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Wind Power Penetration and Integration in Rwanda

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Abstract

Wind energy is the current "star" in the field of renewable energy for electrical production. Still, the power generated from available wind over time is characteristically uneven due to the unpredictable nature of their primary source of power. This only increases the problems inherent to the integration of a great number of wind technologies into power networks, making their contribution rather difficult to manage (regulating voltage and frequency, wind-station operation, etc.). The integration of wind power in the Rwandan electrical system is now an issue in order to optimize the utilization of the resource and in order to continue the high rate of installation of wind generating capacity, which is necessary in order to achieve the goals of sustainability and security of supply. This paper presents and is intended to analyse wind power penetration and integration in the country, impact and challenges that are associated with the integration of wind power into power systems and analyse barriers to wind power penetration and integration in Rwanda. These impacts include effects of wind power on the electrical system, capacity of national grid to accommodate wind power (stability of grid). In addition, the paper suggests the solutions that should be offered to improve the management of wind power generation and increase its penetration in the overall electrical energy production.

Keywords: *Wind power potential, Wind power penetration, Barriers to wind power penetration, National grid of Rwanda, Integration.*

1.0 Introduction

From past century, wind potential in Rwanda has not been fully exploited for power generation although potential wind power that Rwanda has in some areas should provide with possible solutions such as to be used in water pumping systems, windmill, economic activities and electricity generation. A study of wind speed distribution has been made. In this study, the results have been found for the average wind speeds and directions for 5 stations: Kaniga, Kanombe, Gisenyi, Butare and Kamembe from 2010 to 2013. Among the wind records of data collected and used for this analysis were hourly wind records over a 4 years' period from that 5 weather stations (MANIRAGUHA E., 2013).

All of these stations are located in the local airports with windmill type anemometers installed at 10m above ground level; the annual mean wind speed exceeds 4.3 m/s for these 5 stations. These winds confirm that if they could be fully and appropriately exploited can generate enough energy. The study and analysis made proved that available wind resources have the impact as possible energy solution drivers for energy supply in the country based on fact that the current wind resources provide up to 66 Mwh and the trend showed that if the efficient and effective wind technologies are properly installed should produce more energy (REG, 2018).

Rwanda was undertaken to estimate the wind power penetration and integration in the country, the potentials of available wind were deeply studied in terms of penetration and integration across the whole country. In the wind potentials over the country studied; the study sampled a number of data especially data collected from 5 main stations (Kanombe, Gisenyi, Butare, Kamembe and Kaniga) as they are located in different location in the country. The collected set of data have been analysed by the Rwanda Meteorological Authority, institute which is responsible for all whether related data and reports (RMA, 2018). Once again, the data from those 5 synoptic sites were analysed by the Weibull function. The considered data have been used to evaluate the annual frequency of wind speed and the direction of wind, yearly variation of the monthly average, annual and daily variation, and vertical profile of wind energy potential (BIMENYIMANA, 2018).

Nevertheless, more detailed data is still required. A wind system was put in place to serve the Rwanda office of information on Mount Jali overlooking Kigali (RBA, 2012). This is the same site for the 250 kW solar systems feeding to the national grid. Hence, there is a need for more detailed assessment of the wind potential in the country. Due to increasing energy demand in all sectors in the country, the search is underway for other sources of energy. Thus, the application of energy from advanced wind technology has the potential to alleviate many of the problems faced by Rwandan every day especially if done so in a sustainable manner that prioritizes the setted environmental protection policies and regulations (SAFARI, 2019).

1.1 Statement of the Research Problem

Several researches have demonstrated the problem of persistence energy insufficiency in Rwanda (NYAMVUMBA, 2014). This problem has brought a number of negative effects on the development and to environment like accelerated deforestation, pollution, absence of infrastructure and so on. The major part of the energy consumed in Rwanda today still comes from wood (80.4 per cent). Yet studies carried out as far back as 2012 and 2015 already showed a gap of 9,000,000 m^3 of wood for energy needs only. As a result, there is massive deforestation across the country with consequent effects on the environment (SAFARI, 2019).

The installed electricity generation capacity is extremely low at 238.36 MW from all categories. Only 42 per cent of the population has access to electricity, and there is a gap in national production of electricity of more than 50 per cent which is filled by electricity imported from the Democratic Republic of Congo and Uganda (Privatization Secretariat, 2018). The obstinate absence of alternative energy sources is dragging an increased pressure on the available forest resources. “Currently, about 42% of population is connected to the electric network” (75% in urban environment and 8% in farming environment). The deficits in energy affect the economic development of the country in general and off-farming environment in particularly (REG, 2021).

The country progressively tried to find out the solutions that intended to increase the energy sources including signing mutual treaties with other members in East African Community and lobbying private investors to invest in the energy sector striving to have the part of country needed energy totaling at least 516 Twh in the year of 2024 (NISR., 2018).

Currently, Rwanda nation does not have enough wind devices like installed wind turbines in operation to exploit the available wind resources to meet energy demanded by urban and rural areas, this form of energy production is especially useful in remote locations because of the excessive cost of transporting electricity from large-scale power plants (MANIRAGUHA E., 2013).

This research revealed this insufficiency of energy as a problem and a gap to be filled. The level of installations of robust wind devices in all the main stations is an important factor used to analyse wind power penetration and integration in Rwanda.

1.2 Objectives of the Study

i. Establish wind power potential in Rwanda;
ii. Determine the extent of wind power penetration and integration in Rwanda;
iii. Analyse barriers to wind power penetration and Integration in Rwanda;
iv. Analyse the national grid of Rwanda, to see if it is equipped for wind integration;
v. Explore the impacts of wind power integration in Rwanda;
vi. Propose of integrating wind farms technology in exploitation of wind resources in Rwanda.

1.3 Research questions of the study

i. What is the wind power potential of Rwanda?
ii. To what extent is wind power utilised in Rwanda?
iii. To what extent has wind power been integrated in Rwanda?
iv. How well is the national grid of Rwanda equipped for wind power integration?
v. What are the possible social and environmental impacts of wind penetration and integration in Rwanda?

2.0 Wind Power integration in Rwanda

The integration of wind power in the national electrical system is now an issue in order to optimize the utilization of the resource and in order to continue the high rate of installation of wind generating capacity, which is 'necessary in order to achieve the goals of sustainability and security of supply (EWSA LTD., 2014).

2.1 The uniqueness about integrating wind energy

This section of research describes the unique characteristics of wind resources, wind energy policies, and wind devices or generators.

Variable Power

The energy output of Wind Power Device is variable because the wind speed is variable. Variability is in all timescales hour-to-hour, day-to-day, month-to-month, and year-to-year variability. Variability and uncertainty are very different concepts and are often misunderstood. Variability in wind speed is caused by the earth's rotation (day–night cycle), tilt axis of the earth (seasons), and other natural phenomenon. Examples of variability are higher wind speeds occurring in early morning hours and late evening, and higher wind speeds happening in spring and autumn. Hour-to-hour, day-to-day, and month-to-month changes in wind speed cause variability in wind energy production. A conventional base load thermal power devices may be considered to have minimal variability as long as sufficient fuel is delivered to it; any variability is due to planned activities like scheduled maintenance. Among

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variable renewable energy sources, solar dominates intraday variability because of sunrise and sunset. When diurnal variability is removed, then solar and wind have similar variability (LEWETAL, 2013).

Uncertain Power

Uncertainty has to do with unpredictability of wind speed. Continuing with the hypothetical case, the randomness around the variable pattern of wind speed is the uncertainty. Since wind is a weather phenomenon, uncertainty occurs in all time-scales, year-to-year, month-to-month, day-to-day, hour-to-hour, and smaller. A variety of forecasting methods are used to predict wind energy production. The following are true about accuracy of wind energy forecasts: (i) day-ahead forecast is less accurate than hour-ahead forecast, which is less accurate than 15-minute ahead forecast; (ii) forecast accuracy increases as the level of technology increases in a Wind device; and (iii) Forecast accuracy increases as the number of Wind tools and instruments increase and the wind power devices are in geographically diverse locations. Among renewable energy sources, wind energy has higher uncertainty compared to solar.

Geographic Diversity, Size and Distance from Load

Wind devices are located where the wind resource is high. In most parts of the world, areas with high wind resources are far away from population centers. There as it is difficult to live in areas with sustained high wind speeds. Such areas are either not served by a central grid or served by a "weak" grid. A weak grid is characterized by a long transmission line that carries a small amount of power. An implication for wind projects in such areas is the need to build new or upgrade existing transmission lines.

The second geographical aspect of wind power is its density. The output of a wind power device is an aggregate over multiple devices, and if there are multiple wind power instruments in the grid, then wind energy injected into the grid is an aggregate over the wind devices. Aggregation contributes to reduction in uncertainty of wind energy (because all devices do not capture the same wind speed profile) and to a lesser extent reduction in variability of wind energy.

2.2 The possibility of integrating-wind power in the National grid of Rwanda

Grid integration of wind energy is simply a collection of all activities related to connecting wind power devices and technology to the grid. Activities are split into three categories based on when the activities occur. The first stage; planning, includes activities that occur before a wind power device is integrated. Physical connection encompasses activities that occur during the physical connection of the wind device to the grid (PRAMOD J., WIJAYATUNGA P., 2016). The final stage is system operations, which are the activities that occur after the wind power device is connected to the grid (Figure 1).

