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Declaration

I, the undersigned, declare that this thesis project is my original work, and has not been presented for a degree in University of Rwanda or any other universities. All sources of materials used in work have been fully acknowledged in the correct academic format.

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Date of Submission: October, 16 2022

This thesis project has been submitted for examination with my approval as a university advisor.

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Abstract

The global development made energy as a humanity basic need. Thus, leads to the united nation in 2005 to adopt the global goal of electrification by 2030. The enforcement of global electrification is due to that energy is a backbone of poverty reduction, climate change, job opportunity and general population welfare (International Energy Agency, 2017). Through, differences in global relief and economic instability, international energy agency advised that renewable energy mainly solar will be the sustainable solution for both electrification and global climate emissions.

Unfortunately, Africa is the continent with a big number of populations without having access to electricity. This hinders the goal of achieving global electrification by 2030 due to in 2013 only 43% of African has access to electricity (Bernard, 2012). It can be understandable by comparing Africa financial stability and require investment for Africa electrification. International energy agency report highlighted that Africa requires an annual investment of 31 billion USD for achieving 2030 global electrification (International Energy Agency-IEA, 2017).

As shown by IEA (2017), highly population growth in sub-Saharan countries affects economic stability in the region, roughly 600 million of the 674 million people express 0.89 without having access to electricity. It sudden to hear that most of them are located in rural areas. Consequently, the low access to electrification leads to the used of fossil fuel coal and others unfriendly climate energy resources which still raise the crisis of global emission. Favretto *et al.*, (2018) highlighted that, the consequence of global emission causes other inquiries such as climate change hazard as it faces some part of Eastern Africa like droughts in Ethiopia and Somalia.

Rwanda is one of the developing countries that faces a problem of electrification mainly for rural population. Thus, the Government of Rwanda has the target of achieving the global electrification by 2024 by using renewable energy resources as well as off-grid connection. By this, there is attraction of off-grid companies, which will enhance the level of electrification. Solar energy uses

solar panels and batteries, obviously has different price to solar energy customers. The most common solar pricing is PAYGO (Pay-as-you-go), this pricing model allows customers to pay by daily basis. This pricing model settled by considering various factors affecting the pricing for solar energy was very useful and important in the setting of price for solar panel. In solar energy industries relies on the predicting of price through how much amount of money should charge to solar panel and their accessories before providing to the beneficiary, the following factors are mostly important: Cost of solar panel, Solar Radiation, Inflations and Seasonality, those factors are potential in the prediction and settling accuracy and affordable price

Milanés-Montero, Arroyo-Farrona and Pérez-Calderón (2018) on how government can raise the number of populations with access to electricity mainly those in rural areas, recommended that government incentives, tax exemptions, offering of low interest loans to solar power providers are the best methods can be used. Advantageously, the above approaches outcome the setting of solar energy price. Wong (2012) and Panwar, Kothari, and Kaushik (2013) seen that the more the affordability of solar energy the more the inclination in of reduction in carbon emissions, reduction of energy costs and the more in improvement of job opportunity which leads to the sustainable social welfare and improvement of living of standard to the population.

The Feed- in –Tariffs (FITs) policy and Pay-As- You-Go (PAYGO) are the important based method in setting solar energy prices. The significant of FITs is to promote sustainable access to renewable energy mainly solar and wind. Milanés-Montero, Arroyo-Farrona and Pérez-Calderón (2018) noted that the role of FITs in energy are to guarantee grid access for solar power providers, offering of long-term contract almost between 15 to 25 years and offer guarantee cost based purchase prices which means solar power providers are paid in proportion to the resources and capital expended in order to produce the energy.

The PAYGO as a financial technology allows end-users to pay for solar energy in settlement mainly weekly installment and solar power providers sells services to end-users through a pre-paid model. Opportunely, by this methods power providers financing to the end users and the end users become an able to get solar energy, when the customers receive the solar panel at affordable price and good installment payment, this will increase the number of the population use the solar energy. The overall existing literatures emphases on solar pricing as one segment and solar energy pricing as another segment on African countries study based. Therefore, apart from other existing studies which used other analysis methods rather than econometrics price and prediction method, this study come up with econometric analysis method which emphasis on solar energy pricing and prediction as evidence from off-grid solar power providers for a case study of Rwanda. Henceforward, both solar service end-users and solar power providers will benefit on the study outcomes.

Bimenyimana *et al.,* (2018) mentioned that Rwanda is approximately 5peak hours per day while Heeten *et al.,* (2017) witnessed that the peak time of Cambodia is about 2 hours from 19:00 and 21:00 with the work of Adeoye and Spataru (2019) who looked on modelling and provision hourly electricity demand also shown that the peak hour of Ghana is between 17:00 and 22:00, this evening peak hour time is different with that of Rwanda morning hours' peak time. Therefore, we conduct the study on solar energy pricing with evidence from off-grid solar power providers for a case study of Rwanda.

CHAPTER ONE INTRODUCTION

1.1. Problem statement

Access to energy is a challenge to Rwandans especially to those living in rural area far from the national grid connection. Rwanda is known as a land locked country with a thousand hills this relief composed with a lot of mountains is another factor which heavier to population in that region to have access to energy. Lack of energy access to the population directly leads them to low income which continuously affect their wellbeing and wealth. Thus, according to Pereira da Silva *et al.*, (2018), solar energy could be a solution to rural electrification. Even if there is a progress in building solar power plants and attracting private investor like Ignite Power Rwanda and other commercial investors in solar energy sector; their products is still expensive as by average it over 20 USD per watt hour and there is lower capacity to design and deliver sophisticated solar systems and their accessories.

As it presented by EPD Rwanda (2022), the available SHS kits capacity in Rwanda solar accessories market are those of 12W,20W, 40W, 50W, 100W, 120W, 200W and that of 300W. As it presented by EPD Rwanda the average price of that kit is 67,678 FRW. By comparing the average price of Kits and income levels of those population living in remote area, the price cannot be affordable at all. Thus, the study is aimed at ascertaining the most affordable pricing approaches for solar energy of off grid companies and determine how the users should receive the solar energy power at affordable price and the solar providers get an income from their investment.

1.2 Objectives

1.2.1 General objective

The main objective of the study is to conduct solar energy pricing tools for both users and solar power providers.

1.2.2 The specific objectives

i. To access the pricing techniques for solar energy in Rwanda

ii. To identify factors affecting the pricing for solar energy in Rwanda

1.3 Research questions

i. What are the pricing techniques for solar energy in Rwanda?

ii. What are the factors affecting the pricing for solar energy in Rwanda?

1.4 Scope of the study

The study was conducted with the aim of examining solar energy pricing techniques and also assessing factors affecting solar-energy pricing using off-grid companies as the study units The study focusses on solar energy pricing techniques made in solar energy sector. The study identifying why solar energy pricing is important. Solar energy pricing is the dominant renewable energy for raising number of populations with access to electricity mainly in rural area. The private company and government entities considered in the study in fact that they play a vital role in solar energy access. Thus, the study analyzes solar energy pricing for evidence from off-grid solar power providers.

1.5 Expected outcomes and significance of the study

1.5.1 Expected outcome of the study

This study is expected to give suggestions to policymakers in designing the effective, efficiency and affordable solar energy projects price which meets social, economic, and environmental aspects to the users.

