Institutional Reforms and Technology Diffusion: An analysis of energy efficiency in irrigation electricity distribution sector of Andhra Pradesh

Brijesh Bhatt
Humboldt University Berlin
Philippstrasse 13, D-10115 Berlin
(bhattbrx@cms.hu-berlin.de)

Abstract - The power sector in Andhra Pradesh (AP) has undergone major structural changes, coupled with legislative reforms for improving energy efficiency of the economy. For the distribution sector, the major objectives of the reform were to restrain the huge distribution losses, improve the technical performance of distribution networks and increase private participation. The paper describes what impact the reform actually has and how the performance of the distribution sector is affecting various energy efficiency enhancement programs. An analytical framework based on Institutions of Sustainability and socio-technical system is presented to analyze the technological change in the distribution sector with the institutional change. The electricity distribution companies are key actor in the analysis and factors affecting their decisions regarding the choice of energy efficient technology adoption in the distribution networks, are the focus of study. Methodologically, a combination of case study and agent-based modelling and simulation (ABMS) is proposed as an effective approach to analyze the problem.

Key Words: Institutional change, Technological Change, Diffusion, Socio-technical system, Agent-based modelling and simulation.

1. Introduction

In the electricity supply chain, the distribution sector, where the utility interacts with the consumers, is the most crucial segment and the performance of the electricity distribution companies (DISCOMS) has implications on the entire power industry. This is clearly indicated in the mid-term appraisal of the 11th five year plan of India, where it is stated that "[t]he weakest part of power sector remains Distribution which is incurring large losses" (Planning Commission 2010: p327). The case of Andhra Pradesh (AP) is no exception. Dev et al. (2009), for example, state that "[t]he power sector in Andhra Pradesh has one of the highest plant load factors in India but the transmission and distribution sectors still face high losses and poor billing performance" (Dev et al. 2009: p.26).

The following section describes briefly three important features of the distribution sector of AP, namely, (i) the recent structural change and its impact on the utility, (ii) the effectiveness of governance structures[1] in place and (iii) the role of the agricultural consumers. Thereon, it describes how an efficient distribution system would help to achieve and implement various energy efficiency measures (especially in the irrigation sector). The discussion focuses

[1] "Governance structures such as contracts, networks, bureaucracy, cooperation or markets are the organizational solutions for making institutions effective, i.e., they are necessary for guaranteeing rights and duties and their use in coordinating transactions." (Hagedorn 2008: p.360).

around the distribution losses[2] and technology innovations in the DISCOMs. This description in section I lead to the research questions.

1.1 *Structural reforms of the Power Industry and the Distribution Sector*

The Indian power sector has undergone major structural reforms during the past decade. Erstwhile the power industry was organized as a vertically integrated state owned monopoly, governed by the Electricity Supply Act 1948, characterized by loss making public entities, with huge financial debits (24 percent negative rate of returns) (Kodwani 2009). The poor performance and deteriorating financial health of the State Electricity Board (SEB) caught a lot of national and international attention, which lead to a phase of experimentation in some states (Orissa, Haryana, AP) mainly driven by the World Bank (Subramaniam 2004, Singh 2006). In AP, the AP Electricity Reform (APER) Act 1998 was introduced and subsequently the AP Electricity Regulatory Commission (APERC) was established in 1999. In February 1999, the AP SEB was unbundled into APGENCO (responsible for power generation) and APTRANSCO (responsible for both transmission (bulk supply) and distribution). In March 2000, the distribution and retail supply business of APTRANSCO was transferred to four state-owned electricity distribution companies (DICSOMs) namely the Central, Eastern, Southern and Northern Power Distribution Company Ltd. Besides these four DISCOMs nine Rural Electric cooperative societies (RESCOS) are also operating in the state.

It can be said that, partially motivated by the success and lessons learnt from these experiments, a major initiative for institutional change took place at the central level with the introduction of the Electricity Act 2003 (EA 2003) in July 2003. The EA 2003 replaced the existing central legislations[3] (EA 1910, 1948, Electricity Regulatory Commission Act 1998). But section (185(1)) of the EA 2003 lays the provision that the "[…] state Reforms Acts not inconsistent with the provision of the EA 2003 shall remain in force. Therefore APREC continues to be guided by the provision of APER Act 1998" (Dev et al. 2009: p.14) [4].

The EA 2003 led to significant changes like increased participation of the private sector in all the three segments (generation, transmission and distribution) and reduced direct government control, by setting up of an autonomous electricity regulatory commission both at central and state level. According to the EA 2003, decisions of the electricity regulatory commissions can be only challenged in High and Supreme Courts. However, they remain accountable to legislature for their performance (Kodwani 2009, Shukla et al. 2004). Other implications of EA 2003 for the distribution sector include:

- Multiple licensing and open access in distribution
- In rural areas, license free generation and distribution, which could be managed by panchayats, cooperative societies, non governmental organizations etc.
- Subsidy payment through budget (Section 65)
- Mandatory metering of all electricity supply.

---

[2]Distribution losses are combination of physical losses or heat losses (joule effect) caused from the flow of current in the power lines due to poorly maintained networks and commercial losses arising because of unmetered/unaccounted electricity and outright theft of electricity from network (Kodwani 2009, Dev et al. 2009).

[3]Under the Indian constitution, electricity is in the concurrent list, with generation and transmission involving participation of both the central and state governments whereby the distribution is only under the preview of respective state governments.

[4]The inconsistency is still to be explored as the initial understanding of these two Acts gives an impression that both are similar in many respects. So the introduction of APER Act 1998 is also considered as an institutional change.