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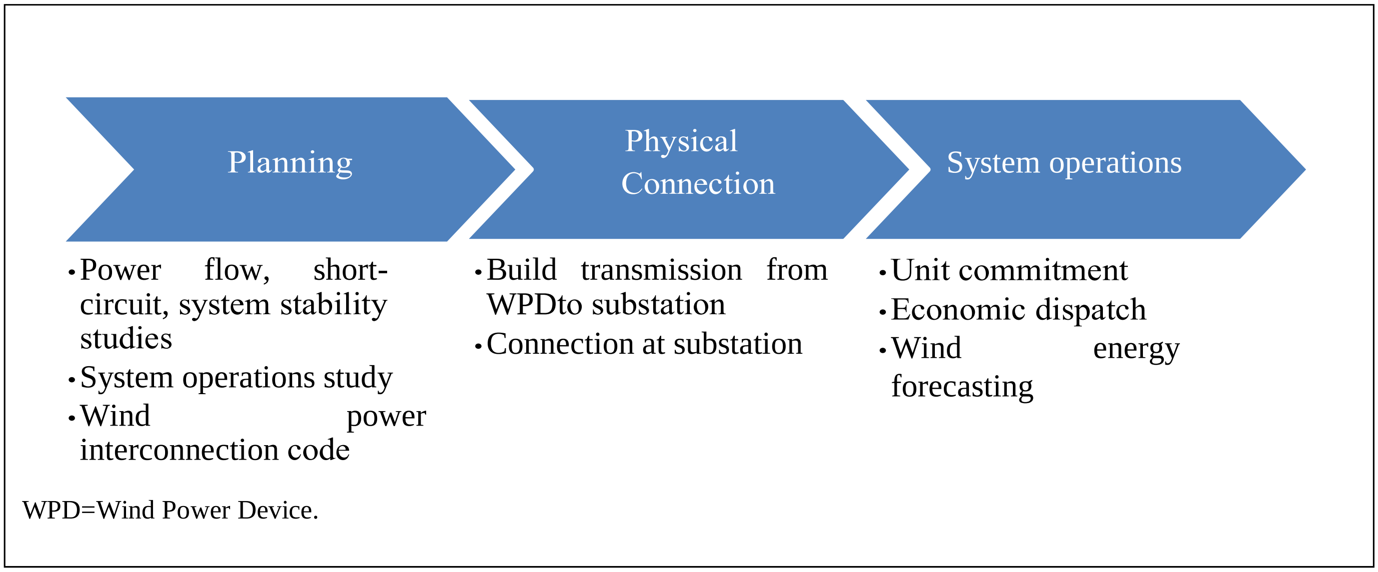

Figure 1: High-Level Activities of Grid Integration

Source: Pramod Jain and PriyanthaWijayatunga, 2016

Planning

There are two distinct types of planning activities related to grid integration: network-wide and project-specific. Network-wide activities set the stage for all future wind power devices; these include grid code development, network-wide system integration studies with scenarios for different levels of wind penetration, and system operations studies. Project-specific planning activities include system impact studies done for a specific wind study. The methodologies for both types of studies are the same, except for input data related to wind power installations. In a network-wide study, the input is wind energy targets by region; while for a project-specific study, the input is wind power instrument installations.

Physical Connection

Physically, a wind power device is connected to an existing high voltage transmission line in a substation. In order to avoid the expense of building a substation, most wind power instruments tend to connect to an existing substation. In the substation, the wind power instrument line is connected to the medium voltage bus bar, which is connected to a transformer to step up the voltage to the high voltage transmission line. The medium voltage line from the WPD to the substation is built by the Wind Power Devices. The detailed design of the interconnection depends on the conditions on the ground (ADB, 2019).

After the WPD is constructed and ready for commissioning, the operation engineers from the transmission operator are involved in the commissioning phase to ensure that it become safe to operate and it produces energy of acceptable quality. After issues related to commissioning are resolved and supervisory control and data acquisition connectivity is established, a request for initial harmonization is made to system operations.

The synchronization or harmonization and subsequent testing process depend on the transmission study's processes and checklists (JAIN, 2010). Primary tests performed include:
(i) Proper functioning of start-up, shutdown, and emergency shutdown;

(ii) Proper function in switch gear in response to a variety of fault conditions;

(iii) Harmonics, flicker, and other quality parameters are within limit; and

(iv) Successful communication of data from WPD to supervisory control and data acquisition system (MATHEW, A., 2001).

System operation

After the wind power device is physically connected to the transmission line, the attention of grid integration turns to system operations, which integrate the production of wind power device into the grid operations. The goal of grid operations is to commit and dispatch all generation units in the system with the objective of meeting demand in a reliable and economical manner. Wind energy forecasting is an important enabler in order to meet these objectives, given the variability and uncertainty of wind resources. Day-ahead hourly wind energy forecasts are used in the unit commitment process and intraday updates to forecasts are used in the economic dispatch process (DEBRA J., 2005).

3.0. Research Methods and Methodology

Based on the nature of the research and characteristics of respondents, the sample of 2 262 respondents from different institutions were selected over the country. The study prioritizes the respondents from energy related entities, meteorology agency, researchers and scholars and members of private sectors who are the stakeholders of the study. A part of respondents has been given the questionnaires to answer different questions while other remaining part were interviewed and their answers were considered, summarized and presented in the table. Table 1 reveal the extent of wind power penetration in the country; establish wind power potential in the country and study whether national grid of the country is equipped for wind integration.

The sample size for the present study was computed using the following Slovin's Formulae as statistical formulae (SLOVING, 2016).

The Sample Size $(n)=\frac{N}{1+N(e^2)}$

For determining the sample size, we used the Taro Yamane formula; Where:

n: Sample size,

N: Number of population under study,

e: Margin of error (Which can be 0.10; 0.5; 0.02;0.01), the usually more used one is 5% or 0.05.

The study used Slovin's formula to find out what sample of a population of 23,475 people the study need to take for a survey on their preferences to get accurate and fair values.

Step 1: In this study, research figured out 98% as our confidence level. Hence with a confidence level of 98 percent (giving the study an alpha level of 0.02), or it might need better accuracy at the 98 percent confidence level (alpha level of 0.02).

Step 2. Inserting the data into the formula. Thus, it uses a 98 percent confidence level with a population size of 23,745 people.

$n = N / (1 + N e^2)$

$23,745 / (1 + 23745 * 0.02^2) = 2, 261.859$

Therefore, the Sample size (n) is equal to **2, 262** People

Table 1: Sample Selection

DESCRIPTION			QUESTIONNAIRE METHOD		INTERVIEW METHOD	
S/ N	**Category of the Respondents (Institution)**	**Number of Populatio n**	**Selected Sample Size**	**Selected Sample Size in Percentage**	**Selecte d Sample Size**	**Selected Sample Size in Percentage**
1	REG	6,937	351	19.9	125	25.0
2	EUCL	3,845	240	13.6	98	19.6
3	RMA	2,894	325	18.4	79	15.8
4	MININFRA	4,683	456	25.9	109	21.8
5	Private Sector (P.S)	5,386	390	22.1	89	17.8
	TOTAL	**23,745**	**1,762**	**100**	**500**	**100**

Source: Primary data, 2021

The study has considered all the institutions in the country which are more likely to be impacted by the energy sector since they are regulators and stakeholders in this sectors and their experience have a great and positive impact in reinforcing the energy sector.

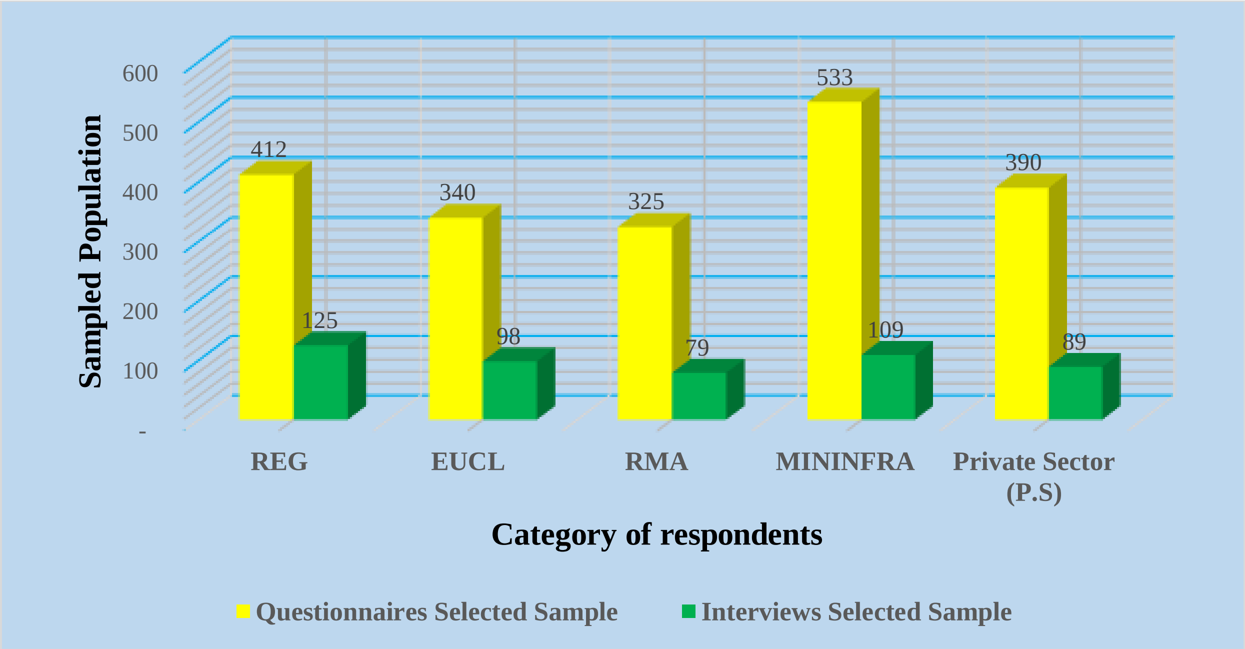

Figure 2: Graph of sampled data from respondents

Source: Primary data, 2021

The figure 2 shows graphical presentation of the sampled respondents where the officers in the Ministry of Infrastructure were most likely chosen for questionnaires with 25.9% and officers from REG comprised a big number on the interviews with 25%.

