EVOLUTION OF RENEWABLE ENERGY TECHNOLOGIES IN INDIA: DEMONSTRATING INNOVATION THROUGH TECHNOLOGICAL SYSTEMS APPROACH

by

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Nothing was possible for me till date without the warmth, love and support showered by my family. In all my endeavours till now, they had supported me overwhelmingly with positive mindset and encouraging zeal.

DECLARATION

I, hereby declare that, the contents of this work are the results of my own research, conducted under the supervision of Professor Asgari Behrooz, and that every source of information used in this paper has been properly acknowledged and appropriately referenced. Therefore, I duly acknowledge my complete responsibility for the contents of this work.

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List of Acronyms and Terms

CEL: Central Electronics Ltd, New Delhi

CEPT: Center for Environmental Planning and Technology, Ahmedabad

CERC: Central Electricity Regulatory Commission, New Delhi

CFCT: Center for Fuel Cell Technology, Chennai

CPRI: Central Power Research Institute, Bangalore

IARI: Indian Agricultural Research Institute, New Delhi

KVIC: Khadi and Village Industries Commission, New Delhi

NAL: National Aerospace Laboratories, Bangalore

NIOT: National Institute of Ocean Technology, Chennai

SERC: State Electricity Regulatory Commission

SNA: State Nodal Agency

ABSTRACT

The present day supply of world's energy is dominated by fossil fuels. Increasingly, humankind has realised that fossilized energy resources are of non-renewable nature and sooner or later, they will expire and also understood the negative consequences of using fossil fuels. Global climatic changes and associated problems have made humans more vulnerable today. This grim situation is further accentuated by the oil embargo (1973), 2008 oil price shock and the like, coupled with the ever increasing oil prices. In this backdrop, the world is taking recourse to renewable energy options as a better and sustainable option. But, the technologies surrounding these renewable energy systems are still evolving, costly and are beyond the utility scope of many nations and users as well.

This paper analyzes the India's Renewable Energy Technological System (IRETS) using Technological Systems Approach (TSA). This is based on the premise that numerous actors are at work to achieve technological excellence in RETs and by no means is the work of a single institution. Using TSA, this paper analyzes the IRETS in terms of its evolution, actors, and relationships etc. that change with time. This is the approach, which helps in unravelling the positives and negatives that went in building up a technological system.

Though a tedious work, just to analyze and present the system is still incomplete as it doesn't portray its performance. Therefore, efforts have also been made to

analyze the performance of IRETS in multidimensional ways - production, trade, achievements, developmental agenda, one of its kind system.

Based on the past and present RETs development and diffusion patterns in the system, this paper tries to predict and analyze the future diffusion patterns and the time frame required to realize the achievable technical potentials. For this purpose, two levels are chosen in the country. Firstly, combined RETs or RETs as a whole are considered for entire India. Secondly, three specific RETs - wind, biomass and small hydro power are chosen for modelling and for each RET, top ten states in India based on their maximum potential are chosen to predict and analyze their future growth patterns in terms of each of the three RETs.

Technological forecasting can be done by multitude of different models describing growth in interaction with a limiting environment. This paper concentrates on two models that have found application in the technological change and in economic modelling and are most popular - the Gompertz function and the Logistic function.

On the question of choosing between the two functions, this paper not only does analyze the normal considerations of visibility, the coefficient of determination (R^2) value, the mean absolute deviation (MAD), the mean square error (MSE), but also analyzes the auxiliary regression as given by PHILIP HANS Franses. The best fitting curve based on the aforementioned criteria is chosen and is analyzed for prediction.

Having analyzed the performance and future growth patterns of the system, conclusions are drawn and policy implications are observed. Suitable recommendations have been put forward to infuse more vitality into the system.

Chapter 1

INTRODUCTION

INTRODUCTION

1.1 Need for RETs in India

In India, more than 400 million people, which include 47.5% of them who live in India's rural hinterland, have no access to electricity till date (MNRE, Decentralized Systems, 2012). This population size is more than the entire population of the United States of America. India has over 90,000 un-electrified villages and over 380,000 partially electrified villages (EngineeringReview, 2012). Transmission losses in India stood at 19.88 % during 2009-10.

Fossil fuels primarily fuel the India's primary energy needs, with more than three quarters of its annual oil consumption coming from imports. The petroleum products usage has grown at a compounded annual growth rate of around 4% during the last seven years. By 2030, it is estimated the country will import 90% of its oil requirement. During the 11th plan period, though a compound annual growth of 7.6% in installed capacity was witnessed by the Indian power sector, power supply has always fell short of the peak demand. For FY 2011–12, the peak demand shortage of power supply was to the tune of over 11% with the country's per capita electricity consumption being 814 kWh, which is about 24% of the world's average (IREDA, 2012).

Prevalence of continuous high international oil prices meant that Import bill continues to be high. Oil imports registered 19.3 per cent growth in 2010-11 which amounts to 28.1 per cent of total imports. Among other factors, such a growth was majorly led by petroleum and related products (MOF, Balance of Payments, 2012). Petroleum, oil, and lubricant (POL) imports accounted for 35.1% of India's imports in 2011-12 (Apr. - Sept.) with a growth rate of 47.6 % compared with the same period previous year (MOF, International Trade, 2012). According to Oil Minister, higher international oil prices will have the following ramifications: domestic inflation, higher input costs, rise in the budget deficit which in turn hikes interest rates and thereby slowing down the economic growth. After registering a growth of 40 per cent, India’s oil import bill stood at $140 billion in 2011-12 shaving off much of the country’s GDP growth rate (BusinessLine, 2012).

In 2010, by importing around 2.2 million bbl/d, *i.e.*, about 70 percent of consumption, India became the world’s fifth largest net importer of oil majority of which is sourced from the Middle East, primarily from Saudi Arabia and Iran (EIA, 2011). These regions are geopolitically sensitive and thus any socio-political turmoil would endanger the supplies thereby undermining India's energy security.

According to the Approach Paper for the 12th Five year Plan (2012-2017), for the GDP to grow at 9 %, 6.5 – 7% per year growth rate of commercial energy supplies is forecasted which signals the need for 100 GW power capacity addition during the period. Increasingly, the world is facing the problems associated with climate change and developing countries like India are in the limelight to cut the emissions.

In this backdrop, India has put a major emphasis on development and diffusion of Renewable Energy Technologies (RETs) to mitigate these problems. RETs are increasingly visualized as the saviour and are called upon play a major role in achieving energy security and access in the shortest time frame and to prepare the Nation for the eminent energy transition (MNRE, Annual Report 2011-2012, 2012).

RETs can help India to enhance its energy security, improve local environment, reduce its carbon footprint, usher in balanced regional development, and make it leader in high-technology industries (Gevorg, Bhatia, Banerjee, Raghunathan, & Soni, 2010). The total installed capacity by March, 2011 was more than 206,526 MW and the estimated potential of Renewable Energies was nearly 89,760 MW (CSO, 2012). Ideally, RETs should have contributed more than 40% of the energy needs, but in reality it was only 11%.

1.2 Research Questions

To comprehend the evolution of IRETS, development and diffusion of RETs in the system, to analyze the performance and predict the future path of the RETs in India, the following questions have been identified:

- To understand and empirically demonstrate the utility of systems approach in unravelling technological development by analyzing India's Renewable Energy Technology System (IRETS). Can this approach help to analyze how the generation, diffusion and utilization of a new technology could happen in a country and how well the identification, absorption, and exploitation of global technological spillovers could occur in the system?

- How to assess the performance of IRETS and how to forecast the future diffusion of Renewable Energy Technologies (RETs) in the system.
- What inferences can be made for policy making aimed at technological development and what policy implications can be drawn to enrich the IRETS?

Chapters 4 and 5 aim to answer RETs development and diffusion, networking in the system, performance analysis of the system and other relevant details. Chapter 6 concludes the analysis of IRETS using Carlsson's four features of the system. Policy lessons and recommendations are explained in chapter 7.

1.3 Research Objectives

To clarify how the networking in the IRETS helped to contribute to development and diffusion of RETs in India being the chief aim of this study, certain micro objectives have been set up and answered such as:

- To identify and explain the role of various actors in the system.
- To clearly establish how these activities promoted by the network could herald in the development of the fruits of RETs.

- To reiterate the relevance of this approach even today and to show that such a systems approach is still the order of the day in IRETS.

1.4 Significance of the Research

The research helps to understand technological development and thereby helps in policy-making. The research focuses on analysing the Renewable Energy Technology System in India. Technology forecasting of RETs in IRETS, aids policy making as well by helping on the time front. It also serves as a tool for the industry and especially entrepreneurs, to know the right time to enter the market based on the position of technologies on the S-Curve.

1.5 Scope and Limitations of the Research

A dynamic analysis could be further carried out which this research couldn't attempt at due to financial, information and time constraints. Each RET is a system in itself. For example, solar technology itself can be analyzed as a system or even solar PV technology can be analyzed as a system. Except for the technology forecasting, this paper considers entire India as one system. For more accurate and specific needs, each RET or even each state can be considered as a unit of study. This paper paves way for such further studies and would help as a guiding tool.

1.6 Structure of the Thesis

This thesis is structured as follows: the second chapter is the Literature Review. In this chapter not only all the concepts utilized in this research are detailed but also previous studies relevant for this field have also been summarized.

In the following chapter, the methodological aspects of this work are explained. The explanation starts with briefing the technological systems approach and its constituents - the technology system and its dynamic picture, system evolution phases and framework for analysis. Technology forecasting is then presented which delves with the logistic and the Gompertz functions and also on methodology for choosing between them. After providing a basic understanding of the methodologies used, this chapter proceeds with explaining the research process, data collection and limitations.

The chapters 4, 5, 6 and 7 are the chapters intended to answer the research questions posed in the introduction chapter.

The fourth chapter gives the entire picture on IRETS. RETs development and diffusion with respect to four major RET types has been clearly analyzed and presented according to each evolution phase - embryo, infant and adolescent. Having understood the evolution of the system, later section provides much more in-depth understanding of open innovation in the system. This is followed by explanation on human resource development initiatives in the system. One of the major hurdles in

RETs diffusion is the costs associated with them. A separate section has been added in this chapter to show how IRETS is handling the costs.

The fifth chapter tries to predict and analyze the future growth patterns of RETs in India. Firstly, RETs growth pattern is analyzed for India as a whole. Secondly, three specific RETs - wind, biomass, small hydro are taken for modeling and top ten states for each of these three RETs based on their potential are chosen for analysis. The logistic and Gompertz functions have been used to model the growth patterns and then based on the set criteria, one of them that fit the best is chosen for the analysis.

The sixth chapter concludes this paper's understanding on the IRETS while the last chapter of this thesis is dedicated to put forward the policy implications and recommendations arising of this research.

Chapter 2

LITERATURE REVIEW

LITERATURE REVIEW

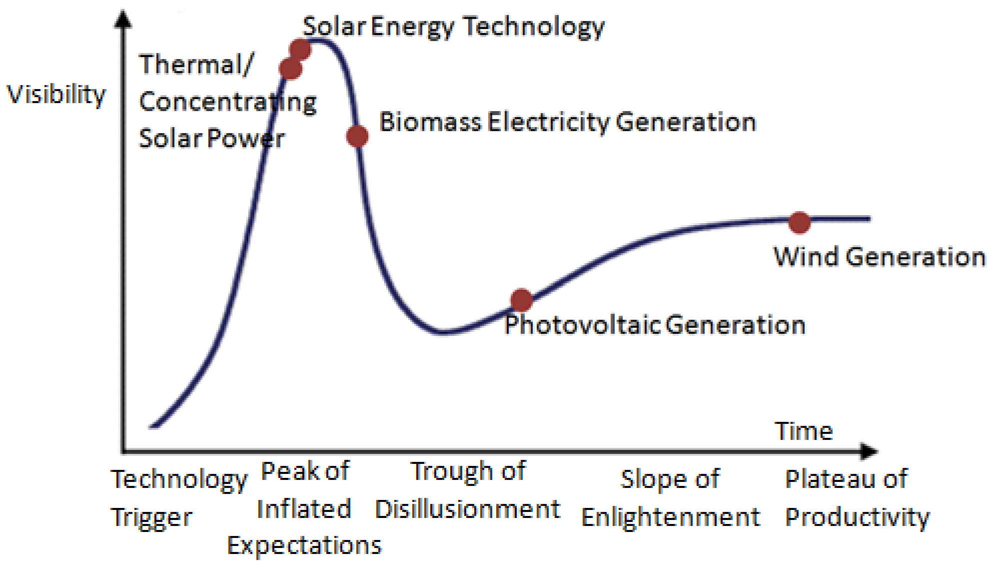
This chapter describes the main concepts utilized in this research. Firstly, the chapter deals with the concept of renewable energy technologies (RETs). Secondly, the hype cycle for emerging RETs is briefly explained followed by the world scenario. Thirdly, future role of RETs is succinctly summarized. Finally, Indian scenario is briefly depicted and previous studies conducted were presented.

2.1 Renewable Energy Technologies

Any energy occurring from natural means and is perennial in nature i.e., replenished continuously, can be termed as renewable energy. Renewable energies, despite occurring in different forms, are primarily driven either by the sun or heat present deep inside the earth. The various forms of renewable energies are: wind, hydropower, biofuel, biomass, solar, hydrogen, ocean and tides (IEA, 2002).

2.2 The Hype Cycle

Whenever a new technology is introduced by a technology trigger, there is a hype surrounding the technology attracting initial customers, followed by a phase of disappointment that the technology is not that promising as expected. Next comes the reality phase, where people start understanding the real benefits of the technology leading to wider diffusion of the technology finally leading to its saturation level.



Source: Author's Elaboration based on (Gartner, 2012)

FIGURE 2.1. THE HYPE CYCLE OF EMERGING RETS.

According to the Gartner Group, which has devised this hype cycle, solar thermal technology is at the peak of inflated expectations, biomass power technology is falling into the trough of disillusionment, solar photo voltaic technology is passing through the slope of enlightenment and wind power technology has reached its maturity and is offering maximum productivity.

2.3 The World Scenario - RETs

Globally, the share of renewable energy accounted for nearly half of the total capacity addition of around 208 gigawatts (GW) during the year 2011 with the splits of individual technologies given as follows: wind (40%), solar photovoltaics (PV) (30%) and hydropower (25%). In 2011, the total global installed renewable power capacity saw a growth of 8% over 2010 standing at 1,360 GW; accounting for more than one-fourth of total power-generating capacity (5,360 GW in 2011) accounting for 20.3% of electricity in the world. Renewable energy of non-hydropower type, registered 390 GW, a 24% growth over 2010 (REN21, Renewables 2012 Global Status Report, 2012).

Solar photo voltaic technologies witnessed the fastest growth during 2006-2011 with 58% average increase annually. Next comes concentrating solar thermal power (37%), wind power (26%) and hydropower and geothermal power averaging 2–3% per year (REN21, Renewables 2012 Global Status Report, 2012).

In the European Union, of the total additional installed capacity in 2011, the share of renewable energy accounted for 71%, bringing the renewable energy share in installed capacity to 31.1%. Germany continues to be in the forefront in the world, as a top user of RETs for power, heating, and transport. In 2011, RETs constituted as follows: final energy consumption (12.2%), electricity consumption (20%), heating demand (10.4%), and transport fuel (5.6%) (excluding air traffic). In the United

States, RETs constitute 11.8% of the primary energy produced in 2011 (REN21, Renewables 2012 Global Status Report, 2012).

For non-hydro renewable electric capacity, the top seven countries—China, the United States, Germany, Spain, Italy, India, and Japan constitute nearly 70% of the total global capacity. At regional level, the EU had around 44% of global non-hydro renewable energy capacity in 2011, and the BRICS constituting 26%; whose share is on the rapid increase in the recent past, with China, India, and Brazil virtually dominating the scenario (REN21, Renewables 2012 Global Status Report, 2012).

In the year 2011, RETs industries saw growth on a continuous basis in equipment's manufacture, market and installation with solar photo-voltaic and onshore wind power experiencing phenomenal downfall in price because of falling costs due to economies of scale and technological improvements and policy support (REN21, Renewables 2012 Global Status Report, 2012).

2.4 Future - Role of RETs

After Fukushima Daiichi nuclear disaster in 2011, Germany has committed itself to rapidly exit from nuclear energy use by 2022 and completely reform the nation's energy sector. The "Energiewende" (Energy Transition), inter alia, focuses on energy efficiency and renewable energy sources, with beacon-like character for many other countries around the world. One of the main drivers propelling renewable energy policies is their potential to create jobs. An estimated 5 millions are employed directly or indirectly in RETs industries in the world. RETs are off late viewed as critical for providing energy access, particularly in rural hinterlands of the third world. Renewable energy is seen as a lever to provide a better quality life to the millions of people across the globe (REN21, Renewables 2012 Global Status Report, 2012).

2.5 India - RETs Scenario

In India, the Ministry of New and Renewable Energy (MNRE) is the highest point of authority in the Government of India for dealing subjects pertaining to new and renewable energies. MNRE classified RETs as follows:

- Grid Connected Power
- Off-Grid Power
- Decentralized Systems
- New Technologies

Grid-based RETs are based on wind, biomass, small hydro and solar technologies that are largely driven by private sector participation, supported by attractive tariff policies setup by State Electricity Regulatory Commissions (SERC). Bio power is generated from agricultural and agro-industrial residues, plantations and urban & industrial wastes which are in turn classified as biomass power / bagasse cogeneration, non-bagasse cogeneration, biomass gasifier, Urban & Industrial wastes. Up to 25MW, hydroelectric power is classified as small hydro power. Under solar power, both solar thermal and solar photovoltaic are included (MNRE, Grid Connected Power, 2012).

Distributed or decentralized RET projects are also essentially wind, biomass and hydro based but also include hybrid systems which are promoted to cater to the energy needs of remote communities that will probably remain un-electrified in the foreseeable future. They include biomass based heat and power projects and industrial waste-to-energy projects, biomass gasifiers for rural and industrial energy requirements, watermills and/or micro hydel projects to meet the remote villages energy demands, small scale wind energy & hybrid systems and solar photo-voltaic roof-top systems for reduction of diesel based power generation in urban areas (MNRE, Off-Grid Power, 2012).

RETs are well suited for distributed applications having significant capability in providing a dependable and secured energy access obviating the need for grid extension or are a good supplement to grid based energy. Because of the vastness of India and remoteness of majority of un-electrified population, RETs have potential to offer an economically viable energy access to such populace. Some of the RETs promoted in villages and rural areas under this category are:

- Family-size biogas plants.

- Solar street lighting systems.
- Solar lanterns and solar home lighting systems.
- Solar water heating systems
- Solar cookers.
- Standalone solar/ biomass based power generators.
- Aditya Solar Shops
- Wind pumps.
- Micro-Hydel plants.

Few of the above mentioned systems are helpful in urban areas helping to reduce the usage of carbon emitting fuels (MNRE, Decentralized Systems, 2012).

According to MNRE, new technologies consist of the following:

- Hydrogen Energy
- Chemical Sources of Energy (Fuel Cells)
- Alternative Fuels for Surface Transportation
- Geo Thermal Energy
- Tidal Energy

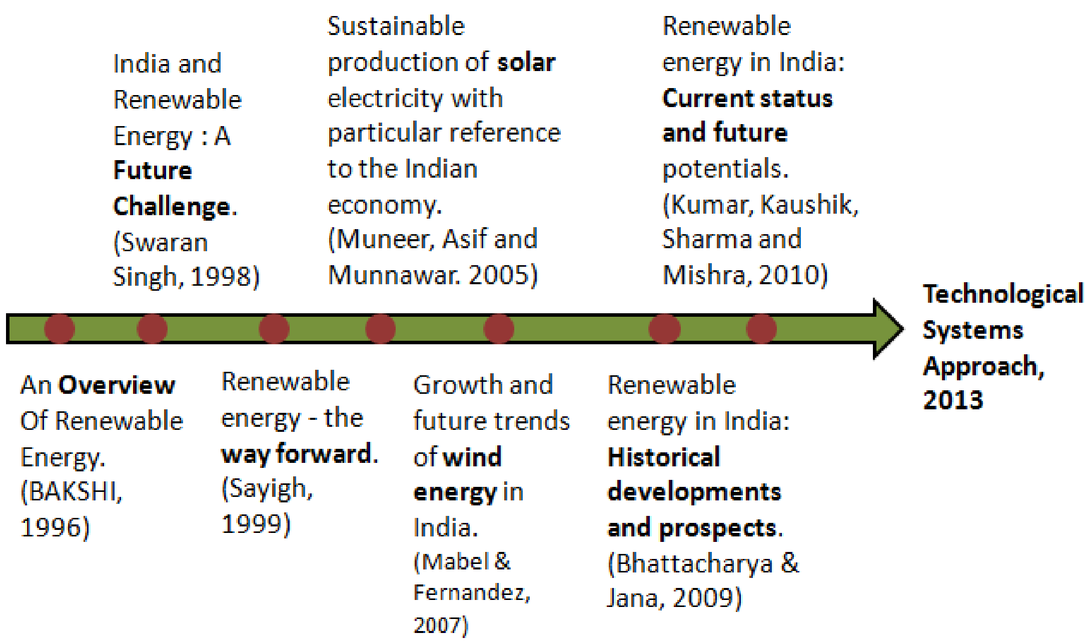
To further the development of these new technologies, research, development and demonstration projects are being promoted at various research, scientific and educational institutes, national laboratories, universities, industry, etc., which constitute the harbingers of domestic research and industrial base development, promoting expertise, providing human resources and developing prototypes and devices in the nation (MNRE, New Technologies, 2012).

2.5.1 Studies on Indian RETs till Date

The 8th Five Year Plan visualized a capacity addition of 2000 MW from RETs. Wind farms were found to be advantageous for corporate bodies to set up captive power generation. According to Rakesh Bakshi, technology advancement coupled with the increasing environmental consciousness and awareness to reduce carbon footprint will lead to faster commercialization of various RETs (Rakesh, 1997).

Among the un- electrified villages, on one hand, about 18,000 villages are remote and far with small load possibilities while on the other hand, about 50,000 villages, have population up to 500. In far flung places, RETs can meet the energy needs. Solar PV is one of the lifeline programmes for such areas catering to the needs such as village, lighting - home and street; water pumping - drinking and irrigation; rural telecommunication. NGOs play a critical role in raising awareness among rural masses on the utility of RETs as well as training them in operation & maintenance. Four problems associated with RET diffusion are high costs, positive perception, will for saving environment and awareness of the people. According to Swaran Singh, such problems could be addressed by coordinated action of government, industry, research centres, finance houses, NGOs and the international bodies (Swaran Singh, 1998).

Garg and Adhikari opined that, a perspective plan with broad goals would speed up the development and commercialisation of RETs. In promoting RETs, an overarching policy framework - institutional, financial and technological is necessary. A strategy aimed at realizing the technological development depends on the extent to which government bodies, NGOs, industry, R&D centres, finance houses and entrepreneurs actively participate (Garg & Adhikari, 1998).



Source: Author's Elaboration

FIGURE 2.2. LITERATURE SURVEY - PAST WORKS.

Public education and introducing good legislation coupled with supporting incentives can fasten the use of RETs (Sayigh, 1999). Demonstration programmes are pertinent for testing new energy technology manufacturing (for example, solar photovoltaics) and energy conversion facilities and evaluate their technical feasibility and economic viability. Prohibitive capital requirements, high required rates of return, high risk, and problems associated in appropriating the long-term benefits may not motivate the private sector to setup demonstration plants. As such, governmental support is crucial apparently when the technology has promising public benefits (Reddy & Painuly, 2004).

Solar energy in conjunction with hydrogen has immense potential as future fuel. Tariq, Muhammad and Saima explored such feasibility for India by 2025. The solar electricity in excess of demand is stored as hydrogen and used later. Using a modular approach, the study asserted that the solar-hydrogen duo is capable of meeting the energy needs of Chennai, Delhi, Jodhpur, Kolkata, Mumbai and Trivandrum by the year 2025. Cost comparison has been proposed for the six cities indicating that power generated by solar photo-voltaic will be cheaper than the fossil fuel derived one (Muneer, Asif, & Munawwar, 2005).

A study conducted by Huang Liming, analysing the current situation of RETs cooperation between China and India indicates that such cooperation between them for RETs is still at a nascent level; for cooperation, common benefits and good atmosphere exist; cooperation strategies have to be explored and designed in the domain of RETs between these two countries. An academics committee, consisting of equal number of members from both the countries would help in drawing a roadmap for cooperation (Liming, 2007).

In India, wind power technologies have advanced well compared to other RETs leading to its wider diffusion till date. Carolin and Fernandez reviewed the wind energy technological development in India and five states therein, namely, Tamilnadu, Maharashtra, Karnataka, Gujarat and Andhra Pradesh. They also forecasted the diffusion of wind energy technologies using the pearl curve. The study predicts that power generation in India through wind energy technology may reach 99% of the estimated wind power potential by 2030, Maharashtra and Karnataka by 2020, Tamil Nadu by 2022 and Andhra Pradesh by 2025. Gujarat would realize 86% of its potential by 2030 (Carolin & Fernandez, 2008).

Though renewable energy programmes were initiated early in India, it has been a laggard in certain RETs. The significance of RETs in meeting energy needs was under-emphasized due to improper resource assessments. Many biogas plants are dysfunctional now in the system. Also, of the 35 million Improved Cookstoves (ICSs) installed so far, an estimate tells that, nearly 6 million are functioning now. Factors that made wind energy technologies in India as the most successful among RETs: the involvement of the private sector, supporting environment provided by the government and lowered costs of wind technologies (Bhattacharya & Jana, 2009).

Chapter 3
METHODOLOGY

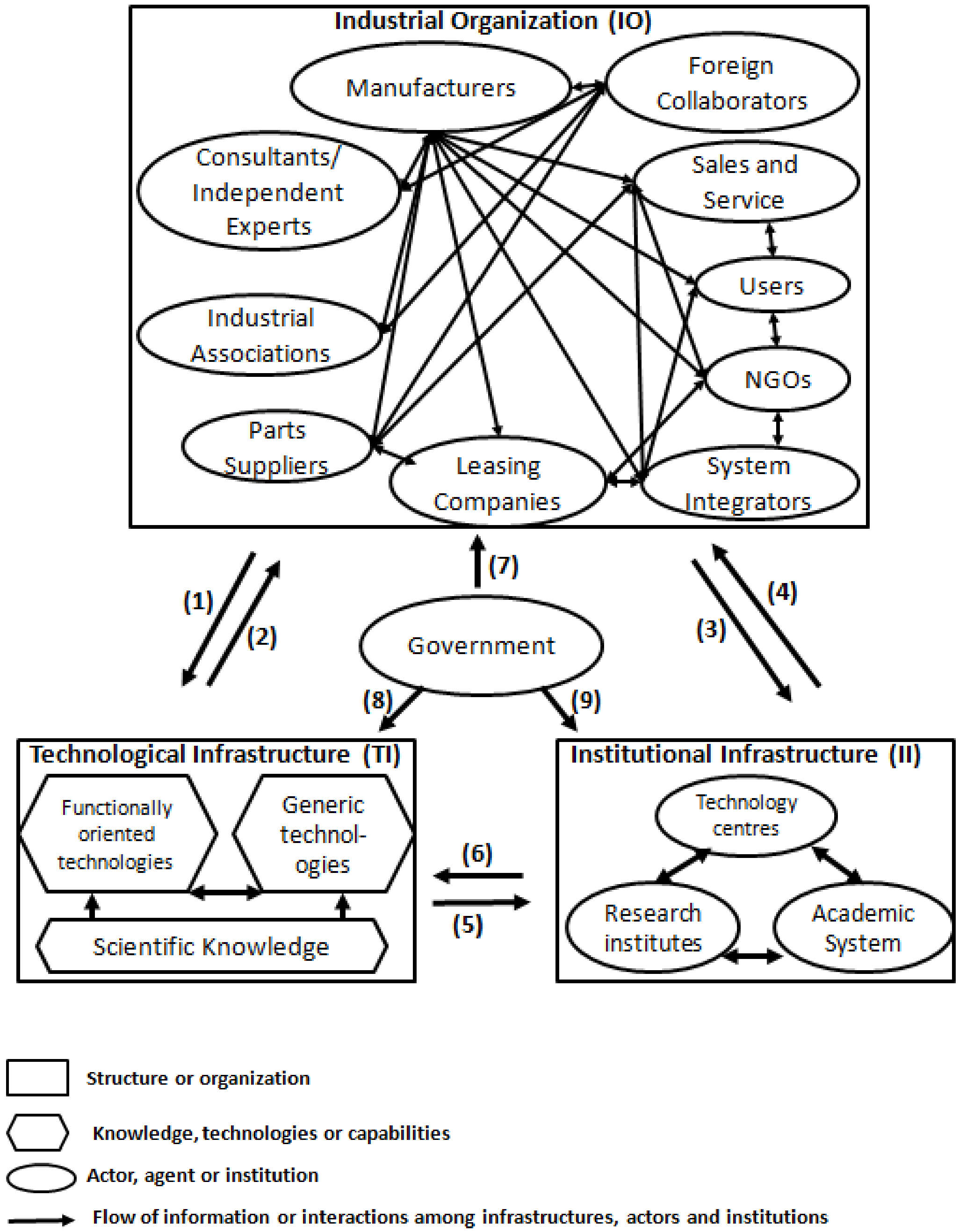
METHODOLOGY

3.1 The Technological Systems Approach

"A technological system is defined as a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology" (Carlsson & Stankiewicz, 1991, p. 93). The major thrust in this approach is on technology or a class of technologies. In this research, the framework is applied on a technology or a class of technologies with a common output which is energy, *i.e.*, Renewable Energy Technologies (RETs).

3.1.1 The Technological System: A Dynamic Picture

The system presented in Figure 3.1 has three major building blocks of the system: Industrial Organization (IO), Technological Infrastructure (TI), and Institutional Infrastructure (II).



Source: Author's Elaboration based on (Sung & Carlsson, 2003)

FIGURE 3.1. THE TECHNOLOGICAL SYSTEM.

3.1.1.1 Industrial Organization

Industrial organization (IO) can be defined as a network wherein actors interact with each other with an aim of producing or purchasing a product (Sung & Carlsson, 2003). When we consider RETs, industry has a greater responsibility of technology development especially through R&D, collaborations, joint ventures for manufacturing, technology transfer etc. The industry consists of the following types of actors: manufacturers, foreign collaborators, consultants/ independent experts, industrial associations, parts suppliers, leasing companies, system integrators, NGOs, sales and service, users.

Manufacturers are those who produce the RET systems like wind turbines, solar cells, turbines for hydro systems etc. Foreign collaborators are those companies who transfer their matured technologies to IRETS through numerous ways like foreign direct investment (FDI), joint ventures, technology licensing etc. Parts suppliers are those who supply various sub components especially for manufacturers like pressure boilers, aluminium frames, erection towers etc. System integrators help the clients throughout the project lifecycle starting from conceptual stage to certification stage.

Consultants/ independent experts are crucial nodes in the IRETS performing facilitating tasks. Some of their functions include: strategic consulting & market analysis like assisting companies in clean technology adaptation with a particular emphasis on renewable energy sources, to assist companies raise equity or debt funding for their renewable energy projects, to help in formulating corporate sustainability blueprint, to help identify equipment & component suppliers as well as technical consultants, helping global companies to formulate a strategy to have a successful foray into the IRETS and provides training in RETs to students, corporate professionals and other interested clients (EAI, 2012).

The technological innovation is achieved by all the above-mentioned actors within them as well as by interacting among themselves. Industrial associations help form the networks that are both formal and informal. Formally, they help to put forward their concerns to the government and, on the other hand, they aid the actors in the industrial organization to share their technical competence by informal means, mostly personal, and professional conferences, meetings, publications, etc that help the growth of networks.

3.1.1.2 Technological Infrastructure

For any technology, the IO and technological infrastructure (TI) support each other (Relations 1 and 2). TI is a whole consisting of science, engineering, and technical knowledge. Functionally-oriented technologies are a group of technologies (e.g., measurement) meant for the performance of certain functions (Sung & Carlsson, 2003).

As for RETs, the technologies that are directly involved are mechanical engineering, control engineering, and electrical engineering. RETs also depend on a multitude of generic technologies, e.g. semiconductor, laser, turbines, and power generation technologies. The generic technologies are supported by functionally-oriented technologies to integrate them into larger factory automation systems and connect to grids. They comprise: sun tracking sensors, calibration methods, communication, evacuation equipment, storage batteries, low voltage power generation engineering etc.

3.1.1.3 Institutional Infrastructure

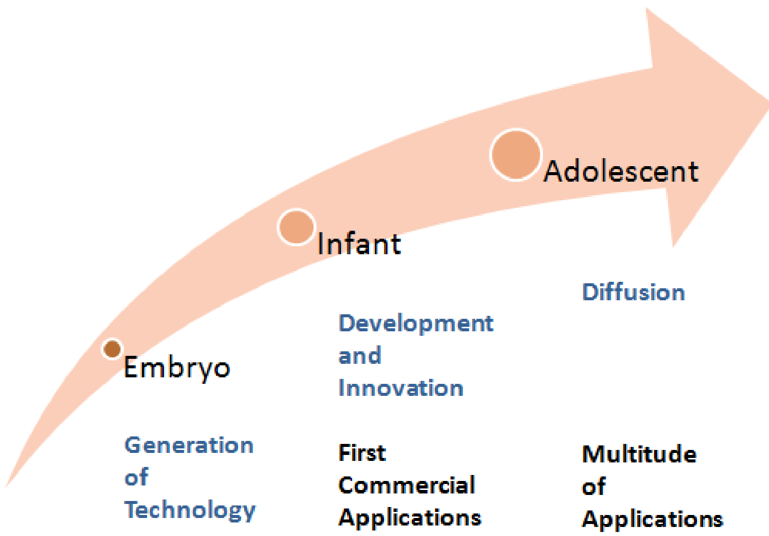
Institutional infrastructure consists of a set of institutional arrangements comprising of government, financial institutions, research organizations, academic system which includes universities, institutes, training centers and technology centers. Some of these institutional infrastructures are either private or public or even public-private partnership entities.

The above-mentioned institutional infrastructure may be categorized into general and technology or product-specific. The academic system, particularly technological universities, performs a dual role - manpower training and research. The interaction between academic system and industry (Relations 3 and 4) helps to channelize university expertise into industry. Institutional infrastructure and technological infrastructure influence each other (Relations 5 and 6).

Government is not depicted as a part of institutional infrastructure directly for its unique and greater role in the system. By virtue of being a policy-maker, it is the main actor which can influence (Relations 7, 8 and 9) all the three building blocks (TI, II and IO) and improves the networking amongst them, leading to enhanced dynamic efficiency in the entire technological system. In periods of rapid technical change, the policy maker, *i.e.*, government has to play an important role in moulding the technological systems. As such, it is viewed as a separate bloc of the technological system (Sung & Carlsson, 2003).

3.1.2 Evolution Phases

Any technological system doesn't develop and operate in a vacuum. It deals with the generation, innovation, and diffusion of technology or technologies and therefore is not static and evolves with time by undergoing modifications in the substance of its components and relationships among actors. As such, it can be classified into three phases: embryo, infant, and adolescent. According to Sung and Carlsson, the embryo stage is the stage which doesn't witness any commercial application of new technology. This means that the phase is only pre-occupied with generation of the technology or technologies which ends with the onset of the infant stage where the technology witnesses its first commercial applications. This means that the infant stage deals with the development and innovation. Finally, the adolescent stage sets in with the newly developed technology being used in numerous applications. This means that the diffusion of technology takes place in the third and final phase (Sung & Carlsson, 2003).



Source: Author's Elaboration on (Sung & Carlsson, 2003)

FIGURE 3.2. EVOLUTION OF TECHNOLOGICAL SYSTEM: PHASES.

At a later stage, the evolving system becomes saturated and complete with respect to TI, II and IO and starts generating sufficient and increased returns to further its development in a self-reinforcing and self-sustaining way (Sung & Carlsson, 2003). A good example is a well developed venture capital replacing the need for government subsidies and incentives.

3.1.3 General Framework for the Analysis

Any system's properties are determined by the interaction among actors within the system. Such interactions can be intentional or may be due to unintended spillovers. A major purpose of any technological system is to capture, diffuse, and magnify spillovers. In this context, the most important characteristics of the system are the knowledge and spillover mechanisms that determines the possible spillovers, the receiver competence which is the absorptive capacity of actors, the connectivity which deals with the intensity with which different constituents in the system are held together, and the various means that aim at creating variety within the system (Carlsson B. , 1997).

TABLE 3.1. FRAMEWORK FOR ANALYSING THE TECHNOLOGICAL SYSTEM

Nature of Knowledge and Spillover Mechanisms System definition The nature of knowledge: tacit vs. codified or articulated component vs. architectural embodied vs. disembodied Spillover mechanisms: who and how?	**Variety Creation Mechanisms** "Bounded vision" - how characteristic? Path dependency; lock-in effects Entry and exit International impulses Role of public policy
Receiver Competence Prime movers Who created/raised awareness Who took the early initiatives? Entrepreneurship How was critical mass created? Market failures/obstacles? How were the obstacles overcome? Role of institutions and public policy Source and role of venture capital Role of finance and financial markets Role of academia Role of educational policy: proactive vs. reactive International links	**Connectivity** Importance of proximity/clustering and in what sense? User-supplier relations Problem-solving networks Network characteristics Who built the networks? Bridging institutions Role of business groups Role of public policy Informal/personal networks

Source: (Carlsson B. , 1997)

3.2 Diffusion and Technological Forecasting

According to Everett M. Rogers, "diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas". The four main elements are the innovation itself, channels of diffusion, time, and the social system. Diffusion of innovation according to Rogers, includes five periods. The first belongs to innovators which is almost 2.5% of total diffusion. Secondly, there is a phase of early adopters and later followed by early majority, late majority and finally by laggards (Rogers, 1995).

Technological forecasting is used to predict diffusion of innovations. Typically, any diffusion process passes through an early adoption stage which is generally slow in nature, that is followed by a rapid adoption phase and thereafter reaching a phase of tapering rate of adoption.

3.2.1 Dominance of Logistic and Gompertz functions

The S shaped or sigmoid curves have been used to explain the diffusion process of new technologies. Though numerous such functions that describe the S-shaped curves exist, the two often followed diffusion models of the S-curve which represent various growth patterns or trends are the logistic and the Gompertz functions (Das, 2012).

The Logistic function is given by,

$$y = f(t) = \frac{K}{1 + e^{-a-bt}}$$

The Gompertz function is given by,

$$y = f(t) = Ke^{-ae^{-bt}}$$

where,

K is the saturation level

a and b are the location and shape factors of the curve, respectively.

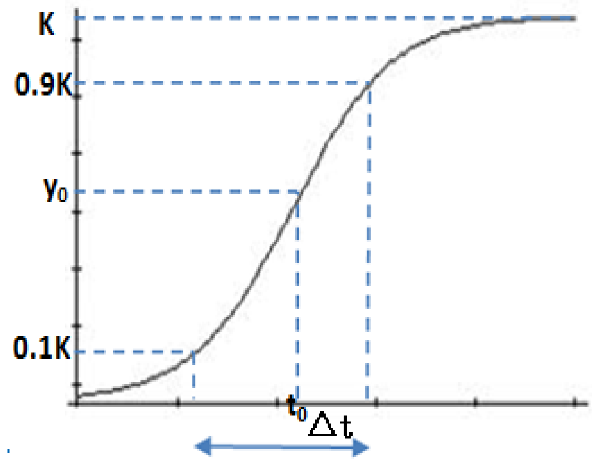


FIGURE 3.3. THE S-CURVE.

The logistic curve, when attains half of the carrying capacity or saturation level *i.e.*, at $y_0 = \frac{K}{2}$, called the point of inflection of the curve, attains its maximum growth rate. This occurs at $t = \frac{-a}{b}$.

For Gompertz, $y_0 = \frac{K}{e}$ and $t = \frac{\ln a}{b}$.

About the point of inflection, both the curves differ from each other. The logistic curve is symmetric while the Gompertz curve is not.

The parameters a and b are estimated by ordinary least square method using K and t.

3.2.2 Choosing between Logistic and Gompertz functions

Using the visibility, the coefficient of determination R^2 value, the mean square error (MSE), the mean absolute deviation (MAD) and auxiliary regression, the better forecast between the two functions is determined and is then used to analyze the diffusion of RETs in India. By super imposing the growth curve for actual data with the two forecast curves, we can clearly understand the trend which the growth pattern follows.

Philip Hans Franses in (Franses, 1994) proposed an alternative method for selecting between the two functions, based on auxiliary regression, and a significance test for one parameter. This selection method is explained in a simple manner below.

The Gompertz function for a time series x_t is given by:

$$x_t = a_1 e^{-b_1 e^{-c_1 t}} \quad \text{...} (1)$$

$$ln\, x_t = ln\, a_1 - b_1 e^{-c_1 t} \quad \text{...} (1a)$$

$$ln\, b_1 - c_1 t = ln\left[-ln\left(\frac{x_t}{a_1}\right)\right] \text{...} (2)$$

where log denotes the natural logarithm.

$$\Delta\, ln\, x_t = ln\, x_t - ln\, x_{t-1} \quad \text{...} (2a)$$

Substituting (2a) in (1a) gives

$$\Delta\, ln\, x_t = e^{-c_1 t}(b_1 e^{c_1} - b_1)$$

Applying *ln* on both sides gives,

$$ln(\Delta\, ln\, x_t) = -c_1 t + ln(b_1 e^{c_1} - b_1) + \varepsilon_t$$

Re-arranging the above equation gives the below form,

$$ln(\Delta\, ln\, x_t) = d_1 - c_1 t \text{ ....(5)}$$

where $d_1 = ln(b_1 e^{c_1} - b_1) + \varepsilon_t$ is a nonlinear function of b_1 and c_1 and

ε_t is error term.

The logistic function for *X*, is given as below:

$$x_t \;=\; a_2(1 + b_2 e^{-c_2\, t})^{-1} \text{ .... (3)}$$

$$1 + b_2 e^{-c_2\, t} = \frac{a_2}{x_t} \text{ ....(3a)}$$

$$ln\, b_2 - c_2 t = ln\left(\frac{a_2 - x_t}{x_t}\right) \text{ .... (4)}$$

Applying $\Delta\, ln\, x_t = ln\, x_t - ln\, x_{t-1}$ in (3) gives,

$$\Delta\, ln\, x_t = ln(1 + b_2 e^{-c_2 t + c_2}) - ln(1 + b_2 e^{-c_2 t}) \text{ .... (5a)}$$

The above equation can be further rewritten as below,

$$\Delta\, ln\, x_t = b_2 e^{-c_2 t}(e^{c_2} - 1) \text{ ....(6)}$$

Substituting (3a) in (5a) gives,

$$\Delta\, ln\, x_t = ln(1 + b_2 e^{-c_2 t + c_2}) - ln\left(\frac{a_2}{x_t}\right)$$

Rearranging the above equation gives,

$$\Delta\, ln\, x_t = b_2 e^{-c_2 t} e^{c_2} - a_2 + x_t$$

Applying ln on both sides,

$$ln(\Delta\, ln\, x_t) = ln\, b_2 - c_2 t + c_2 - ln\, a_2 + ln\, x_t$$

$$ln(\Delta\, ln\, x_t) = d_2 - c_2 t + (ln\, x_t - ln\, a_2) \text{ ....(7)}$$

where d_2 is a nonlinear function of b_2 and c_2.

According to Franses, a simple parametric selection method

between (1) and (3) is given by the auxiliary regression

$$ln(\Delta\, ln\, x_t) = \delta + \gamma t + \tau t^2, \text{ ....(8)}$$

and a test for the significance of the τ parameter based on its t ratio.

The method to choose between the Gompertz and the logistic curve based on (8) uses all the in-sample observations ensuring that, all observations are taken into consideration by out-of-sample forecasting performance evaluation which is useful numerous times when small samples are relied upon (Franses, 1994).

According to Harvey in (Harvey, 1984), the trend of a basic model by fitting logistic function to time series is given by the continuous function,

$$f(t) = \frac{\alpha}{(1 + \beta e^{\gamma t})}$$

where α, β and γ are parameters such that $\alpha, \beta > 0$ and $\gamma < 0$.

$$f(t) = \alpha(1 + \beta e^{\gamma t})^{-1} \text{ ......} \tag{5H}$$

$$\frac{df(t)}{dt} = \alpha(-1)(1 + \beta e^{\gamma t})^{-2}\beta\gamma e^{\gamma t}$$

$$ln\frac{df(t)}{dt} = ln\frac{-\beta\gamma}{\alpha} + 2\,ln\big(f(t)\big) + \gamma t$$

$$ln\frac{df(t)}{dt} = 2\,ln\big(f(t)\big) + \delta + \gamma t \text{ ......} \tag{6H}$$

$$ln\,y_t = 2\,ln\,y_{t-1} + \delta + \gamma t + \varepsilon_t \text{ ......} \tag{7H}$$

From (1) and (5), it is evident that the Gompertz function has no non-linear term.

Also, from (3) and (7), it is evident that the Logistic function has a non-linear term($ln\,x_t - ln\,a_2$).

According to Franses, if the t value of the z parameter is significant at a 5% or 10% level, the Logistic curve is appropriate. If not, the Gompertz curve is a better choice.

3.3 The Research Process

Before looking at the research process, it would be a better idea to give a glimpse of how the author chose the research topic. The author had an interest and passion about renewable energy technologies and their cleaner agenda since undergraduation days. Later, added to this portfolio are: the sustainable development concept which in the opinion of the author would complement renewable energy technologies; the watershed development approach which again complements renewable energy technologies in heralding a sustainable future by converting wastelands to productive lands.

As part of the research, the author tried to fuse the aforementioned approaches, namely, sustainable development, renewable energy technologies and the watershed development approach with commercial touch of exploring the feasibility of an entrepreneur to undertake the said theme as a business model.

For the sake of convenience in terms of language, data and relevance (dry land region), the district of Kadapa (Andhra Pradesh), India was chosen as the unit of research. The author conducted a field trip to Andhra Pradesh, India to collect data on the programmes, implementation, outcome of renewable energy technologies and the watershed development approach in the said region.

The field visit had a mixed outcome. On one hand, data on watershed development programmes was not readily available while on the other hand, copious data and knowledge on renewable energy technologies in India was gathered. After returning to the APU campus, a series of meetings with the supervisor who, after understanding carefully the interests of the author and the available data, had thoughtfully suggested to analyze the Indian Renewable Energy Technological System (IRETS) using technological systems approach. Later, technological forecasting was also logically added to the research.

3.4 Data Collection

In this section, the data collection methods and instruments that are utilized for collecting secondary data are briefed.

In India, the Right to Information Act, 2005 mandates time bound response to citizen requests for information which is available in any public office. Any person, who wants to get any information under this Act, should send a request accompanied by a fee with some exceptions (MLJ, 2012).

In total, 86 questions were prepared amounting to 3482 words and were posed to seven government departments under RTI act. The departments were the Directorate of Economics & Statistics, the Rain Shadow Areas Development Department, the Energy Department, the Department of Municipal Administration and Urban Development, the Department of Animal Husbandry and Fisheries, the Department of Industries and Commerce and the Department of Agriculture and Cooperation. Of the seven departments, only two responded favourably by providing requested data - the Energy Department and the Department of Animal Husbandry and Fisheries.

Thereafter, as mentioned in the previous section, other elements of the research have to be sacrificed for lack of sufficient data and focus was maintained on renewable energy technologies. In this regard, the existing data was supplemented with data from the websites of the Ministry of New and Renewable Energy (MNRE), the Ministry of Statistics and Programme Implementation (MOSPI) and the Central Electricity Regulatory Commission (CERC).

Time Series Data has been chosen for forecasting. For India as a whole, Installed Renewable Energy data in Megawatts (MW) from 1990 to 2011 is being used to forecast the future diffusion of RETs. For States within India, 10 top states based on their estimated potential of wind, biomass and small hydro power have been chosen separately and their data of installed capacities of power in Megawatts (MW) from 2001 to 2011 has been chosen for forecasting their future diffusion.

3.4.1 Methodological Limitations

The data collection process albeit has witnessed certain problems. Lack of proper record keeping, evading responsibility, red-tapism, private sector reluctant to spend time with student researchers like me and time constraints were some of the limitations in the research.

Though the RTI Act mandates response in 30 days under normal circumstances, no useful data was provided within the deadline. Time was not sufficient to further pursue the issue with higher ups in the respective departments. Because of the poor response mentioned above, a private company which was an established one in renewable energy technologies was approached. They also were not of much help. Every time, an appointment was made to meet their personnel, the author was made to wait for hours only to get non-committed promises at the end. Probably, they were of the view that, no revenue would be generated for them by providing the author with needed details.

Later, an energy consultant was approached, with set of questions and doubts who responded well and gave wealth of information by providing various website links which later proved to be of immense benefit to the research.

Chapter 4

INDIAN RENEWABLE ENERGY TECHNOLOGICAL SYSTEM (IRETS)

INDIAN RENEWABLE ENERGY TECHNOLOGICAL SYSTEM (IRETS)

In this chapter, India's renewable energy technological system (IRETS) is explained and analyzed using the methodologies outlined in chapter 3. The structure of the chapter is lucidly explained in this paragraph. Section 4.1 gives an introduction for the RETs development. Section 4.2 explains the evolution of IRETS in three stages. Each stage explains the evolution of four RETs in detail: bio power technologies, solar technologies (photovoltaic and thermal), wind energy technologies and small hydro power technologies. Each of the four technologies was further explained under two headings, namely, development and diffusion. Such a presentation structure would help readers to clearly understand the technological development efforts. Later sections explain open innovation, HRD, costs and regulatory frameworks and finally performance of the system in that order.

4.1 Introduction

The evolution processes of most technological systems are global in nature. However, this study considers the Indian Renewable Energy Technological System (IRETS), which is a subsystem of the global technological system. The research focuses on how RETs are generated, diffused and utilized in India and how RET systems develop. The study helps to understand how the IRETS responded to global technological spillovers and could identify, absorb, and exploit them *i.e.*, how it benefits through open innovation.

4.2 Evolution of IRETS

The evolution of the IRETS is categorized into three phases as explained in Chapter 3: the embryo stage (up to 1980), the infant stage (1981–2009), and the adolescent stage (from 2010). The analysis of the development of IRETS is presented below along this time axis showing the cross-section of its history of formation and major activities.

4.2.1 The Embryo Stage: Up to 1980

4.2.1.1 Introduction

India attained independence in 1947. The Second Five-Year Plan (1956–1961) focused on industrialization, especially heavy industry development paving way towards industrializing India. With the thrust of oil shocks of the 1970s, energy self-sufficiency was recognized as a key priority. Technology has caught a new attention in the mind of policy makers as they realized the heavy dependency on fossil fuels and associated vulnerabilities in terms of price and security. Research and development as well as transfer of technology were resorted to attain the needed technology levels to improve the livelihood conditions of the users.