The reform process was poised to increase privatization and competition with the objective to enhance technological innovations in the distribution sector whereby the increasing losses could be tamed, as indicated by Raghu et al. 2003 “As per reform project time table, 30% of the distribution system is expected to have private sector participation by 2002 and 100% by 2007” (Raghu et al. 2003: p.6). But till today, all four DISCOMS are still state owned. Even their financial health has not improved[5]. Further, regarding the targets for distribution losses for DISCOMS, the initially planned annual decrease of 5% (later 3%) was thought to reduce losses from 35.5% in 2001 to 21% by 2004 (Subramaniam 2004). However, this objective is also not reached and distribution losses are as high as 18.25% (CPDCL 2010) today. All these slow developments in the distribution sector require a reconsideration of the entire reform process and the necessity to explore reasons for its slow progress.

On the one hand, there are the fears that privatization is not the solution, as e.g. reflected in the statement of Raghu et al. 2003 “In case of distribution also scope for competition is very limited. For each distribution zone there will be only one Distribution Company. The consumers of that zone will have no choice but to buy from that company. In the absence of bench marking the performance, consumers cannot be assured of efficient and cheaper supply of power.” (Raghu et al. 2003: p.8). On the other hand, there are successful cases of privatizing distribution sector as in the states of Delhi and Orissa, besides in some major cities like Mumbai, Kolkata, Ahmadabad, Nodia and Surat. In theses cities, by adoption of the private (or franchise based) distribution model, the losses are relatively lower than the publicly owned DISCOMs (Alagh 2010). This reduction in losses can be attributed to the increased adoption of modern technologies and better management practises. It is reflected in the Planning Commission report, where most of the technological innovations in the distribution sector are experienced in privately owned utilities (Planning Commission 2010, Alagh 2010). Thus, it is worth investigating the factors influencing technological changes under these organizational settings.

There is a lack of consensus even on the global level on the best practices for undertaking distribution reforms (Dossani 2004). Alagh (2010) also expresses this concerns stating that whether the separation of “wires” and “supply” can bring efficient results as “wires” being natural monopoly can be regulated and “supply” can be made competitive. A related question is; can “wires” be further disaggregated into “ownership”, “operation”, “operation and maintenance”? These are issues related to the reforms in the distribution sector and to the development of an efficient distribution network, which have not been addressed in AP so far.

1.2 *Reforms and Effectiveness of Governance structures*

An important issue in the performance of the DISCOMs is the enforcement of institutions by the regulators. There are provisions for mandatory measures that DISCOMS need to undertake, which can reduce energy losses but normally DISCOMs oversees these regulations sighting one or other reason and state regulatory commission seems to be least bothered on this issue. Prayas (2010) reviews the energy efficiency (EE) initiatives in AP along with four other states and concludes that investments in EE has a high potential and is equally comparable in terms of environmental benefits. But the state regulatory commissions

[5]For example, the revenue deficit of AP CPDCL is negative 591.6 M euro, 560.88 M euro, 635.1 M euro for 2008-09, 2009-10 and 2010-2011 respectively.

has paid least attention to promote EE whereas stressed mainly on renewable energy purchase at larger premiums.

Kodwani (2009) discusses the political influence in the power industry and weaknesses of the institutional framework. Tracing the regulatory practices followed by different state electricity boards, he found that "[i]n Rajasthan for example we find regulator punishing the DISCOMs for failing to achieve reduction in distribution losses. Same was done in the case of Delhi where the reduction in distribution loss was a key condition in the privatization contract. But on the other hand, the regulator in Haryana instead of punishing the DISCOMs builds up cushion of higher losses to ensure that they would be able to meet demand. This inconsistent interpretation of regulatory powers changes the incentives for energy efficiency improvements" (Kodwani 2009: p.16).

There are policies targeted for the distribution sector like the Revised Accelerated Power Distribution Reforms A and B; Distribution Reform, Upgrade and Management (DRUM) etc. to improve the technical performance of the DISCOMS and thereby to reduce losses. Alongside there are energy efficiency policies which has a direct influence on the performance of distribution (for example the energy standard and labelling program of distribution transformers), still the anticipated results are far from targets. All this points to the effectiveness of governance mechanism in place post reform and questions whether reform process really changed the behaviour of DISCOMS or they still follow the 'state electricity board' approach of pre reform era.

1.3 *Agricultural consumers - Boon or Bane for utility!*

Agriculture consumes 36% of the total electricity in the state of Andhra Pradesh (CMIE 2008: p133). An average annual increase of 6 % is noticed in agricultural electricity consumption from 2003-04 to 2010-11 (CPDCL 2010). This increased share in irrigation electricity consumption is associated with proportional distribution losses. The low voltage system used to distribute power for irrigation leads to high technical losses, which further increases the losses (Tongia 2006). Shah (2009) points out that "[..] actual calorie used by the farmer out of 100 calories generated at the power plant is barely 2%" (Shah 2009: p.6). Since the agricultural supply is unmetered, consumption figures are estimated by the distribution company and it is usual for the DISCOM to cover these losses as agricultural consumption. There are considerable doubts in the "process of estimation of agricultural consumption" (World Bank 2002, Murthy et al. 2009). Sinha 2003 provides a good description of the implications of increasing share of groundwater irrigation in India on the electricity sector and how in the absence of metering, utilities are hiding losses and adding it to agricultural consumption. He writes: "SEB have traditionally followed a practice of fixing a 'reasonable' T&D [distribution] loss figure, and subtracting the loss and non-agriculture metered or estimated consumption from the total power input into the system […..] the general impression has been that the T&D losses have been understated, in order to conceal inefficiency and corruption, and the agriculture consumption is overstated" (Sinha 2003: p.9)

A similar study on the development of power sector in AP also raises much doubt on the figures of agricultural consumption as claimed by state electricity boards. "In order to show improved technical performance AP SEB used to show lesser and lesser T&D losses and more and more agricultural consumption. That is a portion of T&D losses was shown as agriculture consumption" (Sreekumar et al. 2003: p.3). Similar are the findings of Raghu et al. 2003 "While subsidy to agriculture is treated as villain, the T&D losses are escaping the attention it should have received. In fact effective addressing of this problem will solve the problems of the power sector" (ibid: p.16). They further describe that though substantial investments have been made with the implementation of AP Power sector Restructuring Program for improving transmission and distribution networks "[e]ven then T&D losses instead of declining are increasing" (ibid: p.16).

