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Solar Photo Voltaic Power Generation in union territory of Lakshadweep Island: Projected Level Dissemination Using Technology Diffusion Models

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Abstract— **Lakshadweep Island is one of the union territory of India. The main source of electricity in Lakshadweep Island is diesel generators, the diesel being transported from the main land. Due to high energy costs, the islands are proving to be excellent test beds for the introduction of new technologies, and becoming so-called renewable energy islands to satisfy their energy demand mainly from indigenous and renewable energy sources. With its fragile locations, geographical and environmental limitations it is desirable to explore possible strategies to utilize maximum available potential of non-polluting renewable energy sources for this ecologically sensitive island. This paper examines the penetration of renewable energy sources in general and dissemination of solar photo voltaic (SPV) based power generation of electricity in particular for balance solution to the energy problems of Lakshadweep Island using technology diffusion models. It was found that with different diffusion models, the future time frame of SPV based power generation is likely to reach its maximum estimated potential in another 40 years.**

Keywords—power generation; renewable energy technology; dissemination of solar energy; technilogy diffusion models.

I. INTRODUCTION

Energy supply of most Islands depends mainly on expensive oil derivative importation. Some Islands are trying to become so called renewable Islands to satisfy their energy demand mainly or entirely from indigenous and renewable energy technologies (RET), thus increasing the reliability of supply, and employment opportunities, without increasing the cost significantly along with environmental pollution mitigation. A great deal of work has been carried out in this specific aspect of energy supply on different Islands in the world [1]. Unfortunately due to Island specific energy demand profile, resources and different kind of environmental conditions, study of one Island cannot be applied to other Islands as such. Thus there is a need to further explore the energy supply options for different Islands located at different places. This paper presents a case study on Lakshadweep Island. Presently the main source of electricity in Lakshadweep Island is diesel generator (DG) sets [3]. Even though there is an abundance of renewable energy sources such as solar, wind and biomass, but their use are still limited. Geographical location, ecological consideration, environmental concern and energy demand pattern of Union Territory of Lakshadweep (UTL) Islands makes Renewable energy technology (RET) most appropriate and attractive option to meet its energy demand [2]. The decentralized, modular, upgradeable, clean and environment friendly biomass, wind and solar photovoltaic systems provide the most promising and balance solution to the energy needs of UTL Islands [4].In this study a modest attempt has been made to project the future dissemination levels of solar PV power generation of Lakshadweep island using technology diffusion models namely the Pearl model [12] and Logistic model. This paper also elaborates the renewable energy scenario of the island and briefly illustrates the geographical profile of the UTL Island and the existing electrical energy supply system.

II. PROFILE OF LAKSHADWEEP ISLAND

The Lakshadweep Island group lies in the Arabian sea and consists of 36 small size Islands scattered about 200- 400 Km from the western coast of South India between latitude 81°15’ N and 11°45’ N and longitude 72°00’ E and 74°00’ E. Out of these 36 Islands only 11 Islands are inhabited [6]. Out of these 36 Islands only Kavaratti and Androth Islands have area greater than 4 Km^2 and population greater than 10,000 persons and Kavaratti is the Capital of Union Territory of Lakshadweep Island [9]. Lakshadweep has a tropical climate with summers ranging from 35°C to 22°C. Humidity levels are high throughout the year and ranges from 70-80%. The Island experience moderately high rainfall of 1000 mm a year with the major share from the southwest monsoons. The soil of UTL Islands has been derived from coral limestone. It is essentially coral sandy soil underlined by limestone and gravel of different shapes and size. The land has 85 to 98 percent calcium carbonate, which is totally unfavorable for any type of cultivation [10]. Thus the natural eco-structure of these Islands is not conducive to agricultural development. However, it is suited for coconut plantation, which is done here to a great extent. Husk obtained from coconut plantation is also very useful for biomass energy generation which is another method of renewable generation. The geographical location of Lakshadweep Island group is shown in Figure 1.

