A Theoretical Pre-Assessment of Solar Photovoltaic Electrical Production for Commerical Retail Centers

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***Abstract* — The successful implementation of solar photovoltaic technology in retail centers has enabled various consumers the ability to generate and consume electricity on the same premises, reducing electricity costs and dependency on currently utilities. The rooftop mounting solution consists of affixing the photovoltaic modules on existing roof structures of retail centres. Accelerated deployment of photovoltaic technologies in recent history (within developing countries) led to various logistical, technical and bureaucratic barriers arising. A comprehensive understanding of these barriers is required to ensure efficient and effective deployment of the technology in developing countries. This study investigates the assessment considerations for the pre-deployment phase of photovoltaic technologies in retail centres. Environmental-, policy-, technical-, and financial factors are identified as the main barriers affecting the financial viability and Return on Investment of such a project. The evolution of this technology within developing countries and the integration of PV and retail centres are investigated. Finally, various financial evaluation criteria are presented to which the viability of the technology is determined. Understanding of the various barriers ensures effective deployment of the technology in retail centres, commercial and residential sectors of an economy.**

Keywords—Photovoltaic, Renewable Energy, Developing Economies.

I. INTRODUCTION

Solar photovoltaic (PV) electrical energy production utilizes electromagnetic radiation from the sun and converts it into electrical energy. The electrical energy is unified into the microgrid; reducing dependence on current electricity utilities and electricity costs while minimizing operational costs when independent generation (diesel generators, etc.) mechanisms are in operation [1].

Utilization of renewable energy is driven by a need to improve energy security, encourage economic development, and reduce environmental mitigating effects [2]. It is thought that energy availability and accessibility are dependent [3]. Corporate strategies include PV production as a means to reduce current electricity and operational costs in retail centres. The ideal production curve of a PV plant follows a similar electricity consumption trajectory of retail centres. PV deployment in retail centres is based on the rooftop solution (the PV modules are mounted on the roof of various structures of the retail centre). Limited research exists investigating the synergy between Photovoltaic solar electricity production and retail centres.

The objective of this study is to investigate the assessment considerations during the pre-deployment phase of solar photovoltaic technologies, as applicable to retail centres.

The literature review provides information and research pertaining to solar photovoltaic deployment in retail centres. Environmental concerns, policy factors, technical dynamics, and the financial evaluation criteria to consider in deploying solar photovoltaic technology is discussed. It identifies the correlation between solar technology and energy consumption in retail centres. The conclusion reflects and reiterates the document and provide recommendations on future research pertaining to the aim of the document.

II. LITERATURE REVIEW

Solar PV electrical energy production has seen an average annual growth of 43.3% from 1990 to 2016 - more than any other renewable energy alternative. It occupies a 2.0% share in electrical energy production in The Organization for Economic Co-operation and Development (OECD) [4]. From 2005, all the major participants in the OECD have experienced exponential growth pertaining to the development and commissioning of PV electrical production; only Germany and Italy have seen market saturation[4].

There are four aspects, as applicable to each country, to consider when engaging with Solar PV production[2]. Three of those aspects integrate together, affecting the final Return on Investment (ROI). They are the technical aspects of the proposed project, the financial implications of the plant, and the relevant licensing, registration, and policy factors. The fourth aspect to consider is the impact on the environment (environmental concerns can have an impact on the ROI, depending on the renewable energy source and its location) [2]. Fig. 1 summarizes the hierarchy process, as described above.