The recent figures provided by CPDCL also confirm this ambiguity in the agricultural consumption pattern and losses. It is interesting to note that the agricultural electricity consumption increased by 20% from 2005-06 to 2006-07, and then decreased by 13.79% in the next year, followed again by an increase of 12.19% in 2010. Though there are other factors associated with agricultural consumption patterns (like yearly rainfall, cropping pattern etc.) still these drastic changes in electricity consumption within such short time periods are highly unlikely (CPDCL 2010) [6].

Regulators are aware of this faulty estimation procedure of the DISCOMs and have instructed the DISCOMs to install sample Distribution Transformer (DTR) meters and extrapolate the data for the rest of the DTRs under the DISCOM. Still this process is hardly reliable firstly, because sample DTR is based on 2001 census and since then there is lot of variation in connected load. Secondly, the accuracy of reading obtained from the sample meters is also questionable: sample meters are exposed to vagaries of nature, so prone to faults and then there are operational difficulties in recording the readings since reading can be taken only during the supply hours (4 hrs during day time, mostly unscheduled). Thus, it is difficult to assume the correct reading is reported. Even the minimum 50% DTRs metering provision as instructed by regulator is hardly maintained (CPDCL 2010)[7].

From the above discussion it can be concluded that behind the much hyped and execrated agricultural consumption, the poor technical performance of DISCOMs may be a plausible reason. DISCOM finds it easy to blame farmers to conceal its own technical performance and inefficiencies. Hence, there is a need to analyze the technical change in the distribution sector and investigate the efforts made by DISCOMs to reduce the distribution losses and reasons for non-adoption of energy efficient technology in the distribution networks, though there seems sufficient reasons to upgrade the networks (especially in the agricultural supply networks)[8]. This has been successfully demonstrated by DISCOMS in other states like Gujarat where technical change (separation of feeder) helped solving much of the problems of agriculture consumption (Shah et al. 2008, Devaiah 2010).

1.4 *Implications of distribution sector performance*

Firstly, distribution losses have a direct effect on consumers. "The […] higher the distribution losses percentage, higher will be the purchase requirements of DISCOMS to meet the demand. Since the purchase costs are passed on to consumers in full, they bear higher costs due to distribution losses" (Kodwani 2009). Thus, DISCOMS performance is vital for the

[6]The role of regulators is also worth noticing since during all three years the target fixed by the APERC was constant for agricultural consumption.
[7]A new methodology is being developed by the DISCOMs under the guidance of the Indian Statistical Institute (ISI) which was implemented in 2010 but no results have been published yet (CPDCL 2010).
[8]The uncertainties of agricultural subsidy payment by the state (Tongia 2006, Planning Commission 2010) seem to be a good reason for the DISCOMS to invest in energy saving technologies especially in rural networks, as it would reduce losses. By diverting the saved electricity from agricultural consumers to high paying industrial customers the utility can generate extra revenues.

society. Secondly, a major strategy of national and state governments to limit the increasing power deficit[9] by various EE and demand side management programs, which can be achieved when the consumers use (costly) EE appliances. It is well researched that the end use efficiency and the choice of EE appliances depends indirectly on the infrastructure [termed as "Infrastructure of Provision" (Passey et al. 2009)]. For example, farmers would not opt for expensive efficient pumps and accessories unless they are assured of quality electricity. Various projects implemented in this area also reveal that quality electricity is necessary for the success of such programs (RamaMohan et al. 2009). Further, with the ambitious agenda in the power industry to set up smart grids in next five to fifteen years (CESDT 2009) it is necessary to evaluate the technical performance of DISCOMs under the current institutional structure or whether it needs institutional innovation.

In the light of the above discussion the questions which arise and will be addressed in the future course of research are:

I) Effect of Institutional change: Analyze the structural changes in the power sector and its impact on the technical change (energy efficient technology adoption) in DISCOMS.
- How can existing institutions describe the actual technologies in use in the distribution networks?
- Did restructuring facilitate in overcoming the barriers of technology adoption (energy efficiency)?
- Why the structural reform could not bring the anticipated change in the distribution sector?

II) Understand the organization and behaviour of DISCOMs:
- Why are DISCOMs not investing (neglecting) cost effective energy efficient technical solutions, when making broader investment decisions (operational, maintenance and purchasing decisions)?
- What are the different factors that prevent technological innovations in the DISCOMS?
- Can this behaviour of neglect be changed by altering its governance structure?
- What risks do the DISCOMS perceive in shifting to an improved technology and how can institutions help to overcome it?

III) Understanding what if:
- What kind of institutional structure and mechanisms[10] can simulate energy efficient technology adoption in the distribution networks?
- What kind of market infrastructure and capabilities are required?
- What should be the structure of electricity distribution? Can privatization and introduction of competition improve energy efficiency and reduce distribution losses?
- Can tariff rationalization and changes in the subsidy mechanism improve the delivery of services and technology adoption?

The rest of the paper is structured as follows. Section II presents a brief literature review on the studies conducted to study distribution sector. In Section III, an analytical framework based on the Institutions of Sustainability Framework (IoS) is presented, incorporating the fundamentals of a socio-technical system. Section IV presents the methodological issues,

---

[9]5.33% in AP (Dev et al. 2009).