1.5.2 Significance of the study

Solar energy is aninteresting renewable energy sources which is friendly to environment, climate and a solution to the population living far for on grid connection. By this, the study results and recommendation will help government to achieve the target of zero CO_2 emission. Solar energy is a renewable energy which is almost available in all part of the country and have a huge profit for population and investors, thus; the study is a source of information for the investors interested in solar energy.

CHAPTER TWO: LITERATURE REVIEW

2.1 Description of the keywords

For a better understanding of the study, the study key words such as solar energy, solar energy pricing exercised.

2.1.1 Solar energy

The most known solar energy sources are those from solar thermal and from solar shine. Solar shines depend on solar radiation where it availability refers to the 24-hour major period. From 2010 to 2017 the installed capacity from solar energy in Rwanda was 12.08 MW (Bimeneyimana, Asemota, &Li, 2018). The solar energy used photovoltaic (PV) which means converting sunlight into electrical energy, this is done by using a device known as a cell (PV cell). The connection of PV cell made what called solar panels. Those panels are those generate solar electricity. According to Rutibabara & Mutabaruka (2018), solar radiation in Rwanda ranges between 4.8 Kwh m^2 day^{-1} minimum and 5.5 KWh m^2 day^{-1} maximum, this potential solar radiation is enough for the Rwandese mostly those living far of the grid to use solar energy.

2.1.2 Solar energy pricing

Economically, pricing is the act of establishing a value for a product with deciding how much a customer must pay for a product. In solar energy, pricing made on Kit basis. Kit in solar energy means a package of solar panel, charge controller, invertors, batteries, cables and lamp. Solar energy pricing model depends on the agreed time mainly daily, weekly and monthly payment. An example for solar power providers pricing depends on sized solar system which are 30W, 100W and 200W.

2.1.3 Potential factors affecting the pricing for solar energy in Rwanda.

The factors affecting the pricing for solar energy was very useful and important in the setting of price for solar panel. In solar energy industries relies on the predicting of price through how much amount of money should charge to solar panel and their accessories before providing to the beneficiary, the following factors are mostly important: Cost of solar panel, Solar Radiation, Inflations and Seasonality, those factors are potential in the prediction and settling accuracy and affordable price.

2.1.4 Return on investment

If there is a payment of current solar service bill, solar end-user can afford to go to the solar service. The monthly solar service payment will likely be at the same or less than the current electric bill. Even in the short-term, solar end-users are saving or breaking even. In addition, solar end uses will be earning money through solar incentive program. Solar end-users take advantage of this and treat their solar investment as a secondary, passive income. Upon breaking even, solar end-users will get their full return on investment (ROI) and will become cash flow positive

2.2 Theoretical review (theories related to the study)

2.2.1 Pricing Models

Stundza (2008) highlight that price change of any given commodity caused by the change of it basic low materials which consequently affect customer retention, business profit, sales, and market share. Hence, the theory of Marn and Rosiello (1992) mentioned that firms decided to increase price in short term stretches an increase of marginal units and short-term profits, while lowering the price motivate short-term sales and reacts against and disciplines competitors but high price create excludability to customer’s consumption. Price is at the top of market mix, though the success of a business entity depends on the pricing strategy used by the entity.

The literature of Nagle and Holden (1994) advised business entities to use planning pricing strategy for the reason why it is a long run pricing goal dynamic. Planning strategy important business entities as a strategy focused on the transactions categories of market segments, customers, products or services and competitive encounters. The study of Rao (1984) revealed two important types of pricing model which are defined as pricing models ignoring competition and pricing models considering competition.

Great expression of the highlighted pricing models is optimal-pricing rule (Rao, 1984). Hereby, model ignoring competition calculated by $p = \frac{\varepsilon}{1+\varepsilon}.MC$, where p indicates the optimal price, ε indicates the price elasticity of demand and MC indicates the marginal cost per unit. Model considering competition calculated by $p = \frac{\varepsilon+\gamma\eta}{1+\varepsilon+\gamma\eta}.MC$, where γ is the price–reaction elasticity of the competitor price with respect to firm's price and η is the cross-price elasticity of the firm's demand with respect to competitor's price.

2.2.2 Pricing techniques for solar energy

Worldwide, each kind of energy sector adopting the pricing technique depends on the character of that sector. This study tries to emphasis on main common pricing techniques applied in solar energy sector which are flat tariff (standard tariff), time of use, real-time pricing, critical peak pricing and inclining block rate. The highlighted below are some of the explanations for better understanding of each pricing techniques.

Ipakchi and Albuyeh (2009) in their book grid of the future, they explained that flat tariff or standard tariff is the sum of all the costs of generating electricity which cover initial cost, operational cost, and maintenance cost over the total cost of delivering electricity accessories. These types of pricing techniques are disadvantageous to the solar energy customer due to there is no negotiation between the solar energy power producer and customer.

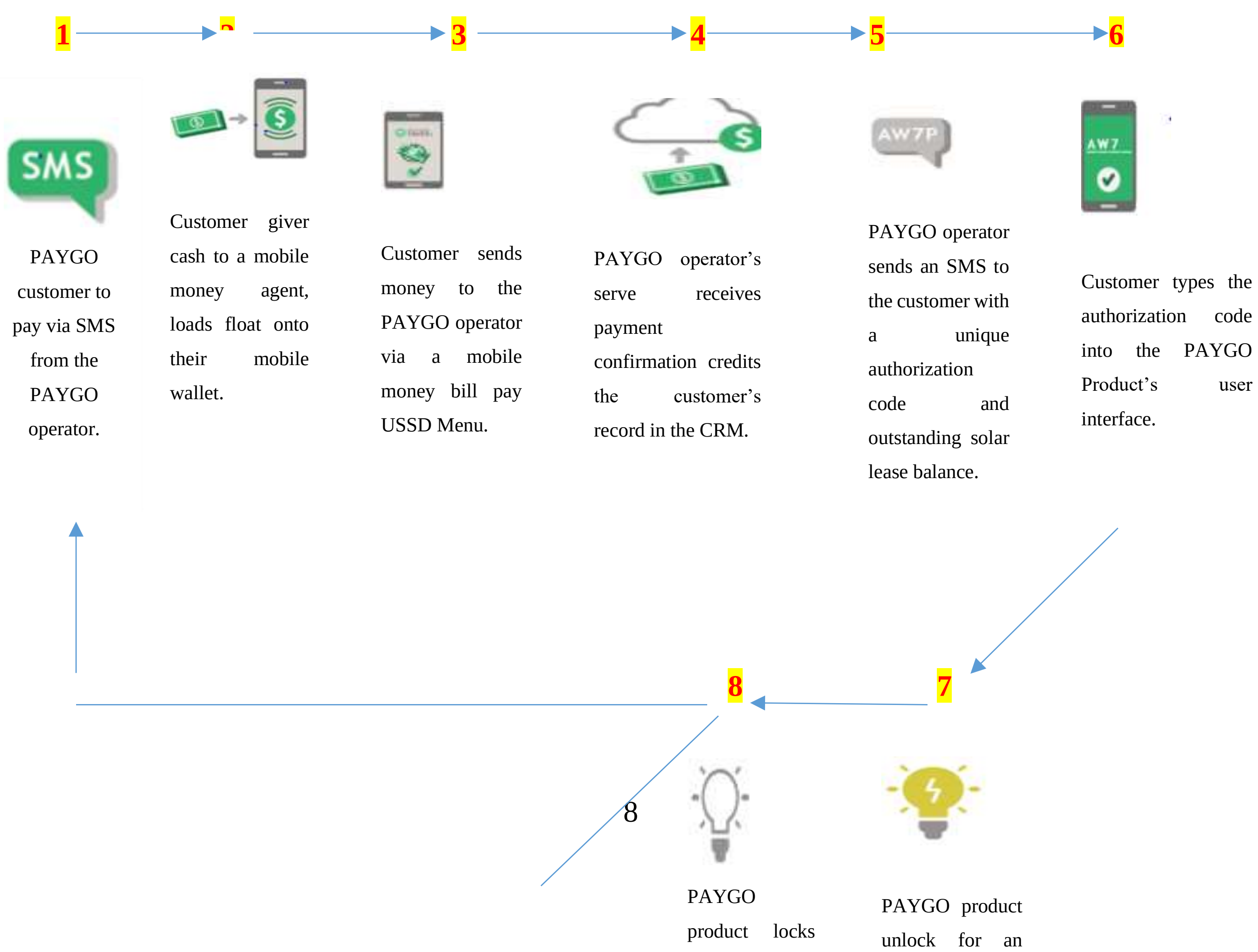
The second type of solar pricing techniques is time of use, by this technical type of solar energy; clients charged based on the time basis generally on daily basis. Rowlands and Furst (2011) said that by daily basis pricing system, solar power producers divided the daily consumption into three main categories such peak time, mid-peak time, and off-peak time. The price changed depends on the time of consumption; in peak time the price is too high compared to the mid-peak time and the price is low in off-peak time, by this solar power producer advised the solar energy end users that it better to shift their consumption from peak time to off-peak time in other to be better off of price. The study where clarifies real time pricing as the pricing on hourly basis Paschalidis *et al.,* (2012), This means that the solar end users announced the amount they pay on a day head basis. While Song, Lee, and Yoon (2019) defended the fourth pricing technique which is critical peak pricing as to forecast the favorable time for event preparation in regard of boosting less consumption of electric energy. Beside the statement, the solar power producer can advise the event managers to postpone the event time for a moral hazard of achieving high revenue for the side of solar power producers.

