

# A Review of Energy Scenario and Diffusion Modeling of Selected Renewable Energy Technologies in India

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**Abstract:** Energy is the most essential element of socio-economic development and nation's economic growth. Renewable energy sources can play an immense role to fulfill this need of energy. These sources will not only enhance independency of energy but also helps in many ways such as mitigation of climate change, swift development of rural areas, improved health status and will be the best way to move towards sustainable development. Renewable energy sources, especially solar and wind, Biomass 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. 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. This paper presents the current energy scenario and 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 status of renewable energy is explored in Indian context. The state wise status, different challenges, issues, barriers, solar and wind power development and policies are discussed in detail 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, Biomass, 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 exponential growth in the rate of energy consumption is the main cause of energy shortage, as well as energy resources depletion worldwide.

Electricity shortage is very common in country like India where most of the population (i.e. over 40 percent) has no access to modern energy services. On an average, electricity demand is expected to rise 7.4 percent annually for next 25 years. According to International Energy Agency, more than 28 percent share of the world's total energy will be consumed in India by the year 2030. Therefore a significant amount of energy must come from renewable sources. National Action Plan on Climate Change (NAPCC) was formed in 2008 for climate change control, has also considered role of renewable energy in total energy production of India. 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 CO<sub>2</sub> 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 CO<sub>2</sub> emissions, accounting for 41 percent of global CO<sub>2</sub> emissions (IEA 2010). This reality clearly makes the reduction of emissions from electricity generation an essential ingredient in any climate change mitigation strategies. In this paper some of initiatives taken are focus of discussion which are primarily necessary for RET diffusion. 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.

## II. WHY RENEWABLE ENERGY?

1. Fossil Fuels are limited: The first and main reason for why governments and businesses are keen to move to renewable energies as soon as possible is that fossil fuels are a finite resource. We may or may not have reached peak oil - the point at which demand outstrips supply - and by current figures, many experts seem to agree we did so around 2008 with only external factors creating fluctuations in demand making it difficult to predict precisely when it will run out. That is another debate entirely that our politicians and economists have argued for decades, and will continue to argue for many years to come. Whichever way we look at it, fossil fuels will run out eventually and it will take some 10,000,000 years to replenish what we have used in around 150 years.

2. Carbon Emissions & Climate Change: In the last few years especially, no part of the world has been untouched by freak weather conditions. Most continents have recorded record high temperatures in summer, record lows in winter and increased frequency of typhoons and hurricanes, record dry spells, drought and flooding. There is no doubt that these freak weather conditions are affecting every country. Most renewable energy sources, and the technology used to harness them, are low carbon emission. In most cases, once installed they have minimal or no carbon output and can still provide our energy needs. We can never go fully carbon neutral as it takes resources to make a solar panel, build a dam and so on, but it is a critical and significant reduction of our carbon output. What we do need to do, is to take the steps we can to reduce our carbon footprint for international regulations, to help those in the developing world, and to protect ourselves against the freak weather.

3. Energy Security: Energy security is a relative newcomer to public perception when we consider the greater need for renewable energy. Energy security will become a much greater factor as fossil fuels begin to dwindle. More than ever before, demands on energy supply often outstrip supply of conventional production forcing prices up. It is expected that increased tension over acquisition and protection of resources could lead to global conflict.

4. Economic Stability: Related to some of the issues mentioned above, where renewable energy offers a constant and sustained supply (such as hydroelectric, wave power, solar and bio-fuels), energy prices are likely to remain stable and in turn, keep the economy stable. In many cases, energy produced from renewable sources is already cheaper than that produced by non-renewable means.

5. Environmental Damage: As fossil fuel supply gets harder to acquire, and prospectors search for new pockets of oil and have to drill longer and deeper to acquire it,

there has been conflict between environmental groups and industry and between governments and both groups when local wildlife and environmentally sensitive areas are threatened.

6. Public Health: Oil, gas and coal drilling and mining have high levels of pollution that are pumped into local environments and the wider atmosphere, so while protestors attempt to prevent the building of pipelines or new prospecting in virgin areas and wilderness, it is as much about public health as it is about conservation. We have known for decades about the knock on effect of industrial processes for public health. Few renewable are entirely emission-free, but their output is much lower than conventional fossil fuel acquisition and processing.