The sample size is determined from the table 1, by considering 2,262 of individuals in the country where both male and female have equal chance to be chosen from the whole population. The research methods used are questionnaires and interviews in different perspective. A variety of data were collected and sample size was determined to facilitate the research to provide accurate and dependable and fair results. A study of wind speed distributions has been made. In this study, the results of primary data collected from the field and questionnaires have been found for average wind speeds and directions for 5 studied station in 2021.

4.0 Results and Discussions

4.1 Wind Power Potential of Rwanda

The table 2 and 3 below show the wind power potential from 5 main stations in Rwanda. These stations are: Kaniga, Kanombe, Gisenyi, Butare and Kamembe respectively.

Table 2: Wind data of Kaniga

Station	Parameter	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Kaniga	Vm(m/s)	3.8	3.8	4	4.1	4.2	3.9	4.2	4.1	4.3	4.2	4.1	4	4.1
	σ(m/s)	3.2	3.3	3.1	3	3.4	2.9	3.4	2.9	3.1	3.2	3.2	2.9	3.2

Source: Rwanda Meteorological Agency, 2021

Table 3: Monthly and Annual Mean Wind speeds and Standard deviations for the investigated Stations

Station	Parameter	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
Kanombe	Vm(m/s)	4.5	6.5	4.3	4.7	5.9	4.4	4.8	3.9	5.9	4.4	6.2	5.4	5.1
	σ(m/s)	3.1	3.9	3.7	3.4	3.8	3.5	3.3	2.7	3.2	3.9	3.3	3.8	3.5
Gisenyi	Vm(m/s)	4.2	3.9	4.8	3.5	5.2	4.5	3.7	4.3	3.8	2.4	3.8	4.7	4.1
	σ(m/s)	3.5	2.4	3.2	2.6	2.8	3.3	3.1	3.3	2.8	2.9	3.2	3.6	3.1
Butare	Vm(m/s)	3.6	3.3	3.8	4.2	3.8	3.5	4.3	3.9	4.9	3.6	4.1	4.7	4.0
	σ(m/s)	2.8	2.9	3.0	3.5	3.3	3.1	3.6	3.8	3.4	3.1	3.7	3.5	3.3
Kamembe	Vm(m/s)	3.3	3.5	4.9	3.4	5.2	3.8	4.2	3.8	4.2	4.8	6.5	4.5	4.3
	σ(m/s)	2.6	2.7	3.5	3.1	3.9	3.2	3.9	3.5	3.6	3.3	3.6	3.8	3.4

Source: Rwanda Meteorology Agency, 2021

Table 2 and 3 show the detailed comparison on monthly and the annual mean wind speeds and the standard deviations of the studied stations and the data found prove that the whole country has the potential to provide energy that may effectively and efficiently contribute to different sectors of activities and domains. Note that Vm stand for mean of wind speed and σ stand for standard deviations as they are expressed in meter per second. The feasibility of data collected on the studied stations intended to investigate the integration of wind energy in Rwanda took 5 stations as appropriate samples that gave fair and accurate findings to be based on. The periodic obtained results were summarised and presented on the following graphical presentation as statistical study approach.

The expected maximum wind of each station was computed using the following formulas:

$$\text{Maximum Share of Wind Power} = \frac{\textit{Maximum wind power generated (MW)}}{\textit{Minimum load} + \textit{Power exchange Capacity}}$$

Source: Carlos Perez Linkenheil, Marie-Louise Niggemeier and Simon Göss., 2017

Table 4: Wind Power Density in the studied stations

S/N	Main Studied Stations	Average Wind Power in MW/m^2	Percentage %
1	Kanombe	22.42	25.66
2	Gisenyi	13.68	15.66
3	Butare	13.17	15.07
4	Kamembe	17.36	19.87
5	Kaniga	20.75	23.75
TOTAL		**87.38**	**100.00**

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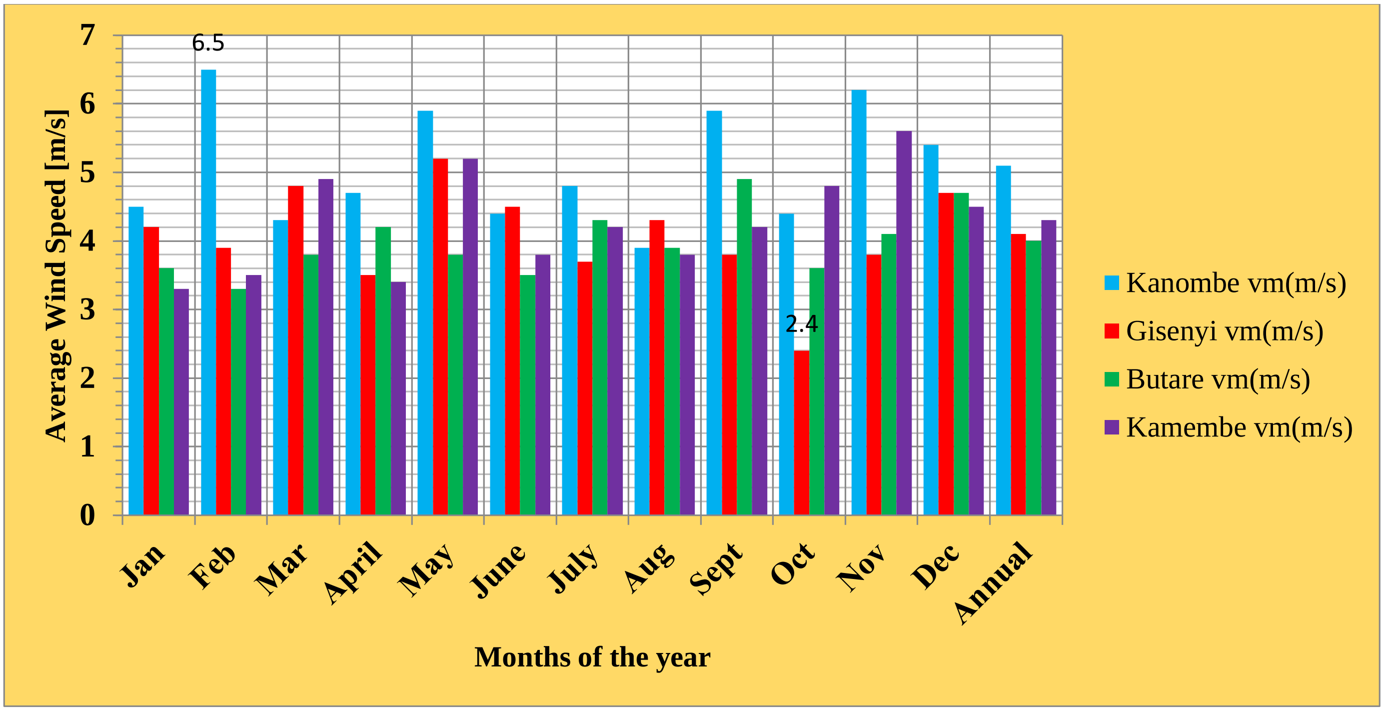

Figure 3: Graphical representation of monthly and annual mean wind speeds for the investigated Stations

Source: Rwanda Meteorology Agency, 2021

In table 2 and 3 variation of wind speeds for the stations are given. It is evident that the speeds range from 2.4 m/s to 6.5 m/s with the minimum occurring in the morning hours while the maximum occurs in the afternoon hours. Since daytime data was available from 6 a.m to 6 p.m for the investigated stations, by inference it can be said that higher wind speeds are prevalent during daytime while at night lower wind speeds dominate perhaps due to higher solar intensity that occurs during the day. The claim is supported by the general decline of wind speeds for all stations from 6 a.m until 8 a.m when the sun's intensity starts to increase. The highest diurnal wind speed of the four stations occurs at Kanombe where the speeds range between 3.9 m/s and 6.5 m/s.

Largely, the speeds are moderate for adequate generation of wind power given that modern wind energy conversion systems start to generate power at a cut-in-speed of 3 m/s. However, for wind device the wind speeds could just be sufficient to provide electric power to domestic and small-scale enterprises since there is wind device installed in the region. The lowest diurnal wind speeds are at Butare stations with mean range varies between 3.3 m/s and 4.7 m/s. Adequate use of available wind energy on a site requires sufficient information about wind characteristics that include level and regularity of wind speeds. The distribution of wind speeds is useful in the design of wind instruments, power generators, and agricultural applications like irrigation and watering as modern techniques applicable in agriculture sector.