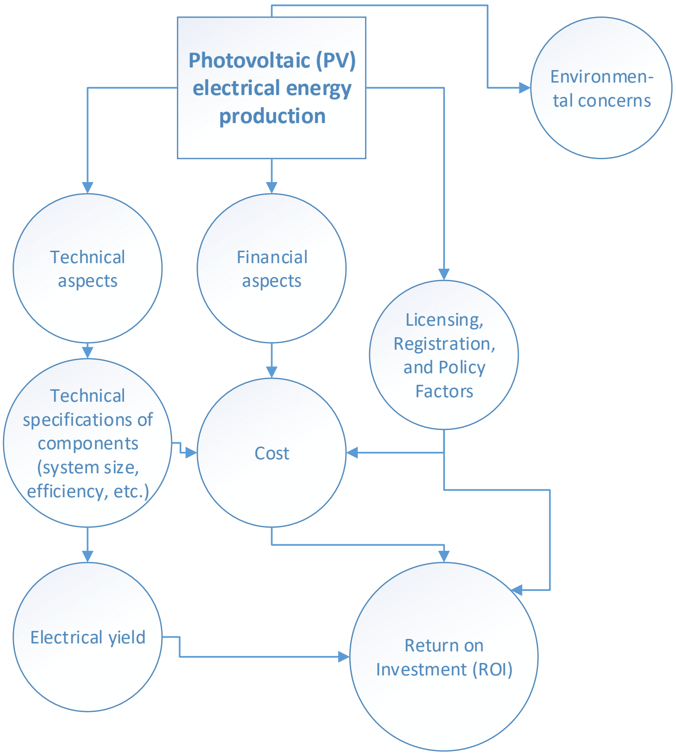

Fig. 1. Flow diagram depicting main pre-considerations of PV production

A. Environmental concerns

PV deployment receives high priority in reducing mitigating environmental concerns, allowing exploitation of natural resources and providing new sources of natural capital [2]. Considerations include the effect of the technology on the local environment, including:

- Interference between PV and current infrastructure (added mass of the modules to the roof structure of the retail centre, AC/DC power quality, etc.);
- Reduction of pollutants from power generation; and
- Influence on local economies.

Discussion on environmental concerns will be limited as it is not the focus of the research article. Numerous articles have been published discussing all of its beneficial factors [2][5].

B. Policy factors

Due to the rapid installation rate experienced in developing economies (specifically in South Africa), updated legislation and policies are either not available or inefficient – resulting in that numerous barriers are encountered [3]. Current licensing and registration processes vary from country to country as policies differ. Developed countries generally require the registration of a plant before commissioning. It is important to investigate applicable policies and factors influencing them [3].

Energy technology deployment is understood in terms of market diffusion theory. The theory assumes that a specific technology grows slowly initially (inception phase), gains development and accelerate with time to attain a certain peak (take-off phase), and then slows down as the market reaches saturation (Consolidation). Technology deployment follows an S-shaped trajectory as in Fig. 2. Due to technology evolution, policy priorities change according to its deployment levels [2].

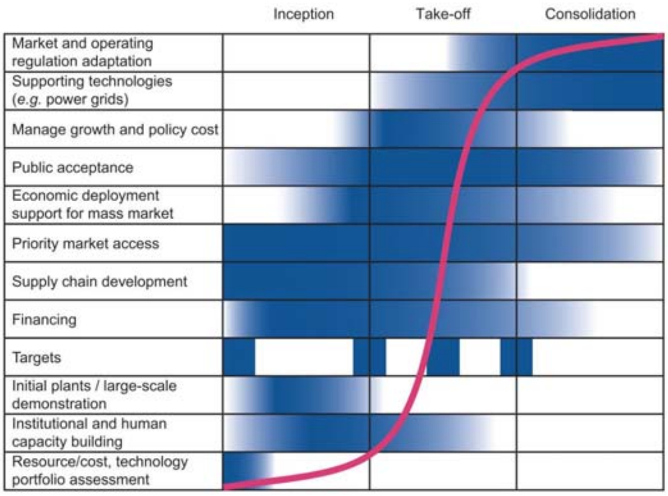

Fig. 2. Market development of a specific technology as per diffusion theory [2]

When Fig. 2 is referred, cell shading reflects the relative significance of an individual issue along the deployment rate. Light shading suggests that intervention with light priority is required. Dark shading requires intervention with high priority. In general, high priority intervention is required when the technology experiences acceleration. The inception phase requires minimal priority due to low market penetration [2].

If demand for residential and commercial solar increases, existing utilities can encounter operational difficulties due to lack of policies [5]. Numerous barriers are proposed that influence policies pertaining to renewable energy [2][6] - barriers provide the highest resistance against any new technology. They are [2]:

- Economic barriers
- Non-economic barriers;
  - Technical barriers,
  - Financial barriers,
  - Market barriers,
  - Public acceptance and environmental barriers, and
  - Infrastructure barriers.