As it highlighted in the study the last type of pricing technique is inclining block rate, this type described by referring to the work of Deng *et al.,* (2015) it seems as the dual-level pricing through the updated consumption of the end users. This type is advantageous for both sides as for the end users side, it protects them to the peak-time power off and for the solar power providers side it safeguards them to the unnecessary overloads which can leads them to regulation cost of fuel in case of meeting the demand. According to Rwanda Utilities Regulatory Authority(RURA), referring to law no 52/2018 modifying law no 21/2011of 23/06/2021 governing electricity law in Rwanda as modified date especially article 29 stipulates that the methodology of electricity setting shall be determined and published by the regulatory authority in consultation with the minister in charge of electricity and the regulatory authority must ensure that the electricity tariffs for renewable energy sources or off –grid electricity for end-users do not exceed the appropriate threshold. The isolated grid end user tariff structure shall consist of energy of energy charge in

Rwandan francs per kilowatt-hour (Frw/Kwh), demand charge if applicable in Rwandan francs per kilowatt-hour (Frw/Kwh) or flat rate tariff in Rwandan francs per period of time.

Kowsari and Zerriffi (2011) specify that PAYGO is the dominant model in solar energy pricing. Since by PAYGO payment settlement are made weekly and monthly depends on the agreement between solar energy providers and end users. The effectiveness of this model is that mostly the payment done by using mobile money or Airtel money depend on the Simcard of the customers. The more effective payment which is better off for both side is use of mobile money due to it easy for end users in making payment and for power providers due to there is a use of keypad verification. The figure below describes how the system of PAYGO by using mobile money operates.

***Figure 1**: PAYGO system*



Return to step 1

Where the customer receives payment reminder via SMS again

9 → 10 → 11

PAYGO operator's CRM tracks ongoing Payments. When Customer's outstanding solar lease balance Hits zero. PAYGO Operator sends an SMS to the customer with one final Authorized code.

Customer types the authorized code into the PAYGO products user interface. PAYGO product unlocks permanently. Giving the customer access to light and appliance for free for the remainder of the products.

(OPTIONAL) PAYGO Operator's data analytics identify the customer as living a good payment record prequalifies the customer for access to product upgrade send an offer via SMS and the call center.

PAYGO customer accounts upgrade after starts a new lease.

2.2.3 Potential factors affecting the pricing for solar energy in Rwanda

Solar power providers face with some of technical challenges in pricing of how they can meet the demand of the consumers (solar energy end users) as it their main mission of the solar power providers. Ahmed *et al.*, (2020) revealed some of those challenges as cost of solar panel, Solar radiation, inflation and seasonality.

Cost of solar panel, we considered cost- based pricing which refers setting the price basing on the cost used by the solar power providers. Both cost and price for solar services measured by Rwandan currency (FRW), Consumer price index (CPI) contribute to the study as the measurement of inflation. Solar radiation for the solar radiation measured by kilowatt-hours per square meter per day, the average of solar radiation is 5KWh/m2/day with a peak sun hour which is 5 hours (Bimenyimana *et al.*, 2018). Inflation, the consumer price index (CPI) contributes to the study as the measurement of inflation. The low rate of electrification lowering the number of enrollment rate. Seasonality, for the energy production of solar panels depends on a range of factors, including the angle of the sun, the length of the day, the weather. Some variation in the output of solar system depending on the season on the surface, the effect of the seasons on solar is easy to grasp summer's longer days mean more sunlight which means more energy production from our solar panels in comparison to the shorter, cloudier days of winter. Solar panels generally produce about 40-60% less energy during the months of December and January than they do during the months of July and August. This means that solar power generation is significantly less during the winter than it is during the summer.

2.3 Empirical review

The aim of solar power providers mainly those exercised in off grid connection is a fully sufficiency of solar home system's load demands. This goal must be achieved with a clear analysis of solar energy pricing. Kiguchi *et al.,* (2019) in their study entitled Predicting intra-day load profiles under time-of-use tariffs using smart meter data; found that solar load prediction not aided only the existing solar power providers but also helps government entities in tariffs formation and in regulation and deregulation solar energy sector.

Consequently, the criticism of Bonan *et al.,* (2020) remarked that PAYGO repayment system is a successive technique than using smart meters' payment techniques. Fortunately, PAYGO is successive technique for long run time period while Gans, Alberini, and Longo (2013) in their project titled: Smart meter devices and the effect of feedback on residential electricity consumption report that smart meter can be used in short term time period as well in real time pricing, this also can reduce electricity consumption but in short term time period.

Apart from the study of Bonan *et al.,* (2020), Jenner *et al.,* (2013) viewed that Feed-in-tariffs (FITs) is another method that can be used in solar energy pricing. The drive of FITs is to promote the development of solar energy as a clean renewable energy source. This captured since FITs cover tariff size, contract duration and digression rate. Furthermore, FITs often used when the production of solar energy is not economically feasible. But the most beneficiaries of FITs are non-commercial solar power providers. The study groups non-commercial solar power providers as homeowners, business owners, farmers, and private investors.

