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Diffusion Modeling and Implementation of Renewable Energy Technologies in India

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Abstract: Energy is a vital input for social and economic development of any nation. Renewable energy technologies can help countries meet their policy goals for secure, reliable and affordable energy to expand electricity access and promote development. Renewable energy sources, especially solar and wind energy, are likely to play a significant role in providing reliable and sustainable electricity to consumers. Renewable Energy (RE) sources form a minuscule portion of India's overall Energy consumption today, with increasing agricultural and industrial activities in the country; the demand for energy is also increasing. Formulation of an energy model will help in the proper allocation of widely available renewable energy sources in meeting the future energy demand in India Many developing countries are increasingly making commitments to promote low carbon economy by adopting sustainable energy technologies. In this regard, different policies could be applied to reducing carbon emissions, such as enhancing renewable energy deployment and encouraging technological innovations. Diffusion of Renewable Energy Technologies (RETs) is governed by the status of the technology in terms of efficiency and techno-economical feasibility. The states plans for the deployment of resources for development, with special reference to sustainable environment and the demand and supply energy model help to provide more focus on the long term goals. This paper presents an approach to apply diffusion modeling technique to review policies supporting Renewable energy technology deployment and use diffusion parameters to provide inputs for designing future programmes. The wind and solar power are selected for detailed analysis. The results show how present trends and future forecasts of electricity-generating technologies change the electricity generation in the country.

Keywords: Renewable Energy Technology (RET), Diffusion, Wind Power, Solar Power, India, Ministry of New and Renewable Energy (MNRE).

I. INTRODUCTION

Developing countries face the twin challenge of developing stronger economies through measures such as expanding energy supply, increasing agricultural production and improving transportation systems, while also playing an active role in global efforts to reduce greenhouse gas emissions. If not well managed, there might be trade-offs between these two important objectives in nations' pursuit of sustainable economic growth. The adoption and diffusion of new renewable energy technologies (RETs) is subject to developments that bring down unit generation costs to a level where these technologies can actually compete with conventional technologies. Such developments can be conveniently learning curves, which indicate the exponential reduction in the unit cost that can be expected as their cumulative production volume increases. The growth of global carbon emissions is nowadays largely driven by the increasing volume coming from within developing countries. Consequently, in 2008 the aggregate energy- related CO2 emissions of developing countries surpassed those of industrialized and transition countries for the first time in history (IEA 2010). Currently, the electricity sector constitutes a major source of energy-related CO2 emissions, accounting for 41 percent of global CO2 emissions (IEA 2010). This reality clearly makes the reduction of emissions from electricity generation an essential ingredient in any climate change mitigation strategies. The essential characteristic of a sustainable energy system is its ability to deliver required services without exhausting resources. The first step to create such a system is to use the existing resources efficiently and increase the use of resources that are renewable. Shifting from non-renewable to renewable energy technologies (RETs) should be the top priority in moving to a sustainable energy system. Increased utilization of RETs will not only meet the growing energy demand but also reduce adverse environmental impacts of energy usage. There are Eight National Missions which form the core of the National Action Plan, representing multi-pronged, long-term and integrated strategies for achieving key goals in the context of climate change. While several of these programmes are already part of our current actions, they may need a change in direction, enhancement of scope and effectiveness and accelerated implementation of time-bound plans. In this paper some of initiatives taken are focus of discussion which are primarily necessary for RET diffusion. The growth of electricity demand coupled with the geographically dispersed nature of many renewable sources makes electricity an attractive energy vector to harness RE where adequate network infrastructure is available. The world energy demand is expected to increase by 35 percent by 2030 from 2005 levels. This increase in demand is driven predominantly by growing population and economic growth in developing countries, even with substantial efficiency gains in all regions. The developing countries account for nearly two thirds of this increase which is spurred by their rapid economic growth. India is both a major energy producer and a consumer. India currently ranks as the world's seventh largest energy producer, accounting for about 2.49% of the world's total annual energy production. It is also the world's fifth largest energy consumer, accounting for about 3.45% of the world's total annual energy consumption in 2004. India is considered a fast growing economy and with a targeted GDP growth rate of 9% during the Eleventh Five-year Plan (2007-12), by 2031 -32, the primary energy use will increase by 4 to 5 times and power generation capacity would increase six-fold from the 2007-08 level of around 150,000 MW even after allowing for substantial reduction in energy intensity. The demand for oil is estimated to be over 480 Million Tonnes (MT) by 2032 of which 70% would have to be imported. There is also a significant share of natural gas in India's primary energy supply. In a competitive marketplace, low impact RETs could satisfy consumer preferences for sustainable energy. Various estimates suggest that renewable energy sources are capable of meeting a significant part of the energy demand even at the current level of technological development. This study presents an investment planning model that integrates the learning curve information of renewable power generation technologies into a dynamic programming formulation that features real options analysis. The model evaluates investment alternatives in a recursive manner and on a year-by-year basis, thereby taking into account that the ability to delay an irreversible investment outlay can affect the prospects for the diffusion of different power generation technologies. The application is based on data for the India electricity supply industry. Significant domestic renewable energy potentials, the ongoing market liberalization process, high pollutant emission levels, a pressing need for the further expansion of electricity generating capacity, and the currently still very low share of new RETs are among the factors that make the India electricity supply situation an especially interesting subject of study. In order to give further thrust to the renewable energy sector, the policies are being aligned with the overall energy and climate change framework. At the national level, India has formulated and adopted the first National Action Plan on Climate Change (NAPCC) under the Chairmanship of Prime Minister. The NAPCC has outlined existing and future policies and programs to address climate mitigation and adaptation issues. The plan identifies eight core "national missions" running through 2017 and envisions a roadmap for increasing the share of renewable in the total generation capacity.

1. National Solar Mission (10,000 MW of grid solar capacity; 1000 MW of off-grid solar applications; and 15 Million sq.m. solar concentrators
2. National Mission for Enhanced Energy Efficiency (10,000 MW energy savings by 2012)
3. National Mission on Sustainable Habitats (waste to energy)
4. National Water Mission (20% water use efficiency improvement)
5. National Mission for Sustaining the Himalayan Ecosystem
6. National Mission for a Green India
7. National Mission for Sustainable Agriculture
8. National Mission on Strategic Knowledge for Climate Change.

II. PRESENT ENERGY SCENARIO IN INDIA

A. WIND ENERGY

Electrical energy obtained from harnessing the wind with windmills or wind turbines. The development of wind power in India began in the 1986 with first wind farms being set up in coastal areas of Maharshtra (Ratnagiri), Gujarat (Okha) and Tamil Nadu (Tuticorin) with 55 kW Vestas wind turbines. Wind energy is one of the most promising alternative energy technologies of the future. During recent years, the amount of energy produced by wind-driven turbines has increased rapidly due to considerable advancement in turbine technologies, making wind power economically compatible with conventional sources of energy. The use of wind power in India has been gaining importance with rapid installation in the last few years. Wind energy makes up the majority about 68 per cent of the total renewable energy capacity installed in India. Wind energy program was commenced in India by the end of the 6th five yearly plan during 1983-84 and in the last few years it has increased considerably. The main objective of the program was the commercialization of wind energy production, support research and development, provide help to wind projects and to create awareness among people.