4.2.1.2 Bio Power Technology

4.2.1.2.1 Development

Bio power technology in this study includes biogas technology, biomass technology, biomass cookstoves, and bagasse co-generation technology. Small-scale biogas technology was given a serious attempt in the IRETS. The initial efforts of biogas R&D started in the third decade of the 20th century. Indian Agricultural Research Institute (IARI), Delhi was one place where research on biogas technology was carried out. The main emphasis of the research was on understanding the technological process and underlying conditions required for attaining efficient anaerobic fermentation process. The first Indian biogas unit which was innovative and different from the existing ones called Gramalakshmi, developed by a social worker, Mr Jashbhai Patel was setup at OU, Hyderabad, in 1950. With this installation, the biogas technology which was until then a mere research topic, could boast of an Indian design though still priced very high and was not practical for diffusion of the same (Gustavsson, 2000).

During 1950's to 1972, experiences were accumulated and more designs were developed and plants were installed by R.K. Mission, Calcutta, Khadi Pratisthan Sodepur, West Bengal and IARI. Experience suggested that user education was a critical element to sustain the functioning of biogas units. This RET saw setting up of a research institution, the Gobar Gas Research Station in Uttar Pradesh (Gustavsson, 2000).

A decisive phase came in 1972-1975. This period witnessed OPEC announcement of cutback in oil production in 1973 followed by Middle East War resulting in the rise of the international crude-oil prices by four times from 1973 to 1974 (Gustavsson, 2000).

To check the skyrocketing oil import bill, the Government of India emphasized thrust on RETs research marking a major event for the biogas technology diffusion. Resources and attention were provided to technology, on a higher scale compared to the past. Many actors like Department of Science and Technology (DST) initiated research programmes (Gustavsson, 2000).

4.2.1.2.2 Diffusion

Biogas technology has the household women as its main users. Khadi and Village Industries Commission (KVIC) started to diffuse the biogas technology throughout the country through its programme in 1961. KVIC supported by Ministry of Agriculture spearheaded the diffusion of biogas technology all over the country and by 1974, there were about 6000 biogas units set up in India (Gustavsson, 2000).

The system has witnessed the All India Co-ordinated Biogas Programme (AICBP), its first large-scale biogas technology diffusion attempt initiated in 1975. The means chosen was to subsidise the farmers to cover a portion of the investment costs along with technical assistance, research and information dissemination. The main target was the rural India with individual rural household as a unit and the units used and operated by women. If not for such national efforts, the installed biogas units in India would have been less (Gustavsson, 2000).

4.2.1.3 Solar Technology

4.2.1.3.1 Development

The same urge for alternative technologies led to the initiation of another major programme on solar technologies. Solar technology in the study involves both solar PV and thermal technologies. The Solar photo-voltaic program was launched in India in 1975 by the DST with CEL, being entrusted with the task of product development. Simultaneously, the R&D labs and academic centres were entrusted with research on solar cells and development of photo-voltaic materials. The solar cells and modules could see their commercial production starting from 1983–1984 (Kathuria, 2002).

According to (Bhargava, 2001), the thrust of solar photovoltaic programme was on developing and nurturing technological capabilities to undertake R&D and to disseminate the technology with the means of demonstration, industrial production and commercialization. The solar cell technology development was emphasized in the industrial organization.

4.2.1.3.2 Diffusion

Embryo stage saw no production of solar cells and modules commercially. As such the stage was solely concerned with developmental efforts alone.

4.2.1.4 Small hydropower (SHP) Technology

4.2.1.4.1 Development and Diffusion

SHP technologies possess the capability to give energy access to remote and mountainous regions. SHP history in India is more than a century old and many projects were commissioned before India attained independence like the Darjeeling project, 130 kW, 1897; Sivasamudram project, 4.5 MW, 1902 etc. Small hydro sources located on canal falls, directly feeding into the distribution networks, their dispersed nature and short gestation period of the projects makes it deserve greater attention. In hilly areas, because of their inaccessibility, SHP is a better alternative to provide decentralized power source (DNES, 1988). No specific developmental or diffusion efforts could be seen for SHP during this stage. SHP seems to have not caught the attention of planners.

4.2.1.5 Wind power Technology

4.2.1.5.1 Development and Diffusion

Wind energy technology development took its roots in India in 1960s at a smaller level when a conventional multi-vane wind mill was built by National Aeronautical Laboratory (NAL). Later, NAL developed other windmills during 1976–1977. In India, windmills were used mostly to supply irrigation water during this stage (Bhattacharya & Jana, 2009).

4.2.1.6 Problems/Barriers

Technology itself was a problem. Though efforts towards introduction of technology were on the right path, assimilation seemed to be neglected, especially for bio power technologies. By emphasizing standardization, the system ran the risk of technology becoming anti user-friendly. Though intended to reduce costs and to control and maintain the quality of the system(s), the standardization measures worked on the contrary. (Gustavsson, 2000).

In the mad rush to take advantage of government subsidies, stove producers created stoves as per government specifications which were not in conformity with the consumers' requirements. Such faulty designs backed with subsidies discouraged the initiatives of entrepreneurs who came out with improved cook stoves for lack of subsidies and higher price compared with the subsidized faulty stoves (Sinha, 2010).

During embryo phase, Central Electricity Authority (CEA) being the sole authority for technical and financial scrutiny and approval of all power projects, small hydro suffered from the big projects bias. Not enough attention was paid to the development of an indigenous manufacturing infrastructure, up gradation of technology and even cost-effective designs of small hydro projects. Longer times for the approval of small hydro projects coupled with lack of central funding have meant that the State Electricity Boards (SEBs) lost interest in SHP and could not dedicate themselves successfully to the implementation of SH concept and implementation thereof (DNES, 1988).

4.2.1.7 Summary of Analysis

The Embryo Stage saw the attempts made by India to understand the basic technologies and processes underlying the various RETs. India could develop small off-grid biogas plants and Small Hydro Power units' heaters in the Embryo Stage. Biogas technologies were ahead of the small hydro technology which in turn seems to be better off than wind and solar technologies. This is evident from the fact that biogas technology witnessed formal diffusion programmes to promote various practical designs while small hydro was neglected for diffusion. Wind and solar were still in technology development stage.

There was no prime mover and co-ordinator for RETs identification and development. As such, there was no focus, direction or vision in the system. Technology development efforts have been largely disparate, local oriented and individualistic. Numerous actors like Central Electronics Limited (CEL), National Aerospace Laboratories (NAL), KVIC, IARI, Indian Institute of Management (IIM), R.K. Mission - West Bengal and individual researchers like Mr Jashbhai Patel were doing stand alone researches.

Moreover, there was lack of proper perspective on RETs. They were mostly viewed as rural substitutes to reduce the usage of fertilizer produced using conventional sources of power, to improve the livelihoods of rural people especially, small and medium farmers as the big farmers were well-off to use conventional energies to run their machines. Even wind power applications were concentrated on supplying irrigation water. Because of this excessive rural orientation, we could see Ministry of Agriculture supporting Biogas technologies and programmes and KVIC implementing the same. This narrow scope stood in the way of realizing the larger potential of RETs. No major thrust was there on power projects in all types of RETs.

Industrial Organisation was nascent and academic system was minimal and inactive. No formal institutional infrastructure were there till then to undertake the RET activities such as no critical mass provider in this phase. Technological development was induced type. RETs are still evolving. They are largely tacit and little codified or articulated. As a result one can see the huge frontier between science and industry. Because of RETs being tacit, spillovers were likely to take place primarily via personal transfers. No prime mover and co-ordinator in IRETS meant that, spillovers were meagre to non-existent. The system was almost functioning in a closed innovation model. IRETS couldn't witness any spillovers in the embryo stage because it had no connectivity either among the actors within the system nor with the global technological system.

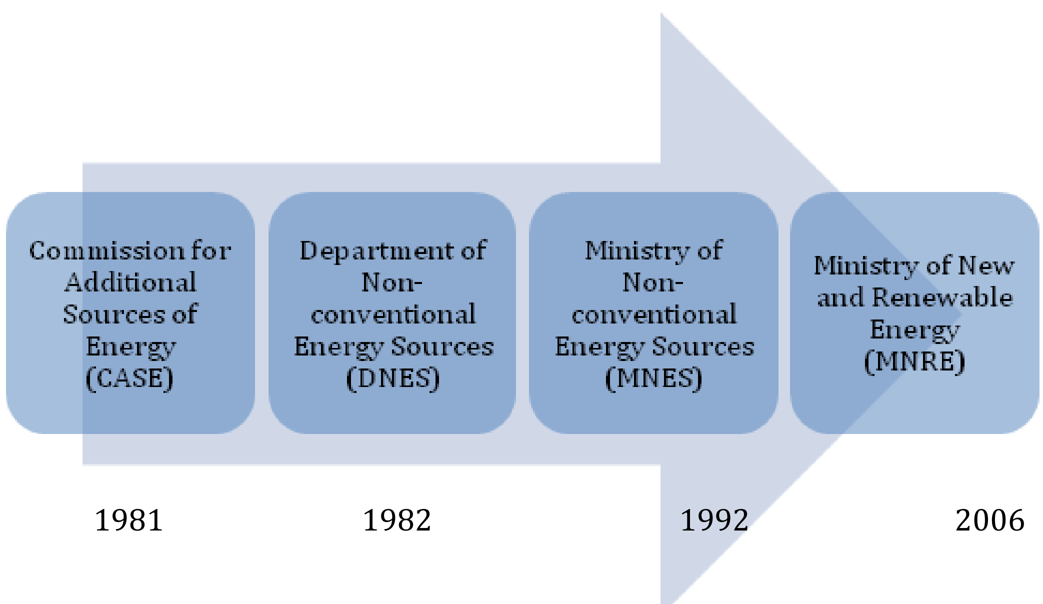
In a nutshell, Bio power technologies, though still being diffused, remained costly and designs were not user friendly. SH technology was neglected with large project bias and Solar and Wind technologies as a renewable energy source to augment the energy needs of the nation were still a distant dream. As such, IRETS can be said to be in embryo stage until 1980.

4.2.2 Infant Stage: 1981–2009

4.2.2.1 Introduction

In India, promotion of RETs was done effectively since the establishment of the Commission for Additional Sources of Energy (CASE), 1981 (Bhattacharya & Jana, 2009). By establishing dedicated institutional infrastructure, the infant stage started by sowing seeds for the rapid RETs development in India by providing incentives and removing barriers and thereby creating a favourable atmosphere that supported commercial development of various RETs.

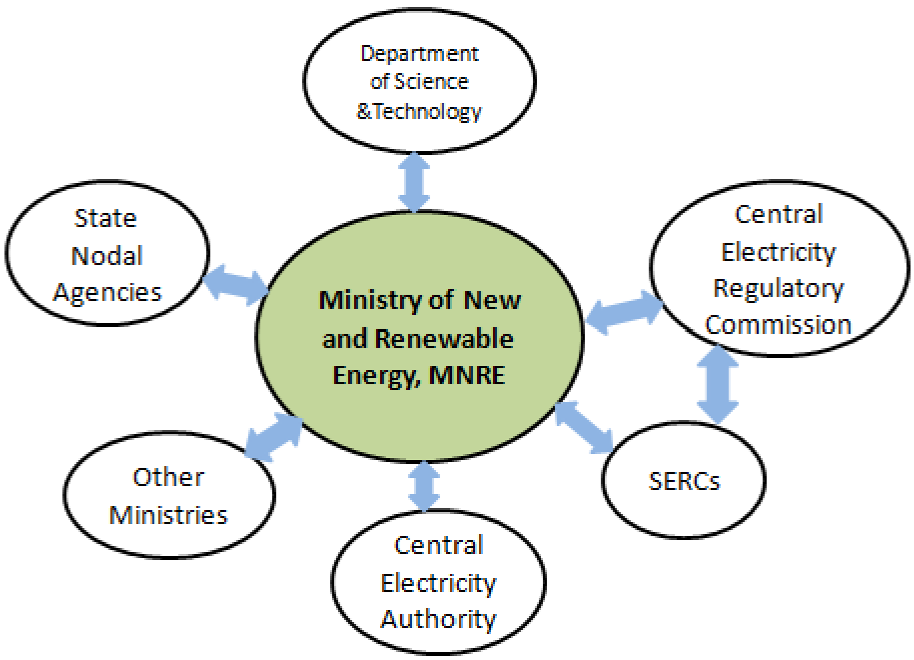
The oil shocks, oil supply insecurities and balance of payment crisis has laid the foundation for the setting up and rise of the main actor in the system, *i.e.*, the government (MNRE). The following figure gives its morphology till date.



Source: Author's Elaboration based on (MNRE, Introduction, 2012)

FIGURE 4.1. EVOLUTION OF MNRE.

CASE was set up in the already established Department of Science & Technology (DST). DNES which amalgamated CASE in it was established within the existing Ministry of Energy. Later, DNES became ministry, MNES which was in turn renamed as MNRE.



Source: Author's Elaboration

FIGURE 4.2. GOVERNMENT: THE MAIN ACTOR.

MNRE, the main actor and the governmental arm of the system performs its role in coordination with other governmental agencies at the central and state level.

4.2.2.2 Bio Power Technology

4.2.2.2.1 Development

Biomass technology development has been slow in India. Gasifier technology has been at the heart of many biomass energy applications. The local manufacturing base was developed by the system for small gasifier technology while large sized gasifier technologies are still in R&D and the pilot demonstration stage (Paliwal et. al, 2010).

Gasifier models were developed by gasifier Action Research Centres (ARCs) supported by MNES. Two co-generation projects and a rice straw based power project started operations in 1992. The latter one ran into technical troubles and was closed. These pilot projects highlighted the scope for enrichment of biomass energy technologies and associated institutional infrastructure to make these technologies much practical (Paliwal et. al, 2010).

On realizing the phenomenal potential of Biomass technologies for energy generation, the MNES has promoted the processes - gasification, pyrolysis, direct combustion. The national programme on biomass power generation and biomass resource assessment programme were launched during this stage (Rajkumar, 2005).

A pilot programme for biomass combustion based power was started in 1994 with the approval of two 5 MW projects. A grid-based biomass gasification R&D-cum-Demonstration project (500 KW capacity) was also initiated under this programme. Another programme started in 1995, supported 10 to 15 MW decentralized projects targeting energy self-sufficiency in power deficit rural areas (Paliwal et. al, 2010).

In 2007-08, Research, Design and Development activities in biogas, bio-energy were started with a view to have more technology focus to cater the needs of biogas technology through RDD&D framework of MNRE. Technology standardization has been one of the objectives of the erstwhile DNES which is still one of the important activities of MNRE. MNRE has been working with the Bureau of Indian Standard (BIS) for formulation of National Standard on composition of compressed biogas and National Centre for Organic Farming for setting up protocol for bio-manure. (MNRE, Annual Report 2011 - 2012 Chap3, 2012).

A project entitled “Advanced Biomass Research Centre (ABRC)” was sanctioned to CGPL, IISc, Bengaluru in October 2008 at a total cost of ₹9.84 crore for four year duration as core funding project for taking up advanced research for promotion of biomass technologies in the country with special focus on engine efficiency improvement, development of standards and test protocols for gasifiers and technology package development for replacing fossil fuels by gasifiers. (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

National Biomass Cookstoves Initiative (NBCI) (December 2009) aimed at ensuring cleaner and efficient alternative energy for the energy deficit lower income sections of the biomass using population by further improving the designs to make them efficient and cost effective. A Steering Committee constituted to provide an oversight for the implementation of the NBCI recommended to support private sector for developing efficient biomass cookstoves by supporting joint R&D by R&D institutions and universities (MNRE, Annual Report 2011 - 2012 Chap3, 2012).

MNRE has augmented three test centres to cater to the requirements of testing of cookstoves industries as per existing BIS standards for different zone in the country which are established at IIT Delhi, Maharana Pratap University of Agriculture Technology, Udaipur and at IMMT (CSIR) Bhubaneswar. The emphasis of the system at present is to develop efficient and cost effective cookstoves and deploy them for field performance evaluation (MNRE, Annual Report 2011 - 2012 Chap3, 2012).

4.2.2.2.2 Diffusion

During 1998 to 2000, MNES has supported establishment demonstration projects of 6 MW size with a grant of 15% of the capital cost. Entrepreneurs led biomass power projects were promoted by providing them interest subsidies that were linked to the boiler pressures thereby encouraging setting up of projects with higher boiler pressures (Rajkumar, 2005).

Fiscal and financial incentives were granted generously aiming at faster diffusion of bio energy technologies. Pilot Scale Demonstration Projects funded by MNRE have been taken up to study the field performance of cookstoves, to create awareness and encourage users to adopt the cookstoves for cooking energy requirements as well as to know the response of users and O&M aspects at local level. Pilot scale projects for deployment of Community Sized Biomass Cookstoves and Family Sized/Portable Biomass Cookstoves are also under implementation. For the 12th Five Year Plan, a National Biomass Cookstoves Programme (NBCP) has been proposed to lead to a business model for biomass cookstoves commercialization in future. A company 'Bioenergy Corporation of India' is sought to be established for promoting the biomass cookstoves in the country. (MNRE, Annual Report 2011 - 2012 Chap3, 2012).

4.2.2.3 Solar Technology

4.2.2.3.1 Development

In 1980, a five-year programme to commercialize the solar photo-voltaic technology was launched which included development and field demonstrations. Under this programme, various technological applications were made (Bhargava, 2001). The Ministry of Non-conventional Energy Sources (MNES) undertook multitude efforts to deploy photo-voltaic systems in rural areas.

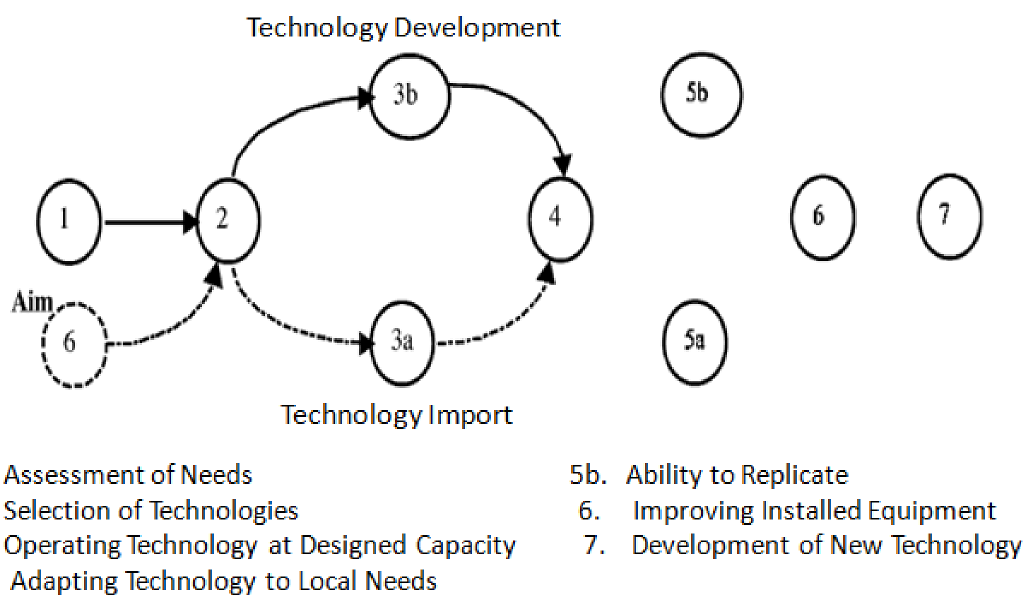
After a decade, the crystalline silicon solar cell technology has attained maturity by the efforts of the industrial organization which was manifested by development, deployment for demonstration, field testing and evaluation of a variety of PV systems. Thin film amorphous silicon solar cell technology development mission was started in 1985. The actors collaborating towards the mission were Solar Energy Centre/DNES, Bharat Heavy Electricals Limited, Central Electronics Limited, Bharat Electronics Limited, National Chemical Laboratory, Pune, IIT Delhi, IACS Calcutta, National Physical Laboratory New Delhi, University of Pune, DST (PC, 1985). The Indian Association for Cultivation of Sciences (IACS), Calcutta, was developing large-area multi junction amorphous silicon solar cell modules. (Bhargava, 2001).

An important feature in the development of industrial organization in the system is the indigenous production of key raw materials and equipments to process and test solar cells, modules and systems (Bhargava, 2001).

The Embryo Stage, as we have seen earlier, was dominated by numerous, disparate, standalone efforts by various actors towards RETs development and diffusion. The Infant Stage started with a realization to form a network between the actors and strive collectively towards the goals of technological development and diffusion through established relationships between them. In 1982, the Department of Non-Conventional Energy Sources (DNES) started Solar Energy Centre (SEC) with United Nations Development Programme (UNDP) assistance to build networking among government, industry, and research institutes at national and international level targeting development and diffusion of solar energy technologies. On the same lines, in 1981, the Solar Thermal Energy Centre project was launched (Kathuria, 2002).

In the Infant Stage, India rose to a level of indigenously developing technology and production capabilities to manufacture PV cells though the module efficiency (12 - 13%) is below the international module efficiency (15% available in the US as of

1992). CEL, which has spearheaded India's solar PV research, development, and production until then in a closed manner, chose open innovation to improve the efficiency of single crystalline silicon solar cells. It initiated the ultrahigh (UHE) project in December 1988 in cooperation with the University Of New South Wales (UNSW), Australia. Before that, in 1986, the Multi-crystalline Silicon Solar Cells Project was collaborated with National Physical Laboratory (NPL) (Kathuria, 2002).



Source: (Kathuria, 2002)

FIGURE 4.3. STEPS IN TECHNOLOGY TRANSFER FOR PV CELL.

The Indian firm (CEL), which embarked on developing the technology itself (*i.e.*, Step 3b instead of Step 3a), could not reach the target level of quality even after several years. To meet this qualitative end, it later chose open innovation and collaborated with foreign manufacturers for technology transfer (*i.e.*, resorting to Step 3a), shown as dotted lines in the Figure 4.3 (Kathuria, 2002).

The IRETS saw solar cells and modules being produced commercially starting from 1983–1984 (Kathuria, 2002). During the last decade, various private sector companies and a number of joint ventures started producing commercially. India is a net exporter of solar photo-voltaic technology, with nearly 66% of the cumulative domestic photo-voltaic production being exported till 2009 (ISA, 2010).

4.2.2.3.2 Diffusion

India witnessed the largest photo-voltaic demonstration program globally, under the aegis of MNES in coordination with the state nodal agencies (SNAs), the electricity boards and NGOs (Kathuria, 2002). Various incentives - fiscal and financial were granted generously aiming at faster diffusion of solar technologies.

4.2.2.4 Small hydropower (SHP) Technology

4.2.2.4.1 Development

One unique aspect of SHP development traditionally and later aided by AHEC is that, water mills have been designed and used for rice hulling, grain grinding purposes apart from mechanical/electricity generation purpose for the hilly regions as well as the plains of the country. With the establishment of DNES and AHEC in 1982, foundations have been laid for a glorious era in SH Technologies. In short span of time, they were able to develop deep into the whole range of activities concerning SH projects. DNES has geared up R&D activity providing greater direction ensuring positive and quicker results alongside with functional reorganization of AHEC. Open innovation in SH technologies took roots now with the beginning of close interaction among scientists and technical personnel from DNES/AHEC, India on one hand and experts from France, Sweden, US, China and the EEC on the other hand leading to improvements/up gradation of technologies of design and equipment (DNES, 1988).

The nature and functions of MNRE has been changing throughout the infant stage regarding SHP development and diffusion. Small and mini hydro projects up to 3 MW capacity came under its ambit since 1989. Finally, hydropower plants up to 25 MW capacity were added to the portfolio of MNES in 1999–2000 (Bhattacharya & Jana, 2009).

DNES, in an attempt to sustain high yield operations, started to focus on taming recurring costs, such as manpower and maintenance costs. Towards this end, it has held consultations with experts and machine manufacturers. Automation and microprocessor controls were discussed with international designers and manufacturers. Special training for operators, cost-effectiveness and reliability were sought to be prioritised. Quality control during the construction stage was also given high regard by encouraging local participation. DNES promoted standardization of designs wherever possible and use of Computer Aided Design (CAD) was advocated (DNES, 1988).

According to DNES, the small hydro manufacturing base in India has remained weak under the shadow of the more attractive large hydro and thermal sector. It was also aware the worldwide trend on SH Fluid Machinery which is of exhaustive R&D on improved and new designs of machines nature. Hence DNES sought active participation from manufacturers in the R&D and technology transfer programmes with academic institutions like AHEC which are having field experience as well to realize the dream of having low cost and efficient machines for SH. (DNES, 1988).

In the Infant Stage, we can see the emphasis of DNES approach to involve as many actors as possible to develop the SH technologies and projects. "It may be worthwhile involving Regional Engineering Colleges, Universities and Diploma Polytechnics having computer facilities for analysis and collection of data for project report preparation. Students and voluntary agencies could be used for data collection. In fact, some of the R&D projects based on operational data collected on running projects could also be assigned to Regional Engineering Colleges, and the funds for the same provided in specific project proposals" (DNES, 1988).

Information management was sought to be a crucial activity for technology development and dissemination. Dissemination of information on R&D efforts and extension works through organisation of seminars, symposia and workshops was sought. To collect, store and retrieve information regarding power potential of SH systems and on feedback obtained from the projects already executed, DNES has proposed National Data Bank of SHP which shall be linked up with the DNES database (DNES, 1988).

4.2.2.4.1.1 Mini Hydro Power Eight Plan (1992-1997) Implementation Programme

One of the objectives of the Plan is "National R&D hook up involving colleges and universities at the regional and national level, in close collaboration with manufacturers and entrepreneurs". The plan proposed a budget of ₹ 15 Crores for joint R&D involving AHEC, Regional Engineering Colleges and equipment manufacturers. Budget was also allocated for design methodologies and standardization, setting up of CAD facilities at various SEBs, training and man power development, information management activities like setting up of data bank, organizing seminars, symposia and publications.

Programme implementation strategies call for the combine technical help of DNES and AHEC. Active help of experienced SEBs engineers was also sought. 21 months time frame was sought for the manufacturers to obtain the state-of-art technology, and assimilate it. AHEC, in collaboration with voluntary agencies to train the local people and subsequently state agencies, thereby relieved AHEC.

The document underscores the evolutionary stage of SH design practices and seeks to offer training programmes of academic nature to serving engineers of state agencies at the doctoral and post graduate level. 2-4 weeks short term training programmes for continuous updating of design practices.

"Availability of low cost microprocessors has virtually revolutionized the whole field. There is immense scope for transfer of technology and indigenous research and development in close collaboration with equipment manufacturers". Microprocessors were to be used for phase co-ordinated distribution network to handle two way power flows between the utility power plant and customers thereby leading to considerable simplification, cost reduction, and better man-machine interface.

The document commends the AHEC technological prowess and identifies the following objectives of it during the Eight-Plan:

1. Work in close co-ordination with DNES for SH development of each state.

2. Training of designers from SEBs with sufficient scope for individual excellence in offering innovative designs. "Guidelines tend to discourage innovative designs".

The document opines that the role of DNES, as the chief co-ordinating agency would be a herculean task with nascent manufacturing infrastructure, shift in technology and personnel from large hydro to small hydro, large project bias of the state agencies which has to be removed and to involve local agencies and private contractors in maintenance of the systems. "Research and Development activity has to be decentralised in various Universities and engineering colleges, to closely co-ordinate with manufacturers in the region".

A special developmental outlook on SH technologies has descended on DNES at this time. Rather than being treated as a 'stand alone' technology system, they were looked upon as 'integrated systems' along with local biomass, wind and solar sources.

4.2.2.4.2 Diffusion

The demonstration projects period from 1989 to 1993 was targeted towards stimulating the state governments and state electricity boards to set up small hydro projects by providing capital subsidies. Since 1993–94, the focus was enlarged to attract private sector participation. IREDA financing to small hydro projects started since mid-Seventh Five Year Plan (1985–90).

The Infant Stage saw demonstration schemes revitalization and setting up of numerous projects like Jubbal (150 KW) with high head (80 m); Manali (200 KW) with medium head (40 m) and Kakroi (300 KW) with ultra-low head (1.8 m). Cost-reduction was achieved significantly. Innovative designs of civil structures, new and high efficiency designs, concepts such as multiple orders on identical sites to facilitate volume production of identical equipment resulted in the reduction of costs from as high as ₹ 49,000 - ₹ 85,000/KW installed to ₹ 25,000/KW installed at canal falls of about 3M head (DNES, 1988).

During the Seventh Five-Year Plan (1985-1990), DNES policy of sanctioning National Demonstration Projects to AHEC located in academic environment paid rich dividends. It gained deeper insights into SH systems investigation, design, execution and monitoring activities as well as rich experience gained on National Demonstration Projects. AHEC compiled a technical document as a guideline for implementation of small hydro programmes. With this success, DNES funded a post graduate programme on renewable sources of energy in AHEC which was approved by University Grants Commission (UGC) (DNES, 1988).

Taking a cue from China, DNES understood the importance of training and involvement of local people in the SH Programme which resulted in substantial savings in O&M costs. As such, it encouraged the same in IRETS as well. DNES also underscored the need for strong training programmes at the post-graduate and doctoral levels for serving engineers of state implementing agencies and a 2-4 week duration state-of-the-art courses for higher level executives (DNES, 1988).

4.2.2.5 Wind power Technology

4.2.2.5.1 Development

In 1983-84, a wind power programme was launched at the national level, with three components: wind resource assessment, demonstration projects and industry-utility partnership. An extensive Wind Resource Assessment has started in 1985 producing five volumes of survey results so far (Bhattacharya & Jana, 2009).

Despite prior existence of incentives and market-oriented policies, private sector presence in wind energy sector could be seen effectively post introduction of the ‘private power policy’, 1991. This finally heralded in commercializing wind energy technologies and significant augmentation of installed capacity in India making the Indian wind industry fourth in the world by the year 1993 (Bhattacharya & Jana, 2009).

Proactive states like Tamilnadu came forward to reap their wind power potential by offering various incentives. With this fillip, wind energy technologies got a new wave of growth, and since 1999 were on a good growth path. Indian wind power technologies reached technological maturity by being suitably modified for the Indian conditions thereby achieving greater capacity utilization. (Bhattacharya & Jana, 2009).

Though India was importing turbines till the 1990s, it could emerge as an exporter of wind turbines in the later stages of the infant stage. Today India manufactures both large as well as small turbines.

4.2.2.5.2 Diffusion

Fiscal and financial incentives were granted generously aiming at faster diffusion of wind energy technologies.

4.2.2.6 Technology Centres

4.2.2.6.1 SOLAR ENERGY CENTRE

Solar Energy Centre (SEC) was setup in 1982 as a premier research, technology evaluation and demonstration facility of MNRE, which works on science and engineering aspects of solar energy technologies. The activities undertaken by SEC are:

1. Solar Resource Assessment through its comprehensive weather station located in the campus along with the battery of 51 Automatic Solar Radiation Monitoring Stations (ASRMS) that are being set up now.
2. Prepares solar maps of monthly and annual DNI and GHI for the country,
3. Solar PV Outdoor Test Facility for various technologies (Mono Crystalline, Thin Film, X500 Concentrator and Mono Crystalline, thin film & HIT).
4. Solar PV Indoor Test Facility for testing and evaluation of solar cells, modules, balance of systems and complete PV lighting systems based on LED as well as CFL. This laboratory confirms to IEC17025 international quality system.
5. Light soaking test station for qualification testing of Thin Film PV modules according to IEC 61646.
6. Numerous R&D projects with various actors in the system.
7. Solar thermal test and evaluation facility to test and evaluate various types of solar thermal devices, and providing technical assistance to manufacturers, developers and users.
8. Solar thermal technology development and evaluation projects in partnership with other research organizations, educational institutions and industry. These projects, partially or fully funded by MNRE, work on finding solutions to the

current technology limitations to make solar energy systems a reliable option by bringing Indian and international scientists and industry to work together.

9. Visitors' Programme - A comprehensive 'visitors' programme' implemented by SEC aims at sharing the facility and expertise developed in the Centre with researchers, academic system and industry for undertaking scientific projects, interactive research, human resource development and thereby expanding the knowledge base in this field (MNRE, Annual Report 2011 - 2012 Chap8, 2012).

4.2.2.6.2 CENTRE FOR WIND ENERGY TECHNOLOGY

Centre for Wind Energy Technology (C-WET) was setup in 1998, as an independent R&D institution by MNRE. It is a knowledge centre offering services and probes to workout total solutions to improve the entire wind energy technologies portfolio by conducting research. Its functions are listed below:

1. Novelty in developments of components and sub-systems that go into wind turbines by collaborating with research institutions and industrial organization.
2. To identify the locations with good wind potential throughout the nation through wind resource micro survey and offering services to the wind technologies promoters, preparing resource map for the country.

3. Establishing global standard paraphernalia for testing of complete Wind Turbine Generator Systems (WTGS) as per international standards (IEC) and Type Approval Provisional Scheme (TAPS-2000).
4. Carrying Provisional Type Certification of Wind Turbines according to the Indian Certification Scheme for Wind Turbines viz. Type Approval - Provisional Scheme - TAPS - 2000.
5. Collects, collates and analyzes data and establishing and updating the database of wind energy. Conducting national and international trainings and workshops. Also promotes a magazine, PAVAN, aimed at dissemination of information in the system and thereby helps diffusion of the technology (C-WET, About Us, 2012).

C-WET, is one of a kind technology centre focussing purely on wind energy technologies in Asia.

4.2.2.6.3 SARDAR SWARAN SINGH NATIONAL INSTITUTE OF RENEWABLE ENERGY (SSS-NIRE)

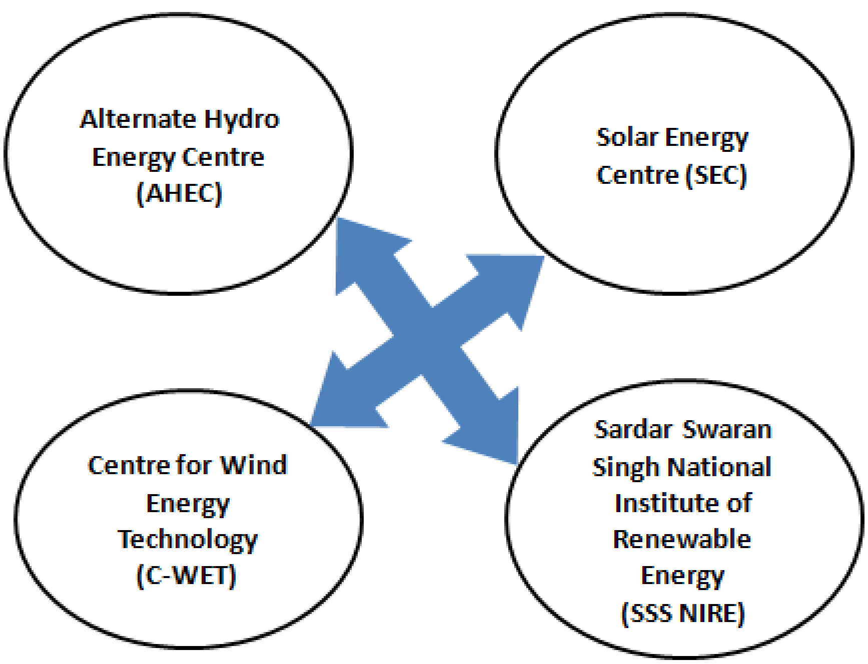
Sardar Swaran Singh National Institute of Renewable Energy is an independent technology centre under MNRE to conduct research, design and development (RD&D) tasks in bio-energy which also includes human resources development (SSS-NIRE, 2012).

Apart from the functions mentioned above, it is also responsible for testing, standardization and technology demonstrations that helps in commercializing RD&D

results focussing on bioenergy, biofuels & synthetic fuels in all states of matter and their potential applications (MNRE, Annual Report 2011 - 2012 Chap8, 2012).

4.2.2.6.4 AHEC

Alternate Hydro Energy Centre (AHEC), is an academic institution set up in 1982 under the aegis of the Ministry of Non-Conventional Energy Sources to develop small hydropower (SHP) technologies and thereby augment installed electricity generation particularly in hilly areas and plain areas to some extent (MNRE, AHEC, 2012).



Source: Author's Elaboration

FIGURE 4.4. INSTITUTIONAL INFRASTRUCTURE: TECHNOLOGY CENTRES.

4.2.2.7 Problems/Barriers

According to (Kathuria, 2002), three barriers that hinder the diffusion of ecologically friendly technologies are technology, market and government related barriers.

Technology-related barriers

Proper estimation of the potential of renewable energies like wind power and bio power was a major technological problem which in turn stimulates the approach towards their development and diffusion. Solar technologies are yet to prove their commercial potential.

Market-related barriers

The absence of the expected rate of returns is one principal market-related barrier. In the absence of adequate profits, the private sector does not make any efforts to rapidly diffuse the technologies. Other market associated barriers are lack of proper and adequate information, lean resale prospects, lack of finance, and short-time horizons for financiers. Any newly introduced technology, takes substantial time to gain acceptance of the customers due to lack of information. Marketing commitment is a must to overcome this problem. But, marketing expenses are sunk costs if an investment fails. High initial up-front investments meant that availability of finance is a major obstacle (Kathuria, 2002).

The above problems discourage large firms from committing to technologies, whereas smaller and start up firms that are ready for lower profit margins would enter to serve the market. They neither can pledge adequate R&D nor realize economies of scale in manufacturing resulting in high costs and the consequential slow market widening and technology diffusion. A developing country like India is also characterized by low per capita income. Customers, as a consequence, give priority to up-front investments in comparison to the full life cycle costs necessitating higher implicit consumer discount rates (Kathuria, 2002).

Government-related barriers

The Government of India subsidizes fossil fuel technologies along with RETs which work against market penetration of cleaner RETs. Such a policy means that the main actor in the system is still lacking proper knowledge on the diffusion requirements.

MNES has forestalled subsidies provided to the solar flat plate collectors and solar cooker producers since 1993 and 1994, respectively. Scientific staff of SEC, many of them, who were sent abroad on various occasions for training and who were supposed to be core scientists were seconded to MNES once the training was finished rendering the training a waste (Kathuria, 2002).

Government lacked proper perspective on the utility of RETs thereby reducing them as supplement for rural and small scale applications rather than an alternative and additional source of energy for the nation.

The remoteness of most of the installations has meant that regular service is difficult. The absence of user participation in the system has retarded the diffusion process.

4.2.2.8 Summary of Analysis

Development of few technologies like small gasifiers and wind energy were successful which was made possible by coordination of major actors - MNRE, IREDA and industrial organization. On the other hand, RETs developing alternative transport fuels witnessed initial development problems due to lack of coordination among different actors (Bhattacharya & Jana, 2009).

By the mid 1990s, the domestic market dwindled resulting in wastage of production capacity and brimming warehouses with producers forcing them to find markets elsewhere to survive. As such, the system started exporting the same. Outsourcing by producers to be re-exported to markets abroad has also created a new export opportunity for Indian solar PV industry (Srinivasan, 2005).

Indian module manufacturing being labour-intensive is more cost competitive than the western plants. The processes and products have been certified internationally. This acts as an image enhancer in the highly competitive markets abroad (Srinivasan, 2005).

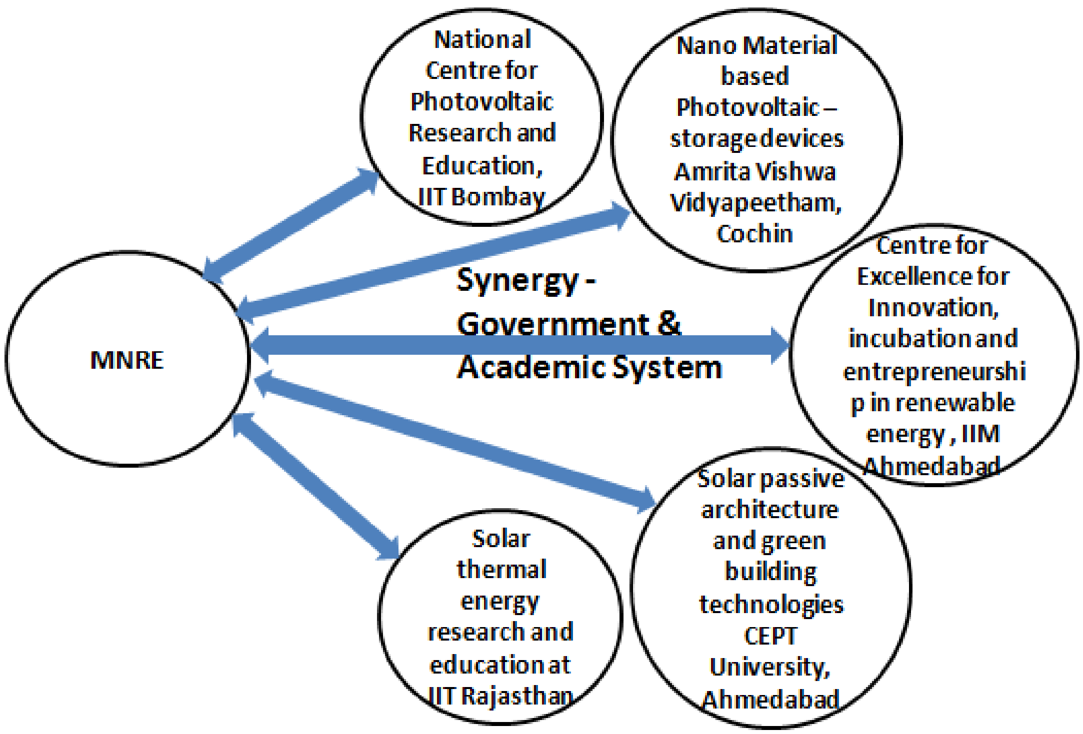
The RETs are more component-oriented and embodied in equipments necessitating high receiver competence, especially the systems know-how (Carlsson B. , 1997). That is the reason why Wind Power could not take off until the mid 1990's because of the nascent private sector and inefficient public sector. Only after LPG, India could see rising private sector which in turn got augmented by way of technology transfer from foreign technological systems, especially in Wind Power.

Raising awareness and taking early initiatives were always under the domain of MNRE even until today. Numerous efforts for MNRE - funding for R&D projects, financing for commercialization through IREDA, providing technical services through the four technology centres, collaborating with foreign technological systems, networking in the technology system etc have created critical mass.

Once the private sector made its presence they further added to the critical mass especially for the Wind Power. No critical mass can be seen for Bio Power as the grid connected MW scale bio power is not fully developed at least indigenously. Critical mass for Solar Power is expected to be provided by the recently launched JNNSM looking at its approach and framework.

In the infant stage, wind technology and to a lesser extent, solar technology have become little codified and the IRETS could develop the needed infrastructure already thereby making it easy to collaborate with foreign technological systems (open innovation) to access better technologies through various means, joint R&D, joint ventures, technology transfers. As the knowledge of RETs is embodied in artefacts, IRETS developed the needed receiver competence in the infant stage which paved way for numerous collaborations.

DNES and later, MNES have raised the receiver competence in the system significantly by funding R&D initiatives, infusing vitality into academic system by way of funding and supporting their R&D initiatives, upgrading certain institutions as Centres of Excellence, linking the IRETS to global technological system, setting standards, personnel transfers who in turn raise the competence of their institutions once they return etc.



Source: Author's Elaboration on (MNRE, Annual Report 2011-2012 Chap6, 2012)

FIGURE 4.5. MNRE: FIVE CENTRES OF EXCELLENCE FOR SOLAR TECHNOLOGIES R&D.

IRETS could develop dense network of links among the actors as well as with foreign technological systems in infant stage which paved way for identifying, absorbing and exploiting spillovers. The problem-solving network consists of the academic system, research institutions, technology centres and manufacturers making them as the key nodes in the IRETS.

The 'national community network' which is largely non-formal has been constantly strengthened by MNES by promoting personal contacts through various activities like seminars, symposia, workshops etc. This network extends from top scientists and researchers right up to the users of the RET systems. Such a network promotes information dissemination at all levels of the system thereby strengthening development, diffusion, utilization of RETs in the country.

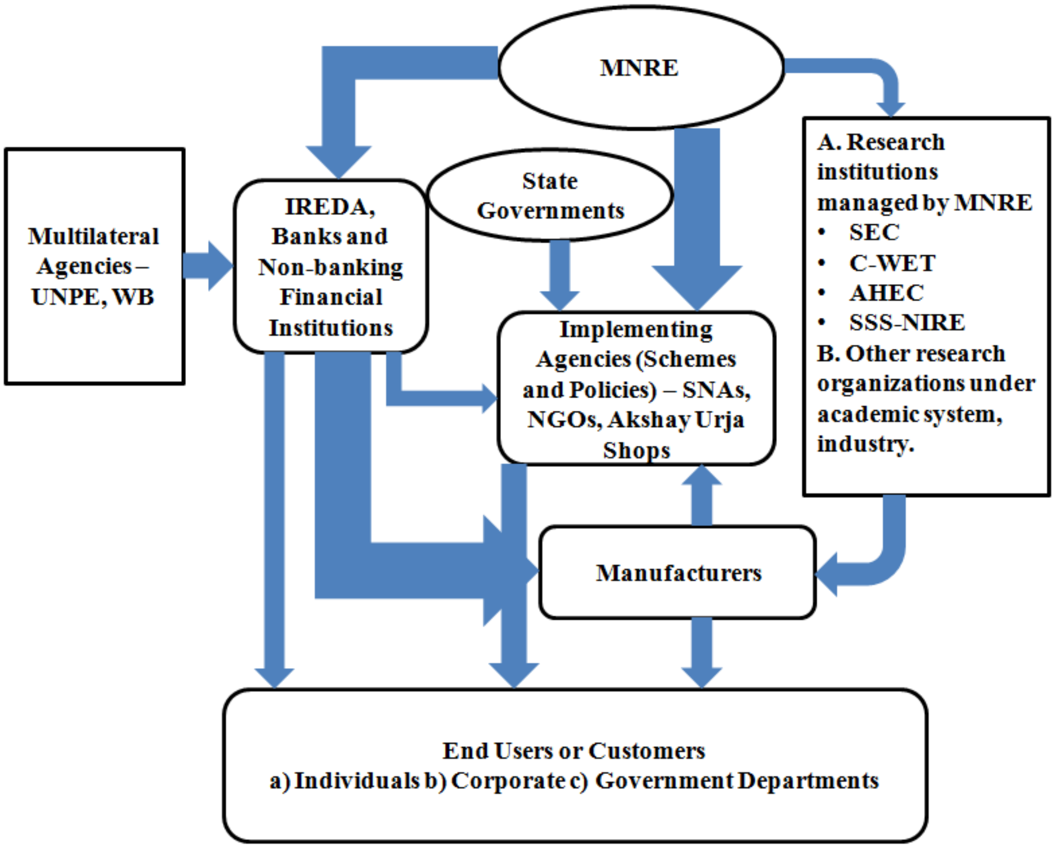
As the industry gained competence and saw birth of many entrepreneurs as well as established private sector companies moving into RET sector, the system witnessed the onset of bridging institutions at national as well as state levels like Wind Energy Association (WEA), Indian Wind Turbine Manufacturers’ Association (IWTMA), Solar thermal federation of India (STFI), Indian Solar (PV) Manufacturers Association (ISMA), Biomass Developers Association, Indian Biomass Power Association etc. With these bridging institutions promoting the cause of RETs, IRETS is poised to speed up the technological development, diffusion and utilization.

4.2.3 Adolescent Stage: From 2010

4.2.3.1 Introduction

Wind energy technologies overwhelm India's RETs diffusion which accounts for 70% of installed capacity (16 GW), followed by small hydropower (3.3GW), biomass power (3.0 GW) and solar power (445 MW) (MNRE, Annual Report 2011 - 2012 Chap5, 2012). The focus of the IRETS now is on indigenization of technology, product development and resource assessment. Research & development is the major thrust of MNRE, directed towards cost reduction, efficiency improvement, reliability, durability and production of whole systems. RDD&D projects in the area of solar thermal power, solar PV, hydrogen and fuel cell, biofuel, and biomass cook stoves are presently sanctioned and sponsored by the MNRE, collaborating with national laboratories, universities, scientific & educational institutions and industry (MNRE, Annual Report 2011-2012, 2012).

Technology Demonstrations are still a major part of MNRE activities to attract the entrepreneurs and private sector to commercialize the proven innovative and indigenous RET applications. Solar concentrating systems with vapour absorption machines have been demonstrated for air conditioning purposes. Others include solar steam cooking and biogas bottling (MNRE, Annual Report 2011-2012, 2012).



Source: Adopted from (APCTT-UNESCAP, 2010) and Modified by Author

FIGURE 4.6. RETS IN INDIA: ENABLING INFRASTRUCTURE.