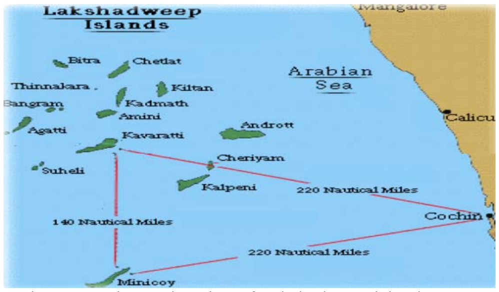

Fig.1. Location and setting of Lakshadweep islands group

III. TECHNOLOGY DIFFUSION MODELS

Empirical studies have shown that in a large number of cases the growth of technology over time conforms to an S- shaped curve, which is a combination of simple and modified exponential curves [13]. The S-shaped curves are characterized by a slow initial growth, followed by rapid growth after a certain take-off point and then again a slow growth towards a finite upper limit to the dissemination. Some of the commonly suggested technology diffusion models are briefly presented below and the same have been used in this study to estimate the utilization potential of renewable energy technology i.e., SPV technology for power generation at different time periods. The Individual Innovativeness theory [11] states individuals who are predisposed to being innovative will adopt an innovation earlier than those who are less predisposed.

A. Rate of adoption

The third widely-used diffusion theory discussed by [7-8] is the theory of Rate of Adoption. Rate of Adoption theory states that innovations are diffused over time in a pattern that resembles an S shaped curve (Fig.2). Rate of Adoption theorizes that an innovation goes through a period of slow, gradual growth before experiencing a period of relatively dramatic and rapid growth. An example of how rate of adoption might typically be represented by an s-curve [14] is shown in Fig.2. The theory also states that following the period of rapid growth, the innovation's rate of adoption will gradually stabilize and eventually decline.

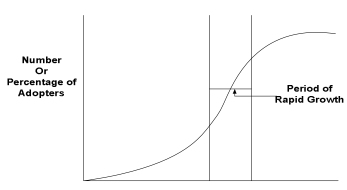

Fig.2. S-Curve representing rate of adoption of an innovation over time

B. Bass model of technology diffusion

Bass developed an empirical diffusion model in which the later adopters of a technology are influenced by earlier adopters [5]. As per the Bass model, the cumulative number, N (t), of the renewable energy technology adopted up to a particular period (t^{th} year) can be estimated by the following expression;

$$N(t) = M\,[(1 - e^{-(p+q)t}) / (1 + (q/p)\, e^{-(p+q)t})] \qquad (1)$$

Where M represents the estimated maximum utilization potential of the renewable energy technology in the country, p the coefficient of innovation and q the coefficient of imitation. The values of p and q can be estimated using the past data on diffusion of the technology.

Assumptions and the model

The likelihood of diffusion at time T given that no diffusion has yet been made is:

$$[f(t)] / [1 - f(t)] = p + q/m\, Y(t) = p + q\, F(t) = P(t)$$

Where f (t) is the likelihood of diffusion at T and

$$F(T) = \int_0^T f(t)dt \qquad F(0) = 0.$$

Since f (t) is the likelihood of diffusion at T and m is the total number diffusion during the period for which the density function was constructed,

$$Y(t) = \int S(t)\, dt = m \int f(t)\, dt = mF(t)$$

Is the total number diffusion in the (0, T) interval. Therefore total diffusion at

$T = S(t) = mf(t) = P(t)\,[m - Y(t)] = [p + q \int S(t)\, dt/m]\,[m - \int S(t)\, dt]$.

Expanding this product we have

$$S(t) = p\,m + (q - p)\, Y(t) - q/m\, [Y(t)]\, 2.$$

The behavioral rationale for these assumptions is summarized;

a) Initial diffusion of technology is made by both "innovators" and "imitators," the important distinction between an innovator and an imitator being the buying influence. Innovators are not influenced in the timing of their initial purchase by the number of people who have already bought the technology, while imitators are influenced by the number of previous buyers. Imitators "learn," in some sense from those who have already bought.
b) The importance of innovators will be greater at first but will diminish monotonically with time.
c) We shall refer to p as coefficient of innovation and q as the coefficient of imitation.

