and commercially viable business plan. Capacity building measures should be extended to these local institutions to equip them with

[128] Figure 4: Electrification Subsidy Received from National Government, National Electrification Administration, Status of Energization, Compliance Report on Performance of ECs 1st Quarter 2014, http://www.nea.gov.ph/compliance-report-on-performance-of-ecs-1st-qtr-2014

adequate technical, financial and operatonal skills. Apart from capacity building, it might be beneficial and more efficient to involve a private or public entity to take care of the specialized technical or financial aspects of the undertaking. The main advantage of this model is the buy-in and support of the local community enabling a long-term sustainable operation.[129]

In the Philippines, this model has been applied in one of the technical assistance projects of ADB. The RENEW Negros project organized a community into a local co-operative to execute the construction of a micro-hydro plant. The co-operative was trained to operate and manage the power generation and distribution system. [130]

2.3.5.2. Utility-Based Model

A public utility is defined as "*a business organization (as an electric company) performing a public service and being subject to special governmental regulation*".[131] The main advantage of rural electrification through public utilities lies in the fact that utilities are experienced in electrification projects and usually have the technical and financial means to successfully implement and manage them. Due to their public or quasi-public status they might have a privileged legal position as well as facilitated access to financing. Budgetary constraints and increasing liberalization on the other hand might lead utilities on the contrary to focus more on profitable undertakings than on expanding services to remote, low revenue mini-grids. Another challenge might also be that without inclusion of the local community and the end-consumer, local circumstances might not be taken into account appropriately. Therefore the project might potentially get rejected by the local community.[132]

In the Philippines NPC-SPUG is mandated by law to act as power provider of last resort for areas not serviced by DUs and other QTPs. This model is used on a large scale in the Philippines, with NPC-SPUG currently operating diesel-generator powered generation plants in 233 island grids. NPC-SPUG is the primary power generator in small islands and isolated grids (SIIGs) with a total generation of 463 GWh.[133] The produced electricity is distributed to the end-consumer by the local electric cooperative (EC).

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[129] Alliance for Rural Electrification: Hybrid Mini-Grids for Rural Electrification: Lessons Learned, p. 21, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf

[130] Asian Development Bank: Technical Assistance Consultant Report - Republic of the Philippines, Rural Community based Renewable Energy Development in Mindanao (TA-7781-PHI), p. 29

[131] Merriam Webster, definition public utility, http://www.merriam-webster.com/dictionary/public%20utility

[132] Alliance for Rural Electrification: Hybrid Mini-Grids for rural electrification: lessons learned, p. 28, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf

[133] Department of Energy, 2012-2016 Missionary Electrification Development Plan

2.3.5.3. Private Sector-based Model

Private sector-led mini-grids can take different forms according to the ownership of the system, whether the contracting partner is the end-consumer or a utility or whether subsidy support is involved or not. There are several advantages of the private sector-based model - it supposedly delivers electricity services more efficiently, reliably and at lower cost. In addition the main concern of rural electrification projects, namely sustainable operation and maintenance of the mini-grid can be addressed more appropriately by this model as the private sector company is supposed to have the technical capability to address urgent problems. Apart from the technical side, the private sector also has the investment capacity and financial strength to finance operations in rural areas. Due to the limited affordability in some remote rural areas, commercially viable and profitable operations might not be possible. As such public financial support is crucial to create the incentives for private sector companies to implement rural electrification projects.[134]

In the Philippines the government has created the legal basis for private sector companies to become power producers through the New Power Providers (NPP) scheme. In order to qualify as NPP a competitive selection process has to be gone through where the company proposing the lowest true generation costs will be selected to serve the predetermined area. The scheme is framed by a 15 years concession agreement and anchored by a power supply agreement (PSA) with the electric cooperatives. The NPPs basically have two sources of income to make their operations commercially viable, on the one hand they receive the "Subsidized Acceptable Generation Rate" (SAGR) from the cooperatives under the PSA. On the other hand they receive an output-based aid subsidy from the PSALM Corp., which covers the difference between the true generation costs and the price paid by the end-users.[135] Currently nine New Power Providers (NPPs) operate plants in off-grid areas in the Philippines.[136] The graph below depicts in detail the scheme available for New Power Providers (NPP).

(2012 MEDP), http://www.spug.ph/2012%20MEDP.pdf

[134] Alliance for Rural Electrification: Hybrid Mini-Grids for rural electrification: lessons learned, p. 26, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf

[135] Ibid, p. 25

[136] Department of Energy, EU SWITCH-Asia Program, GIZ, Dialogue Forum on Integration of Renewable Energies in the Philippine Off-grid Areas, October 28, 2014

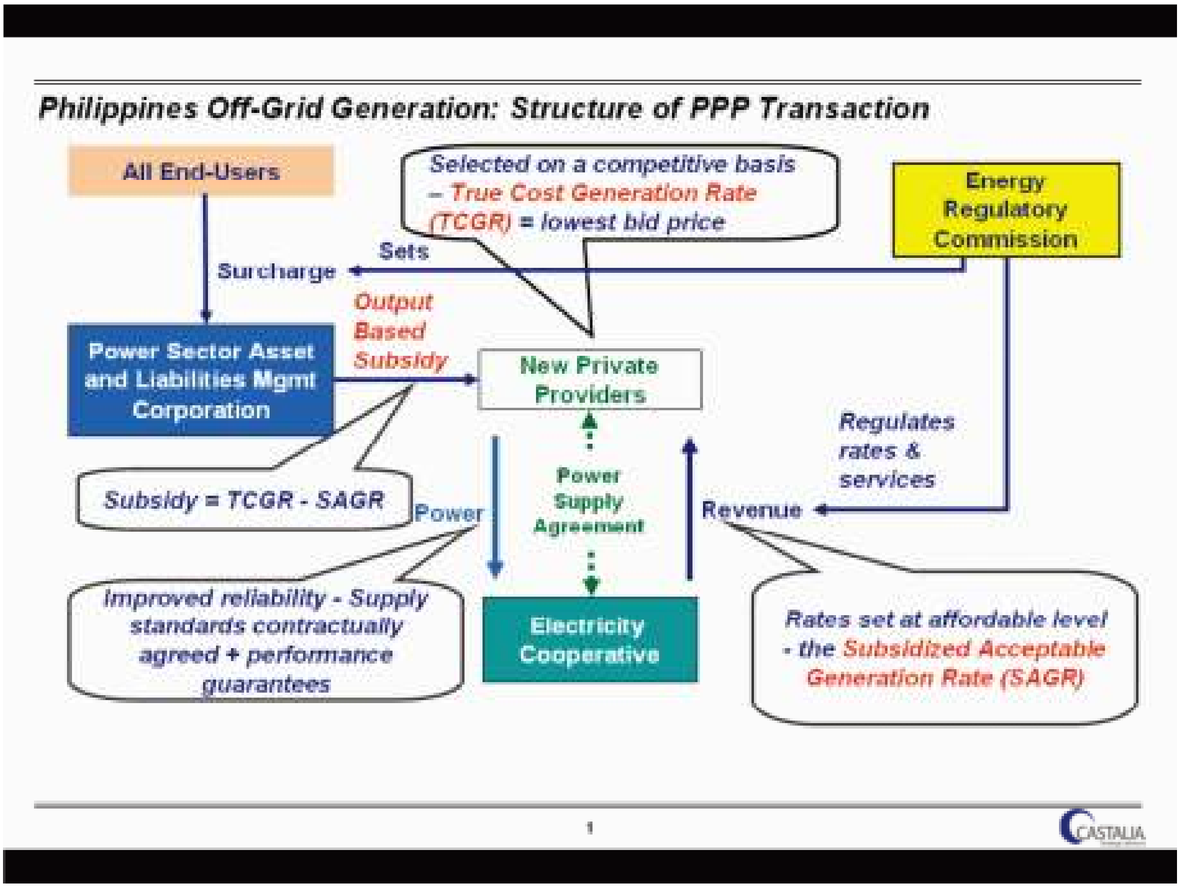

Figure 5: Hybrid Mini-Grids for Rural Electrification, PPP transactions in the SPUG projects, Philippines[137]

Qualified Third Party Model

Since the Electric Power Industry Reform Act of 2001 (EPIRA), unviable areas have been opened up to Qualified Third Parties (QTPs) allowing them to build, own and operate not only power generation plants but also the associated distribution lines. QTPs are qualified to generate and distribute electricity but also to collect payments from the end-user.[138] The QTP scheme is elaborated on in more detail in the chapter “Legal Framework“, specifically in the section that deals with the Electric Power Industry Reform Act of 2001 (EPIRA).

2.3.5.4. Hybrid Business Models

Hybrid business models combine different business model approaches, to take advantage of the strength of the individual model and to avoid or minimize their possible shortcomings. A

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137 Figure 5: Hybrid Mini-grids for Rural Electrification, PPP transactions in the SPUG projects, Philippines

138 Asian Development Bank: Technical Assistance Consultant Report - Republic of the Philippines, Rural Community based Renewable Energy Development in Mindanao (TA-7781-PHI), p. 25

hybrid approach with regard to ownership could be a structure where one partner owns the grid or the immovable assets and one partner the generation facility.

The partnering entities could also be a utility or a private company that implements and owns a renewable energy mini-grid power system, a community-based entity that manages the system on a daily basis and a private company that provides the technical back-up and management advice. The strength of the model lies in the technical expertise and experience of the utility. In addition, it might benefit from economies of scale in the realization of infrastructure works, e.g. transmission grids. The collaboration combines the advantages of involvement and buy-in of the community with the financial investment, technical expertise and efficiency of a private company.[139]

Another approach under the hybrid business model is the collaboration between the national state-owned utility and local distribution entities. The generation facilities and the transmission grid is owned by the utility and the power is sold at a wholesale rate to local distribution entities, which could be private operators cooperatives or affiliates of the national utility. The scheme can bring cost savings for the utilities as they can make use of the expertise and local knowledge of the local cooperative or private sector company.[140] This model is also used in the Philippines where the state-owned utility, NPC owns the generation facilities and ECs are responsible for the distribution of the electricity.

A model that also has been used in the Philippines is the involvement of LGUs in rural electrification. The funding provided by the local congressional representative is used to purchase small diesel generators. LGU hires operators to run the generation facility for use in LGU facilities or also for provision of power to nearby households. The advantage of such a model is the quicker access to financing, as municipal LGUs usually have easier access to funds as compared to barangay LGUs. The Development Bank of the Philippines offers a special window for LGUs to develop projects, including electrification projects.[141]

Another model in use in the Philippines is the Electric Cooperatives-Based Model, where electric cooperatives, that are owned by the communities but are legally considered private entities, increasingly start producing their own power**.** Traditionally electric cooperatives in the Philippines were permitted to only distribute electricity that they had mainly purchased

[139] Alliance for Rural Electrification: Hybrid Mini-Grids for Rural Electrification: Lessons Learned, p. 28, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf
[140] Ibid
[141] Asian Development Bank: Technical Assistance Consultant Report - Republic of the Philippines, Rural Community based Renewable Energy Development in Mindanao (TA-7781-PHI), p. 27

from NPC. The National Electrification Administration Reform Act 2013 explicitly allows cooperatives to engage in power generation within their franchise areas. This shall contribute to greater efficiency and lower cost of operations. ECs may engage in power generation through either constructing generation facilities themselves or by acquiring existing NPC-SPUG generation facilities.[142]

[142] Department of Energy (DOE), National Electrification Administration Refor Act of 2013, Department Circular No. DC 2013-07-0015, Rule III, The Electric Cooperatives, www.nea.gov.ph/ao39/ra-10531/

3. THEORETICAL FOUNDATIONS

3.1. Renewable Energy Technologies

This subchapter gives a brief overview of selected renewable energy technologies, specifically solar, wind and biomass, as those will are technologies used in the case study.

3.1.1. Solar

The photo-electric-effect was discovered in 1839 by the French physicist Alexandre Edmond Bequerel. When sunlight hits a photovoltaic (PV) cell, the cell absorbs some of the photons and the photons' energy is transferred to an electron in the semiconductor material, i.e. photovoltaic materials and devices convert sunlight into direct-current electrical energy. [143].[144] [145]

The nominal rated maximum (kWp) power output of a solar array of modules, is defined as:

$$kW_p = n \times W_p \ / \ 1000$$

kWp= peak nominal power (based on $1kW/m^2$ radiation)
n = number of panels
Wp = peak power of one panel

The available solar radiation (E_{ma}) varies depending on time of the year and weather conditions. The average PV system energy yield is estimated based on the average annual radiation for a specific location, incorporating the efficiency (η) of the cell into the formula: [146]

$$E_p = E_{ma} \times kW_p \times \eta$$

E_p = PV system energy yield
E_{ma} = available solar radiation
kWp = peak nominal power
η = efficiency

[143] Solar Electricity Basics, http://www.homepower.com/articles/solar-electricity/basics/what-solar-electricity
[144] MSc Renewable Energy in CEE, Module 3, Solar Energy – Solar Heaing & Photovoltaics, Fechner H., et al. (2012)
[145] U.S. Department of Energy, Photovoltaic Technology Basics, http://energy.gov/eere/energybasics/articles/photovoltaic-technology-basics
[146] My Electrical Engineering, Photovoltaic (PV) – Electrical Calculations, http://myelectrical.com/notes/entryid/225/photovoltaic-pv-electrical-calculations#myID1310032

The figure below depicts the typical configuration of a stand alone PV system with the major components being the PV-modules (solar panels), the charge controller, the inverter and a battery.