4.2.3.2 Bio Power Technology

4.2.3.2.1 Development

The Biomass power programme is promoted with an aim of harnessing the potential to obtain grid-quality power using biomass materials such as bagasse, rice husk, etc. following different conversion technologies. Wide range of technology choices exists for the development of KW ranges gasification based systems to both small (1-2 MW) and large scale (5-12 MW) combustion based systems. Biomass system provides certain advantages like decentralized power production, quick capacity augmentation with reduced process delays. The cumulative biomass power generation capacity up to 31.01.2012 was about 1142.6 MW (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

Development status of biomass logistics and conversion, inter-alia, is crucial for the development of biomass based power generation. Biomass technologies for rice husk has matured while, technology for straw and stalks is at the initial stage of development. Hence states like Punjab, Haryana, Bihar, where straw is the major resource are yet to see any major development, especially Punjab, the state with highest biomass potential in India (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

Bagasse Cogeneration technology involves extracting power from the bagasse produced by sugar mills by adopting technically and economically optimum levels of cogeneration. Bagasse Cogeneration technology has been quite successful with continuous improvement in the technology starting with the initial 45 kg/cm2 and 440C steam pressures to 110 kg/cm2 and 5350C in 2011, with intermediate stages of 65 kg/cm2 and 4850C (1994) and 87 kg/cm2 and 5150C (2004). The most heartening development witnessed with the start of adolescent stage of IRETS is the country's first 110 ATA/535OC & 180 TPH Capacity Co-Generation Project on Build, Own, Operate and Transfer (BOOT) basis with the technology being developed indigenously. Pressure boiler and turbine were supplied by private sector and financed by MNRE and a consortium of three Nationalized Banks (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

Conducive policy at the Central and State levels promotes diffusion of biomass technologies in the country by providing fiscal concessions and electricity duty exemption (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

TABLE 4.1. COLLABORATIONS IN TECHNOLOGY DEVELOPMENT

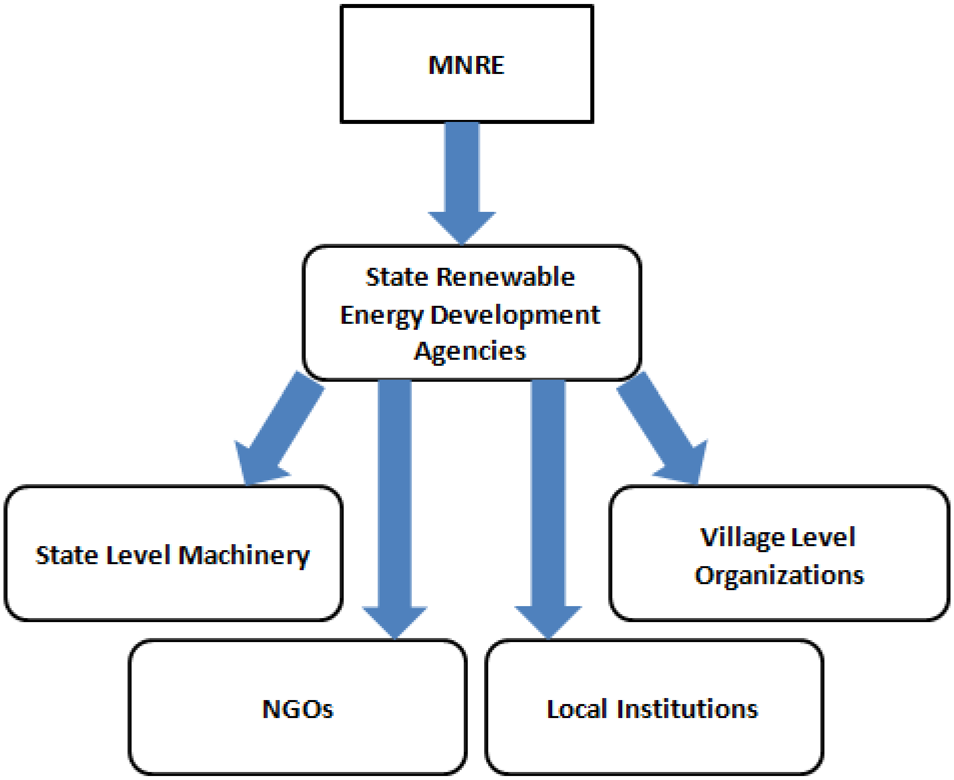
Actor	Name	Focus
Technology Centre	SSS-NIRE, Kapurthala	Bio-crude production
	National Institute for Interdisciplinary Science and Technology, Trivandrum	Sorghum Stover based Bio refinery for Fuels and Chemicals
Research Institute	Phyco Spectrum Environmental Research Centre, Chennai	Development of a hybridized bio-reactors – open pond cultivation system integrating sinusoidal magnetic fuel technology to enhance the qualitative and quantitative efficacy to algal biomass production
	NEERI, Nagpur	Enhanced Butanol production from Lignocellulosic Biomass
Industry	Abellon Clean Energy Ltd.,	Dual operating bio-reactor systems

	Ahmedabad	
Academic System	Vidyabharti Trust Institute of Technology & Research Centre, Surat	Co-pyrolysis of de-oiled cake of Jatropha and waste plastics to produce upgraded biofuels
	University of Delhi South Campus	Pre-treatment strategies and bioprocess
	Indian Institute of Petroleum, Dehradun	Hydro pyrolysis of lignocellulosic biomass to value added hydrocarbons

Source: Author's Elaboration based on (MNRE, Annual Report 2011 - 2012 Chap7, 2012)

4.2.3.2.2 Diffusion

The present implementation pattern of National Biogas and Manure Management Programme (NBMMP) clearly highlights the importance of involving numerous actors and the kind of co-ordination required at the field level. MNRE's network of institutions used for diffusion of technological applications is given below.



Source: Author's Elaboration

FIGURE 4.7. MNRE - IMPLEMENTATION MECHANISM.

To support them with training and for backing technically, Biogas Development and Training Centres (BDTCs) were established in the system in various academic institutions and other related centres (MNRE, Annual Report 2011 - 2012 Chap3, 2012).

MNRE, with the support of UNDP (GEF) is implementing a project to accelerate the adoption of ecologically benign biomass technologies by eliminating the hurdles for diffusion and commercialize the biomass technologies providing greater financial resources. The project has two components – Identification of barriers for large scale deployment of biomass power projects through Technical Assistance (TA) and support setting up of Model Investment Projects (MIPs) which would act as the 'Best Practices' for faster replication of biomass power in the country. (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

Under the above project, first of its kind, 1.2 MW Grid Connected Power Plant Based on Gasification Technology has been operational in Gujarat, India since 2011. 100% producer gas engines were imported from M/s Shendong Power Machinery Company Ltd., China and development of Entrepreneurs for Secure and Sustained Fuel Supply are the highlights of this project. A one day stakeholder's consultative workshop on 'Biomass Power – Potential Issues and Challenges' was organized in September 2011 with more than 85 participants from State Governments, State Nodal Agencies, Private Sector, Civil Society and Officers from MNRE.

4.2.3.3 Solar Technology

4.2.3.3.1 Development

The Jawaharlal Nehru National Solar Mission (JNNSM) launched in 2010 aims to achieve 20,000 MW of installed grid based solar power by 2022. It is to be to be achieved majorly by cost reduction in the technologies. Critical means chosen are intensive R&D and indigenous production of key raw materials, and sub components with an aim to realize grid parity in tariff by 2022 (MNRE, Scheme / Documents, 2012).

NTPC Vidyut Viper Nigam (NVVN), the chosen power purchasing company is mandated to purchase 1,000 MW of solar power connected to 33 KV and above grid line, equally (500 MW each) from solar thermal and solar photovoltaic (PV) technology route, from the project developers (MNRE, Annual Report 2011-2012 Chap6, 2012).

Enabling Provisions

1. The Payment Security Mechanism (PSM) is provided under JNNSM Phase 1, covering the risk of defaults by the state utilities / distribution companies. MNRE is implementing the scheme with NVVN.

2. The National Tariff Policy for Power Sector was amended to incorporate solar power purchase obligation for States under Renewable Purchase Obligations (RPOs). This assures the private developers and entrepreneurs of uninterrupted market access.

3. Components and equipment required for setting up of solar power projects are exempted from excise duty and eligible for concessional custom duty, in case of imports (MNRE, Annual Report 2011-2012 Chap6, 2012).

> " Technology trends from solar power projects under JNNSM, indicates dominance of parabolic trough collectors for solar thermal power plants, and equal sharing of crystalline silicon and thin film technologies under solar photovoltaics" (MNRE, Annual Report 2011-2012 Chap6, 2012).

TABLE 4.2. SOLAR TECHNOLOGY R&D - ACTORS AND INTERACTIONS

Actor	**Name**	**R&D Project Purpose**
Global Organization	UNDP/GEF	Global Solar Water Heating Project on Comparison Study of FPC (Flat plate collectors) and ETC (Evacuated Tube Collectors) type Solar Water Heating Systems.
Industry	Megawatt Solutions (MWS) Private Limited, Chennai	Development and demonstration of a uniquely engineered solar dish concentrator of 87 square meter aperture area that can be installed either as a standalone or in an array of any quantity for providing high quality, high temperature thermal energy for industrial applications such as heating, cooling and power generation as a solar-fossil hybrid test loop.
	ONGC Research Centre	Evaluation of three Stirling engines based on solar parabolic dish collectors at SEC
	Ecolibrium Energy Pvt. Ltd., Ahmedabad	"Establishment of Model Smart Micro Grid at SEC" with the objective of demonstrating the smart use of electricity by integrating mix of renewable power to the grid, support for energy savings, evaluation and showcasing the actual benefits
	M/s Thermax Limited, Pune	Indigenously developed 100 kW solar air-conditioning system that consists of triple effect vapour absorption machine (VAM), medium temperature parabolic trough collectors for the collection of solar energy, thermal energy storage in the form of Phase Change Materials (PCM), chilled water ducting system and the fan coil units. The system provides cooling in summer and heating in winter to 13 rooms of Solar Energy

		Centre.
Industry, Research Institute, Foreign Research Organization	M/s Thermax Limited, Pune, TERI, CSIRO Australia	Solar-biomass hybrid cold storage for remote village application: The system essentially consists of a 50 kW biomass gasifier based electricity generating system. The heat that is waste emanated by the gas engine generator would operate an absorption refrigeration chiller to produce -5 degree C temperature in a cold storage chamber of 5 ton capacity.
Industry Academic System	Indian Oil Corporation, Centre for Alternate Energy Research, University of Petroleum and Energy	Examining the efficacy of production of hydrogen from solar energy through photovoltaic route, a Solar Hydrogen R&D project funded by MNRE.

Source: Author's Elaboration based on (MNRE, Annual Report 2011 - 2012 Chap8, 2012)

Enhanced Institutional Infrastructure

For implementation of the JNNSM, Institutional Infrastructure has to be enhanced. Solar Energy Corporation of India (SECI), New Delhi, a Company not for profit, has been set up by MNRE to assist it and function as the implementing and executing arm of the JNNSM for development, diffusion and commercialization of solar energy technologies (MNRE, Annual Report 2011-2012 Chap6, 2012).

Solar Energy Research Advisory Council (SERAC) consisting of renowned scientists, technical experts and academic and research representatives with a view to guide on the overall strategy for technology development under JNNSM has been setup. The

Council is also expected to assess and upgrade the technology road map targeting faster technology innovation and driving down costs (MNRE, Annual Report 2011-2012 Chap6, 2012).

Under JNNSM, Solar Energy Industry Advisory Council (SEIAC) is established to promote the development and growth of domestic industrial base in the solar energy sector in the country. Currently headed by Shri Anand Mahindra from Industry, it advices MNRE on various technology related matters, international technology trends and collaborations with foreign technological systems (MNRE, Annual Report 2011-2012 Chap6, 2012).

TABLE 4.3. SOLAR TECHNOLOGY R&D - INSTITUTIONAL INFRASTRUCTURE

Actor Type (Number of Actors)	**University/Institute**	**Solar Technology**
Academic System	Bengal Engineering & Science University, Kolkata,	Thin Film Silicon Solar Cells and PV Systems
	Indian Institute of Technology Kanpur	Organic solar cell sub-modules
	CUST, Cochin	Stable and low cost thin film solar cells using automated spray technique
	IIT Bombay	Development of high efficiency HIT (Heterojunction with Intrinsic Thin layer) solar

		cells.
Research Institute	IICT, Hyderabad & NCL, Pune.	Dye sensitized solar cells covering quantum dots
	National Physical Laboratory (NPL), New Delhi	Thin film silicon solar cell based on two distinct microstructures of silicon and CIGS based solar cells and module
	Indian Council of Medical Research (ICMR).	Development of solar powered portable incubator and a baby warmer
	Central Electrochemical Research Institute (CECRI)	Failure analyses of the 12V/50Ah lead-acid batteries in the existing solar photovoltaic applications [after two years of operation in the field]
Research Institute Public Sector Enterprise	Indian Association for Cultivation of Science (IACS) Central Electronics Limited (CEL)	Development of secondary reference solar cells and modules. Fabrication of the basic solar cells and modules has been completed. Calibration facilities have been established and calibration of these devices is in progress in different laboratories.
International	International Financial	Quality assurance

Funding Organization	Corporation (IFC)	framework for LED based solar lanterns and off -grid lighting systems on Internationally harmonized test methods.
UK Partners	UK Partners	Stability and performance of photovoltaic. Identification of PV technologies for testing, performance monitoring equipments including ways to measure the weather conditions and the layout of test beds.

Source: Author's Elaboration based on (MNRE, Annual Report 2011 - 2012 Chap8, 2012)

4.2.3.3.2 Diffusion

The scheme for Roof top and grid based small solar power plants (below 33 kV) was launched in June, 2010 with an objective to spread solar power to as many States as possible and to generate database on the performance of solar plants under different climatic and grid conditions (MNRE, Annual Report 2011-2012 Chap6, 2012).

For off-grid solar PV applications, multiple channel partners are being encouraged. They are Renewable Energy Service Providing Companies (RESCOs); microfinance institutions and other financial institutions who are aggregators; financial and system integrators; and programme administrators.

Under Off-grid Solar PV Applications Scheme – subsidy level of 30% of the project cost and/ or loan at 5% annual interest rates for installation of solar lighting systems, water pumping systems and stand-alone power plants. Subsidy of 90% of project capital or ₹ 243/- per watt peak whichever is smaller was available for Special Category States. For assessing the technology diffusion, independent consultants and national level monitors (NLMs) are constituted.

For accelerating the diffusion of solar thermal applications like solar water heating systems, certain measures have been put in place: rebate in property tax and electricity tariff, BIS standards & test facilities for flat plate solar collectors, Solar Energy Centre & four Regional Test Centres for certification and developmental testing, National Building Code, Energy Conservation Building Code (ECBC), and GRIHA have been suitably modified, promoting Energy labelling scheme, over 60 manufacturers accredited by Bureau of Indian Standards (BIS) for producing solar water heating systems using flat plate collectors, in addition over 100 manufacturers have been empanelled for evacuated tube collectors, tested water solar heaters systems.

Extensive publicity and awareness campaigns have been taken up by MNRE. Manufacturers are also provided support for publicity. Seminars, workshops and business meets are being conducted for various stakeholders - Builders, Developers, Housing boards, Development Authorities, Manufacturers and Banks.

4.2.3.4 Small hydropower (SHP) Technology

4.2.3.4.1 Development

In India, Hydro power projects of 25 MW capacity and below are categorized as Small Hydro and MNRE is responsible for developing SHP technologies and projects (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

IMAGE 4.1. SHP PROJECTS.

(a) 22.5 MW Bhilanana Small Hydro Power Project in Uttarakhand

(b) 5 MW Andhra-II Small Hydro Power Project in Himachal Pradesh

(c) 6 MW Nera Small Hydro Power Project in Deoighar, Maharashtra

(d) 20 MW Samal Small Hydro Power Project in Odisha

(e) 7 MW Uiiankal Small Hydro Power Project In Kerala
Source: (MNRE, Annual Report 2011 - 2012 Chap5, 2012)

AHEC organizes training on all aspects of SHP technologies development. It is also striving to promote standardization of SHP technologies under the aegis of MNRE. Presently, a small hydro hydraulic turbine R&D laboratory is being set up at AHEC providing global standard facilities for further technology development (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

4.2.3.4.2 Diffusion

In order to diffuse SHP technologies, MNRE has been offering various incentives and services to various actors that include, finance, surveying and investigation, preparing DPRs, project supervision and training. Electrifying remote and inaccessible villages is one of the key objectives in promoting SHP technologies. To realize this goal, micro hydel projects (100 KW and below) are being promoted by involving local organizations.

4.2.3.5 Wind power Technology

4.2.3.5.1 Development

MNRE's bolsters wind technologies development via supporting surveying and assessing of wind potential, facilitating implementation of technologies - by offering a variety of fiscal and promotional incentives. The Centre for Wind Energy Technology (C-WET) assesses the wind potential along with state arms of MNRE (SNAs). MNRE supports R&D projects through C-WET for in house R&D projects and also through research institutions, national laboratories, universities and industries. C-WET is presently formulating India specific Standards on wind turbine technologies, in co-ordination with Bureau of Indian standards (BIS) (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

India, presently has 18 wind turbine manufacturers with unit size of models ranging from 250 – 2500 KW. The majority of them are joint ventures or are having licensed production agreements, or are foreign subsidiaries in India. The manufacturing base seems to have reached a mature stage, as the industrial organization houses companies which manufacture wind turbines without any foreign collaboration (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

4.2.3.5.2 Diffusion

Promotional Policies: Fiscal incentives include, allowing faster depreciation, rebate on customs duty for certain crucial sub-components, no excise payments, no income over gains on electricity generating capacity, renewable energy purchase obligations, generation based incentives (GBI) (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

4.2.3.6 New Energy Technologies

Under hydrogen energy technologies, inter alia, hydrogen production, its storage and utilization for stationary, motive and portable power generation applications using internal combustion engines and fuel cell technologies are being pursued under RD&D programme (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

MNRE has supported an R&D project for the development of a hydrogen fuelled internal combustion engine at IIT Delhi (Academic System). Later, with Mahindra & Mahindra (Industry) single cylinder hydrogen fuelled engine for a three wheeler was developed jointly. Recognising this development, UNIDO's International Centre for Hydrogen energy Technologies at Istanbul provided partial financial support for its further development by a consortium of IIT Delhi, Mahindra & Mahindra, Air Products and India Trade promotion in 2008-09" (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

TABLE 4.4. NEW TECHNOLOGIES - R&D COLLABORATIONS

Actors Type	**Collaborators**	**Purpose**
Government, Bridging Institutions, Industry	MNRE, SIAM, IOCL, Automobile manufacturers (5)	Hydrogen as a fuel (up to 30%) in CNG
	IIT Delhi	Development of hydrogen fuelled internal combustion engine
	IIT Kharagpur (Lead institute)	Hydrogen production through biological route
	Indian Institute of Technology Kanpur	Experimental investigations on combustion characteristics and emission reductions of a laser fired hydrogen engine
	BHU, Varanasi (Lead institute)	Hydrogen storage in hydrides
Academic	IIT Chennai, Madras (Lead	Carbon materials

System	institute)	
	Birla Institute of Technology – Goa Campus	Analytical and modelling tasks of fuel cells technologies
	Institute of Minerals and Materials Technology, Bhubaneswar and IIT Delhi	SOFC and direct alcohol fuel cells

Source: Author's Elaboration based on (MNRE, Annual Report 2011 - 2012 Chap7, 2012)

4.2.3.6.1 Fuel Cells

MNRE emphasizes research on fuel cell technologies that include processes, key inputs, components and sub-components especially supporting RD&D efforts in this field. RD&D projects on hydrogen storage, applications of hydrogen and fuel cells were continuously reviewed by the concerned Project Monitoring Committees (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

4.2.3.6.2 Tidal Energy Programme

India's long coastline with numerous estuaries and gulfs witnessing stronger tides are ideally suited for promoting tidal energy technologies which are not yet commercialized and are still in the development stage. Under the Tidal Energy Programme, a 3.75 MW tidal power demonstration plant in West Bengal was financed by MNRE (90%) and the Government of West Bengal (10%) (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

Gujarat is promoting studies for realizing tidal energy potential along its coast in association with the private sector. These technologies have some merits over and above the barrage/dam technology like the migratory fishes could get through, a part of section which would be open to allow a ship through, and the tide level further be controlled etc (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

4.2.3.6.3 Geothermal Energy

National Geophysical Research Institute (NGRI), Hyderabad, is a pioneer research institute in India associated with geothermal energy which is conducting Magneto-telluric (MT) studies to assess the deep reservoir temperature of potential sites.

As the geothermal technologies were successfully developed and deployed in many countries and these being a new RET for India, India chose the technology transfer route. Memorandums of Understandings were signed with Governments of Australia, Iceland and Philippines for scientific co-operation, research. Three Indian Companies have already formed collaboration agreements with Icelandic Companies in Geothermal Energy Sector - Reykjavik Geothermal (Iceland) and Thermax (India); A Joint - Venture i.e. Bhilwara Mannvit Green Energy Ltd (BMGEL) by Icelandsbanki (Iceland), Mannvit (Iceland) and Bhilwara Group (India); Kaldara Iceland and Hindustan Turbomachinery, Bengaluru (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

4.2.3.6.4 Battery Operated Vehicles

The MNRE has formulated guidelines for promoting battery operated vehicles including hybrid varieties through the States/ UTs/ SNAs / IREDA resulting in substantial increase of sale in Indian open market. Technologies related to Battery Operated Vehicles are also considered under the framework of Research, Design, Development and Demonstration which includes different types of Batteries, ultra capacitors, super capacitors, control system, battery management systems, motors, light weight chassis and other components (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

A central subsidy of 20% of the ex-works cost of battery operated and hybrid vehicles is available, subject to the limit fixed for each type under the program. This subsidy is available to all categories of users. MNRE is collaborating with various stakeholders to develop and diffuse these technologies at a faster pace (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

4.2.3.7 OFF-GRID RENEWABLE POWER

MNRE is supporting Small Wind Energy & Hybrid Systems (SWES) programme to develop the wind solar hybrid system with the objective of commercializing them with collaboration of industry and users. The manufacturers of the small aerogenerators are getting their machines tested under C-WET's Type testing scheme as per the IEC standards. To introduce use of wind resource maps to develop proposals for wind–solar hybrid systems, "Orientation/ Introduction Programme" are conducted for SNAs (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

IMAGE 4.2. WIND SOLAR HYBRID SYSTEM.

8kW Wind Solar Hybrid System at Satyaniketan Sanstha, Rajur, Akola, Ahmednagar, Maharashtra.
Source: (MNRE, Annual Report 2011 - 2012 Chap5, 2012)

Central Financial Assistance @ ₹2.25 lakh / kW is available for SWES projects that qualify certain locational and technical specifications (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

4.2.3.7.1 BIOMASS GASIFIER PROGRAMME

MNRE is encouraging multifaceted biomass gasifier technology based electricity generation that uses variety of feedstock like small wood chips, rice husk, arhar stalks, cotton stalks and other agro-residues. The actors involved in the implementation are: Independent Power Producers (IPPs), Energy Service Companies

(ESCOs), industries, Co-operative, Panchayats, SHGs, NGOs, manufacturers, entrepreneurs, industries, promoters and developers (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

4.2.3.7.2 SOLAR APPLICATIONS

The solar technology applications are decentralized in nature serving huge and dispersed clientele. They require numerous actors to fulfil the needs of the system. The applications include hybrid technologies to cater to lighting, heating and cooling needs; Solar photo voltaic systems (up to 100 kWp per site); smaller grids to electrify villages (up to 250 kW capacity per site) and to produce heat including steam generation (MNRE, Annual Report 2011-2012 Chap6, 2012).

4.2.3.7.2.1 Solar Thermal Applications

4.2.3.7.2.1.1 Solar Water Heating Systems

In India, the achievable technical and economic solar water heating potential is around 40 million sq. m. of collector area. Till now, a total of nearly 5 million sq. m. collector area is covered. Ministry of Urban Development issued model regulation / building bye-law to all States and Union Territories for installation of rooftop systems. MNRE is collaborating with municipalities and State Electricity Regulatory Commissions (SERC) to offer properly tax concessions and electricity tariff concessions for the users of these systems respectively (MNRE, Annual Report 2011-2012 Chap6, 2012).

Various codes and rating systems, such as, National Building Code (NBC), Energy Conservation Building Code (ECBC), and GRIHA are being promoted for the diffusion of these technological applications. Standards have been instituted in coordination with BIS for flat plate solar collectors, evacuated tubular collectors (ETC), solar water heating systems and test facilities. In the testing network, besides Solar Energy Centre, there are four Regional Test Centres for certification and developmental testing (MNRE, Annual Report 2011-2012 Chap6, 2012).

Solar water heating systems are promoted in various sectors including hotels, hospitals, industries and commercial establishments. Central government ministries are being requested to adopt these systems in their respective sectors (MNRE, Annual Report 2011-2012 Chap6, 2012).

Information dissemination is given a higher priority for the diffusion of these technologies. MNRE is supporting publicity and awareness programmes via print and electronic media. Industry efforts are also incentivised for this purpose. Seminars, workshops and business meets are being conducted for different state holders namely, the builders, developers, housing boards, development authorities, manufacturers and banks were organized" (MNRE, Annual Report 2011-2012 Chap6, 2012).

4.2.3.7.2.1.2 Concentrating Solar Technologies (CSTs) for Community Cooking, Process Heat and Cooling Applications

Concentrating solar technologies are ideally suited for cooking food in community kitchens like in jails, religious places, schools, hotels etc. They are also suitable for process heat, laundry and food processing industries (MNRE, Annual Report 2011-2012 Chap6, 2012).

4.2.3.8 Research, Design, Development and Demonstration (RDD&D)

MNRE promotes RDD&D aimed at developing new RETs. The portfolio includes processes, material inputs, parts, sub-components, technical specifications and assessing potential to achieve indigenous production of RET systems. Efforts of industrial organization are also ably supported under this initiative. (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

During the year 2011-12, 29 RDD&D projects with total budget of cost ₹118.60 crores in the area of solar thermal power, solar photovoltaics, hydrogen and fuel cell, biofuel, and biomass cookstoves have been recommended. The RDD&D projects taken up facilitated strengthening R&D capacities of the R&D institutions, organizations, industries, etc. in pursuing research for technology development with commercial potential in the long term. The Intellectual Property Rights (IPR) related activities are also an integrated part of R&D support of MNRE (MNRE, Annual Report 2011 - 2012 Chap7, 2012).

4.2.3.9 Problems/Barriers

Though the IRETS could move into adolescent stage, it is still fraught with problems. Resource Assessment has been one of the foremost problems leading to under estimation of the potential of various RETs. This is clearly visible from certain proactive states that have crossed the estimated potential already - Tamilnadu (Wind) and Karnataka (Small Hydro).

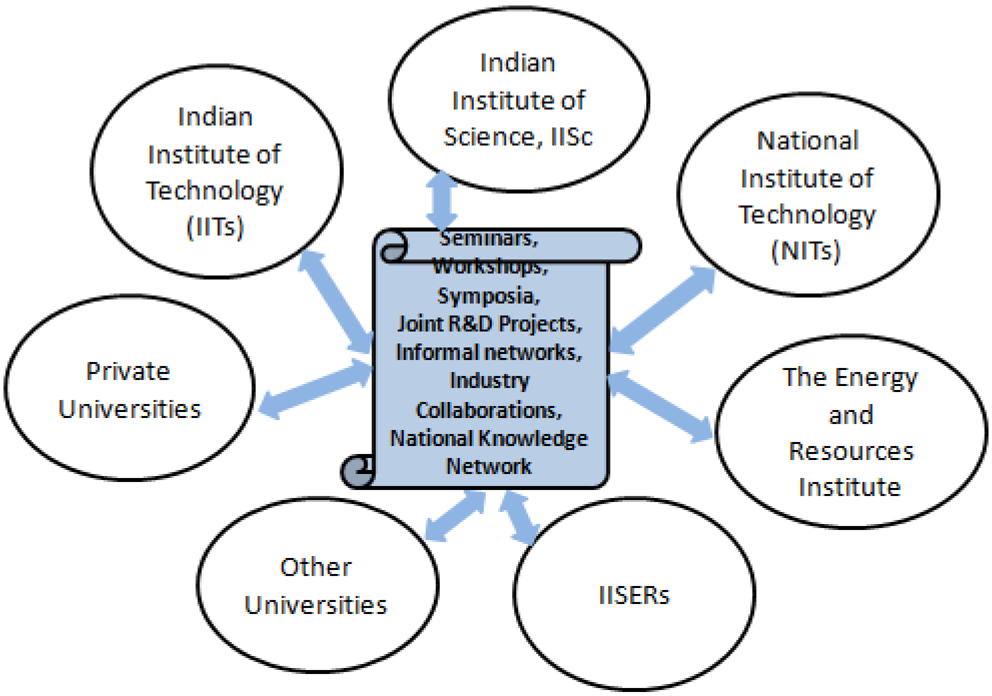
The manufacturing sector though has gained proficiency in certain RETs like solar PV, wind etc, seems to be lagging in MW scale biomass technologies. This is evident from the fact that even in the adolescent stage, India's First 1.2MW Grid-connected Biomass Power Generation System is 100% imported from M/s Shendong Power Machinery Company Ltd., China (MNRE, Annual Report 2011-2012, 2012).

With the launch of JNNSM, Solar technologies seem to get overwhelming attention at the expense of others especially Small hydro and new energies.

4.2.4 Evolution of IRETS: Summary

IRETS has seen a sea of change from being a majorly public sector driven system to private sector driven, which implies that the system is moving towards sustaining itself. In Wind energy technologies, C-WET is presently formulating India specific standards in association with Bureau of Indian Standards. The industry has 18 manufacturers in the country manufacturing 42 models ranging from unit size from 250 – 2500 KW with current annual production capacity 3500 - 4000 MW. In SHP technologies, AHEC is conducting international and domestic training courses signifying the kind of maturity it has gained in the technology.

Today the system could boast of numerous actors in each building block engaged in development and diffusion of various RETs and their constituents. MNRE has been providing a significant direction and leadership in the system by establishing networking amongst them.



Source: Author's elaboration

FIGURE 4.8. INSTITUTIONAL INFRASTRUCTURE: ACADEMIC SYSTEM.

The evolution of IRETS has been summarized in the following table:

TABLE 4.5. THE DEVELOPMENT OF IRETS

	Embryo (until 1980)	Infant (1981–2009)	Adolescent (from 2010)
Industrial organization	Private Entrepreneurs, Social worker, Mr Jashbhai Patel. Rama Krishna Mission, Calcutta. Khadi Pratisthan Sodepur, West Bengal. Central Electronics Limited (CEL), 1974.	CEL, BHEL, BEL, Private Sector, Entrepreneurs, Foreign Firms, Joint Ventures	
Institutional infrastructure	Indian Agricultural Research Institute (IARI), Gobar Gas Research Station, UP. Department of Science and Technology (DST). State Electricity Boards (SEBs). National Aeronautical Laboratory (NAL).	DST. DNES, 1982. MNES, 1992. NCL, University of Pune, AHEC, IIT Delhi, IACS, SEC, NPL.	SERAC, SEIAC, SECI

Technological infrastructure	Large hydro design capabilities, Biogas technology.	CAD, Microprocessors, Semiconductor technology, Accumulation of technological knowledge from foreign collaborations.	Superior R&D partnerships,
Government policy	Biogas technology R&D, since 1920s All India Co-ordinated Biogas Programme (AICBP), 1975. The Solar Photo Voltaic program, 1975.	Solar Thermal Energy Centre Project, 1981. National Biogas and Manure Management Programme (NBMMP), 1981-82. National Programme on Improved Stoves (NPIC), December 1983. National Wind Power Programme, 1983–1984. Thin film amorphous silicon solar cell technology development mission, 1985. National Programme	Renewable Energy Certificate (REC) National Solar Mission

		for Demonstration of Gasification Technology, 1987 Research, Design and Development activities in biogas, bio-energy, 2007-08 National Action Plan on Climate Change, 2008 Solar Cities Development Programme, 2008. GRIHA Certification, 2008. National Biomass Cookstoves Initiative (NBCI), 2009.	
Major interactions/ connectivity		Foreign Collaborations for technology transfer & manufacturing. DNES co-ordinated domestic technology development involving research institutions, academic system, users,	Foreign Collaborations in R&D. MNRE co-ordinated technology development and diffusion involving research institutions,

		manufacturers, voluntary agencies, entrepreneurs.	academic system, users, manufacturers, voluntary agencies, entrepreneurs
Critical mass		DNES Foreign Collaborations	MNRE
Bridging institutions	KVIC	CII	CII, Wind Energy Association (WEA), Indian Wind Turbine Manufacturers' Association (IWTMA), Solar thermal federation of India (STFI), Indian Solar (PV) Manufacturers Association (ISMA), Biomass Developers Association, Indian Biomass Power Association.

Source: Author's Analysis

MNRE as the nodal agency for RETs development and diffusion in IRETS could provide network with the foreign technological systems. MNRE is strengthening the vigour of the system, especially by promoting competition in the industry as well as sponsoring time bound R&D projects to research institutes and academic system with continuous evaluation by project monitoring committees. MNRE is also providing time bound incentives and subsidies for the development and diffusion of RETs which means that the industry over a period of time achieves highest level of efficiency in order to compensate the decreasing benefits and as such the whole system becomes self sustainable.

In the Adolescent Stage, Solar Power is being developed with numerous R&D projects both domestic as well as collaborating with foreign technological systems.

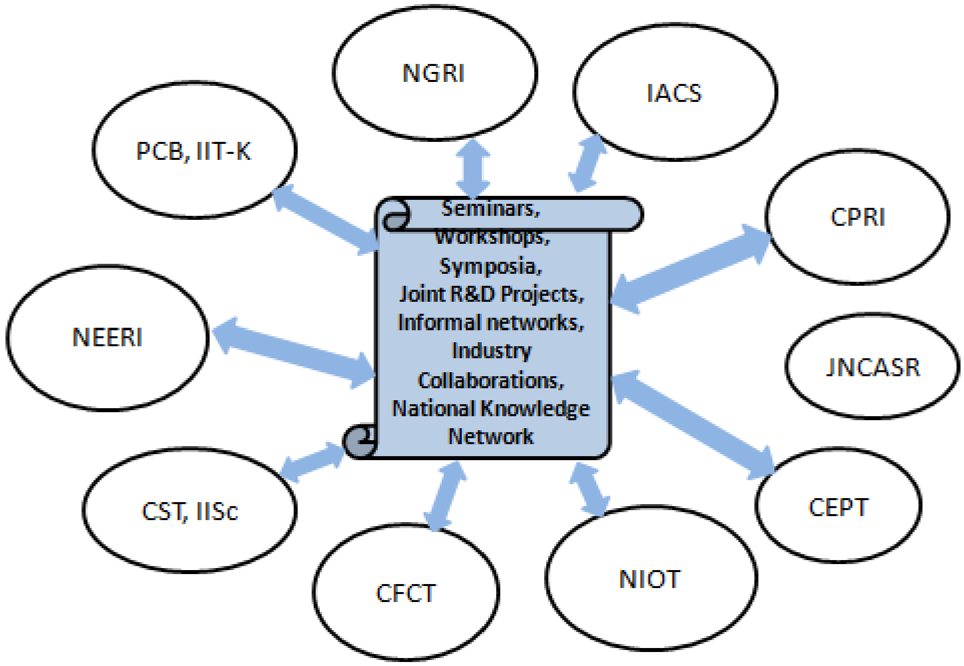
Since RETs are still evolving in terms of improving Capacity Utilization Factor (CUF), declining costs, widening applications etc., path dependency and resistance to change seems to be less. MNRE has been striving to provide numerous networks within the system as well as with global technological system to make sure that the system continuously evolves without any stagnation. The aim of the system is to be as open as possible.

Role of public policy, especially that of MNRE is quite vivid from its multitude of measures and policies to develop, diffuse, utilize and/or identify, absorb, exploit RETs to meet the national energy and developmental needs and also towards adapting to climate change imperatives. It is boosting technology development through its RDD&D policy, supporting entrepreneurs through various fiscal incentives, accelerating RETs diffusion by financing the system, improving the delivery system by engaging numerous actors at cutting edge level and finally enhancing receiver competence through its support programmes.

With the launch of National Action Plan on Climate Change in 2008 and National Solar Mission as one of its key missions in 2010, RETs came to a centre stage. By 1st February, 2012, IRETS could boast 545 of 775 CDM registered renewable energy projects, making it the largest in the world signalling the rapid growth and maturity of IRETS with superior industrial organization, finance and other infrastructure (MNRE, Annual Report 2011-2012, 2012).

Along with the private sector and joint ventures, other public sector companies like Central Electronics Limited (CEL), Bharat Heavy Electricals Limited (BHEL), and Bharat Electronics Limited (BEL) have become pioneers in solar PV manufacturing. CEL developed state-of-the-art solar PV technologies indigenously and its products have qualified International Standards EC503/IEC1215 (CEL, 2012).

Credit goes to MNRE for initiating, handling and overseeing the IRETS development. It has created the technology centres, upgraded certain academia to Centres of Excellence, encouraged entrepreneurs; setup IREDA for financing the projects. As such MNRE established multitude of structures and provided networking amongst them infusing the needed vitality. MNRE was often the source of all other actors to collaborate with foreign technological system. Through numerous initiatives, it could bring together various actors like academia, industry, research institutes, NGOs, SNAs and others.



Source: Author's Elaboration

FIGURE 4.9. INSTITUTIONAL INFRASTRUCTURE: RESEARCH INSTITUTES.

Today the system has 5 manufacturers producing 11 types of small aerogenerators approved by C-WET. India has a wide manufacturing base for small scale hydropower equipment, with 20 active domestic manufacturers with equipment manufacturing total capacity of 300 MW per year. Additionally, there are about five manufacturers producing equipment for micro hydro and watermills (REN21, Renewables 2011 GLOBAL STATUS REPORT, 2011).

4.3 Open Innovation

Though the embryo stage saw attempts by the system to understand the technologies, most of the effort was internal, *i.e.*, no much interaction with the foreign technological systems. It is from the infant stage, that the open innovation has been practised by the system and is being continued till now in a big way. Among the RETs, wind, solar and new technologies are being developed through higher degree of open innovation whereas small hydro and biomass technologies are developed more internally.

The Indo–US Project, 1993 has augmented the capability of the Ramakrishna Mission Ashram (RKM), West Bengal leading to rapid development and diffusion of Solar PV technology in the state of West Bengal (Srinivasan, 2005). C-WET's Wind Turbine Test Station (WTTS) was established under technical assistance of RISO National Laboratory, Denmark under Danish International Development Agency (DANIDA) grant along with partial financial assistance MNRE.

TABLE 4.6. SOLAR TECHNOLOGY R&D: MULTI-INSTITUTIONAL ACTORS

Actors Type	Collaborators	Purpose
Government,	MNRE IIT Bombay (Main implementer) Consortium of	Megawatt Scale National Solar Thermal Power Testing, Simulation and Research Facility

Academic System Industry	Industries (7)	
	MNRE IIT Bombay Industry in Nashik	Liquid Desiccant based Solar Multi-Utility Heat Pump
Government, Industry Global Research Institutions	MNRE Sunborne Energy, Research institutions in USA, Spain and Switzerland	1 MWth solar tower with largest size heliostats in the world
Government, Charitable Trust, Industry German Govt. German Research Institution	MNRE, World Renewable Spiritual Trust, Mt. Abu German Government. Fraunhaufer Institute for Solar Energy, Germany	1 MW solar thermal power plant using dish technology for direct steam generation mode

Source: Author's Elaboration based on (MNRE, Annual Report 2011-2012 Chap6, 2012)

TABLE 4.7. WIND TECHNOLOGY DEVELOPMENT - OPEN INNOVATION

Foreign Firm		**Indian Firm**	**RET**
Country	**Firm Name**		
Germany	Enercon GmbH	Enercon (India)	Wind
	Suzlon Energy	Suzlon Energy Ltd	Wind

	GmbH		
	Wind Technik Nord	Siva Windturbine India	Wind
	TTG Industries Ltd (Husumer Schiffswerft, Germany)	Shriram EPC Ltd	Wind
	VENSYS Energy AG's Technology	Regen Powertech	Wind
	Kenersys GmbH	Kenersys India	Wind
Spain	Gamesa Innovation and Technology, S.L	Gamesa Wind Turbines Private Ltd	Wind
USA	GE Infrastructure Technology International	GE India Industrial Pvt. Ltd	Wind
Austria	AMSC-WINDTEC GmbH	Inox Wind Ltd	Wind
The Netherlands	WindFin B.V.	Leitner Shriram	Wind
Denmark	Vestas Wind Systems A/S	RRB Energy Ltd	Wind
		Vestas Wind Technology India Pvt Ltd	Wind
Finland	Winwind Oy	Winwind Power Energy Pvt. Ltd	Wind

Source: Author's Elaboration based on (C-WET, RLMM, 2012)

4.4 IRETS - Human Resource Development

Support Programmes were always an important component of MNRE's activities. Information and public awareness programmes, international relations, seminar and symposia, human resources development (HRD) were crucial among them.

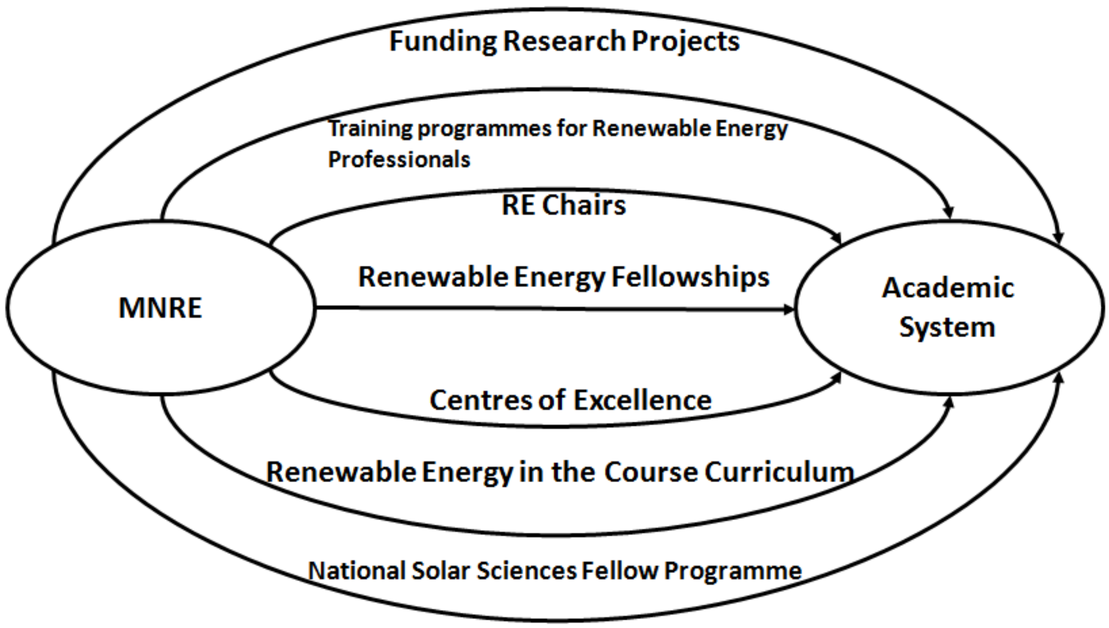
TABLE 4.8. MNRE - SUPPORT PROGRAMMES

Type of Education/Training	**Technology**	**Purpose**	**Target Audience**
Awareness seminars	Solar	Market development of solar water heaters	Various sectors
Training programmes	Solar	Preparing DPRs	Local consultants, SNAs, Programme Administrators, Builders and Architects, Installers, Technicians, etc. in Urban clusters, Technicians/engineers and Industrial consultants in pharmaceuticals, chemical, metal and auto component industries.
Online tools, Fact sheets, Reference manuals, Checklists and Case studies	Solar	Solar Water Heating	Hospitality sector

Publicity and Awareness Campaign through Print media, MNRE Website, Toll free helpline number, Electronic monthly newsletter, Emails, Hoardings, User's Handbook	Solar	Solar Water Heating	Public
SWH calculator, Training Manuals	Solar	Solar Water Heating	Installers, Trainers, Builders & Architects & other stakeholders
Model project reports for setting up of SWH manufacturing units & Model Entrepreneurship	Solar	Solar Water Heating	Entrepreneurs
Interaction	Solar	Solar thermal energy applications	Individual industrial sectors
Participating in Exhibitions	Wind	Wind Energy Awareness	Public

Source: Author's Elaboration based on (MNRE, Support Programmes, 2012)

MNRE supports various HRD programmes and initiatives to institutionalize the renewable energy education and training. It strengthens selected educational institutions, which have already been active in renewable energy education. Provisions of award of renewable energy chairs, support for lab and library upgradation, fellowships, course development have been incorporated in the HRD programme of the Ministry besides supporting the innovation and incubation activities (MNRE, Support Programmes, 2012).



Source: Author's Elaboration on (MNRE, Support Programmes, 2012)

FIGURE 4.10. MNRE - HRD INITIATIVES.

The four technology centres in the system namely - SEC, C-WET, AHEC and SSS-NIRE also undertake HRD initiatives at a more formal academic level by offering graduate and post-graduate programmes in RETs based on their core competence. The following table summarizes various HRD initiatives taken by different actors in the system.

TABLE 4.9. IRETS - HUMAN RESOURCE DEVELOPMENT

Actor (Name)	Actor (Name)	HRD Initiative
Technology Centre (SEC)	Academic System (IIT Bombay)	Development of course material on power electronics for students on solar photovoltaic technology.
Technology Centre (C-WET)	Industrial Association, Academic System (PSG College of Technology, Coimbatore and Amrita school of Engineering, Coimbatore)	Organized three 6- month certificate courses two 9-month post graduate diploma courses on different aspects of operation and maintenance of wind energy installations respectively.
	C-WET	National Training Course on "Wind Energy Technology"
		International Training Course on "Wind Turbine Technology & Applications"
Technology Centre (C-WET) & Industrial Association	C-WET, IWTMA	One day seminar on "The Challenges and Opportunities in Indian State Grid System for RE penetration"
	Academic System (IIT Roorkee and IIT Kharagpur)	Renewable Energy Chairs
	Academic System (IIT Kharagpur)	Establishing Department of Energy Science at IIT Kharagpur, Formulation of its academic programme, Starting Courses on Bio-Energy in

Government (MNRE)		collaboration with University of Berkeley, Formation of a core group of faculty members from related departments to work on energy related programme and research.
	Research Fellows	Under the National Renewable Energy Fellowship Programme, 62 National Renewable Energy Fellows were provided fellowships during 2009-10 and 2010-11.
	Government (Directorate General of Employment and Training (DGET), Ministry of Labour) Academic System (Advanced Training Institutes)	To cater the requirement of technicians at grass root level, Solar lighting systems, solar cooker, solar hot water systems and small hydro were incorporated in the syllabus of seven trades of two years certificate course of ITI. These institutions were provided some systems and equipment for practical training. These institutes are now undertaking regular training courses for instructors of various ITIs in the country
	Government (State Nodal Agencies)	Short-term training programmes on solar energy systems (based on syllabus developed for ITIs) to be implemented in collaboration of local ITIs.
	Research Fellows	National Solar Science Fellowship Scheme was initiated during the year 2010-11. Selection process for awarding National Solar Science Fellows has been initiated.
	Academic System	MNRE has been supporting Centre for Innovation, Incubation and

	(IIM Ahmedabad)	Entrepreneurs (CIIE) of IIM Ahmedabad to promote innovation in renewable energy area and to provide start-up support. This Centre is being developed as a Centre of Excellence to help in scouting and mapping, designing, development and piloting of new and innovative ideas in solar and other renewable energy sector. CIIE Initiatives has launched an “Indian Fund for Sustainable Energy (INFUSE)” under this project

Source: Author's Elaboration based on (MNRE, Support Programmes, 2012)

4.5 Costs and Regulatory Frameworks in the System

Costs are the overriding barrier that is standing in the way of faster diffusion of RETs. Even today, costs are prohibitively high for entrepreneurs to venture into the system as well as for users to enjoy the fruits of RETs. Invariably, all over the world, governments have to step in to fill the gap by way of offering incentives and subsidies. In India, MNRE has shouldered this responsibility to a larger extent complemented by various regulations and policies.

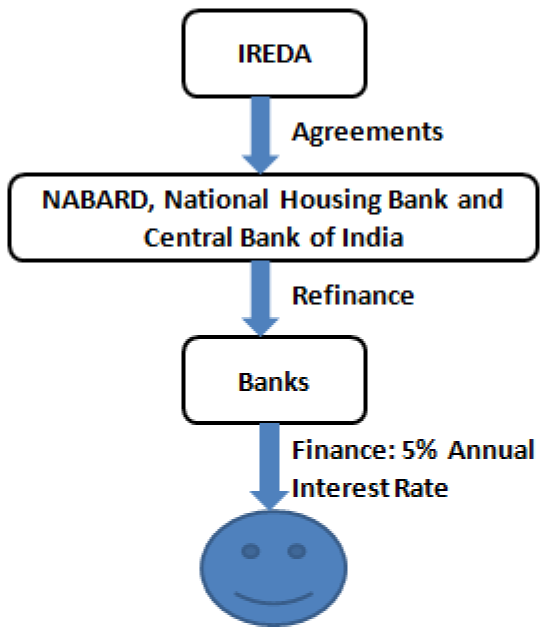
TABLE 4.10. CAPITAL COST TRENDS ACROSS VARIOUS RETs

		Capital Cost Norm derived by CERC in ₹[a] Lakh[b]/MW			
		2009-10	**2010-11**	**2011-12**	**2012-13**
Wind		515	467.13	492.52	575
Solar	PV	1700	1690	1442.00	1000
	Thermal	1300	1530	1500	1300
Biomass		450	402.54	426.03	445
SHP	HP, Uttarakhand and NES (less than 5 MW)	700	634.94	669.42	770
	HP, Uttarakhand and NES (5MW to 25 MW)	630	571.44	602.48	700
	Other States (below 5 MW)	550	498.88	525.97	600
	Other States (5MW to 25 MW)	500	453.53	478.16	550
Non-fossil fuel based co-generation projects		445	398.07	421.3	420

Source: (CERC, Orders, 2012)
a. ₹ is Indian Rupees (INR)
b. One Lakh = 100,000

The above table shows the capital cost in lakhs per MW of each RET type. Solar PV has shown a consistent down trend which is also a drastic reduction in just four years. Technological changes, government promotions have been major factors behind such capital cost reduction. On the other hand, all others have shown a mixed trend of increasing and decreasing. This can be attributed to changing government promotional incentives to some RETs (Wind), remote and inaccessible locations (SHP), lack of availability of raw material (Biomass).

Capital has been infused into the system by establishing IREDA, a public sector company in 1987, as an arm of MNRE to provide term loans for RET projects. IREDA has played a seminal role in attracting private sector participation for setting up renewable energy projects. Entrepreneurs were encouraged in a big way with these loans who are now shouldering significant role in industrial organisation block. For off-grid applications, IREDA financing system is depicted below:

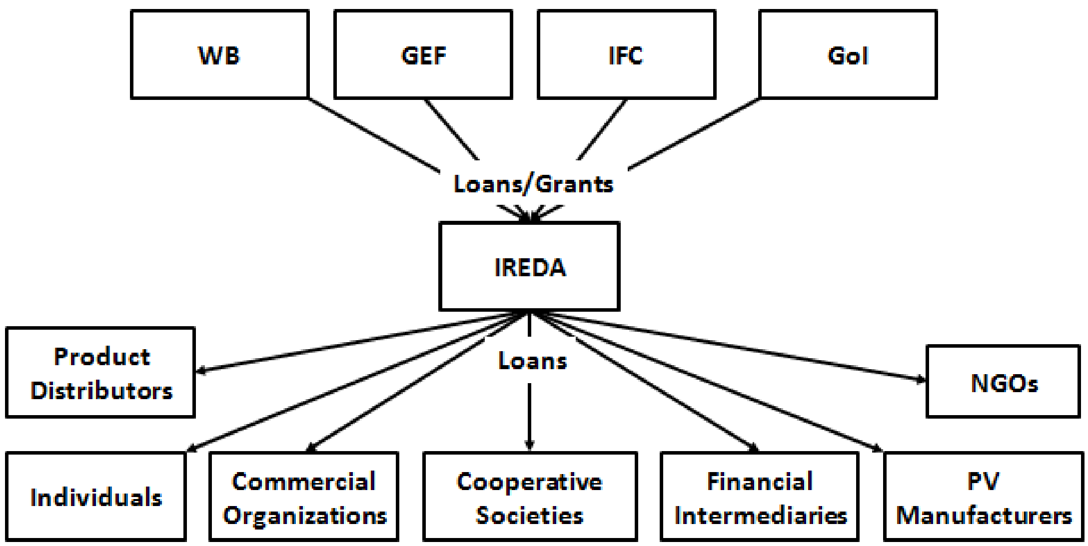


Source: Author's Elaboration on MNRE, 2012.

FIGURE 4.11. IREDA - OFF-GRID APPLICATIONS FINANCE SYSTEM.

Fiscal concessions mentioned previously along with 100% foreign direct investment are promoted to take care of the cost requirements in the system (MNRE, Annual

Report 2011-2012, 2012). The Electricity Act 2003 (EA 2003), National Electricity Policy 2005, National Tariff Policy (NTP) 2006, Integrated Energy Policy, 2006, have various provisions related to tariff determination for grid connected RETs as well as roles and responsibilities of Central Electricity Regulatory Commission (CERC), SERCs, Central Electricity Authority (CEA) are established clearly for promoting RETs in terms of finances.