Developing countries have historically followed a different inception and development phase compared to developed countries [7]. Research conducted by Liu et al [8] investigated the role of knowledge-based organizations and local government in China (world leader in utilizing PV technology). They concluded that collaboration between government and science, as well as government and industry is present, but collaboration between science and industry is lacking. They further concluded that policy-makers should develop effective mechanisms to foster knowledge diffusion between science and industry that will aid the transition in the inception phase. They also concluded that it is imperative that governments must amend policies while the product is in the inception phase; inadequate decision-making will affect the product and other parties [8]. Numerous research papers published cautions against a rapid transition from current infrastructure [2][3]. Grubler [7] provided three precautionary insights pertaining to energy supply – implying that the drivers of energy transitions is complex and not a single dimensional driver. They are [7]:

- The importance of energy end-use in driving energy transitions – energy transition is dependent on the technology and the transformation of the involved institution,
- The rate of change – developed countries with stable infrastructures require an extended transition period, and
- Distinction in successful patterns – the technological design and industry standardize to enter market saturation while industry growth becomes dependent on the globalization of the technology and practice.

Local governments must implement PV policies and legislation with a longer time horizon considered [2]. Lack of policies will affect both the Independent Power Producer (IPP) and existing power utilities [9].

C. *Technical dynamics*

The inception phase of a proposed project includes the conduction of an Environmental Impact Assessment (EIA) and a financial evaluation of the project based on the ROI. Due to lack of policies, the tenderer must consider additional aspects such as the effect of licensing and inadequate policies. The IEA suggests that PV production must not surpass 5% of the Total Primary Energy Supply (TPES) of a network; surpassing this recommendation will induce frequency variation during sudden interruption resulting to enforce load control [10].

Rooftop solar PV systems are the most cost-effective method of independent electricity generation in Australia - the electricity supply and demand are located on the same premises, minimizing distribution losses and reducing installation costs commonly incurred with stand-alone structures [11]. In addition, the generation and load curve tend to follow the same trajectory.

Fig. 3 depicts the average daily energy consumption for a given retail centre. The centre is located in the southern hemisphere resulting in that peak summer is observed during the months of November, December and January. Peak winter is observed during the months of June, July and August.

From Fig. 3, electrical load progressively decreased from 00:00 to 06:00 to attain its average monthly minimal at 06:00 (approximately 27.2% of the maximum summer load). The highest average monthly consumption occurred during the summer seasons between 12:00 to 14:00. The reasons for the increased load demand are twofold; firstly, the average load increases in that particular period because the average ambient temperature attains its maximum, resulting in increased cooling loads, and secondly, consumer load increases.

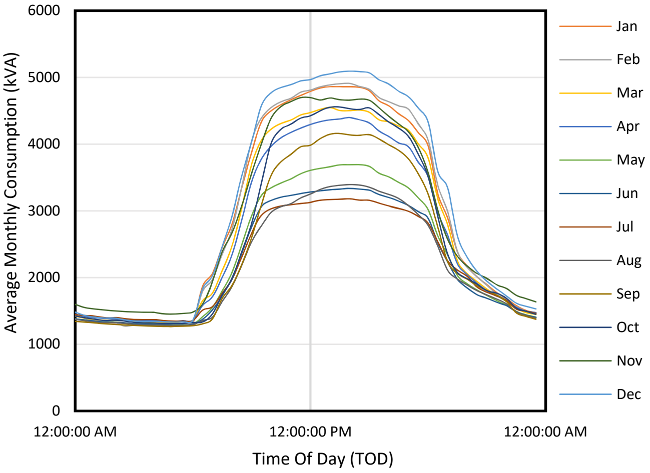

Fig. 3. Average daily electrical energy consumption for retail centres

Fig. 4 depicts the ideal electrical energy production by PV throughout the duration of the year. The data from the figure is from a location on the same celestial meridian to that of the data depicted in Fig. 3, preventing electrical production and consumption mismatch due to deviation in sun position as a function of TOD. The plant is constructed with a 3° module pitch and a 20° angle on the azimuth (North North-West). The plant is rated 1 MWp (DC input) and 998 kVA (AC output). The average global horizontal irradiation (GHI) is 2100 kWh/m^2 for the geographical location [12].