## III. PRESENT ENERGY SCENARIO IN INDIA

### A. WIND ENERGY

The Wind power programme in India was initiated towards the end of the Sixth Plan, in 1983-84. A market-oriented strategy was adopted from inception, which has led to the successful commercial development of the technology. The broad based National programme includes wind resource assessment activities; research and development support; implementation of demonstration projects to create awareness and opening up of new sites; involvement of utilities and industry; development of infrastructure capability and capacity for manufacture, installation, operation and maintenance of wind electric generators; and policy support. The programme aims at catalyzing commercialization of wind power generation in the country. The Wind Resources Assessment Programme is being implemented through the State Nodal Agencies, Field Research Unit of Indian Institute of Tropical Meteorology (IITM-FRU) and Center for Wind Energy Technology (CWET). Wind in India are influenced by the strong south-west summer monsoon, which starts in May-June, when cool, humid air moves towards the land and the weaker north-east winter monsoon, which starts in October, when cool, dry air moves towards the ocean. During the period March to August, the winds are uniformly strong over the whole Indian Peninsula, except the eastern peninsular coast. Wind speeds during the period November to March are relatively weak, though higher winds are available during a part of the period on the Tamil Nadu coastline. 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 Maharashtra (Ratnagiri), Gujarat (Okha) and Tamil Nadu (Tuticorin) with 55 kW Vestas wind turbines. 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. 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 2012 to March 2017) fixed a reference target of 15,000 MW in new capacity additions, and an aspiration target of 25,000 MW. Table 1 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 provides state wise installed wind power capacity in India (up to Aug- 2014). As per MNRE Reports the highest wind energy installed state Tamil Nadu, which has total installed capacity of 7372 MW till Aug- 2014 and total installed capacity in India as of Aug-2014 (MW) is approximately 21,821 MW. The figure. 1 shows The Wind Energy across states in India.

Table 1 State wise installed Wind Power Capacity in India

| State          | Installed capacity Aug-2014 (MW) |
|----------------|----------------------------------|
| Tamil Nadu     | 7372                             |
| Gujarat        | 3520                             |
| Maharashtra    | 4141                             |
| Karnataka      | 2532                             |
| Rajasthan      | 2845                             |
| Madhya Pradesh | 494                              |
| Andhra Pradesh | 878                              |
| Kerala         | 35                               |
| Others         | 4                                |
| Total          | 21,821                           |

**B. SOLAR ENERGY**

India is endowed with vast solar energy potential. About 5,000 trillion kWh per year energy is incident over Indias land area with most parts receiving 4-7 kWh per sq. m per day. Hence both technology routes for conversion of solar radiation into heat and electricity, namely, solar thermal and solar photovoltaic's, can effectively be harnessed providing huge scalability for solar in India. Solar also provides the ability to generate power on a distributed basis and enables rapid capacity addition with short lead times. Off-grid decentralized and low-temperature applications will be advantageous from a rural electrification perspective and meeting other energy needs for power and heating and cooling in both rural and urban areas. From an energy security perspective, solar is the most secure of all sources, since it is abundantly available. Theoretically, a small fraction of the total incident solar energy (if captured effectively) can meet the entire countries power requirements. It is also clear that given the large proportion of poor and energy un-served population in the country, every effort needs to be made to exploit the relatively abundant sources of energy available to the country. While, today, domestic coal based power

generation is the cheapest electricity source, future scenarios suggest that this could well change. . 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, Gujarat has the largest share of solar power generation of 33.562% (919.1 MW) and Gujarat share is 26.949% i.e 738 MW as on Aug- 2014. The figure. 1 shows Solar Energy across states in India.

Table 2 State wise installed Solar Power Capacity in India

| State          | Installed capacity Aug-2014 (MW) |
|----------------|----------------------------------|
| Tamil Nadu     | 99.5                             |
| Gujarat        | 919.1                            |
| Maharashtra    | 280.8                            |
| Karnataka      | 44.0                             |
| Rajasthan      | 738.0                            |
| Madhya Pradesh | 355.1                            |
| Andhra Pradesh | 164.1                            |
| Orissa         | 29.5                             |
| Uttar Pradesh  | 29.0                             |
| Punjab         | 16.5                             |
| Jharkhand      | 16.0                             |
| Haryana        | 12.8                             |
| Others         | 33.3                             |
| Total          | 2738.5                           |