Source: Author's Elaboration on (Bhargava, 2001)

FIGURE 4.12. IREDA: BORROWER AND LENDER.

4.6 Performance of the IRETS

Performance is a multi-dimensional concept. Though the locus of performance assessment of the IRETS comprises of production, trade, costs, development, energy augmentation and energy access, the focus is confined to the development, especially providing energy access to rural and inaccessible areas and thereby opening up a new wave of socio-cultural and economic opportunities for them.

Renewable energy has increasingly making visible and dominant impact on the Indian energy scenario. In India, the total installed grid based renewable capacity was 23 GW till January, 2012 which is around 12% in the national total installed capacity. Decentralized and distributed RETs systems have supported India's innumerable village population by catering to their basic energy needs - cooking and lighting (MNRE, Annual Report, 2011 - 2012, 2012).

> "The social and economic benefits include reduction in drudgery among rural women and girls engaged in the collection of fuel wood from long distances and cooking in smoky kitchens, minimization of the risks of contracting lung and eye ailments, employment generation at village level and ultimately improvement in the standard of living and creation of opportunity for economic activities at village level" (MNRE, Annual Report, 2011 - 2012, 2012, p. 1).

4.6.1 An Implicit Rural Development Approach

MNRE is promoting Remote Village Electrification (RVE) Programme to provide electricity for basic needs using RETs in unelectrified, isolated and remote villages where conventional technologies could prove costly or are not feasible to be connected to grid in foreseeable future. This is implemented in coordination with Ministry of Power, Rural Electrification Corporation, Ministry of Panchayati Raj and Planning Commission. MNRE has been conducting training, awareness and orientation programmes in different states to involve various stakeholders. One such testimony is detailed below (MNRE, Annual Report 2011-2012, Chap3, 2012).

IMAGE 4.3. PICHILIGUDA VILLAGE.

Source: (MNRE, Annual Report 2011 - 2012 Chap3, 2012)

The tribals of Pichiliguda Village, Rayagda District, Odisha hardly have any access to modern amenities. To meet their illumination needs at night, people use only kerosene wick lamps (debris) often rationing the little kerosene. Under RVE programme, 37Wp solar home lighting systems to each household and community centre and 5 numbers of 75Wp solar PV street lighting systems in prominent places in the village were installed. Village Energy Committee which oversees the maintenance and upkeep of the systems was constituted and trained in assembling and installing solar lighting systems by the vendor M/s Central Electronics Limited. The trained village youths are taking care of routine maintenance of the systems like cleaning of modules, topping up of the batteries etc. Every household gets reliable illumination for 4 to 5 hours after darkness and 5 street lights glow from dusk to dawn illuminating the village streets and approach roads. Now after darkness, children are studying under the light, people have enhanced opportunity for productive applications such as leaf stitching etc. In addition, people are able to save a part of their expenditure on kerosene (MNRE, Annual Report 2011-2012, Chap3, 2012).

MNRE has conceptualized and has been implementing Village Energy Security Test Projects to provide energy security using RETs particularly through biomass based technologies which were developed in the 10th Plan and 65 such projects have been commissioned so far (MNRE, Annual Report 2011-2012, Chap3, 2012).

4.6.2 Production and Trade Indicators.

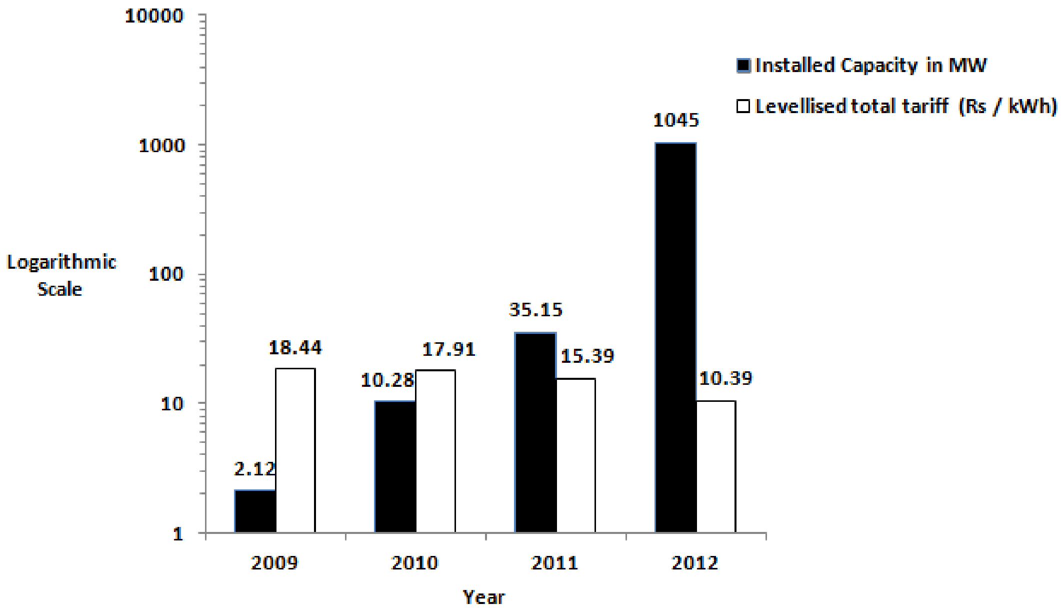
Bagasse cogeneration has seen the following improvements in process parameters, especially higher pressure/ temperature configuration which ensures high energy efficiency & better utilization of bagasse resulting in more steam and hence more electricity. For example, an additional power generation of about 6% was made possible by 105 kg. / Sq.cm and 5200C configuration.

TABLE 4.11. BIOMASS TECHNOLOGY - IMPROVEMENTS IN PROCESS PARAMETERS

Year	Pressure/ Temperature Configuration
1980	45 kg/sq.cm./440^{0}C
1994	65 kg/sq.cm/485^{0}C
2004	87 kg./ sq.cm and 515^{0}C
2009	105 kg./ sq.cm and 520^{0}C
2011	110 ata./535^{0}C

Source: Author's Elaboration based on (MNRE, Annual Report 2011 - 2012 Chap5, 2012)

Solar PV technologies have been improving remarkably year on year and the system has seen the technologies becoming cheaper and affordable. Also it is noticeable that the installed capacity in solar PV has taken a giant leap in the year 2012 compared to the modest figures until 2011, thanks to JNNSM. Figure 4.1.3 below signifies such a trend clearly.



Source: Author's Elaboration on (PIB, 2012) and (CERC, Recent Orders/Records of Proceedings, 2012)

FIGURE 4.13. SOLAR PV: TRENDS IN COSTS AND INSTALLED CAPACITY.

Trade balance of the IRETS for the years 2005 to 2009 remained positive in favour of the system. Though India is a developing country, it could develop it's RET system to such a level where it is strong and competitive enough to maintain a positive trade balance. Being a labour intensive industry, inter alia is a major reason for having trade surplus in IRETS.

TABLE 4.12. SOLAR PV - TRADE SCENARIO

Year	Exports	Imports	Trade Balance	Net Export Ratio
2005-06	318	182	136	0.272
2006-07	499	415	84	0.091904
2007-08	956	677	279	0.170851
2008-09	2452	1750	702	0.167063

Source: Elaboration based on (ISA, 2010)

4.6.3 Achievements

The achievements of the IRETS in terms of grid-interactive power, off-grid/captive power, remote village electrification and other renewable energy systems are summarized below in the table as of 31.01.2012.

TABLE 4.13. CUMULATIVE DEPLOYMENT OF VARIOUS RET SYSTEMS AND/OR DEVICES IN INDIA AS ON 2012.01.31

Renewable Energy Programme or System		**Up to 2012.01.31 (Cumulative Achievement)**
I. Power From Renewables:		
A. Grid-interactive Power (Capacities in MW)		
Wind Power		16179
Small Hydro Power		3300.13
Biomass Power		1142.6
Bagasse Cogeneration		1952.53
Waste to Power	Urban	20.2
	Industrial	53.46
Solar Power (SPV)		481.48
Total		23129.4
B. Off-grid/Captive Power (Capacities in MW_{Eq})		
Waste to Energy	Urban	3.5
	Industrial	89.43
Biomass (non-bagasse) Cogeneration		347.85
Biomass Gasifiers	Rural	15.99
	Industrial	132.27
Aero-Generators/Hybrid Systems		1.45
SPV Systems (> 1 kW)		81.01
Water Mills/Micro hydel (Nos.)		2025
Total		671.5
II. Remote Village Electrification		
No. of Remote Village/Hamlets provided with RE Systems		9009
III. Other Renewable Energy Systems		
Family Biogas Plants (No. in Lakh)		44.75
Solar Water Heating - Coll. Areas (Million m^2)		4.98

Source: (MNRE, Annual Report, 2011 - 2012, 2012)

A solar 37/74 Wp PV module provides light for 4-5 hours a day which can also run a television and a fan. These are used in the states of Jammu & Kashmir, Rajasthan, Himachal Pradesh, Uttar Pradesh and West Bengal. The solar lantern has replaced the kerosene hurricane lantern in many rural areas. Now the users are free from insufficient lighting, pollution and fire hazards. Rural clinics, hostels, police stations, etc are benefitting from solar lanterns (Bhargava, 2001).

Notable and proud achievement of RETs in IRETS is the electrification of villages in Andaman, Nicobar and Lakshadweep islands through stand-alone PV power plants of 1- 25 kW capacity thereby freeing these islands from generating power using generators fuelled by diesel that is shipped from the mainland (Bhargava, 2001).

MNRE engaged seven independent Consultants to carry out monitoring and evaluation of off-grid SPV systems installed in 27 States and Union Territories in the initial years of the 11th Five Year Plan (2007–2012). According to the reports for many of the states, more than 90% of the solar lighting systems and solar power plants are in working conditions and about 70% of solar street lighting systems are found to be in working order. Also appointed were the National Level Monitors (NLMs) to carry out independent evaluation of off-grid SPV systems installed during 2010-11, in seven States. As per them, most of the systems were found in working order (MNRE, Annual Report 2011-2012 Chap6, 2012).

4.6.4 One of a Kind Technology System

IRETS could boast of many one of its kind technological initiatives and achievements within the global technological system. In the year 2011, Country's First 110

ATA/5350C & 180 TPH Capacity Co-Generation Project was commissioned and has achieved a PLF of 80% in first three months of commercial operation. A 1.2 MW Grid Connected Power Plant Based on Gasification Technology, first power project of this size, has been commissioned in the country and has been operational since October 2011 (MNRE, Annual Report 2011 - 2012 Chap5, 2012).

The world's first solar thermal cooling system using triple effect Vapor Absorption technology was successfully implemented in the system during 2011. It combines low cost high efficient parabolic trough concentrators integrated with triple effect vapor absorption machine that provides the highest efficiency at the lowest cost thereby leading to significant reduction in the requirement of the solar field resulting in reduced cost and the foot print of these systems. A heliostat of 150 sq.m surface area has been designed and developed in the system which is one of the largest size heliostats in the world. Cost effective pedestal mechanism for azimuth drive of the heliostat is also developed indigenously (MNRE, Annual Report 2011-2012 Chap6, 2012).

ARUN® solar dish – a Fresnel Paraboloid Solar concentrator with point focus has been developed indigenously by the system for Industrial process heat & cooling. It saves an equivalent of 35,000 to 40,000 litres of HSD per annum. In a first of its kind, a 1 MWe grid interactive solar thermal power plant is being set up using parabolic trough technology for indirect heat generation (about 3 kWth) while the linear Fresnel collectors are used to generate direct steam (about 2 kWth) (MNRE, Annual Report 2011-2012 Chap6, 2012).

Chapter 5

TECHNOLOGY FORECASTING

TECHNOLOGY FORECASTING

5.1 Introduction

Technological forecasting is related with the diffusion of an innovation i.e., to predict their growth and direction. A typical diffusion process passes through an early adoption stage which is generally slow, followed by a rapid adoption phase and reaching a phase of tapering rate of adoption. The S shaped or sigmoid curves have been used to explain this diffusion process and the spread of new technologies. Though there are various functions that describe the S-shaped curves, the two popular diffusion models of S-curve depicting various growth patterns are the logistic and the Gompertz functions (Das, 2012).

5.2 Logistic and Gompertz

As mentioned in chapter 3, the following forms of Logistic function and Gompertz function are used in the technology forecasting. To model the growth pattern of renewable energy technologies in India as a whole and wind, small hydro and biomass renewable energy technologies in top ten states (based on their maximum potential in each energy type) in India, the logistic function used is given by:

$$y = f(t) = \frac{K}{1+e^{-a-bt}}$$

The Gompertz function used for the modelling purpose of renewable energies in India as well as for wind, small hydro and biomass renewable energies in top ten states (based on their maximum potential in each energy type) in India is given by:

$$y = f(t) = Ke^{-ae^{-bt}}$$

where,

K is the saturation level

y is the state of growth at time t

a and b model the location and shape of the curve, respectively.

The forecasting process is carried out using two software tools - Microsoft Excel and IIASA - Logistic Substitution Model II. The differences in terms of the results given by the two tools have been observed and compared where necessary. Excel helps in providing a clear picture of the diffusion trend till the carrying capacity is reached. IIASA model helps in performing Fisher-Pry transform of the Logistic fit to understand the orderliness of the diffusion process. It also helps to see the other S-shaped forecasting functions like Sharif-Khabir, Floyd, Exponential and Linear.

5.3 Choosing Between the Logistic and the Gompertz Functions

Based on the visibility, coefficient of determination (R^2), the mean square error (MSE), the mean absolute deviation (MAD) and auxiliary regression as given by

Franses (Franses, 1994), one of the two functions is chosen and used for forecasting the required renewable energy.

The estimated potential of total renewable power reserves (the carrying capacity or saturation level K) in India as on 31.03.11 is 89760 MW which was taken from the Energy Statistics, 2012 published by the Ministry of Statistics and Programme Implementation, Government of India. This potential is nothing but the aggregate of state wise and source wise potential of the renewable power reserves which are also given in the publication.

TABLE 5.1. RENEWABLE ENERGIES AND RESPECTIVE TOP TEN STATES CHOSEN

Wind Power		Small Hydro Power		Biomass Power	
States	**Potential in MW as on 31-03-2011**	**States**	**Potential in MW as on 31-03-2011**	**States**	**Potential in MW as on 31-03-2011**
Gujarat	10609	Himachal Pradesh	2268	Punjab	3172
Karnataka	8591	Uttarakhand	1577	Maharashrta	1887
Maharashrta	5439	Jammu & Kashmir	1418	Uttar Pradesh	1617
Andhra Pradesh	5394	Arunachal Pradesh	1329	Madhya Pradesh	1364
Tamilnadu	5374	Chhattisgarh	993	Haryana	1333
Jammu & Kashmir	5311	Madhya Pradesh	804	Gujarat	1221
Rajasthan	5005	Karnataka	748	Karnataka	1131
Madhya Pradesh	920	Maharashrta	733	Tamilnadu	1070
Odisha	910	Kerala	704	Kerala	1044
Kerala	790	Tamilnadu	660	Rajasthan	1039

Source: (MOSPI, 2012)

Based on the aforementioned criteria, for India, Gompertz function is the best fit (See Appendix 1). For the states, for each RET, one of the two functions that fit better has been chosen (See Appendix 1 for both the curves) as given below:

TABLE 5.2. STATES, RETs AND MODELLING FUNCTION

Wind Power		**Small Hydro Power**		**Biomass Power**	
States	**Forecasting Function**	**States**	**Forecasting Function**	**States**	**Forecastin g Function**
Gujarat	Logistic	Himachal Pradesh	Gompertz	Punjab	Gompertz
Karnataka	Gompertz	Uttarakhan d	Gompertz	Maharashrt a	Gompertz
Maharashrt a	Gompertz	Jammu & Kashmir	Logistic	Uttar Pradesh	Logistic
Andhra Pradesh	Gompertz	Arunachal Pradesh	Gompertz	Madhya Pradesh	
Tamilnadu	Gompertz	Chhattisgar h	Gompertz	Haryana	Logistic
Jammu & Kashmir		Madhya Pradesh	Gompertz	Gujarat	
Rajasthan	Gompertz	Karnataka	Gompertz	Karnataka	Gompertz
Madhya Pradesh	Gompertz	Maharashrt a	Gompertz	Tamilnadu	Gompertz
Odisha		Kerala	Gompertz	Kerala	
Kerala	Gompertz	Tamilnadu	Gompertz	Rajasthan	Gompertz

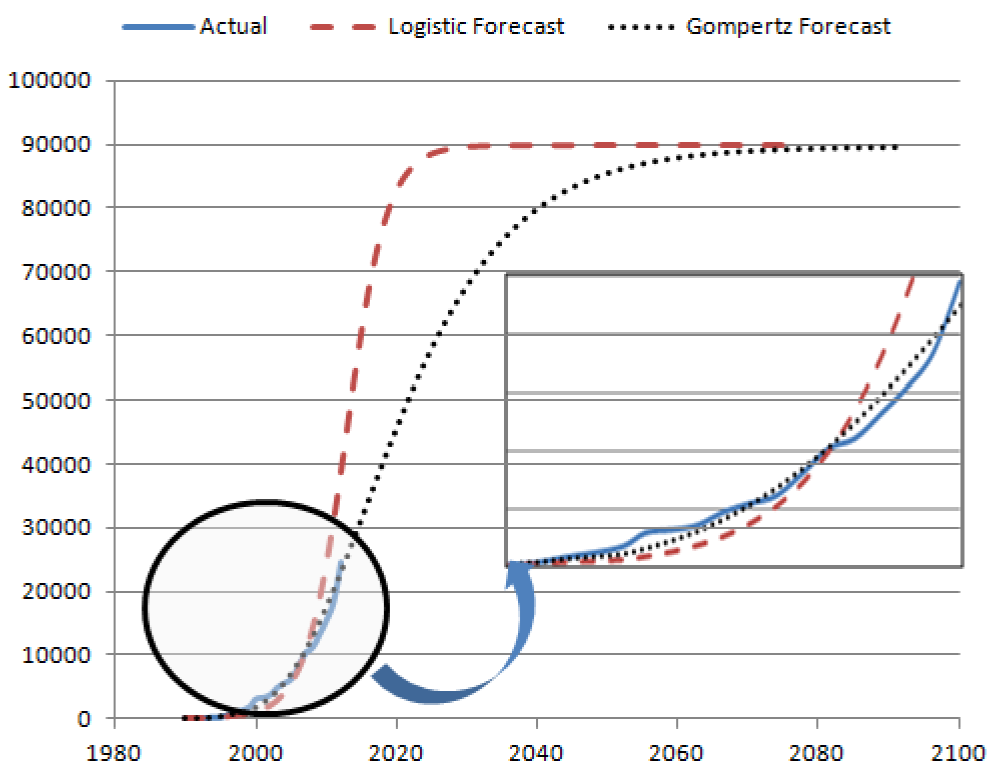
Source: Author's Analysis and Elaboration

#Grey Cells indicate no development of particular RET despite having good potential.

The results given by the IIASA model are considered to be more accurate than those given by the Excel. Therefore, for analysis purpose, the IIASA results are chosen. See Appendix for the results given by the Excel.

5.4 India - RET Projections

With the Excel, the visibility criteria are much more pronounced in the case of RETs scenario for India. It is clearly established that the actual growth pattern is strictly following the Gompertz function as shown in the Figure 5.1.



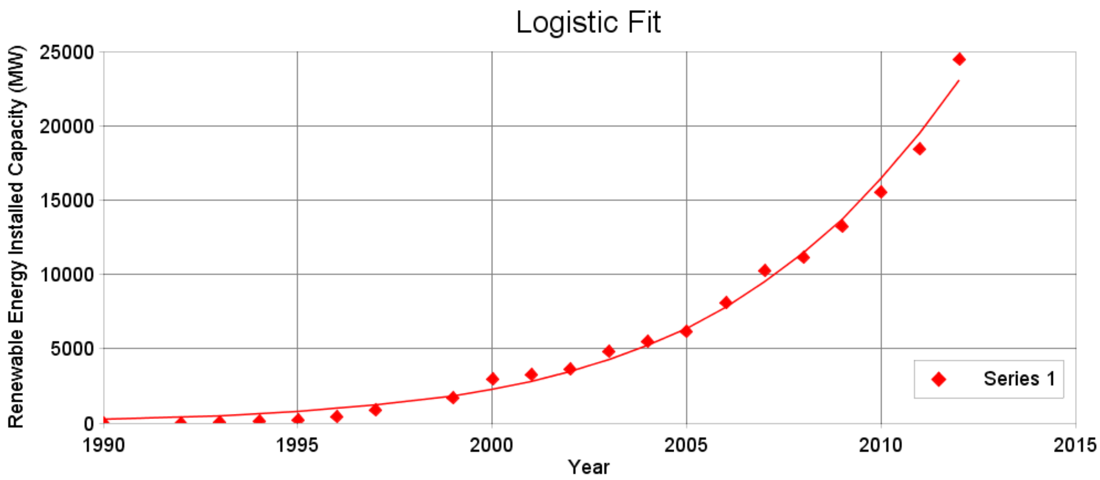
Source: Author's Analysis

FIGURE 5.1. INDIA - PROJECTED RENEWABLE ENERGY INSTALLATION CAPACITY.

The projection of RETs installation in India along the time axis is shown in Figure 5.1. The S-pattern of the curve reiterates that, growth is very slow in the initial years indicating the presence of various barriers to implement new technology followed by a phase of rapid growth which at a later stage slows down while approaching the saturation level, K. Upto the inflection point, growth rate or capacity addition increases and beyond the inflection point, growth rate increase is decelerating.

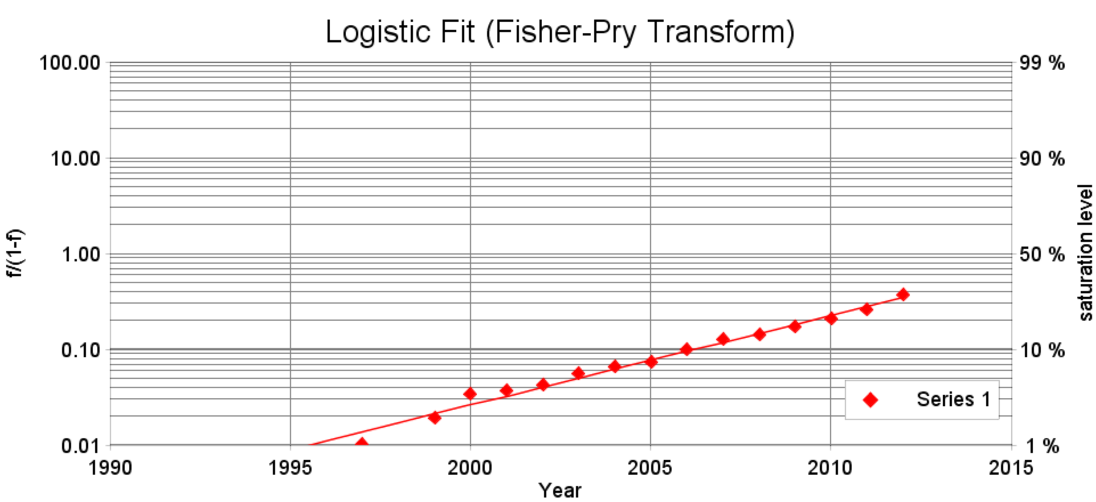
For India and those states where the Gompertz function seems to fit better means that, growth is relatively rapid during initial phase and increasingly slows down in the attempt to reach the saturation level than that of logistic model. It exhibits maximum rate of growth during earlier phase when compared to the logistic model. For those states whose RETs future growth is best explained by the logistic function means that, the growth is slow during early phase and more rapid towards the maturity. The logistic model witnesses a higher rate of growth during the later phase in comparison with the Gompertz model.

The growth of RETs in India has witnessed a rapid pace in the recent past and assuming the same trend, according to this study, the Gompertz function suggests that, India could achieve 99% of its potential in RETs by the year 2068 *i.e.*, 88862 MW. This means that, in India, the diffusion of RETs as an energy alternative could reach 99% of the estimated RETs potential by the year 2068 (From Excel). For India, the time period required to achieve its RETs potential from 10% to 90% is 36.14 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2017 (based on the IIASA model).



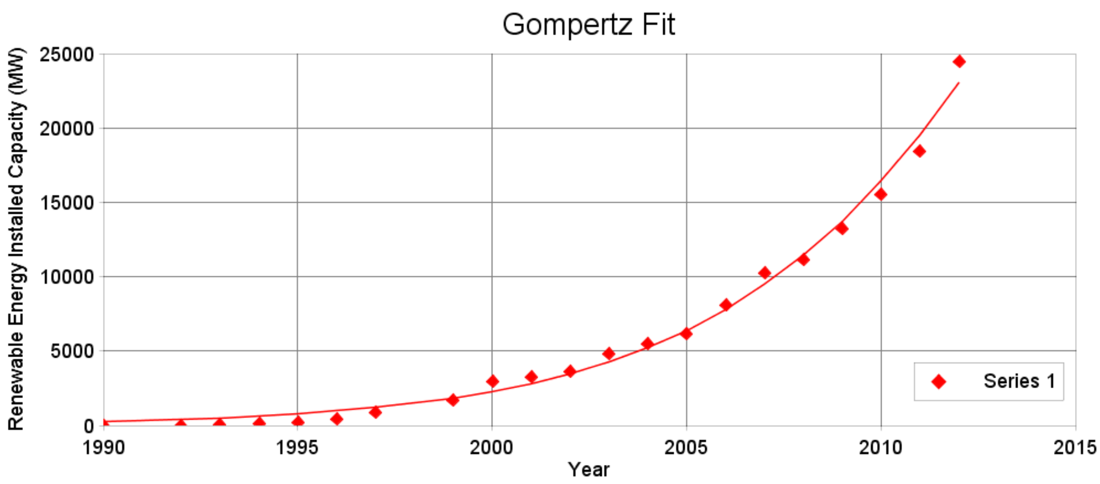
Source: Author's Analysis.

FIGURE 5.2. LOGISTIC FIT - IIASA MODEL.



Source: Author's Analysis.

FIGURE 5.3 LOGISTIC FIT (FISHER-PRY TRANSFORM) - IIASA MODEL.

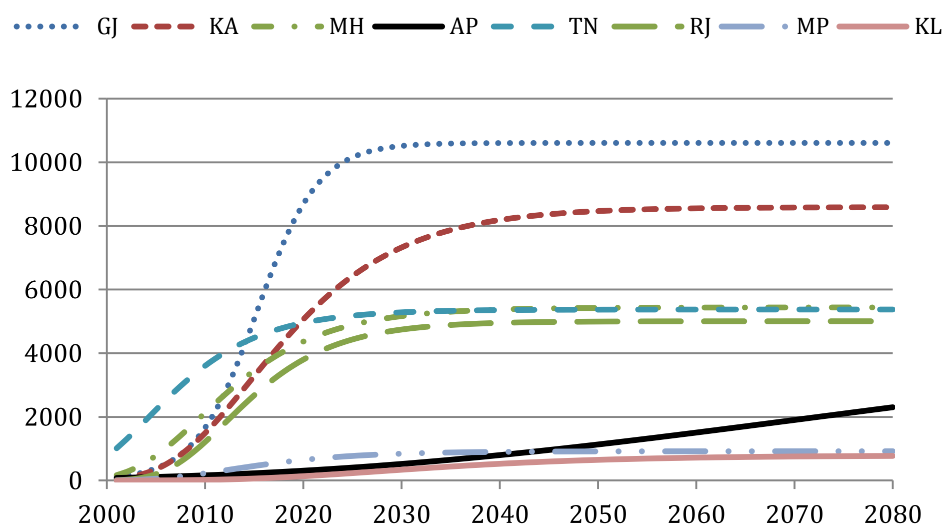


Source: Author's Analysis.

FIGURE 5.4 GOMPERTZ FIT - IIASA MODEL.

5.5 States and Wind Energy Technologies

The modelling for states in wind energy technologies is shown in the figure.



Source: Author's Analysis

FIGURE 5.5. STATES - PROJECTED WIND ENERGY INSTALLATION CAPACITY.

Gujarat could achieve 99% of its potential in wind energy technologies by the year 2030 *i.e.*, 10513.99 MW. This means that the diffusion of wind energy technologies as an energy alternative in Gujarat could reach 99% of the estimated potential by the year 2030 (from Excel). For Gujarat, the time period required to achieve its wind energy technologies potential from 10% to 90% is 13.83 years. The inflection point as explained by the logistic function is reached nearly by the year 2016 (based on the IIASA model).

Karnataka could achieve 99% of its potential in wind energy technologies by the year 2053 *i.e.*, 8504.27 MW. This means that, the diffusion of wind energy technologies as an energy alternative in Karnataka could reach 99% of the estimated potential by the year 2053 (from Excel). For Karnataka, the time period required to achieve its wind energy technologies potential from 10% to 90% is 29.14 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2016 (based on the IIASA model).

Maharashtra could achieve 99% of its potential in wind energy technologies by the year 2041 *i.e.*, 5382.63 MW. This means that, the diffusion of wind energy technologies as an energy alternative in Maharashtra could reach 99% of the estimated potential by the year 2041 (from Excel). For Maharashtra, the time period required to achieve its wind energy technologies potential from 10% to 90% is 20.65 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2010 (based on the IIASA model).

Andhra Pradesh could achieve 99% of its potential in wind energy technologies by the year 2301 *i.e.*, 5340.06 MW. This means that, the diffusion of wind energy technologies as an energy alternative in Andhra Pradesh could reach 99% of the estimated potential by the year 2301 (from Excel). For Andhra Pradesh, the time period required to achieve its wind energy technologies potential from 10% to 90% is 129.67 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2063 (based on the IIASA model).

Tamilnadu could achieve 99% of its potential in wind energy technologies by the year 2033 *i.e.,* 5318.62 MW. This means that, the diffusion of wind energy technologies as an energy alternative in Tamilnadu could reach 99% of the estimated potential by the year 2033 (from Excel). For Tamilnadu, the time period required to achieve its wind energy technologies potential from 10% to 90% is 7.54 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2005 (based on the IIASA model).

Rajasthan could achieve 99% of its potential in wind energy technologies by the year 2040 *i.e.,* 4953.27 MW. This means that, the diffusion of wind energy technologies as an energy alternative in Rajasthan could reach 99% of the estimated potential by the year 2040 (from Excel). For Rajasthan, the time period required to achieve its wind energy technologies potential from 10% to 90% is 16.34 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2012 (based on the IIASA model).

Madhya Pradesh could achieve 99% of its potential in wind energy technologies by the year 2053 *i.e.,* 916.2 MW. This means that, the diffusion of wind energy technologies as an energy alternative in Madhya Pradesh could reach 99% of the estimated potential by the year 2053 (from Excel). For Madhya Pradesh, the time period required to achieve its wind energy technologies potential from 10% to 90% is

17.38 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2012 (based on the IIASA model).

Kerala could achieve 99% of its potential in wind energy technologies by the year 2053 *i.e.,* 916.2 MW. This means that, the diffusion of wind energy technologies as an energy alternative in Kerala could reach 99% of the estimated potential by the year 2053 (from Excel). For Kerala, the time period required to achieve its wind energy technologies potential from 10% to 90% is 37.15 years. The inflection point as explained by the Gompertz function is reached in 27.73 years *i.e.*, nearly by the year 2026 (based on the IIASA model).

5.5.1 Notable Distinct Features

As per the forecasting, the states of Tamilnadu, Maharashtra, Rajasthan and Madhya Pradesh have already reached the inflection point. These states, though they witness growth beyond the inflection point, the growth rate will be decelerating.

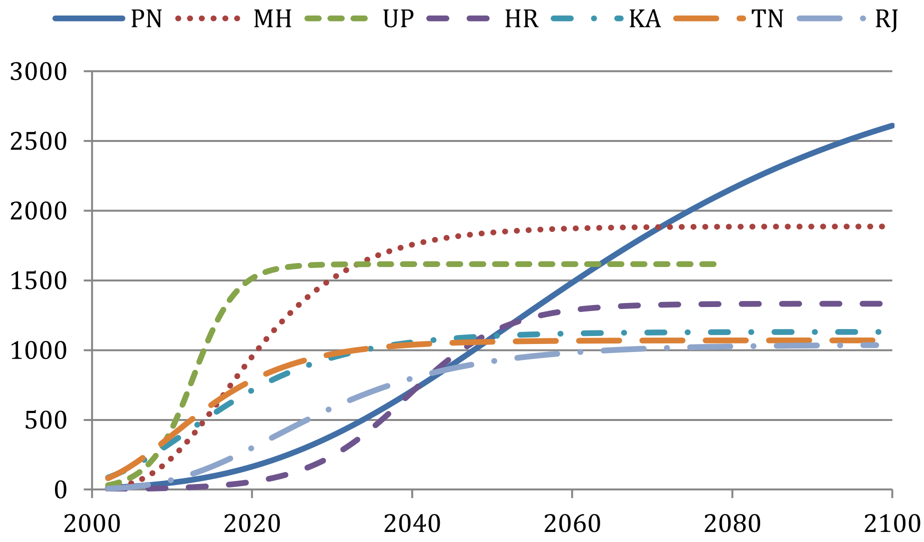
Tamilnadu has already exceeded its maximum technical potential (as of 31.03.2011) of 5374 MW and stood at 5904.12 MW by 2011 and presently achieved 6987.62 MW by 2012. This can be explained by the less accurate resource assessment of RETs in India. Resource assessment has always been fraught with inefficiency and many a times, resources were underestimated in India.

A distinction between Excel and IIASA model is pertinent to be made about Tamilnadu. Though both of them could predict that the inflection point would be reached by Tamilnadu by the year 2005, Excel gives the time period to grow from 10% to 90% of the potential as 19.4 years while the IIASA model predicts it as 7.54 years which is in conformity with the reality (See Appendix 2 for more details). Even the saturation level predicted by the IIASA model is much higher which means that the model is more in consonance with the practice. Such models with superior algorithms would help policy making to be more practical.

Andhra Pradesh is taking invariably more time (nearly 130 years) to reach 10% to 90% of its potential. The state has been witnessing acute power shortages in the recent past. Also, the state is one of the fast developing states in India. We also see that, Jammu & Kashmir and Odisha states despite having high wind energy potential, haven't witnessed any initiatives in promoting the technologies. This may be attributed to the insurgency and internal security problems in the respective states.

5.6 States and Biomass Energy Technologies

The modelling for states in biomass energy technologies is shown in the figure.



Source: Author's Analysis

FIGURE 5.6. STATES - PROJECTED BIOMASS ENERGY INSTALLATION CAPACITY.

Punjab could achieve 99% of its potential in biomass energy technologies by the year 2189 *i.e.*, 3140.28 MW. This means that, the diffusion of biomass energy technologies as an energy alternative in Punjab could reach 99% of the estimated potential by the year 2189 (from Excel). For Punjab, the time period required to achieve its biomass energy technologies potential from 10% to 90% is 70.34 years.

The inflection point as explained by the Gompertz function is reached nearly by the year 2042 (based on the IIASA model).

Maharashtra could achieve 99% of its potential in biomass energy technologies by the year 2057 *i.e.,* 1867.19 MW. This means that, the diffusion of biomass energy technologies as an energy alternative in Maharashtra could reach 99% of the estimated potential by the year 2057 (from Excel). For Maharashtra, the time period required to achieve its biomass energy technologies potential from 10% to 90% is 17.32 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2014 (based on the IIASA model).

Uttar Pradesh could achieve 99% of its potential in biomass energy technologies by the year 2025 *i.e.,* 1600 MW. This means that, the diffusion of biomass energy technologies as an energy alternative in Uttar Pradesh could reach 99% of the estimated potential by the year 2025 (from Excel). For Uttar Pradesh, the time period required to achieve its biomass energy technologies potential from 10% to 90% is 10.08 years. The inflection point as explained by the logistic function is reached nearly by the year 2012 (based on the IIASA model).

Haryana could achieve 99% of its potential in biomass energy technologies by the year 2069 *i.e.,* 1319.67 MW. This means that, the diffusion of biomass energy technologies as an energy alternative in Haryana could reach 99% of the estimated potential by the year 2069 (from Excel). For Haryana, the time period required to achieve its biomass energy technologies potential from 10% to 90% is 4.15 years. The inflection point as explained by the logistic function is reached nearly by the year 2015 (based on the IIASA model).

Karnataka could achieve 99% of its potential in biomass energy technologies by the year 2060 *i.e.*, 1120 MW. This means that, the diffusion of biomass energy technologies as an energy alternative in Karnataka could reach 99% of the estimated potential by the year 2060 (from Excel). For Karnataka, the time period required to achieve its biomass energy technologies potential from 10% to 90% is 33.55 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2013 (based on the IIASA model).

Tamilnadu could achieve 99% of its potential in biomass energy technologies by the year 2049 *i.e.*, 1059 MW. This means that, the diffusion of biomass energy technologies as an energy alternative in Tamilnadu could reach 99% of the estimated potential by the year 2049 (from Excel). For Tamilnadu, the time period required to achieve its biomass energy technologies potential from 10% to 90% is 24.51 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2010 (based on the IIASA model).

Rajasthan could achieve 99% of its potential in biomass energy technologies by the year 2082 *i.e.*, 1070 MW. This means that, the diffusion of biomass energy technologies as an energy alternative in Rajasthan could reach 99% of the estimated potential by the year 2082 (from Excel). For Rajasthan, the time period required to achieve its biomass energy technologies potential from 10% to 90% is 33.01 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2023 (based on the IIASA model).

5.6.1 Notable Distinct Features

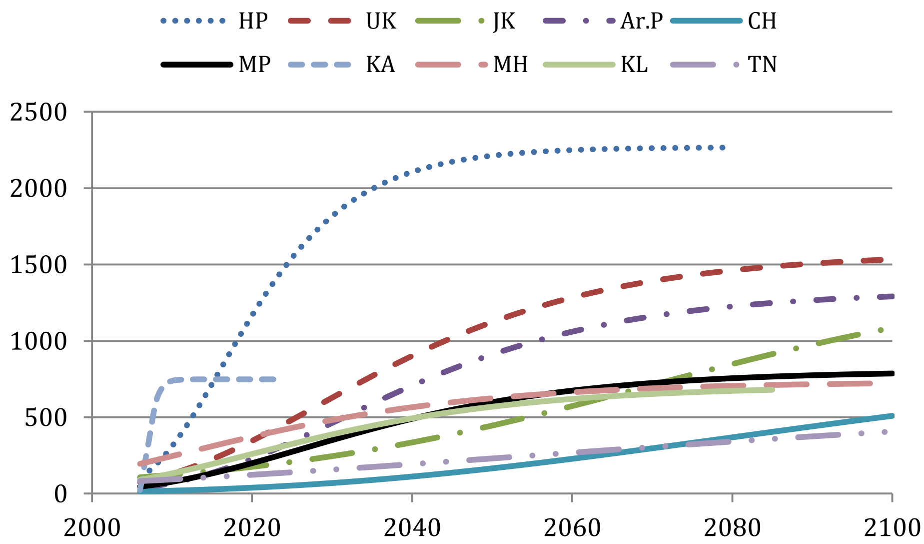
Punjab and Haryana despite having higher biomass energy potential (Punjab is the highest biomass potential state in India), the diffusion of relevant technologies seems to be unduly slow. For Punjab, 70.34 years is needed to grow from 10% to 90% of its potential. On the other hand, Madhya Pradesh, Gujarat and Kerala have seen no initiatives at all in promoting biomass energy technologies.

A distinction between Excel and IIASA model is pertinent to be made about Haryana. The IIASA model predicts faster diffusion of biomass technologies in Haryana, where as in reality, the diffusion is very slow. This is well depicted by the Excel (See Appendix 2 for more details).

Except Uttar Pradesh, all other states would achieve their 90% potential in the second half of the 21st century. The time period seems to be very high. Especially, when the diffusion of RETs is viewed from rural development perspective, such long time frames are not really plausible.

5.7 States and Small Hydro Power Technologies

The modelling for states in small hydro power (SHP) technologies is shown in the figure.



Source: Author's Analysis

FIGURE 5.7. STATES - PROJECTED SHP INSTALLATION CAPACITY.

Himachal Pradesh could achieve 99% of its potential in SHP technologies by the year 2058 *i.e.*, 2245 MW. This means that, the diffusion of SHP technologies as an energy alternative in Himachal Pradesh could reach 99% of the estimated potential by the year 2060 (from Excel). For Himachal Pradesh, the time period required to achieve its SHP technologies potential from 10% to 90% is 26.36 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2016 (based on the IIASA model).

Uttarakhand could achieve 99% of its potential in SHP technologies by the year 2120 *i.e.*, 1561 MW. This means that, the diffusion of SHP technologies as an energy alternative in Uttarakhand could reach 99% of the estimated potential by the year 2120 (from Excel). For Uttarakhand, the time period required to achieve its SHP technologies potential from 10% to 90% is 65.16 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2030 (based on the IIASA model).

Jammu & Kashmir could achieve 99% of its potential in SHP technologies by the year 2188 *i.e.*, 1403.82 MW. This means that, the diffusion of SHP technologies as an energy alternative in Jammu & Kashmir could reach 99% of the estimated potential by the year 2188 (from Excel). For Jammu & Kashmir, the time period required to achieve its SHP technologies potential from 10% to 90% is 108.11 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2068 (based on the IIASA model).

Arunachal Pradesh could achieve 99% of its potential in SHP technologies by the year 2120 *i.e.*, 1315.2 MW. This means that, the diffusion of SHP technologies as an energy alternative in Arunachal Pradesh could reach 99% of the estimated potential by the year 2120 (from Excel). For Arunachal Pradesh, the time period required to achieve its SHP technologies potential from 10% to 90% is 60.13 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2032 (based on the IIASA model).

Chhattisgarh could achieve 99% of its potential in SHP technologies by the year 2314 *i.e.,* 983.07 MW. This means that, the diffusion of SHP technologies as an energy alternative in Chhattisgarh could reach 99% of the estimated potential by the year 2314 (from Excel). For Chhattisgarh, the time period required to achieve its SHP technologies potential from 10% to 90% is 183.23 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2092 (based on the IIASA model).

Madhya Pradesh could achieve 99% of its potential in SHP technologies by the year 2058 *i.e.,* 661.5 MW. This means that, the diffusion of SHP technologies as an energy alternative in Madhya Pradesh could reach 99% of the estimated potential by the year 2058 (from Excel). For Madhya Pradesh, the time period required to achieve its SHP technologies potential from 10% to 90% is 63.21 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2028 (based on the IIASA model).

Karnataka could achieve 99% of its potential in SHP technologies by the year 2012 *i.e.,* 740.52 MW. This means that, the diffusion of SHP technologies as an energy alternative in Karnataka could reach 99% of the estimated potential by the year 2012 (from Excel). For Karnataka, the time period required to achieve its SHP technologies potential from 10% to 90% is 6.77 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2006 (based on the IIASA model).

Maharashtra could achieve 99% of its potential in SHP technologies by the year 2108 *i.e.,* 726 MW. This means that, the diffusion of SHP technologies as an energy alternative in Maharashtra could reach 99% of the estimated potential by the year 2108 (from Excel). For Maharashtra, the time period required to achieve its SHP technologies potential from 10% to 90% is 63.5 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2012 (based on the IIASA model).

Kerala could achieve 99% of its potential in SHP technologies by the year 2109 *i.e.,* 697 MW. This means that, the diffusion of SHP technologies as an energy alternative in Kerala could reach 99% of the estimated potential by the year 2109 (from Excel). For Kerala, the time period required to achieve its SHP technologies potential from 10% to 90% is 62.23 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2021 (based on the IIASA model).

Tamilnadu could achieve 99% of its potential in SHP technologies by the year 2351 *i.e.,* 653.4 MW. This means that, the diffusion of SHP technologies as an energy alternative in Tamilnadu could reach 99% of the estimated potential by the year 2351 (from Excel). For Tamilnadu, the time period required to achieve its SHP technologies potential from 10% to 90% is 202.37 years. The inflection point as explained by the Gompertz function is reached nearly by the year 2055 (based on the IIASA model).

5.7.1 Notable Distinct Features

Small hydro technologies seem to be the problematic child of the IRETS. What was conceived as an energy alternative that can meet the energy demands of hilly and mountainous people is poised to achieve 90% its potential in such states only in the 22nd Century. Rural development and livelihood improvement cannot happen that long.

Karnataka has already exceeded its maximum technical potential (as of 31.03.2011) of 748 MW and stood at 783.35 MW by 2011. This was predicted more accurately by the IIASA model than the Excel (see Appendix 2 for more details).This can be explained by the less accurate resource assessment of RETs in India. Arunachal Pradesh and Uttarakhand are following similar patterns and are more or less marching together.

Grim situation in J&K and Chhattisgarh states can be attributed to internal security and under development related problems. But, a progressive state like Tamilnadu which is leading in the nation in wind power technologies seems to lack interest in SHP technologies. This may be partly due to over emphasis on wind technologies thereby concentrating on core competence. Interstate river water disputes associated with the state may also have stood in the way of grabbing the attention of policy makers. The case with Maharashtra is more or less same like that of Tamilnadu.

Chapter 6

CONCLUSION

CONCLUSION

According to (Carlsson B. , 1997), the four technological system features that showcase the extent of technological commercialization are: the nature of knowledge and spillover mechanisms; the receiver competence of actors; the connectivity within the system and the vigour of variety creation and selection mechanisms.

6.1 Nature of Knowledge and Spillover Mechanisms

> "The characteristics of knowledge in each area of technology determine both the likely carriers of such knowledge and the mechanisms through which it can be transferred and diffused" (Carlsson B. , 1997, p. 284).

RETs are more embodied in knowledge and artefacts. As we saw in the evolution of IRETS, the academic disciplines which constitute the knowledge base are well established in IRETS. The strength in practical application of this knowledge is also high especially adapting to various developmental needs. As RETs are strongly component-oriented and embodied in equipment, moderate receiver competence is needed, especially for operation and maintenance (O&M) purposes which in turn determines the sustainable usage of such systems.

RETs development being more experimental in nature, the dependence on close R&D relationships between academic system, research institutes and industry is stressed in the system. Interestingly, one can observe that, there is no shift in technology base from one technology to other. Rather, all RETs are being developed simultaneously and diffused in parallel based on the needs of diverse users.

Wind, Solar, Bio Power, Small Hydro technologies along with the hybrid systems are in adolescent stage though scope for improvement is still high. New technologies on the other hand, like Tidal, Geothermal, Hydrogen Energy, Fuel Cells are still in embryonic stage where R&D, demonstration projects are going on. Commercially, they still have a long way to go. Open innovation approach followed in this regard like in geothermal technologies should help the system to reduce the learning period.

6.2 Receiver Competence

RETs are relatively new and IRETS has no long history of their development. Their development and diffusion is largely induced type. Technology development was largely induced, which means that, programmes aimed at technology development which is deliberately launched by the governments and development bodies, providing the needed fillip through finance (Cernea, 1993).

Setting up of DNES and its consequent open innovation focus could help the system to quickly identify and absorb RET technological nuances leading to improvements in the performance of the system. The first efforts of India towards development of Solar PV technology was spearheaded by the Public Sector Enterprise, Central Electronics Limited (CEL). The first users of the Solar PV modules in the country were again the Public Sector Units/Departments like Department of Telecom (DOT), Indian Railways and other PSUs. "From the stage of silicon material to the final PV system integration India has indigenously developed technology and production facilities" (Kathuria, 2002).

The domestic users like oil industry, railways and telecommunications of Solar PV systems created a market which was non-existent before and thereby created first mover advantage for CEL, the first supplier of PV systems, while the critical mass is yet to develop. Financially risky and technologically evolving nature of RETs meant that, users are not ready to either develop or diffuse the same. As such, most of the risks (R&D and diffusion) in the system have been borne by MNES (now MNRE). Capital has been infused into the system by establishing IREDA, under MNRE for providing term loans for renewable energy and energy efficiency projects. It has played a seminal role in attracting private sector participation for setting up renewable energy projects. Entrepreneurs were encouraged in a big way with these loans who are now shouldering significant role in industrial organisation block.

What was started as a public sector dominated buyer competence and supplier competence has moved to private sector dominated buyer and supplier competence with public sector still intact. This shows the level of maturity the system has gained over a period of few decades.

Raising awareness and taking early initiatives was always the domain of MNRE even until today. MNRE has envisioned and build the institutional infrastructure in IRETS.

Its emphasis on standardization of technologies, adoption and promotion of international standards is in turn helping the industry to gain access to huge markets even abroad. Today India is a net exporter of Solar PV Technology products.

Private sector on the other hand has been playing a complementing role on the supply side. Large business houses like TATA, Reliance Industries etc., have diversified into RET sector. The internal finance within these companies was a critical source to meet their financial needs. Role of academic system has been multifaceted. On the one hand, they are handling key areas of technological research in collaboration with other actors, especially industry. On the other hand, the universities were not proactive in increasing the supply of human resources in RETs, particularly engineers. That's why; we could see the technology centres C-WET, SSS-NIRE, AHEC are offering graduate and/or post graduate courses.

6.3 Connectivity

Connectivity holds together the multitude actors in the system and helps to leverage technological spillovers. The problem-solving networks are largely influenced by the government policies and agencies. CERC has evolved transparent and robust criteria in determining the tariffs of power generated from RETs. Collaborations among various types of actors’ acts as a problem-solving network for technology related aspects.

6.4 Variety Creation Mechanisms

Any natural system that exhibits more complex networks and energy paths is more resilient. Likewise, a technological system should always maintain continuous variety of knowledge, technological skills, actors and networks to progress against the entropy.

In IRETS, the large number of diverse actors has been ensuring a variety of technical approaches and multitude of R&D projects being handled simultaneously by the system on diverse RETs. Information exchange is also being attempted to help diffuse the same. Open innovation promoted by MNRE makes sure that the system is abreast of innovations in the global technological system.

The role of public policy, especially that of MNRE and suitably complemented by other relevant ministries like Ministry of Power, Ministry of Urban Development etc., has been largely supportive by initiating various initiatives like GRIHA etc., and thereby adding variety to the system and ensuring that the system always alive. The key tool of the public policy in building the IRETS is via procurement. Renewable Energy Certificates (RECs), Renewable Purchase Obligations (RPOs) etc are the tools of public policy which ensures that the actors in the system are ensured of demand for their plants and products.

Since RETs are still evolving, MNRE with its technological centres has been in the forefront of initiating R&D and setting up demonstration projects which in turn will attract entrepreneurs to further diffuse them. In the embryonic stage, we see even private sector involved in demonstration projects thereby enhancing the variety and complexity in the system. Burgeoning entrepreneurs in the IRETS encouraged by IREDA may counterbalance any path-dependency of the larger firms and hence variety increases.

Wind technologies sector, having relatively matured technologies and manufacturing base since the later part of infant stage, government incentives have been reduced like Generation Based Incentives.

In IRETS, varieties of technical approaches have been followed to make use the most of all available RETs based on the need. Grid-Connected Power has been given various industrial sops for the private sector to take in the reigns. Off-Grid power was mainly emphasized in rural, remote and inaccessible areas which are not seemed to be connected by the grid in the near future. Improved Cooking Stoves, Small biogas plants, Small Hydro Power, Solar Lighting and Cooking Systems, Aerogenerators, Windmills, Wind - Solar hybrid etc have been developed and are being deployed appropriately.