Under this program Ministry of New and Renewable Energy (MNRE) has done various modification regarding incentives, schemes and policies for wind energy The development of wind power in India began in the 1990s, and has progressed steadily in the last few years. The short gestation periods for installing wind turbines, and the increasing reliability and performance of wind energy machines have made wind power a favoured choice for capacity addition in India. Currently, India has the fifth largest installed wind power capacity in the world. Wind power accounts for 6% of India's total installed power capacity, and it generates 1.6% of the country's power. In 2012, despite a slowing global economy, India's electricity demand continued to rise. Electricity shortages are common, and over 40% of the population has no access to modern energy services. India's electricity demand is projected to more than triple between 2005 and 2030. In the recently released National Electricity Plan (2012) the Central Electricity Authority projected the need for 350-360 GW of total generation capacity by 2022. Despite major capacity additions over recent decades, power supply struggles to keep up with demand. Under the New

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Policies Scenario of the World Energy Outlook (2011), total power capacity in India would reach 779GW in 2035. To reach 779 GW in 2035, capacity must grow at a CAGR of 5.9%, or over 20GW per year from 2009 through 2035. The largest addition per year up to now was nearly 18GW during fiscal year 2011-2012; this scale of expansion could pose a challenge for the government [IEA, 2012] without a significant role for renewable. During the year 2011-2012, wind energy alone delivered over 3GW to India's new installed capacity, accounting for over 16.5% of total new installed capacity. By the end of the 11th Plan period in March of 2012, the total installed capacity had reached a total of 17,351.6 MW. Renewable Energy in the 12th Five-Year Plan [2012-2017]: Historically, wind energy has met and often exceeded the targets set for it under both the 10th Plan (2002-2007) and 11th Plan (2007-2012) periods. During the 10th Plan period the target set was of 1,500 M W whereas the actual installations were 5,427 MW. Similarly during the 11th Plan period the revised target was for 9,000 MW and the actual installations were much higher at 10,260 MW. The report of the sub-group for wind power development appointed by the Ministry of New and Renewable Energy to develop the approach paper for the 12th Plan period (April 2012 to March 2017) fixed a reference target of 15,000 MW in new capacity additions, and an aspiration target of 25,000 MW. Importantly, the report recommends the continuation of the Generation Based Incentive scheme during the 12th Plan period. More than 95 percent of total nation's wind energy generates from just five states located in southern and western India i.e. Gujarat, Maharashtra, Karnataka, Tamil Nadu and Andhra Pradesh. These five states are also accounted for approximately 85 percent of total installed capacity before the end of 11th five yearly plan. It clearly indicates that these five states have been leaders in wind energy generation while other states like Madhya Pradesh, Rajasthan and Kerala are also quickly increasing their capacity.

Table 1 State wise installed Wind Power Capacity in India

State	Installed capacity as of March 2016 (MW)
Tamil Nadu	7633.27
Gujarat	3930.94
Maharashtra	4655.25
Karnataka	2877.95
Rajasthan	4031.99
Madhya Pradesh	2165.49
Andhra Pradesh	1432.95
Kerala	55.80
Others	76.7
Total	26860.34

Table-1 provides state wise installed wind power capacity in India (up to March 2016). As per MNRE Reports the highest wind energy installed state Tamil Nadu, which has total installed capacity of 7633.27 MW till March 2016 and total installed capacity in India as of March-2016 (MW) is approximately 2686.34 MW. The figure. 1 shows Wind energy across states in India.

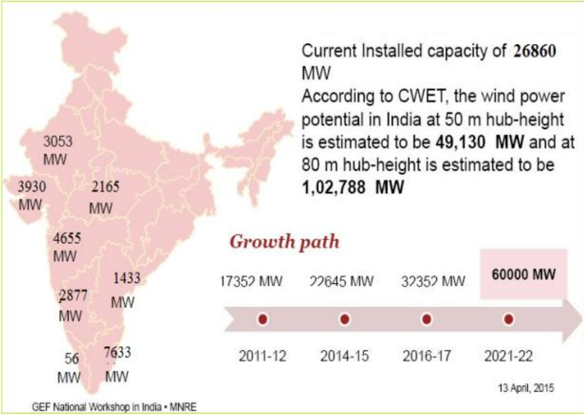

Figure. 1Wind Energy across states in India

B. SOLAR ENERGY

Solar energy is radiant light and heat from the Sun harnessed using a range of ever-evolving technologies such as solar heating, photovoltaic's, solar thermal energy, solar architecture and artificial photosynthesis. India is endowed with vast solar energy potential; most parts of India get 300 days of sunshine a year. About 5,000 trillion kWh per year energy is incident over Indian land area with most area receiving 4-7 kWh per sq. meter per day. Solar also provides the ability to generate power on a distributed basis. Assuming 10% conversion efficiency for PV modules it is three orders of magnitude greater than the likely electricity demand for India on the year 2015. On 16 May 2011, India's first 5 MW of installed capacity solar power project was registered under the Clean Development Mechanism. The project is in Sivagangai Village, Sivaganga district, Tamil Nadu. January 2015, the Indian government significantly expanded its solar plans, targeting US$100 billion of investment and 100 GW of solar capacity by 2022. It can be observed that highest annual global radiation is received in Rajasthan and northern Gujarat. India is ranked 11th in solar power generation in the world as on Jan. 2014. Government funded solar energy in India only accounted for about 6.4MW/yr of power as of 2005. In 2010 capacity of 25.1MW was added and 468.3MW in 2011. In 2012 the capacity increase more than two times and become 1205 MW. During 2013 capacity added by 1114MW and during2014 capacity added by 313MW. The Table 2. Provides state wise solar installed capacity in India, Rajasthan has the largest share of solar power generation of 28.4% i.e 1199.7 MW and Gujarat share is 24.4% (1000.05 MW) as on September 2015. The figure. 2 show solar energy across states in India.

Table 2 State wise installed Solar Power Capacity in India

State	Installed Capacity Sept. 2015
Tamil Nadu	157.98
Gujarat	1000.05
Maharashtra	378.7

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Karnataka	104.22
Rajasthan	1199.7
Madhya Pradesh	673.58
Andhra Pradesh	279.44
Punjab	200.32
Others	352.828
Total	4346.818

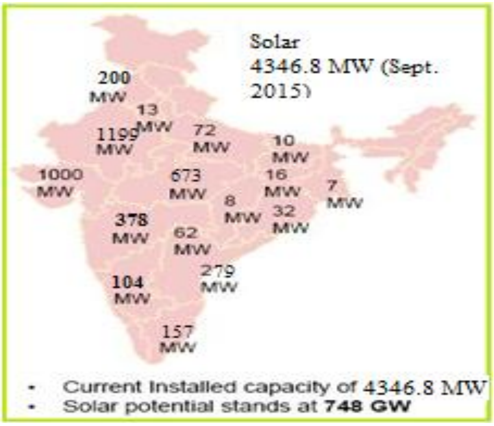

Figure. 2 Solar Energy across states in India

India has a vast supply of renewable energy resources and it has one of the largest programs in the world for deploying renewable energy products and systems. The total installed capacity of 263.66 GW and RE capacity of 34.35 GW (13% of Installed capacity and approximately 7% of electricity produced) as on March 2015.The present Energy scenario is shown in figure 3.