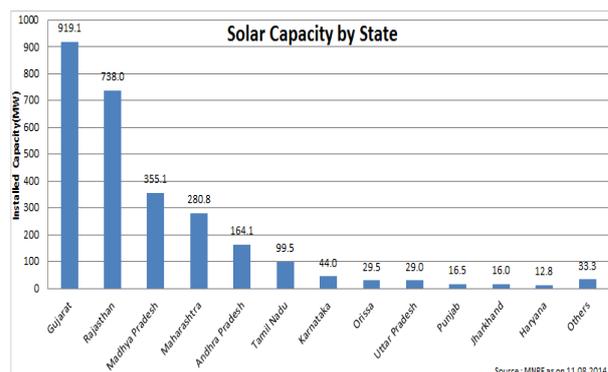


Fig. 1 Solar Energy across states in India

**C. BIOMASS ENERGY**

Biomass has always been an important energy source for the country considering the benefits and promises it offers. It is a carbon neutral fuel source for the generation of electricity; and apart from providing the much needed relief from power shortages; biomass power projects could generate employment in rural areas. About 32% of the total primary energy use in the country is derived from biomass and more than 70% of the country’s population depends upon it for their energy needs. The Ministry of New and Renewable Energy (MNRE), Government of India has realized the potential and role of biomass energy in the Indian context and has initiated a number of programmes for the promotion of efficient biomass conversion technologies to be used in various sectors of the economy to ensure derivation of maximum benefits. Table 3 State wise installed Biomass Power Capacity in India.

Table 3 State wise installed Biomass Power Capacity in India

| State wise biomass power and cogeneration projects |               |
|--|---------------|
| State  | Capacity (MW) |
| Andhra Pradesh & Telangana                         | 389.75        |
| Bihar  | 43.42         |
| Chhattisgarh                                       | 264.90        |
| Gujarat  | 55.90         |
| Haryana  | 52.30         |
| Karnataka  | 737.28        |
| Madhya Pradesh                                     | 36.00         |
| Maharashtra  | 1,112.78      |
| Odisha   | 20.00         |
| Punjab   | 140.50        |
| Rajasthan  | 111.30        |
| Tamil Nadu   | 662.30        |
| Uttarakhand  | 30.00         |
| Uttar Pradesh                                      | 936.70        |
| West Bengal  | 26.00         |
| Total  | 4,761.00      |

(Source: MNRE Annual Report- 2015)

The major barriers and challenges of biomass power as: Unlike solar and wind, biomass is relatively a much reliable source of renewable energy free of fluctuation and does not need storage as is the case with solar. But it is not the preferred renewable energy source till now, mainly due to the challenges involved in ensuring reliable biomass supply chain. This is because of the wide range in its physical properties and fluctuation in availability round the year depending on cropping patterns. Biomass from agriculture is available only for a short period after its harvesting, which can stretch only for 2-3 months in a year. So there is a need to have robust institutional and market mechanism for efficient procurement of the required quantity of biomass, within this stipulated short time, and safe storage till it is finally used. The major

challenge in ensuring sustained biomass supply at reasonable prices are: Increasing competing usage of biomass resources, leading to higher opportunity costs; unorganized nature of biomass market, which is characterized by lack of mechanization in agriculture sector, defragmented land holdings, and vast number of small or marginal farmers. Another major challenge is the cost of biomass storage and transportation to power plants, which is consistently rising rapidly with time.

There is the need to evolve a robust organized biomass market through innovative business models, motivating rural entrepreneurs to take up the responsibility of supplying biomass to processing facilities. There is also the need to develop and exploit energy plantations to take up energy crops on marginal and degraded land, as a substitute for crop wastes.

Some of the Indian states leading the pack in establishing biomass based power supply are Uttar Pradesh, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, and Chhattisgarh. Ironically, many states with agriculture based economy, despite good biomass power potential, have not properly been able to utilize the opportunity and figure low in biomass power achievements. Only Uttar Pradesh in north India has utilized large part of the biomass potential, which can be attributed to its sugarcane industry, with cogeneration power plants. There is also wide variation in tariff being offered for biomass power plants in different states. Government policy can play a big role in enhancing the viability of biomass power plants and in supporting investment growth in the biomass power sector in states with high biomass power potential.