IRETS seems to be away from "bounded vision". Though there has always been an element of renewable energy promotion in the country, it took concrete form from the

Infant Stage since 1981. This was the lesson taught by the two oils shocks in 1970s. The evolving nature of the RETs and the costs associated with them could not really attract the interest of a developing country like India in developing RETs.

Path Dependency

Existence of Technology Centres and superior academic institutions like IISc, IIT Bombay etc. has meant that path dependency was relatively mild. With the high receptivity to new technology and collaboration with foreign technological systems, technology transfer has occurred especially in wind power and the local manufacturing capabilities have been reinforced. By expanding the life span of domestic manufacturers, path dependency has been reinforced.

NGOs and other local players have been roped in to take care of the best implementation in this sector. Their role has been commended in numerous technology dissemination projects that were vividly portrayed in numerous studies like (Bhargava, 2001), (Kathuria, 2002) and (GTZ, 1993).

Chapter 7

POLICY IMPLICATIONS AND RECOMMENDATIONS

POLICY IMPLICATIONS AND RECOMMENDATIONS

As on 31st March 2012, the total installed Renewable Energy capacity was 25 GW which comprised of 17.35 GW of wind power, 3.4 GW of small hydel power, 3.32 GW of bio-mass power and about 1 GW of solar power. The growth of the sector, however, is linked to several factors. High initial investment costs resulting in high generation costs, land related issues hampering timely completion of projects, reduction or withdrawal of the policy benefits and the weak financial position of the state utilities are some of the challenges faced by the Renewable Energy sector. Sustainability of the sector requires a favourable policy framework which is simultaneously stable over a foreseeable term as also flexible in its responsiveness to changing market dynamics. Given the steadily increasing demand for power due to consistent growth of the Indian Economy, accelerated use of Renewable Energy is regarded as vital for India's growth and securing its energy supplies by contributing to source diversification, import dependence reduction and fuel price volatility mitigation and addressing environmental concerns (IREDA, 2012).

7.1 Policy Implications for Technology Development

Technology development doesn't happen in vacuum. As we understood from previous chapters, especially chapter 4, it requires a battery of infrastructure, actors and network amongst them. Certain policy considerations which can be proposed based on the study are given below.

Technology development needs a particular infrastructure - institutional, business and academic system with all of them being coordinated and supported by a prime mover like the government. The policy required to nurture any technology itself is dynamic and should change according to the position of technology on the S-Curve.

Open innovation plays a critical role in technological development. It hastens the process, infuses new technical skills, and helps to focus more on the core competence by shedding off the routine/simple aspects.

Policies aimed at providing incentives/subsidies for technological development should be time bound and should lead the entire system towards maturity and self-sustaining mode. Caution should be exercised as such measures might discourage entrepreneurial efforts at making the technology more appealing and user-friendly. Proper feedback from the end users should be collected and analysed to know the efficacy of incentives/subsidies in making the technology user-friendly.

Costs and financing is a major barrier that has to be borne by the system in the initial stages of technological development. A dedicated organization promoted by the government would be a better choice for this task.

Both, development and diffusion are equally important and steps should be taken for promoting both the aspects of technology. It is in the diffusion, more actors come into picture requiring astute coordination among them.

7.2 Policy Implications for Enrichment of IRETS

Chapters 4 and 5 have dealt in with major aspects of the IRETS and have thrown light on interesting and important aspects as well. Though the performance of the system is quite impressive, there is still room for further improvements which can be achieved by handling certain issues. Some of the recommendations are given below.

States that have already exceeded their exploitable technical potential - Wind (Tamilnadu), SHP (Karnataka) as well as those states which have reached the inflection point - Wind (Maharashtra, Tamilnadu), SHP (Karnataka, Maharashtra) needs further steps to hook them to the path of RETs diffusion. Proper resource assessment should be undertaken by the technology centres if needed in collaboration with foreign technological systems and reassess the potential. Suitable policy measures have to be put in to launch a new wave of incentives aimed at further diffusion of RETs. For those states, which exceeded their potential in on-shore wind, the untapped off-shore wind potential has to be assessed and suitable steps taken for their exploitation as well. For on-shore, reassessment of potential should be taken at higher elevations. Also focus should shift to other promising RETs as well which were neglected till now in the states.

As we saw in chapter 5, certain states with high potential in certain RETs like Wind (Jammu & Kashmir and Odisha), Biomass (Gujarat, Kerala, Madhya Pradesh) have not seen any initiatives in diffusing the RETs. MNRE should act immediately and try to plug the barriers that are coming in the way of promoting RETs.

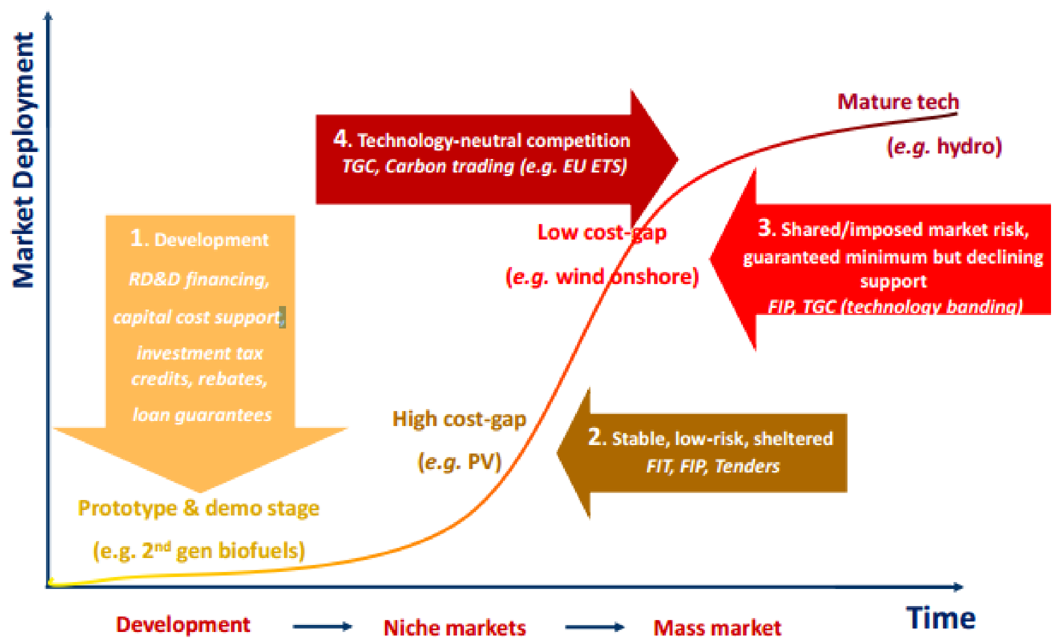
Certain states like Tamilnadu which are performing well in certain RETs like Wind are neglecting other RETs like SHP. They should be sensitized of the issue and initiatives should be taken immediately to realize the potential of all possible RETs.

Small hydro technologies seem to be the problematic child of the IRETS. What was conceived as an energy alternative that can meet the energy demands of hilly and mountainous people is poised to achieve 90% its potential in such states only in the 22nd Century. Rural development and livelihood improvement cannot wait for a century. Policy decisions have to be made to choose appropriate RETs for faster achievement of the said goals. A kind of revitalizing is needed for this RET to explore the possibility of any further refinements and to reduce the time period for the technology to diffuse.

India's wasteland resources have to be reassessed scientifically with a view of promoting the cultivation of short gestation, high yielding and quick rotation fuelwood tree species based on the agro-climatic conditions. MNRE should also support research projects aimed at developing such genetically modified fuelwood trees. A dedicated programme has to be launched to promote wasteland cultivation in coordination with other concerned ministries.

Chapter 4 has clearly highlighted the role open innovation has played in the development of IRETS. Therefore, it is imperative that the system should be as open as possible in all its future endeavours.

In Chapter 4, we have that, as RETs evolve through different stages, so are the changes needed in the supporting policy regimes. As such, MNRE should always put in place dynamic policies, in order to promote existing as well as 'New Technologies' in the system.



Source: (Frankl, 2008)

FIGURE 7.1. FOSTERING RET'S TRANSITION TOWARDS MASS MARKET INTEGRATION.

The total installed capacity of grid connected solar power projects in the system as on 31.10.2012 is over 1045 MW which was just 2.12 MW in the year 2009. Thanks to JNNSM, IRETS could achieve such an incredible exponential growth in solar technologies.

40 per cent of the domestically produced modules aggregating 120 MWp went into establishing Grid- connected Solar PV power plants under JNNSM as on 31.10.2012. Domestically produced modules account for 99 per cent of Off-grid solar PV systems with aggregate capacity of 31MWp deployed under JNNSM so for the same period (PIB, 2012). This shows the gaining strength of the domestic module industry. Yet, there is a cause for concern. Domestic production of solar PV modules is largely skewed towards crystalline silicon technology where as other technologies are relatively relegated to background. These technologies should also be promoted and their domestic manufacturing base needs to be nurtured.

In Chapter 4, we have seen that IRETS took three decades to come out of the infant stage which is very high. Steps have to be taken to ensure that the 'New Technologies' as classified by MNRE shouldn't take longer time for their development and diffusion. IRETS should follow as much open innovation as possible to achieve the technological breakthroughs in them.

In Chapter 5, we have seen that many states despite having very good potential in certain RETs, have not initiated any steps so for in promoting the same. This calls for immediate action on the part of the policy makers in the respective states as well as MNRE. Wind power in Jammu & Kashmir and Odisha, Biomass power in Gujarat, Kerala and Madhya Pradesh has to be promoted without any delay.

In promoting Wind energy technologies, the efforts have been channelled towards exploiting the on-shore potential till now. Little efforts were made at assessing as well as exploiting the off-shore potential. Though recently states like Gujarat have started promoting the same, more efforts are needed in assessing the potential and promoting off-shore installations along the India's coastal line of around 15, 000 KM. Also, IRETS has only 5 manufacturing companies producing 11 models of small aerogenerators which are empanelled by C-WET. More steps need to be taken in this respect to increase the number of manufacturers as well as the technological base.

The portfolio of RETs in IRETS seems to be narrow or this local system appears to be disassociated with the global technological system. As suggested by (Bhattacharya & Jana, 2009), certain promising technologies like biomass integrated gasification combined cycle (BIGCC), cofiring, cellulosic ethanol, Stirling Engine are to be promoted in the system.

India is bestowed with innumerable river systems. In this context, SH technologies are to be further developed and promoted. IRETS should consider the latest developments in the field elsewhere as well as promote R&D through AHEC and other identified actors. A number of technologies have been developed for low head higher flow sites relying on 'reaction' rather than 'impulse' machines. Such reaction machines develop torque by reacting to the weight and low pressure of water and are lighter as well as cheaper to manufacture (Dalton, 2012).

Recent trend at promoting SHP technologies is centred towards achieving as higher MW as possible (MNRE is responsible for 25 MW and below). Though the advantages are obvious in promoting higher capacities, the utility of smaller capacities is equally important. The system should not lose this sight. More locations qualify and potential would increase as the capacity is lowered. Especially when one of the objectives of promoting RETs is to provide energy access to remote and inaccessible regions, smaller capacity SHP technologies become more relevant. Karnataka has been a pioneer in promoting diffusion of Pico-hydro technologies in the state. Its success has to be replicated in the entire system.

MNRE 'Support Programmes' should make sure that using RETs should become a part of culture or a way of life. People should embrace them as a necessity rather than a luxury. What telecom revolution has made to India, MNRE 'Support Programmes' coupled with technological breakthroughs should do the same to RETs.

No doubt, energy is at the heart of continuation of human civilizations. Within that, RETs help us in assuring a habitat which is safer and sustainable. They ensure equity, equality and result in empowerment of the world's innumerable populace.

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APPENDICES

Appendix 1: Choosing between the Gompertz and the Logistic functions based on Auxiliary Regression.

		MSE		MAD		Auxiliary Regression			
India/States	**RETs**	**Logistic**	**Gompertz**	**Logistic**	**Gompertz**	***t Stat***	***P-value***	**Significant at 10% Level**	**Suggested Fit**
India	RE	20040683	1727764.4	2528.448	1364.3947	1.653999	0.116473	No	Gompertz
Karnataka	Wind	74382.8	9080.9659	179.6921	71.22742	-1.64322	0.138962	No	Gompertz
	Biomass	427.0487	206.75434	15.40085	10.699871	0.789307	0.459977	No	Gompertz
	SHP	13971.39	22831.74	104.0335	127.06764	0.971631	0.433725	No	Gompertz
Maharashrta	Wind	37417.61	21910.263	161.225	114.54546	-0.327	0.752058	No	Gompertz
	Biomass	1092.573	1599.4494	18.84263	24.594609	0.22501	0.836427	No	Gompertz
	SHP	152.8335	160.49456	9.882978	10.19217	-0.05136	0.967334	No	Gompertz
Tamilnadu	Wind	1173147	1481892.1	797.5385	918.09751	-1.0464	0.325959	No	Gompertz
	Biomass	352.822	682.63955	14.27825	19.566342	0.628375	0.563853	No	Gompertz
Rajasthan	Wind	24312.59	14014.658	120.8163	83.192595	1.718636	0.124002	No	Gompertz
	Biomass	52.15961	63.674962	4.936806	5.5227048	2.639795	0.230528	No	Gompertz
Madhya Pradesh	Wind	2769.888	4047.5304	36.81591	45.676004	-1.01549	0.349057	No	Gompertz
Kerala	Wind	35.16393	28.542711	3.898488	3.8609782	0.69948	0.611422	No	Gompertz
	SHP	47.99707	42.272279	5.452278	5.1519876	-3.59194	0.172859	No	Gompertz
Gujarat	Wind	22760.1	30974.012	119.0841	138.61731	-2.03828	0.075877	Yes	Logistic

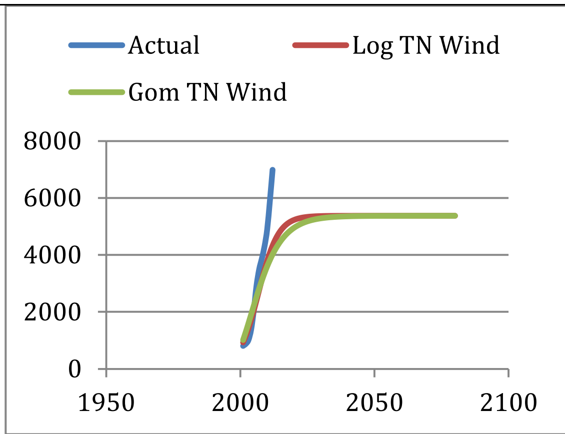
Andhra Pradesh	Wind	477.1455	494.56778	15.35013	15.842452	1.593784	0.162093	No	Gompertz
Himachal Pradesh	SHP	209.9587	299.89942	11.61953	15.347713	-1.08899	0.389891	No	Gompertz
Uttarakhand	SHP	92.72998	81.74541	8.155329	7.7121345	-2.61254	0.120579	No	Gompertz
Punjab	Biomass	78.1946	83.485116	6.784753	6.9923498	-0.27599	0.828566	No	Gompertz
Uttar Pradesh	Biomass	2421.324	3558.3764	34.01138	46.174597	-3.16067	0.034162	Yes	Logistic

Appendix 2: Comparison of Forecasting Results from Excel and the IIASA Model.

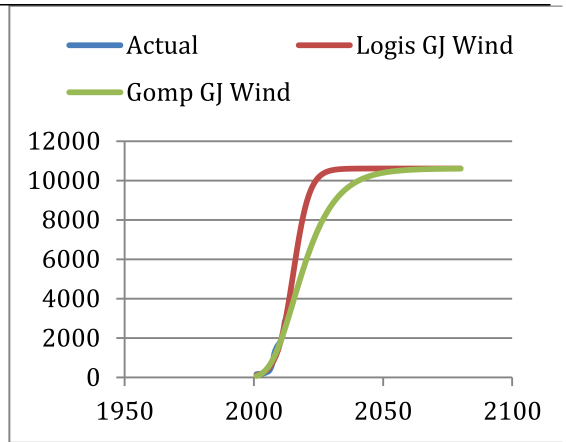
RETs	India/ States	Δt^a (No. of years)		$T_m{}^b$ (by the year)	
		Micro-soft Excel	IIASA - Logistic Substitution Model II	Micro-soft Excel	IIASA - Logistic Substitution Model II
Renewable Energies	India	34.8	36.147	2015	2017
Wind	Karnataka	25.7	29.14	2015	2016
	Maharashtra	21.2	20.65	2010	2010
	Tamilnadu	19.4	7.54	2005	2005
	Rajasthan	18.8	16.34	2013	2012
	Madhya Pradesh	22.24	17.38	2014	2012
	Kerala	42.08	37.15	2029	2026
	Gujarat	13.7	13.83	2016	2016
	Andhra Pradesh	152.69	129.67	2074	2063
Biomass	Karnataka	32.3	33.55	2013	2013
	Maharashtra	27.3	17.32	2018	2014
	Tamilnadu	26.2	24.51	2011	2010
	Rajasthan	39.7	33.01	2026	2023
	Punjab	90.72	70.34	2053	2042
	Uttar Pradesh	12	10.08	2014	2012
	Haryana	27.18	4.15	2041	2015
SHP	Karnataka	2.22	6.77	2008	2006
	Maharashtra	64.2	63.5	2013	2012
	Tamilnadu	198.77	202.37	2055	2055
	Madhya Pradesh	59.6	63.21	2028	2028
	Kerala	60	62.23	2021	2021
	Himachal Pradesh	28	26.36	2018	2016
	Uttarakhand	62	65.16	2030	2030
	Arunachal Pradesh	60	60.13	2032	2032
	Chhattisgarh	157	183.23	2081	2092
	Jammu & Kashmir	112	108.11	2071	2068

a. Time period to grow from 10% to 90% of the potential
b. Year when the inflection point is reached.

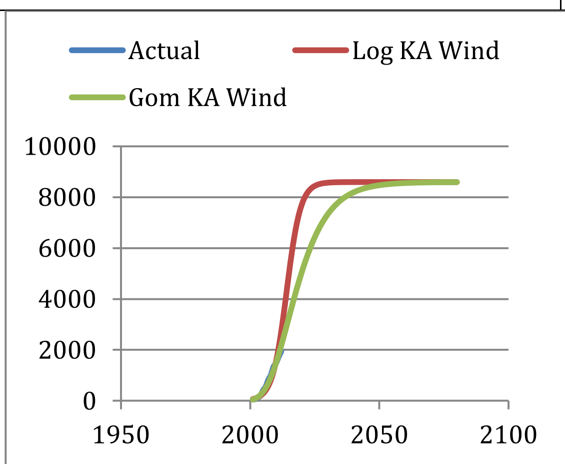
Appendix 3: Forecasting - Wind Energy Technologies (using Excel)



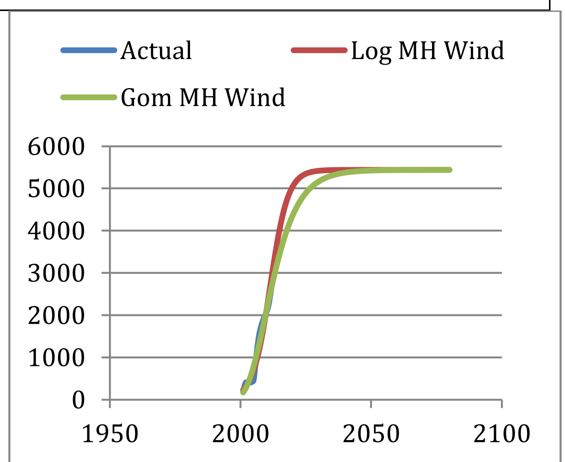
State: Tamilnadu



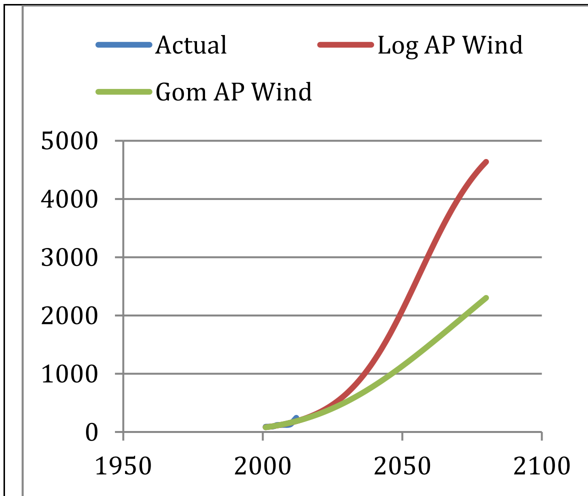
State: Gujarat



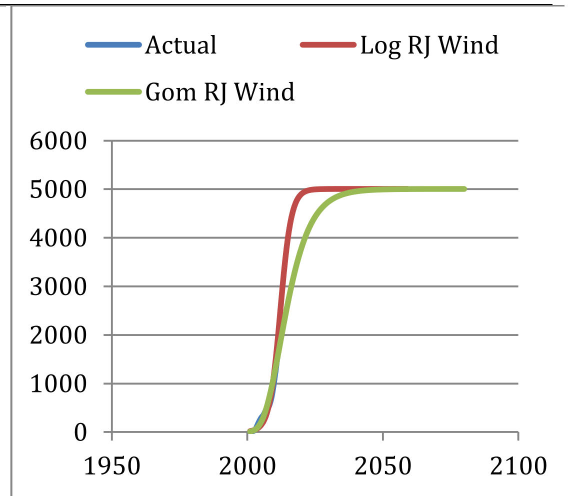
State: Karnataka



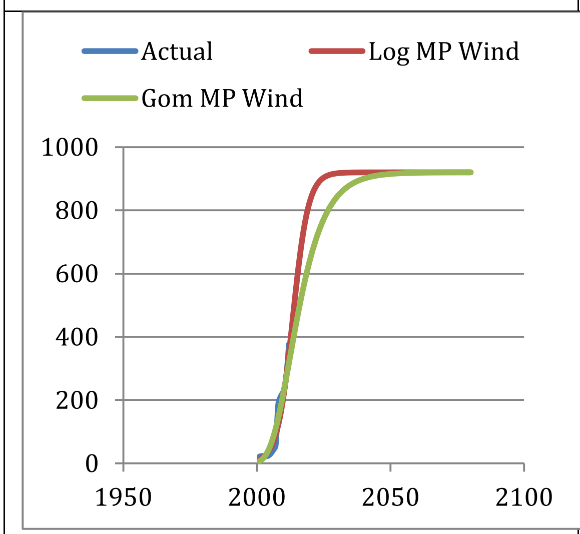
State: Maharashtra



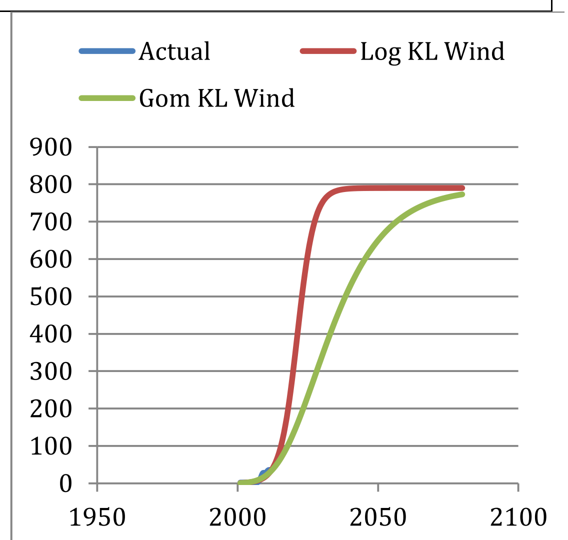
State: Andhra Pradesh



State: Rajasthan

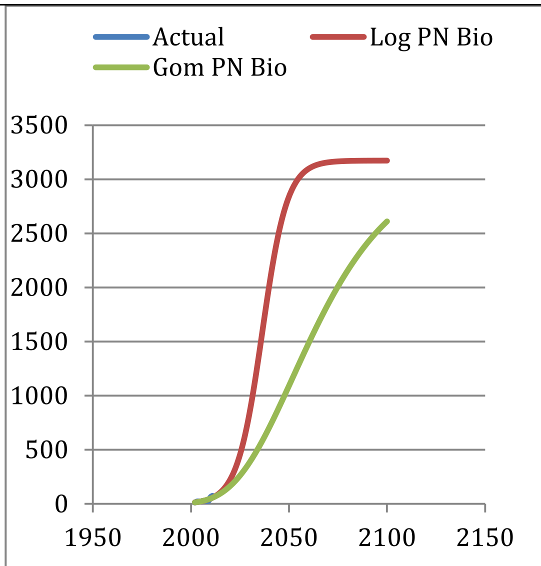


State: Madhya Pradesh

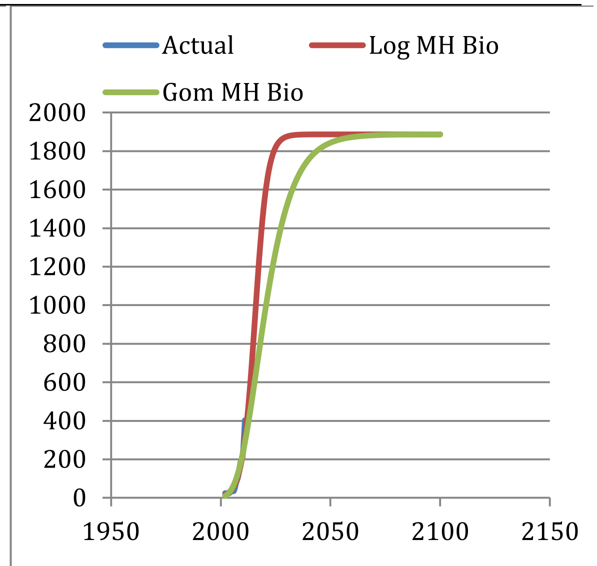


State: Kerala

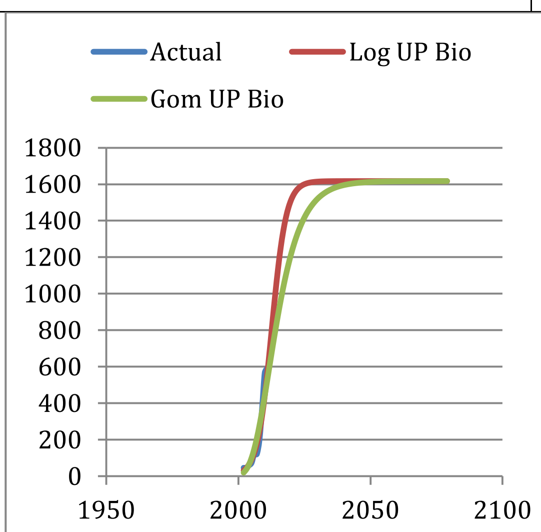
Appendix 4: Forecasting - Biomass Energy Technologies (using Excel)



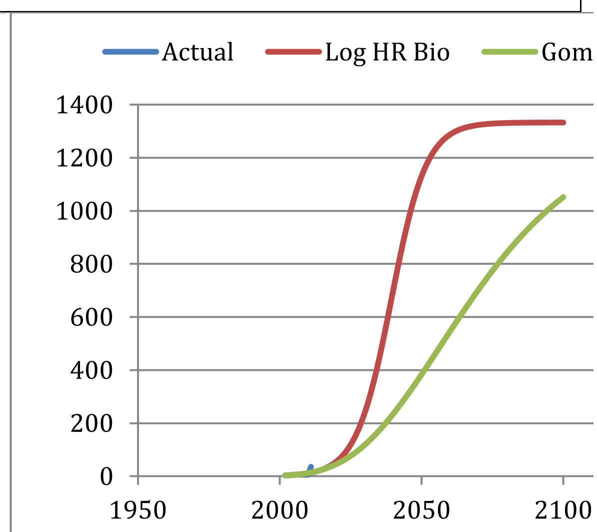
State: Punjab



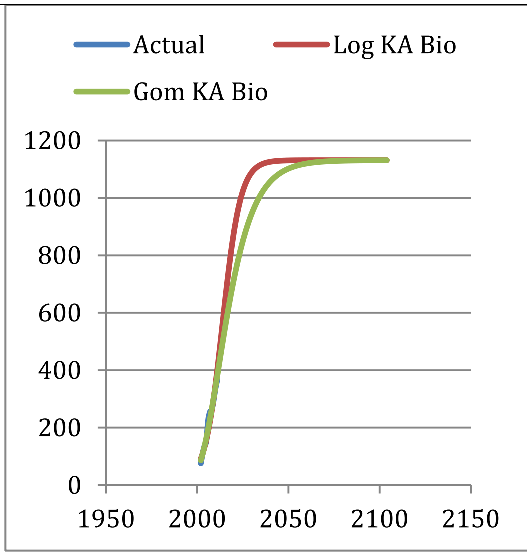
State: Maharashtra



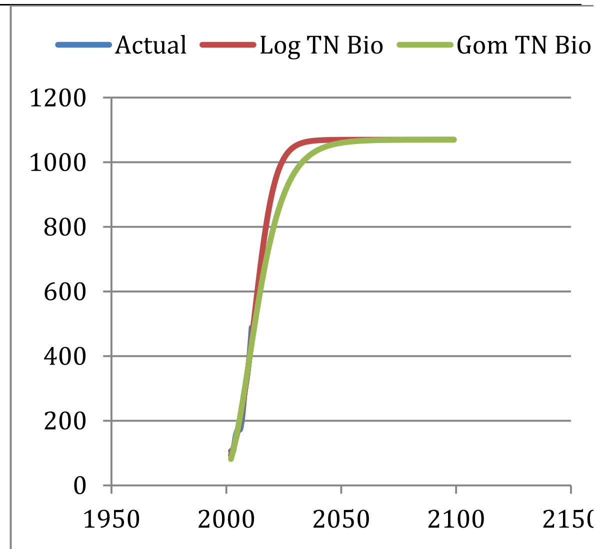
State: Uttar Pradesh



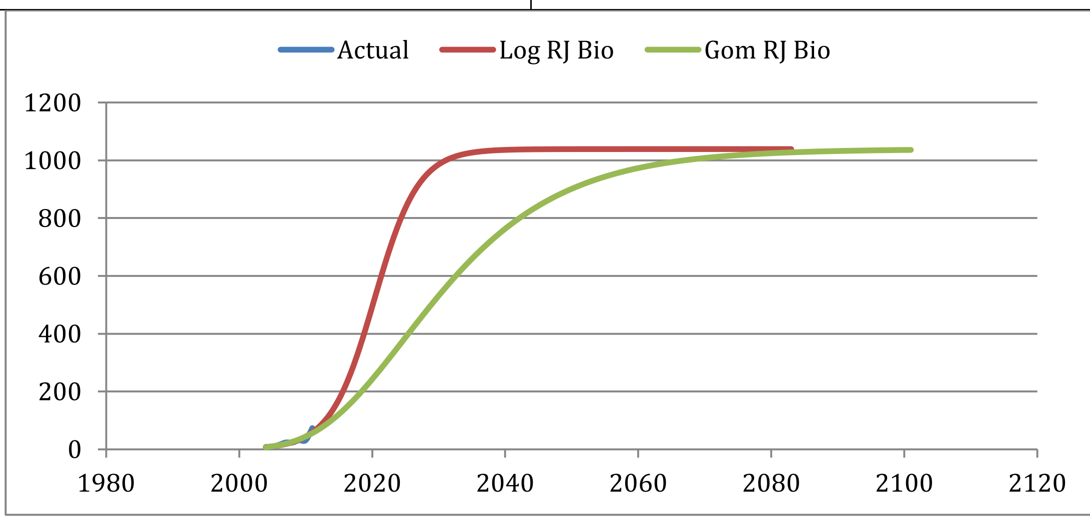
State: Haryana



State: Karnataka

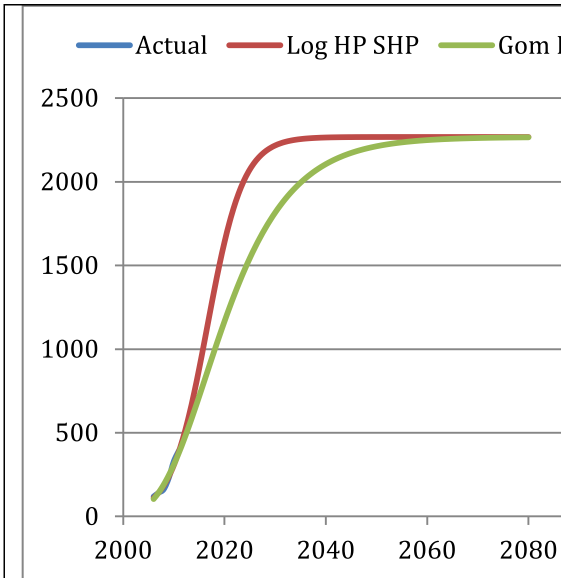


State: Tamilnadu

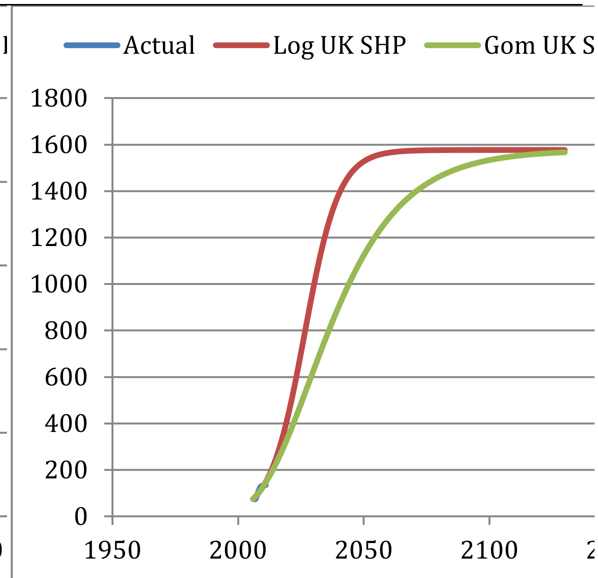


State: Rajasthan

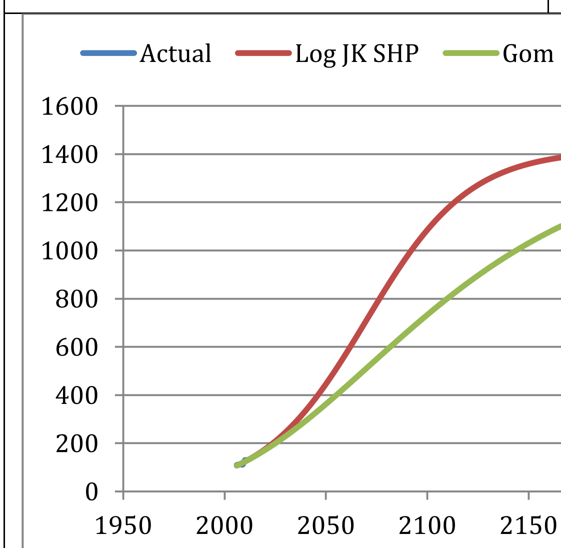
Appendix 5: Forecasting - Small Hydro Power Technologies (using Excel)



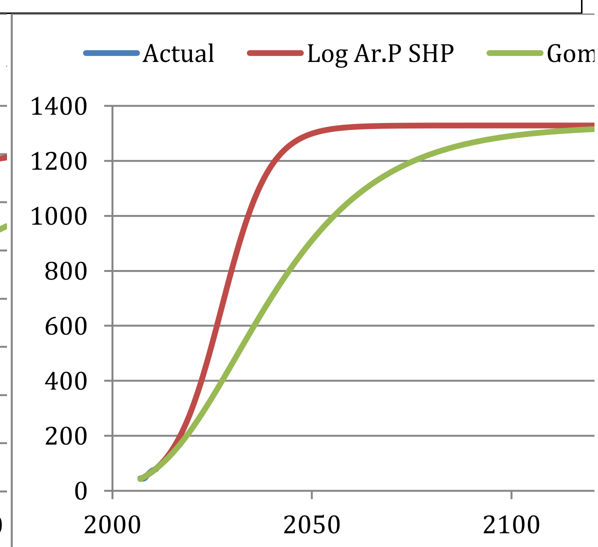
State: Himachal Pradesh



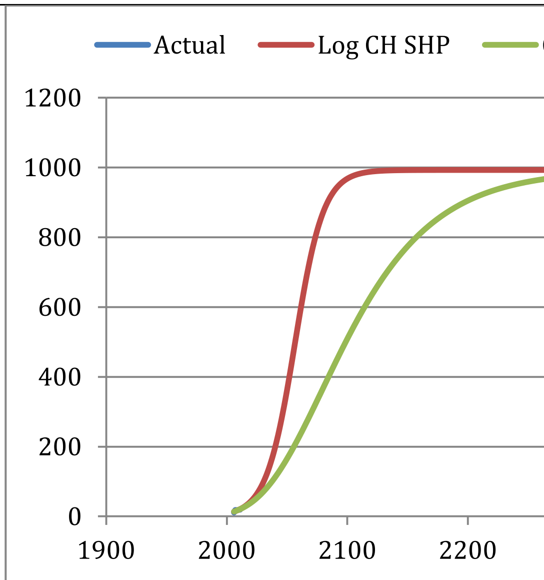
State: Uttarakhand



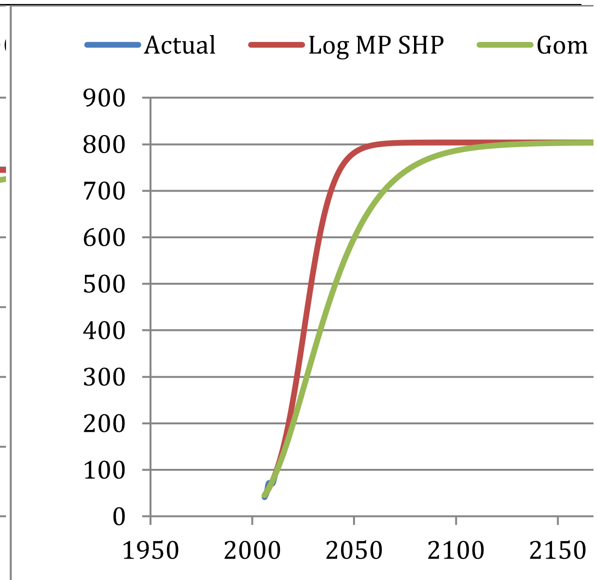
State: Jammu & Kashmir



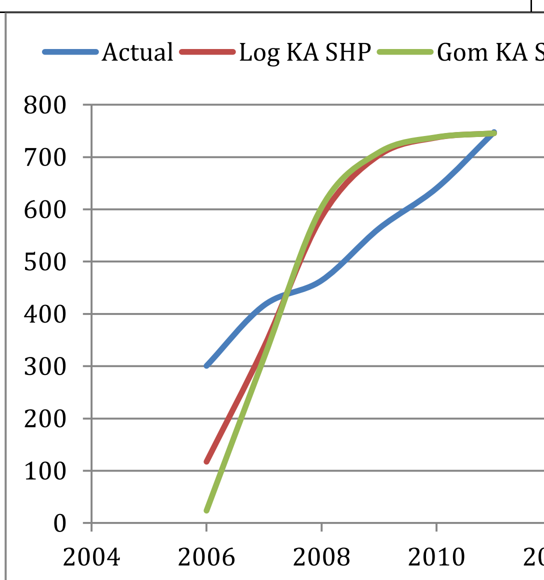
State: Arunachal Pradesh



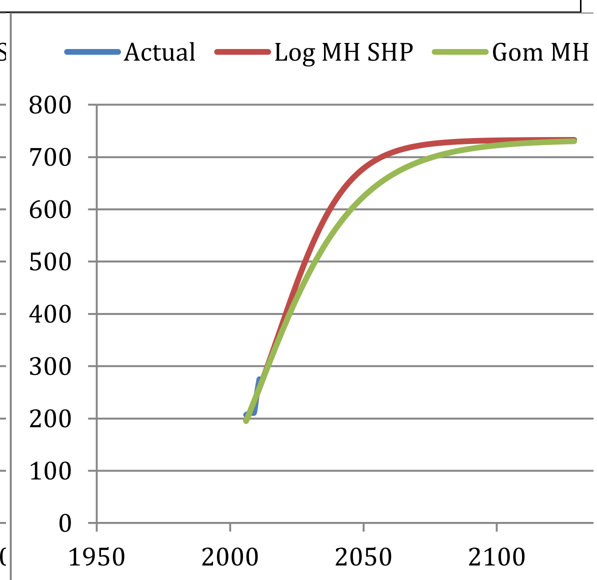
State: Chhattisgarh



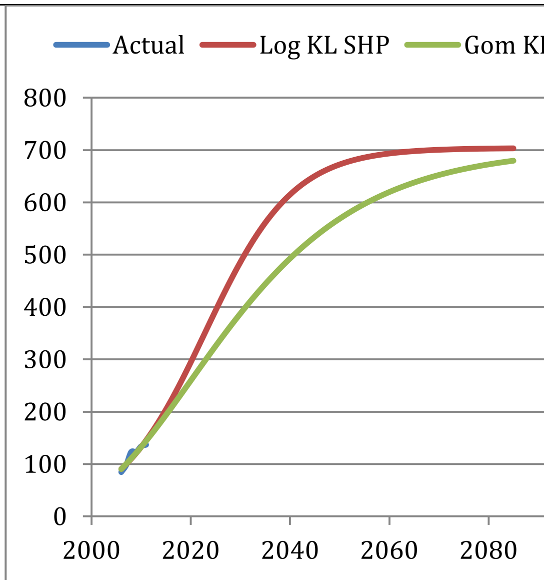
State: Madhya Pradesh



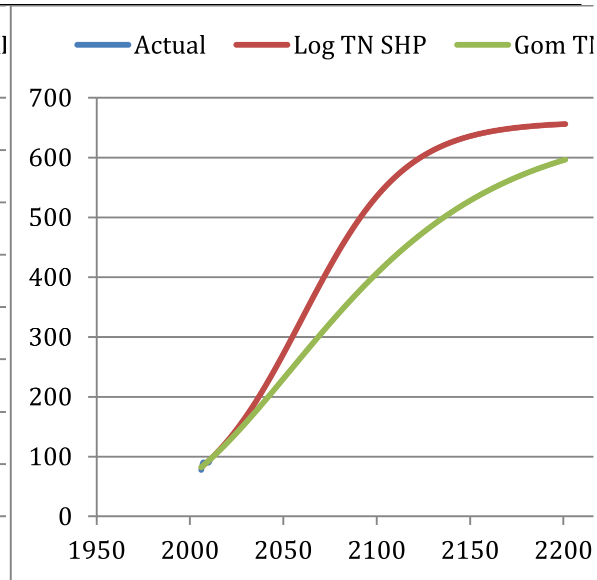
State: Karnataka



State: Maharashtra



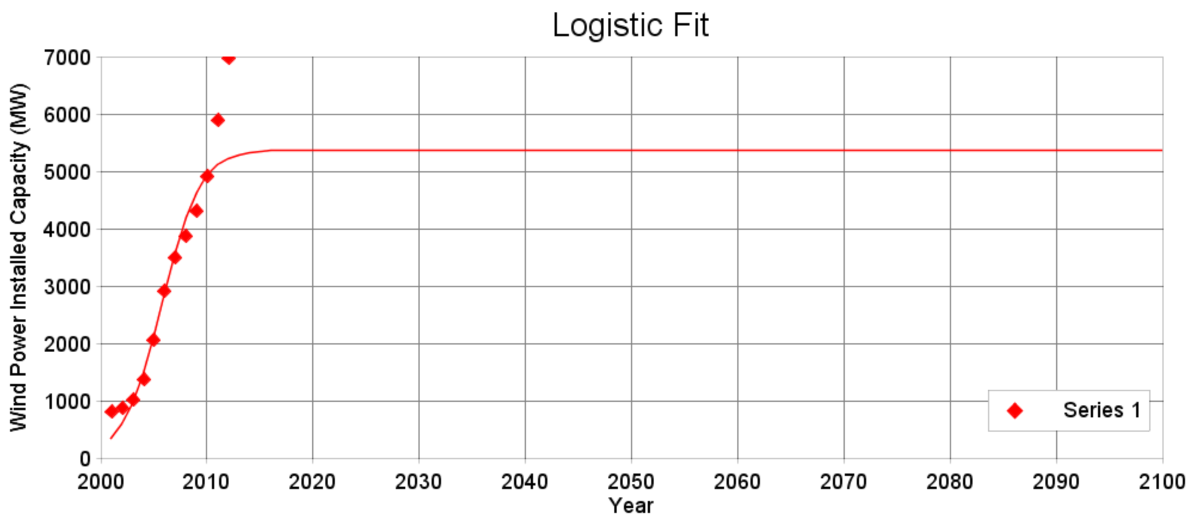
State: Kerala

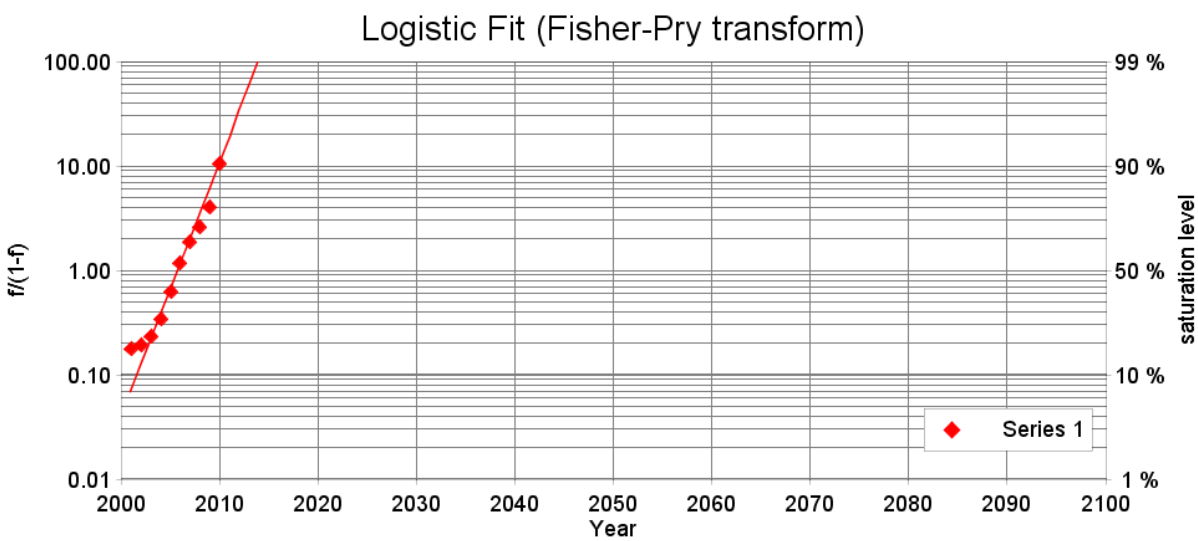


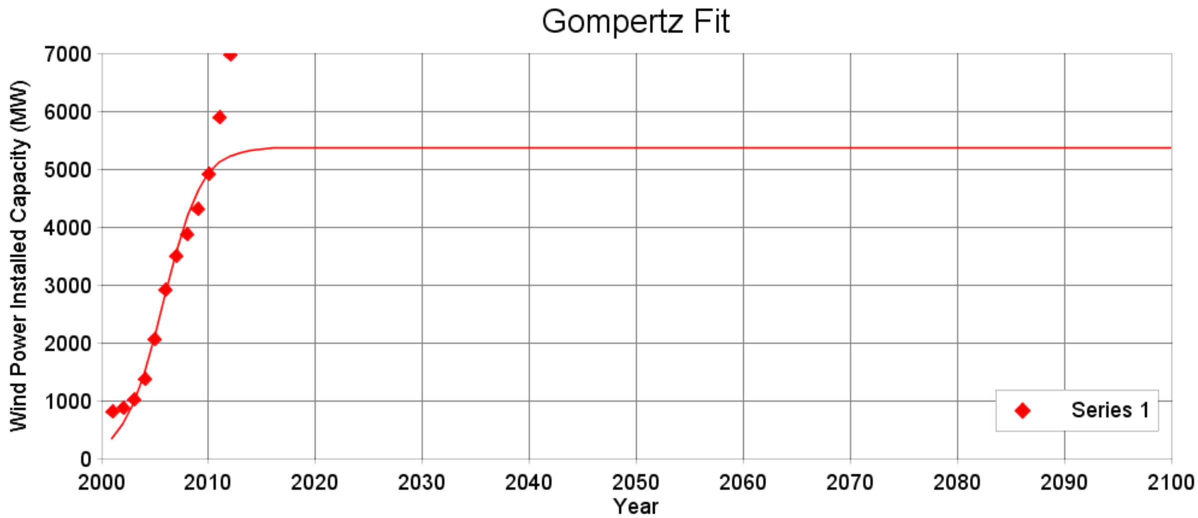
State: Tamilnadu

Appendix 6: Forecasting results for Wind Energy Technologies (IIASA Model)

Tamilnadu







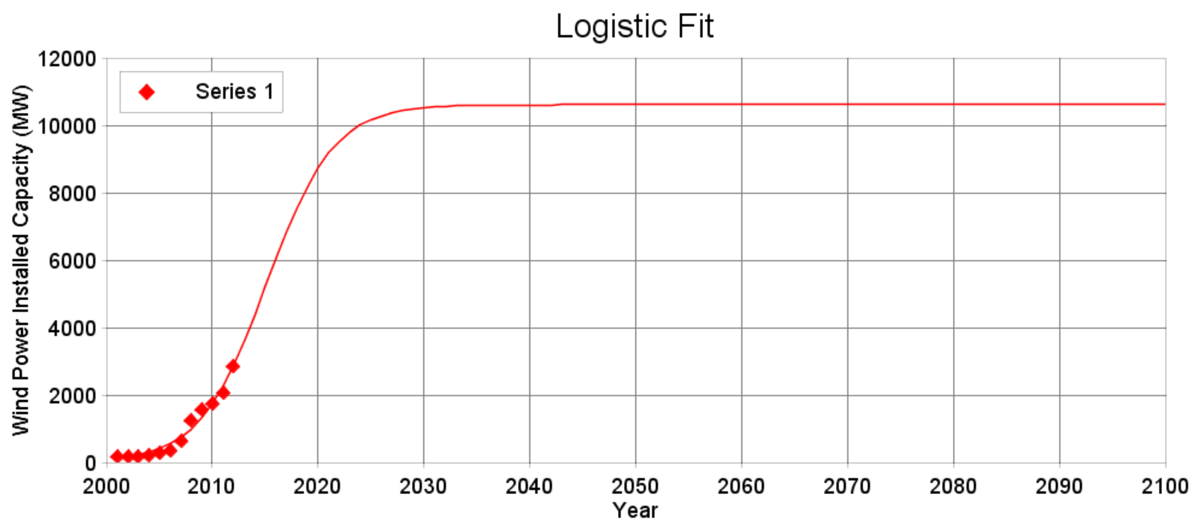
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	5,374	2,005.737	7.816	0.562	4,296,352.807	0.923
Gompertz	Series 1	5,374	2,004.578	7.541		5,548,927.573	0.899
Sharif-Khabir	Series 1	17,119.67	2,012.131	31.835		2,345,225.514	0.983
Floyd	Series 1	21,508.13	2,012.897	47.71		2,758,618.518	0.983
Exponential	Series 1		-411.207		0.209	185,074,646.516	0.812
Linear	Series 1	-1,127,341.684			563.445	1,540,903.583	0.967