Most of successive FITs are that in long term purchase agreements in the time between 10 to 25 years. Nonetheless, the consideration of technology type, project size, resource quality and project location of solar power providers (Menanteau *et al.*, 2003, iea, 2008). The approaches to set FITs such as leverized cost of solar energy generation, value of the solar energy generation, fixed price incentive and auction-based mechanisms must be adopted. The value of solar energy generation measured by wealth impacts, social impacts, and environmental impacts (Klein 2008, Grace et al 2008). For finding the solution of solar energy price, two techniques such fixed- price FIT payment and premium-price FIT payment proposed.

Unmistakably fixed- price FIT payment creates a stable investment condition which result on lowering financing cost for solar power providers. Moreover, the effectiveness of FITs based on the implementation options resembling as eligibility, utility role, contract duration, capacity, and grid accessibly. Grace *et al.,* (2008) eligibility shows eligible participant like citizens, governmental and non-governmental entities. The contract duration is one of the key issues to be noticed in FITs, generally the period varying in the period between 5 to 25 years but the majority of the time duration between 15 to 20 years.

The complexity of the FITs pushed Keane and Sundblad (2017) to emphasis on the PAYGO and noted that PAYGO is the key driver for the growth of solar power providers. Furthermore, PAYGO leads to the development of end-users by the improvement of job creation, education enhancement and social well fare. The success of PAYGO continues arising due to the shifting in the payment techniques from using the financial institution to mobile money paying techniques.

The attainment of PAYGO fits financial condition of developing countries the fact that the end users can afford the small installments and pay for their solar energy needs depends on the financial capacity. This lowers the effect of credit risk and lower the households lighting expense. The most known lighting expense in Rwanda includes phone charging expenses. In Rwanda non-lighting citizens walk around a half and beyond of an hour to the place where can afford electricity and cost them the minimum amount of 200Frw. Burger (2017) identified that PAYGO generate the opportunity of having access to electricity which leads to the lowering of the kerosene expenses to the citizen in remote areas. This is the fact that most of the Rwandese household spent around two US dollar per week to buy kerosene a source of righting.

The view of Weron and Ziel (2018) stated that artificial intelligence and machine learning is the method used in solar energy. The statement of pricing is the future prediction based on the past events. But due to some missed historical data there is a use of machine to generate the missed data. This technique is almost used in solar energy as a successive technique which reveal the recent and future solar energy price and generated profits. pricing combination and ensemble for the energy is the second methods which combines facilitate for solar energy pricing as shown by Zheng *et al.*, (2020).

Linking the paper of Gajowniczek and abkowski (2017) with the above cited, solar energy pricing provides information which enables solar energy end users mainly households to aware of their future electricity usage and in preparation of their energy consumption regarding to the forecasted behavior change in price. Whenever less the predicted results, solar energy end users and solar power provider must provide feedback on the launched predicted model. The feedbacks can lead to the prevention of heavy solar power services over price and underprice.

2.4 Gaps in the literature

The difference in geographical location has a great influence in the difference in weather condition which finally making differences in solar energy output of a given location. This statement shows the gap in the literature of Aung *et al.*, (2012) who emphases on the electricity load pricing in France and Reunion Island, the differences in the income of these countries and difference weather conditions associating to the situation of Rwanda as a case study of the study shows the extreme gap in the literature.

Solar energy influenced by weather condition, the most emphasis condition is sun peak time and solar radiation period. Bimenyimana *et al.*, (2018) mentioned that Rwanda is approximately

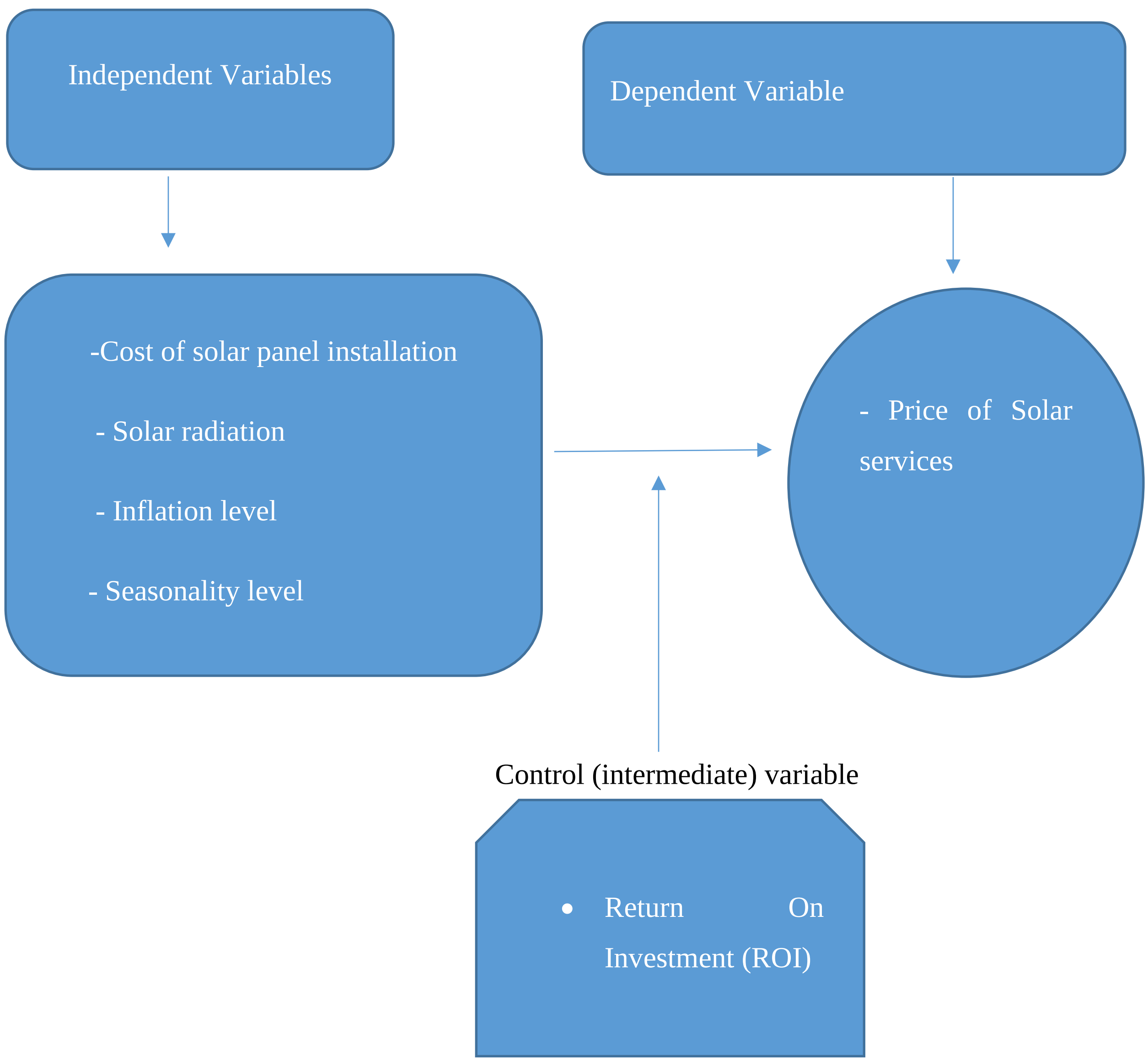
5peak hours per day while Heeten *et al.,* (2017) witnessed that the peak time of Cambodia is about 2 hours from 19:00 and 21:00 with the work of Adeoye and Spataru (2019) who looked on modelling and provision of hourly electricity demand also shown that the peak hour of Ghana is between 17:00 and 22:00, this evening peak hour time is different with that of Rwanda morning hours' peak time.