**D. BIOMASS POWER & COGENERATION PROGRAMME**

**1. Introduction:** This is implemented with the main objective of promoting technologies for optimum use of country’s biomass resources for grid power generation. Biomass materials used for power generation include bagasse, rice husk, straw, cotton stalk, coconut shells, soya husk, de-oiled cakes, coffee waste, jute wastes, groundnut shells, saw dust etc.

**2. Technology:**

**Combustion:** The thermo chemical processes for conversion of biomass to useful products involve combustion, gasification or pyrolysis. The most commonly used route is combustion. The advantage is that the technology used is similar to that of a thermal plant based on coal, except for the boiler. The cycle used is the conventional ranking cycle with biomass being burnt in high pressure boiler to generate steam and operating a turbine with generated steam. The net power cycle efficiencies that can be achieved are about 23-25%. The exhaust of the steam turbine can either be fully condensed to produce power, or used partly or fully for another useful heating activity. The latter mode is called cogeneration. In India, cogeneration route finds application mainly in industries.

**Cogeneration in Sugar Mills:**

Sugar industry has been traditionally practicing cogeneration by using bagasse as a fuel. With the advancement in the technology for generation and utilization of steam at high temperature and pressure, sugar industry can produce electricity and steam for their own requirements. It can also produce significant surplus electricity for sale to the grid using same quantity of bagasse. For example, if steam generation temperature/pressure is raised from 400°C/33 bar to 485°C/66 bar, more than 80 KWh of additional electricity can be produced for each ton of cane crushed. The sale of surplus power generated through optimum cogeneration would help a sugar mill to improve its viability, apart from adding to the power generation capacity of the country.

**3. Deployment:**

The Ministry has been implementing biomass power/cogeneration programme since mid nineties. A total of approximately 500 biomass power and cogeneration projects aggregating to 4760 MW capacity have been installed in the country for feeding power to the grid. In addition, around 30 biomass power projects aggregating to about 350 MW are under various stages of implementation. Around 70 Cogeneration projects are under implementation with surplus capacity aggregating to 800 MW. States which have taken leadership position in implementation of bagasse cogeneration projects are Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra and Uttar Pradesh. The leading States for biomass power projects are Andhra Pradesh, Chattisgarh, Maharashtra, Madhya Pradesh, Gujarat and Tamil Nadu.

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 2.

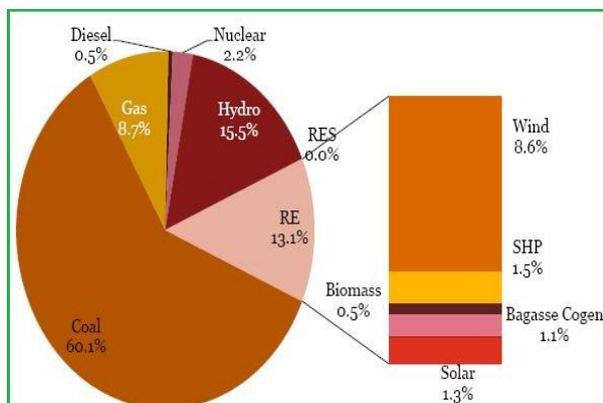


Fig. 2 Present Power Scenario of India

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

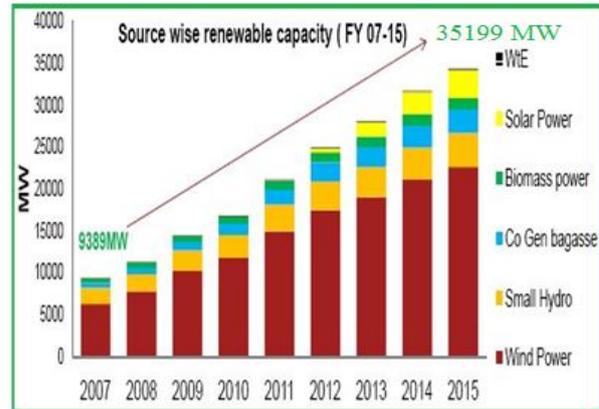


Fig. 3 The source wise Renewable Energy status

Table 4 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                  |

As per the information MNRE the estimated power requirement is expected to increase by 200% from FY 14 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. 4 and 5 respectively.