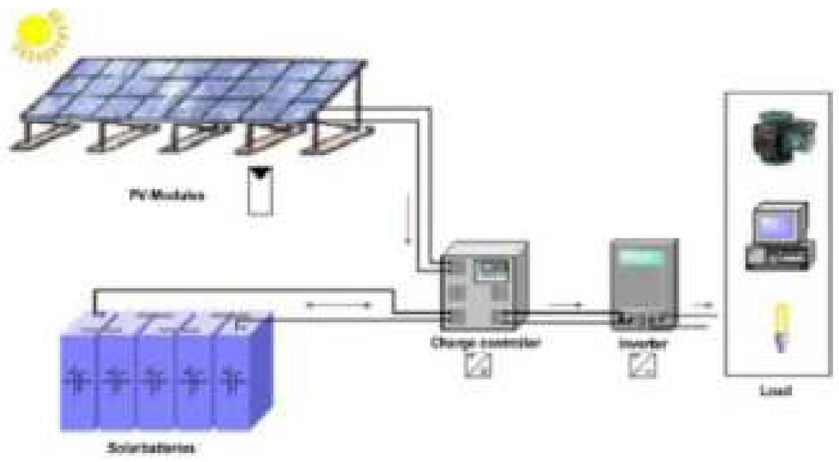

Figure 6: Stand-Alone PV System, Fechner H., et al., MSc Renewable Energy in CEE[147]

3.1.1.1. Solar Panel

A solar panel respectively solar module consists of a number of PV cells incorporated into a unit. Modules are rated according to their "peak" power (Wp) which is their output under standard testing conditions of 1000W/m^2 and 25 degrees Celcius.[148] Modules usually provide DC electricity at 12 or 24 volts.[149] The figure below exemplifies a polycristalline photovoltaic solar panel.

Figure 7: Polycristalline Photovoltaic Solar Panel, GOGREEN SYSTEMS[150]

147 Figure 6: Stand-alone PV System, Fechner H., et al., MSc Renewable Energy in CEE, Module 3, Solar Energy – Solar Heating & Photovoltaics, Fechner H., et al. (2012)
148 IEA, Task 9, Renewable Energy Services for Developing Countries, p. 11
149 Ibid
150 Figure 7: Polycristalline photovoltaic solar panel, GOGREEN SYSTEMS, http://www.gogreensystems.co.uk/esppage_2107318.html

In general, PV cells can be differentiated according to the material they are made of. The two main categories of PV cells used are either made from crystalline silicon or thin film. Although thin film technology is expected to expand its market share taking into account several inherent benefits like low material consumption, low weight and smooth visual appearance, currently crystalline silicone PV cells still dominate the market. This is due to the fact that the material is widely available, well understood and makes use of the same techology developed for the electronics industry.[151]

Crystalline silicon solar cells can be divided into mono crystalline silicon and poly crystalline cells. Commercial modules of mono crystalline silicon cells have a higher efficiency, reaching around 18% compared to commercially available poly crystalline silicon cells which have a lower efficiency of around 15%. The advantage of poly crystalline silicon cells is that they are less expensive than its mono crystalline counterpart.

Solar cell efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. It can be calculated by dividing a cell's power output (in watts) at its maximum power point (Pm) by the input light (E, in W/m^2) and the surface area of the solar cell (Ac in m^2).[152] [153]

$$\eta = \frac{P_m}{E \times A_c}$$

3.1.1.2. Inverter

The light of the sun absorbed by the PV panel generates direct current (DC). To inject electricity into the grid or to use most of electric applications an inverter is needed to convert the direct current (DC) electricity produced by the PV panel to alternating current.[154] Chapter 3.2.2. Hybrid – Diesel/ Renewable Energy Mini-Grids elaborates in more detail on AC and DC applications of mini-grids**.**

A solar power plant consists of several solar modules. The graph below describes different systems how modules can be connected to inverters, either by connecting each module to a

[151] MSc Renewable Energy in CEE, Module 3, Solar Energy – Solar Heaing & Photovoltaics, Solar Cells Fechner H., et al. (2012)
[152] PV education.org, Efficiency, http://pveducation.org/pvcdrom/solar-cell-operation/efficiency
[153] Wikipedia, Solar Cell Efficiency, http://en.wikipedia.org/wiki/Solar_cell_efficiency
[154] Solar Alaska, http://www.solaralaska.com/primer/ac_dc.htm

micro inverter or through string inverters.[155] For the use of the string inverter the PV plant is divided into several parallel strings which are assigned to a designated inverter. For the micro inverter, which is a module integrated inverter, one inverter is used for each module. This is usually used for smaller systems between 50-400 W.[156]

As can been seen in the graph below the main disadvantage of the string inverter system is that power output can be affected by shading of the PV modules or unclean modules. As the solar panels are connected in series leading to a string inverter at the end of the circuit the overall system only works as well as the weakest module. In case e.g. there is shading on one panel, the entire output of a series-connected system will be affected.[157] [158]

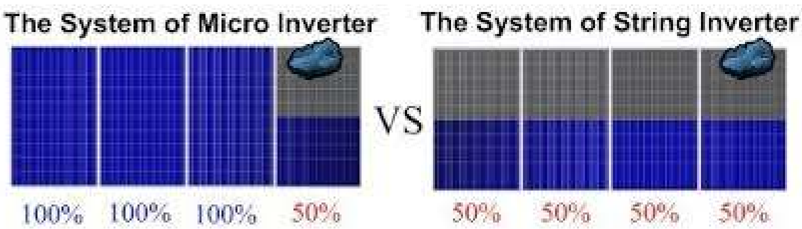

Figure 8: ReneSola, Selecting Micro Inverters for Your Residential Projects, Micro Inverter vs. String Inverter[159]

3.1.1.3. Charge Controller

The main function of a charge controller is to prolong the battery life of a PV system through prevention of over charging and/ or low discharge of the battery system.[160] [161] The controller is supposed to sense the battery voltage and is supposed to reduce or stop the charging process in case the voltage is high enough. Controllers are usually rated in terms of the amperage they are able to handle. The controller should be able to withstand over amperage for a certain period of time to survive events like occasional edge-of-cloud-effects, when the sunlight increases dramatically. In order to allow for future expansion of the generation

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155 ReneSola, Selecting Micro Inverters for Your Residential Projects, Micro Inverter vs. String Inverter, http://blog.renesola.com/theme/blog/blogarticle.jsp?id=27
156 MSc Renewable Energy in CEE, Module 3, Solar Energy – Solar Heating & Photovoltaics, Planning, Simulation, Design, Dimensioning, Fechner H., et al. (2012)
157 Air Care, SolarEdge String Inverters, http://www.aircarebakersfield.com/solar/stringinverters.php
158 renewable energy Focus.com, Micro-inverters vs. string inverters for solar PV,http://www.renewableenergyfocus.com/view/10472/micro-inverters-vs-string-inverters-for-solar-pv/
159 Figure 8: ReneSola, Selecting micro Inverters for Your Residential Projects, Micro Inverter vs. String Inverter, http://blog.renesola.com/theme/blog/blogarticle.jsp?id=27
160 MSc Renewable Energy in CEE, Module 3, Solar Energy – Solar Heating & Photovoltaics, Planning, Simulation, Design, Dimensioning, Fechner H., et al. (2012)
161 Solar Direct, Solar PV Electric, Charge Controller, http://www.solardirect.com/pv/pvlist/control/control.html

system a controller could be used that has more amperage capacity than currently needed for generation.[162]

3.1.1.4. Battery

Electrical batteries store electricity as chemical energy and are especially common in off-grid applications. The main technologies for electrical batteries currently available are lead-acid and lithium-ion batteries.[163] Traditional lead-acid batteries offer a low cost solution (capital cost of USD 1.5 to 2/ W) but short life times, with only about 4 to 8 years lifetime, and can create environmental disposal problems. Compared to lead acid, lithium ion batteries offer high efficiencies and a life time between 8 and 15 years but are considerably higher in cost with around USD 2.5 to 3/ W.[164] Other technologies available include NaS – sodium sulfur and vanadium redoc flow cells. Those technologies will not be elaborated on in detail as they are not yet fully commercialized.

Picture 5: Battery Bank, Tropical Energy Solutions[165]

[162] Ibid
[163] IEA-ETSAP and IRENA© Technology Policy Brief E18 – April 2012, Insights for Policy Makers
[164] IEA-ETSAP and IRENA© Technology Policy Brief E18 – April 2012, Technology Status and Performance
[165] Picture 5: Battery Bank, Tropical Energy Solutions, Beetaloo Station, Off-Grid Hybrid Power System, http://www.tropicalenergysolutions.com.au/projects/beetaloo-station.html

3.1.2. Wind

A wind energy plant collects the energy that is contained in the shifting air mass by means of wind turbines and converts it first into mechanical and then into electrical energy.[166]

3.1.2.1. Wind Power Calculations

The amount of energy contained in the shifting air mass is being calculated according to the formula below:

$$P = 1/2 \times \rho \times A \times V^3$$

P = Power (Watts)
ρ = Air Density (about 1.225 kg/m^3 at sea level)
A = Swept Area of Blades (m2)
V = Velocity of the wind[167]

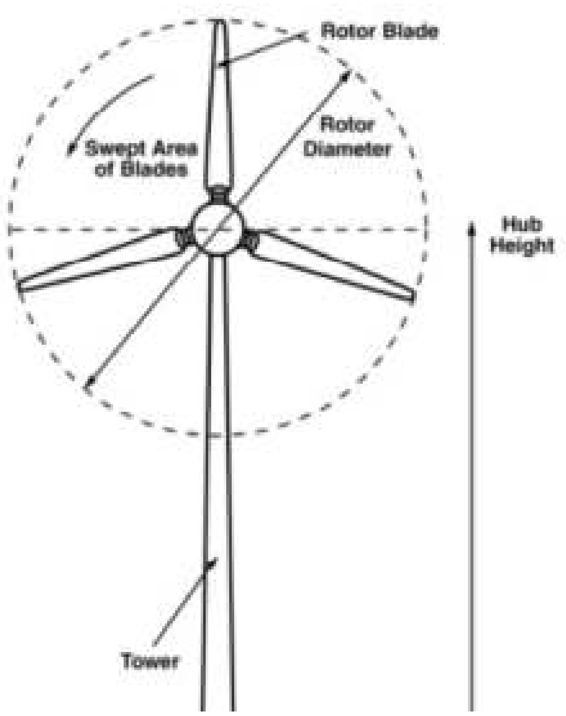

Figure 9: Wind Energy Math Calculations, Minnesota Municipal Power Agency[168]

[166] MSc Renewable Energy in CEE, Module 4, Wind Power, Krenn A., et al. (2012)
[167] Minnesota Municipal Power Agency, Wind Energy Math Calculations, http://www.mmpa.org/Uploaded_Files/ab/ab5c7c5c-79d9-48bd-b64d-833001b7e230.pdf
[168] Figure 9: Wind Energy Math Calculations, Minnesota Municipal Power Agency, http://www.mmpa.org/Uploaded_Files/ab/ab5c7c5c-79d9-48bd-b64d-833001b7e230.pdf

The wind speed is added in the calculation in the form of its third power, while air density and rotor area are recorded in linear dimensions. While 1.225 kg/m3 is taken as the reference value for air density, the actual value depends upon the height of the location above the sea level, the temperatureand and the air pressure.[169]

3.1.2.2. Wind Measurement

Information about wind conditions through wind measurement is essential to identify the most economic sites for the installation of a wind power plant. It is crucial to measure on site and to compare the information with long-term measurement data of a meteorological measuring station.