[10]"Mechanisms are initiatives that aim to overcome policy and program barriers that prevent the pursuit of cost-effective energy efficiency and load management activities [...]" (Vine et al. 2003).

concluding that case study and agent-based modelling and simulation is an effective approach to analyze the problem; it also gives a review of related studies that have used agent-based modelling and simulation. In section V, a preliminary agent based model is outlined. Section VI, summarises the paper.

2. Empirical review

The literature reviewed on electricity distribution sector, can be broadly categorized under three heads namely, organizational issues, performance evaluation and utility energy efficiency enhancement. No study has been found that explicitly evaluate technological change in the electricity distribution sector, though there have been studies focusing on specific technology and demonstrating its potential for distribution sector[11]. The following section presents a brief review of important known literature in the three categories:

2.1Organizational studies

Dossani 2004 studies the reform process in India and stress on the need of a second organizational reform in the distribution sector. He analyzes four alternative institutional structures, namely small privately owned DISCOMS; small municipal or state owned DISCOMS; cooperatives; and large private firms. Based on different political and economic assumptions and objectives of reform he analyzes pros and cons of different arrangements. Stating the drawbacks of the current institutional reforms, he concludes "..[the] reform policies will not be sufficient to achieve reliable, efficient power because distribution reform – an economically and politically complex task – has not been done" (Dossani 2004: p.1287). Totare et al. 2010 present the case of power sector reforms in Maharashtra and concludes that the initial phase of reforms was successful based on a "Ten Point Action Plan" leading to reduced distribution losses. The study also evaluates the performance of the franchise-based distribution model (public-private partnership) and recommends its extension to other divisions.

2.2 Performance evaluation studies

Yadav et al. 2010 evaluate the relative performance of 29 electricity distribution divisions (EED) in northern hilly state of Uttaranchal using non-parametric frontier analysis technique (data envelopment analysis). Considering network operation and maintenance costs, and number of employees as the input factors; energy sold, number of customers, average duration of interruption, distribution line length, and transformer capacity as outputs the study benchmarks the performance of different EEDs and suggests for reorganization of some EEDs. The study does not reflect specifically on the technological performance of EEDs. Filippini et al. 2004 employs stochastic frontier method to identify the best network maintenance practices and its cost to different distribution utilities in Slovenia by using data from1991-2000.

2.3 Utility energy efficiency

The detailed study of Vine et al. 2003 describes different objectives for reforms in power industry (commercialization, privatization, unbundling and introduction of competition) and the implications these reforms may have on energy efficiency and load management activities of a distribution company. The study also describes how the barriers to energy efficiency in utilities can be addressed by structural changes and adoption of new 'mechanisms'. Adopting

[11]These studies adopt a technological perspective and based on these studies, I assumes that there are ample technologies available in the market and deployment of these can drastically improve the distribution sector.

a linear optimization approach Pezzini et al. 2010 analyzes the DISCOMs behavior, that need to adopt energy efficient distribution transformers under the obligation of Spanish Distribution regulation policy and European environmental plans such as ’20-20-20’. Dasti et al. 2010 proposes a model to evaluate energy efficiency programs which include the effect of governance decisions like subsidy and urban planning using artificial neural networks. Kadam et al. 2009 reviews the performance of eight different state utilities, in terms of distribution loss and effect of government subsidies.

3 Theoretical Review: Defining technological change and developing an analytical framework

Technological change may relate to the development of new technology or to the accelerated diffusion of already existing technologies. This change leads to either reduction in inputs used in production process or an increase in outputs. Technological change may occur when either a single element of a large interconnected production process is replaced with a new technology (*incremental innovation*) or when the complete or major elements of production process are replaced by new sets of technology (*radical innovation*). The adoption of a new technology can be a lengthy process (involving many actors, market and institutions) and depends on the behaviour of individual/organization (Foxon et al. 2008). Technological change is an important area of research as it plays a crucial role in developing alternative energy sources as well as in realizing energy efficiency improvements (Mulder 2005: p.3).

The question what factors affect the decision of individuals /organizations that inturn determine the technological changes in a firm/sector has been addressed in literature in different sectors and using different theoretical lenses. However, still the empirical realities of technological change are difficult to understand. The following section presents a brief account of past studies, tracing the theoretical developments in the area of technological change.

3.1 Technological change studies using neo–classical theory

“Economic theorizing on technological change has its roots in economic theories of economic growth” (Mulder 2005: p.15). The earliest description of technological change is found in the study of Solow (1956) and Swan (1956) in their economic growth model (exogenous growth theory) where technological change is introduced in terms of an aggregate parameter, reflecting the current state of labour augmenting technological knowledge. It is considered to grow at an exogenously determined constant rate. However, this assumption as well as the fact that they equated ‘total factor productivity’ with ‘technological change’ was often criticized by other scholars. These shortcomings then led to the development of “endogenous growth theory” (Arrow 1962, Romer 1986) which considered that ‘technological change’ is all about knowledge creation (Mulder 2005). An increase in knowledge capital and a gain in experience by using the technology (learning curves) are the main ways of endogenizing technological change (Berglund et al. 2006). It also gave way to the ‘demand pull-supply push’ notion of technical change, which was later criticized and found to be seriously flawed (Ruttan 2001, Mowery and Rosenberg, 1979).

3.2 Criticism of the neo-classical approach of technological change:

Although used frequently, the neo-classical approach of technological change is criticized very often based on the behavioural assumption on which it builds up. The critic of neo-classical approach is evident in the following writing:

“The neo-classical production function can be defined as the specification of all conceivable modes of production in the light of existing technological knowledge about input-output relationship. It is common practice among neo-classical economist to distinguish between a movement along the production function, referring to factor input substitution, and a shift of the production function, referring to technical progress….[past research have argued] that this view of production and technological progress suffers from providing no insight into the occurrence of technical innovation processes, because development of new technique (‘blueprints’) is exogenous to the economic progress (a criticism that does not apply to the class of endogenous growth models). Further evolutionary economists argue that the neo-classical production function does not comply with what empirical research tells us about the nature of technological change and characteristics of innovative firms.” [12](Mulder 2005: p.23). Furthermore, in the words of Nelson and Winter “[t]he weakness of (neo-classical) theoretical structure is that it provides grossly in-adequate vehicle for analyzing technical change. In particular, the orthodox formulation offers no possibility of reconciling analyses of growth undertaken at the level of economy or the sector with what is known about the process of technical change at the micro level” (Nelson and Winter 1982: p.206).