Since $f(t) = [p + q\,F(T)]\,[1 - F(t)] = p + (q - p)\,F(t) - q\,[F(t)]^2$,
Thus the basic model is: $S(T) = pm + (q - p)\,.Y(T) - q/m\,.Y^2$

(T). For estimating the parameters p, q and m from discrete time series data we use the following analogue:
$S_T = a + bY_{T-1} + cY^2_{T-1}$. T= 2, 3… where; S_T = diffusion at T, and $Y_{T-1} = \sum^{T-1}_{t=1} S_t$ = cumulative diffusion through periodT-1. Since 'a' estimates pm, 'b' estimates q'-p', and 'c' estimates –q'/m: -mc = q', a/m = p'.
Then q'-p' = -mc-a/m = b, and $cm^2 + bm + a = 0$, or m = (-b ± √ b^2 – 4ca/2c), and the parameters p' q' and m are identified.
For small values of T the equation becomes: $S_T = a + b'Y_{T-1} + c'Y^2_{T-1}$, where b' = kb, and c' = k^2c.Then m = km' , q = 1/kq',and p = 1/kp'. On the basis of relationship between k and (p + q),1/k = 0.97 - 0.4(p + q), (p'/q')q = q = 1/kq' = 0.97q' / (1 + 0.4(1 + 4θ)q',where θ =q'/p' = q/p,and p = (p'/q')q' = 0.97p' / (1 + 0.4(1 + θ)p'.

The values of the coefficient of innovation and the coefficient of imitation using Bass model have been estimated by regression of the time series data for the installation of renewable energy technology extracted from the annual reports of the ministry of non- conventional energy Sources of the Government of India.

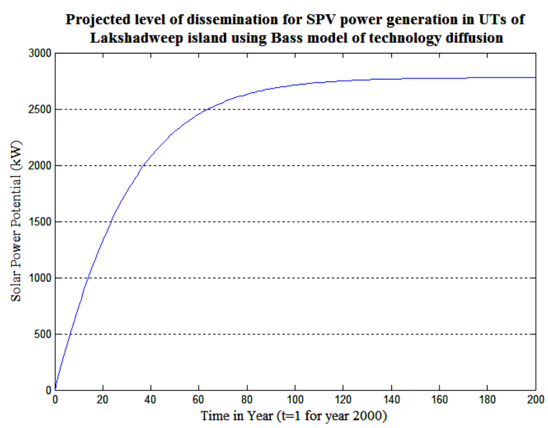

Fig.3. Graph showing the utilization of SPV potential in UTL w.r.t. time (**Bass** model)

Table1. Dissemination of SPV power in UTL w.r.t. time (Bass Model)

Year	**Utilization of SPV power (kW)**	**Year**	**Utilization of SPV power (kW)**	**Year**	**Utilization of SPV power (kW)**
1999	35.0	2016	1170.187	2033	1902.094
2000	82.0368	2017	1224.436	2034	1933.962
2001	162.4482	2018	1277.157	2035	1964.769
2002	241.2191	2019	1328.374	2036	1994.544
2003	318.3374	2020	1378.109	2037	2023.313
2004	393.7943	2021	1426.389	2038	2051.106
2005	467.5839	2022	1473.239	2039	2077.95
2006	539.7031	2023	1518.685	2040	2103.872
2007	610.1519	2024	1562.755	2041	2128.899
2008	678.9325	2025	1605.475	2042	2153.058
2009	746.05	2026	1646.874	2043	2176.373
2010	811.5117	2027	1686.981	2044	2198.871
2011	875.3272	2028	1725.824	2045	2220.577
2012	937.5082	2029	1763.432	2046	2241.516
2013	998.0683	2030	1799.833	2047	2261.71
2014	1057.023	2031	1835.058	2048	2281.184
2015	1114.39	2032	1869.136	2049	2299.961