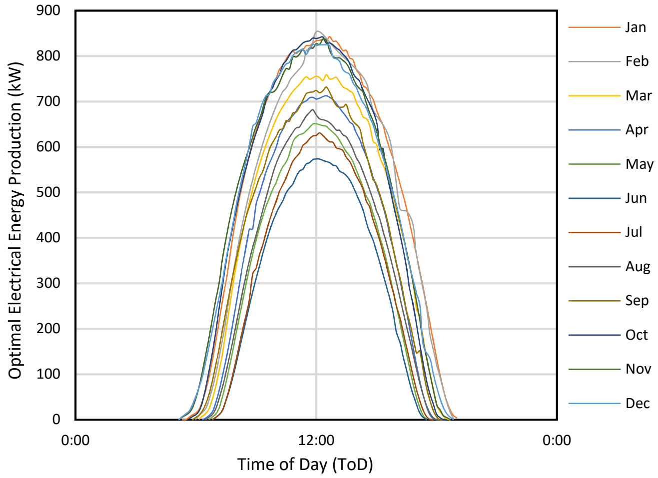

Fig. 4. Optimal PV electrical energy production

From the data in Fig. 4, it is seen that because of the irradiation variation (seasonal change), PV electrical energy production deviate seasonally. Peak production incurs during peak summer periods while minimum production is during winter periods. However, production is not proportional to irradiation as the system efficiency is also affected. Increased radiation increases average ambient temperature, resulting in a reduction in the module, inverter, and transmission (increased voltage drop across a cable between generation and consumption points) efficiency [13].

Fig. 5 depicts the interaction between load demand and PV electricity production as a function of TOD. It indicates that the trajectory between electricity consumption and PV electricity production is similar. Peak grid penetration of 19.68% is experienced during the winter season because of reduced grid load. Summer season sees a grid penetration 17.54%. However, due to the climatic conditions of the case study, overall ideal PV generation is observed during the winter season as a sudden interruption (due to cloud covering) is less frequent compared to the summer season.

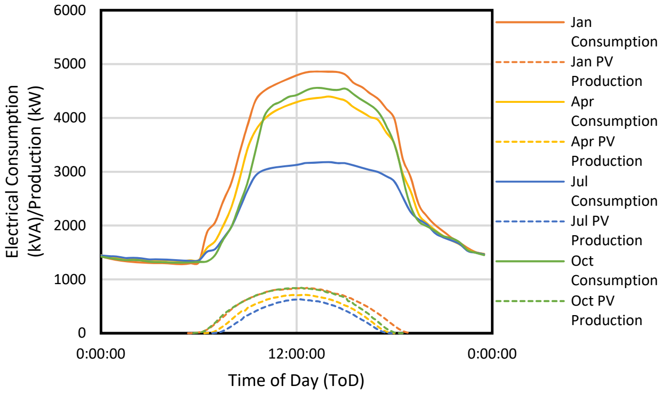

Fig. 5. The interaction between load demand and PV electrical production

The theoretical energy savings incurred by utilizing a rooftop PV plant is, therefore, the difference between the total electrical consumption and the sum of the corresponding PV electrical production. A reduction in building cooling load is also experienced; building cooling load is reduced due to the installation of the PV modules on the roof structure. The roof structure undergoes comparatively high surface temperatures when exposed to irradiation. Kotak conducted research on the effect of installing multiple modules on top of a roof and found that the theoretical cooling load for the exposed roof sheet area can be reduced by 73% to 90% [14].

Once all the considerations pertaining PV electrical energy production are considered as per Fig. 1, then project commencement in the form of a tender process will occur. The tender process will be either invite only or open to all prospective contractors; the aim being to generate an Engineering, Procurement, and Construction (EPC) agreement between the respective parties. The EPC agreement will ensure that the tenderer (contractor) is held responsible for the design, procurement, construction, commissioning and handover phases of the project [13].