Though facing much of criticism, the research on technical change employing neo-classical framework continues, with attempts to refine it further (Zon et al. 2003, Wene 2008). But still the main underlying assumption of neo-classical theory, the “rational behaviour” of economic agents, with economic agents having perfect information, immense computational skills, well-defined and spacious choice sets performing actions about which they have no prior experience, seems contradictory to the real world situations and is largely questionable (Williamson 1985, Nelson and Winter 1982). Thus, it is necessary to further follow the path of evolutionary theory.

3.3 From neo-classical to evolutionary theory of technical change

Evolutionary theory (Nelson and Winter 1982, Dosi 1982) inspired by evolutionary tradition in economics (Veblen 1898, Schumpeter 1934) builds upon negating the basic neo-classical assumption of rationality, and considers economic agents as “bounded rational”. Evolutionary economics puts forth that the choices of economic agents are bounded by a small range (limited by the information processing capabilities and imperfect foresight), and actions are driven by the “routines” they have mastered in the past. Further, it states that learning of new routines is time consuming, costly and risky. Dosi and Nelson state that evolutionary theory aims to “explain the movement of something over time, or to explain why that something is what it is at a moment in time in terms of how it got there” (Dosi and Nelson 1994: p.154). The theory explains technological change in firms as a dynamic process instead of static analysis like in neo-classical economics. Evolutionary economist lay emphasis on the fact that decisions (actions) made by individuals/organizations have to be understood in behavioural terms with improvements/changes with individual and collective learning. Evolutionary theories analyse the behaviour of firms as decision rules that are applied routinely over an extended period of time, and are guided more by past experiences (routines) instead of solely driven by the profit maximization behaviour as assumed in neo-classical theory.

[12]Evolutionary theories use concept of replicator equations (used extensively in biology to describe the evolution of population) instead of production function.

3.4 Institutional analysis, an important element of evolutionary theory of technical change

As stressed by Hinnells et al. 2008 there are five essential features when the evolutionary approach is applied to non-biological change, namely competition, variety, some mechanism of ensuring transmission of the attributes of fitness to a new generation, some mechanisms for the production of novel entities and changes in the rules of fitness. In the biological world 'rules of fitness' are laws of nature and in humanly shaped society the 'rules of fitness' to certain extent are controlled through legislations and norms. Institutions play an important role in governing the interaction (way of organizing work, development of new kinds of markets, new laws, and new form of collective action) between the agents. Policy instruments like energy labelling, minimum energy standards may create discrimination in the technology available in the market, may provide advantage to one technology (tax deductions, rebates and subsidy), which all determines the technology in use and acceptance or rejection of a new technology. Parto 2003 utilizes the concept of institutional analysis to analyze the technological transition in the telecommunication industry.

The linkage between evolutionary theory of technology adoption and institutional analysis is well described by Neslon et al. 2002 as they point out that "increasingly evolutionary economist are coming to see "institutions" as moulding the technologies used by a society and technological change itself. However, institutions have not yet been incorporated into their formal analysis" (Nelson et al. 2002: p. 267). They also accept the paucity of research in this direction as neither stream have exchanged knowledge from each other as is visible in the lines "institutionalists have yet to include technology and technological change explicitly into their formulation" (Nelson et al. 2002: p. 267). Defining institutions as "social technologies", Nelson et al. 2002 argue that this definition is in line with the definition of institutions followed by Veblen, North and Willianson.

The evolutionary theory of Nelson and winter presents a macro-economic view of inter firm competition and technological change. It also helps to understand the process of technology adoption at a firm level, but for the case of a regulated industry like electricity (or infrastructure per se) where technology adoption is dependent on the interaction of much larger number of actors than in a firm, it require much more broader framework to analyze the process of technological change.

3.5 Convergence of evolutionary and institutional approaches and the development of system approach –suitable to analyze infrastructure transition

Recently the research on analysing the technological change is focussing towards a more "system approach"[13] (Foxon et al. 2008, Chaminade et al. 2006, Soete et al. 2010), which takes insights from all the four strands dealing with technical change, i.e. evolutionary, economic, institutional and organizational. The system approach is based on the behavioural assumption of bounded rationality. "...[system approach].. provides a strong micro-level foundation based on the behaviour of actors with bounded rationality within the system.."(Foxon et al. 2008). It is especially suited to study technical change in the infrastructure sector (electricity, transport, port aviation etc.) which involves a high degree of complexity with interactions between large number of technical and social systems.

[13]System approach may take a national, sectoral or technological view in explaining technological change.

Describing system approach[14]*:* The system approach to study infrastructure is mainly attributed to Hughes (1987), where he uses the term "technological system" and define it as "socially constructed and society shaping systems" consisting of physical, organizations, scientific components and legislative artifacts. Nelson and Samphat 2001 distinguish the components of system describing them as "physical technologies" and "social technologies". Lately "technological system" is being replaced by "socio-technical system" (ST system) which better captures the complexity involved in the study of such systems (Weijnen and Bouwmans 2006, Gheel 2004).