Different instruments are available to measure wind speed, turbulence, wind shear, wind direction, pressure, temperature and humidity. For the measurement of wind speed cup, propeller and ultrasonic anemometers are being utilized.[170] To measure the wind speed the anemometers have to be installed at a mast which should have the same height as the expected hub height of the wind turbine to be used.[171] The wind should be measured for at least one year to calculate the mean wind speed.[172]

As alternative to anemometers the remote sensing techniques SODAR (Sound Detection And Ranging) and LIDAR (Light Detection And Ranging) are available. Those are based on sound and light emmission of a certain frequency. Remote sensing has some advantages over the use of traditional anemometers like the measurement of the wind speed over the whole and not only at the center of the rotor.[173]

As exemplified in figure 10, wind speed and distribution of wind direction can be visualised in a wind rose, showing the statistical repartition of wind speed per direction.[174]

[169] MSc Renewable Energy in CEE, Module 4, Wind Power, Krenn A., et al. (2012)
[170] MSc Renewable Energy in CEE, Module 4, Wind Power, Krenn A., et al. (2012)
[171] Danish Wind Industry Association, Wind Speed Measurement in Practice, http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wres/wndsprac.htm
[172] The European Wind Energy Association, Wind Energy's Frequently Asked Questions (FAQ), http://www.ewea.org/wind-energy-basics/faq/
[173] Remote Sensing the Wind using Lidars and Sodars, Wind Energy Department, Riso National Laboratory, Technical University of Denmark, http://www.risoe.dk/rispubl/art/2007_133_paper.pdf
[174] The European Wind Energy Association, Wind Energy's Frequently Asked Questions (FAQ), http://www.ewea.org/wind-energy-basics/faq/

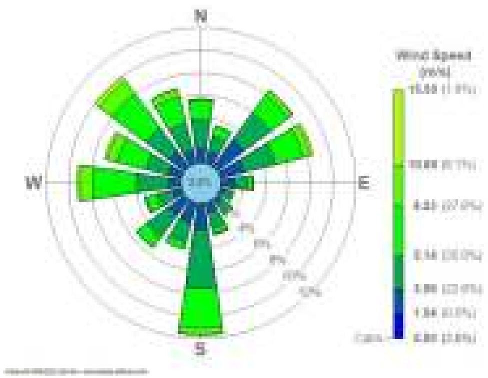

Figure 10: Wind Rose Plot, Station #14732, LaGuardia Airport, New York, New York[175]

3.1.2.3. Components Wind Turbine

The basic components of a wind turbine with regard to the mechanical transmission include all rotating mechanical parts from the rotor to the generator.[176]

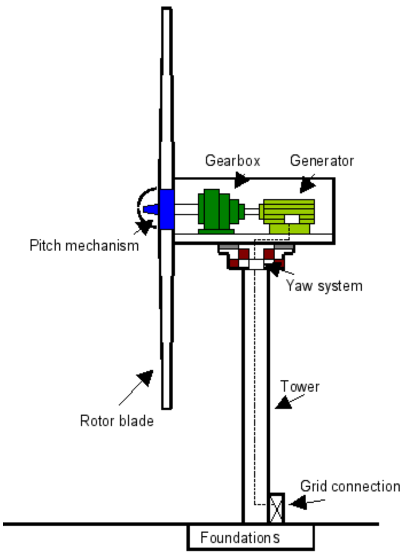

Figure 11: altenergymag.com, Main components of a Wind Turbine[177]

Rotor

With the rotor of the wind turbine, the horizontally directed flow energy of the wind is converted into a rotational movement that is being channeled to the axle. In order to control

[175] Figure 10: Wind rose plot, Station #14732, LaGuardia Airport, New York, New York, http://upload.wikimedia.org/wikipedia/commons/7/70/Wind_rose_plot.jpg
[176] MSc Renewable Energy in CEE, Module 4, Wind Power, 03 – Technical systems, Krenn A., et al. (2012)
[177] Figure 11: altenergymag.com, Main components of a wind turbine, http://www.altenergymag.com/emagazine.php?issue_number=08.06.01&article=smallscalewind

the energy consumption there are different rotor blade technologies available. For Stall Controlled Wind Turbines where the rotor blades are fixed firmly on to the hub, a self-regulating mechanism, which is called aerodynamic "stall", is used. The rotor blade profile has been aerodynamically designed in a way that at the moment a certain wind speed is exceeded, it creates turbulences and the flow at the rotor blade diminishes leading to a braking effect. Pitch Controlled Wind Turbines have the ability to adjust the rotor blade's angle of setting mechanically. In case the power output becomes too high the rotor blade pitches slightly out of the wind. The pitch regulation offers some advantages compared to fixed blade wind turbines like improved starting behaviour or better efficiency rates in the partial load range of under 7m/s. Output limitations can be conducted effectively and accurately after the nominal power has been reached.[178] [179]

Generator

The generator of the wind turbine converts mechanical into electrical energy. Typically there are two generator types, synchronous and asynchronous generators. Features of the synchronous generators are that they are highly efficient and that they can be coupled with the grid directly or via an inverter. Asynchronous generators are robust and do not need much maintenance but show slightly lower rates of efficiency. [180] [181]

Gearbox

Wind turbines can also be differentiated according to the drive train concept, i.e wind turbines with a gearbox and gearless wind energy plants. A gearbox increases the rotational speeds from about 30-60 rotations per minute (rpm) to about 1,000-1,800 rpm, which is the rotational speed required by most generators to produce electricity.[182] The gear system is a relatively high-maintenance component, expensive in terms of operating cost and also a heavy part of the wind turbine. The gearless wind turbines in contrast have the advantage of lower susceptibility to faults, lower maintenance and improved efficiency rates.[183]

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[178] MSc Renewable Energy in CEE, Module 4, Wind Power, 03 – Technical systems, Krenn A., et al. (2012)

[179] Danish Wind Industry Association, Power Control of Wind Turbines, http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wres/wndsprac.htm

[180] MSc Renewable Energy in CEE, Module 4, Wind Power, 03 – Technical systems, Krenn A., et al. (2012)

[181] Danish Wind Industry Association, Power Control of Wind Turbines, http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wres/wndsprac.htm

[182] U.S. Department of Energy, The Inside of a Turbine, Gear box, http://energy.gov/eere/wind/inside-wind-turbine-0

[183] MSc Renewable Energy in CEE, Module 4, Wind Power, Krenn A., 02 – Construction and Aerodynamics of Wind Energy Plants, et al. (2012)

Yawn Mechanism

The wind turbine yaw mechanism is used to turn the nacelle, which houses the generator and the gearbox with the wind turbine rotor, against the wind. It is operated by a electronic controller which senses the wind direction using the wind vane. [184] [185]

3.1.2.4. Constructional Design

The rotation axis is one of the most distinguished features of a wind turbine with the vertical axis turbine and horizontal axis turbine being the two major wind turbine constructional designs.[186]

Vertical Axis

The vertical axis as the oldest rotor design has several advantages over the horizontal axis design, like operation regardless of wind direction, the simple mechanical construction with mechanical and electrical components easily accessible and located at ground level. On the other hand there are also disadvantages like that they are designed as purely high-speed turbines and that they are not capable of starting using their own power.[187]

Picture 6: Vertical Axis Wind Turbine, Panoramio[188]

[184] Danish Wind Industry Association, The Wind Turbine Yawn Mechanism, http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wtrb/yaw.htm
[185] Wind Power in Wisconsin, Parts of a Turbine, The Nacelle, http://www.ecw.org/windpower/web/cat2a.html
[186] Krenn A., et al., MSc Renewable Energy in CEE, Module 4, Wind Power, 02 – Construction and aerodynamics of wind energy plants, et al. (2012)
[187] Ibid
[188] Picture 6: Vertical axis wind turbine, Panoramio , http://www.panoramio.com/photo/44800016

Horizontal Axis

Wind turbines with a horizontal axis are the most common technology with almost all systems available currently based on this design. The main advantages are the high technical maturity of the individual components, the level of efficiency and the ability to solve problems related to technical control, oscillation and dynamics.[189]

Picture 7: Triblade Horizontal-Axis Wind Turbine, Quora[190]

[189] Krenn A., et al., MSc Renewable Energy in CEE, Module 4, Wind Power, 02 – Construction and Aerodynamics of Wind Energy Plants, et al. (2012)
[190] Picture 7: Triblade horizontal-Axis Wind Turbine, Quora, Wind Energy: What is the Most Efficient Design for a Wind Turbine?, http://www.quora.com/Wind-Energy/What-is-the-most-efficient-design-for-a-wind-turbine

3.1.3. Biomass

Biomass is stored source of solar energy collected by plants during the process of photosynthesis, whereby carbon dioxide is captured and converted to plant material. The term biomass includes crop residues, forest and wood process residues, animal wastes, food processing wastes, purpose grown energy crops and short rotation forests. The solid or liquid biomass feedstock can be converted into other energy carriers that are more convenient to transport and store like wood chips, pellets or briquettes. There are also multi-product plants that produce a main product like sugar, rice or pulp but were the “waste“ product like sugar mill bagasse or rice husk can also be used for heat and power generation. [191]

Biomass can contain considerable amounts of water. The moisture content is typically higher than in fossil fuels or municipal solid waste and is one of the key parameters of biomass fuel and of crucial importance with regard to the grate combustion process in terms of burning rate and energy generation rate. In table 7 selected biomass fuels and their moisture content in % of weight are being showcased.

On a moisture and ash free basis any biomass is made of 50% carbon, 44% oxygen and 6% hydrogen by weight; with the Gross Calorific Value (GVC) being around 20 MJ/kg on a moisture and ash free basis (maf). Around 3.6 MJ generates 1 kWh, therefore assuming a system efficiency of 25%, 14.4 MJ of maf biomass generates 1 kWh of electricity [3.6 MJ/0.25]. That results in 0.72 kg of maf biomass whatever biomass fuel is being used [(14.4 MJ)/(20 MJ/kg)]. Taking into account 20MJ/kg and the moisture and ash content of the individual biomass fuel it can be calculated how much feedstock is needed to generate 1 kWh of power, e.g. for rice husk with 14% moisture in terms of weight and 20% in terms of ash results in 13.2 MJ/kg GVC. Therefore 1.09 kg of rice husk is needed to produce 1 kWh of power [14.4/13.2].

In the table below some selected biomass feedstock is being analyzed with regard to GVC, moisture and ash in per cent of weight and in terms of how much of kg of feedstock is needed to produce one kWh of power.[192]

[191] International Energy Agency, Good Practice Guidelines, Bioenergy Project Development & Biomass Supply, Section 1, The Biomass Resource

[192] The calculations are done for a power plant between 3MW to 7MW which has a system efficiency (η) of around 20% -25% based on GVC and gross generation.

Biomass fuel	HHV[193] MJ/kg maf[194]	Moisture % weight	Ash % weight	as fired HHV MJ/kg	kg fired per kWh
Rice husks	20	14%	20%	13.2	1.09
Bagasse	20	50%	3%	9.4	1.53
Rice straw	20	10%	13%	15.4	0.94
Wood	20	25%	1%	14.8	0.97
Coconut shell	20	8%	0.5%	18.3	0.79

Table 7: EnergyManagerTraining, How much Biomass does a Biomass Power Plant need to Generate one kWh of power[195]

The thermal conversion of biomass can be performed in three different ways and is mainly differentiated by the quantitiy of oxygen added. In the combustion process thermal conversion of organic matter takes place with complete oxidation at high conversion temperatures above 800 Celsius. The product of the combustion process is primarily a flue gas consisting of carbon dioxide and water for heat utilization. Gasification is the process of thermal conversion of organic materials at high temperatures of more than 700 Celsius, whereby the product is a usable gas like product or synthesis gas. Pyrolysis is thermal conversion of organic matters in the absence of oxygen and at lower temperatures of around 400 to 600 Degrees Celsius. The primary product produced are liquids.[196]

In the context of this thesis only power production through gasification is elaborated on in detail. The main advantage of biomass gasification is the high electric efficiency as power is produced by gas engines.

The gasification process in a plant consists of several steps as depicted in the graph below. The solid biomass delivered needs to undergo fuel conditioning, like drying, required for the gasification process. The conditioned fuel enters the gasification process to produce the raw product gas. In order to achieve the product quality gas for further utilitations it has to be cleaned. The cleaned gas can be used in a next step for the production of electric power or heat, etc.[197]

[193] Higher Heating Value
[194] Moisture and ash free
[195] Table 7: EnergyManagerTraining, How much biomass does a biomass power plant need to generate one kWh, www.energymanagertraining.com/kaupp/Article24.pdf
[196] Ortner M., MSc Renewable Energy in CEE, Module 2, Fundamentals of Biomass Utilization (2012)
[197] BIOS BIOENERGIESYSTEME GmbH, Overview Biomass Gasification, http://www.bios-bioenergy.at/en/biomass-gasification.html

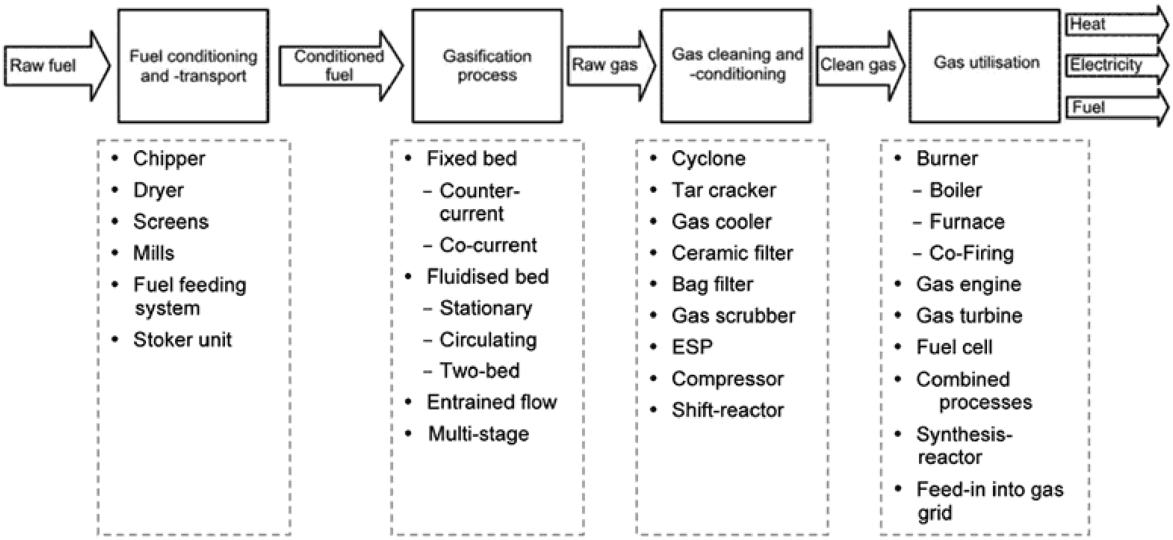

Figure 12: Overview Biomass Gasification, BIOS BIOENERGIESYSTEME GmbH[198]

A more detailed description of the gasification process is described in the graph below. The process can be broadly broken down into 4 stages. First the biomass is **dryed** to drive the water-vapour off the biomass. **Pyrolysis** - as the temperature increases the dry biomass is decomposed into organic vapours, gases, carbon (char) and tars. In a next step – **reduction** - the water vapour reacts with carbon, producing hydrogen, carbon monoxide and methane. Carbon dioxide reacts with carbon to produce more carbon monoxide. In the combustion process some of the char and tars burn with oxygen from air to give heat and carbon. The combustion heat enables the other stages to take place.