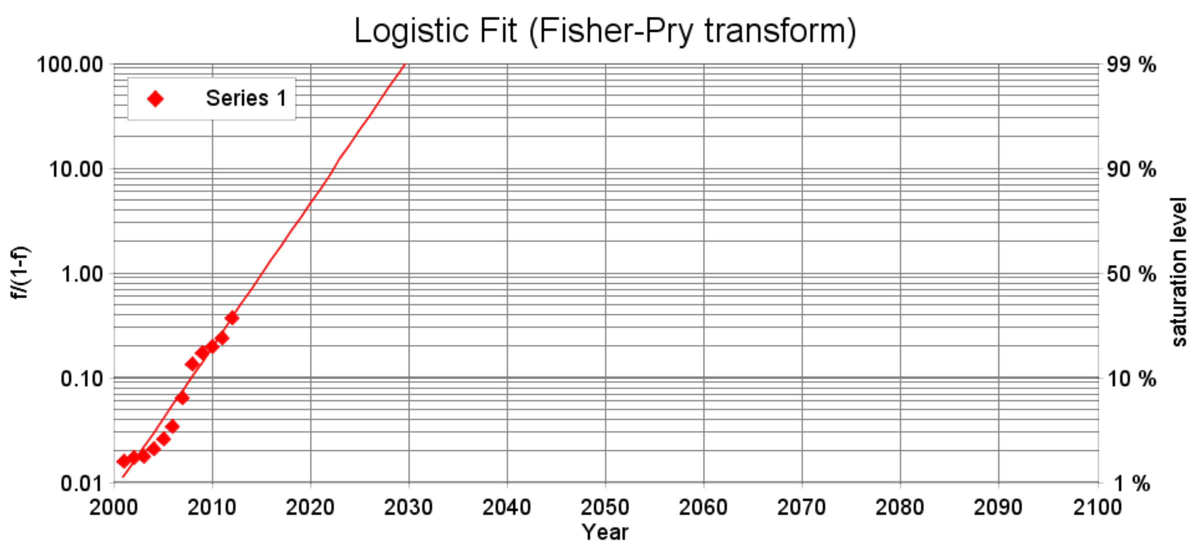
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	10,896.88	2,010.26	15.739	0.279	641,556.507	0.986
Gompertz	Series 1	22,760.812	2,013.974	31.669		534,373.489	0.989
Sharif-Khabir	Series 1	17,119.67	2,012.131	31.835		2,345,225.514	0.983
Floyd	Series 1	21,508.13	2,012.897	47.71		2,758,618.518	0.983
Exponential	Series 1		-411.207		0.209	185,074,646.516	0.812
Linear	Series 1	-1,127,341.684			563.445	1,540,903.583	0.967

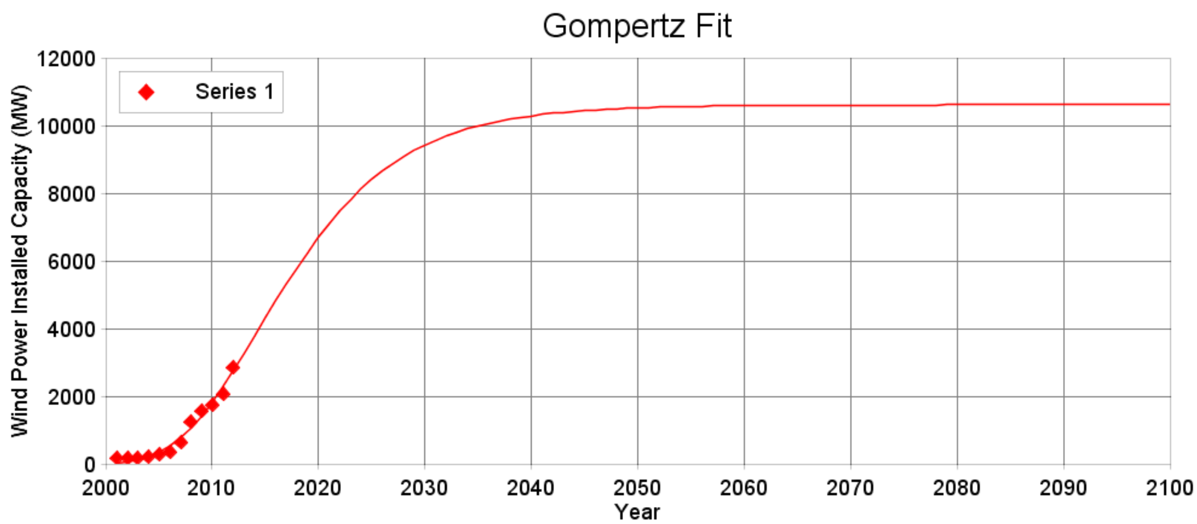
Gujarat



Logistic Fit
Series 1
Wind Power Installed Capacity (MW)
12000
10000
8000
6000
4000
2000
0
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year



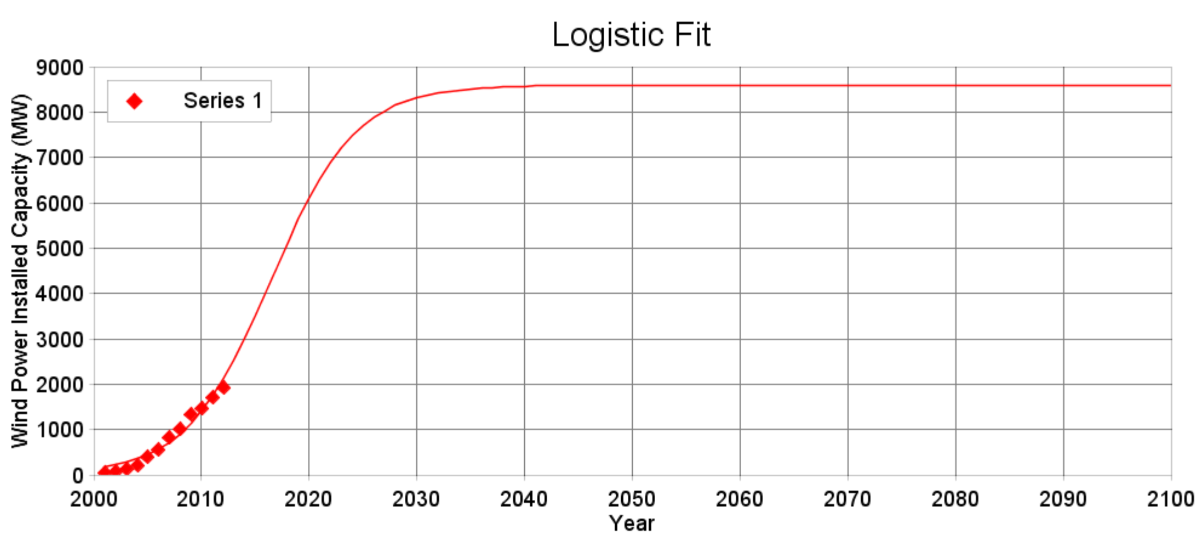
Logistic Fit (Fisher-Pry transform)
Series 1
f/(1-f)
100.00
10.00
1.00
0.10
0.01
99 %
90 %
50 %
10 %
1 %
saturation level
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year

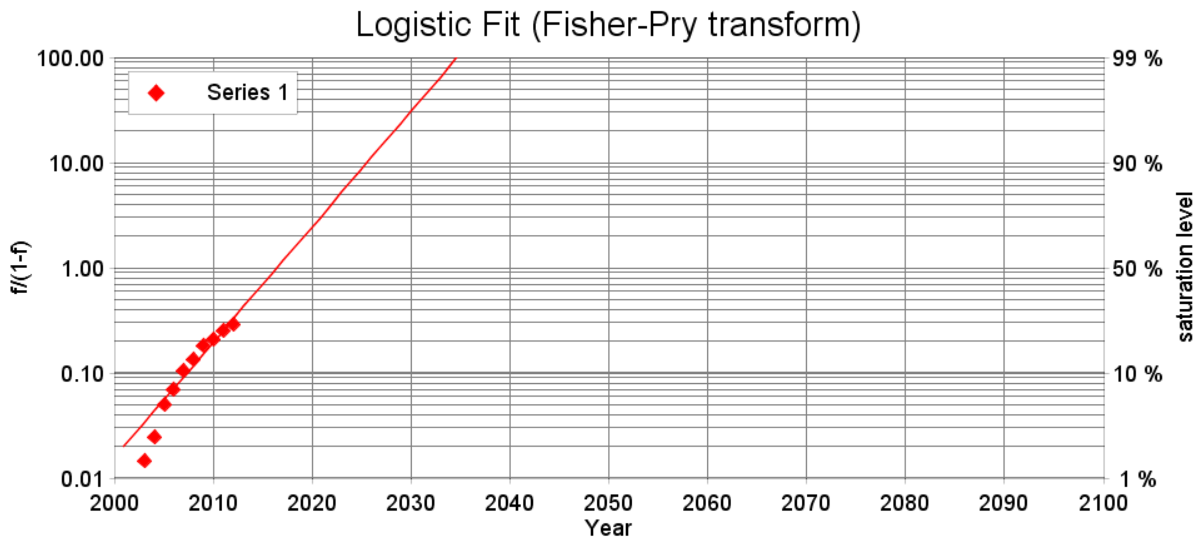


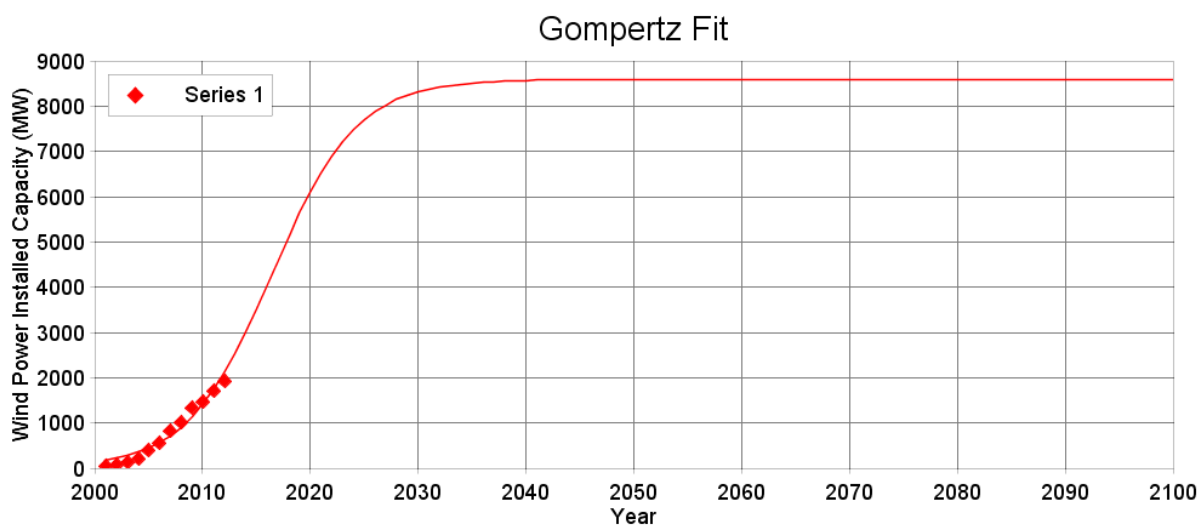
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	10,609	2,015.134	13.833	0.318	237,084.907	0.975
Gompertz	Series 1	10,609	2,014.213	22.908		200,910.953	0.979
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-583.986		0.294	19,186,301.69	0.833
Linear	Series 1	-474,644.953			237.033	1,005,872.993	0.9

Karnataka



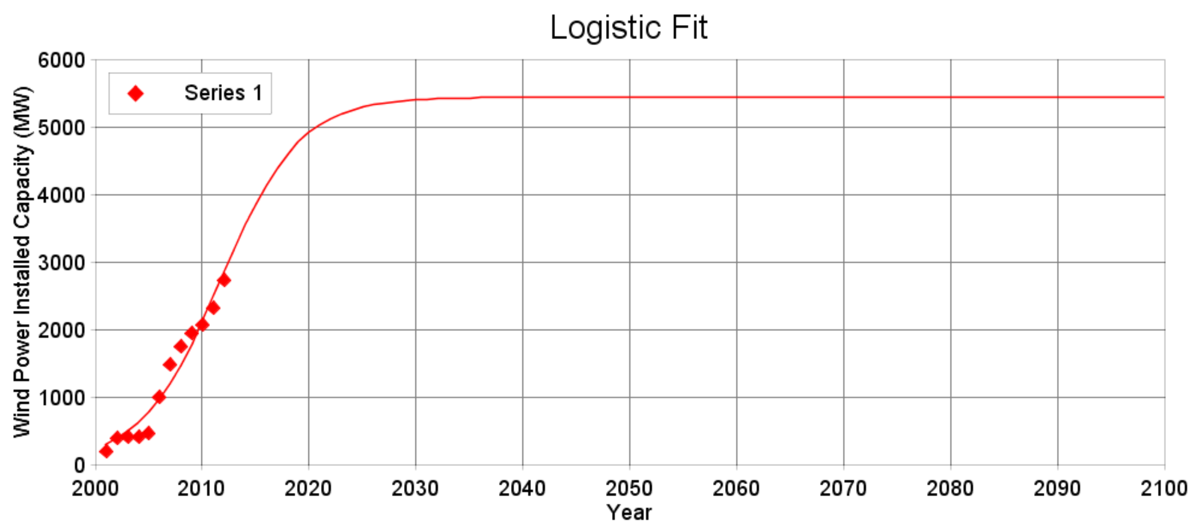


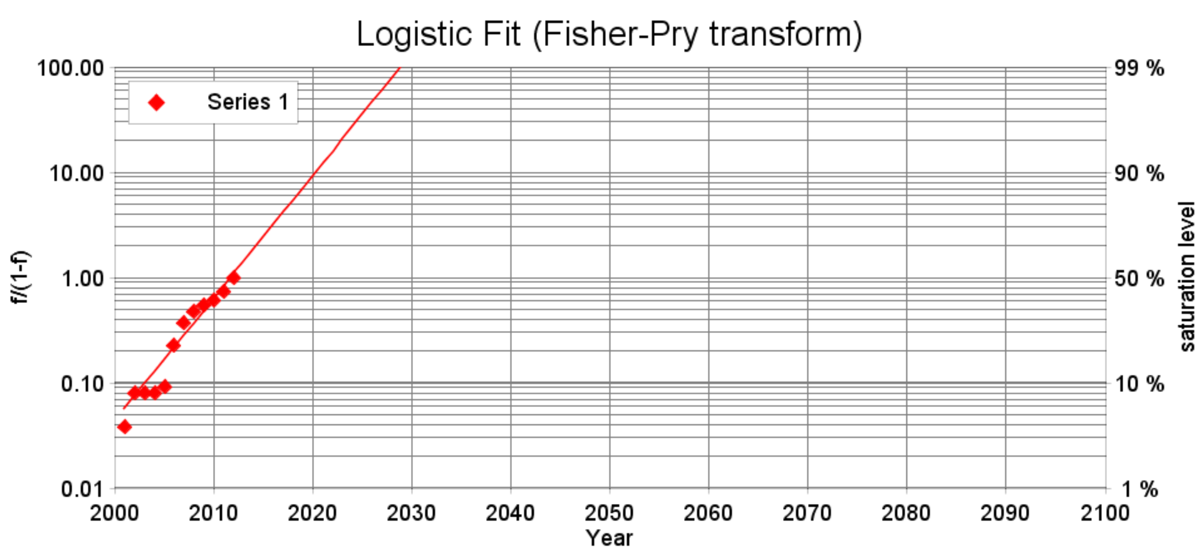


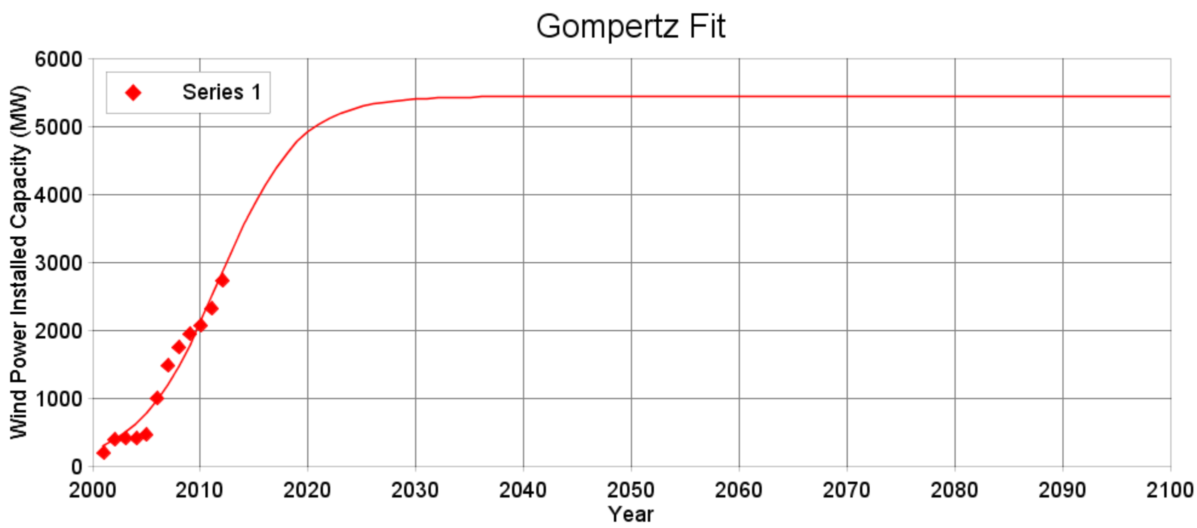
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	8,591	2,016.457	17.368	0.253	173,632.553	0.969
Gompertz	Series 1	8,591	2,015.422	29.14		59,423.89	0.989
Sharif-Khabir	Series 1	2,742.118	2,008.363	16.117		57,486.05	0.996
Floyd	Series 1	3,108.312	2,008.342	23.28		60,593.438	0.996
Exponential	Series 1		-685.534		0.345	19,440,636.101	0.593
Linear	Series 1	-369,050.543			184.331	104,858.06	0.983

Maharashtra



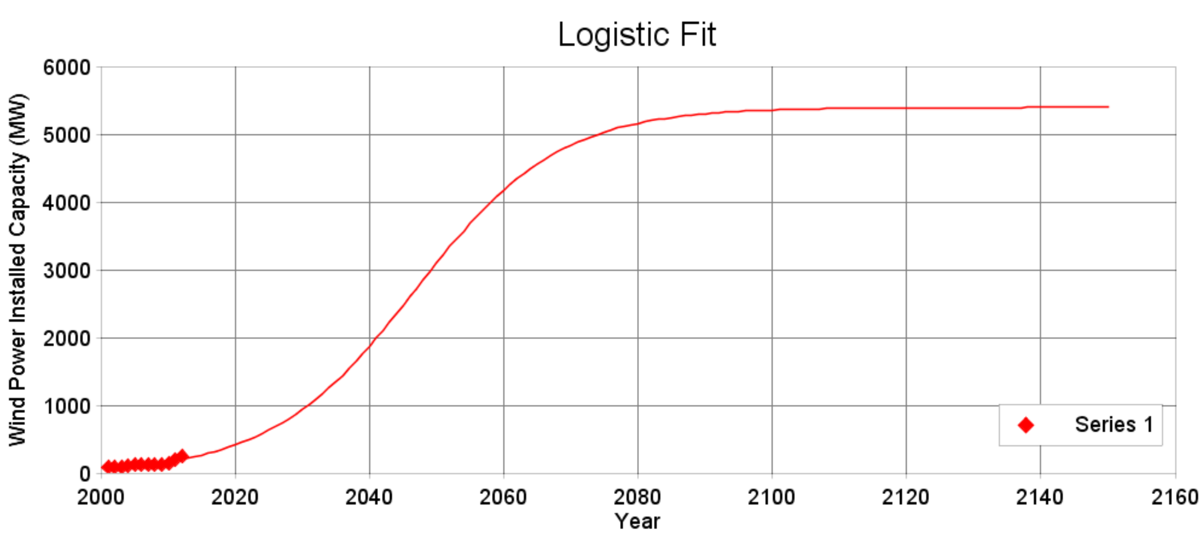


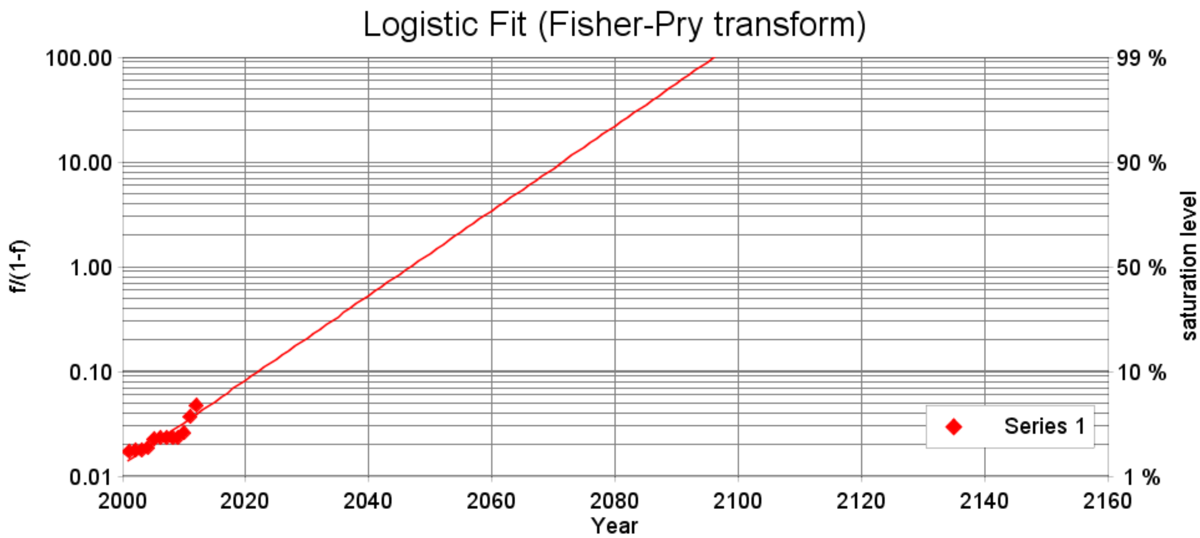


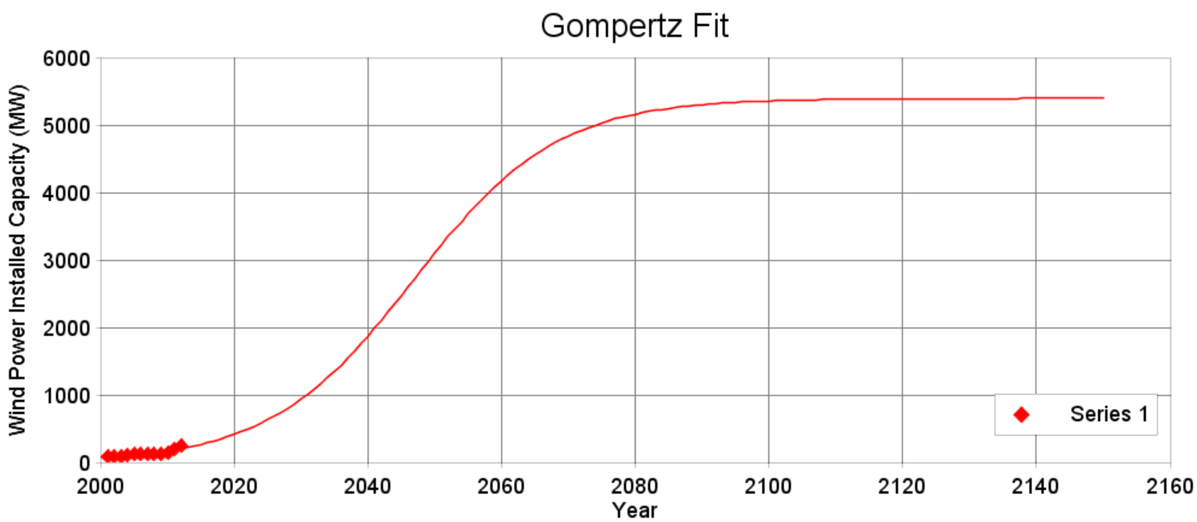
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	5,439	2,011.683	16.389	0.268	379,732.229	0.957
Gompertz	Series 1	5,439	2,009.489	20.655		258,047.574	0.971
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-472.935		0.239	30,982,560.457	0.744
Linear	Series 1	-482,105.055			240.902	426,638.944	0.951

Andhra Pradesh



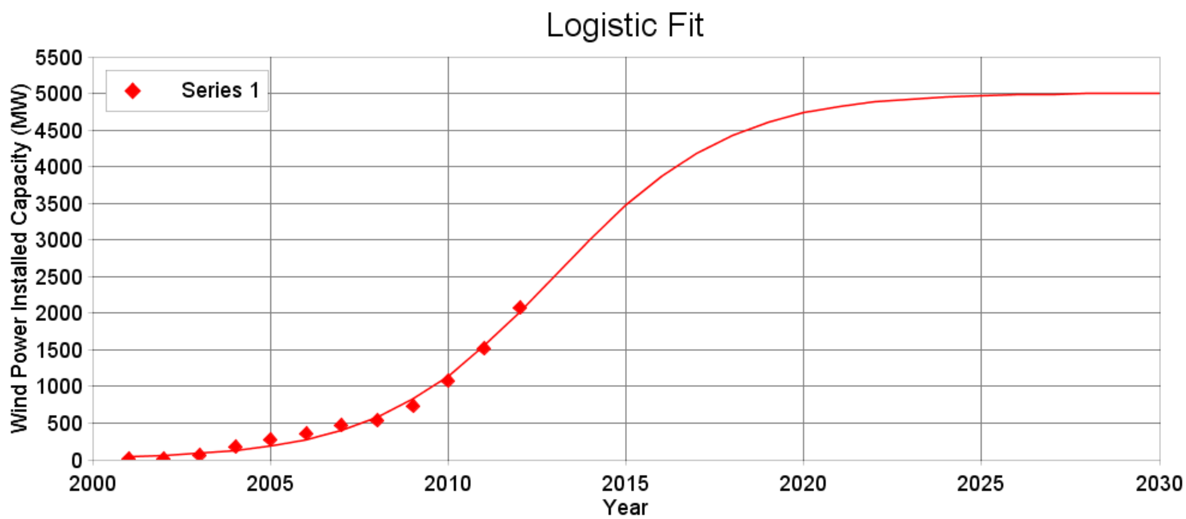




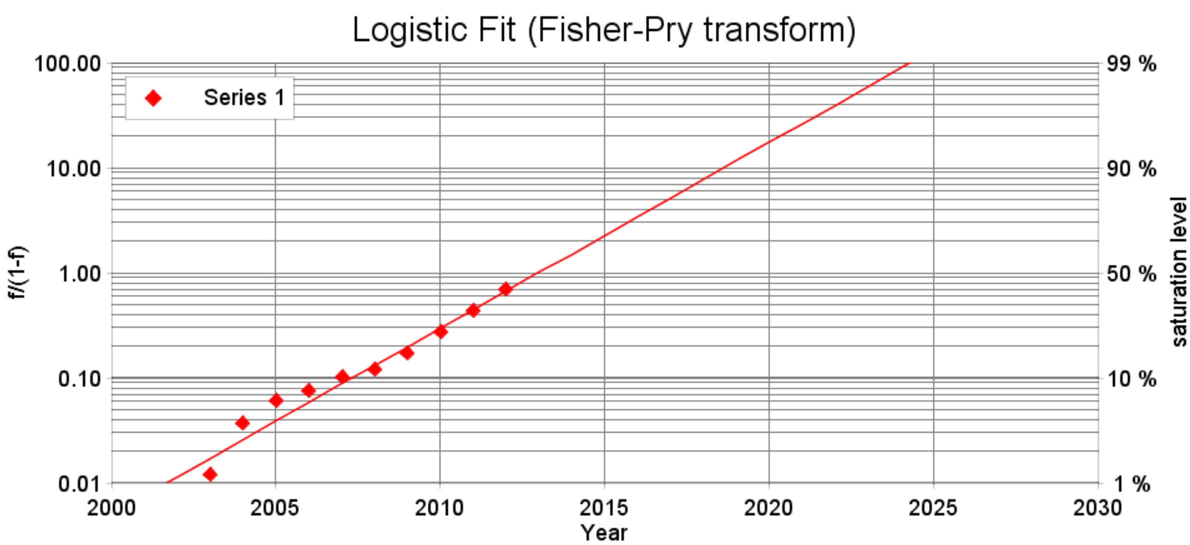
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	5,394	2,046.783	47.154	0.093	5,062.168	0.778
Gompertz	Series 1	5,394	2,062.213	129.672		5,544.274	0.756
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-142.794		0.074	195,808.622	0.85
Linear	Series 1	-20,896.49			10.479	6,901.555	0.695

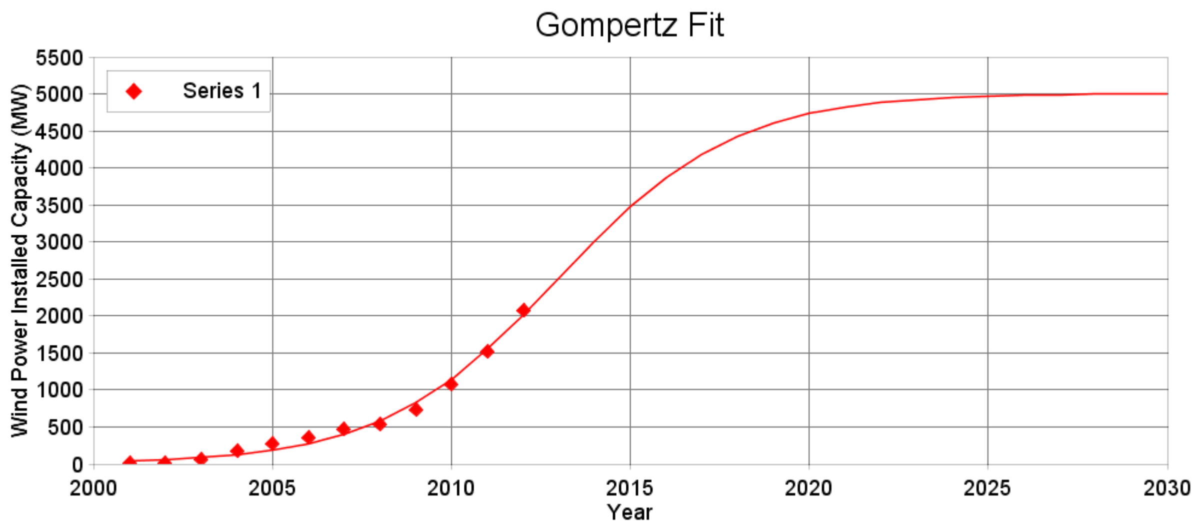
Rajasthan



Logistic Fit
Series 1
Wind Power Installed Capacity (MW)
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2000
2005
2010
2015
2020
2025
2030
Year



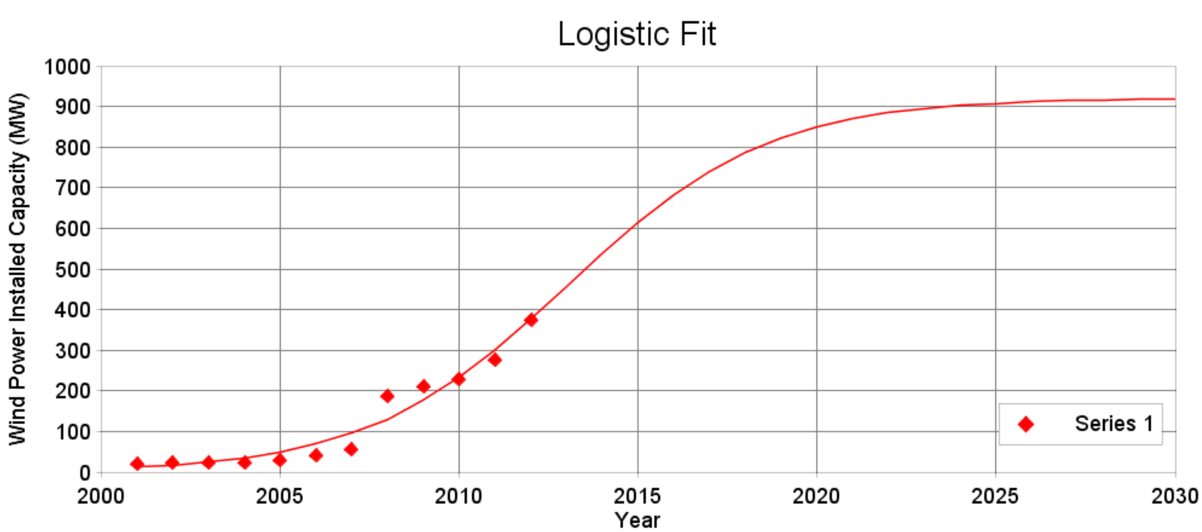
Logistic Fit (Fisher-Pry transform)
Series 1
f/(1-f)
100.00
10.00
1.00
0.10
0.01
99 %
90 %
50 %
10 %
1 %
saturation level
2000
2005
2010
2015
2020
2025
2030
Year

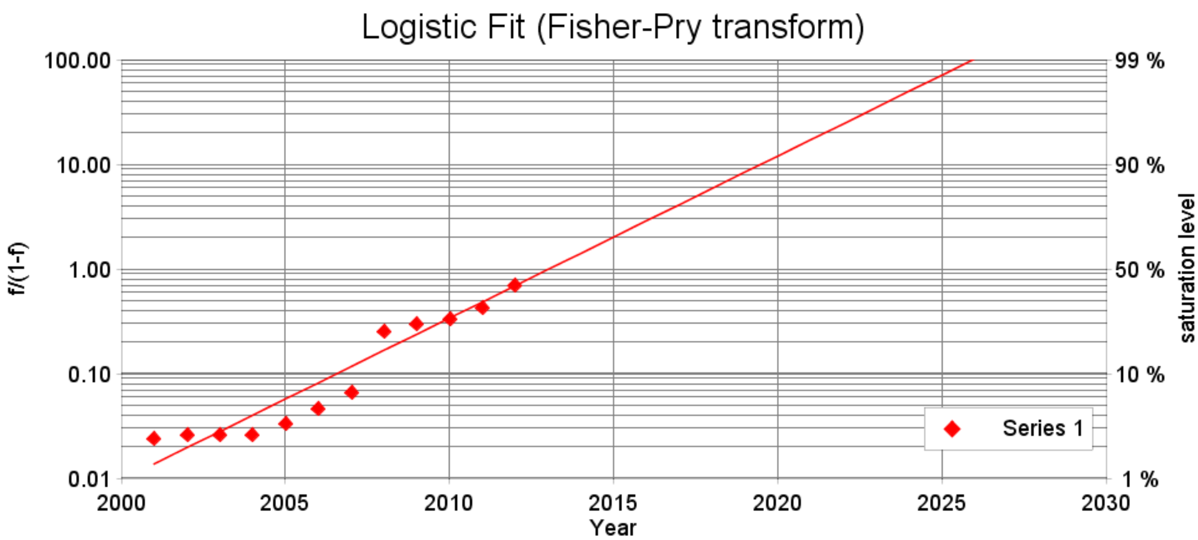


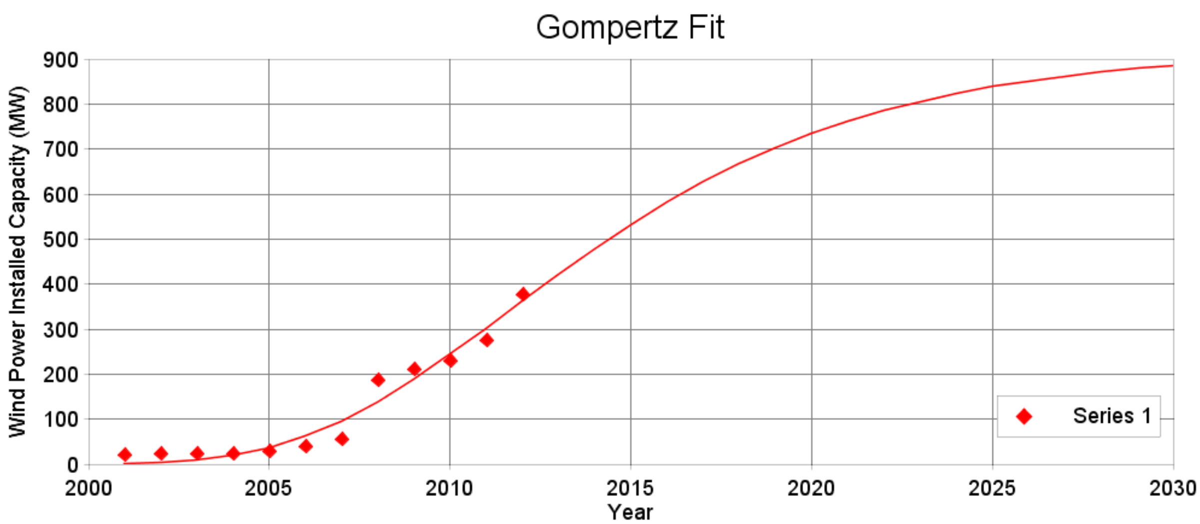
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	5,005	2,012.992	10.803	0.407	43,663.782	0.991
Gompertz	Series 1	5,005	2,011.868	16.342		137,984.246	0.972
Sharif-Khabir	Series 1	3,574.303	2,010.5	15.677		123,596.725	0.977
Floyd	Series 1	4,199.166	2,010.658	23.189		127,944.939	0.977
Exponential	Series 1		-907.472		0.455	17,009,215.186	0.495
Linear	Series 1	-330,047.591			164.794	616,189.631	0.879

Madhya Pradesh



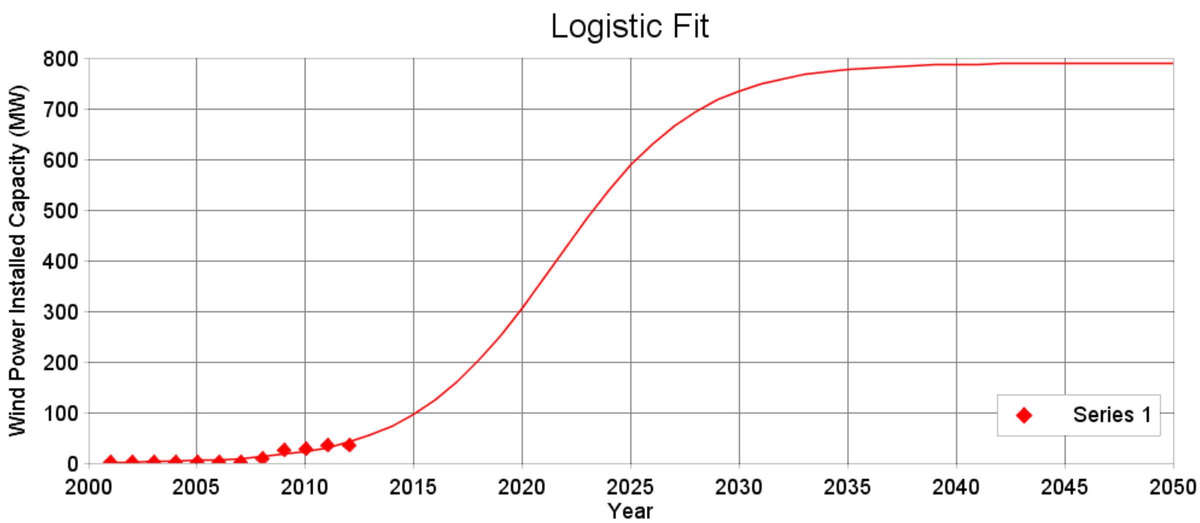




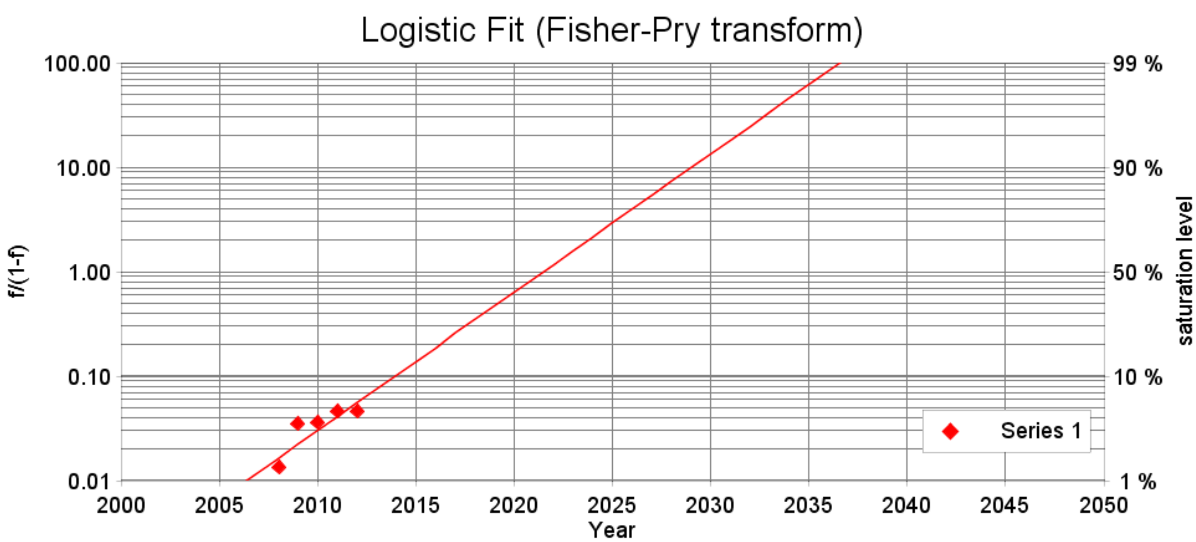
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	920	2,013.035	12.312	0.357	8,088.67	0.953
Gompertz	Series 1	920	2,011.599	17.388		7,103.507	0.96
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-603.87		0.303	300,657.153	0.817
Linear	Series 1	-63,424.548			31.672	21,940.262	0.882

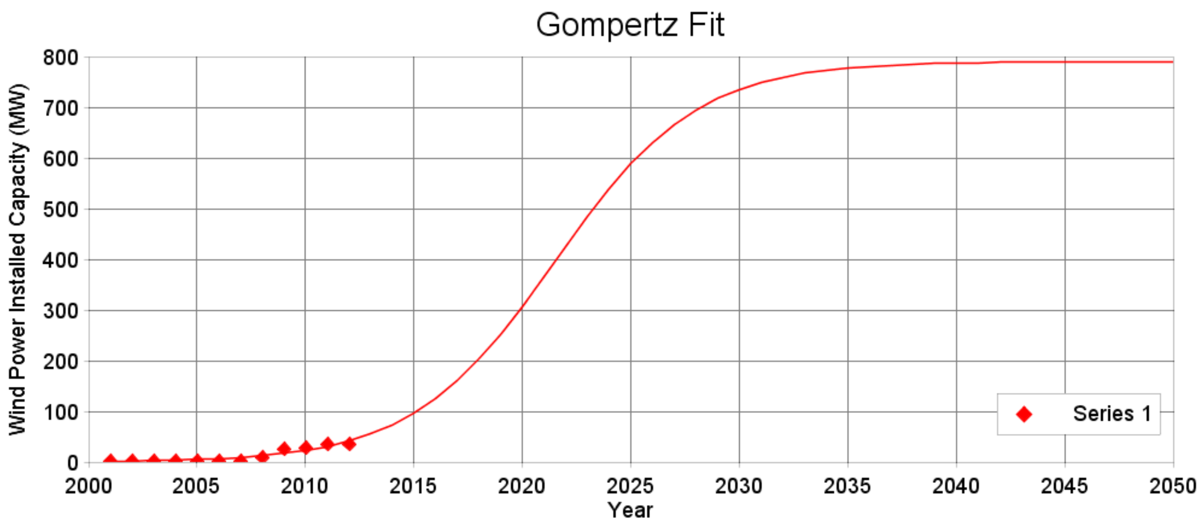
Kerala



Logistic Fit
Wind Power Installed Capacity (MW)
800
700
600
500
400
300
200
100
0
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Year
Series 1



Logistic Fit (Fisher-Pry transform)
f/(1-f)
100.00
10.00
1.00
0.10
0.01
99 %
90 %
50 %
10 %
1 %
saturation level
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Year
Series 1

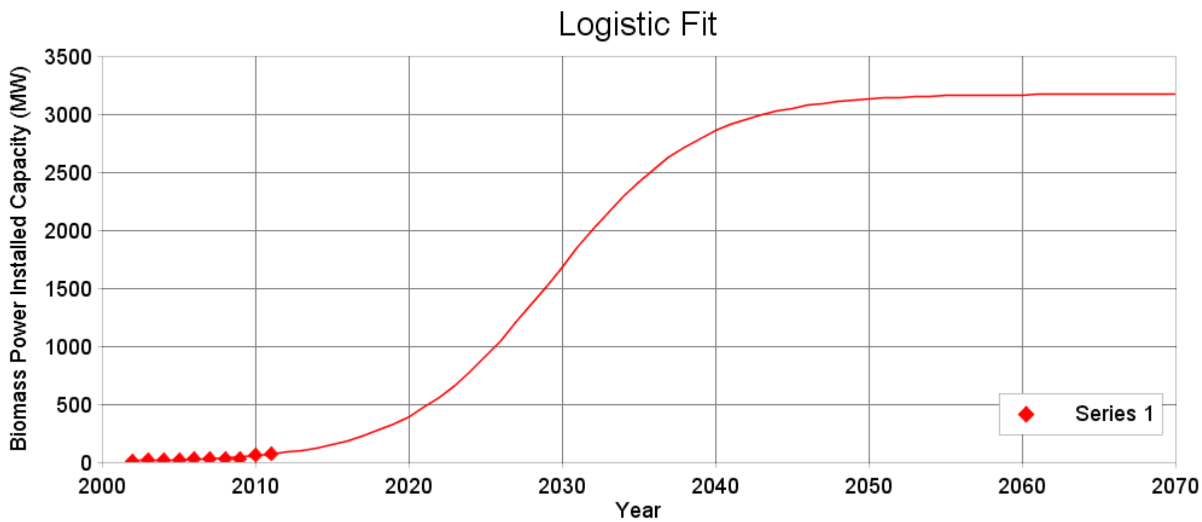


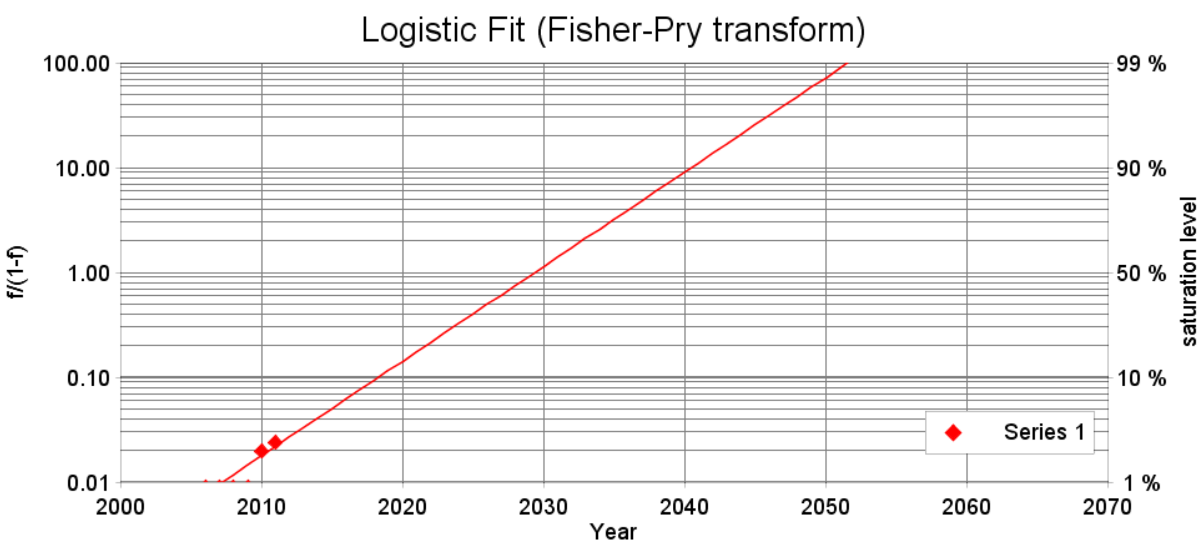
Fit Parameter

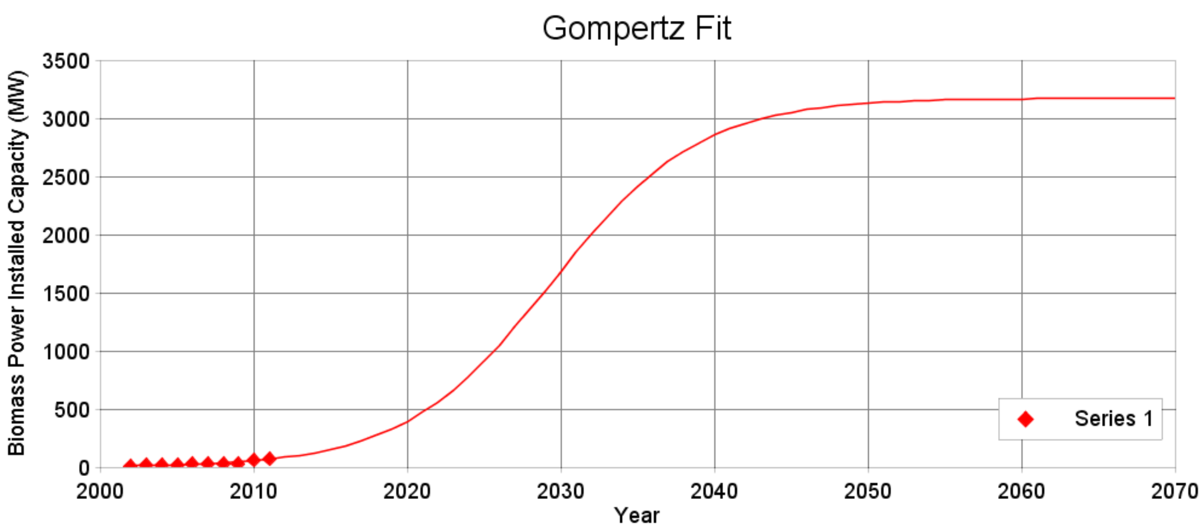
	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	790	2,021.49	14.407	0.305	274.626	0.882
Gompertz	Series 1	790	2,025.056	37.156		223.214	0.901
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-656.115		0.328	1,863.167	0.786
Linear	Series 1	-6,968.882			3.479	425.625	0.828

Appendix 7: Forecasting results for Biomass Energy Technologies (IIASA Model)