In table 2 and 3, the monthly and annual mean wind speed Vm and standard deviation σ for the stations are presented and they were calculated from measured data. It is apparent that monthly mean wind speeds among the stations range between 2.4 m/s and 6.5 m/s with the lowest monthly mean wind speed of 2.4m/s reported in October at Gisenyi station while the highest speed (6.5 m/s) occurs at Kanombe in the months of February.

The table 2 and 3 reveal that Kanombe has higher wind speeds 5.1 m/s with highest variability compared to wind speeds Gisenyi, Butare and Kamembe stations. The standard deviation varies from a low of 2.4 m/s in Gisenyi to a high of 3.9 m/s in Kanombe. The Weibull parameters are shown in table 2 and 3 where the annual value of k appears in the range $4.3 \leq k \leq 5.1$ and that of the scale parameter c varies between 2.4 m/s and 6.5 m/s.

The wind data obtained are summarized and briefly presented in the following Pie chart.

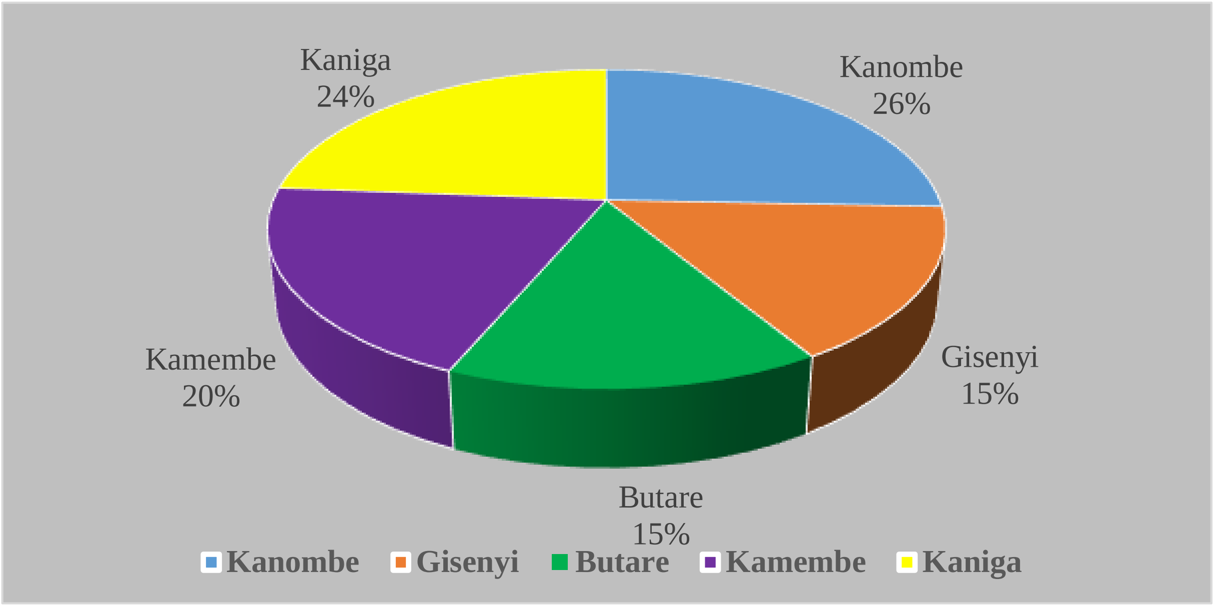

Figure 4: Average Wind Power Density in W/m^2

Therefore, the annual wind power densities for Kanombe, Gisenyi, Butare, Kamembe and Kaniga have been estimated on average as 22.42W/m^2, 13.68W/m^2, 13.17W/m^2, 17.36W/m^2 and 20.75W/m^2 respectively, from the yearly mean wind speeds of 5.1m/s, 4.1m/s, 4.0m/s, 4.3m/s and 4.1m/s. From the results, it is obviously that Kanombe shows the possibility and probability of greatest wind power potential of all the five sites studied hence it is a promising site for installing a technological wind instruments for moderate-scale power generation. Large-scale wind power generation require that mean wind speeds exceed 7m/s to generate at least 200W/m^2. Using the results, the sites are classified under wind power class 1 since most of their mean velocities are below the 4.4m/s threshold and its potentials should be used to generate energy.

4.2. Results analysis and interpretation

The summarised findings are the results obtained from questionnaires and interviews studied on 2,262 respondents of different categories and analysis and interpretation of results were conducted using different statistical method include using mean or averages and standard deviations to analyse wind power penetration and integration in Rwanda.

In the table 5 the study has presented the number of respondents who answered the research questions. In evaluation, summarising and presenting responses from respondents some responses were classified as either valid or invalid. All the valid cases were considered to find the reliability of the research. Since in interpretation and analysis the study needed the accurate figures to rely

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on, only the valid responses have been carefully considered to forecast the opinions and recommendations.

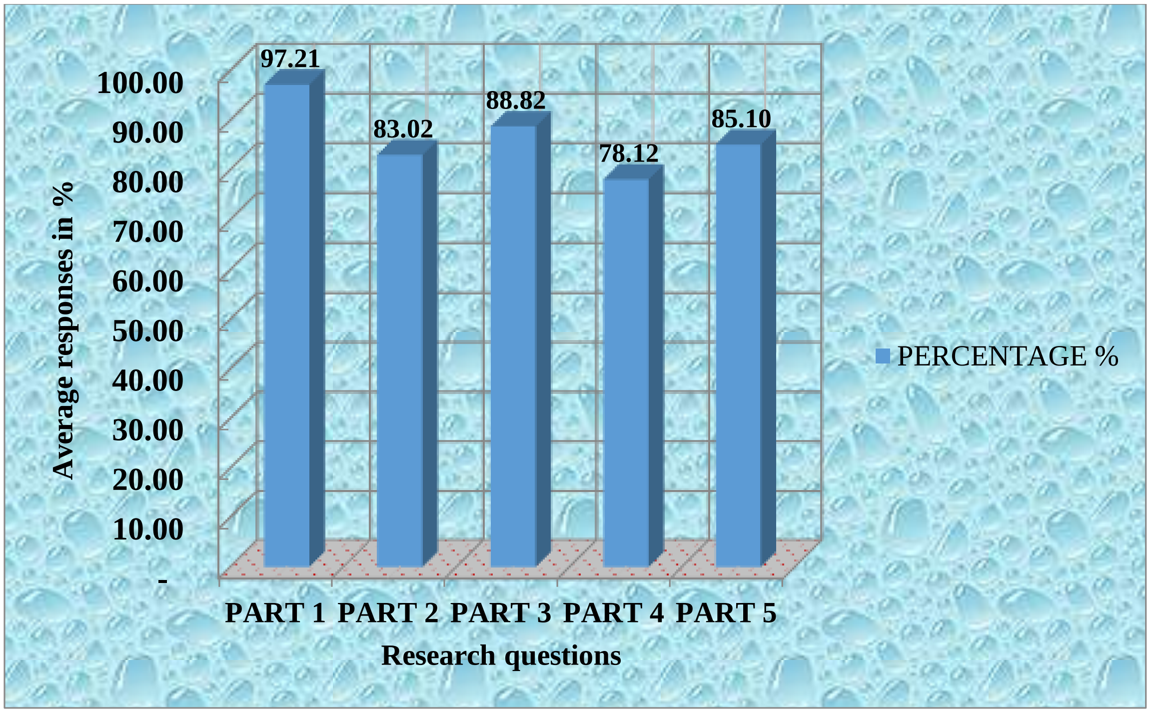

Figure 5: Valid Responses from Research Questions

Source: Primary data from Questionnaire and Interviews, 2021

Based on the result summarised and presented in the figure 5; the study shows that most respondents were highly excited by the first part of research questions which talked about the barriers and problems against wind power penetration in Rwanda with up to 97%. Thus, by referring the available research questions of this study, as per table 8 the research has summarized the obtained results of each part of research questions and corresponding charts were drawn in the table.