Various barriers (available space, legislative constraints, etc.) commonly determine the size of the plant. Either the client or the discretion of the tenderer determines the system size. Tenderers guarantee the electricity production by utilizing simulation software. The software is dependent on various input parameters made available to the tenderer before submission of his solution. Fig. 6 illustrates the various stages modelled by utilizing sizing and simulation programs [15]. In some cases, final design solutions are based on the results of the programs.

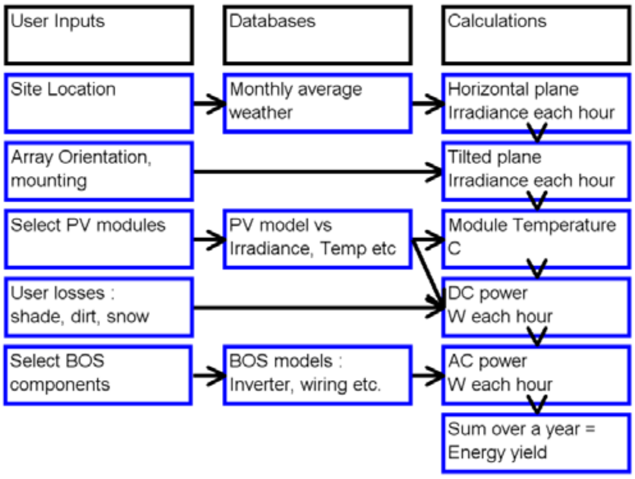

Fig. 6. Various stages modelled by sizing and simulation programs [15]

The tenderer will guarantee the performance of the plant based on its annual Performance Ratio (PR) or its actual yield over a given period.

The PR is sensitive to various variables; some variables are in Table 1. These variables can result in that a maximum deviation of 6% can occur from location-to-location. The biggest attribute of the deviation is a variation in irradiance sensor readings and plant performance [13][15].

Table 1: Variables affecting the PR of a plant [15]

Variable	For different locations	For the same location
Availability, inverter Loss, PV Module performance	Unknown	Unknown
Soiling	±1%	0%
Irradiance Sensor Calibration	±2%	0%
Yearly Insolation Variability	±4%	0%
Reference Module Calibration	±2%	±2%
Module Power Class	±2.5%	±2.5%
Degradation	<+1%/y	<-1%/y

The PR is the conventional performance metric defined by the International Electrotechnical Commission (IEC) such that [13]:

$$PR = Y_f / Y_r \tag{1}$$

$$Y_f = E_{AC} / P_o \tag{2}$$

$$Y_r = \tau_r \text{ x } (\Sigma_{day} G_I) / G_{I,ref} \tag{3}$$

Where:

PR = Performance Ratio;

E_{AC} = Electricity measured at the tie-in point (kWh);

P_o = DC output at Standard Test Conditions (STC) (kWp);

τ_r = Recording interval (Hours);

G_I = In-plane irradiation (kWh/m^2); and

$G_{I,ref}$ = Reference in-plane irradiance = 1 kW/m^2.

However, due to the operational nature of the irradiance sensor module, the Temperature Corrected Performance Ratio (TCPR) and the Weather Corrected Performance Ratio (WCPR) must be calculated. After application of these corrections, a continuous PR throughout the duration of the year can be calculated [13]. Due to contractual obligations, third parties must monitor the PR for a plant over the validity period of the EPC agreement [13].

In some cases, the EPC opt to guarantee the production of the plant against simulation software. This type of agreement is dependent on the yield probability factor generated by the simulation software. This method of guaranteeing the performance of the system exposes the EPC in that weather variability is not considered. Wittmer conducted research comparing the output of a plant against predicted output as per the simulation software. They conceded that discrepancies between simulation and actual output are common [16]. Less interpretation of data is required for this method. EPCs' guarantee the system output as a function of the simulation data such that:

$$E_{AC} = x.E_{sim} \tag{4}$$

Where:

x = Factor of output (%); and

E_{sim} = Simulated output (kWh).