Punjab



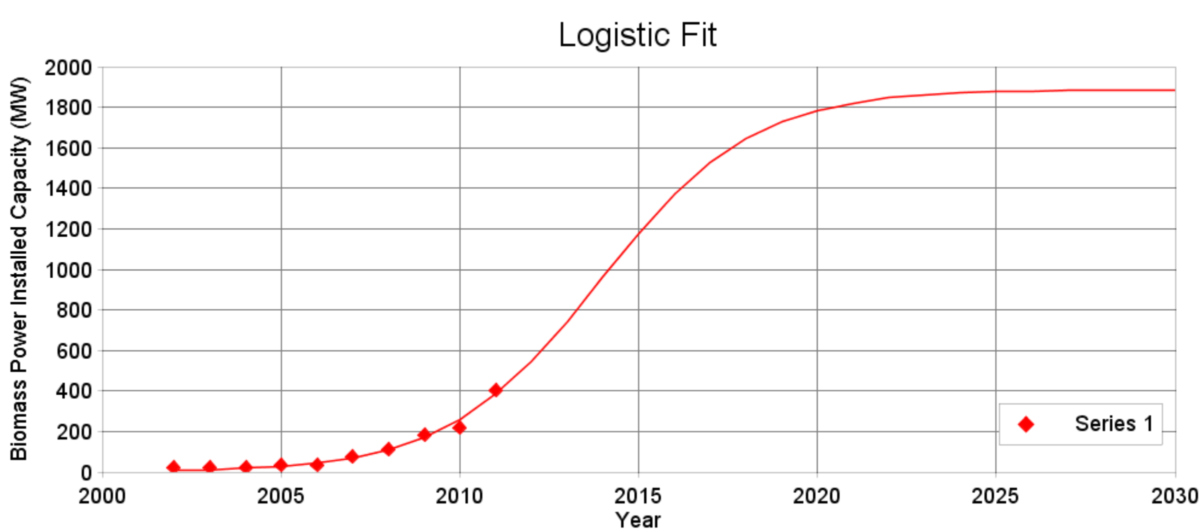


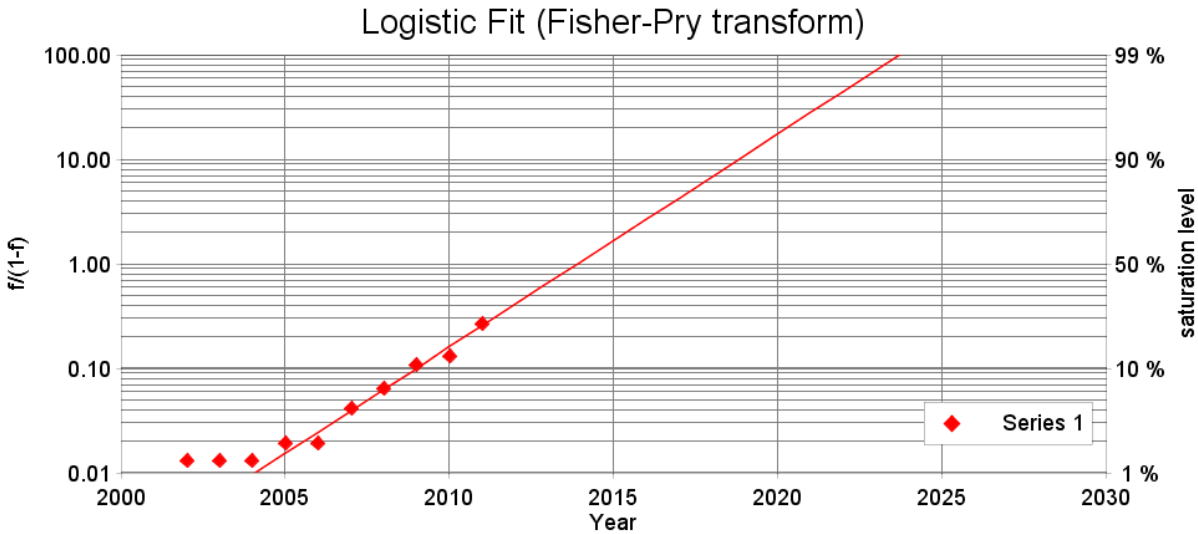


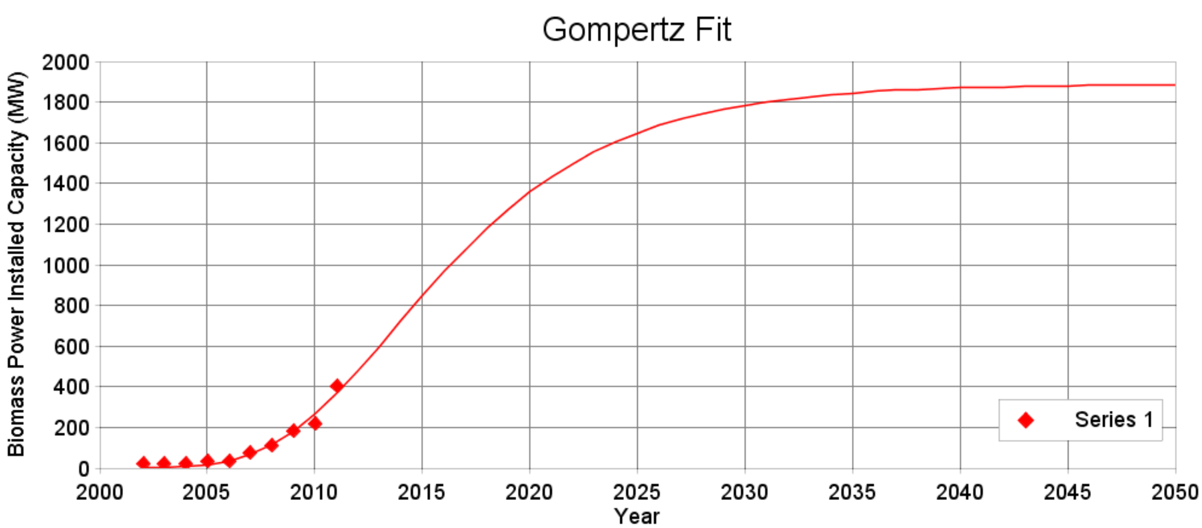
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	3,172	2,029.404	21.174	0.208	601.914	0.833
Gompertz	Series 1	3,172	2,041.913	70.344		696.891	0.805
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-308.824		0.156	9,725.494	0.84
Linear	Series 1	-10,838.882			5.418	1,073.673	0.693

Maharashtra



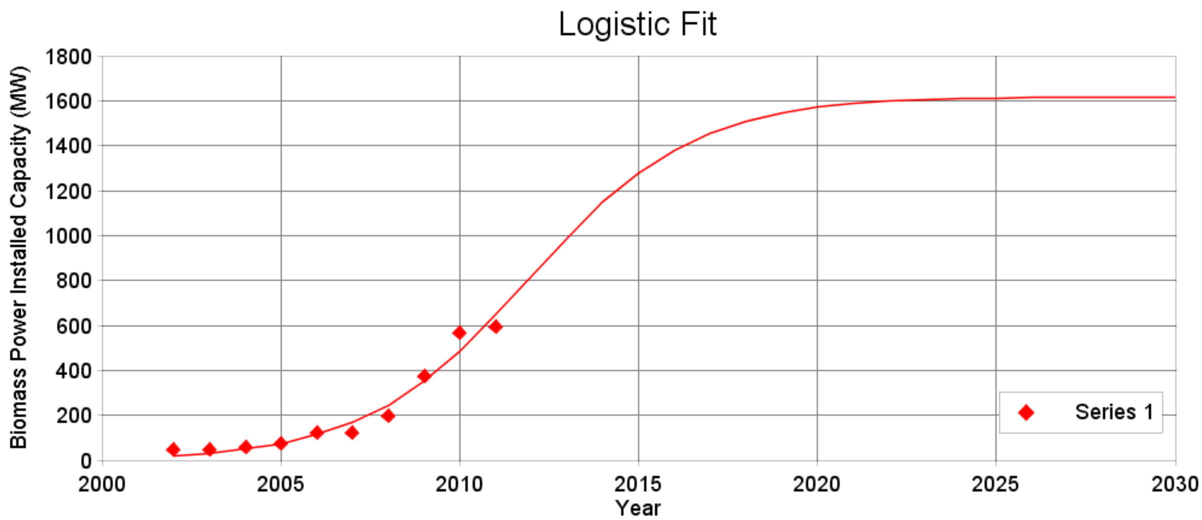


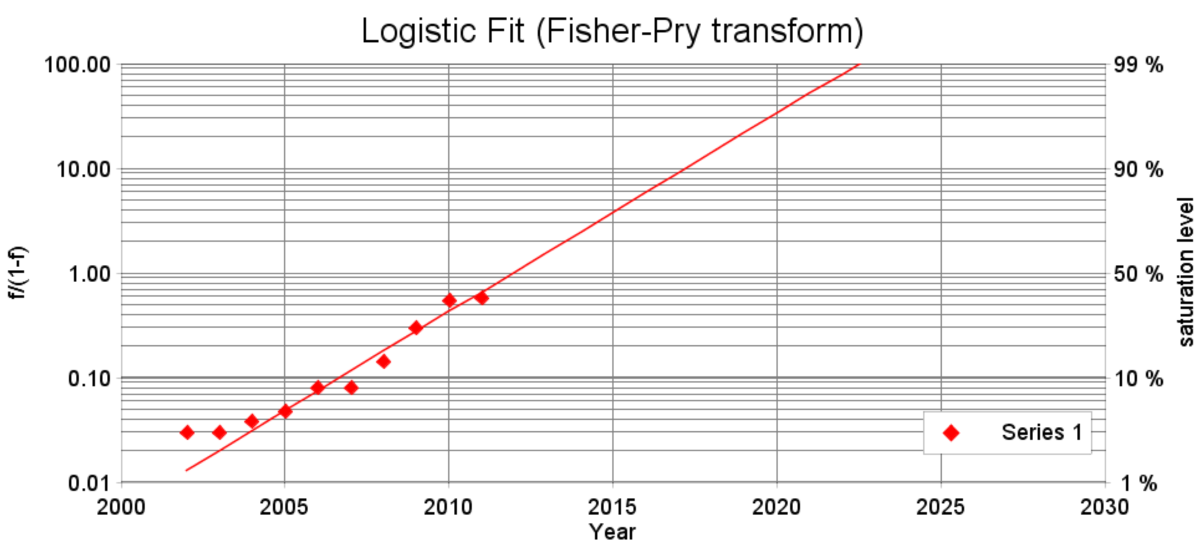


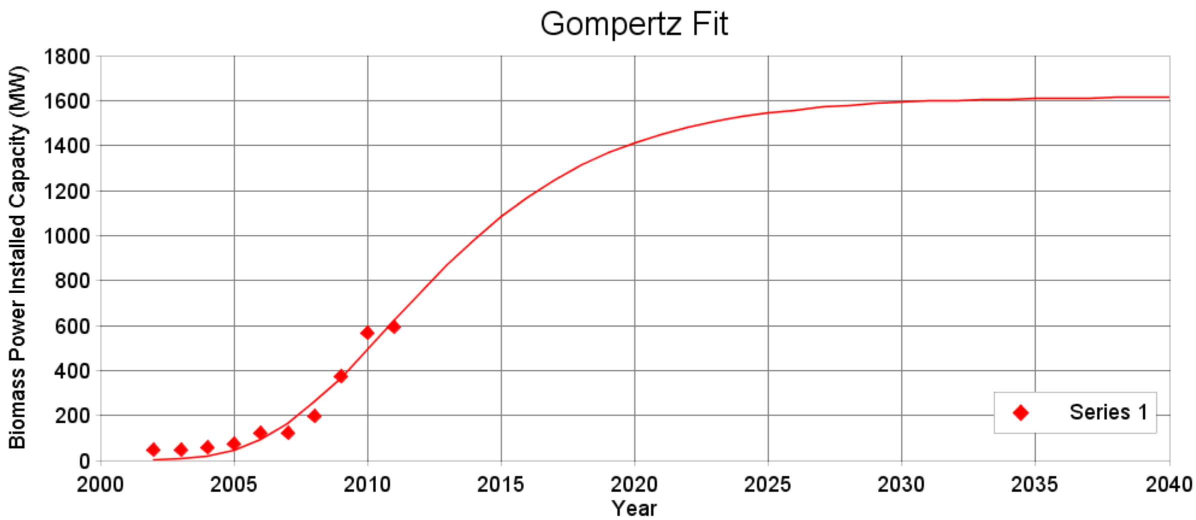
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	1,887	2,013.916	9.373	0.469	2,976.538	0.98
Gompertz	Series 1	1,887	2,013.756	17.317		5,514.86	0.967
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-662.721		0.332	188,293.271	0.925
Linear	Series 1	-70,946.252			35.415	28,905.368	0.8

Uttar Pradesh



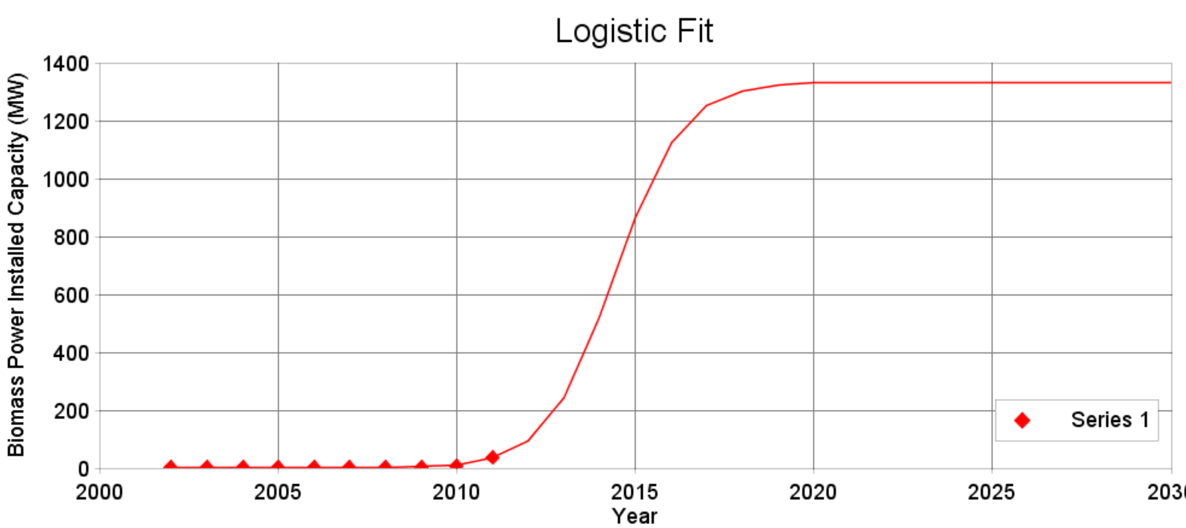


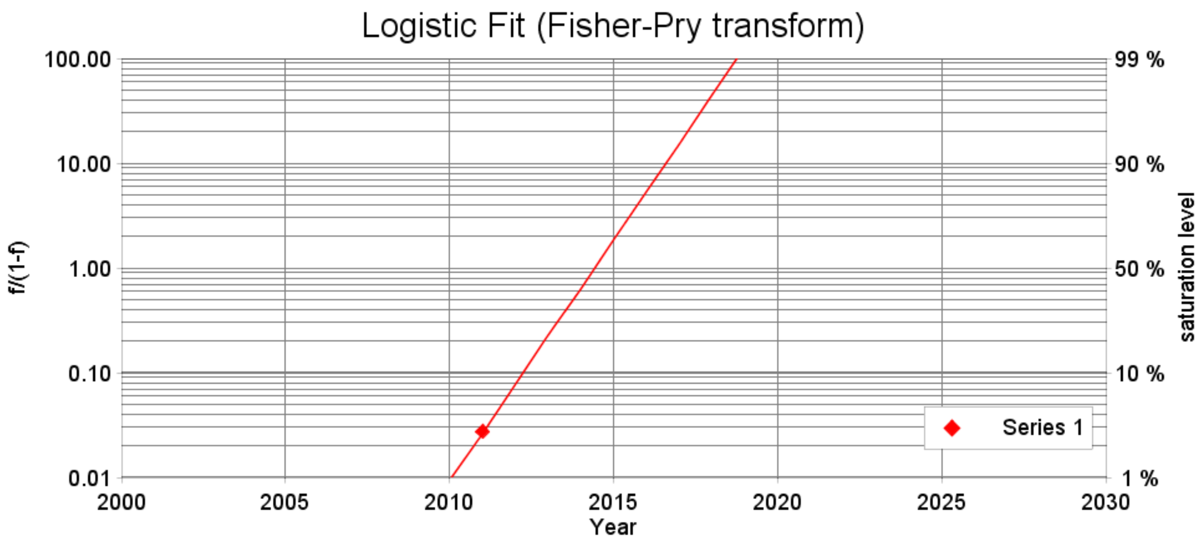


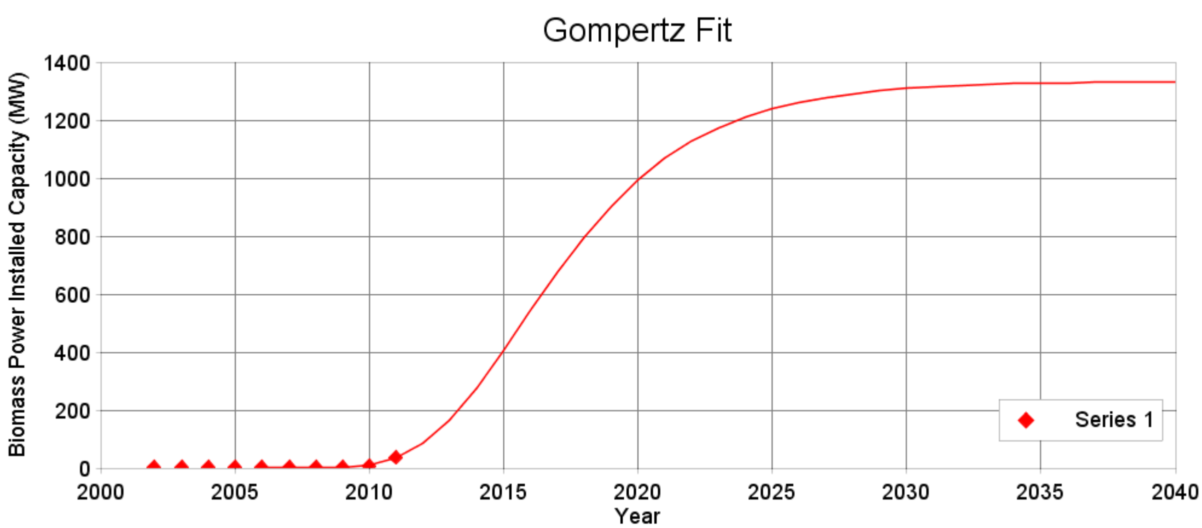
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	1,617	2,011.946	10.077	0.436	15,121.264	0.963
Gompertz	Series 1	1,617	2,010.79	14.188		17,975.357	0.963
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-635.357		0.319	735,521.125	0.905
Linear	Series 1	-127,557.518			63.682	64,489.687	0.848

Haryana



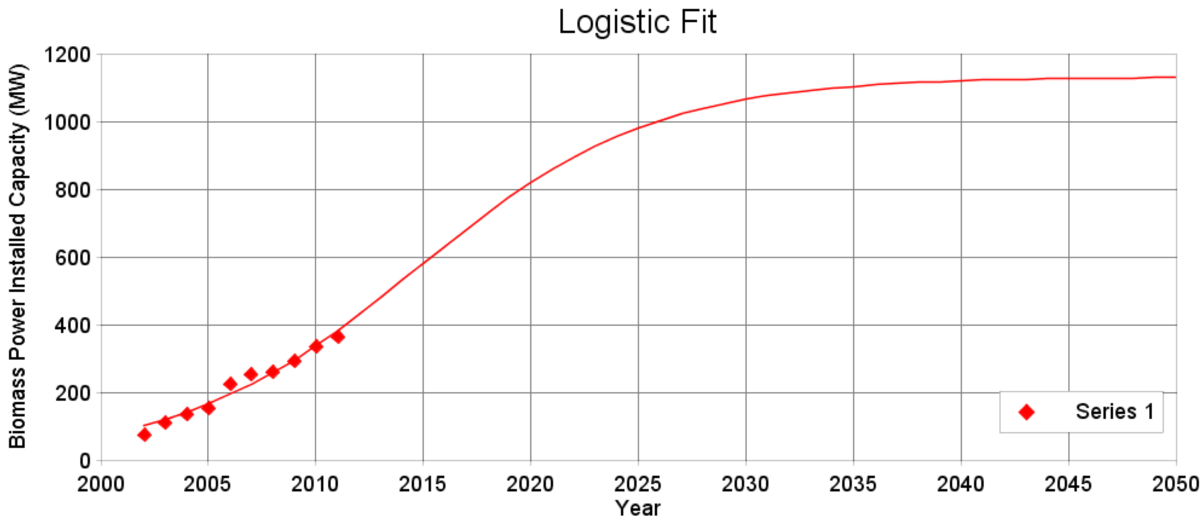




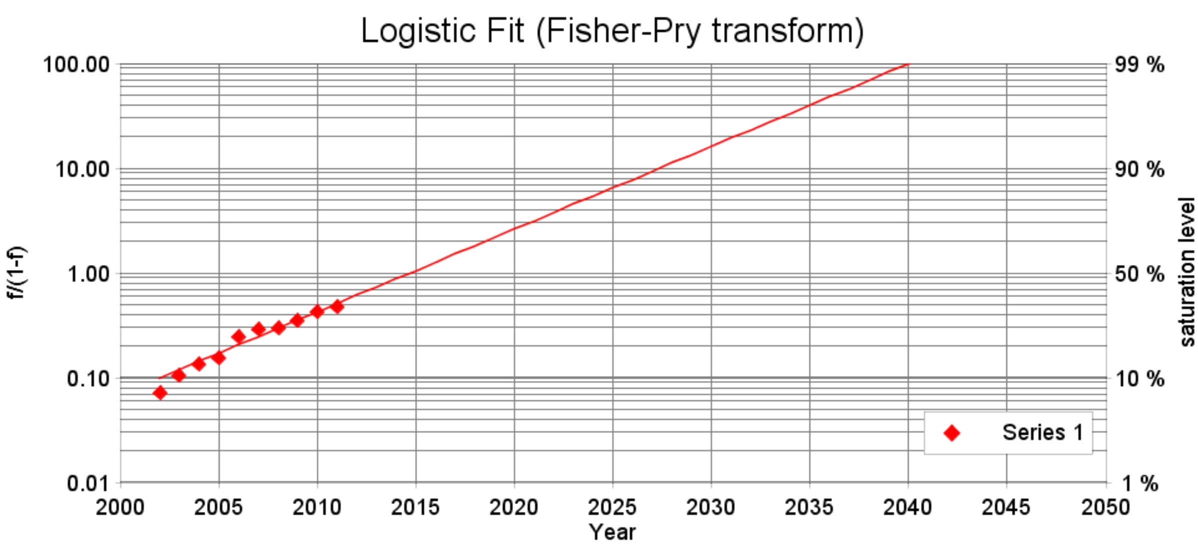
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	1,333	2,014.423	4.154	1.058	191.299	0.926
Gompertz	Series 1	1,333	2,015.623	11.043		211.831	0.944
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-319.494		0.16	363.981	0.685
Linear	Series 1	-3,916.884			1.956	519.978	0.379

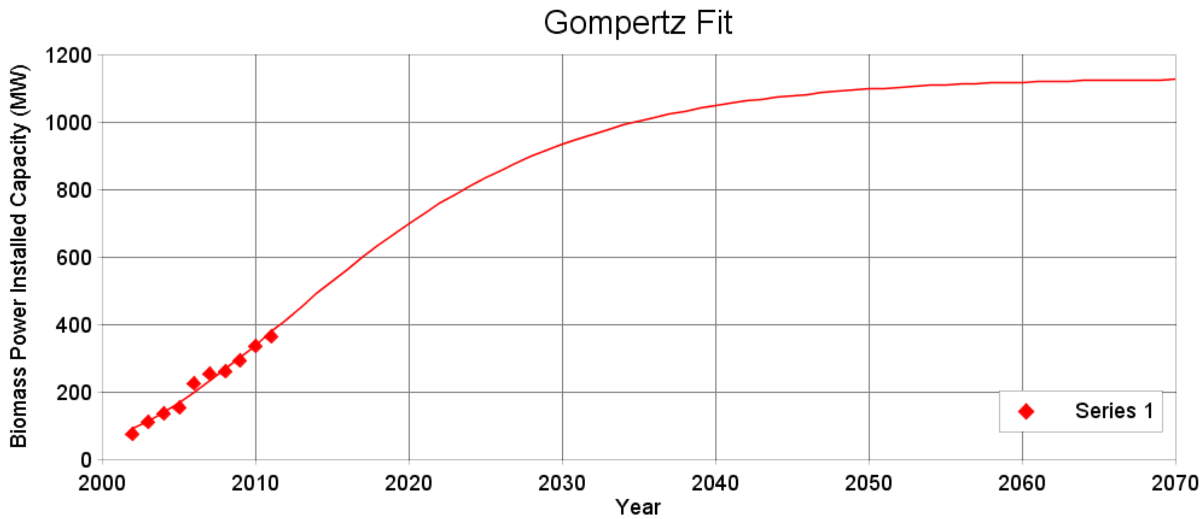
Karnataka



Logistic Fit
Biomass Power Installed Capacity (MW)
1200
1000
800
600
400
200
0
2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
Year
Series 1



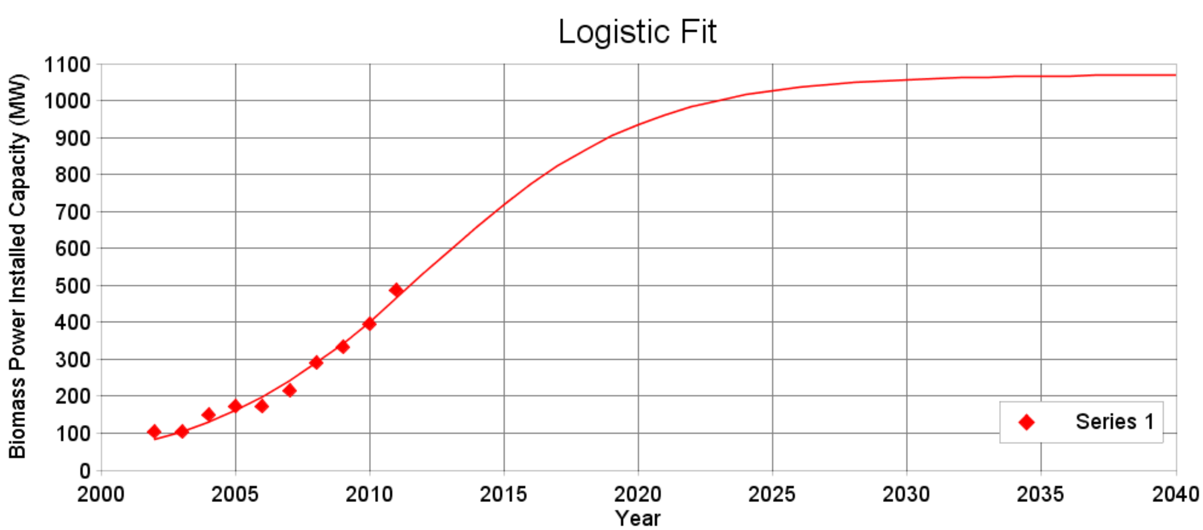
Logistic Fit (Fisher-Pry transform)
f/(1-f)
100.00
10.00
1.00
0.10
0.01
99 %
90 %
50 %
10 %
1 %
saturation level
2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
Year
Series 1

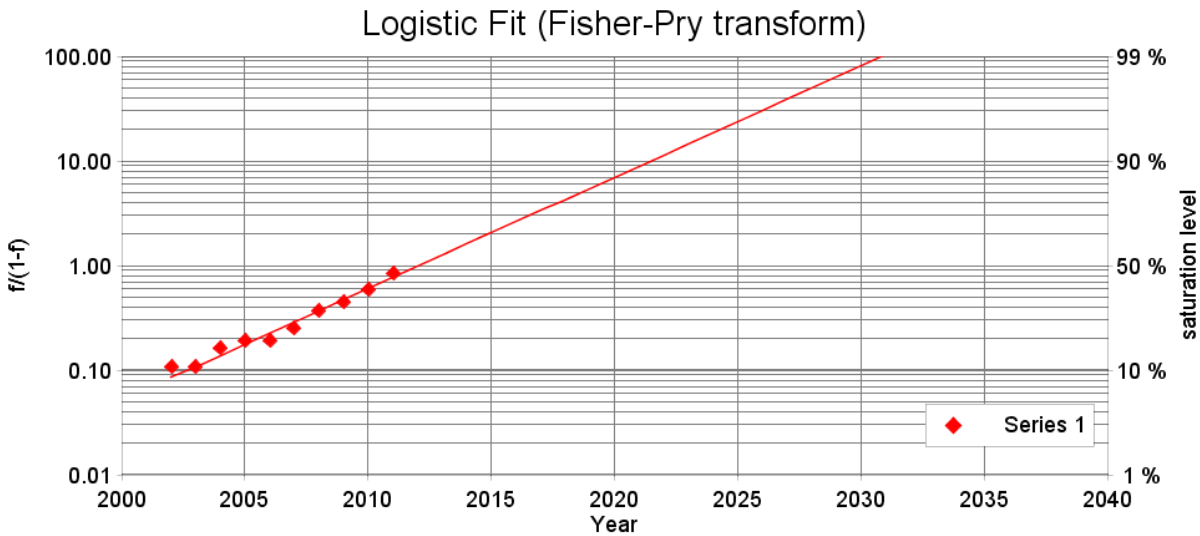


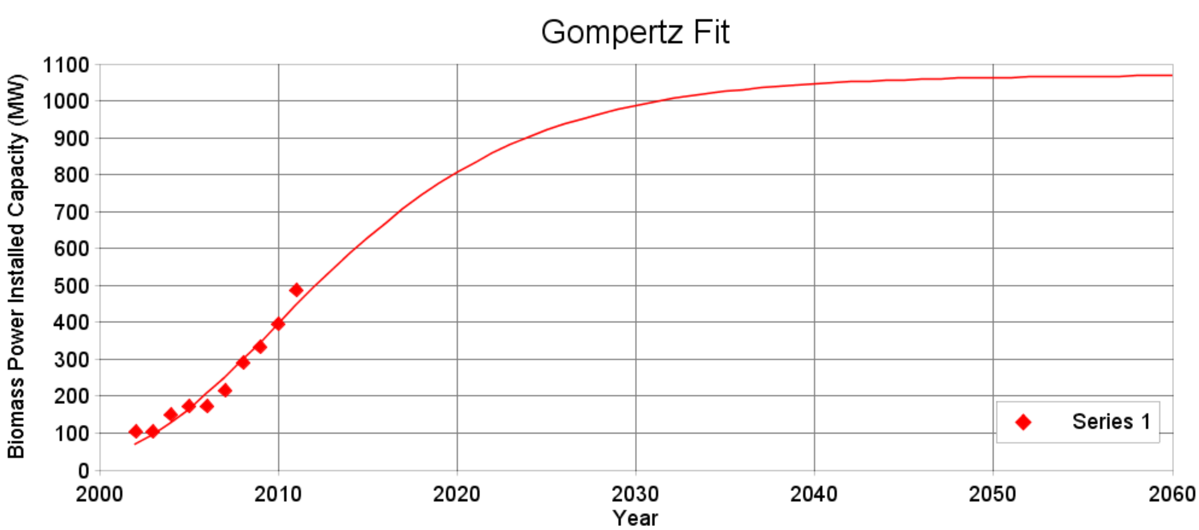
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	1,131	2,014.702	24.175	0.182	3,292.435	0.963
Gompertz	Series 1	1,131	2,012.066	33.557		1,957.871	0.978
Sharif-Khabir	Series 1	621.002	2,007.601	27.589		4,590.335	0.981
Floyd	Series 1	735.037	2,007.901	40.611		5,283.62	0.98
Exponential	Series 1		-331.273		0.168	575,817.993	0.825
Linear	Series 1	-64,820.353			32.415	1,241.07	0.986

Tamilnadu



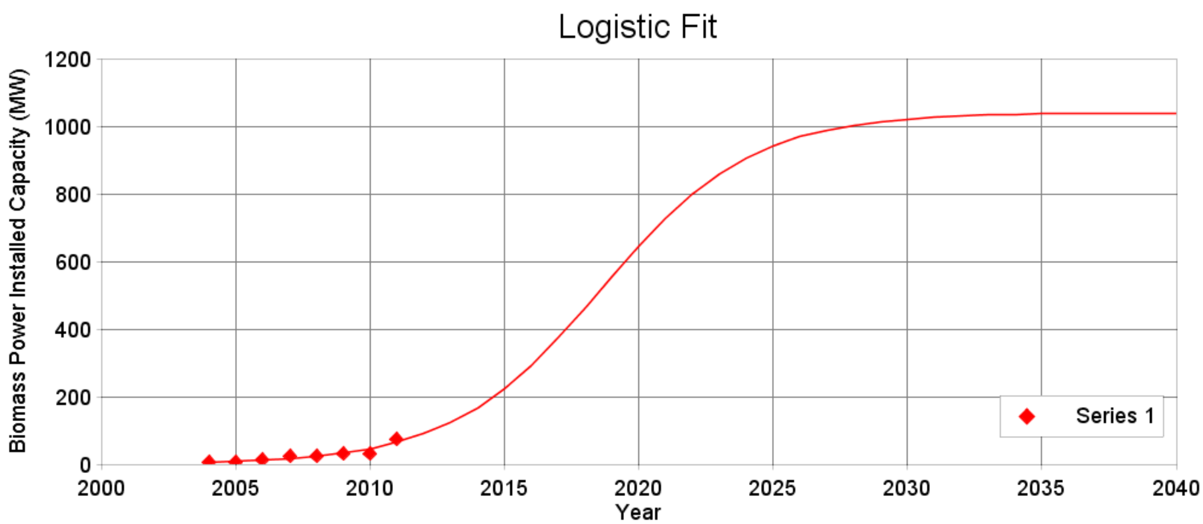




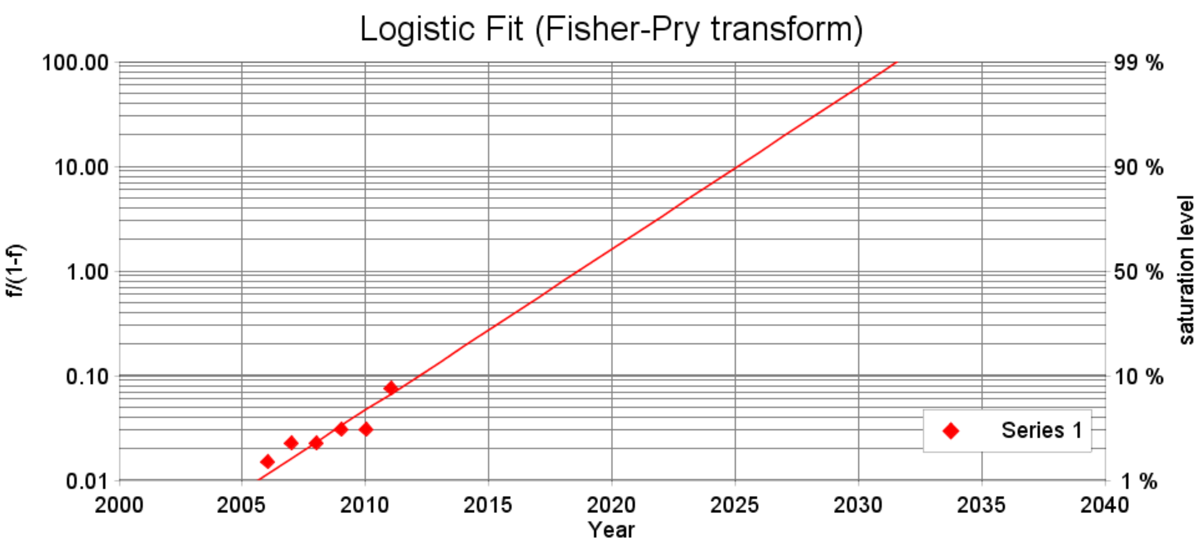
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	1,070	2,012.07	17.946	0.245	2,893.804	0.981
Gompertz	Series 1	1,070	2,009.944	24.517		6,297.296	0.959
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-343.911		0.174	698,404.679	0.958
Linear	Series 1	-82,189.89			41.083	11,328.36	0.925

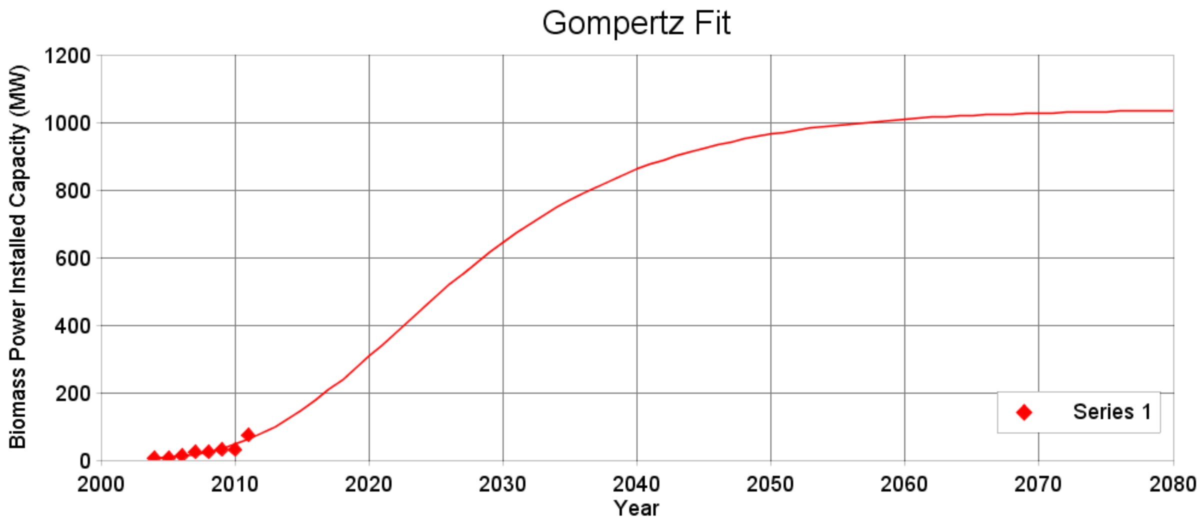
Rajasthan



Logistic Fit
Biomass Power Installed Capacity (MW)
1200
1000
800
600
400
200
0
2000
2005
2010
2015
2020
2025
2030
2035
2040
Year
Series 1



Logistic Fit (Fisher-Pry transform)
f/(1-f)
100.00
10.00
1.00
0.10
0.01
99 %
90 %
50 %
10 %
1 %
saturation level
2000
2005
2010
2015
2020
2025
2030
2035
2040
Year
Series 1

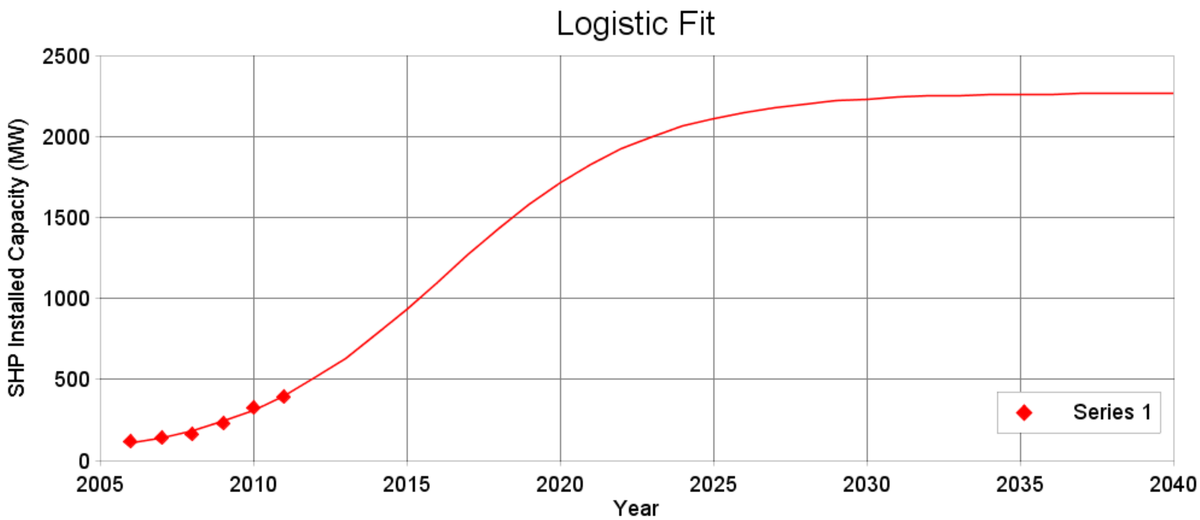


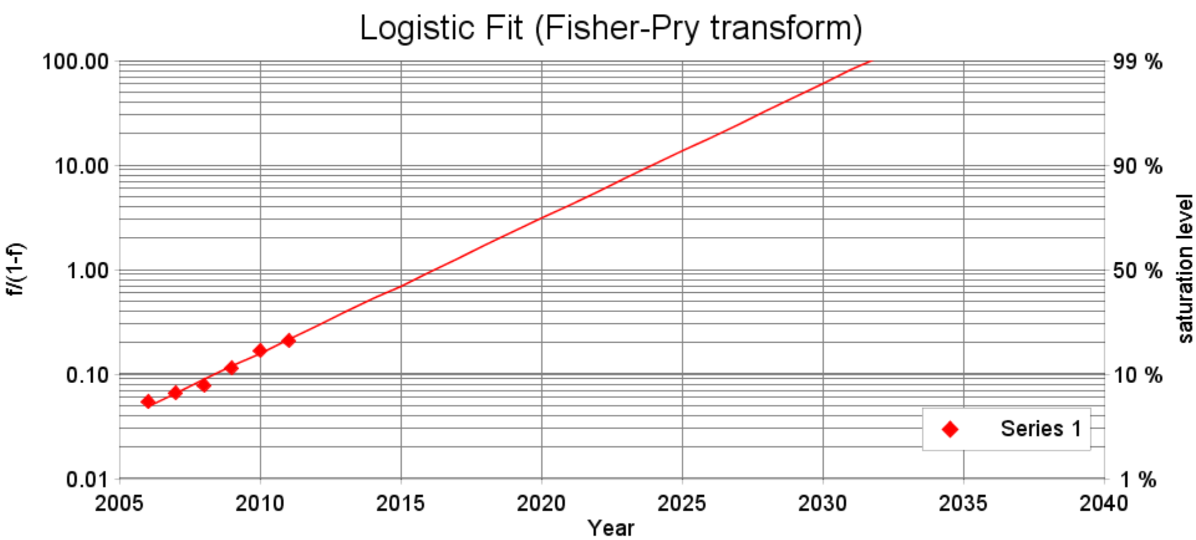
Fit Parameter

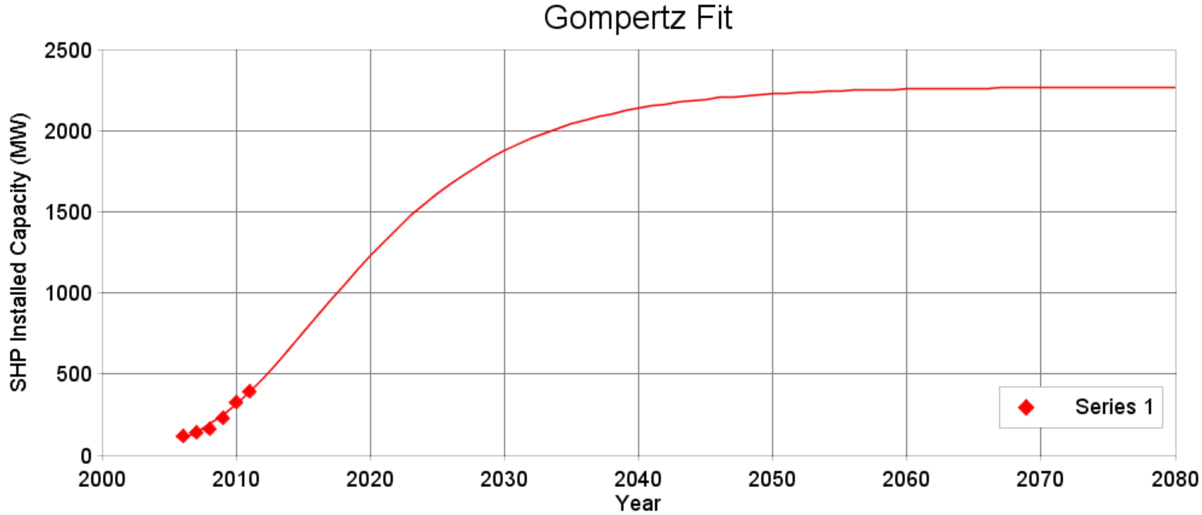
	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	1,039	2,018.629	12.353	0.356	364.909	0.885
Gompertz	Series 1	1,039	2,022.113	33.013		450.157	0.857
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-589.121		0.295	6,291.001	0.863
Linear	Series 1	-14,886.182			7.429	763.661	0.752

Appendix 8: Forecasting results for SHP Technologies (IIASA Model)

Himachal Pradesh



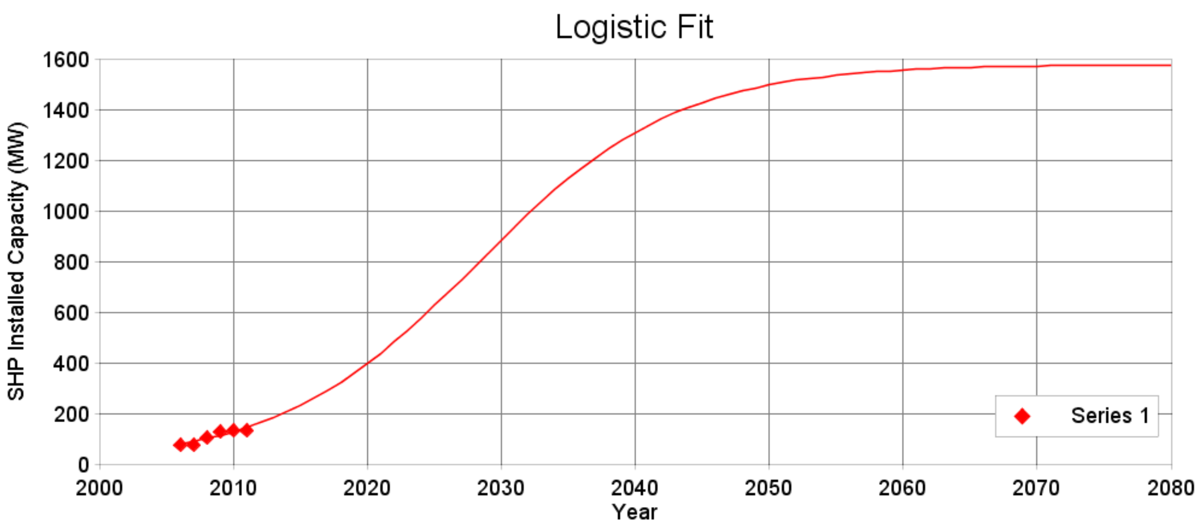


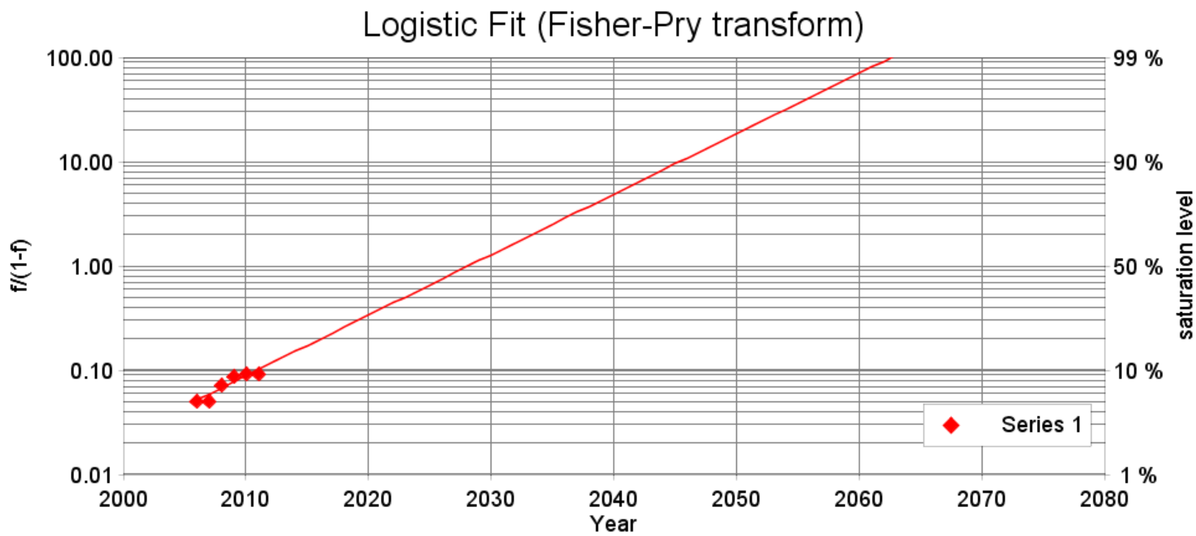


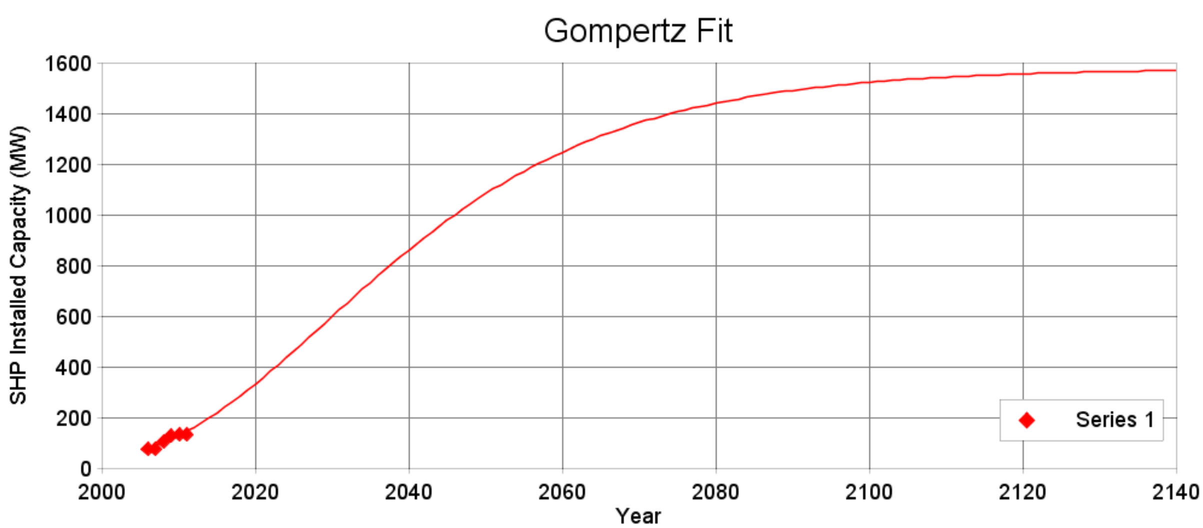
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	2,268	2,016.206	14.817	0.297	1,109.56	0.982
Gompertz	Series 1	2,268	2,015.817	26.358		1,592.03	0.974
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-503.524		0.253	354,838.488	0.972
Linear	Series 1	-114,906.156			57.324	3,934.788	0.936