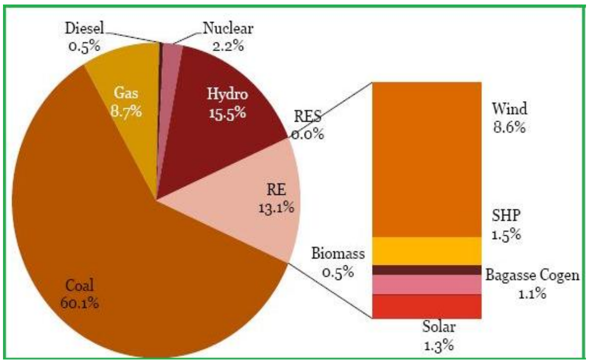

Figure 3 Present Power Scenario of India

The source wise Renewable Energy capacity for the FY 07-15 is increasing from 9389 MW to 35199 MW is shown in figure. 4 and the revised total target capacity till 2022 is 1, 75,000MW is provided by the table 3.

Table 3 Renewable Energy Revised targets

Capacities in MW				
Source	Installed capacity by end of 11th Plan (March 2012)	Current installed Capacity (March 2015)	Target as per 12th Plan (March 2017)	Revised Targets till 2022
Solar Power	941	4,346	10,941	1,00,000
Wind power	17,352	22,645	32,352	60,000
Biomass Power	3,225	4,183	6,125	10,000
Small Hydro	3,395	4,025	5,495	5,000
Total	24,914	35199	54,914	1,75,000

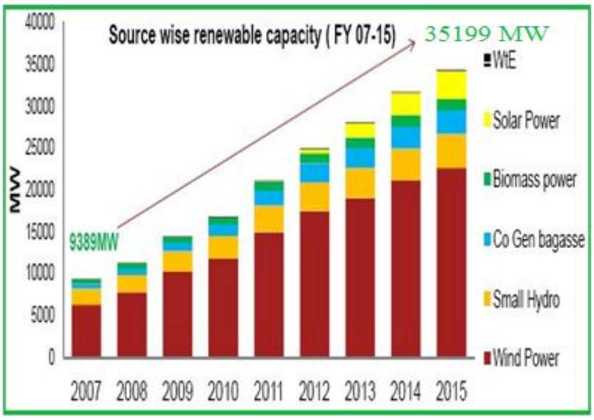

Figure 4 The source wise Renewable Energy status

As per the information MNRE the estimated power requirement is expected to increase by 200% from FY 15 to FY 30 is approximately 755719 MW and contribution of Renewable Energy of entire power consumption till 2022 in India is nearly 175 GW (18.9%) and corresponding data is shown in figure.5 and 6 respectively.

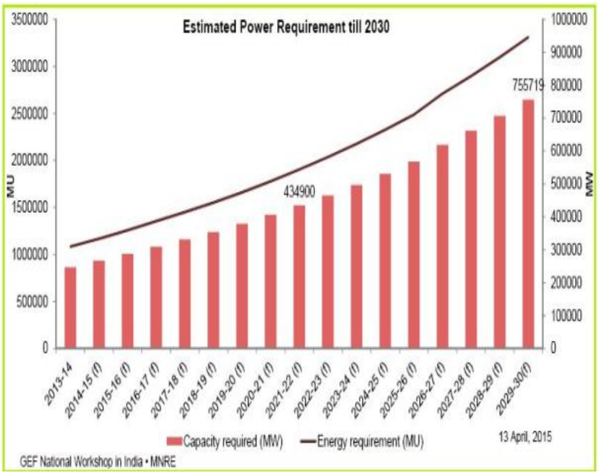

Figure. 5 Estimated power requirement till 2030

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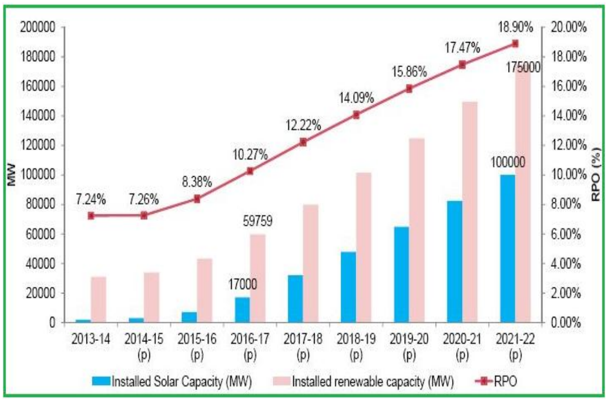

Figure. 6 Contribution of Renewable Energy in 2022

III. DIFFUSION THEORY AND MODELING

The diffusion of an innovation has traditionally been defined as the process by which an innovation is communicated through certain channels over time among the members of a social system. There are four elements in the diffusion process: the innovation, channels of communication, time and the social system. Technology Diffusion is understood as a process by which a new technology or an innovation is propagated through certain channels over time among the units of system. Schumpeter (1939) sees diffusion as the final stage of the technology development. Rogers (1962) describes diffusion of new product as a five-stage process - awareness, interest, evaluation, trial, and adoption. Grubler (1998) describes the diffusion as widespread adoption of technologies over time, in space and between social strata. The elements of technology diffusion comprise of innovation, propagation, time, and units of social systems (Narayanan, 2001). Strategies to commercialize technologies is expected to follow a path way set in stages of imagining, incubating, demonstrating, promoting and sustaining technologies (Vedpuriswar, 2003). Diffusion is considered as the stage after invention and innovation of a technology The diffusion process passes through filtering, tailoring and acceptance of a technology. Many inventions may or may not reach the stage of diffusion. The diffusion processes in general follow an S curve (Figure 7).

The curve generally comprises of three distinct phases:
i) an initial slow growth ,
ii) a rapid take-off period and
iii) a flattening of growth, signifying a near completion of diffusion.

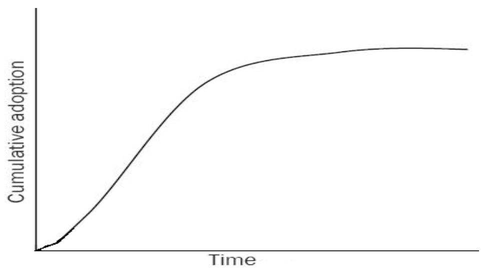

Figure 7 Diffusion curve - cumulative adoption vs time

There are diverse examples for depicting this S shaped pattern in the natural growth of many phenomena including diffusion of Cistercian monasteries in Europe one thousand years ago and life expectancy of creative geniuses (such as Mozart) (Grubler,1996).
Diffusion modeling captures the diffusion process or behaviour in a mathematical form that allows quantifying the diffusion parameters for further diffusion analysis. Models can be used to explain the diffusion rates and estimate parameters that measure the coefficients of diffusion in a given context. Different diffusion models have been used, particularly since the 1960s to capture this diffusion trend in the form of mathematical equations (Meade and Islam, 2006). These models have been applied to study various diffusion processes that include population of cars, television, computers, consumer goods, etc. as well as frequency of economic booms and busts, number of fatal car accidents, incidence of major nuclear accidents, technological change in the computer industry and number of deaths from AIDS (Fisher and Pry, 1971; Meade and Islam, 1998; Mahajan, Muller and Wind 2000). They correspond to different stages of consumers' adoption during market development classified as innovators/early adopters, early and late majority and laggards according to the time of adoption, since the technology is introduced in the market (Figure 8). The central line signifies t* (peak adopters or the Point of Inflection) at 32.1% of total adopters and according to Bass (1969), approximately 9.5 to 20% would be early adopters, 29.1 to 32.1 % belong to early majority, 29.1 to 32.1 % late majority and 21.4 to 23.5 % would be laggards.