The most important aspect in understanding technological change is the behaviour and attitudes of the actors as a result of interactions between the different components of system. There exists ample literature explaining the failure of energy efficient technology adoption by the existence of "barriers" (Sorrel et al. 2004, Reddy 1991, Reddy et al.2007, Reddy et al. 2009, Sanstad et al.1994). A barrier is defined as a mechanism that inhibits a decision or behaviour that seems to be energy efficient, thereby preventing investment in cost-effective energy technologies by the organizations/individuals. By adopting a system approach one can examine how barriers arise, i.e. "through the interaction of technological, institutional and behavioural factors, for example by actors following habits or routines or being guided by inappropriate institutional drivers. This implies the need for institutional changes to overcome these barriers" (Foxon et al. 2008). How and what type of governance structures should be formed, which create incentives that can drive the actors behaviour towards adoption of EETs needs to be analyzed.

Infrastructure sector such as electricity can be described as a type of socio-technical system (ST system) which consists of a technical component (either hardware or software) and a social component with actors (users, network operators, government authorities, regulators, maintenance companies and other organizations) and institutional environment (formal and informal rules, which constraint or liberate actions of actors). There exists significant interdependency between the component sub-systems of a ST system, which has significant impact on the overall performance of system. For e.g. in technical sub-system, the interconnection between power technologies and IT technologies (e.g. use of GIS for metering) and interconnection between social sub-system, e.g. producer of technology and its users. These sub-systems are linked to each other and cannot function independently. Both of them follow laws, physical laws (e.g. Newton's laws, Archimedes' principle, Einstein's theory of relativity) for technologies being used and social laws (e.g. legislation, unwritten codes of behaviour, economic contracts) for actors involved which govern their actions and influence the performance of the system (Ottens et al. 2006).

By adopting a system approach, many studies have demonstrated the importance of institutional factors in the adoption of technological innovations (Hendry et al. 2008, Bergek et al. 2008). Now an analytical framework is presented that will be used in the study and is suited to study the broader research objective, i.e. impact of institutional change on technological change.

[14]Often said, 'innovation system' but the study avoid using 'innovation system' since, the focus is only on a part of it namely, diffusion of innovation, considering development of innovation as given.

3.6 Developing an analytical framework

To analyze the research problem an analytical framework is developed by interlinking the Institutions of Sustainability (IoS) framework (Hagedorn 2008, Hagedorn et al. 2002) with the concept of socio-technical system described above. The modified framework helps to analyse the complex linkages between technical, social and institutional arrangements and how it leads to institutional change. The IoS framework includes characteristics of actors and properties of transactions and the related governance structures and institutions that govern the behaviour of actors. The decision making process is studied in the action arena. The interrelations between the four components i.e. actors, transactions, institutions and governance structure have implications for change of institutions. Institutions are defined as sets of conventions, norms and formally sanctioned rules that coordinate human interactions (Vatn 2005). The basic unit of analysis is the transaction.

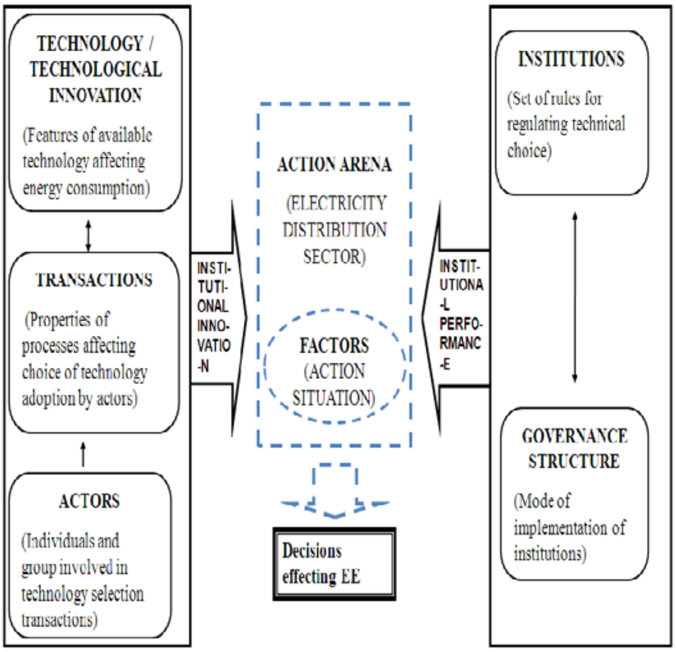


Figure 1. Analytical framework with interactions that shape consumer's decisions and influence energy intensity of the economy (adapted from Hagedorn 2008 and Hagedorn et al. 2002)

As "technology" is crucial element in the interaction between human actors and institutions, a change in the characteristics of technology or development of new technology influences whole system. Moreover, if the new technologies need to be adopted by the society (for greater environmental benefit) then it may require changes in the existing institutions and governance structure. Thus, a new component of "technology" is added to the IoS framework, which involves the study of characteristics of technology (and in the present study context deals with a particular characteristic of "energy consumption" of technologies related to electricity distribution and water pumping). The "action arena" is then composed by the attributes of three sub-systems namely technical (hardware and software), social (actors /organizations) and institutional (rules of the game), now added with a technical dimension (Figure 1).

Based on the modified framework the study aims to analyse the impact of structural change in the power sector on the technical advancement in the electricity distribution networks. Thus, in addition to the theory of technical change (evolutionary and system theory), the study would involve the theory of institutional change, Transaction cost theory (TCE), and organizational theory.

4 Methodological issues and search of methods:

Yin 2003 differentiates five major research methods in the social sciences namely case study, history, archival analysis, survey, and experiments. He describes how the selection of one of these methods depends on the type of research questions being asked, the need for behavioural control and whether the focus is on contemporary events or not? For "how and why" question Yin suggests "Case Study" approach.