Fig. 4 Estimated power requirement till 2030

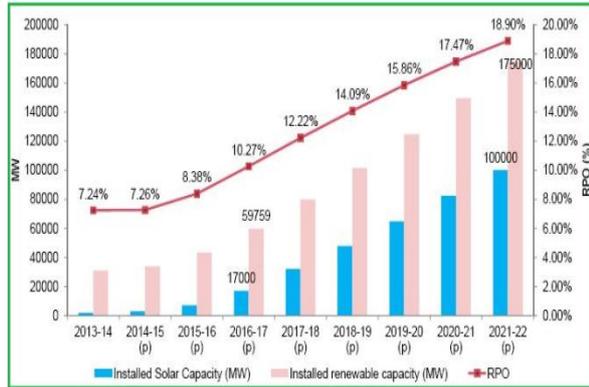


Fig. 5 Contribution of Renewable Energy in 2022

IV. 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 6). 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.

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

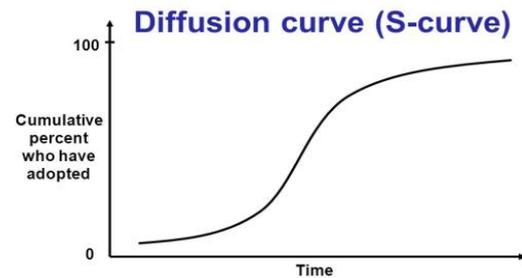


Fig. 6 Diffusion curve - cumulative adoption vs time

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 7). 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.

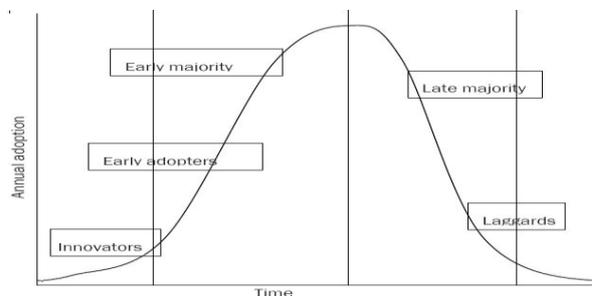


Fig. 7 Diffusion curve - adopters vs. time

A. BRIEF REVIEW OF 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.

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

Where N(t) is the cumulative adoption at time t and N<sup>u</sup> 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<sup>u</sup>); p represents the coefficient of innovation (a in the above equation) and q is the coefficient of imitation (b in equation(1)= q/ N<sup>u</sup>) 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.
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
  - 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 5 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 6). 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 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, Eliashberg 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. 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.

Table 5 Summary of diffusion model categories and their applications

| Category | Diffusion rate equations represented as dF/dt or dN(t)/dt;<br>F- Fraction of adoptions (F=N(t)/N <sup>u</sup> ; 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<br>$dF/dt = a(1-F)$   | Coleman et al (1966)<br>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.<br>New drug by physicians in four mid-western communities; Number of labour strikes and political assassinations in 64 developing nation over a 20 year period. |
|                             | Logistic Internal Influence:<br>$dF/dt = bF(1-F)$  | Mansfield (1961)   | Mansfield investigated several industrial innovations such as pallet loaders, diesel locomotives, and continuous mining machines  |
|                             | Gompertz function<br>$\frac{dN(t)}{dt} = bN(t)[\ln N^u - \ln N(t)]$  | Griliches (1957)<br>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<br>Gray investigated diffusion of 12 public policy innovations among the 48 contiguous United States.  |
|                             | Mixed Influence:<br>$dF/dt = a + bF(1-F)$  | Dixon (1980) Bass (1969)   | Forecast sales of television sets, dish washers, and clothes dryers   |
|                             | Modifications of Mixed influence   | Webber (1972)<br>Lekvall and Wahlbin (1973)<br>Warren (1980)   | Modified to study the impact of location, simulate effect of certain internal and external influences on diffusion patterns, 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 et al, 1981)   | Diffusion of two medical innovations – CAT head scanners and CAT body scanners  |
|                             | Non-Uniform Influence (NUI) $(a + bF^\delta) (1-F)$<br>$\frac{b}{1-\phi} F^\phi (1 - F^{1-\phi})$ ; $0 < \phi$   | NUI (Eastingwood et al, 1983) Von Bertalanffy (1957)   |   |
| Extension and Refinements   | Dynamic Diffusion Models<br>$\frac{dN(t)}{dt} = (a + bN(t)) [f(\xi(t)) - N(t)]$<br>$N(t) = -\frac{a}{b} + \frac{\exp\{a(t-t_0) + b\phi(t)\}}{\left[\frac{b}{(a+bN_0)} + b \int_{t_0}^t \exp\{a(x-t_0) + b\phi(x)\} dx\right]}$ | Mahajan and Peterson (1978)<br>Chow (1967) Chow examined the natural growth of computers 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       |