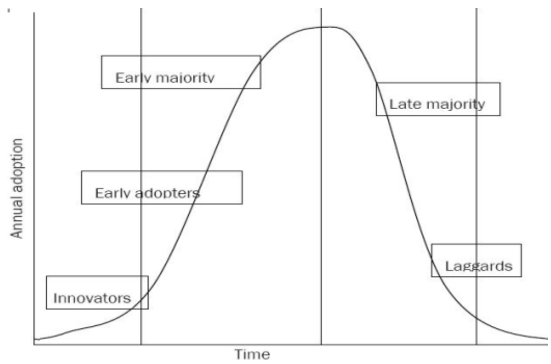

Figure 8 Diffusion curve - adopters vs. time

A. BRIEF REVIEW OF TECHNOLOGY OR PRODUCT DIFFUSION MODELS

Modeling technology diffusion processes was initially derived from the theory of growth of a colony of biological cell in a medium. Since the growth of a cell would be limited due to limited nutrients or space, it would slow down and saturate resulting in an S-curve pattern. Similarly, technology diffusion models assume that the growth of a technology or an innovation is dependent on the total potential adopters and the rate of increase is represented by the following fundamental diffusion equation referred to as the internal influence diffusion model.

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$$\frac{dN}{dt} = bN(t)(N^u - N(t)) \text{ ----------------- (1)}$$

Where N(t) is the cumulative adoption at time t and N^u is the ultimate potential; b is the coefficient of diffusion.
Equation (1) is basically a logistic growth curve and is directly used in technology diffusion which assumes diffusion process is influenced by the previous adopters. If the influence on diffusion is external, the equation for the external influence model is given by equation (2) below as:

$$\frac{dN}{dt} = [a(N^u - N(t))] \text{ -------------------(2)}$$

Where N(t) is the cumulative adoption at time t and N is the ultimate potential; a is the coefficient of diffusion
A mixed influence model which combines the above Eqns. (1) and (2) was first presented by Bass to represent the first purchase growth of a new product durable in marketing (Bass, 1969). The Bass model is a mixed influence model with three parameters p, q and m (N^u); p represents the coefficient of innovation (a in the above equation) and q is the coefficient of imitation (b in equation(1)= q/ N^u) and m is the total potential. The Bass diffusion model is given by:

$$\frac{dN}{dt} = [p + \frac{q}{N^u}(N(t))][(N^u - N(t)] \text{ -----------(3)}$$

Mahajan and Peterson (1985) classify diffusion models as follows
1. Fundamental diffusion models (internal, external and mixed influence): these models basically assume that the diffusion process is binary, there is a distinct and constant total potential, coefficients are constant over time, etc.
2. Flexible diffusion models: the assumptions remain similar to fundamental diffusion models but are relatively flexible with respect to the point of inflection (where the diffusion rate is maximum) or symmetry with respect to point of inflection.
3. Refinements and extensions: many of the assumptions were modified to develop improved or revised diffusion models that are sub-categorized as under:
a. Dynamic diffusion models: This considers the maximum technical potential as dynamic and not static,
b. Multi innovation diffusion models: the innovation is considered as not completely independent of all other innovations but independent in a functional sense and are complementary, contingent and substitutes for other innovations,
c. Space and time diffusion models which assumed primarily that the growth in the number of adoptions in each region would vary and the relative number of adoptions would be greater in those regions closest to the regions of innovation origination,
d. Multistage diffusion models which consider adoption as multi stage process and not binary,
e. Multi adoption models which capture repeat purchases and
f. Diffusion models with influencing /change agents, which consider diffusion as not just a function of time but coefficients as a function of technology specific parameters.

Table 4 provides examples of the above diffusion model categories and applications (Mahajan and Petersen, 1985). Meade and Islam (2006) classified diffusion models as: a) models for cumulative adoption and b) non linear autoregressive models (Table 5). An attempt on rationalization of different diffusion models (Jain et al, 1991) indicate that most diffusion equations are reduced to two parts. The first part represented in the form G (1-F) as a function of potential adopters and absorbing the remaining terms in A(F) which is a conversion factor and determines how many of the potential adopters can be converted; F represents the fraction of adopters at any given time and $0 \leq A(F) \leq 1$ and $0 \leq G(1-F) \leq 1$ (Table 6).

There are several notable reviews of diffusion modeling approaches (Meade, 1984; Mahajan, Muller and Bass, 1990, 1993; Bapitsa, 1999; Mahajan, Muller and Wind, 2000; and Meade and Islam, 2001, 2006). They show the rich and increasing knowledge on theoretical and empirical research in the diffusion of new products, services and technologies. In such reviews the advancement and improvements of the models are covered. It is highlighted that Robinson and Lakhani (1975) introduced marketing variables in the parameterization of the models and examined optimal pricing policies associated with the diffusion of new products. As the diffusion processes are influenced by many decision variables, a generalized Bass model (GBM) was developed. The GBM was considered useful for managerial purposes when possibly the empirical support for cases where prices and advertising data are decision variables were used though the simple Bass model fits the data without including the decision variables, an explanation that is lacking in the other diffusion models that include decision variables. Norton and Bass (1987) attempted diffusion of successive generations of technology and Gatignon, Eliashaberg and Robertson (1989) generalized the models to consider innovations at different stages of diffusions in different countries. In all the diffusion models, the estimation of parameters and its interpretation is central for assessment or quantification of the influence of the diffusion process. Several estimation procedures are also deliberated in the literature and in the diffusion model context; they are generally a non-linear problem. Therefore, most attempts of parameter estimation are linear transformations followed by ordinary least square (OLS) methods. Some of the techniques suggested for parameter estimations include in addition to OLS, algebraic estimation (AE), non linear least square and maximum likelihood estimation. Meade and Islam (2001, 2006) argue that the empirical comparisons have received least attention. The choice of diffusion models and parameter estimation methods are specific to their applications for specific situations and requirements. It is important that the selection of the model is guided by appropriate forms of parameters than relying on any mathematical expression which fits the data.