Uttarakhand



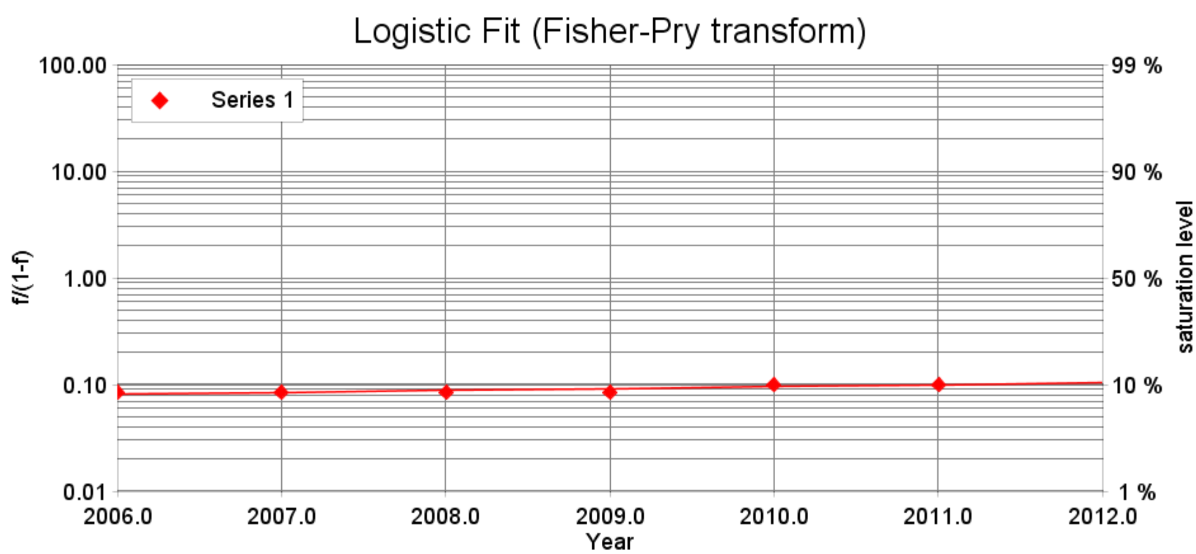


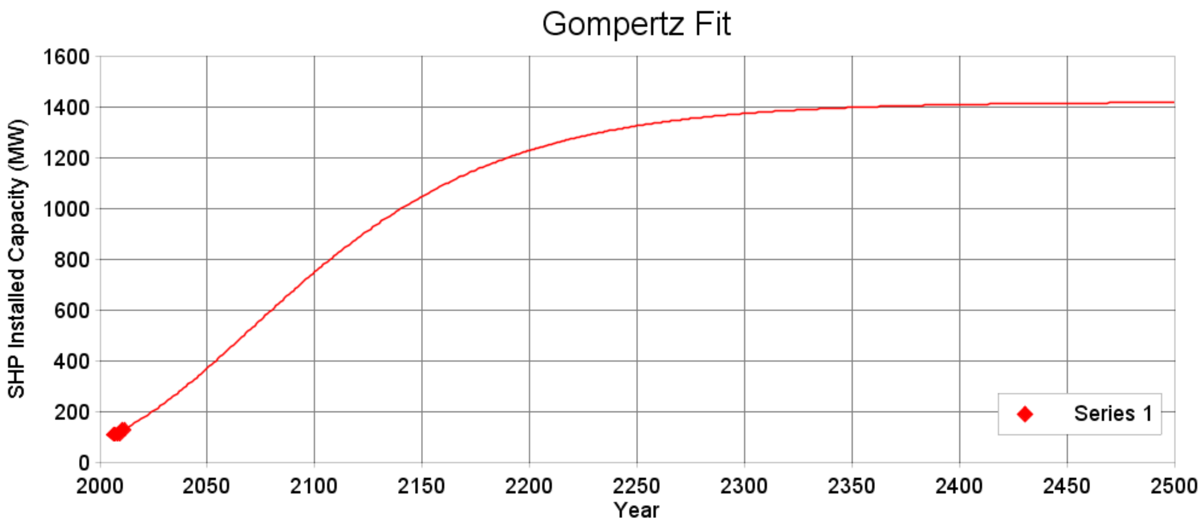


Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	1,577	2,028.156	32.904	0.134	528.81	0.863
Gompertz	Series 1	1,577	2,029.4	65.162		480.705	0.875
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-269.722		0.137	68,198.573	0.829
Linear	Series 1	-28,033.338			14.011	401.579	0.895

Jammu & Kashmir

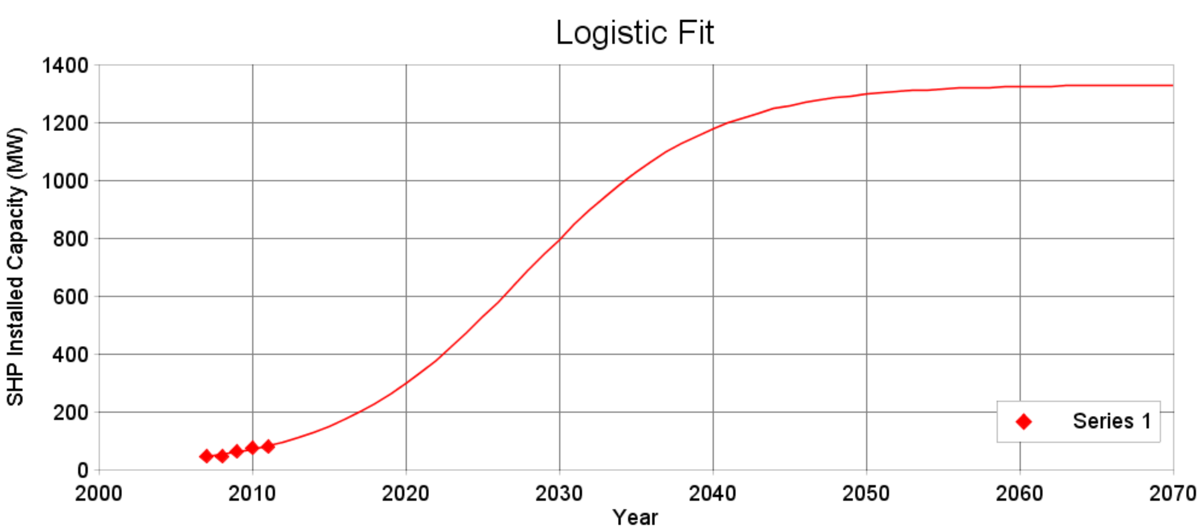


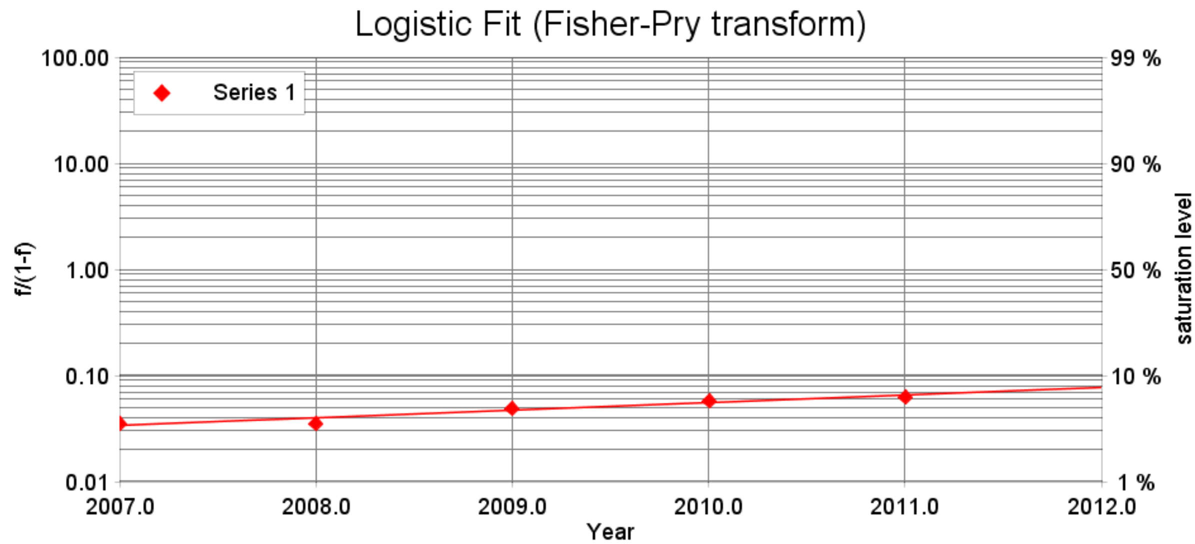


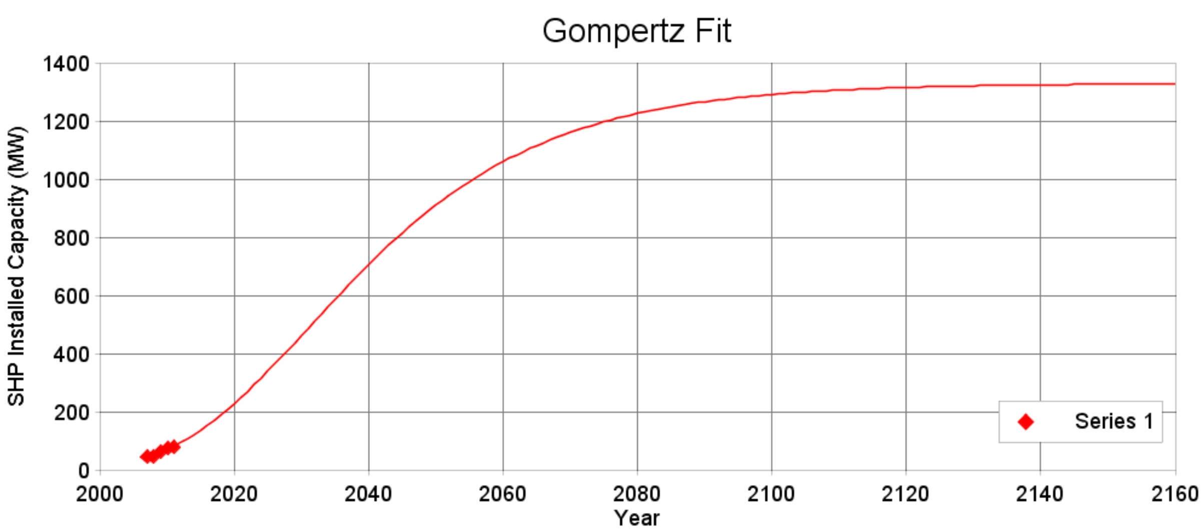
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	1,418	2,067.737	108.112	0.041	107.427	0.754
Gompertz	Series 1	1,418	2,069.904	207.299		109.29	0.75
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-67.396		0.036	76,205.361	0.759
Linear	Series 1	-8,516.366			4.299	112.997	0.741

Arunachal Pradesh



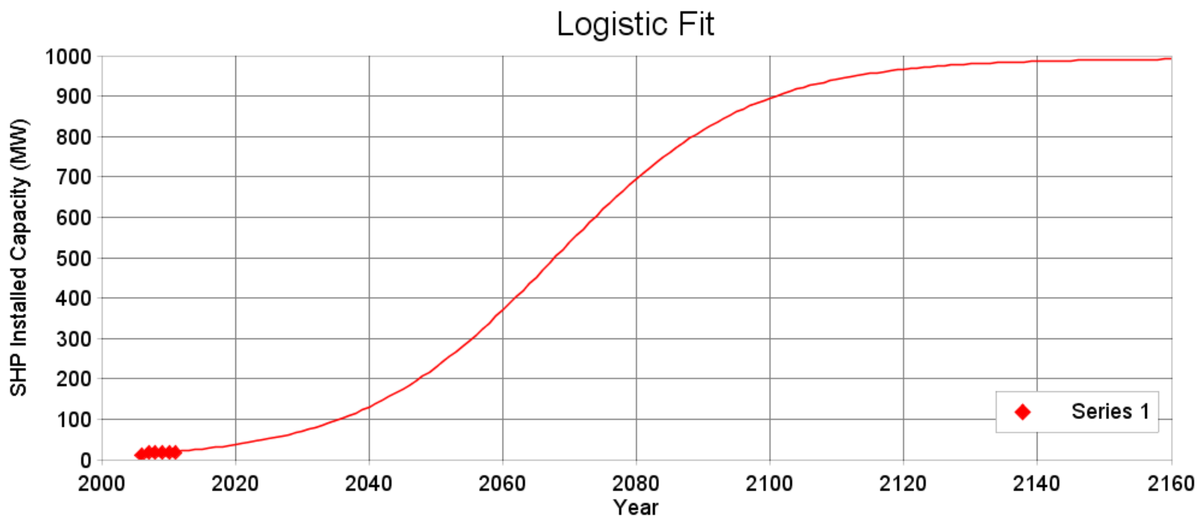


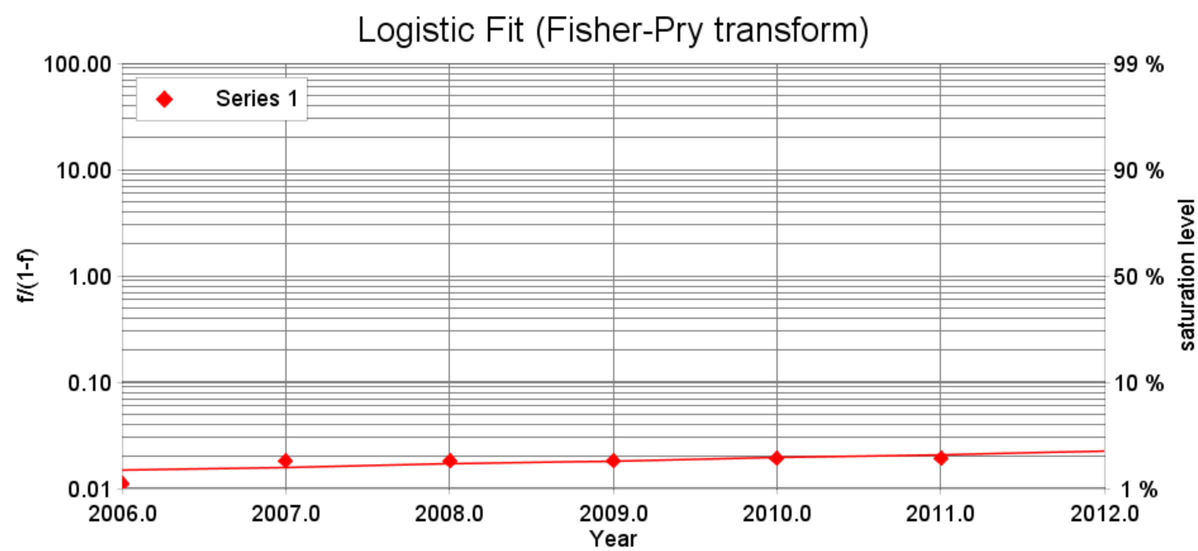


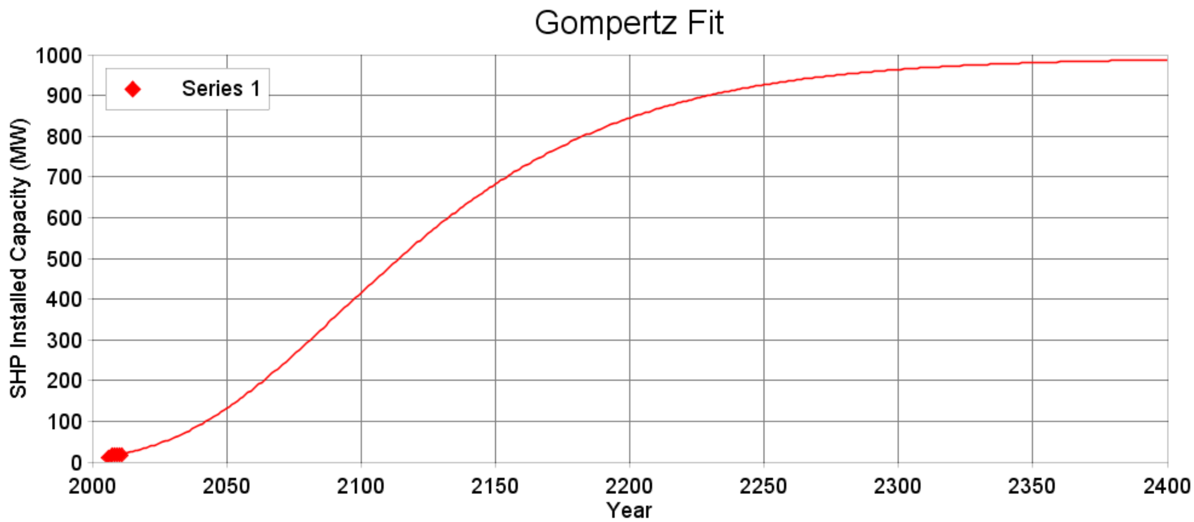
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	1,329	2,027.573	26.656	0.165	58.54	0.94
Gompertz	Series 1	1,329	2,031.066	60.133		56.417	0.942
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-316.373		0.16	16,927.29	0.919
Linear	Series 1	-19,101.03			9.538	59.468	0.939

Chhattisgarh



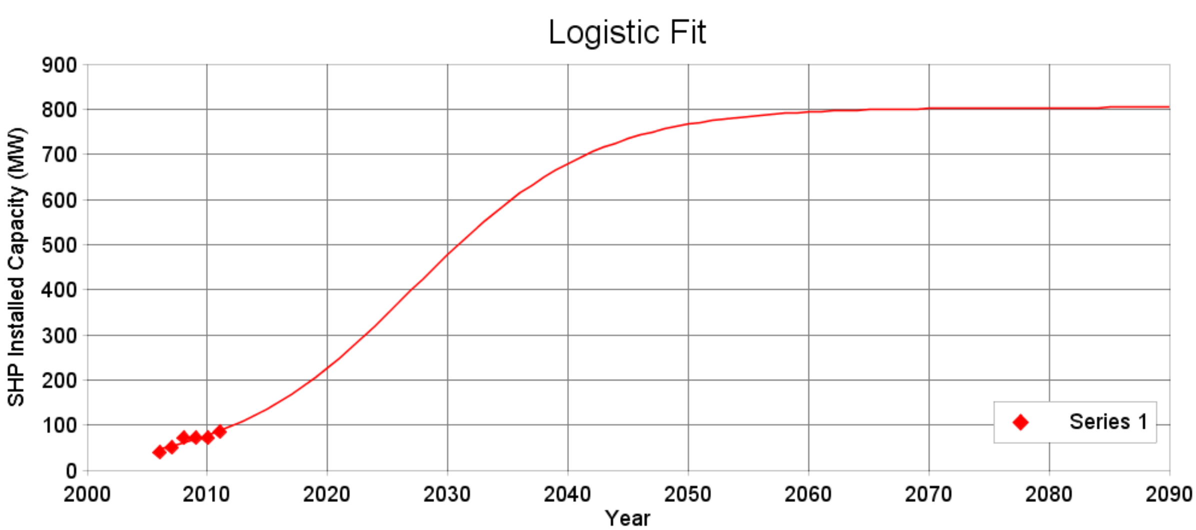


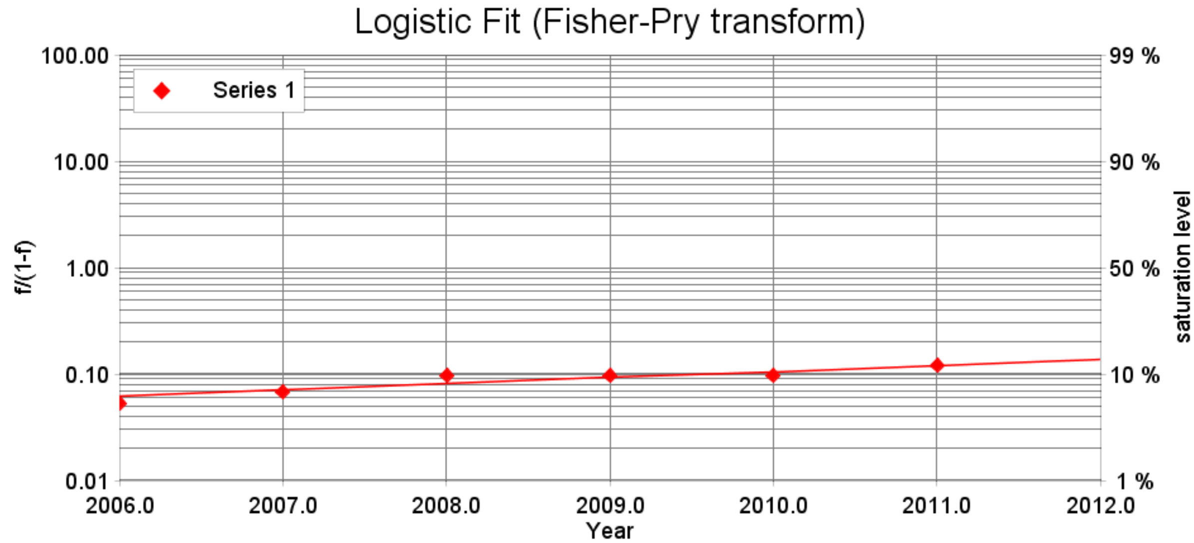


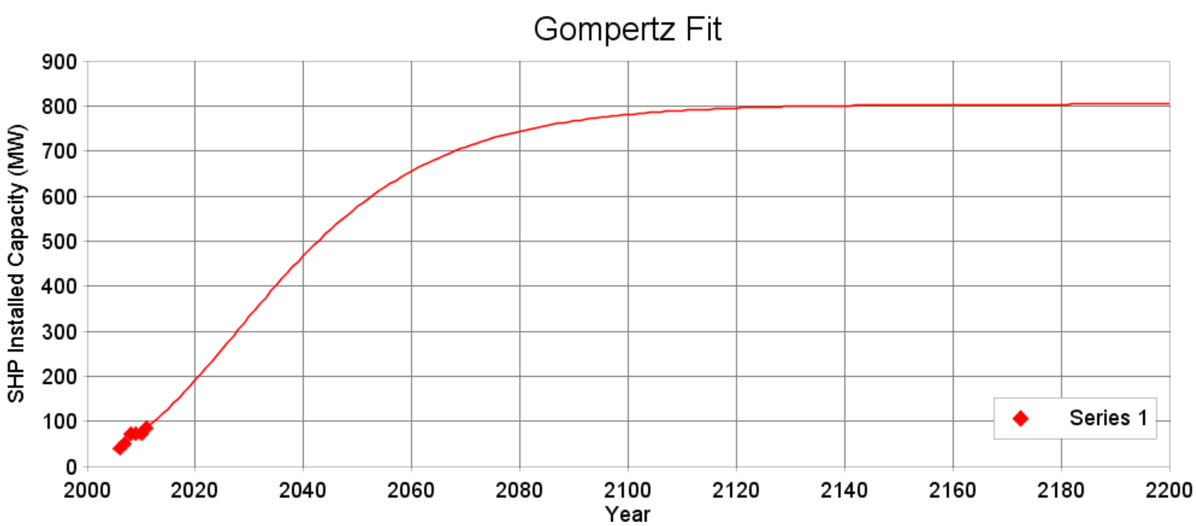
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	993	2,067.618	64.241	0.068	22.455	0.527
Gompertz	Series 1	993	2,091.743	183.239		22.079	0.535
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-164.027		0.083	1,252.103	0.489
Linear	Series 1	-2,464.724			1.236	20.73	0.563

Madhya Pradesh



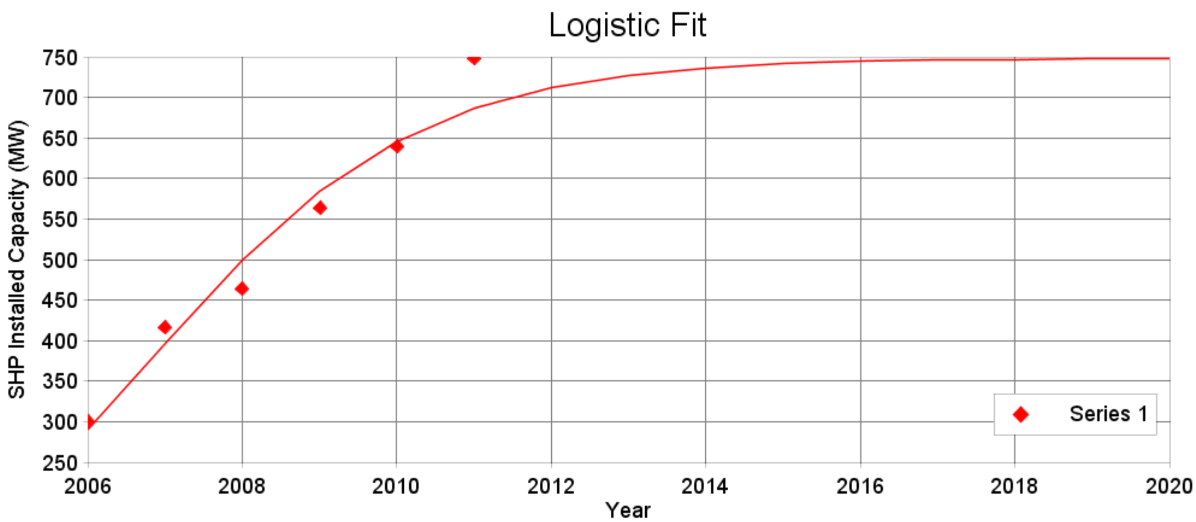


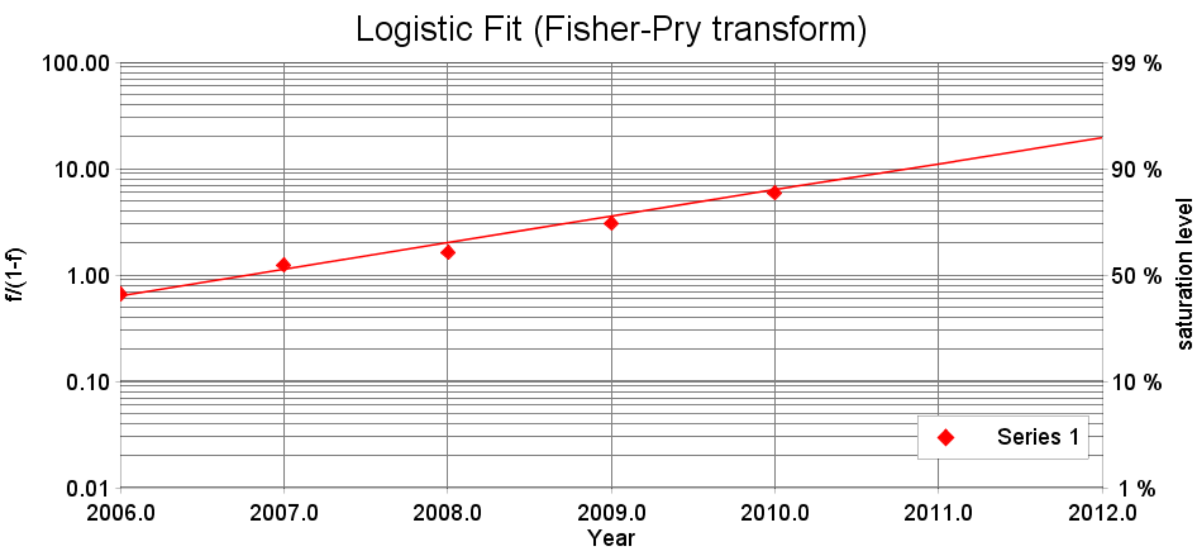


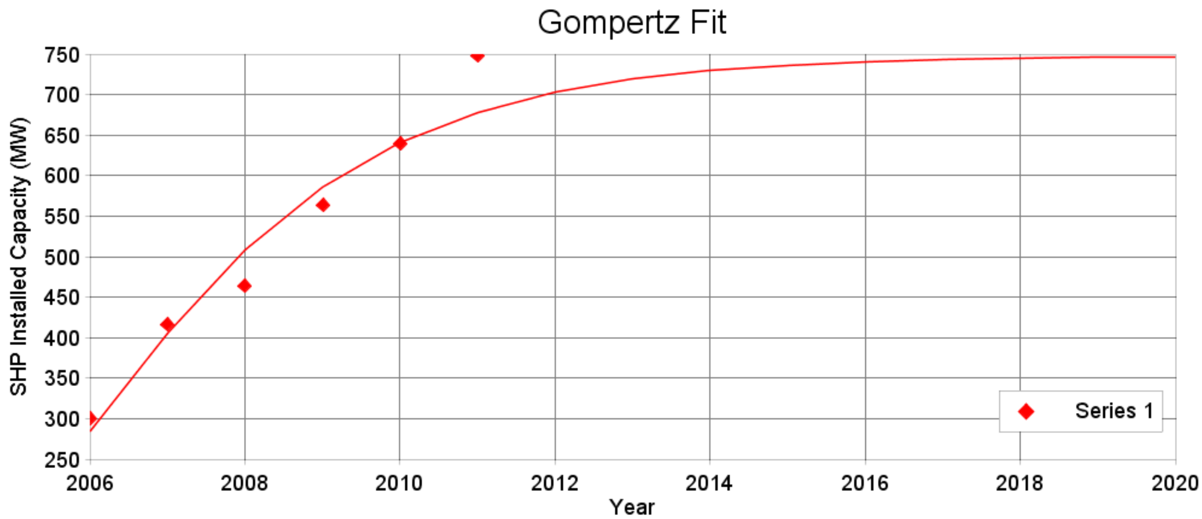
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	804	2,027.097	33.419	0.131	199.377	0.849
Gompertz	Series 1	804	2,027.463	63.209		186.068	0.859
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-264.622		0.134	23,592.794	0.802
Linear	Series 1	-16,289.602			8.143	160.476	0.879

Karnataka


Logistic Fit
SHP Installed Capacity (MW)
750
700
650
600
550
500
450
400
350
300
250
2006
2008
2010
2012
2014
2016
2018
2020
Year
Series 1


Logistic Fit (Fisher-Pry transform)
f/(1-f)
100.00
10.00
1.00
0.10
0.01
99 %
90 %
50 %
10 %
1 %
saturation level
2006.0
2007.0
2008.0
2009.0
2010.0
2011.0
2012.0
Year
Series 1



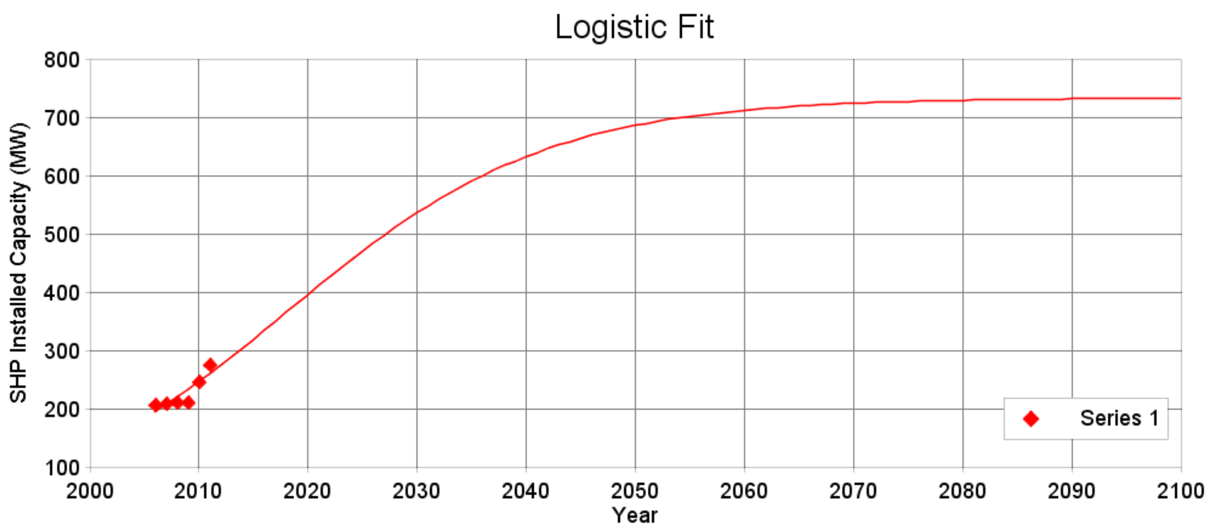
Fit Parameter

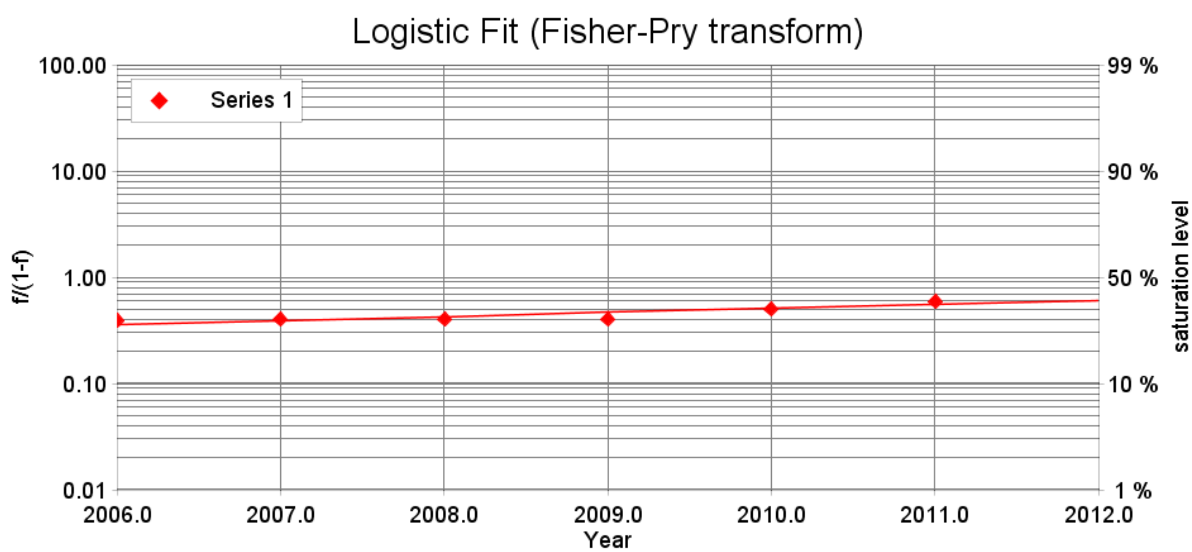
	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	1,263.463	2,009.782	15.185	0.289	1,187.079	0.991
Gompertz	Series 1	1,939.2	2,010.688	24.17		1,085.372	0.992
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-340.509		0.173	1,736,973.374	0.932
Linear	Series 1	-172,073.989			85.933	1,050.119	0.992

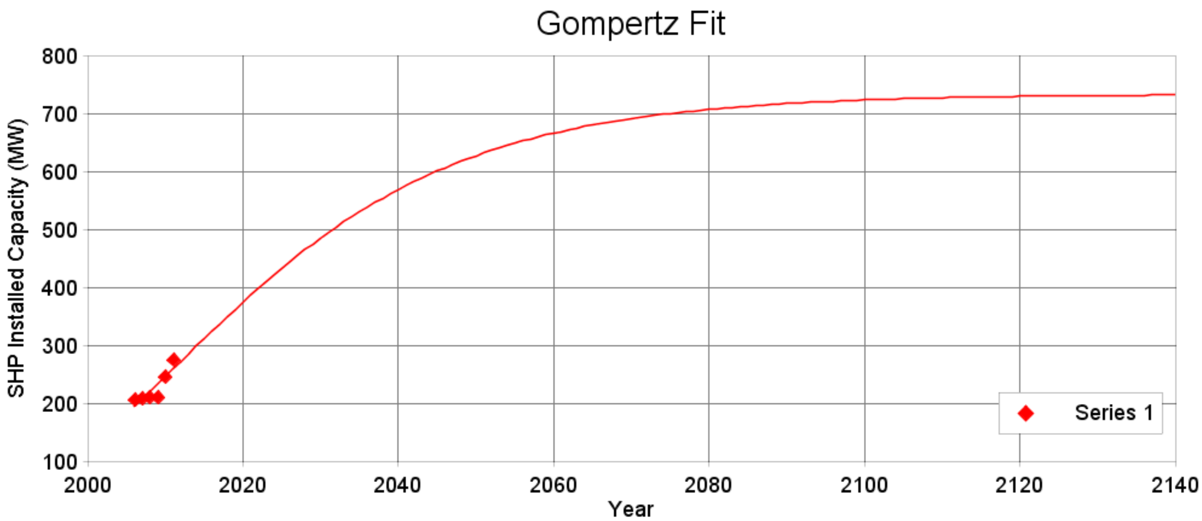
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	748	2,006.787	7.68	0.572	5,901.155	0.957
Gompertz	Series 1	748	2,005.922	6.767		7,658.743	0.945
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-340.509		0.173	1,736,973.374	0.932
Linear	Series 1	-172,073.989			85.933	1,050.119	0.992

Maharashtra



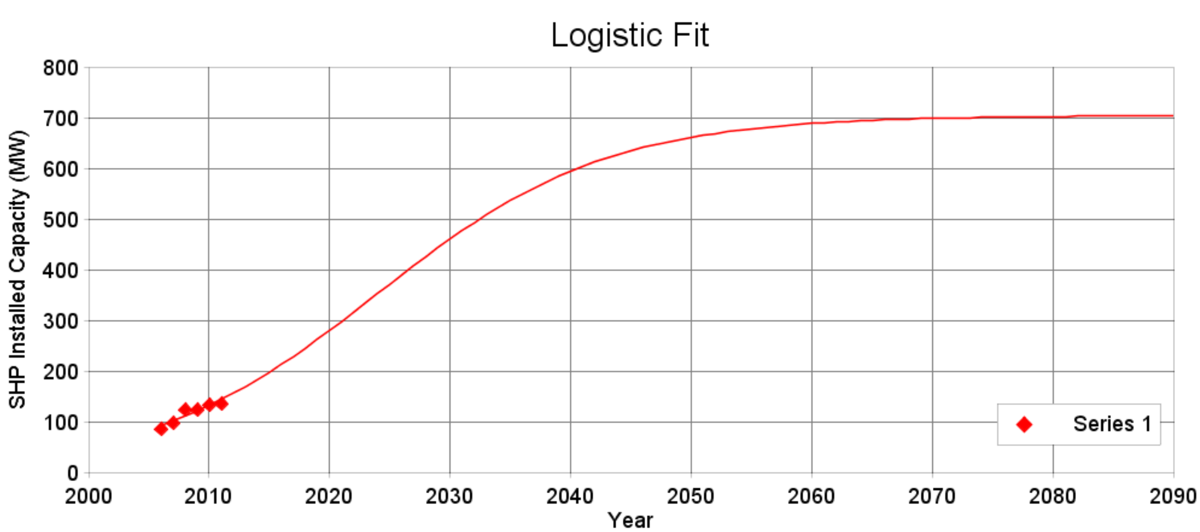


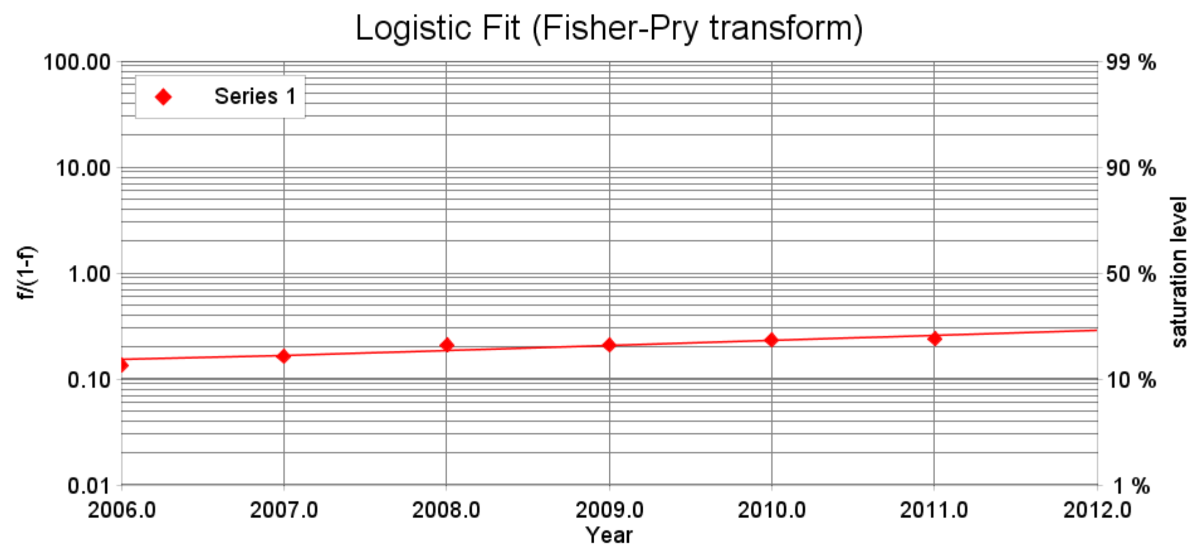


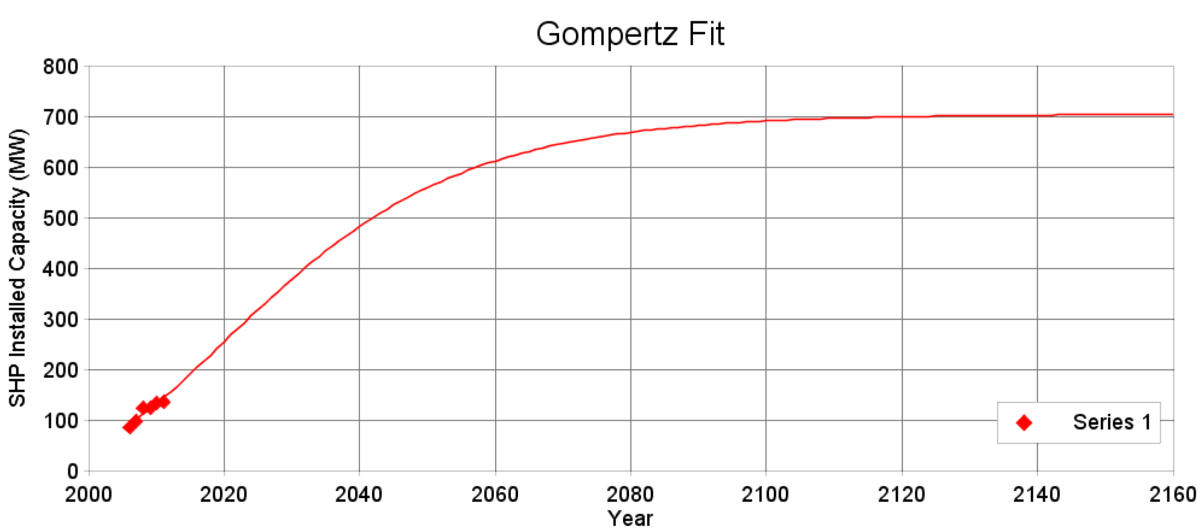
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	733	2,018.118	52.275	0.084	910.392	0.764
Gompertz	Series 1	733	2,011.819	63.504		962.538	0.75
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-103.43		0.054	295,157.894	0.787
Linear	Series 1	-25,496.558			12.807	981.201	0.745

Kerala



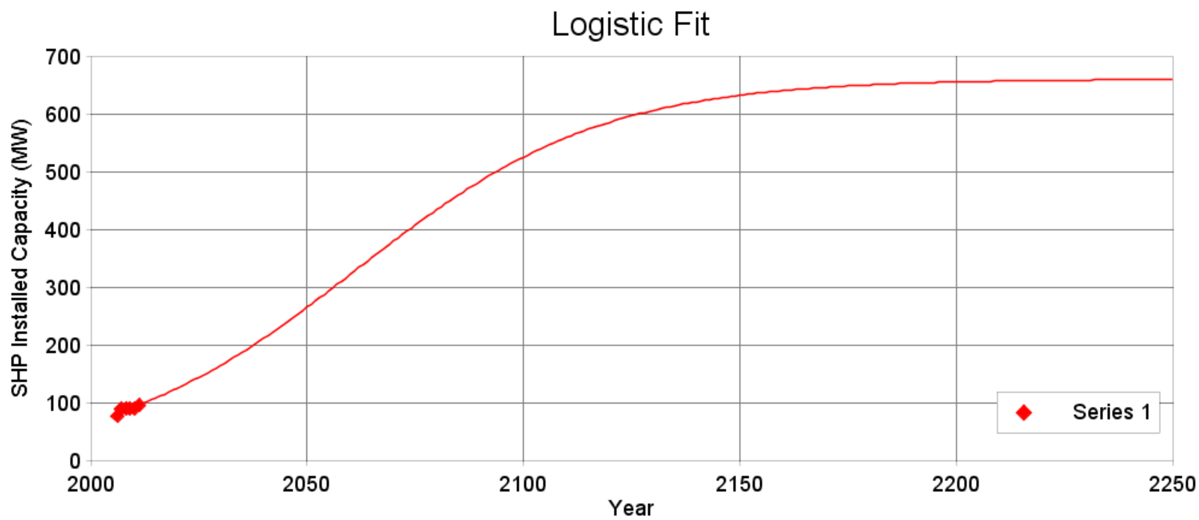


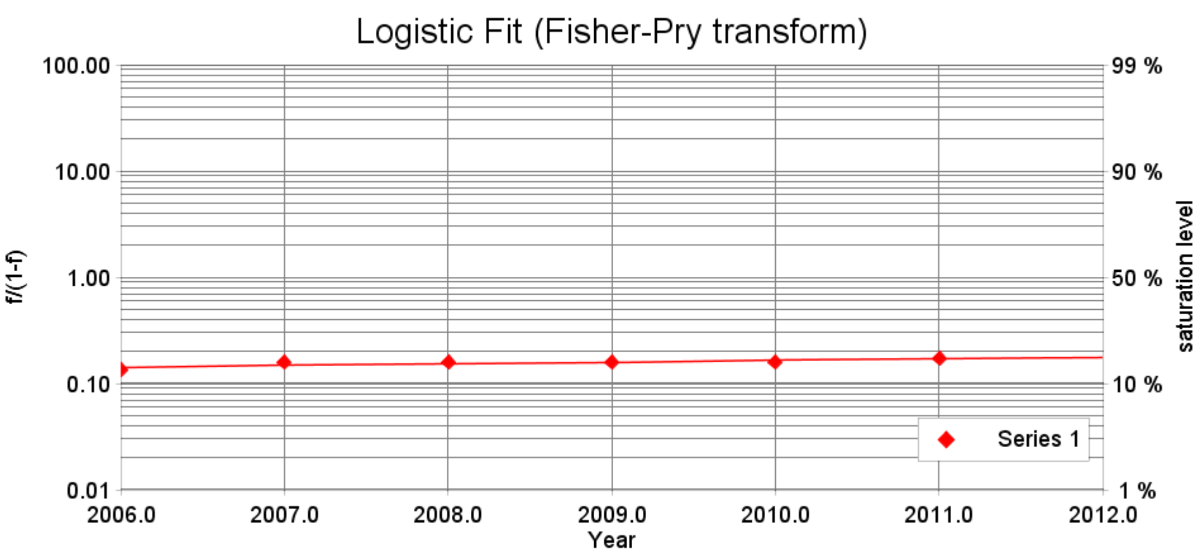


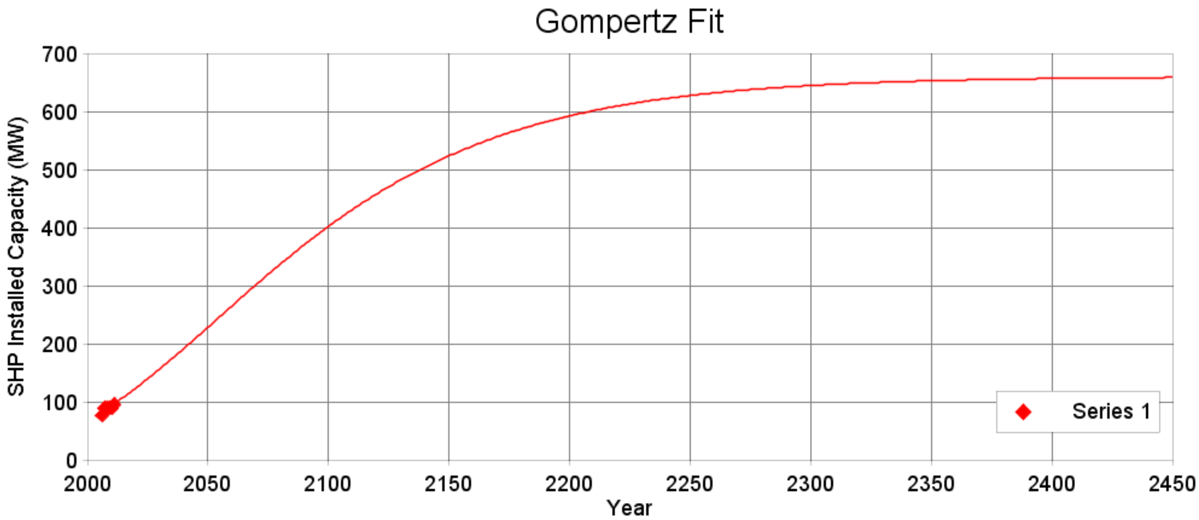
Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	704	2,023.969	41.784	0.105	277.555	0.872
Gompertz	Series 1	704	2,020.391	62.239		250.746	0.884
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-186.714		0.095	77,005.045	0.83
Linear	Series 1	-21,030.016			10.529	218.486	0.899

Tamilnadu


Logistic Fit
700
600
500
400
300
200
100
0
SHP Installed Capacity (MW)
2000
2050
2100
2150
2200
2250
Year
Series 1


Logistic Fit (Fisher-Pry transform)
100.00
10.00
1.00
0.10
0.01
f/(1-f)
99 %
90 %
50 %
10 %
1 %
saturation level
2006.0
2007.0
2008.0
2009.0
2010.0
2011.0
2012.0
Year
Series 1



Fit Parameter

	Series	K	Tm (beta)	delta T	alpha	ObjFunc	Rsqare
Logistic	Series 1	660	2,061.416	124.979	0.035	58.482	0.689
Gompertz	Series 1	660	2,054.133	202.369		57.963	0.691
Sharif-Khabir	Series 1						
Floyd	Series 1						
Exponential	Series 1		-58.73		0.031	42,890.842	0.672
Linear	Series 1	-5,399.985			2.733	57.168	0.696