2.5 Conceptual framework.

The study uses price as the dependent variable with cost of generating solar services, solar radiation, inflation, and seasonality level as the independent variables. The higher cost for generating solar services negatively affecting the rate of solar service pricing on behalf of the end-users. Both cost and price for solar services measured by Rwandan currency (FRW). The less availability of solar radiation sky locates the price of solar service due to solar power providers needs to use hybrid connection to meet the demand of the end-users and vice-versa. Based on the geographical location of Rwanda as solar radiation measured by kilowatt-hours per square meter per day, the average of solar radiation I Rwanda is 5KWh/m2/day with a peak sun hour almost 5 hours (Bimenyimana *et al.,* 2018).

The overall change in price affecting both solar power providers by expensive cost of input and end users by lowering their average consumption per a day. Consumer price index (CPI) contribute to the study as the measurement of inflation. The low rate of electrification lowering the number of enrollment rate. Regrettably low level of electrification harmed by the price fixed by solar power providers. The study considering the pricing techniques, and pricing strategy. For pricing techniques, we had consider cost- based pricing this technique refer to where we set the price by depending on the cost used by the solar power providers this technique is merit because the they facilitate in the setting of price, the competition-based pricing this technique is used by comparing the benchmark of the different competitors and decide the price that should be affordable by comparing to competitors, for pricing strategy we had have various techniques for setting the solar power providers price for being sustainability. Cost-benefits techniques as the total costs used by solar providers for the installation of the solar, means that the price setting depends on the cost and that cost facilitate the solar power providers to gain the benefits or positive results that facilitate in their sustainability. Error term covers other remaining variables do not target by the study.

Figure 2: Conceptual framework



CHAPTER THREE: METHODOLOGY

3.1 Data source

The nature of the study possesses the use of secondary data. For that reason, different hard and electronic documentation from solar power providers in Rwanda, Rwanda Energy Group (REG), International Energy Agency (IEA) and World Bank used as data sources.

3.2 Econometric model of solar power provider's specification.

The study took price as the main constraint for solar power providers to make a generating profit and as for the end users to make service buying profit. To make pricing the study used econometrics estimation method. Therefore, the model below painstaking.

$$ln\,Price_t = \beta_1 + \beta_2 ln\,cost_t + \beta_3 ln\,rad_t + \beta_4 inf_t + \beta_5 ln\,s_t + \varepsilon$$

Where:

$ln\,Price_t$: present logarithm natural of price in time

$ln\,cost_t$: Present logarithm natural of cost for generating solar services in time

$ln\,rad_t$: Present logarithm natural of available solar radiation

inf_t: Present inflation level

$ln\,s_t$: Present logarithm natural of seasonality level

ε: present other factors which are not covered by the study

Solar energy price is almost determined by the cost of PV module since between 35 and 55% of total PV system based on the cost of PV module. Therefore, presence of price and that of the cost for generating solar services measured by available balance in currency. According to the international standard unit, solar radiation measured by available Watts per square meter (W/m^2). Level of inflation measured as a percentage rate and error term cover all remaining data not covered by the model.

3.3 Measurement of variables

3.3.1 Measurement of dependent variable

3.3.1.1 Price of solar services

The study considering price of solar services (pricing technique) as dependent variable. For pricing techniques, we considered cost- based pricing which refers setting the price basing on the cost used by the solar power providers.

3.3.2 Measurement of independent variables

3.3.2.1 Cost of Solar Panel Installation

The study considered price of solar services (pricing technique) as dependent variable. For pricing techniques, we considered cost- based pricing which refers setting the price basing on the cost used by the solar power providers. Both cost and price for solar services measured by Rwandan currency (FRW). Consumer price index (CPI) contribute to the study as the measurement of inflation

3.3.2.2 Solar radiation

Rwanda solar radiation measured by kilowatt-hours per square meter per day, the average of solar radiation is 5KWh/m2/day with a peak sun hour which is 5 hours (Bimenyimana *et al.*, 2018).

3.3.2.3 Measurement of Inflation level

Consumer price index (CPI) contribute to the study as the measurement of inflation. The low rate of electrification lowering the number of enrollment rate.

3.3.2.4 Measurement of seasonality level

The energy production of solar panels depends on a range of factors, including the angle of the sun, the length of the day, the weather. Some variation in the output of solar system depending on the season on the surface, the effect of the seasons on solar is easy to grasp summer's longer days mean more sunlight which means more energy production from our solar panels in comparison to the shorter, cloudier days of winter. Solar panels generally produce about 40-60% less energy during the months of December and January than they do during the months of July and August. This means that solar power generation is significantly less during the winter than it is during the summer

3.3.3 Measurement of control variable

3.3.3.1 Return on Investment

If there is a payment of current solar service bill, solar end-user can afford to go to the solar service. The monthly solar service payment will likely be at the same or less than the current electric bill. Even in the short-term, solar end-users are saving or breaking even. In addition, solar end uses will be earning money through solar incentive program. Solar end-users take advantage of this and treat their solar investment as a secondary, passive income. Upon breaking even, solar end-users will get their full return on investment (ROI) and will become cash flow positive. When installing, solar end-users can add a home storage system to save energy for future use with or without sunshine. Payback period is the amount of time it takes for your upfront solar investment to pay for itself through solar energy savings. A ROI (Return on investment) gives an idea of how much money one can save over the entire lifetime (typically 25 to 30 years) of a solar project.

Return requires a long-term investment strategy as the solar power providers. For solar power providers that only install panels for customers who pay all at once, however, this requires a steady stream of new contracts.

3.4 Data analysis

Data collected processed and analyzed using E-views10. This involved some test such as normality test, stationary test, multicollinearity test and presentation of descriptive statistics.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Descriptive statistics

Table 4.1 presents descriptive statistics for the variables used in this study with regard to their means, standard deviations, minimum, and maximum as follows:

Table 4.1: Descriptive statistics

	Mean	Std. Dev	Min	Max
Ln (price)	11.82725	0.144707	11.724	12.10349
Ln (cost)	11.45156	0.090769	11.30836	11.53273
Ln (radiation)	1.59679	0.110648	1.391282	1.757858
Inflation	1.474574	0.568082	0.530628	2.197225
Ln (seasonality)	0.186822	0.03678	-0.61434	0.598837

Source: Author's calculation

Descriptive statistics for study variables are reported in Table 4.1 As highlighted in the description of descriptive statistics, mean is used for measuring central tendency and standard deviation is used for measuring the variation.

The sample data collected from solar power providers which is represented by the price and cost, the mean of price was 11.8273, mean of cost was 11.4516, mean of radiation was 1.59, mean of inflation was 1.47, mean of seasonality was 0.18. Researcher uses natural logarithms to ensure linearity in the model and fulfilling the normality assumptions for classical best linear unbiased estimator.