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Table 4 Summary of diffusion model categories and their applications

Category	Diffusion rate equations represented as dF/dt or dN(t)/dt; F- Fraction of adoptions ($F=N(t)/N^u$; N or N(t) cumulative adoption at any given time; Nu – Ultimate potential; a, b, etc. – diffusion coefficients; t – time	Author	Applications
Fundamental Diffusion Model	External Influence $dF/dt = a(1-F)$	Coleman et al (1966) Hamblin et al, (1973)	Assumption that Mass media -newspapers, radio, and magazines is a major influence; and members of the social systems do not interact and are isolated. New drug by physicians in four mid-western communities; Number of labour strikes and political assassinations in 64 developing nationsover a 20 year period.
	Logistic Internal Influence: $dF/dt = bF(1-F)$	Mansfield (1961)	Mansfield investigated several industrial innovations such as pallet loaders, diesel locomotives, and continuous mining machines among firms
	Gompertz function $\frac{dN(t)}{dt} = bN(t)[lnN^u - lnN(t))]$	Griliches (1957) Gray (1973)	Griliches studied diffusion of hybrid corn in 31 States and 132 crop reporting areas among farmers. Dixon applied Gompertz function to Griliches hybrid seed corn data Gray investigated diffusion of 12 public policy innovations among the 48 contagious United States.
	Mixed Influence: $dF/dt = a + bF(1-F)$	Dixon (1980) Bass (1969)	Forecast sales of television sets, dish washers, and clothes dryers
	Modifications of Mixed influence	Webber (1972) Lekvall and Wahlbin (1973) Warren (1980)	Modified to study the impact of location, simulate effect of certain internal and external influences on diffusion patters, forecast market potential of new solar technology and diffusion of educational innovations
Flexible Diffusion Models	Non-Symmetric Responding Logistic (NSRL) $bF^{\delta}(1-F)$	NRSL (Eastingwood etal, 1981)	Diffusion of two medical innovations –CAT head scanners and CAT body scanners
	Non-Uniform Influence (NUI) $(a + bF^{\delta})(1-F)$ $\frac{b}{1-\emptyset} F^{\emptyset}\left(1 - F^{[1^{-\emptyset}]}\right)$; $0 < \emptyset$	NUI (Eastingwood et al, 1983) Von Bertalanffy (1957)	
Extension and Refinements	Dynamic Diffusion Models $\frac{dN(t)}{dt} = \left(a + bN(t)\right)\left[f\left(\underline{S}(t)\right) - N(t)\right]$ $N(t) = -\frac{a}{b} + \frac{\exp\{a(t-t_0) + b\Phi(t)\}}{\left[\left(\frac{b}{a+bN_0}\right) + b\int_{t_0}^{t} \exp\{a(x-t_0) + b\Phi(x)\}dx\right]}$	Mahajan and Peterson (1978) Chow (1967) Chow examined the natural growth of computers (Gompertz internal influence model)	Mahajan and Peterson applied their model to membership in UN during the period 1945-1974 Chow examined the natural growth of computers (Gompertz internal influence model) and included “technological change price reduction” effect. Lackman studied growth of a new plastic product in the automotive industry

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Category	Diffusion rate equations represented as dF/dt or dN(t)/dt; F- Fraction of adoptions ($F=N(t)/N^u$; N or N(t) cumulative adoption at any given time; Nu – Ultimate potential; a, b, etc. – diffusion coefficients; t – time	Author	Applications
Extension and Refinements	Multi-Innovation Diffusion Models $\frac{dN_1(t)}{dt} = a_1[N^u - N_1(t)] + b_1 N_1(t)[N_1^u - N_1(t$ $-c_1 N_2(t)[N_1^u - N_1(t)]$	Peterson and Mahajan (1978)	Used to hypothesize relationships between innovations. Mahajan and Peterson compared sales growth rate of colour and black & white TV and found the sales growth of black and white complemented that of colour sets.
	Space and Time Diffusion Models $N=f(x,t)$; $\frac{\partial N}{\partial y} = 0$ $\frac{\partial N(x,t)}{\partial y} = (a(x) + b(x)N(x,t)[N^u(X)- N(x,t)$ $N(x,t)= N^u(X)-\frac{a(x)(N^u(X)-N_0(x))}{a(x)+b(x)N_0(x)}$ $\exp\left(-\frac{a(x)+b(x)N^u(x)(t-t_0)}{1+\frac{b(x)(N^u(x)-N_0(x))}{(a(x)+b(x)N_0(x))}\exp(-a(x)+b(x)N^u(x)(t-t_0))}\right)$	Mahajan and Peterson (1979) Gatignon, Eliashaberg and Robertson (1989)	Mahajan and Peterson reanalyzed data documenting the tractors in 25 states in the central agricultural production region of the US for the period 1920-1964
	Multistage Diffusion Models $\frac{dy}{dt} = \beta x(y+z) + (\mu x + \gamma y)$ $\frac{dy}{dt} = \gamma y$ $\frac{dN(t)}{dt} = \gamma[N^u(t) - N(t)]$	Midgley(1976) Dodson and Muller(1978) Sharif and Ramanathan (1982) Mahajan, Muller and Kerin (1984)	Model divides the potential adopters (customers) and current adopters (triers) into two groups, each based on positive or negative nature of communicated information. Mahajan applied their model to forecast attendance for the movie "Gandhi" in the Dallas, Texas area..
	Multi-adoption Diffusion Models $N(t+1) = a(N^u - N(t)) + b\left(\frac{N(t)}{N^u}\right)^{\delta}(N^u - N(t) + cN(t)$	Wind et al (1981) Lilien et al (1981) Mahajan et al (1983) Mahajan et al (1983)	Forecasting sales for product innovations Lilien model to forecast sales of ethical drugs
	Diffusion Models with Influencing /change Agents $a(t) = A(\underline{S}(t))$ $b(t) = B(\underline{S}(t))$ $N^u(t) = N^u(\underline{S}(t))$	Robinson and Lakhani (1975) Mahajan and Muller (1979) Dolan and Jeuland (1981) Jorgenson (1983) Kalish (1983) Horsky and Simon (1983) Mahajan and Wind (1985) Mahajan, Muller and Bass (1990) Jain (1992)	Incorporating the influence of pricing, advertising, promotion and technological change into the model.

Table 5 Diffusion model categories

Category	Model –Equation	
Models of Cumulative Adoption	1.1.Bass Model	dF/dt =a+ bF(t)(1-F(t))
	1.2. Cumulative lognormal	$N(t) = N^u \int_0^t \frac{1}{y\sqrt{2\pi\sigma^2}} \exp(-\frac{(\ln(y)-\mu)^2}{2\sigma^2}\ dy$

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	1.3. Cumulative Normal	$N(t) = N^u \int_{\infty}^{t} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(y-\mu)^2}{2\sigma^2}\right) dy$
	1.4. Gompertz	N(t) N^uexp(-b(exp(-at))
	1.5. Log Reciprocal	$N(t) = N^u \exp\left(\frac{1}{at}\right)$
	1.6. Logistic	$N(t) = \frac{N^u}{1+c\exp(-at)}$
	1.7. Modified Exponential	N(t)= $N^u - b$exp(-at)
	1.8. Weibull	$N(t) = N^u \left(1 - \exp\left(\left(\frac{t}{b}\right)^a\right)\right)$
2. Non-Linearised Trend and Non-Linear Autoregressive Models	2.1. Harvey	$\ln(N(t) - N(t-1) = a + b_1 t + b_2 \ln(N(t-1))$
	2.2. Floyd	$\left[\frac{1}{1-N(t)}\right] + \ln\left(\frac{N(t)}{1-N(t)}\right) = a + bt$
	2.3. Sharif and Kabir	$\ln\left(\frac{N(t)}{1-N(t)}\right) + \sigma\left(\frac{1}{1-N(t)}\right) = N^u + at$
	2.4. KKKI	$\left(\frac{bN^u - a^2}{bN^u}\right) \ln(a + bN^u N(t)) - (a+1)\ln(1-N(t)) = b + (bN^u + a)t$
	SBB (Sharma, Basu, Bhargava(1993)	$N(t) = N(t-1)\exp(a(1 - N(t-1)))$