D. Financial evaluation criteria

The economic feasibility of a project is determined based on an evaluation criterion. Mathematical techniques used to compare the costs and benefits of a project in regards to commercial, economic and social aspect determines the theoretical viability of a project. These mathematical techniques also determine the prioritization criteria for selecting and ranking a project. The most commonly applied criteria are [17]:

1. Net present value (NPV),
2. Internal Rate of Return (IRR),
3. Benefit/cost (B/C) ratio, and
4. Payback period.

1) Net present value (NPV)

The NPV method is the most widely used analysis method of investment projects. It is the difference between the net cash inflow (provided during the economic life of the project) and the present value of cash outflows over a period [18]. The NPV must be greater or equal to zero for the project to meet the acceptance criteria such that (NPV ≥ 0). The NPV has the highest priority in considering alternatives [17]. The NPV can be determined by the following equations [17]:

$$NPV = C_0 + PV = C_0 + \frac{C_n}{(1+r)^n} \tag{5}$$

$$FV = C_0(1+r)^n \tag{6}$$

Where:

PV = Present Value,
C_n = Cash flow after n period (year),
r = Interest rate (%),
n = Number of periods (year),
NPV = Net Present Value,
C_0 = Initial cash flow, and
FV = Future Value.

The initial cash flow is generally equal to the initial investment costs and has a negative value.

2) The Internal Rate of Return (IRR)

The internal rate of return (also referred as Return On Investment – ROI) is defined as the rate earned on the unrecovered balance of an investment so that the final payment or receipt brings the balance to exactly zero with interest considered[18]. Numerically, i can range from -100% to infinity such that:

$$-100\% \le i \le \infty \tag{7}$$

When i = -100%, then it is indicative that the entire investment/amount is lost. The annual return is calculated using the following equation [18]:

$$A = PV\,(\frac{i(1+i)^n}{(1+i)^n - 1}) \tag{8}$$

Where:

A = Annual worth, and
i = Rate of Return (%).

3) Benefit/cost (B/C) ratio

The benefit/cost ratio is an analysis for projects in various sectors, including the public sectors. In financial terms, the B/C ratio is defined as the Present Worth of the investment benefits as a function of the Present Worth of the investment costs[17]. The guideline is as follows:

- If B/C ≥ 1.0, then the project is acceptable based on economic value, and
- If B/C < 1.0, then the project is not economically acceptable.

4) Payback period

The payback period is the required duration for the obtainment of the net inflow of money from the investment to meet or exceed the amount of an investment cost. The payback period can be calculated as follows [17]:

$$Payback\ period = \frac{Investment\ cost}{Annual\ net\ inflow} \quad (9)$$

Income from the project is acquired by comparing the electricity costs of current utilities to the electricity generation from the PV plant.

In conducting the pre-assessment of such a project, all of the above financial model criteria will be applied to determine the viability of the project [11].

III. CONCLUSION

The introductory section of the paper established a need in utilizing solar PV technology in retail centres and the parameters to consider when initiating such project.

The literature review presented the four pre-considerations pertaining to PV electrical production in retail centres, namely:

- *Environmental concerns;*
  The interaction of the technology and its surrounding environment affects the overall performance of the plant. Environmental pollution, interface into current infrastructure, etc. affect the local environment.
- *Policy factors*;
  The various factors influencing the policies local governments implement pertaining to the generation of independent electricity. Each technology undergoes the inception, take-off, and consolidation phase as part of its evolution in a market (known as diffusion theory). Local governments must consider diffusion theory when implementing new policies; each policy is considered in conjunction with its associative barriers in advance before the technology enters a new phase of the theory. Lack of proper policy factors influences IPPs and current utilities.
- *Technical dynamics;*
  The technical aspects of the project are considered in its inception phase. System size, yield, etc. are estimated by simulation software and refined by the EPC. System sizing is based on the load curve of the retail centre and legislative barriers. The EPC guarantee the performance of the plant based on the PR of the plant or the actual yield of the plant.
- *Financial evaluation criteria;*
  Mathematical financial models determine the financial viability of a prospective project. The NPV, IRR, B/C ratio, and payback period are factors considered in evaluating the financial feasibility of a project.

The research presented a holistic approach in evaluating the viability of PV deployment for developing countries. For future research, it is recommended that each of the four considerations are isolated in order to conduct a comprehensive study for each.

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