C. Pearl model of technology diffusion

As per this model, the following expression can be used for cumulative number "N(t)", of the solar technology disseminated up to the t^{th} year (with the coefficients b and k determined from the earlier data on the diffusion of technology).
The logistic reliability growth curve has an S-shaped curve and is given by equation (1)

$$N(t) = 1/(1 + be^{-kT_a}), b > 0, k > 0, T_a \geq 0 \quad (2)$$

The least squares estimators of the logistic growth curve parameters are:

$$\hat{b} = e^{\hat{b}_0} \quad (3)$$

$$\hat{k} = -\hat{b}_1 \quad (4)$$

where:

$$\hat{b}_1 = \sum_{i=0}^{N-1}(T_i Y_i - N\overline{T}\overline{Y}) / \sum_{i=0}^{N-1}(T_i^2 - N\overline{T}^2) \quad (5)$$

$$\hat{b}_0 = \overline{Y} - \hat{b}_1 \overline{T} \quad (6)$$

$$Y_i = \ln(1/R_i - 1) \quad (7)$$

$$\overline{Y} = 1/N.\sum_{i=0}^{N-1} Y_i \quad (8)$$

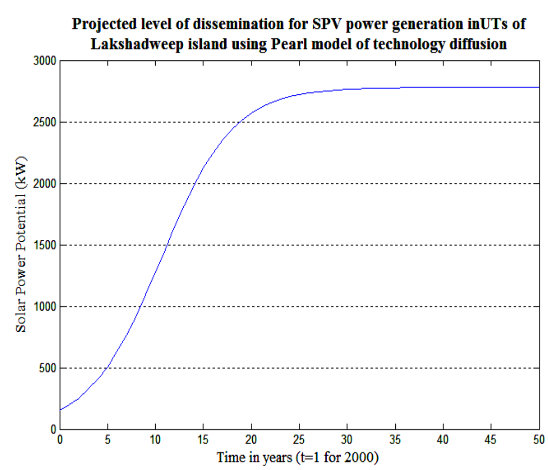

Fig.4. Graph showing the utilization of SPV potential in UTL w.r.t. time (Pearl model)

Table2. Dissemination of SPV power in UTL w.r.t. time (Pearl Model)

Years	Utilization of SPV power (kW)	Years	Utilization of SPV power (kW)	Years	Utilization of SPV power (kW)
1999	154.2	2016	2352.0	2033	2774.6
2000	198.0	2017	2440.0	2034	2775.9
2001	253.0	2018	2512.0	2035	2776.8
2002	321.5	2019	2570.0	2036	2777.6
2003	405.6	2020	2616.4	2037	2778.1
2004	507.1	2021	2652.9	2038	2778.6
2005	627.2	2022	2681.7	2039	2778.9
2006	766.3	2023	2704.1	2040	2779.2
2007	922.9	2024	2721.5	2041	2779.4
2008	1094.2	2025	2735.0	2042	2779.9
2009	1275.5	2026	2745.4	2043	2779.5
2010	1460.7	2027	2753.4	2044	2779.6
2011	1643.5	2028	2759.6	2045	2779.7
2012	1817.6	2029	2764.4	2046	2779.8
2013	1978.0	2030	2768.0	2047	2779.8
2014	2121.4	2031	2770.8	2048	2779.9
2015	2246.1	2032	2773.0	2049	2779.9

D. Logistic model of technology diffusion

The Logistic curve relates the independent variable, X to rolling mean of dependent variable, P ($\overline{Y}$). The formula to do so may be written either

$$P = \frac{e^{a+bX}}{1+e^{a+bX}} \tag{9}$$

Or

$$P = \frac{1}{1+e^{-(a+bX)}} \tag{10}$$

Where P is the probability of 1(the proportion of 1's, the mean of Y), e is the base of natural logarithm (about 2.718) and 'a' and 'b' are the parameters of the model. The value of a yields P when X is zero, and b adjusts how quickly the probability changes with changing X a single unit (we can have the standardized and unstandardized b weights in Logistic regression, just as in ordinary linear regression).