The producer gas contains combustible carbon monoxide, hydrogen and methane, and inert nitrogen and dioxide. Compared to pure methane which has an energy content of around 50 MJ/ kg, producer gas has a rather low energy content of around 4 MJ.

In small scale gasifiers the reaction takes place in a stationary or fixed “bed“ of biomass. As depicted in the graph below different technologies are available. There are several differences between an updraught and a downdraught gasifier. For an updraught gasifier the biomass is loaded at the top of the gasifier, the air intake is at the bottom and the gas leaves at the top. Major advantages of this technology are its simplicity, high charcoal burn-out and internal heat exchange that leads to low gas exit temperatues and high equipment efficiency. In contrast to downdraught gasifiers it can operate with many types of feedstock (sawdust,

198 Figure 12: Overview Biomass Gasification, BIOS BIOENERGIESYSTEME GmbH, http://www.bios-bioenergy.at/en/biomass-gasification.html

cereal hulls, etc). A drawback is that the producer gas is contaminated by tar, hence too dirty to be used in an internal combustion engine.[199] [200]

For the downdraught gasifier air is drawn downward through the biomass. Tars and volatile gases break down into carbon monoxide and hydrogen at much higher temperatures than in an updraught gasifier. A more or less complete breakdown of the tar is achieved, depending on the temperature in the gasifier. This is the main advantage of this technology, as the producer gas contains less tar and is therefore more ready for engine applications. The producer gas leaves at a temperature of over 600 degrees Celsius but still contains fine particles of ash and tar. It therefore still needs to be cleaned before it can be used in an engine. Disadvantages that come with this technology are its inability to operate on a number of unprocessed fuels, its lower efficiency as there is no internal heat exchange and the lower heating value of the gas.[201] [202]

The graph below depicts the process of biomass gasification in an updraught and downdraught gasifier.

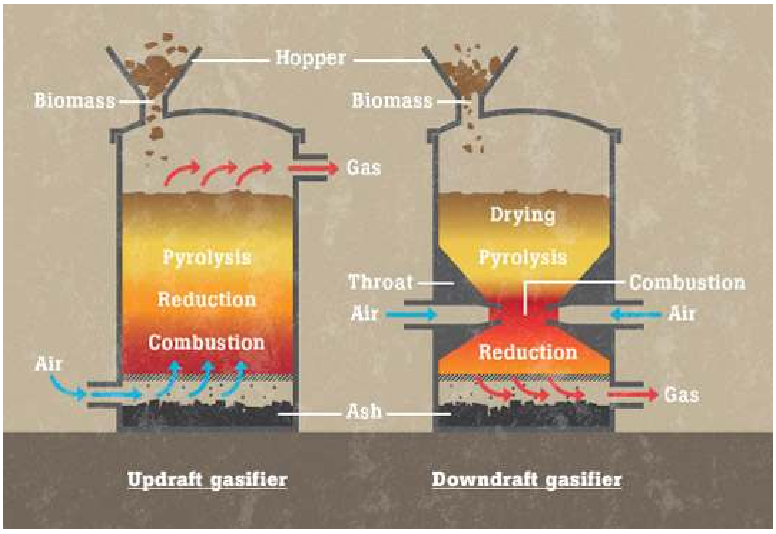

Figure 13: Biomass Gasification, Ashden Sustainable Solutions[203]

[199] Ashden Sustainable solutions, Better Lives, Biomass Gasification, http://www.ashden.org/biomass-gas
[200] Food and Agriculture Organization of the United Nations, 2.3. Types of Gasifiers, www.fao.org/docrep/t0512e/T0512e0a.htm#TopOfPage
[201] Ashden Sustainable Solutions, Better Lives, Biomass Gasification, http://www.ashden.org/biomass-gas
[202] Food and Agricutlure Organization of the United Nations, 2.3. Types of Gasifiers, www.fao.org/docrep/t0512e/T0512e0a.htm#TopOfPage
[203] Figure 13: Biomass gasification, Ashden Sustainable Solutions, Better Lives, http://www.ashden.org/biomass-gas

The picture below shows an example of a biomass gasification plant with biomass feedstock operated in Bihar, India.[204]

Picture 8: Biomass Gasification Equipment and Wood, Saran Renewable Energy - 2009 Ashden Award Winner, Ashden Awards[205]

[204] Ashden Awards Case Study, Case Study Summary, Saran Renewabel Energy, India, http://www.ashden.org/files/Saran%20full.pdf

[205] Picture 8: Biomass Gasification Equipment and Wood, Saran Renewable Energy - 2009 Ashden Award Winner, Ashden Awards https://www.flickr.com/photos/ashdenawards/4072197890/in/set-72157622813781314/

3.2. Mini-Grids

There are various different definitions of mini-grids, especially when it comes to the kW size of a respective installation. Mini-grids are village- and district-level networks, according to different definitions with a load size of up to 3MW[206] although typically the size is defined as being between 5kW and 300KW.[207] Mini-grids can be defined "as one or more local generation units supplying electricity to domestic, commercial or institutional consumers over a local distribution grid". Such mini-grids can be operated on a stand-alone basis or can be connected with the central transmission grid.[208]

Mini-grids are specifically used in the context of off-grid rural electrification where connecting a remote area to the transmission grid is physically not possible due to geograhic difficulties or due to the fact that it is uneconomic to extend the grid within dispersed and low populated areas.

Increased use of mini-grids for the electrification of rural and peri-urban areas has supported and lead to a stronger integration of renewable energy in those systems and, together with technical advances, also to a stronger integration of information and communication technology applications for power management and end-user services. [209]

3.2.1. Diesel Powered Mini-Grids

Although it is rarely the lowest cost option in the long run, diesel generators are frequently used in rural electrification. The size of gensets usually used for rural electrification is between 1kW to several hundred kWs.[210] Typically the lower upfront cost compared to renewable energy sources is the main reason why diesel powered electrification is the preferred option in many remote rural areas. Apart from the lower upfront cost there are several other advantages related to diesel gensets like easy maintenance, availability of

[206] GVEP International: Global Village Energy Partnership, Policy Briefing, (2011)
[207] Alliance for Rural Electrification, Rural Electrification with Renewable Energy, Technologies, Quality Standards and Business Models, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf,
[208] Deshmukh Ranjit, et al., Sustainable Development ofRenewable Energy Mini-Grids for Energy Access: A Framework for Policy Design, p. 2 http://www.schatzlab.org/docs/Sustainable_Development_of_Renewable_Energy_Mini-grids_for_Energy_Access.pdf
[209] Renewables 2014 Global Status Report.(Ren 21), p. 21, http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_full%20report_low%20res.pdf
[210] Alliance for Rural Electrification: Hybrid Mini-Grids for Rural Electrification: Lessons Learned, p. 54, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf

continuous energy service (24hours) and suitability for income generating activites and productive uses.[211]

The drawbacks of power generation through diesel gensets are also numerous. The uncertainty and dramatic increase of fuel costs in recent years and the cost of transport of the fuel to remote areas leads to levelized cost of electricity that are much higher outweighing the advantage of the initial lower procurement cost of diesel generators. Fuel consumption over the lifetime of the system is the major portion of the cost, especially compared to renewable energy systems, where the up-front costs are the most critical cost factor. Consumption patterns vary but in general a modern diesel generator will consume between 0.28 and 0.4 l of fuel per kWh.[212] Apart from the financial cost also the environmental cost in terms of production of CO_2 and local air and noise pollution has to be taken into account.[213]

Generators usually supply AC power and can be connected directly to the distribution feeder bus bar. The average lifetime of a diesel generator in continous use is between 3 and 5 years taking into account the most beneficial use, i.e. the genset running on high capacities.[214]

3.2.2. Hybrid - Diesel/ Renewable Energy Mini-Grids

Diesel generators can be used in conjunction with various different renewable energy sources like solar, wind, biomass or hydro, making it a hybrid system.[215] The so called hybrid mini-grid uses renewable energy as the primary source and a diesel genset for back up electricity supply.[216] Combining different sources of generation can have a strong influence on the levelized cost of electricity, lifetime of the sytem and affordability for end-users. A sole diesel based mini-grid will be more expensive over the lifetime of the installation and is heavily dependant on continous fuel supply making the system less autonomous. RE powered mini-grids can make a system totally independent while a hybrid diesel/ RE combination can make it at least less dependent on fossil fuel supplies. The renewable

[211] Rural Electrification in India, Economic and Institutional aspects of Renewables, p. 9, http://nexus.som.yale.edu/design-selco/sites/nexus.som.yale.edu.design-selco/files/imce_imagepool/IndianRuralElectrification.pdf
[212] Energy Solutions in Rural Africa: Mapping Electrification Costs of Distributed Solar and Diesel Generation versus Grid Extension, http://iopscience.iop.org/1748-9326/6/3/034002/fulltext/
[213] Alliance for Rural Electrification: Hybrid Mini-Grids for Rural Electrification: Lessons Learned, p. 54, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf
[214] Ibid
[215] Ibid
[216] Alliance for Rural Electrification,, Rural Electrification with Renewable Energy, Technologies, Quality Standards and Business Models, p. 27, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/ARE_TECHNOLOGICAL_PUBLICATION.pdf,

component of hybrid systems typically generates between 75% – 90% of total supply but can also be substantially higher due to the good performance of the RE source. Sometimes the diesel genset can serve as pure back-up to assist in periods of high loads or low RE power availability. [217]

With a hybrid system using several different RE sources, the specific advantages of each renewable energy source can be utilized. If used in conjunction the individual shortcomings of each technology are balanced out, specifically with regard to the intermittent nature of the different renewable energy sources. Small hydropower has the potential to provide a low cost solution but is very site-specific and dependant on seasonal effects. Solar has a high requirement for storage, especially taking into account that no generation takes place during night hours. Small wind is intermittent due to the varying availability of wind and power production dependant on the wind profile of the specific site. Diesel gensets in a hybrid system can serve as backup in order to balance out the intermittent production of RE sources, especially when renewables are not generating or when the battery reaches a low stage of charge (SoC).[218]

The specific RE sources used for hybrid mini-grids will be elaborated on in more detail in the following paragraphs, with a focus on solar PV, wind and biomass as those are the resources applied for the HOMER simulations in the case study.

Solar PV

Use of solar technology brings specific advantages over other renewable energy sources: Every location in the world receives solar energy. This is the reason why solar PV is seen as a first option for hybrid systems compared to wind, hydro and biomass where the renewable energy resource is much more site specific. Worldwide insolation levels are well known and do not vary much on a local level, taking into account the optimal installation on site, i.e. best orientation, avoiding of direct shadowing, etc. Compared to time consuming wind resource assessment and assessment of a potential hydro site, solar PV does not need extensive time for data gathering. Some of the other advantages of solar PV over wind and hydro are that solar panels do not produce emissions or noise and that no mechancial devices are needed to absorb the kinetic energy. Compared to wind and hydro the installation of PV panels is

[217] Alliance for Rural Electrification: Hybrid Mini-Grids for Rural Electrification: Lessons Learned, p. 13, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf

[218] Alliance for Rural Electrification: Hybrid Mini-Grids for Rural Electrification: Lessons Learned, p. 54

easier as it can be done by local qualified technicians that have received appropriate training.[219] PV modules usually provide DC electricity at 12 or 24 volts.[220]

Wind

Wind turbines use the energy in the wind to convert its kinetic into electric energy. Usually hybrid mini-grids use small wind turbines in the range between 1 kW and 20 kW. As with all technologies used in remote rural areas, proven technology for increased reliability and especially high quality standard system components is key for sustainable operations of an installation. The most commonly used wind turbines in hybrid mini-grid systems are horizontal axis models with 2 or 3 blades. Small wind turbines usually generate DC power at 12 or 24 V, while larger turbines produce AC power.[221]

The thorough assessment of local wind resources is of high importance as it will have a substantial impact on the commercial viability and sustainability of the operations. Wind speeds in the range of 4 – 5 m/s would be required to run a system profitably. As already elaborated on, wind energy resources and wind speed are very site specific, with site topography and obstacles being important factors influencing wind speeds. Wind power is also dependant on the season and can even vary substantially during the day. Those are the reasons why thorough wind measurement conducted over a longer period and on an hour-by-hour and day-by-day basis, in conjunction with meterological data, is needed to make reliable predictions.

Biomass

Utilsation of biomass for electricity generation will only be elaborated on in the context of producing gas from biomass pyrolisis and power generation through biomass gasifiers. A thorough analysis of the biomass resources at the village level is essential to have certainty of biomass availability, specifically taking into account other competing uses and seasonal variability of biomass. [222] The biomass to be used can be wood and wood waste, agricultural

[219] Alliance for Rural Electrification, Rural Electrification with Renewable Energy, Technologies, quality standards and business models, p. 28, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf
[220] IEA, Task 9, Renewable Energy Services for Developing Countries, p. 11
[221] Alliance for Rural Electrification: Hybrid Mini-Grids for Rural Electrification: Lessons Learned, p. 56, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf
[222] Deshmukh Ranjit, et al., Sustainable Development of Renewable Energy Mini-Grids for Energy Access: A Framework for Policy Design, p. 18 http://www.schatzlab.org/docs/Sustainable_Development_of_Renewable_Energy_Mini-grids_for_Energy_Access.pdf

waste, other biomass residue or energy crops from plantation for biomass fuel supply (see also 2.2.4 Biomass). The quality and energy content of the fuel will influence installation, operations and maintenance (O&M) costs. The location of the biomass resource respectively transport distance of the resource to the generation facility will also directly impact costs, taking into account also the existing infrastructure like appropriate roads for the transport.[223] Apart from the logistics, another essential criterion for the sustainable and viable operation of a biomass fuelled mini-grid is the continuous supply of feedstock including steady prices. In case the operator of the installation does not own or produce the biomass needed for power generation, long-term supply contracts for the biomass with external suppliers need to be concluded. This is crucial to secure the availability of feedstock over a longer period of time at guaranteed prices.