Table 5: Summarised Presentation of Data collection

Question	**NUMBER OF RESPONDENTS FOR EACH QUESTION**						
Answers	**a**	**b**	**c**	**d**	**e**	**Total number**	**Findings and comments**
PART I	**What are the barriers and problems against wind power penetration in Rwanda?**						
1	490	374	562	450	323	2199	Research has revealed that there are a number of barriers and problems include lack of enough researches, study and feasibility analysis on Wind power; Climatic changes that hinder the scholars and institutions to predict and forecast on wind and lack of appropriate technology and sufficient fund to invest in renewable energy sectors.
2	76	628	701	321	152	1878	
3	1359	903	0	0	0	2262	
4	81	267	704	527	389	1968	
5	179	1198	341	216	0	1934	
6	679	380	338	395	438	2230	
7	826	179	369	469	397	2240	
8	1457	786	0	0	0	2243	

https://doi.org/10.53819/81018102t4035

9	285	485	527	389	312	1998	
PART II	**To what extent is wind power utilized and integrated in Rwanda?**						
1	579	798	341	216	0	1934	Based on the results of this part of the study, research showed that even if wind power is used; there is a gap that wind energy was not fully exploited to the fullest and yet there are a few number of research in this field that should be fulfilled. Deep studies on wind are highly recommended and encouraged.
2	679	480	368	439	0	1966	
3	879	826	369	58	43	2175	
4	1457	786	0	0	0	2243	
5	285	485	527	389	312	1998	
6	679	380	338	395	438	2230	
7	258	407	301	294	752	2012	
PART III	**What are the possible impacts of wind power penetration and integration in Rwanda?**						
1	692	474	362	350	223	2101	The study showed that there are environmental and social impacts arise from wind power penetration and exploitation including using energy sources that do not emit polluting gases in the atmosphere and that are available in the country at low cost of exploitation.
2	276	628	701	321	152	2078	
3	81	267	704	527	389	1968	
4	751	627	24	327	309	2038	
5	573	480	358	395	89	1895	
6	179	826	369	469	397	2240	
7	347	311	85	39	1259	2041	
8	258	480	338	439	679	2194	
9	279	426	369	258	659	1991	
10	279	426	369	278	759	2111	
PART IV	**How well is the national grid of Rwanda equipped for wind power integration?**						
1	214	371	102	327	971	1985	With the results of this part, the study proved that the grid integration under the current institutional arrangements come with important benefits. Although there are technical issues that need further investigation and corrective actions, it is recommended that the government of Rwanda maintains the conducive regulations to encourage private-public partnership to expand their production and usage.
2	309	498	689	216	359	2071	
3	217	198	358	395	779	1947	
4	205	526	899	269	0	1899	
5	347	311	985	213	139	1995	
6	285	215	1136	289	312	2237	
7	258	465	715	439	124	2001	
8	279	426	369	867	74	2015	
9	279	426	369	298	759	2131	
PART V	**How can integrating wind farm technology contribute to social and environmental protection in Rwanda?**						
1	861	198	358	495	146	2058	The results showed that use of modern wind turbine technology might play an important role in increasing the capacity of available energy and produce less
2	205	426	376	892	108	2007	
3	347	311	429	985	139	2211	
4	753	328	446	59	300	1886	

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5	258	535	914	214	104	2025	carbonated energy which can be used as environmental protection driver.
6	379	526	369	240	789	2303	

Source: Primary data from Questionnaire and Interviews, 2020

In the table 5 the study has presented the number of respondents who answered the research questions. In evaluation, summarising and presenting responses from respondents some responses were classified as either valid or invalid. Only all the valid cases were considered to find the reliability of the research. Since in interpretation and analysis the study needed the accurate figures to rely on, only the valid responses have been carefully considered.

4.3 Questionnaire results analysis and interpretation

The questionnaires given to respondents during the research process served as the facts and evidences to the obtained figures and findings presented in table 5. Since each question of the study has its own uniqueness and purpose the study has analysed each question independently from others as they are detailed in the following presentations and narrations. Briefly questions were analysed in table 6.

Table 6: Findings from questionnaires and its interpretations

Question	**SUMMARY OF RESULTS FROM QUESTIONNAIRE ANALYSIS**			
PART I	What are the barriers and problems against wind power penetration in Rwanda?	Total no of answers	Percen tage %	Summary of the study findings and interpretations
1	In which institution did you employ in?	2199	25.56	Out of 2199 sample respondents, their majority of 25.56% were employees for Meteorology Agency
2	How old are you?	1878	37.33	In the respondents used in this research 37.33% comprised a large portion. The study proved that they range between 41 to 50 years old.
3	What is your gender?	2262	60.08	The study used 2262 people where 60% of them were male and comprise the majority.
4	What is your education level?	1968	35.77	In the research, the findings have proved that out of 1986 who answered, 33.77% have the required knowledge, ability and capacity to represent the whole population. A good number of them are graduates
5	What is your Marital Status?	1934	61.94	By considering the marital status, it has been shown that in 1934 (61.91%) of the sampled population were married.
6	What is your province of residence?	2230	30.45	In the sample of 2230 people who consists 30.45% majority were resident in Kigali City but other regions were represented

7	What type of housing do you live in?	2240	36.88	The research discovered that the majority of respondents lived 36.88% in town houses.
8	Have you ever used/consumed wind energy any time here in Rwanda?	2243	64.96	In 2243 respondents studied, 39.9% has consumed on wind energy and they have some related discussion.
9	How did you first hear about wind energy utilization in Rwanda?	2098	25.12	The research carried out had demonstrated that there is a part of them heard and experienced in consuming and using wind power energy with 36.82% out of 2098.
PART II	To what extent is wind power utilized and integrated in Rwanda?			
1	In studying wind energy impacts in Rwanda, would you say that the noise wind turbine used has any effect on your health?	1934	41.26	Out of 41.26% of the total respondents have approved that in generating wind energy sometimes wind instruments used generate noise which may affect people health and habitant of some animals.
2	How do you evaluate the overall sound environment at your dwelling?	1966	34.54	The statistical findings show that 34.54% in the study of wind energy, the instruments tend to generate weak sound that cannot have negative impacts on the environment and their tones is low.
3	What are the environmental impacts of large wind devices in the country?	2175	40.41	In the 2175 valid responses the respondents show that 40.4% has demonstrated that actual large wind devices have no impacts except some methods used which are averse to environmental promotion and protections standards that are manageable and can be shall be regulated.
4	What are the social impacts resulted from using wind energy in the country like Rwanda?	2243	64.96	The results obtained proved that using wind energy people's health would increase overtime about 64.9% support the idea of using wind energy.
5	What are the environmental benefits of wind energy compared to other energy sources currently used in Rwanda?	1998	26.38	In 1998 respondents who showed the environmental benefits of wind energy, a great number of them have showed that wind energy produce energy without harming environment, they are economically exploitable resources and maximize the opportunities for industrial, economic and rural development.

6	Grid integration issues are a challenge to the expansion of wind power in most regions of Rwanda, Solutions such as aggregation of wind device technology, forecasting and modelling have to be implemented to facilitate higher and deepest penetration of wind power''. What is your position to this statement?	2230	30.45	The results show that 30.45% of the chosen sample strongly agree with the statement. The results propose that as aggregation of wind device technology, forecasting and modelling have to be implemented to facilitate higher and deepest penetration of wind power.
7	In formulating strategies to tackle the challenges of wind power grid integration; the concerned parties are encouraged to implement some measures and techniques include to:	2012	37.38	The majority of the respondents which is 37.38% recommend to conduct effective research and development, planning of designs intended to reinforce and extends the existing interconnected grid and set wind farm as appropriate infrastructures that could fill available energy gap.
PART III	What are the possible environmental impacts of wind penetration and integration in Rwanda?			
1	Choose the type of energy you currently use the most	2101	32.94	At the time all respondents were requested to present the energy they mostly consume, 32.94% of them were found that they use biomass which is against environmental promotion standards.
2	Based on your skills, experience and observation, "Shall the wind power integration in Rwanda bring on the existing power system stability, reliability and efficiency?	2078	33.73	The research proved that they agree with the alternative hypothesis wind power integration in the country shall bring on the existing power system stability, reliability and efficiency which were supported by 37.38%.
3	From your experience, Rate the extent to which wind power in Rwanda is used	1968	35.77	The obtained rate on the extent to which wind power in Rwanda classified, where 35.77% confirmed that wind power penetration is at low level.
4	Based on your experience, what is the level of wind variability per period on your Station?	2038	36.85	In this research the level of wind variability per period on the stations showed high level of variability up to 36.85%.
5	Based on your personal experience, what types of resources in your area that could be used to generate additional sources of energy to satisfy energy insufficient problem in Rwanda?	2201	60.93	In addressing the problem of energy shortage gap, the analysis has proposed that wind energy utilization should be maximized to the highest level of exploitation to address the problem where 60.9% are on this argument.

6	Based on your experience and skills, how does wind power cost to produce energy compared to the other forms of energy?	1895	30.24	The results have proved that using wind energy is cheaper than other available sources of energy as it was confirmed by 30.24%
7	If the farms are built, how will they affect future growth in the country?	2240	36.88	Based on the current energy situation, the future projections show that the economic growth and development could be accelerated if advanced technology of wind devices like wind farms are applied in the country to boost the capability of maximize the exploitation of available energy resource with 36.88%.
8	According to you, what are the barriers against wind power penetration in Rwanda?	2041	61.69	The obtained figures have represented that lack of enough researches, Climatic changes, Lack of appropriate technology and sufficient fund to invest in renewable energy sectors and Weak government laws, regulations related to wind power penetration as the main barriers against wind power penetration in Rwanda the statistics showed that with 61.69%
9	What do you think as the advantages of using wind energy over other available energy sources in Rwanda?	2149	31.55	The research shows that wind produces energy that has fewer effects on the environment than many other energy sources where a big number prefer and propose to shift from traditional sources to wind energy with 31.55%.
10	How often do you either see a physical wind turbine or heard of them in Rwandan Community?	2194	30.95	The majority of respondents show that they do not more likely to have knowledge and experiences about wind energy. For example, most of them are far from the information and the capacity to be used.
PART IV	Is the national grid of Rwanda well equipped to accommodate wind power integration?			
1	The research revealed that integrating wind energy to the national grid of Rwanda has beneficial impact to the country development and protecting environment" What is your standpoint on this statement based on your experience and knowledge?	1985	48.92	The large part of the study with 48.92% strongly support the statement. They support that integrating wind energy to the national grid of Rwanda has beneficial impact to the country development and protecting environment.