Now, on taking log of equation (9) on both sides we get,

$$\ln\left(\frac{P}{1-P}\right) = \mathrm{a} + \mathrm{bX} \tag{11}$$

The above equation (1) can also be written as:

$$N(t) = M\left[\frac{e^{(a+bt)}}{1+e^{(a+bt)}}\right] \tag{12}$$

Where N(t) is the cumulative number of the renewable energy technology disseminated up to a particular period (t^{th} year) and M is the total potential. a and b are the regression coefficients which are to be estimated by a linear regression of log-log form of Eq. (12) as given below.

$$\ln\left[\frac{\frac{N(t)}{M}}{1-\frac{N(t)}{M}}\right] = a + bt \tag{13}$$

The Excel function SLOPE and INTERCEPT, when applied to data array from equation (13), will produce a least squares regression estimate of the growth rate of equation (13).

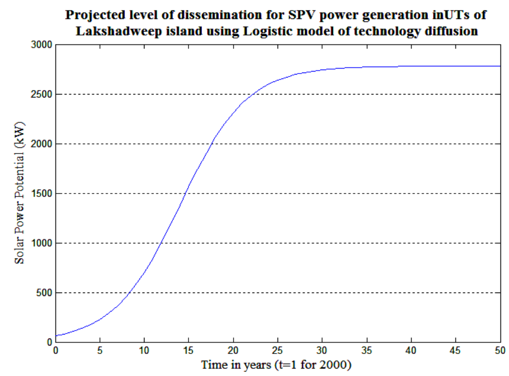

Fig.5. Graph showing the utilization of SPV potential in UTL w.r.t. time (Logistic model)

Table.3. Dissemination of SPV power in UTL w.r.t. time (Logistic Model)

Years	Utilization of SPV power (kW)	Years	Utilization of SPV power (kW)	Years	Utilization of SPV power (kW)
1999	62.9	2016	1910.2	2033	2766.7
2000	81.6	2017	2061.8	2034	2769.8
2001	105.7	2018	2195.0	2035	2772.2
2002	136.6	2019	2309.2	2036	2774.0
2003	175.9	2020	2404.9	2037	2775.4
2004	225.5	2021	2483.6	2038	2776.5
2005	287.6	2022	2547.4	2039	2777.3
2006	364.3	2023	2598.5	2040	2778.0
2007	457.8	2024	2639.0	2041	2778.4
2008	569.6	2025	2670.8	2042	2778.8
2009	700.5	2026	2695.7	2043	2779.1
2010	849.8	2027	2715.0	2044	2779.3
2011	1015.5	2028	2730.0	2045	2779.5
2012	1193.5	2029	2741.6	2046	2779.6
2013	1378.3	2030	2750.5	2047	2779.7
2014	1563.5	2031	2757.4	2048	2779.8
2015	1742.7	2032	2762.7	2049	2779.8

IV. RESULT AND DISCUSSION

Table 4 shows the values of different input parameters used in projecting the time trend of the dissemination of the solar technology for power generation in UTL Island with the help of Bass, Pearl and Logistic models.

Table 1, 2 & 3 shows the time variation of the projected cumulative number of solar energy technologies for power generation using Bass, Pearl and Logistic technology diffusion models respectively. Results of this study indicate that in UTL Island the dissemination of solar energy technology for power generation is likely to reach its maximum estimated potential in another 40 years. However, on seeing the worldwide scenario for the growth of SPV technology it may be noted that in the long run solar photo voltaic technology is expected to contribute a major fraction of total Power generation in UTL.

Table4. Total SPV Plant Capacity in Lakshadweep Islands Total Solar potential in UT of Lakshadweep Island: 2780kW

S.No.	Year	Total Plant capacity (kW)
1	1999	35
2	2000	235
3	2001	235
4	2002	685
5	2003	685
6	2004	810
7	2005	865
8	2006	865
9	2007	865
10	2008	865
11	2009	1065
12	2010	1065
13	2011	1065
14	2012	2150
15	2013	2150

V. CONCLUSION

Though the projected level of dissemination of the solar technology for power generation using Bass, Pearl and Logistic technology diffusion models appears to be on the optimistic side (as against the reported existing levels of diffusion) their contribution to the overall power generation is rather small. On the other hand, a substantial amount of investment is required even to achieve this level of dissemination.

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