Mini-grids can provide sufficient power to satisfy local community needs for lighting, communication, refridgeration and water supply, for public services like health centres and schools but also for productive uses, income generating activities and local businesses. One of the big advantages is that, due to its modular nature, such a system can easily be scaled up when the power demand grows within a community. [224] For the initial electrification of an off-grid community the primary demand of households will be power for lighting, fan, radio and TV. To increase the load and make a system more commercially viable it is often necessary to incorporate productive, income-generating uses in the load mix.[225]

Hybrid mini-grid systems can also be differentiated according to the type of voltage they use and the type of bus line that links the different generation components together. The mini-grid could therefore be an Alternate Current (AC) or Direct Current (DC) coupled system. While DC is directly usable only for DC loads like DC energy saving lamps, radios, DC TV, mobile phone charger and special fridges, AC power is required for appliances like light, electronic equipment and is also able to support productive loads like drilling machines and grain mills. For bigger distribution systems and long wire runs, AC is more efficient and less expensive than low voltage DC equipment.[226] [227]

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[223] U.S. Export Council for Renewable Energy, The Renewable Energy Policy Manual, Chapter 1. Renewable Energy Overview, https://www.oas.org/dsd/publications/Unit/oea79e/ch05.htm#TopOfPage

[224] Alliance for Rural Electrification, Rural Electrification with Renewable Energy, Technologies, Quality Standards and Business Models, p. 27, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/ARE_TECHNOLOGICAL_PUBLICATION.pdf

[225] ESMAP Technical Paper 007, Mini-Grid Design Manual 21364, September 2000

[226] Alliance for Rural Electrification, Rural Electrification with Renewable Energy, Technologies, Quality Standards and Business Models, p. 10,11, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/ARE_TECHNOLOGICAL_PUBLICATION.pdf

Electricity Generation coupled at AC Bus Bars

As depicted in the graph below, the generating units like solar PV, wind, hydro or genset are connected to an AC bus line. The components generating AC are directly connected to the AC bus line while for the DC generating units like solar PV an inverter is needed to convert DC to AC.

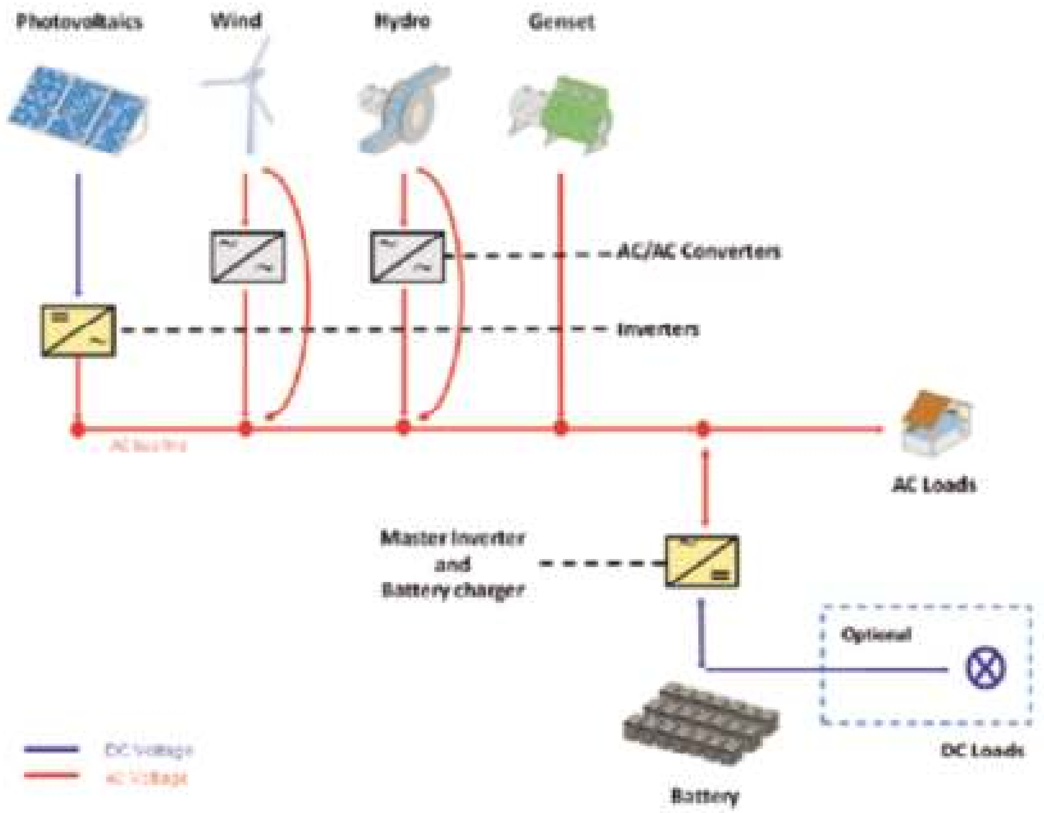

Figure 14: AC Coupled Hybrid System, Alliance for Rural Electrification[228]

Electricity Generation coupled at DC Bus Bars

The generating components are connected to a DC bus line. While the DC generating units can directly serve the DC loads or charge the batteries, the AC power generating components can be either connected to the AC bus line or the generated AC power needs to be converted to DC to charge the battery or supply the DC loads.

[227] Solar Alaska, http://www.solaralaska.com/primer/ac_dc.htm
[228] Figure 14: AC Coupled Hybrid System, Alliance for Rural Electrification, Rural Electrification with Renewable Energy, Technologies, Quality Standards and Business Models, p. 28, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/ARE_TECHNOLOGICAL_PUBLICATION.pdf

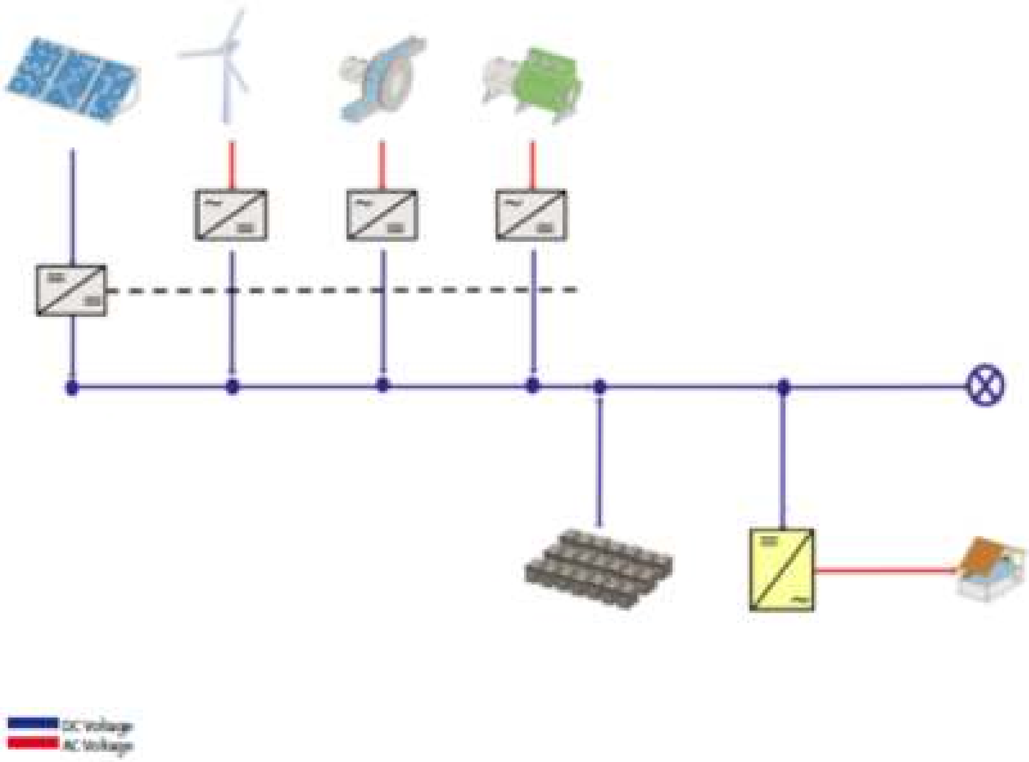

Figure 15: DC Coupled Hybrid System, Alliance for Rural Electrification[229]

Which type of configuration is used depends on various site specific factors like load and consumption profile, distribution grid, village size and renewable energy resources available.[230]

3.2.3. Challenges for Implementation of Hybrid Energy Mini-Grids

Many mini-grids, also in the Philippines, are powered by diesel generators. This is mainly due to the lower upfront costs and the long lasting experience with this well known technology. The use of diesel as the source of energy entails a number of implications that have to be taken into account when evaluating the advantage of the lower upfront cost of the system. The high volatility of diesel prices and price hikes as well as the difficulty and high cost related to transporting the fuel to remote areas leads to higher lifetime cost of diesel powered

[229] Figure 15: DC Coupled Hybrid System, Alliance for Rural Electrification, Rural Electrification with Renewable Energy, Technologies, Quality Standards and Business Models, p. 29, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/ARE_TECHNOLOGICAL_PUBLICATION.pdf

[230] Alliance for Rural Electrification, Rural Electrification with Renewable Energy, Technologies, Quality Standards and Business Models, p. 29, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/ARE_TECHNOLOGICAL_PUBLICATION.pdf

systems compared to systems hybridized with renewables. [231] [232] Apart from those considerations, the environmental aspect with high greenhouse gas emissions and related climate change effects and other negative implications on the local communities (e.g. air pollution) has to be taken into account as well. Those are reasons that would favour the implementation of renewable energy mini-grids or hybrid systems, where diesel gensets only serve as back-up. Although mini-grids seem to be a suitable option for off-grid rural electrification, barriers to a successful implementation respectively scale up still remain.

Challenges for a successful implementation could be on the hand technical and on the other economic. The technical design of the mini-grid needs to match the energy demand, the village load profile, the available local natural resources and needs to incorporate correctly forecasted future loads in order to avoid over- or undersizing of the system. The design therefore has to be based on a detailed analysis of the site specific circumstances including current load profile and demand, future demand, renewable energy resources available, village topography, local conditions affecting the system components, time series data such as weather, supply chains and current and future energy policies. [233] [234]

Apart from the challenges on the technical side, economic challenges remain that need to be addressed as well. Limited affordability and willingness of the end-consumers to pay are key paramenters to be considered in a preliminary research. The limited ability of the end-users to pay for the services is a crucial factor as the electricity tariff charged has to allow for commercially viable and long-term sustainable operations. The high upfront cost of renewable energy technology might also hamper the ability of the local community to acquire such a system. Those problems can be addressed by an appropriate sustainable financing scheme to cover the high capex upfront cost and an appropriate business model that allows for a level of tariff that makes electricity affordable to local communities. Local buy-in and participation of the local community will also increase the chance of successful implementation. Community-based business models and other business models for mini-grid implemention are discussed in detail in chapter 2, Business Models in Off-Grid Areas.

Long term sustainability of a mini-grid requires also several additional components that need to be taken into consideration. Although the economic situation in areas with low affordability pushes for least-cost technologies, the quality of the system components have a substantial

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[231] Alliance for Rural Electrification: Hybrid Mini-Grids for Rural Electrification: Lessons Learned, p. 5 http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf

[232] Pump price for diesel fuel (US$ per liter), http://data.worldbank.org/indicator/EP.PMP.DESL.CD

[233] GVEP International: Global Village Energy Partnership, Policy briefing, (2011)

[234] Journal of Energy in South Africa, Considerations for a Sustainable Hybrid Mini-Grid System: A Case for Wanale Village, Uganda

influence on the long term lowest generation costs. High quality components can extend the lifetime of the entire system substantially. Another important factor to bring down costs and increase efficiency gains is the appropriate sizing of the system and the use of energy efficient appliances; this will have a strong influence on the energy load and the amount of power generation required. It will also decrease the investment cost of the installation overall.[235]

Critical for the successful operation of a system over an extended period of time is a financial and technical composition, that allows for long-term sustainable operations, maintenance and management (O&M&M). Regular maintenance of generation and distribution equipment is crucial to operate efficiently and to extend the lifetime of the installation. The lifetime of a mini-grid is usually expected to be around 20 to 30 years but can be up to 50 years with proper maintenance. The cost for O&M&M therefore has to be incorporated into the financial planning and business plan from the very beginning to generate sufficient cash flow for sustainable operations or there also might be subsidies available to cover those costs over the lifetime of the mini-grid. Who will be responsible for O&M&M is also dependant on the ownership structure and, finally also the on business model applied.[236]

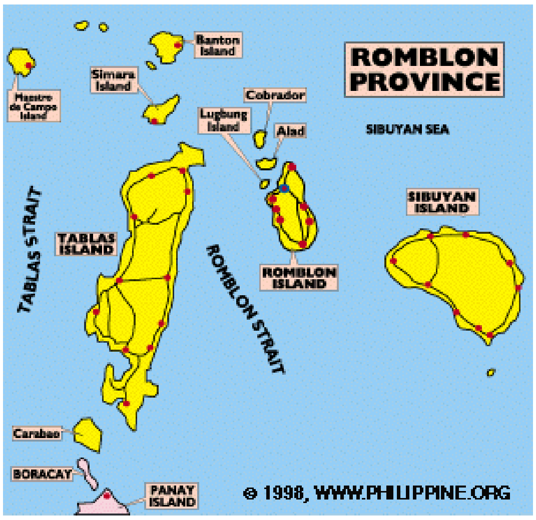
[235] Alliance for Rural Electrification: Hybrid Mini-Grids for Rural Electrification: Lessons Learned, p. 5 http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf
[236] Ibid, p. 31

4. CASE STUDY

4.1. Overview of Romblon Province and Target Island

The island that is being chosen to to identify the least-cost electrification option is located in the province of Romblon. Romblon province covers a total land area of approximately 1,355.9 km^2 consisting of three major islands Tablas, Sibuyan and Romblon, and 17 minor and small islands. Located at 12°33′N 122°17′E the capital of the province is Romblon. The islands are surronded by deep waters and are only accessible by sea, except Tablas Island which has a domestic airport.