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2	If someone is interested and meets all the required conditions to get electricity from national grid of Rwanda, how long it takes for the installation to take place?	2071	33.27	The study findings have revealed that due to insufficient infrastructure which provide energy low energy it could even take more than a year to be connected to the national grid where more than 33.27% support.
3	Is the national grid of Rwanda well equipped to accommodate wind power integration?	1947	40.01	The results obtained show that more than 40% strongly agree that the national grid of Rwanda are well equipped to accommodate wind power integration.
4	In terms of satisfying energy needs in the country; how do you rate the performances of national grid of Rwanda compared to overall energy needed in the country?	1899	47.34	In terms of satisfying energy needs in the country, the study shows that the performances of national grid are at the lowest level as it was responded by 47.34%
5	Which one do you consider as the best "on shore Grid" Or "off shore Grid" connection in energy utilization in Rwanda as case study?	1995	49.37	The study has demonstrated that 49.37% of the studied respondents have preferred both on shore grid and off shore grid connection as the best approaches.
6	Rwanda has very ambitious targets to achieve 516 MW installed power generation capacity, from its current 238 MW (2021) power generation and have universal access (100%) by 2024. How to reach on that objectives and targets:	2237	50.78	The results of 50.78% presented prove that to reach to the target of having universal access in the case both on-grid and off-grid connections will be considered.
7	Does national grid of Rwanda produce stable and enough electricity?	2001	35.73	The obtained results of 35.73% proved that the available electricity are not enough and not stable.
8	What are the major current sources of energy used in Rwanda?	2015	43.03	With 43% of major current sources of energy used in Rwanda originate in both imported energy, renewable and non-renewable sources
9	Which one is the most important requirement for interconnecting wind power devices to a national grid?	2131	35.62	The study has shown that the most important requirement for interconnecting wind power devices with national grid is 35.62% supported the protection and power quality requirement to be implemented.
PART V	How can using wind farms technology contribute to environmental protection in Rwanda?			
1	Which of the following do you see as the biggest concerns regarding wind power penetration and integration in Rwanda?	2058	41.84	The study revealed that 41.87% of respondents support the statement that less researches and study related to wind

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				resources exploitation is a challenge to be addressed to meet energy supply gap.
2	What should be the most important considerations in setting sustainable and efficiency wind power supply for consumption?	2007	44.44	In the study 44.4% respondents suggested that the most important considerations in setting sustainable and efficiency wind power supply for consumption both costs of installations, purchasing power of the consumers and stability of the power supply system have to be the stand point
3	In wind resource exploitation activities; how does installation of wind power devices impact wildlife in your area?	2211	44.45	The averaged 44.5% of the study findings state that in exploitation of wind resources it affects both habitant fragmentation and causes collisions.
4	What are the most variables and drivers of wind energy production?	1886	39.93	Up to 39.9% of the results presented show that most variables and drivers of wind energy production to rely on as the most is the wind speed
5	How can you rate the level of technology which the country used to exploit the available wind resources?	2025	45.14	The study discovered weak level of technology used, out of 2025, 45.1% with outdated, old and obsolete technology.
6	How can using wind technology contribute to environmental protection in Rwanda?	2303	34.26	The results obtained in this study 34.26% of the findings showed that wind produces energy that has fewer effects on the environment than many other energy sources

Source: Primary data, 2021

Arguments to support the results and findings:

The barriers and problems against wind power penetration in Rwanda

The study shows that electric power production capacity and electricity access in the country are low and the size of infrastructure is insufficient to meet the demand. Ageing infrastructure, unexploited wind resources, High cost of energy, inefficiencies, exacerbated by high technical and power losses, require urgent and timely intervention to achieve the confirmed energy targets. This study has revealed energy inefficiency in the country; the most urgent needs for energy efficiency relate to the largest source of current energy consumption which is biomass, mainly for household cooking applications. The issues and actions outlined are mainly addressed at improving efficiency in this area, so that these issues should be addressed.

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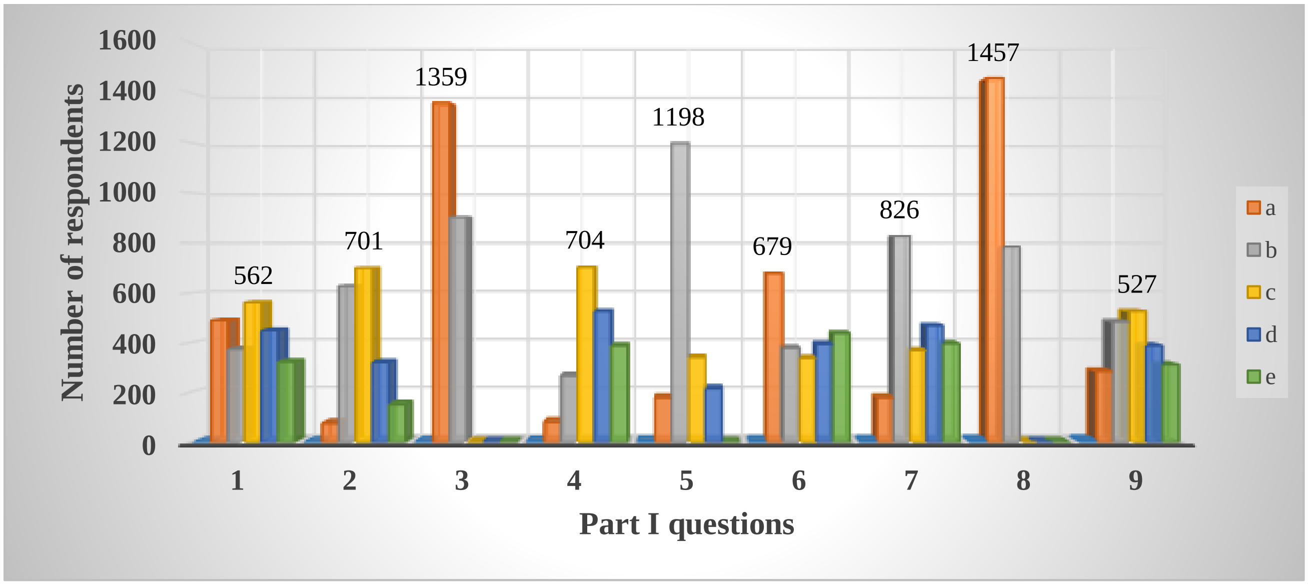

Figure 6: The barriers and problems against wind power penetration in Rwanda

Source: Primary data, 2021

Figure 6 has revealed that there are a number of barriers and problems include lack of enough researches, study and feasibility analysis on Wind power; Climatic changes that hinder the scholars and institutions to predict and forecast on wind and lack of appropriate technology and sufficient fund to invest in renewable energy sectors.

The extent at which wind power was integrated and penetrated in Rwanda

According to recurring official statistics publications; from National Institute Statistics of Rwanda (NISR, 2020). Rwanda's energy intensity in terms of primary energy consumption per unit of GDP has improved over the period 1990-2020 at a similar rate to that of sub-Saharan Africa in general. These measures are however rather crude for a country like Rwanda, where much of the primary energy is consumed is the biomass especially in rural area, and where modern fuel consumption levels for example electricity and petroleum products remain developing. However, it seems likely that Rwanda has a chance to benefit from global improvements in product efficiency, and needs to boost the energy production where possible not to lock-in to inefficient infrastructure as its economy grows.

The research proved that the total currently wind devices installed on the stations generate electricity capacity of 87.38MW annually (Primary data, 2021); which means approximately more than 16.9% of the country needed energy comes from wind based on installed stations. Rwanda has envisaged increasing electric power supply by maximizing use of various indigenous energy resources and reach its ambitious target of 516 MW (domestic generation + imports) with electricity access of 70% (on-grid and off-grid) by the end of 2024 (GWENDOLYN S, 2014). The wind power in Rwanda have to be effectively and efficiently exploited to the fullest to optimize its usage.

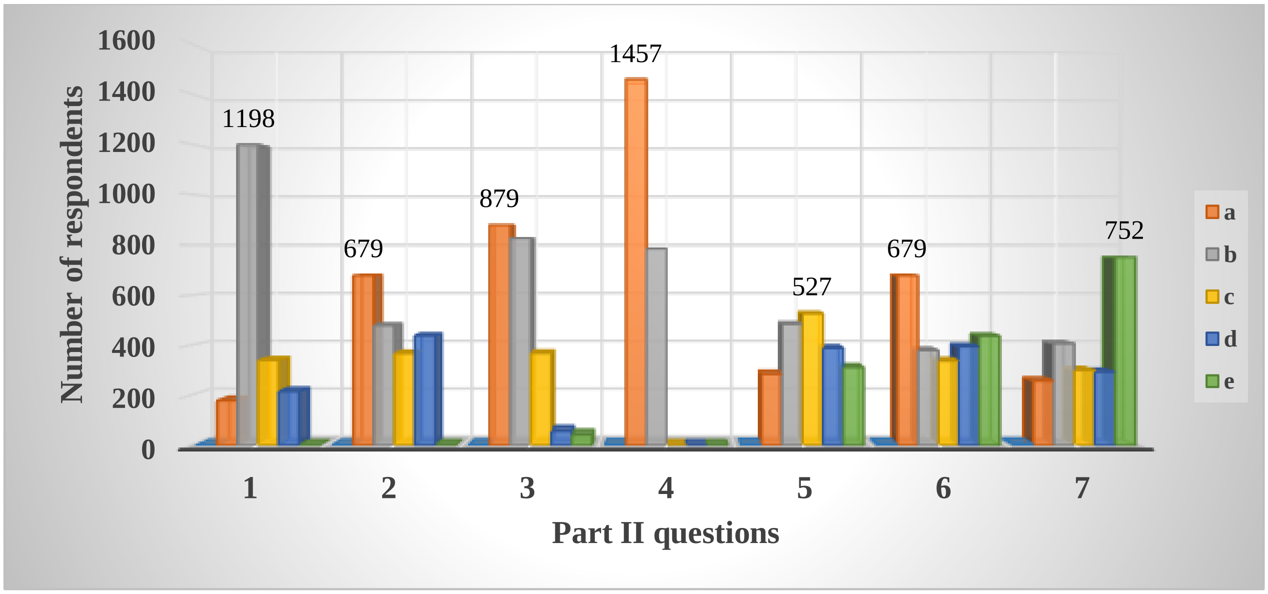

Figure 7: Extent on which wind power utilized and integrated in Rwanda

Source: Primary data, 2021

Based on the results found as it is presented on the figure 7, research showed that even if wind power is used; there is a gap that wind energy was not fully exploited to the fullest and yet there are a few number of researches in this field that should be fulfilled. The obtained statistics shows that only 5.7% of country energy consumed comes from wind but the level of wind integration is still low.