4.2 Description of solar pricing techniques

Off-Grid Solar Power Providers, Mobisol's different sized solar systems (30W,100W and 200W) are sold in Rwanda at the price shown in Table 4.2. the focus of the grant was the 100W and 200 W systems with the charging business kit, which includes the MobiCharger for multiple phone or laptop charging and 20 lanterns for rental. The standard components for the 100 W system including three lights, a solar lantern, phone charging kit,17" DC TV, solar radio and Mobisol T-shirt. The 200W system comes with the same components, but with a total of six lights. For an additional cost, customers can add up to 10 lights to the 100W and up to 20 lights to the 200 W system. Mobisol sells these systems as well as a small system without the business kit. The company's product design is done in-house, and manufacturing takes place in China and Germany. The prices below are standard, although Mobisol gave discounts to the first 100 customers (the majority of which were business kit customers as these sales were prioritized for the grant). Mobisol also gives discounts to all customers who complete payments early, within one or two years. In additional to the down payment and monthly prices below, mobisol charges a non-refundable commitment fee which helps cover the costs of credit scoring and stocking units.

Table 4.2 summarizes Mobisol products and prices in Rwanda

Panel Size/System type	Down Payment	Monthly Payment
30W	USD 26.46	USD 9.66
100W	USD 37.66	USD 23.94
100Wwith business kit	USD 37.66	USD 31.92
200W	USD 81.06	USD 44.10
200W with business kit	USD 81.06	USD 53.20

Source: Mobile for development utilities Mobisol Pay-as-you-go solar for entrepreneurs in Rwanda

Originally, Mobisol Rwanda products include 80W and 120W systems, which could be purchased with the business kit these were replaced by the 100W system based on the average hours of sunlight in Rwanda and only needing one size to suit that range of usage. Mobisol communicates monthly pricing requirements to their customers but allows them to pay in more or fewer instalments. Thus, each monthly payment above corresponds to the requirement for 30.5 days regardless of level of use each day.

Table 4.3 summarizes the pricing of solar power package and payment procedure for five years since 2016.

Table 4.3 Solar Energy pricing

Year(s)	Price of solar power(Frw)	Weekly Payment(Frw)
2020	123,500	1,184
2019	123,500	1,184
2018	180,500	1,731
2017	130,000	1,247
2016	130,000	1,247

Source: Author’s calculation, data information from Solar Power Providers

According to Rwanda Utilities Regulatory Authority(RURA), referring to law no 52/2018 modifying law no 21/2011of 23/06/2021 governing electricity law in Rwanda as modified date especially article 29 stipulates that the methodology of electricity setting shall be determined and published by the regulatory authority in consultation with the minister in charge of electricity and the regulatory authority must ensure that the electricity tariffs for renewable energy sources or off –grid electricity for end-users do not exceed the appropriate threshold. The isolated grid end user tariff structure shall consist of energy of energy charge in Rwandan francs per kilowatt-hour (Frw/Kwh), demand charge if applicable in Rwandan francs per kilowatt-hour (Frw/Kwh) or flat rate tariff in Rwandan francs per period of time. The energy and demand charge if applicable to consumers provided with metering devices with the ability to measure those parameters. The set and approved end-user tariff shall be the threshold that the license or registrant is eligible to charge its customers, the applicant shall design their tariff structure consistent with the following principles: incentives for the efficient use of energy , due consideration of affordability for the end-use customers, undue discrimination in rates and tariffs between customers shall be prohibited, but the applicant may, for the purposes of setting tariffs, treats customers differently when the load characteristics or other cost components of serving a customers or category of customer justify disparate treatment, to the extent that the different customer classes are identified , the revenue responsibility allocated to each class shall reflect the costs of serving that class, customer classes shall be identified based entirely on their energy related characteristics such as load factor, demand costs, and level of consumption, to the extent that cross-subsidies are required to provide electricity to the lowest-income households within mini grid's service area , the cost of providing this cross-subsidy may be added to the cost of service allocation of other customer classes. Such cross-subsidies must be designed and implemented so as to provide benefits solely for those clearly identified customers for whom the benefits are intended to serve and to minimize the cost burden on the remaining customers; tariffs should take particular account of the fixed-variable cost ratio of the isolated grid system and its generating source(s);

customer specific bills may be supplemented to reflect the costs of financing the costs connections and /or internal wiring.

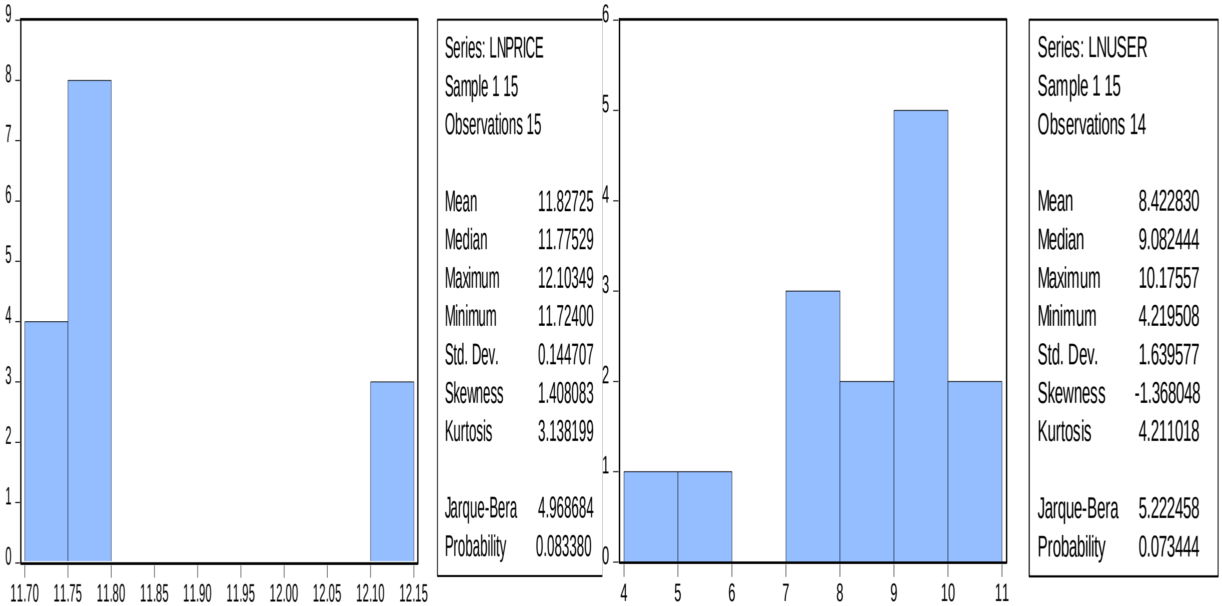
Table 4.3 summarizes the pricing used by Off-grid solar power providers for five years (2016 to 2020). Results show that prices are cost based specifically the cost of panel and its accessories (torches, TV, telephone, and charges). For many years respectively 2016, 2017, 2018,2019 and 2020, the pricing of solar panel was: Frw 130,000, Frw 130,000, Frw 180,500, Frw 123,500 and Frw 123,500, the solar end-users paid this amount on installments but not more 24 months and paid on weekly basis. The end-user's weekly payment for 2016 was Frw 1247 as the same as in 2017, in 2018 was Frw 1731 and in 2020 was Frw 1184 and after the payment of all installments the end-users own the solar panel. Our research results in table 4.2 that the solar power providers setting the price of solar power by considering, the standard components for the 100 W system including three lights, a solar lantern, phone charging kit,17" DC TV, solar radio and Mobisol T-shirt. The 200W system comes with the same components, but with a total of six lights. For an additional cost, customers can add up to 10 lights to the 100W and up to 20 lights to the 200 W system. Mobisol sells these systems as well as a small system without the business kit. The prices above table 4.2 are standard, although Mobisol gave discounts to the first 100 customers (the majority of which were business kit customers as these sales were prioritized for the grant). Mobisol also gives discounts to all customers who complete payments early, within one or two years. In additional to the down payment and monthly prices below, mobisol charges a non-refundable commitment fee which helps cover the costs of credit scoring and stocking units. RURA laws and regulations states the set and approved end-user tariff shall be the threshold that the license or registrant is eligible to charge its customers, the applicant shall design their tariff structure consistent with the following principles: incentives for the efficient use of energy , due consideration of affordability for the end-use customers, undue discrimination in rates and tariffs between customers shall be prohibited, but the applicant may, for the purposes of setting tariffs, treats customers differently when the load characteristics or other cost components of serving a customers or category of customer justify disparate treatment, to the extent that the different customer classes are identified , the revenue responsibility allocated to each class shall reflect the costs of serving that class, customer classes shall be identified based entirely on their energy related characteristics such as load factor, demand costs, and level of consumption, to the extent that cross-subsidies are required to provide electricity to the lowest-income households within mini grid's service area , the cost of providing this cross-subsidy may be added to the cost of service allocation of other customer classes , the off- grid solar power providers charge affordable price to the end user as we compare to the RURA laws and regulations.