Continued

|          |   |        |              |
|----------|---|--------|--------------|
| Category | Diffusion rate equations represented as $dF/dt$ or $dN(t)/dt$ ;<br>F- Fraction of adoptions ( $F=N(t)/N^u$ ; N or N(t) cumulative adoption at any given time; $N^u$ – Ultimate potential; a, b, etc. – diffusion coefficients; t – time | Author | Applications |
|----------|---|--------|--------------|

|                           |  |   |   |
|---------------------------|--|---|---|
| Extension and Refinements | <p>Multi-Innovation Diffusion Models</p> $\frac{dN_1(t)}{dt} = a_1 [N^u - N_1(t)] + b_1 N_1(t) [N_1^u - N_1(t)] - c_1 N_2(t) [N_1^u - N_1(t)]$   | 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..  |
|                           | <p>Space and Time Diffusion Models</p> $N=f(x,t); \frac{\partial N}{\partial y} = 0$ $\frac{\partial N(x,t)}{\partial y} = (a(x) + b(x)N(x,t)) [N^u(X) - N(x,t)]$ $N(x,t) = N^u(X) \frac{a(x)(N^u(X) - N_0(x))}{a(x) + b(x)N_0(x)} \exp\left(-\frac{a(x) + b(x)N^u(x)(t - t_0)}{1 + \frac{b(x)(N^u(x) - N_0(x))}{(a(x) + b(x)N_0(x))} \exp(-a(x) + b(x)N^u(x)(t - t_0))}\right)$ | Mahajan and Peterson (1979)<br>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   |
|                           | <p>Multistage Diffusion Models</p> $\frac{dy}{dt} = \beta x(y + z) + (\mu x + \gamma y)$ $\frac{dN(t)}{dt} = \gamma [N^u(t) - N(t)]$   | Midgley(1976)Dods on and Muller(1978)<br>Sharif and Ramanathan (1982)<br>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. |
|                           | <p>Multi-adoption Diffusion Models</p> $N(t + 1) = a(N^u - N(t)) + b \left(\frac{N(t)}{N^u}\right)^\delta (N^u - N(t) + cN(t))$  | Wind et al (1981)<br>Lilien et al (1981)  | Forecasting sales for product innovations Lilien model to forecast sales of ethical drugs   |
|                           | <p>Diffusion Models with Influencing Agents</p> $a(t) = A(\underline{z}(t))$ $b(t) = B(\underline{z}(t))$ $N^u(t) = N^u(\underline{z}(t))$   | Robinson and Lakhani (1975)<br>Mahajan and Muller (1979)<br>Dolan and Kalish (1983)<br>Horsky and Simon (1983)<br>Mahajan and Wind (1985) | Incorporating the influence of pricing, advertising, promotion and technological change into the model.   |

Table 6 Diffusion model categories

| Category                      | Model –Equation           | Equation   |
|-------------------------------|---------------------------|--|
| Models of Cumulative Adoption | 1.1. Bass Model           | $dF/dt = a + bF(t)(1-F(t))$  |
|                               | 1.2. Cumulative lognormal | $N(t) = N^u \int_0^t \frac{1}{y \sqrt{2\pi\sigma^2}} \exp\left(-\frac{(\ln(y) - \mu)^2}{2\sigma^2}\right) dy$  |
|                               | 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             | $N(t) = N^u \exp(-b(\exp(-at)))$   |
|                               | 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                        | $\ln(N(t) - N(t-1)) = a + b_1t + b_2 \ln(N(t-1))$   |
|  | 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                          | $\left( \frac{bN^u - a^2}{bN^u} \right) \ln(a + bN^uN(t)) - (a+1)\ln(1-N(t)) = b + (bN^u + a)t$ |
|  | SBB (Sharma, Basu, Bhargava(1993)) | $N(t) = N(t-1)\exp(a(1-N(t-1)))$  |