Table 6 Rationalized forms of various diffusion models

S.N	Models	A(F)	G(1-F)
1	Coleman	A	(1-F)
2	Mansfield	bF	(1-F)
3	Bass	A+bF	(1-F)
4	Floyd	bF	$(1\text{-}F)^2$
5	Sharif- Kabir	bF/[1-F(1-e)]	$(1\text{-}F)^2$
6	a) Easingwood- Mahajan Mulle (NSRL) b) Modified NSRL	bF^d bF	(1-F) $(1\text{-}F)^d$
7	Non Uniform Influence (NUI)	$(a+bF)^d$	(1-F)
8	Jeuland	(a+bF)	$(1\text{-}F)^{1+r}$
9	a) Nedler b) Von Bertalanffy	bF $[b/(1\text{-}e)]F^e$	$(1\text{-}F)^e$ $(1\text{-}F^{1\text{-}e})$
10	a)Generalized Rational Model (GRM-I) b) Generalized Rational Model (GRM-II)	bF/(1-F+eF) bF/(e+F – eF)	(1-F) (1-F)
11	Other Possibilities	$a+ bF+rF^2$ [a/(1+F)+bF] [a/(1+F)+bF]	(1-F) (1-F) $(1\text{-}F)^2$

B. DIFFUSION ANALYSIS OF RET AND APPLICATIONS

In the above analysis, it was evident that there is limited use of diffusion models in renewable energy technology (RET) analysis. RETs convert natural resources such as solar, biomass, wind, and hydro into useful forms of energy. Their adoptions have been mainly driven by impending environmental and energy security considerations arising from use of fossil fuel based energy (from coal, oil and gas) and the fact that fossil based energy sources are finite. Unlike other commercial products or technologies, RETs have been promoted with start-up support for demonstration projects, followed by significant financial and fiscal incentives from the government or public agencies. Despite direct policy efforts and inherent environmental and socio-economic advantages of renewable energy technologies, diffusion of these alternative forms of energy has been very limited. RETs are characterized by low load factor (wind, small hydro), need for energy storage (solar PV), small size (in kilo Watt range), high upfront costs and absence of level playing field (subsidies for conventional fuels). These factors have put RETs at a disadvantage, and thus the need for special support for the increased diffusion of RETs. RET diffusion analysts have mainly focused on analytical frameworks based on policies or barriers to diffusion of RETs. The process of commercialization of RET occurs in stages. Lund (2006) describes the process as beginning with Research and Development, followed by demonstration and pilot production. This leads to early market introduction and finally, market diffusion. While different RETs are at different phases of market development, the research in diffusion analysis in renewable energy sector points towards the following approaches.

1. Economies of scale, experience and learning curve approaches to establish cost reductions
2. Economic analysis of RETs for its viability among the given Alternatives
3. Stakeholders' perspectives and barrier analysis frameworks and barriers mitigation approaches

C. POLICY ANALYSIS AND INFLUENCES ON THE RET ADOPTION

Several articles discuss the influence of policies and institutional frameworks on the growth of RETs. It has been noted that not all policies impact favourably and due to regular changes in policies and the uncertainty of compliance period, the effectiveness of policy decreases. Many of the policy elements especially the case of subsidies for wind technologies, which were phased-in and phased-out, and for which not only the extent of support but also the criteria have been under continuous revision in many countries. Dinica (2006) proposed an investor-oriented perspective to analyze the diffusion potential of support systems for RETs, particularly, policies such as feed in tariffs and quota model. Though the RETs have huge potential to fulfill the global demand of electric power, the initial cost incurred in setup of such technology and difficulty in getting financial support is a major barrier for the technology diffusion. Ravindranath et al (2000) analyzed RET policies and point out to the continuing barriers to the large scale adoption of RETs in India. Bhatia (1990) noted that the incentives and subsidy programs for biogas engines in India were arbitrarily designed and were not profitable for adopters. This was based on an analytical conceptual framework that categorized various factors which influence the diffusion and adoption process as technology characteristics, microenvironment, government's role, types of users and market structure. It was further argued that lack of large scale success does not imply the inappropriateness of technology; rather efforts would be required to create an environment to promote the adoption of such technology. As the adoption process begins with the interaction of user, society and government in a complex manner, it is necessary to understand those interactions from areas where it has been successfully adopted and to create similar environments in areas where rate of adoption is less. Similarly, a review of dissemination of cooking energy alternatives in India by Pohekar et al (2005) points to low dissemination of biogas and solar cookers and highlights the need for government intervention in terms of favorable policy and incentives to promote their use in households. Theocharisetal (2005) and Lund (2006) point out environment pressures and Kyoto mechanisms driving the RET adoption and innovations. Based on Roger's theory, Theocharisetal (2005) recognized the interaction of technological, social and organizational elements require a policy that enhance supply and more demand. They state that the pattern of diffusion of the new paradigm, still escapes the attention of policy makers and analysts. They also indicate barriers to the sustainable diffusion of RETs and identified the main problem to lie in the implicit assumption of policy makers that diffusion is simply a matter of substitution. Purohit and Michaelowa (2006) presented a diffusion analysis of solar PV pumps in India and estimated the CDM potential for SPV pumps. They argued that though the governmental subsidy is available to farmer, still other options (electric and diesel pump sets) are more attractive. Theocharis et al argued that strategy and policy tend to focus on the performance of individual RETs. The project-based measures fail to take into consideration two dynamic elements 1) The need for technological choice and regulation to exploit the role and the experience of users; and 2) The multiple economic impact of the mass diffusion of RETs, initially in the construction and service sectors of the economy. Based on their analysis, they suggested that a successful renewable oriented policy should be the conceptualization of renewable as a radically different technological system from that of conventional sources (fuels and nuclear).

Also, the development of RETs was connected with the parallel growth of innovation systems with national or regional character Purohit and Kandpal (2005) attempted to estimate projected levels of dissemination, energy delivery and investment requirements for RETs for irrigation water pumping in India using available diffusion models. Rao and Kishore (2009) attempted to apply theory of diffusion of innovation and new technologies for analyzing the growth of wind power technology in different states of India. Although the policies of the government of India encouraged growth of the wind power sectors, individual states had varying policy measures resulting in different rates of diffusion in wind energy in different states. The state level data of cumulative wind power installed capacity is used to obtain the diffusion parameters using a mixed influence diffusion model (Bass model). The diffusion parameters obtained, especially the point of time when an inflection occurs in the diffusion curve (t*) and the rate of diffusion at the point of inflection (RPI) is used to rank the different states.