The possible impacts of wind power penetration and integration in Rwanda

This study summarizes the 3 particular issues as the biggest, which face Rwanda's energy sector include but not limited to: misalignment of power supply and demand, limited financing for off-grid institutions and limited affordability of electricity solutions for rural households and businesses. The above aforementioned issues are still prevalent in the country.

The study has found out that wind power in generating electricity has positive impacts on environment especially on atmosphere, water and land, peoples' health as well. They emphasize friendship character on the environment because wind energy shows the ability to decrease at 68% negative effects arising in using other mostly used sources of energy in the country which play an important part on the climate change and environmental pollution. In analyzing the impacts of wind power penetration the various factors and parameters were highly considered including social, demographic, economic, political aspects.

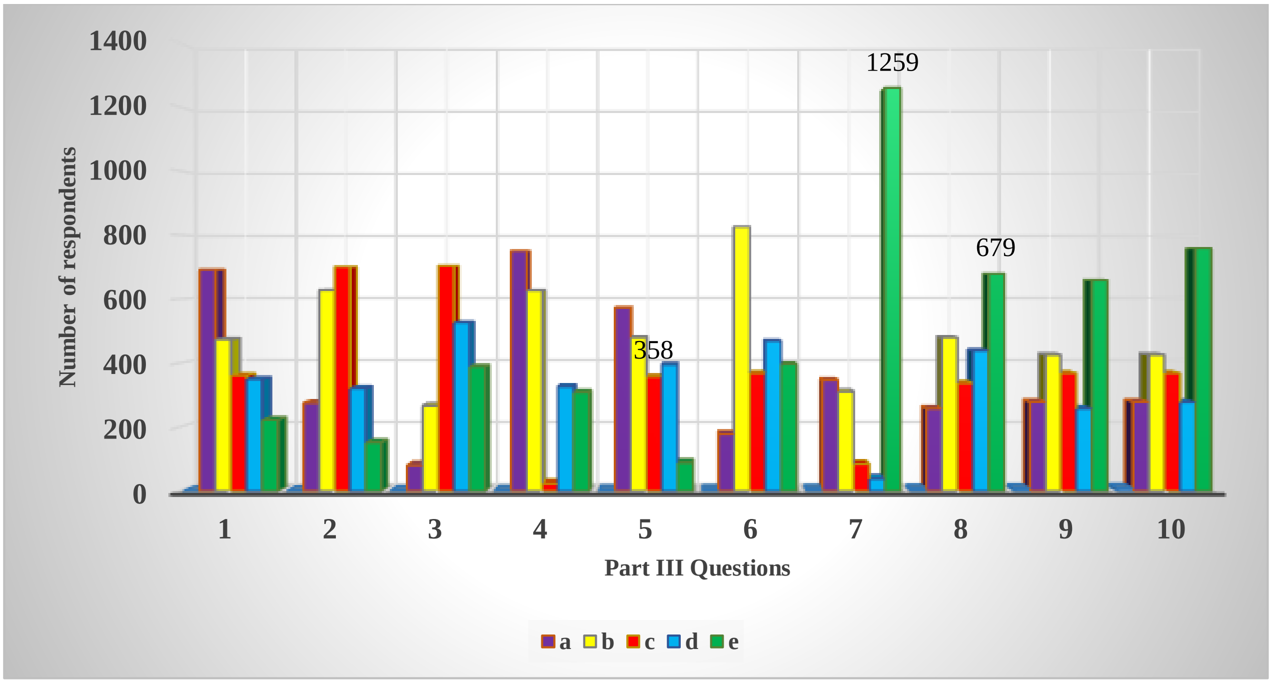

Figure 8: Impact of Power Penetration and Integration in Rwanda

Source: Primary data, 2021

According to the results presented in figure 8 the study showed that there are no negative impacts arise from wind power penetration and exploitation. It was observed that wind energy sources do not emit dangerous and polluting gases in the atmosphere and thus are available in the country with moderate cost of exploitation.

Capacity of National Grid of Rwanda to accommodate wind power integration

The obtained results revealed the capability of studied stations in the country and measure the relationship and impacts arise from linking them to national grid. The annual wind power densities for Kaniga, Kanombe, Gisenyi, Butare and Kamembe have been estimated on average as 20.7568W/m^2, 22.42W/m^2, 13.68W/m^2, 13.17W/m^2 and 17.36W/m^2 respectively, from the yearly mean wind speeds of 5.1m/s, 4.1m/s, 4.0m/s and 4.3m/s. Also the wind speed in Kaniga is estimated at 4.6 m/s annually. From the results, it is obvious that Kanombe shows the possibility and probability of greatest wind power potential of all the five sites studied hence it is a promising site for installing a wind technological devices for power generation.

The results showed that interconnecting a number of wind mini grids into one common grid leads to better technical and improved performance. Moreover, the more mini grids connected, the better the performance and the more the power available for the national grid for supply to consumers. The national grid of Rwanda is well equipped to accommodate wind power integration. So the appropriate approach should be enforced to strengthen this system.

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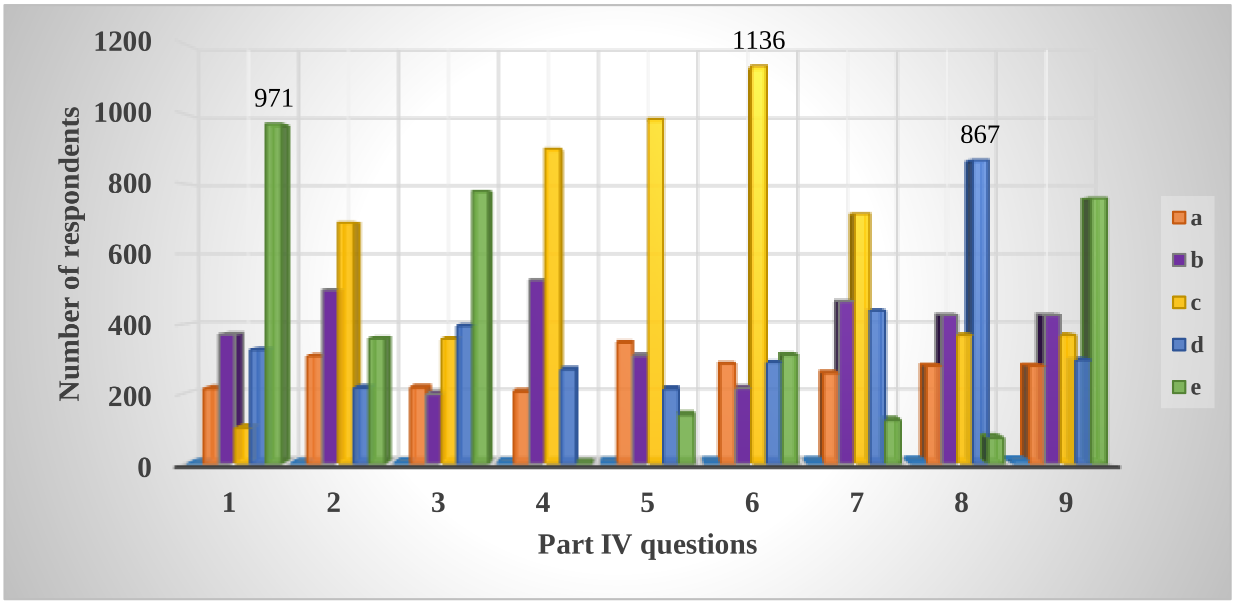

Figure 9: Capacity national grid of Rwanda to accommodate wind power integration

Source: Primary data, 2021

Using figure 9, the study proved that the grid integration under the current institutional arrangements come with important benefits. Although there are technical issues that need further investigation and corrective actions, it is recommended that the government of Rwanda maintains the conductive regulations to encourage private-public partnership to expand their production and usage. Using wind energy to large extent could empower existing national grid.

Proposition of wind farms technology and its impacts on social and environmental protection in Rwanda

The study proved that most other sources of energy pollute the air like power plants that rely on combustion of fossil fuels such as coal or natural gas, which emit particulate matter like carbon oxides, nitrogen oxides, and sulphur dioxide-causing human health problems, economic damages, environmental pollution and climate changes that lead to global warming.