Table 7 Rationalized forms of various diffusion models

| S.No | 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-F) <sup>2</sup>   |
| 5    | Sharif- Kabir                                   | bF/[1-F(1-e)]           | (1-F) <sup>2</sup>   |
| 6    | Easingwood- Mahajan Muller (NSRL) Modified NSRL | bF <sup>d</sup>         | (1-F)                |
|      |   | bF                      | (1-F) <sup>d</sup>   |
| 7    | Non Uniform Influence (NUI)                     | (a+bF) <sup>d</sup>     | (1-F)                |
| 8    | Jeuland   | (a+bF)                  | (1-F) <sup>1+r</sup> |
| 9    | Nedler Von Bertalanffy                          | bF                      | (1-F) <sup>e</sup>   |
|      |   | [b/(1-e)]F <sup>e</sup> | (1-F) <sup>1-e</sup> |
| 10   | a) Generalized Rational Model (GRM-I)           | bF/(1-F+eF)             | (1-F)                |
|      | b) Generalized Rational Model (GRM-II)          | bF/(e+F - eF)           | (1-F)                |
| 11   | Other Possibilities                             | a+ bF+rF <sup>2</sup>   | (1-F)                |
|      |   | [a/(1+F)+bF]            | (1-F)                |
|      |   | [a/(1+F)+bF]            | (1-F) <sup>2</sup>   |

**B. DIFFUSION ANALYSIS OF RET**

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. Theocharis et al (2005) and Lund (2006) point out environment pressures and Kyoto mechanisms driving the RET adoption and innovations. Based on Roger's theory, Theocharis et al (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 pumpsets) 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:

Selection of RETs for diffusion analysis

Selection of a Diffusion Model

Applying the selected diffusion model to selected RETs

Developing diffusion curves

Obtaining diffusion coefficients

Interpretation and analysis

Development of a Composite Policy Index

Examination of diffusion factors, coefficients/parameters and diffusion rates

Estimation of weights for different parameters

Study the correlation between diffusion parameters and policy parameters.

#### **E. SELECTION OF RETS 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 RETS**

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)

$$N(t + 1) - N(t) = a_1 + a_2N(t) + a_3N(t)^2 \text{ ----- (4)}$$

$$a_1 = aXm;$$

$$a_2 = -a + bXm + 1;$$

$$a_3 = -b;$$

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  $p = a; q = bXm$  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 is 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.

**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:

Identification of diffusion factors; different diffusion factors would be identified based on literature survey, research and expert’s opinion. 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. The States policies are ranked according to their merit - most favourable to less favourable and compared with the diffusion parameter values. Table 9 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.

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:

1.  $t^*$  vs. CPI
2.  $dN(t)/dt$  at  $t^*$
3. Normalized Growth Rate at the Time of Inflection (NGRTI)  $[(dN(t)/dt \text{ at } t^*/m)*100]$

Table 8. 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<br>Capital Subsidy = The actual subsidy/Maximum amount of subsidy allowed (cumulative for the years) | 0 to maximum value 1                           | W1<br>0.356   | Y1           |
| X2<br>Concessional loans =Interest subsidy allowed Actual values  | Actual values                                  | W2<br>0.244   | Y2           |
| X3<br>land allotment Policy == Pvt land/ Public or govt. Lands  | 0.1 - >70% public land 1.0 - >70% private land | W3<br>0.178   | Y3           |
| X4  |  | W4            | Y4           |
| X5  |  | W5            | Y5           |
| X6  |  | W6            | Y6           |

Table 9 \* Estimation for Weights for Diffusion Factors

| Weight                 |   |   |   |   |   |   |       |        |
|------------------------|---|---|---|---|---|---|-------|--------|
| Diffusion factors      | 1 | 2 | 3 | 4 | 5 | 6 | Total | Weight |
| 1.Capitalsubsidy       | 1 | 3 | 3 | 3 | 3 | 3 | 16    | 0.356  |
| 2.Concessionall oans   |   | 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. DIFFUSION CURVES AND BEST CURVE FITS**

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

$$N(t + 1) - N(t) = a_1 + a_2N(t) + a_3N(t)^2;$$

where

$$a_1 = aXm; \quad a_2 = -a + bXm + 1;$$

$a_3 = -b$  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 8. Cumulative wind and Biomass diffusion curve is shown in figure 9 & 10