Map 6: Map of Philippines, Kamusta Philippines[237]



Map 7: Map of Romblon Province, Romblon Diocesan Seminarians Association[238]

The province is in general mountainous with 40% of the area having slopes greater than 50%. The primary means of transport in the province are jeepneys, motorcycles, mini buses and tricycles for inter-municipal movements. For transport from one island to another island

[237] Map 5: Map of Philippines, Kamusta Philippines, http://kamustaphilippines.wordpress.com/category/personal-travel-guides/region-ivb-mimaropa/
[238] Map 6: Map of Romblon Province, Romblon Diocesan Seminarians Association, online map, http://home.catholicweb.com/rodsa/index.cfm/map

motorized barcas are used, for transport outside the province Roll On / Roll Off (Roro) ships are used.[239] The wet season is usually from June to November where the islands are not easily to accessible. Currently the main source of energy used for power generation is diesel while also renewable energy sources in the form of individual solar home systems and hydro are being employed. The province is comprised of 17 municipalities and 219 barangays and, as of 2010, has a population of 283,930.[240]

Romblon province is known for its marble industry as it holds marble deposits that serve as the basis for the industry in addition to large deposits of kaolin clay, nickel, magnesium, quartz, silica, zinc, copper, silver, limestone and sulfide ores. Apart from its marbel industry its primary livelihood and sources of income are agriculture crops (mainly coconut, palay, corn and banana), fishery and forestry.[241] [242]

Electricity in the province is supplied by NPC-SPUG while two electric cooperatives, Romblon Electric Cooperative (ROMELCO) and Tablas Island Electric Cooperative (TIELCO) and 3 LGUs are distributing power.[243] [244] There is a electricity supply gap due to the limited power generation equipment available, therefore electricity demand is not fully met. The municipality of Romblon enjoys 24 hours of electricity while the other major municpalities only receive power between 6 and 12 hours per day.[245]

4.1.1. Socio-economic profile of Target Island

The island consists of around 435 households. The community's income generating activities are similar to the ones in the province: households are engaged in agriculture, fishery and forestry while 100 of the households in the island are engaged in the marble processing industry, which includes quarrying and cutting of marble in pieces for sale.[246]

[239] Definition Barca: Small Boat Found in Pacific Waters especially around the Philippines; Merriam Webster, http://www.merriam-webster.com/dictionary/banca
[240] The Official Website of the Provincial Government of Romblon, Sulong Romblon http://www.romblonprov.gov.ph/pages.php?m=romblon_province
[241] Romblon Travel Guide, Facts and Figures, http://romblon.homestead.com/factsandfigures.html
[242] Romblon Travel Guide, Industries, http://romblon.homestead.com/industries.html
[243] The Official Website of the provincial government of Romblon, Sulong Romblon http://www.romblonprov.gov.ph/pages.php?m=romblon_province
[244] Expert Interview with Fely Arriola, Energy Access Specialist with the ADB's Energy for All Initiative
[245] Expert Interview with Fely Arriola, Energy Access Specialist with the ADB's Energy for All Initiative
[246] Expert Interview with Fely Arriola, Energy Access Specialist with the ADB's Energy for All Initiative

4.1.2. Electricity Consumption/ Generation in Target Island

The target islands currently only enjoys 12 hours of electricity per day which is generated by diesel generators. Power is produced by a 50 kW diesel genset which is owned by NPC-SPUG. The genset consumes around 25,000 liters of diesel per year which is also provided by NPC-SPUG. Overall electricity generation in the island is currently around 68,500 kWh per year.

The distribution network currently connects 185 of the island's households to the existing diesel mini-grid. The households in the island own appliances like TV and refridgerators, etc. and are also partly engaged in the marble industry. The households that are not yet connected are mainly dependent on kerosene for lighting while only a few also possess SHS.[247] The current load profile for the 12 hours operation shows the current peak demand of around 37 kW between 7.30pm and 8.30pm.

4.1.3. Renewable Energy Resources Available

For the calculation of the least-cost option three renewable energy resources will be taken into account: solar, wind and biomass. For the HOMER simulations, the NREL study on solar and wind resources assessments will be the basis of the calculations.

Solar Resource

For the solar component data gathered from NREL has been used with the map below clustering the Philippines into different sub-areas for a more detailed definition of the solar resource available. The solar profile depicted in the specific cell is the basis for the solar profile used for the HOMER simulations.

The solar profile for the islands is depicted below. It serves as the basis for the solar component calculation.

[247] Expert Interview with Fely Arriola, Energy Access Specialist with the ADB's Energy for All Initiative

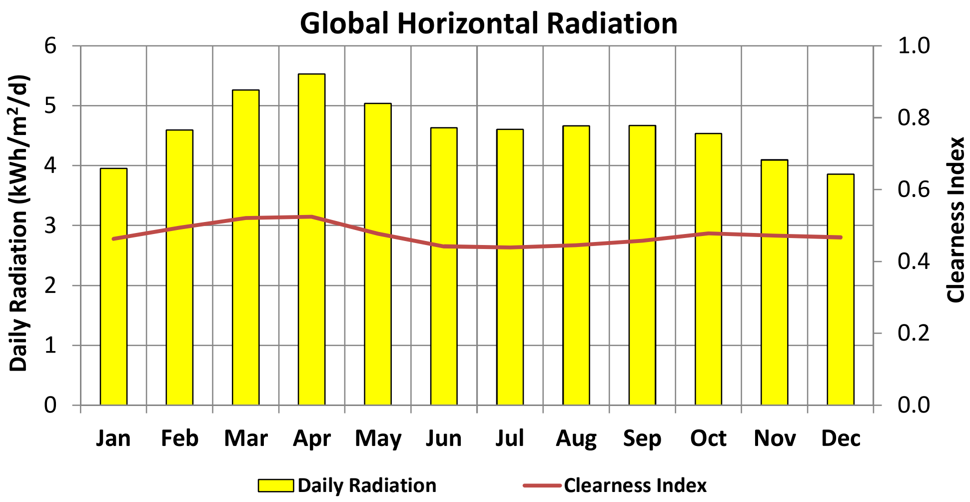


Figure 16: Solar Profile Target Island, HOMER Energy[248]

Wind Resource

The wind profile used for the HOMER simulation is depicted below. As no data for Romblon province is available, the closest neighbouring region (Westcoast Mindoro) was taken as reference data for the simulations.

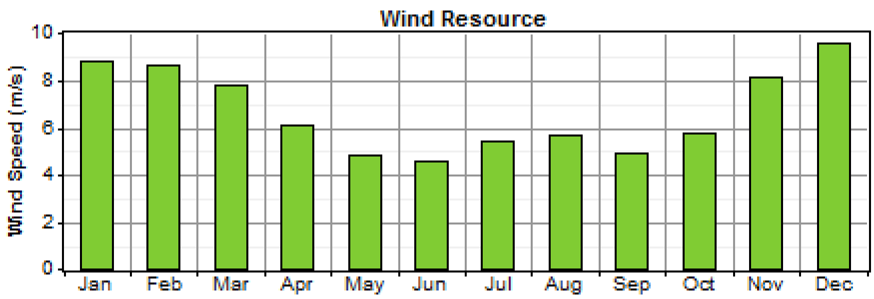


Figure 17: Wind Profile Westcoast Mindoro, HOMER Energy[249]

Biomass Resource

The most abundant biomass resource available in the Romblon province is coconut. For the HOMER simulations the fuel used for gasification is coconut shell. Romblon is one of the

[248] Figure 16: Solar Profile Target Island, HOMER Energy, HOMER-Ready Resource Files, https://users.homerenergy.com/pages/file_download#resource
[249] Figure 17: Wind Profile, Westcoast Mindoro, HOMER Energy, HOMER-Ready Resource Files, https://users.homerenergy.com/pages/file_download#resource

largest producers of coconut in the Philippines with a production of 720,000 coconuts daily, ranking second after the province of Quezon.[250]

4.2. Assumptions for Technical Design/ Financial Analysis

This subchapter will describe the basic cost assumptions for the renewable energy technologies for solar PV, wind and biomass and the diesel component which are incorporated into the HOMER simulations to calculate the least-cost electrification option.

4.2.1. Cost Assumptions Solar PV

The solar PV components are sourced internationally. For the PV component a high quality 250 W module by Canadian Solar (CS6P-250P) with a shelf price of EUR 150 per module and a PV SMA Sunny Island 5048 inverter, priced at around EUR 2,325 is used. The SMA Multicluster Box MC-BOX 12.3 comes at a price of around EUR 3,920. The average cost per watt including other accessories like cabling, accessories for battery systems etc. amounts to EUR 2 per watt which translates to around USD 2.75[251] per watt.[252] Assumed life time of the sytem components is 25 years.

4.2.2. Cost Assumptions Wind

For the HOMER calculation a PGE 11/35 horizontal axis wind turbine with a rated power of 35 kW AC, produced by Energie PGE has been chosen. An investment cost of USD 9 W per watt is being assumed, also taking into account the cost of logistics and transport to the remote island. This leads to total investment cost of USD 315,000. The life time of the systems is assumed to be 15 years. [253] [254]

4.2.3. Cost Assumptions Biomass

For the gasification of the coconut shells the assumed cost of the Ankur WBG-20 10 kW biomass gasifier is around USD 28,000, while the Ankur WBG-40 20 kW is considered with a cost of around USD 45,000. The assumed lifetime of the equipment before replacement is

[250] Department of Science and Technology, Mediacore, PCIERD, Romblon CME Plant Produces Clean Coconut-Based Fuel, http://sntpost.stii.dost.gov.ph/frames/JultoSept05/Romblon_CME_plant_produces_clean_coconut_pg26.htm

[251] FX rate EUR/ USD (1.3527) – 22. July 2014

[252] Expert Interview with Lyndon Azuceno, local renewable energy expert

[253] World Wind Energy Association, 2014 Small Wind World Report, March 2014, http://small-wind.org/wp-content/uploads/2014/03/2014_SWWR_summary_web.pdf

[254] Expert Interview with Lyndon Azuceno, local renewable energy expert

15,000 operating hours. The cost of sourcing coconut shell in the target island is assumed to be 1PHP (USD 0.023)/ kg.[255] [256]

4.2.4. Cost Assumptions Battery

The chosen battery for the system is a Hoppecke 24 OPzS 3000 2v vented lead-acid, tubular-plate, deep-cycle battery with a nominal capacity of 3000 Ah and a nominal voltage of 2V. The overall cost for the 24 batteries considered in the HOMER simulation is around USD 31,000.[257]

4.2.5. Cost Assumptions Diesel Generator

The cost of the possible diesel component is estimated with around USD 400/ kW. Suitable 100 kW generators could be sourced from e.g. Caterpillar. The cost assumption for the diesel fuel is around USD 1.20/ liter.

4.3. Economic Evaluation, System Design and Modelling of Least-cost Option

One of the most difficult and crucial elements when designing a system is preventing over- or undersizing of the mini-grid installation and accurate estimation of the future demand. For a precise future forecast estimation one has to take into account the fact that - with increased availability of electricity - consumption patterns in a community will change. Consumers/ households will aspire for more electric appliances and also use of power for income generating activities and businesses will increase. It is hard to estimate the exact increase in electricity demand over time. This can only be determined after the conduct of a detailed survey which can give some more concrete insights into the aspirations of the local and business community. Even then, there is still considerable risk that the future predictions will not materialize. This can lead to a substantially oversized system, increasing the total investment cost and posing a barrier to financing and implementation or the system. The system could also be undersized which could lead to serious power outages endangering the reliability of the system, the trust of the consumers as well as their willingness to pay for electricity.

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[255] FX rate PHP/ USD (0.023) – 6. September 2014
[256] Expert Interview with Lyndon Azuceno, local renewable energy expert
[257] Hoppecke, OPzS, Vented led-acid battery, http://www.hoppecke-us.com/tl_files/hoppecke/brochures/us/OPzS_us0612.pdf

In the case of the island the future demand will also be dependant on how quickly the power demand of potential businesses in the marble industry and other businesses (e.g. refrigeration and chilling facilities for fish and other agricultural products) will pick up over time. The marble industry can provide a substantial load requirement because it is energy intensive from the extraction to the processing of the raw materials. Those new businesses would be strongly reliant on more and reliable power supply.