D. CONCEPTUAL FRAMEWORK

Based on a review of the theoretical aspects of diffusion and the significance of diffusion as a tool to study diffusion processes, the following methodology has been adopted: The principles provided by the theory of diffusion modeling was thoroughly assessed in the context of RET, and considered to analyze the influence of different factors on diffusion of innovation or new technologies or products or applications including RETs. The parameters from a select diffusion model can provide insights to comparative analysis of diffusion under different socio economic and environmental conditions. The rate of diffusion of technologies, products and applications depending on various socio-economic, technical and institutional parameters can thus be assessed using mathematical modeling techniques. This theoretical approach involves the following steps:

1. Selection of RETs for diffusion analysis
2. Selection of a Diffusion Model
3. Applying the selected diffusion model to selected RETs
    a. Developing diffusion curves
    b .Obtaining diffusion coefficients
    c .Interpretation and analysis
4. Development of a Composite Policy Index

Examination of diffusion factors, coefficients/parameters and diffusion rates

a. Estimation of weights for different parameters
b. Study the correlation between diffusion parameters and policy parameters.

E.SELECTION OF RET'S FOR DIFFUSION ANALYSIS

Many renewable energy technologies are promoted in India due to diverse presence of resources. Not all RETs have reached the stage of diffusion. In order to select RETs for in-depth analysis from a diffusion perspective, the RETs have been first classified as follows:

a) Decentralized and centralized RET applications
b) Stages in technology development cycle (also with reference to indigenous or foreign) and status of commercialization
c) Potential and achievement
d) Target Markets – infrastructure, rural, urban etc.
e) Broad Policy and stakeholders - subsidy or market driven and private or public sector driven

F.APPLYING THE SELECTED DIFFUSION MODEL TO SELECTED RET'S

1**) Developing diffusion curves**

a) Data Sources: The data on year wise installations of RETs are collected from published sources. The Annual Reports of the MNRE and industry association books are key sources of this information. The details on policies are collected from various sources – including research reports of government agencies, industry and research reports.

b) Draw diffusion curves: Once the data on installations is collected, they are plotted in a graph N(t) vs t. The shape and trend of the diffusion is observed. Then N(t+1) Vs N(t) is plotted and drawn.

2) Estimate values of diffusion coefficients – p, q, m:

The next step would be to fit the model equation to the diffusion curve.

The Bass Model equation above has been rewritten in discrete form as equation (4)

$$N(t+1) - N(t) = a_1 + a_2 N(t) + a_3 N(t)^2 \text{ -----------(4)}$$

$a_1 = aXm$;
$a_2 = -a + bXm + 1$;
$a_3 = -b$;

The values of a_1, a_2 and a_3 are obtained from the non-linear regression equation obtained through curve fitting of the observed N (t) and N (t+1).

The potential m is estimated by $m = \frac{-a_2 \pm \sqrt{a_2^2 - 4a_1a_3}}{2a_3}$

The coefficients 'a' and 'b' are obtained by substituting the values obtained above for of a_1, a_2 and a_3. Further, substituting for p = a; q = bX m and m all the parameter values are determined. The parameters obtained from the above numeric method are used as reference parameters and are then optimized for the given market potential by MNRE. The Error Sum of Squares (SSE), the sum of squares of the deviations of the fitted values from the observed values is computed for a range of values of p, q and m. The values are optimized for minimum SSE which are used for the final analysis.

3) Interpretation and analysis:

This would be in two parts – 1) identifying RET diffusion factors 2) interpretation of the parameter values. There would be two sets of diffusion factors - push and pull factors in line with the model theory. The push factors are attributable to policy influence (at both Central and State levels) and "pull" factors attributable to the factors such as the general investment climate and the dynamics of investors (at the State level). A list of what constitutes 'push' and 'pull' factors for a specific technology are thus identified for the selected technology based on secondary sources. Both the push and pull factors would correspond to the parameter values from the selected Bass diffusion model that further enables to analyze the differential impacts of the diffusion factors on the diffusion rates of RETs.

E. G. DEVELOP A COMPOSITE POLICY INDEX

Since the model by itself does not have explanatory variables, an approach is developed to measure various policy interventions and impacts. To be able to compare different mix of policies, it would be necessary to have a single parameter which can then be analyzed with reference to diffusion variables or parameters. Thus a Composite Policy Index (CPI) is proposed. The estimation of CPI would involve the following steps:

- 1. Identification of diffusion factors; different diffusion factors would be identified based on literature survey, research and expert's opinion.
- 2. The next step would be to assign weights for different policy elements; for every factor, a weight is assigned by mutual comparison. Each factor is compared with the other from the point of view of diffusion and the more important of the two is given a score. Score of 2 or 3 is given depending on whether the difference in the importance of the two factors is small or large. Basic score of 1 is given to the factor which does not earn any score in the above process. The weight is obtained by dividing the individual score for each factor by the total score for all the factors.
- 3. Once the weights for every diffusion factor are obtained, the score obtained for different diffusion factor is multiplied by weights to get the Composite Policy Index Value. A high value indicates most favourable condition.

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- 4. The States policies are ranked according to their merit – most favourable to less favourable and compared with the diffusion parameter values.
- Table 7 briefly describes the process of quantifying the diffusion factors. There are several policy instruments which drive RET diffusion which are identified; Feed in tariff, capital subsidy, etc.

5. Correlating parameters obtained and CPI From the Bass equation, p, q, m and t* are correlated to CPI to analyze the diffusion trends. The following analysis is made:

a. t* vs. CPI

b. dN(t)/dt at t*

c. Normalized Growth Rate at the Time of Inflection (NGRTI) [(dN(t)/dt at t*/m)*100]

Table 7 Policy Index (P.I) = Sum of Y1 to Y6; Highest value corresponds to Rank 1 and lowest Rank 4.

Diffusion Factor (1)	score (2)	w-weight * (3)	total = (2*3)
X1 Capital Subsidy = The actual subsidy/Maximum amount of subsidy allowed (cumulative for the years)	0 to maximum value 1	W1 0.356	Y1
X2 Concessional loans =Interest subsidy allowed Actual values	Actual values	W2 0.244	Y2
X3 land allotment Policy == Pvt land/ Public or govt. Lands	0.1 - >70% public land 1.0 - >70% private land	W3 0.178	Y3
X4		W4	Y4
X5		W5	Y5
X6		W6	Y6

Table 8 * Estimation for Weights for Diffusion Factors – example

Weight								
Diffusion factors	1	2	3	4	5	6	Tot	Weight
1.Capitalsubsidy	1	3	3	3	3	3	16	0.356
2.Concessionalloans		1	3	3	2	2	11	0.244
3.landallotment policy			1	3	2	2	8	0.178
……				1	2	2	5	0.111
…..						1	1	0.022
Total							X	

H.WIND POWER DIFFUSION CURVES AN BEST CURVE FITS

The diffusion model equation (4) in discrete form can be written as

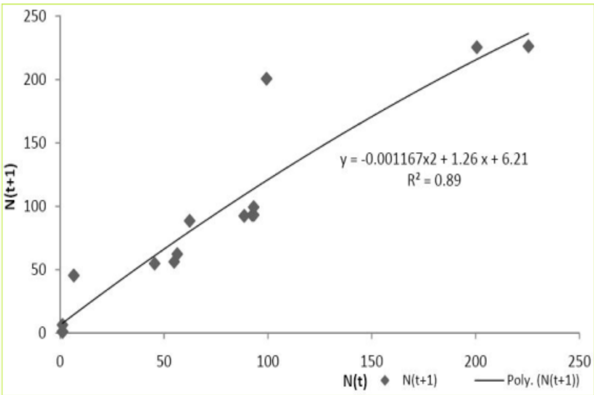
$N(t+1) - N(t) = a_1 + a_2 N(t) + a_3 N(t)^2$;

where

$a_1 = aXm$;