Wind farms and turbines do not release emissions that can pollute the air or water (with rare exceptions), and they do not require water for cooling. Wind turbines may also reduce the amount of electricity generation from fossil fuels, which results in lower total air pollution and carbon dioxide emissions. The use of appropriate technology in wind power penetration study shall mitigate and address the emerging issues as an environmental protection technique.

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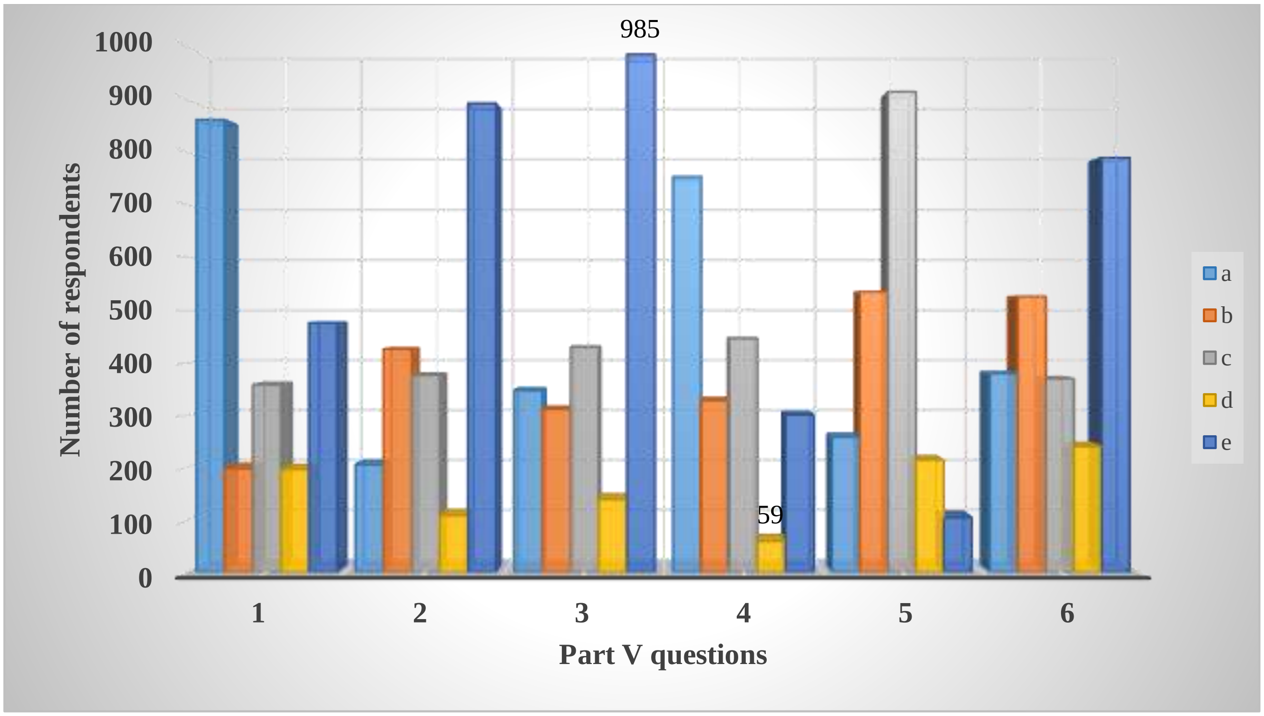

Figure 10: Wind farms technology and its impact on social and environmental protection in Rwanda

Source: Primary data, 2021

As it is represented on figure 10, the results showed that use of modern wind turbine technology might play an important role in increasing the capacity of available energy and produce less carbonated energy which can be used as environmental protection driver. In addition, the study discovered the problem of lack of modernized technology in the wind study that need to be addressed in progressive journey to meet energy need in the country. The feasibility study discovered that if wind farm technology is used can play a big role in addressing the energy insufficiency problem that a country experience for a long period of time.

5.0 Conclusion

Experience around the country has demonstrated that wind energy can be integrated into power systems reliably and economically. Hence the wind data available from these considered stations provide a fairly good idea about attractive locations for wind energy installations.

The barriers and problems mentioned such as highly controlled energy sector; lack of awareness and information; restricted access to technology; lack of competition; high transaction costs; poor market infrastructure; high investment requirements; climatic changes that hinder the scholars and institutions to predict and forecast on wind. Policies to support wind power penetration are often designed to align with broader objectives including diversification of electric generation sources to increase long-term price stability; reduction of greenhouse gas emissions and water use; and technology innovation to increase global competitiveness; establishing long-term renewable energy targets that increase over time to support sustained wind growth and supporting a broader enabling policy environment. Objectives specific to national and subnational contexts can provide broader framing for tailored design and implementation of wind power policies described in this paper.

The study showed that even if wind power is used; there is a gap that wind energy was not fully exploited to the fullest. The evidence showed that the total currently installed devices generate electricity capacity of 95.21 MW; which means approximately more than 18% of the country needed energy comes from wind based on installed stations. The wind power in Rwanda and related infrastructures have to be effectively and efficiently exploited to the fullest to optimize its usage and integrate them in the useful components to rely on in stabilizing the energy sector.

The study has described in details that there are environmental impacts that arise from wind power penetration, integration as well as exploitation. This means that some visual impact is unavoidable, whether in open countryside or a populated area. Impact can be minimized by avoiding locating wind instruments in sensitive landscapes, setting them carefully to take account of views from sensitive locations and making use of screening from landscape features such as trees and hills. Apart from the impacts that should arise, it is very important to use wind energy sources because they do not emit dangerous and polluting gases in the atmosphere as other sources and they are available in the country. Large wind power penetration is expected to reduce drastically the greenhouse gases emissions.

The study proved that the grid integration under the current institutional arrangements come with important benefits. The results showed that interconnecting a number of wind mini-grids into one common grid leads to better technical and improved performance. Moreover, the more mini grids connected, the better the performance and the more the power available for the national grid for supply to consumers. Therefore, special care should be given to the careful design of Grid Codes and market regulations by the regulatory bodies in order to ensure the security of supply in terms of both system security and generation capacity adequacy.

The connection of wind instruments to electricity grids requires in many cases the construction of significant new transmission infrastructure (lines, substations) which is not always an easy task due to the continuous increase of public opposition against high voltage installations. Also, the long construction time needed, especially for new transmission lines (mainly due to the complicated authorization procedures and public opposition), may be a strong barrier to the wind exploitation. The national grid of Rwanda is well equipped to accommodate wind power integration. So the appropriate approach should be enforced to strengthen this system.

This research has found out that no wind power integration in the country. Wind turbines/wind farms technology are not used in Rwanda but it has demonstrated the potential for contributing to the energy needs in the country. If the sites with acceptable wind characteristics were fully utilized, they could contribute up to about 18 percent of the nation's electrical energy needs. The limitation is based on utility system stability issues rather than available site locations. As in all energy investment decisions, the ultimate penetration level will be driven by the cost of energy that is produced. In turn, this is decided by the initial cost of the wind energy plant and the annual cost for maintenance and operation. The use of such appropriate technology in wind power penetration should mitigate and address the emerging energy shortage and be used as an environmental protection driver.

6.0 Recommendations

(a) However, to get exact knowledge about certain locations, measurement of wind availability over several years would be appropriate. The country should not only depend to biomass-related efficiency issues, Rwanda has to address the mentioned gaps and barriers include: Data requirements, minimizing system losses (A loss in energy between generation and consumption is an inherent feature of electricity networks and such losses cannot be totally eradicated), New priority area as the best way to boost energy issues.

(b) Promote, disseminate and scale-up the uptake of improved renewable energy, specifically wind energy. The wind energy should be affordable, sustainable and consider the safe environment. It would be prudent for the Government to institute a body responsible for quality control of the improved wind energy.

(c) Wind farms installations are proposed and encouraged to increase household accessibility to electricity by electrifying the rural areas and reducing (subsidizing) the connection costs of hydropower.

(d) Promote this wind energy for household cooking and heating.

(e) Regularly and consistently provide adequate and well-targeted extension education services to the community so as to change their habits, way of thinking and attitudes towards environmental protection issues.

The personal recommendation is that wind farm to be planted should be carefully selected to ensure that their energy output is comparable to the preferred natural forest species. It is further recommended that the public/or private sector should make available improved wind farm production technologies in their respective areas.

Environmental protection committees from local population surrounding the climate change management should be involved in all steps of sustainable energy undertaken at all district level. They should have both sense of ownership of forest resources and responsibility for its management. If the local community is not dedicated towards management of their surrounding renewable energy resources, no amount of efforts from higher levels will bring about a sizeable change towards a desired outcome. It is with this understanding that the following recommendation is tasked to the village-level leaders:

(a) At Village level ensure that all households use improved stoves when using the charcoal;

(b) The forests should be monitored by the Village and the Cell leaders or environmental management committees to ensure that all should be required to use improved energy production technology;

(c) Local authority leaders should devise a mechanism which will ensure that households have individual wood lots for energy purposes.

The wind data available from the studied stations provide a fairly good idea about attractive locations for wind energy installations. However, the usage of wind farm technology in exploitation of wind resources to address energy gap in the country is highly recommended to meet the country's goals of economic growth and development.

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