The simulations conducted in this chapter will therefore cover two possible scenarios. In the first scenario, which is relatively more conservative, the load demand is expected to increase from currently 68,480 kWh per year to around 248,700 kWh per year while the second scenario sees the demand increasing to around 363,300 kWh per year.

Current generation cost is around 30 PHP (appr. USD 0.68)[258] / kWh and current electricity cost for the end consumer is 37 PHP (appr. USD 0.81)[259] / kWh[260], i.e. in order to ensure the consumers ability and willingness to pay, the new tariff for the hybrid solution must not be above USD 0.68/ kWh. At the same time it is crucial that the new tariff is sustainable and at least covers the system's running and replacement costs (break-even tariff). In order to attract private operators the tariff must be financially viable, i.e. in addition it needs to cover a reasonable profit for the private operator.[261]

The least cost option is determined by two key financial indicators calculated by the HOMER software: the Net Present Cost (NPC) and the Cost of Energy (COE). The total NPC is the net present value of all cost while the COE is the total annualized cost divided by the total load served.[262] Usually the Net Present Value (NPV) is used to determine the Net Present Cost. The NPV is the equivalent value of a series of future net expected cash flows which are discounted for time and risk, summing those cash flows and deducting the initial period cash flow investment.

[258] FX rate USD/ PHP (44,33) – 28. September 2014
[259] FX rate USD/ PHP (44,33) – 28. September 2014
[260] Expert Interview with Fely Arriola, Energy Access Specialist with the ADB's Energy for All Initiative
[261] Alliance for Rural Electrification – Hybrid Mini-Grids for Rural Electrification: Lessons Learned, p. 7, http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Hybrid_Mini-grids_for_Rural_Electrification_2014.pdf
[262] HOMER Energy, Knowledgebase, http://support.homerenergy.com/index.php?/Base/Search/Index

Please find below the Net Present Value formula: [263]

$$\text{Net Present Value} = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} - C_0$$

The COE which is also called levelized cost of energy (LCOE) is an economic assessment of the system which covers all costs over the lifetime of the installation, including initial investment, operations and maintenance (O&M), cost of fuel and cost of capital. The LCOE therefore would be the minimum price at which the energy can be sold in order for an energy project to break even. [264]

Please find below the respective formula for LCOE: [265]

$$lcoe = \frac{Capex + \sum_{i=1}^{N} \frac{Opex_i}{(1+r)^i}}{\sum_{i=1}^{N} \frac{e_i}{(1+r)^i}}, \quad \begin{cases} r & \text{Discount rate} \\ e_i & \text{Specific energy yield [kWh/kWp]} \\ \text{N} & \text{Lifetime [years]} \end{cases}$$

4.3.1. Simulation 1 – 24 Hours Electricity Supply/ Low Load Forecast

In the first simulation the electricity supply is being extended from currently 12 hours/ day to 24 hours/ day with an expected increase of electricity consumption from 68,480 kWh per year to around 248,700 kWh per year. Electricity generated - which is currently sourced solely from diesel generators - shall be substituted with a least-cost hybrid electrification option taking into account the available renewable energy sources of solar, wind and/ or biomass.

Load Profile

The load profile is an essential component for the design of the system as it shows the consumers‘ electricity use and the peak load throughout the day. Figure 18 depicts the seasonal profile, i.e. monthly consumption patterns throughout the year.

[263] Pollard Grant, The Cost Decision: A New Discount Approach for Net Cost Projects, http://external-apps.qut.edu.au/business/documents/discussionPapers/2005/No%20199%20-%20Pollard.pdf

[264] National Renewable Energy Laboratory, Energy Analysis, Levelized Cost of Energy, http://www.nrel.gov/analysis/tech_lcoe_documentation.html

[265] Green Rhino Energy, Levelized Cost of Energy, http://www.greenrhinoenergy.com/blog/?p=55

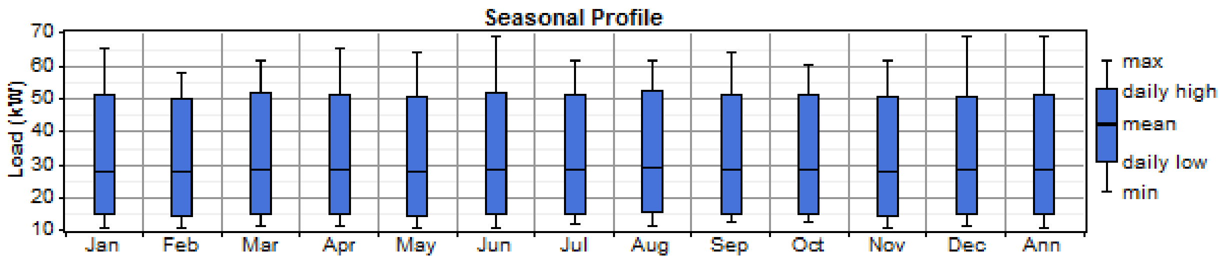

Figure 18: Homer Legacy, Homer Simulation 1, Seasonal Profile[266]

The daily profile shows the pattern of consumption on a daily basis. As can be seen in figure 19 peak load of 50 kW is recorded between 6pm and 9pm.

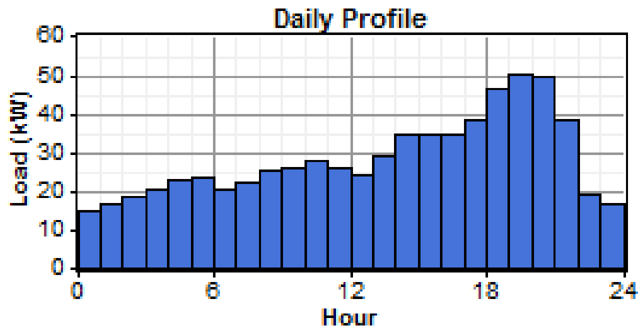

Figure 19: Homer Legacy, Homer Simulation 1, Daily Profile[267]

4.3.1.1. Least-Cost Option

For scenario 1 the least-cost solution, simulated and suggested by HOMER, is a 100% renewable energy system with solar PV and biomass being the only sources of power generation.

System Components

PV (kW)	GM (kW)	GM (kW)	GM (kW)	H3000	Converter (kW)	Renewable fraction	Biomass (t)	GM (hrs)	GM (hrs)	GM (hrs)
180	20	20	20	144	80	1.00	402	700	4,829	277

Table 8: Homer Legacy, Homer Simulation 1, Capacity System Components, Optimization Results [268]

[266] Figure 18: Homer Legacy, Homer Simulation 1, Seasonal Profile8
[267] Figure 19: Homer Legacy, Homer Simulation 1, Daily Profile
[268] Table 8: Homer Legacy, Homer Simulation 1, Capacity System Components, Optimization Results

The system would be composed of 180 kW solar PV, three separate biomass gasifiers with a capacity of 20 kW each and therefore have a renewable energy fraction of 100%. The system would be consuming 402 tons of biomass per year with the three biomass gasifiers operating 700 hours (gasifier 1), 4,829 hours (gasifier 2) and 277 hours (gasifier 3) per year.

Monthly Average Electricity Production

The figure below depicts the contribution of the different sources (Solar PV, Biomass) to power generation on a monthly basis, with Solar PV contributing the major portion throughout the year. The varying monthly combinations will meet the island's yearly electricity demand of 248,700 kWh.

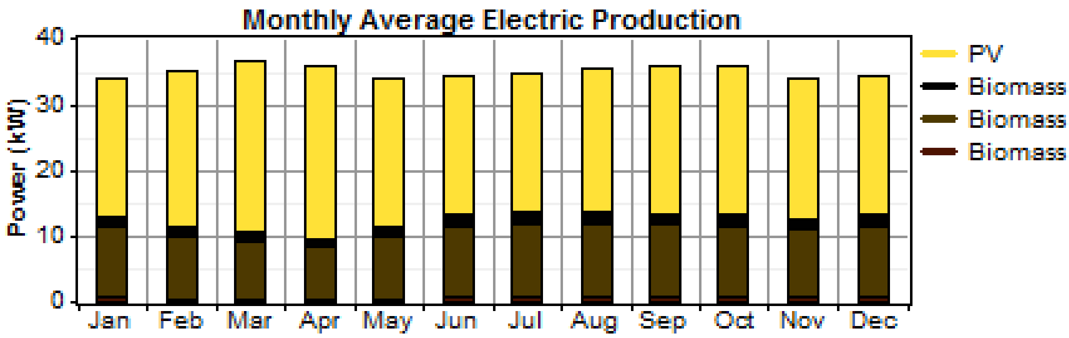

Figure 20: HOMER Legacy, Homer Simulation 1, Monthly Average Electric Production, Optimization Results[269]

System Cost Calculation

Table 9 shows the initial capital cost of the system components, operating costs over the lifetime of the installation and the Total Net Present Cost in USD per year. The cost of electricity as laid down below is USD 0.547/ kWh. The cost-effectiveness of the system overall is based on its Total Net Present Cost (NPC). In this case the total NPC of USD 1,176,830 is the least-cost system configuration taking into account a life time of 25 years for the solar PV component and 15,000 hours of lifetime of the biomass gasifier. The cost of energy as calculated by HOMER is around USD 0.55/ kWh.

[269] Figure 20: HOMER Legacy, Homer Simulation 1, Monthly Average Electric Production, Optimization Results

Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)
$ 786,200	44,857	$ 1,176,830	0.547

Table 9: Homer Legacy, Homer Simulation 1, Cost Calculation, Optimization Results [270]

As can be seen in the cash flow summary below, solar PV and batteries are the components contributing the major part to the Net Present Cost (NPC).

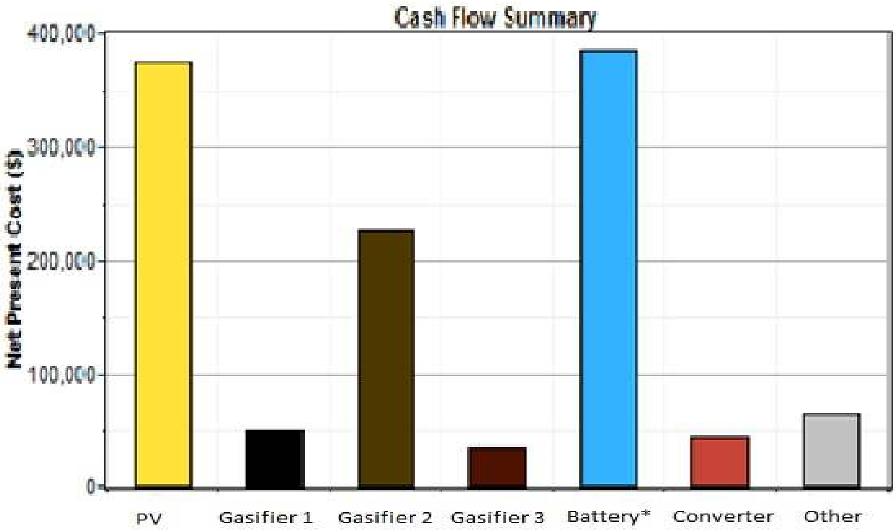

Figure 21: HOMER Legacy, Homer Simulation 1, Optimization Results, Cash Flow Summary[271]

*Battery: Hoppecke 24 OpzS 3000

4.3.2. Simulation 2 – 24 Hours Electricity Supply/ High Load Forecast

In simulation 2 electricity supply is again extended to 24 hours per day, but compared to simulation 1, assuming a much higher load forecast of 363,300 kWh/ year.

Load Profile

The seasonal profile as depicted below shows that throughout the year, peak load can reach around 70 kW.

[270] Table 9: Homer Legacy, Homer Simulation 1, Cost Calculation, Optimization Results
[271] Figure 21: HOMER Legacy, Homer Simulation 1, Optimization Results, Cash Flow Summary

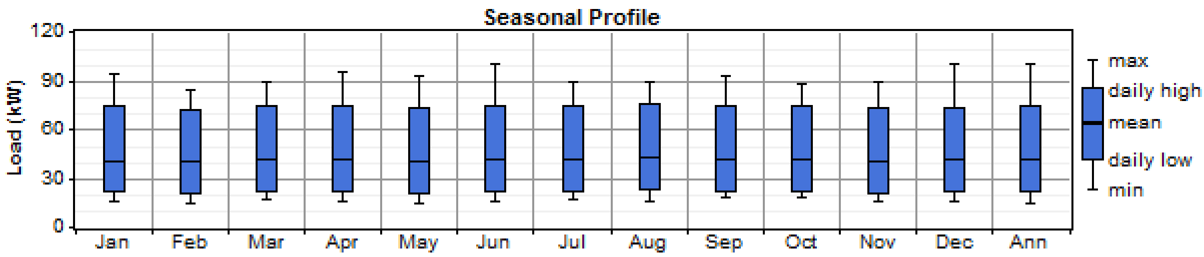

Figure 22: Homer Legacy, Homer Simulation 2, Seasonal Profile[272]

The daily profile of simulation 2 is assumed to be similar to the profile in simulation 1, except that the load is increased proportionally.