$a_2 = -a + bXm+1$;

$a_3 = -b$ are the coefficients of the nonlinear regression equation obtained through curve fitting of the observed N (t) and N (t+1). N (t) is the cumulative installation at time t in Megawatt and N(t+1) is the cumulative capacity after at t+1. The values of p and q are then used as initial values/guesses to obtain the parameters for the 'forced' S curve where m is taken as equal to the ultimate technical potential by using optimizing technique. fitted and actual values of N(t+1) vs.N(t). Diffusion curve based on the fitted values and projected for future is shown in Figure 9. And Cumulative wind power installations is shown in figure 10.



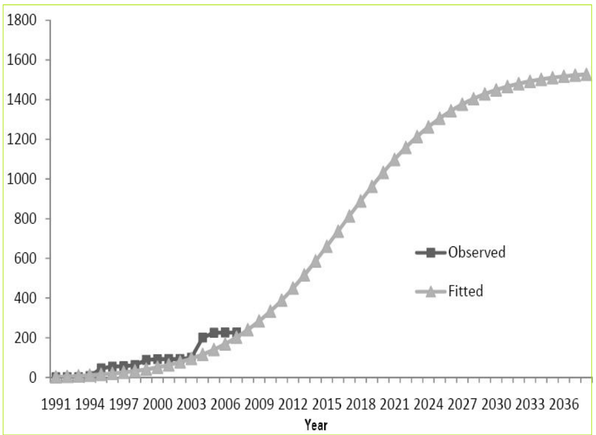


Figure 10 Cumulative wind power installations (MW) (Best Fit for p=0.001, q=0.195, m=1550)

VI. RENEWABLE ENERGY TO CREATE A SUSTAINABLE ENERGY FUTURE

The Strategies that India can Implement, Beginning Today To reach the goal of 100% of renewable energy by 2050 the following steps are recommended.

1. Aggressively expand large-scale deployment of both centralized and distributed renewable energy including solar, wind, hydro, biomass, and geothermal to ease the strain on the present transmission and distribution system – and allow more off-grid populations to be reached. Facilitate growth in large scale deployment by installing 100 million solar roofs and large utility-scale solar generation, through both centralized and distributed energy within the next 20 years;

2. Enact a National Renewable Energy Standard/Policy of 20% by 2020 – to create demand, new industries and innovation, and a new wave of green jobs;

3. Develop favorable government policies to ease the permitting process, and to provide start-up capital to promote the exponential growth of renewable energy. Create and fund a national smart infrastructure bank for renewable energy;

4. Accelerate local demand for renewable energy by providing preferential Feed-in-Tariffs (FIT) and other incentives such as accelerated depreciation; tax holidays; renewable energy funds; initiatives for international partnerships/collaboration, incentives for new technologies; human resources development; zero import duty on capital equipment and raw materials; excise duty exemption; and low-interest rate loans.

5. Phase out all conventional energy subsidies. Force petroleum products to compete with other fuels like biomass and biogas, etc.;

6. Accelerate the development and implementation of cost-effective energy efficiency standards to reduce the long-term demand for energy. Engage States, industrial companies, utility companies, and other stakeholders to accelerate this investment;

7. Initiate a move to electrify automotive transportation or develop Electric Vehicles – plug-in hybrids – such as the Nissan Leaf, Tesla Model S, or Chevy Volt, etc. Develop and implement time-of-day pricing to encourage charging of cars at night. Adopt nationwide charging of electric cars from solar panels on roofs, and solar-powered Electric Vehicle charging stations around the country. Thousands of these solar-powered recharging stations could spread across India just like the present public call office (PCO), giving birth to the "Green Revolution." These recharging connections could be deployed at highly-concentrated areas including shopping malls, restaurants, and public places where vehicles are usually parked for extended periods;

8. Aggressively invest in a smart, two-way grid (and micro-grid). Invest in smart meters, as well as reliable networks that can accommodate the two-way flow of electricity. Such networks need to be resilient enough to avoid blackouts and accommodate the advanced power generation technologies of the future;

9. Develop large-scale solar manufacturing in India (transforming India into a global solar manufacturing hub). Promote and establish utility-scale solar and wind generation parks and farms. Also, establish R&D facilities within academia, research institutions, industry, government and private entities to guide technology development.

10. Work towards a Hydrogen Economy development plan. Hydrogen can be fed into fuel cells for generating heat and electricity – as well as for powering fuel cell vehicles. Produce hydrogen from renewable energy sources such as solar and wind. If done successfully, hydrogen and electricity will eventually become society's primary energy carriers for the twenty-first century.

V.CONCLUSIONS AND SCOPE FOR FURTHER WORK

The difference in diffusion parameter values correspond to not only different policy environments but different responses to the same set of policies in different environments. There are several RETs in India that are yet to realize their potential. Diffusion modeling can be an important tool to assess and design future programmes. It is seen that the policy framework of a government is critical for promotion of RETs in a country. The following are the key recommendations emerging from this study for policy formulation, design and implementation of the future programmes in RETs:

1. The policies can make use of diffusion analysis for setting targets

- Different RET diffusion curves can be constructed to review the resource requirements for meeting the stated goals/targets.
- Use of diffusion coefficients in planning and implementation of programmes - based on p, q, t* and m

• 2. The development of policy regimes should take into account the slower diffusion process at the initial stages as compared to the linearized straight line assumption adopted in policy formulation, usually resulting in under spending in the initial years and higher demand for funding during later years. The funds for promoting RETs can be more rationally allocated based on the theory of diffusion.

• 3. The dynamics of diffusion process in reality should be monitored and the funding pattern should be adjusted accordingly; hence the programme has to be flexible with possibilities of adjusting activities and funding levels continuously.

The application of diffusion theory for promoting of RETs is nascent as judged by the handful of technical papers on the subject. Besides, the policy impact studies are limited due to political and other considerations. Considering the global significance of the subject, there is a strong need for developing this area of study. Results obtained from diffusion of market friendly technologies need to be analyzed systematically and applied for faster diffusion of supposedly slow diffusing RETs. The present study has applied diffusion modeling approach to wind and solar technologies, but it is important to undertake model analysis for other RETs in India and in other countries with a view to get more policy insights and accelerate the pace of adoption of RETs across the world by adopting appropriate policies at various stages of diffusion process. The Composite Policy Index as a measure of policy impacts is developed for the first time in the study and needs to be further developed for its universal adaptability and applicability. Also, there is a need for greater research for developing information and database on policy variables and their impacts for better ranking and assigning of weights as this could be a useful tool for policy makers to analyze the impacts of different policies on diffusion rates and decide diffusion pathways for future. Finally, the uncertainties in the assessment of potential for various RETs needs to be reduced for effective diffusion strategies.

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