4.3 Preliminary tests

The first step in data analysis is testing for normality. This is conducted by setting hypothesis assumption. Statistically, normality test used to determine if data set is well modelled and normally distributed. Histogram is one of the appropriate methods used for testing normality of the model for quantitative data. Testing for normality allows to confirm if response and predictors have corrected functional form or not. This meaning that if residuals are normally distributed, explained, and explanatory variables have a correct functional form and vice versa.

Figure 4.1: Normality test for price

Figure 4.2: Normality test for solar end user



Source: Author's calculation

H_o: Data do not follow normal distribution

H_1: Data follow normal distribution

To report whether data follow normal distribution or not, compare the p-value to the significance level. The study considers significance level of 10% which is denoted by alpha (α).

P-value ≤ α: The data follow specified distribution (Reject H_o).

P-value ≥ α: The data do not follow specified distribution (Fail to reject H_0).

The results from Figures 4.1 and 4.2, the alternative hypothesis states that the data follow a normal distribution. That is due the results shown by figure 4.3; the p-value is 0.083 which is less than the significance level of 10%; the decision is that data follow normal distribution. Also, Figure 4.4 presents that the p-value is 0.073 which is less than the significance level of 10%; the decision is that data follow normal distribution.

Unit root test is another test used to test for stationarity and non-stationarity of a time series. Thus, a time series has stationarity if the shift in time does not cause a change in the character of the distribution. The commonly known methods used for testing stationarity are Augmented Dickey Fuller (ADF) which is commonly used and Phillips-Perron (PP) which is specifically used for large dataset. A unit root is a feature of processes that evolves through time that can cause problems in statistical interpretation involving time series models. Most of the time series that appear in the economic variables will have to be differenced in order to become stationary.

Table 4.4: Unit root test

Variable	ADF Test statistics	1% Test statistic	5% Test statistic	10% Test statistic	Prob
LNPRICE	-5.19653	-4.992279	-3.875302	-3.38833	0.0075
LNCOST	-5.22009	-4.992279	-3.875302	-3.38833	0.0073
LNRAD	-6.93919	-4.992279	-3.875302	-3.38833	0.0008
INF	-4.85208	-4.886426	-3.828975	-3.36298	0.0106
LNS	-5.24867	-4.992279	-3.875302	-3.38833	0.0071

Source: Author's calculation

The outcomes from Table 4.4 presents that, the ADF test by taking first difference at constant and trend, the probability value of 0.0075 shown that ln price is stationary at all level (1%, 5% and 10%). The absolute value of ADF statistics which greater than all t-statistics critical values also show stationarity. This is similar to the ADF test by taking first difference at constant and trend, the probability value of 0.0104 shown that ln user is stationary at all level (1%, 5% and 10%). The absolute value of ADF statistics which greater than all t-statistics critical values also show stationarity. The probability value of 0.0073 shown that ln cost is stationary at all level (1%, 5% and 10%). The absolute value of ADF statistics which greater than all t-statistics critical values also show stationarity.

By taking first difference at constant and trend, the probability value of 0.0008 shown that ln radiation is stationary at all level (1%, 5% and 10%). The absolute value of ADF statistics which greater than all t-statistics critical values also show stationarity. The probability value of 0.0106 shown that ln inflation is stationary at all level (1%, 5% and 10%). The absolute value of ADF statistics which greater than all t-statistics critical values also show stationarity. With the first difference at constant and trend, the probability value of 0.0071 shown that ln seasonality is stationary at all level (1%, 5% and 10%). The absolute value of ADF statistics which greater than all t-statistics critical values also show stationarity

In research correlation matrix used as a tool for summarizing large dataset with the objectives of identifying, visualizing the patterns in given data, displaying the correlation coefficients for different variables, and investigating whether changes in one variable are associated with changes in other variables. With correlation matrix, correlation coefficient can be bivariate statistic when it summarizes the relationship between two variables and can be multivariate statistic when it summarizes more than two variables. Notably, correlation coefficient always varies in the range between one and negative one. The change in signs of coefficient allowing to decide whether variables change in the same direction if there is a positive value of variable and vice versa.

Table 4.5: Correlation matrix

	LNPRICE	**LNCOST**	**LNRAD**	**INF**	**LNS**
LNPRICE	1.00000	0.59436	0.28319	-0.23496	-0.00617
LNCOST	0.59436	1.00000	-0.3219	-0.70447	-0.51524
LNRAD	0.28318	-0.32190	1.00000	0.32118	0.00841
INF	-0.23497	-0.70447	0.32119	1.00000	0.52232
LNS	-0.00617	-0.51524	0.00841	0.52232	1.00000

Source: Author's calculation

Table 4.5 presented that in time period of the study; there is moderate correlation between price and cost, while there is low correlation between price and radiation, the results also shown that there is a low negative correlated between price and inflation. The results also presented that, there is a weak negative relationship between seasonality and solar price. The results also shown that there is a moderate relationship between solar radiation, inflation, cost, and solar price. In addition, the higher cost of materials affects the price to be higher means that when the cost of materials increases, the price also increases and vice versa, the result presented that the price correlate directly to cost.

4.4. Regression analysis

The presentation of regression analysis for the study plays the role of predicting the value of explained variable which is determined by the value of the explanatory variables. Thus, the study took price as the main constraint for solar power providers to make a generating profit and as for the end users to make service buying profit. In addition, the characteristics of the model such as stationarity and fitness of the model allows the use of ordinary least square estimation method. Moreover, the explanation and measurement of the variables was presented in previous section. Therefore, the model below painstaking.

$$ln\ Price_t = \beta_1 + \beta_2 ln\ cost_t + \beta_3 ln\ rad_t + \beta_4 inf_t + \beta_5 ln\ s_t + \varepsilon$$

As mentioned above, the results from the regression analysis aided in the prediction of the value of explained variable which is sourced from the values of explanatory variables. The results after running the regression provided below presented equations.

previous section. Therefore, the model below painstaking.

$$ln\ Price_t = \beta_1 + \beta_2 ln\ cost_t + \beta_3 ln\ rad_t + \beta_4 inf_t + \beta_5 ln\ s_t + \varepsilon$$

Where: $ln\ Price_t$: present logarithm natural of price in time

$ln\ cost_t$: Present logarithm natural of cost for generating solar services in time

$ln\ rad_t$: Present logarithm natural of available solar radiation

inf_t: Present inflation level

$ln\ s_t$: Present logarithm natural of seasonality level

ε: present other factors which are not covered by the study

The results from regression analysis summarized by the regression equation. The equation assisted for easy understanding of the relationship between study variables both explained variable and explanatory variables. With this understanding, the equation of ln price as dependent variable shown that with ceteris paribus; ln price is affected positively with its independent variables. holding other factors constant.