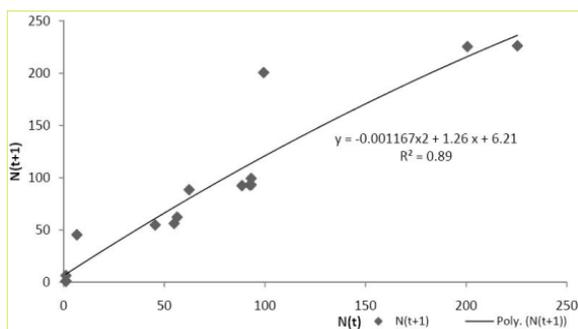


Fig. 8 Diffusion curve based on the fitted values and projected for future

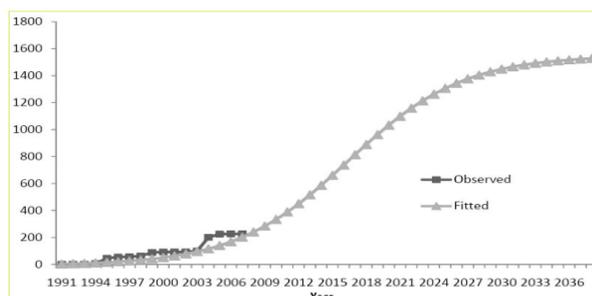


Fig. 9 Cumulative wind power installations (MW) (Best Fit for  $p=0.001$ ,  $q=0.196$ ,  $m=1550$ )

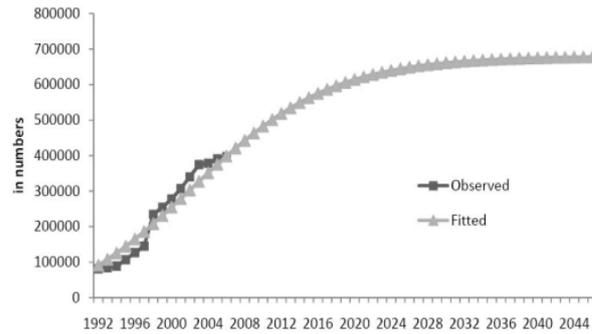


Fig. 10 Biogas plant diffusion curves Best Fit for  $p=0.011$ ,  $q=0.12$ ,  $m=680000$

**V. PROMOTIONAL POLICIES**

**A.SOLAR**

Fiscal and financial incentives in the form of accelerated depreciation, concessional/nil customs and excise duties, preferential tariffs and generation based incentives are being provided to improve viability of solar power generation units. An enabling policy and regulatory environment is being created through measures like solar specific RPOs under National Tariff Policy {0.25% in Phase 1 (2013) to increase to 3% by 2022}, State Specific Solar Policies and RPO targets, and REC mechanism. Capital subsidy is being provided for off-grid/decentralized solar power generation systems. Solar Parks are being planned in various parts of the country to achieve cost reductions of solar power generation units through utilization of common infrastructure. A scheme for promotion of grid-connected roof-top PV systems with a provision for 30% subsidy has also been formulated. The R&D in solar is also being encouraged. Ministry provides financial support to industry for R&D project.

**B.WIND**

A package of fiscal and financial incentives is available which includes concessions such as 80% accelerated depreciation, concessional custom duty on specified items, excise duty exemption, sales tax exemption, income tax exemption for 10 years, etc. In addition, State Electricity Regulatory Commissions (SERCs) are determining preferential tariffs. Indian Renewable Energy Development Agency (IREDA) provides loan for setting up wind power projects.

**C.BIOMASS**

Besides the Central Financial Assistance, fiscal incentives, concessional import duty, excise duty, tax holiday for 10 years, bank loans of up to Rs 15 crore for biomass-based power generators will be considered part of PSL etc., are available for Biomass power projects. The benefit of concessional custom duty and excise duty exemption are available on equipments required for initial setting up of biomass projects based on certification by Ministry. In addition, State Electricity Regulatory Commissions have determined preferential tariffs and Renewable Purchase Standards (RPS). Indian Renewable Energy Development Agency (IREDA) provides loan for setting up biomass power and bagasse cogeneration projects.

## VI. 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:

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  $m$
- The development of policy regimes should take into account the slower diffusion process at the initial stages as compared to the linear 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. 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 biogas 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. Detailed resource assessments and technical potential estimation needs to be carried out on a continuous basis.

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