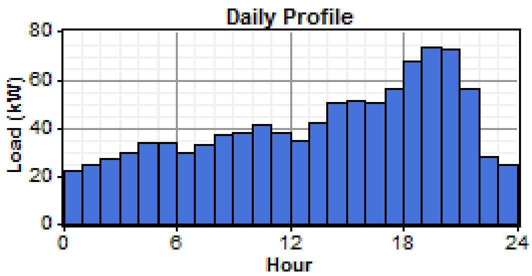

Figure 23: Homer Legacy, Homer Simulation 2, Daily Profile[273]

4.3.2.1. Least-Cost Option

System Components

Wind	GM (kW)	GM (kW)	GM (kW)	Dsl (kW)	H3000	Converter (kW)	Renewable fraction	Diesel (L)	Biomass (t)	GM (hrs)	GM (hrs)	GM (hrs)	Dsl (hrs)
1	20	20	20	100	48	80	0.77	28,49	658	2,221	6,316	711	899

Table 10: Homer Legacy, Homer Simulation 2, Capacity System Components, Optimization Results [274]

The least-cost system calculated by Homer for the predicted 363.300 kWh power demand per year is composed of one 35 kW wind turbine, three biomass gasifiers with 20 kW each and one 100 kW diesel generator which results in a renewable energy fraction of the system of 77%. The yearly consumption of the system would be 658 tons of biomass, and 28.490 litres of diesel. The three biomass gasifiers would be operating overall 9,248 hours per year (gasifier 1: 2,221 hours / gasifier 2: 6,316 hours/ gasifier 3: 711 hours).

[272] Figure 22: Homer Legacy, Homer Simulation 2, Seasonal Profile
[273] Figure 23: Homer Legacy, Homer Simulation 2, Daily Profile
[274] Table 10: Homer Legacy, Homer Simulation 2, Capacity System Components, Optimization Results

Monthly Average Electricity Production

Figure 24 shows the contribution from different energy sources (Wind, Biomass, Diesel) to power generation on a monthly basis. The figure clearly shows that the lower wind speeds from May to October would require more biomass and diesel resources to compensate for the gap. The varying monthly combinations will meet the island's yearly electricity demand of 363,300 kWh.

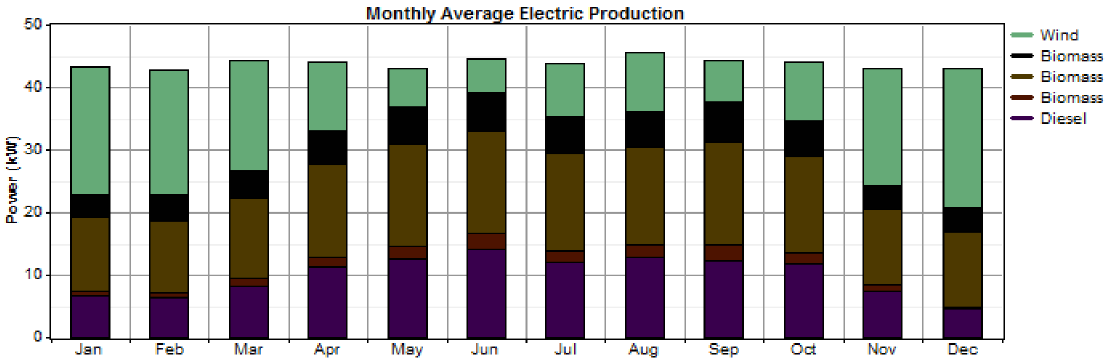

Figure 24: HOMER Legacy, Homer Simulation 2, Monthly Average Electric Production, Optimization Results[275]

System Cost Calculation

In simulation 2 the initial capital cost of the system is USD 620,400 while the operating cost is USD 134,063. The total net present cost (NPC) is USD 1,787,863 resulting in a cost of electricity of around USD 0.57/ kWh.

Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)
$ 620,400	134,063	$ 1,787,863	0.569

Table 11: Homer Legacy, Homer Simulation 2, Cost Calculation, Optimization Results [276]

The cash flow summary below shows that, in HOMER system simulation 2, the continous diesel supply required to operate the system, contributes by far the most to the total net present cost of the overall system.

[275] Figure 24: HOMER Legacy, Homer Simulation 2, Monthly Average Electric Production, Optimization Results
[276] Table 11: Homer Legacy, Homer Simulation 2, Cost Calculation, Optimization Results

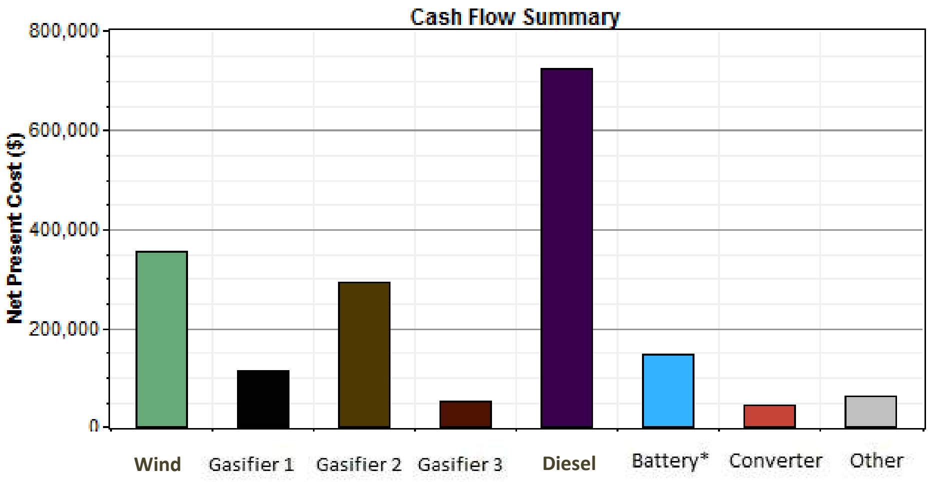

Figure 25: HOMER Legacy, Homer Simulation 2, Optimization Results, Cash Flow Summary[277]
*Battery: Hoppecke 24 OpzS 3000

[277] Figure 25: HOMER Legacy, Homer Simulation 2, Optimization Results, Cash Flow Summary

5. CONCLUSION

The core objective of this thesis is to prove that energizing islands in the Philippines through renewable energy sources will, in the long run, be more cost efficient than power generation through diesel and conventional fossil fuel. Actual implementation on the ground and replication of power production through renewables on a larger scale will only happen if there is enough evidence that shows that power production through renewable resources or hybrid diesel/renewable energy systems is the least-cost electrification option and if the legal framework and policies in rural electrification are well understood. In this context, the thesis thoroughly describes the legal, institutional and regulatory framework of electricity production in the Philippines, especially in the off-grid space. It also elaborates in detail on the policies of the Government of the Philippines in rural electrification and priorities as well as incentives available to accelerate the pace of rual electrification in the country.

The current energy policies for electrification and the legal framework in the Philippines, especially EPIRA, the National Electrification Administration Reform Act of 2013, and the Renewable Energy (RE) Act of 2008, strongly support and encourage electrification of remote off-grid areas, especially through renewable energy sources. The Government aims at electrifying 100% of all sitios until 2015 and intends to have 90% of all households energized by 2017. Currently, through NPC-SPUG, the Government takes the responsibility of electrification of off-grid areas that are not being served by the private sector and heavily subsidizes the end-consumer‘s electricity bill. Areas served by NPC-SPUG rely solely on power produced through diesel mini-grids, which brings along strong dependance on expensive and environmentally harmful diesel as fuel supply. The fact that the fuel has to be supplied to remote islands which are not easily accessible, especially during the rainy season, contributes to even higher fuel costs. Under the current subsidy system the amount of subsidies granted by the Government increases in line with the rise in the price of the fuel supply. This affects negatively the state budget and hence reduces the funds available for a change to an energy system based on renewable energy sources.

Along with the objective of total electrification of the country, the Government also aims at maximising the use of renewable energy sources. Through the use of renewable sources, the negative environmental impacts of diesel shall be mitigated and the overall power generation costs are expected to go down. Hence the amount of subsidies, being spent by the Government, is expected to go down as well. The Philippines is endowed with abundant renewable energy resources which is ideal for setting up hybrid renewable energy mini-grids. Solar and biomass are the most promising while hydro and wind are available in some areas.

NPC-SPUG provides power in 233 remote islands through diesel powered mini-grids. Out of those only 9% enjoy 24 hours of power supply. There is huge potential to substitute existing diesel mini-grids by hybridizing them with renewable energy sources, at the same time extending the hours of power supply or to set up new renewable energy systems in currently unenergized islands.

As the implementation of new power generation units, especially those powered through renewable energy sources, requires high upfront costs the Government, due to budgetary constraints, is not able to implement those installations on a large scale. For a successful introduction and large scale replication of hybrid renewable energy power generation and mini-grids in the Philippines, specifically in remote islands, it is therefore not only the technology that is important but also the delivery mechanism and business model. This is one of the reasons why the new legal framework, especially EPIRA, encourages private sector participation in power generation, both in off-grid and on-grid areas.

Implementation of hybrid renewable energy mini-grids will only be a feasible option if potential investors are sure that power production cost in the long run will be lower than generation through a conventional diesel mini-grid. Proof of commercial viability and long term sustainability will also be a precondition for commercial bank financing.

In this thesis a specific island with an existing island diesel powered mini-grid operating only 12 hours serves as the example for the case study to prove that hybrid renewable energy mini-grids can lower the long term power generation cost. Using the HOMER software, for renewable energy microgrid and distributed generation power system design and optimization, the objective was to prove that a hybrid energy power generation plant, making use of locally available renewable energy resources, will lower the power generation cost in the long run.

In the first HOMER simulation the current 12 hour power supply has been extended to 24 hours per day assuming an increase of power demand from the current level of electricity consumption of 68,480 kWh to around 248,700 kWh per year. The least-cost option simulated by HOMER suggests a 100% renewable energy mini-grid composed of 180 kW solar PV and three biomass gasifiers with a capacity of 20 kW each. The investment cost of this power generation plant would be around USD 786,200, operating costs USD 44,860 and the cost of electricity around USD 0.55/ kWh. This results in cost of electricity lower than the current generation cost of USD 0.68/ kWh for power generated by the diesel power plant.

The second HOMER simulation again extends the current 12 hour supply to 24 hours but assumes an increase of power demand to 363,300 kWh per year. The least-cost option in this case has a renewable energy fraction of 77%. The system overall would be composed of a 35 kW wind turbine, three biomass gasifiers of each 20 kW and a diesel generator. The investment cost would be USD 620,400 and operating cost around USD 134,060. The cost of electricity would amount to USD 0.57/ kWh which is still lower than the current generation cost of USD 0.68/ kWh.

Comparing the two simulations it can be stated that initial capital cost of the system in simulation 2 is USD 620,400, hence USD 165,800 cheaper than the system in simulation 1, although the system generates around 114,600 kWh more per year. The operating cost with USD 134,063 on the contrary is around three times as much in simulation 2 compared to USD 44,857 in simulation 1. The high operating cost in simulation 2 can be traced back to the continous fuel supply needed and the high cost of diesel, while simulation 1 is a 100% renewable energy mini-grid. The Total Net Present Cost (NPC) is USD 1,787,863 in simulation 2 compared to USD 1,176,803 in simulation 1 proving again that the higher renewable energy portion leads to overall lower total cost.

Both simulations prove that either a 100% renewable energy system (simulation 1) or a hybrid diesel-renewable energy generation system (simulation 2) in the long term are the least-cost option compared to a solely diesel powered generation plant. Both of the systems decrease the cost of electricity for the end consumers. Apart from this, multiple other benefits will materialize through substituting or at least partly substituting diesel powered generators with renewable energy sources. Less harm to the environment, mitigation of greenhouse gas emissions, less noise pollution and decrease of dependance on expensive imported diesel fuel, to name a few.

Of substantial importance when designing a least-cost system for the electrification of an island or remote area in general is a precise estimation of the projected future electricity demand in order to avoid over- or undersizing of the system. A detailed household survey on site needs to be conducted in order to learn about the aspirations of the end-consumers in terms of electric appliances that they are planning to acquire as soon as power is available 24/7, their willingness and financial ability to pay. The demand of all potential electrical appliances has to be calculated in order to get the aggregated demand for the end-consumers. The same goes for the power demand of businesses and other income generating activities that are planned by the local community. In the scope of this thesis no actual household survey was conducted on the ground. The case study has therefore covered two cases assuming in two simulations that the marble industry on the island will develop strongly and become an essential power consumer.

A crucial component, and main barrier, for the successful implementation of renewable energy mini-grids and rural electrification in general but also in the Philippines, is the question of financing of the upfront costs of renewable energy systems. The Government encourages the private sector to play a more dominant role in rural electrification and therefore has adopted a legal framework to allow private players to start generating electricity as NPPs or under the QTP scheme. Although commercial banks in the Philippines have financed hydropower generation plants, commercial financing of solar, wind or biomass renewable energy mini-grids is still the exception. In this context it is of utmost importance that potential financiers and investors have trust in the commercial viability of such an undertaking. Reliable assessment of the locally available renewable energy resource, the willingness and affordability of the local end-consumers to pay for the generated electricity and finally a HOMER simulation, proving that renewable energy mini-grids can be the least-cost electrification option, can make a strong case to convince commercial banks of the commercial viability of renewable energy for rural electrification.

The proof that renewable energy mini-grids are the least-cost electrification option for islands in the Philippines will hopefully lead to the implementation of commercially viable, sustainable pilot projects. The abundant indigenous renewable energy sources in the Philippines together with the financial and other incentives offered by the Government can make it a perfect showcase for sustainable off-grid power generation. That could also pave the way for large scale replication of those environmentally friendly power generation systems, not only in the Philippines but also in other off-grid areas around the world, and can contribute to lifting the 1.3 billion people worldwide, that are still without access to electricity, out of energy poverty.

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