Table 4.6: Regression analysis

Dependent Variable:	LNPRICE			
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-9.96	3.791	-2.628	0.025
LNCOST	1.78	0.32	5.564	0.000
LNRAD	0.8	0.195	4.1	0.002
INF	0.02	0.051	0.42	0.068
LNS	0.20	0.067	3.081	0.011
R-squared	0.81	Mean dependent var		11.82
F-statistic	11.066	Durbin-Watson stat		2.031
Prob(F-statistic)	0.001			

Source: Author's calculation

Table 4.6 summarizing the estimation results for Ln price as dependent variable. The results from the table pointed that one percent increase in cost of providing solar service increases solar service price about 1.78 percent, the increase of one percent in solar radiation increase the solar service price about 0.80 percent, an increase of one percent in inflation rate increases solar service price about 0.02 percent and one percent variation in seasonality increases solar service price about 0.20 percent.

After performing diagnostic checking and given that the all coefficients are significant with probability less than 5 percent, the model can be used to forecast the energy pricing in Rwanda

The values of Durbin-Watson for both models which are not far of two which approves that there is a zero-autocorrelation on study variables. The values of probability (F-statistics) for both models which is below the significance level of five percent also shown that sample data provide sufficient evidence to conclude that there is a fitness of regression model.

In addition, Researcher performed serial correlation test and found that probability is equal 0.9 which is above 5 percent hence the null hypothesis which state that there is no serial correlation in the residuals cannot be rejected.

Regarding the prediction, prediction valuation such as mean absolute error, mean percentage error and root mean square error was chosen. Low root mean square error better pricing predication results.

CHAPTER FIVE: MAJOR FINDINGS, CONCLUSION AND RECOMMENDATION.

5.0 Introduction

This chapter summarizes the results from the study which aim was to analyze the Solar Energy Pricing: Evidence from Off-Grid Solar Power Providers.

Our study discussed the solar energy pricing for solar energy in Rwanda and the potential factors affecting the solar power pricing in Rwanda, solar energy price factors including cost of solar panel, solar radiation, inflation and seasonality. All factors considered were found to be crucial to influence the price for energy in Rwanda.

5.1. Discussion of findings

Findings are discussed according to the main study specific objectives as follow:

5.1.1. To access the pricing techniques for Solar Energy in Rwanda

According to Rwanda Utilities Regulatory Authority(RURA), referring to law no 52/2018 modifying law no 21/2011of 23/06/2021 governing electricity law in Rwanda, the pricing shall be ensuring that the electricity tariffs for renewable energy sources or off –grid electricity for end-users do not exceed the appropriate threshold. The set and approved end-user tariff shall be the threshold that the license is eligible to charge its customers. Our research results in table 4.2 that the solar power providers setting the price of solar power by considering, the standard components for the 100 W system including three lights, a solar lantern, phone charging kit,17" DC TV, solar radio and Mobisol T-shirt. The 200W system comes with the same components, but with a total of six lights. For an additional cost, customers can add up to 10 lights to the 100W and up to 20 lights to the 200 W system. Mobisol sells these systems as well as a small system without the business kit. The prices above table 4.2 are standard, although Mobisol gave discounts to the first 100 customers (the majority of which were business kit customers as these sales were prioritized for the grant). Mobisol also gives discounts to all customers who complete payments early, within one or two years. In additional to the down payment and monthly prices below, mobisol charges a non-refundable commitment fee which helps cover the costs of credit scoring and stocking units. RURA laws and regulations states the set and approved end-user tariff shall be the threshold that the license or registrant is eligible to charge its customers, the applicant shall design their tariff structure consistent with the following principles: incentives for the efficient use of energy , due consideration of affordability for the end-use customers, undue discrimination in rates and tariffs between customers shall be prohibited, but the applicant may, for the purposes of setting tariffs, treats customers differently when the load characteristics or other cost components of serving a customers or category of customer justify disparate treatment, to the extent that the different customer classes are identified , the revenue responsibility allocated to each class shall reflect the costs of serving that class, customer classes shall be identified based entirely on their energy related characteristics such as load factor, demand costs, and level of consumption, to the extent that cross-subsidies are required to provide electricity to the lowest-income households within mini grid’s service area , the cost of providing this cross-subsidy may be added to the cost of service allocation of other customer classes , the off- grid solar power providers charge affordable price to the end user as we compare to the RURA laws and regulation

5.1.2. To identify factors affecting pricing for solar energy in Rwanda

The conducted study titled solar energy pricing: evidence from off-grid solar power providers. This is conducted via specific objectives questions which are expressing the solar energy pricing factors including cost of solar panel, solar radiation, inflation and seasonality. The cost of material is much correlated with the price, i.e. the cost should affect the price to be increased or decreases, when the cost of solar panel increase link directly the increase of the selling price vice versa and cost is very crucial to solar energy pricing. Solar radiation as factor of solar energy pricing is critically essential in the solar power storage, when the solar radiation from the sun right decrease should affect the solar power pricing. Inflation as a major part of consumer price index should affect the price for the increasing of the currency value and price of material increase at huge level this inflation rate should be adjusted to the solar energy pricing. Seasonality also are essential to part of solar energy pricing depends on the period, where they are at higher level of sun shine the solar power is abundant and also be part of solar power pricing. All factors considered were found to be crucial to influence the price for energy in Rwanda

5.2. Conclusion

The study conducted with the main objective of examining solar energy pricing tools for both users and solar power providers. Two important questions including what the pricing techniques for solar energy are and what are the factors influencing solar energy price, used to achieve the objective of the study. The study revealed that PAYGO is the suitable pricing technique among other pricing techniques for both solar power providers and solar end-users.

Furthermore, the study found that inflation and seasonality influencing negatively solar energy pricing. Access to energy still a challenge to Rwandans especially to those living in rural area far from the national grid connection. For that motivation, the study contributing to the obtainable writings the appropriate methods and means that can be followed by land locked developing nations for sky locating the rate of population with having access to energy specifically those living far of the grid.

5.3. Recommendation

5.3.1 Recommendation to the entities

The study revealed that inflation and seasonality is the major challenges for both solar power providers and solar end-users. Therefore, the study recommended solar power providers to use hybrid connection to meet the seasonality issues. For the case of inflation, the study recommended government of Rwanda to offer some subsidies and incentives to solar power providers in case of hyperinflation as it done in case of higher price increase for petroleum commodities. Solar end-users are recommended to use available energy efficiently and pay at time the offered services from solar power providers.

5.3.2 Recommendation to future researchers

Time scale of the study limit the researcher to wholly enter in the pedigrees of all factors that are associated with the subject of solar energy pricing. For that reason, the researcher recommended future researchers to examine other factors that can influence solar pricing.

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