CASE STUDY: The criteria for the selection of cases and brief description of each case are as follows:

Criteria for selection of cases:

1. Total quantity of electricity purchased.
2. Share of farmers in the total consumer base of DISCOM. This also determines the subsidy received by the DISCOM from the government.
3. Percentage of distribution losses.
4. Successful case of technological innovation in the DISCOM.
5. Different or same regulatory commission: In an attempt to analyze the role of regulators, DISCOM under two different regulatory commissions should be selected.
6. In-house versus major functioning outsourced in the DISCOMS (public private partnership versus fully state owned DISCOM).

CASE 1: AP Central Power Distribution Company Ltd. (APCPDCL)
APCPDCL is the distribution company supplying electricity to Hyderabad and surrounding districts. It purchases the maximum electricity from APTRANSCO as compared to the other three DISCOMS in the state and serves the minimum percentage of farmers. It receives the minimum subsidy from the state. The implementation of 'spot billing' practice is a big innovation adopted by APCPDCL in distribution sector.

CASE 2: AP Northern Power Distribution Company Ltd. (APNPDCL)
APNPDCL is the distribution company supplying electricity five northern districts of AP. It purchases the minimum electricity from APTRANSCO as compared to the other three DISCOMS in the state and serves the maximum percentage of farmers. No major technological innovation has been adopted by APNPDCL.

CASE 3: BSES Rajdhani Power Ltd. (BRPL)
BRPL is one of the distribution companies operating in Delhi. It has significantly reduced losses in the recent past following adoption of many technological innovations.

The case study would involve semi-structured and open ended interviews with the managers and engineers of the three distribution companies. Besides distribution companies, the study would also involve meetings and interviews with state and central regulatory bodies; major suppliers of technologies[15] to the DISCOM; energy efficient technology manufacturers and suppliers; technical and management experts in the electricity distribution domain from education, research and consultancy.

Along with "*why and how*" research questions, many questions are related to "*What*", so there is a need to explore other methods beyond those suggested by Yin, which fits to the analytical framework and helps to analyze the issue of institutional and technological change together. The method should be suited to analyze the complex interactions involved in infrastructure development and institutional analysis.

---

[15]Only few technologies would be considered most likely distribution transformers and high voltage distribution system.

Beckmann et al. 2009 suggest agent-based modelling as one of the four key methods for an institutional analysis. They argue that agent-based modelling, in contrast to other modelling techniques, allows to model heterogeneity of agents, information asymmetry, bounded rationality and learning among the agents. Wackerle et al. 2009 used agent-based modelling to analyze institutional change and concludes that simulation studies are much useful for institutional economics as it can lead to "useful, credible and replicable insights", not gained by non-simulative methods. Ma et al. 2009 provides the comparative advantages and disadvantages of using ABM and optimization models in studying energy systems. They suggest that while "optimization models with endogenous technical change assume decision makers make a long term strategic plan with perfect foresight and while considering cost of technical change", ABM on the other hand assumes "decision makers make adaptive plan based on the results created by their previous decisions, and technological change is a result of the decision makers adaptive behaviours" (Ma et al. 2009: p. 878). These arguments are similar to Dawid et al. 2006, which shows that agent-based modelling technique is in line with the evolutionary theory of technical change, which is also the theoretical base for our empirical studies. ABM has been successfully used for analyzing institutional arrangement, actors behaviour and market design in the electricity sector (Dawid et al.2006, Wackerle et al.2009, Chang et al. 2006, Marks 2006, Li et al. 2010, Dam 2009, Sensfuss et al. 2007). Ma et al. 2009 show that in ABM it is easy to include energy demand responses to price changes endogenously, unlike other methods. Furthermore, Dam 2009, Ottens et al. 2005, and Chappin et al. 2008 have demonstrated that agent-based modelling techniques is a potential method for analyzing technological change in the complex socio-technical systems of infrastructure management.

In conclusion, the insight gained from the literature review on the applicability and usefulness of ABM it is found as an appropriate technique for institutional analysis and institutional change, and well suited to study technical change in socio-technical systems. Further, our approach of adopting a combination of two research methods is supported by Janssen and Ostrom 2006, as they also demonstrates that it is reasonable to integrate case-study analysis with agent-based modelling.

Similar to any other research method ABM also possess certain disadvantages and as stated by Beckmann et al. "..agent-based modelling can only prove primary theoretical concepts, but [is] difficult to verify by empirical observation" (Beckmann et al. 2009: p. 347). David et al. 2008 while discussing the immense potential of ABM in policy design sphere, consider "typical inertia of the profession to pick up new methods" along with some shortcomings of ABM like "..to what extent is the dynamics of the economic system in the simulation method is indeed a good representation of the impact it would have in reality" (Dawid et al. 2008: p. 352), as the reasons for slow adoption of ABM and considering it "as a standard tool for economic policy analysis". But the research conducted alongside to overcome these shortcomings, will provide some systematic guidelines about how to deal with empirical validation issues (Fagiolo et al. 2007, Windrum et al. 2007).

5 Agent-based modelling and simulation and preliminary outline of the model:

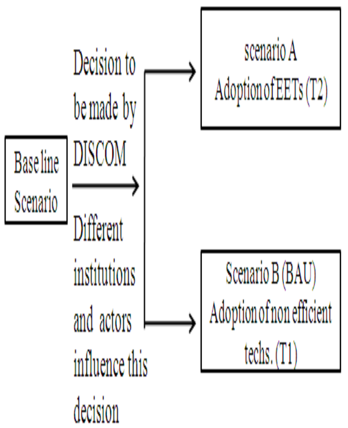
This section describes the basics of ABMS and presents the preliminary design of the model to study DISCOM behaviour.

i) Agent based modelling and simulation: Agent Based Modelling[16] and Simulation[17] (ABMS) has its theoretical foundation mainly in complex system modelling (or complex adaptive systems which are built on the theory that 'system are built from the ground up' in contrast to the top down view taken by systems dynamics), artificial life and swarm intelligence (Zho et al. 2007). Bonabeau 2001 demonstrates that ABMS main roots are in modelling human social and organizational behaviour and individual decision making. An agent based model consists of three basic elements:

- *Agent:* An agent is an artificial representation of a real world actor, with a set of characteristics and rules governing its behaviour and decision making capability (Macal and North 2007). The rules are based either on theory or empirical evidences. Agents have the ability to extract information about its internal and external states, and to learn and adapt its decisions based on experiences.
- *Environment:* It is the space where agents simulate (interact). It is spatially heterogeneous and evolves over time (Zho et al. 2007).
- *Rules:* Rules are the guidance for the system state transitions and can be classified in three types, namely agent-agent rule; agent-environment rule; environment-environment rules. While the agent-agent rules determine agent actions and interactions, the agent-environment rule helps the agent to decide on how to react to the changes in the environment. Environment-environment rules determines how the environment influences each other, when the environment is heterogeneous (Zho et al. 2007).

As per Li et al. 2010 the first step in ABMS is to design a model with assumptions about agents and their interaction; adding salient aspect of institutional design with structural constraints. The second step, specifies initial conditions, and finally run simulations to study how the system evolves solely driven by agent interaction. In this way, the dynamic consequences of assumptions are visible.

ii) Preliminary description of the model: The model analyzes the behaviour of electricity distribution companies towards the use of energy efficient technologies (EETs) in the electricity distribution network. It identifies the important factor, which can accelerate the adoption of EETs at DISCOM level and role played by other actors in electricity sector. Two important features are (i) to study the role of regulator and (ii) evaluate the strategies followed by DISCOM under different situations.



- Base line scenario, characterized by high T&D losses.
- Scenario A, least T&D losses by adoption of EETs leading from innovation in governance.
- Scenario B, less adoption in EETs, business as usual

Fig. 2 Transition of electricity distribution network towards an energy efficient network

DISCOM purchases electricity from upstream market [transmission and generation (either directly or indirectly)] and provides it to different consumers (household, industries and farmers) at a rate which is determined by the DISCOM and the regulator (sometimes the

[16]A model is a simplification of reality, designed to learn something about the reality. It depends on the modeler and research questions which components of reality are included in the model.

[17]A simulation is goal directed experiment with a computer program.

government may be involved in the negotiations). The tariff charged from agriculture is less than that from households, which is less than that charged from industries. For supplying electricity the DISCOM need to invest in distribution networks and its repair and maintenance. The fund for these operations has to be covered partially from the revenues generated by the DISCOM and partially by the funds provided by the government. The shaping of distribution network is determined by the interaction, cooperation and decisions made by all the elements of ST system, but DISCOM plays a major role. DISCOM can choose between costly but energy efficient technologies, which require skilled labour, or relatively cheaper, easily available less efficient technologies to build distribution network. But this decision of DISCOMS may be determined by regulator along with the financial capabilities and its internal structure (Fig. 2)

Model Description:

Agents:

I) DISCOM: It is the most important agent whose behaviour in terms of using either EET or non-EET is to be observed in terms of how other agents, environment and rules affect it.

II) Regulator: Its objective is to force DISCOM to use EET but at the same time decides for tariffs for consumers and their welfare.

III) Consumers: Three categories of consumers which differ in terms of their electricity needs and paying capacity.

IV) Standardization agencies: Independent organizations which provide quality assurence about EET.

V) Finiancial institutes: Provides funding to the DISCOM for using EET.

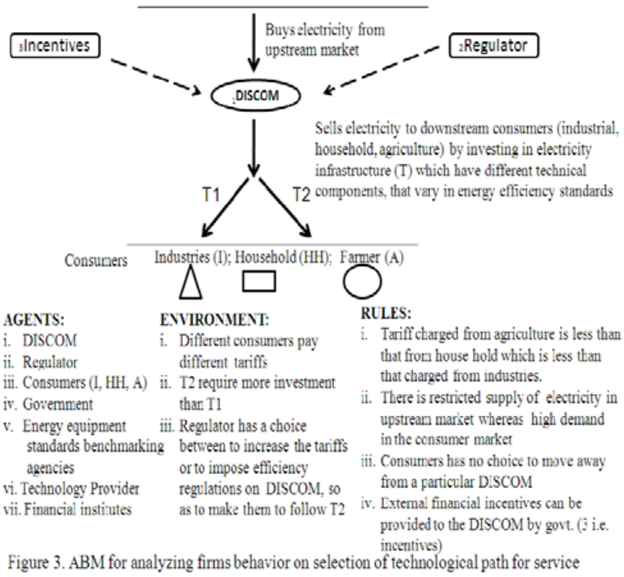


Figure 3. ABM for analyzing firms behavior on selection of technological path for service delivery

Environment:

The medium through which all the transaction take place(as indiacted in fig. 3 below).

Rules:

Overall guidance for system transition (as indiacted in fig. 3 below).

Expected Results:

i) Does the proportion of different consumer's effects DISCOMS choice of EETs?
ii) How much the decision of DISCOM is motivated by the tariff paid by the consumers?
iii) How the decision of DISCOM changes with the changes in rules?
iv) For regulator which option is beneficial to increase the tariffs or to impose efficiency regulations on DISCOM?

The model is planned to be developed in the following stages:

- Develop dummy model: Specify agents, environment and rules; assign behavioural rules to the agents arbitrarily based on the existing knowledge of the problem.
- First model: Agents, environment and the behaviour of agents is based on theory. Run simulations with this model and compare the outcome with empirical surroundings.

- Actual model, post empirical data collection: Agents, environment and behaviour of agents is based on theory and empirical findings.
- Run simulations and analyze the data sets.
- Empirical validation of model.

6 Conclusion

The paper discussed the structural reform of the power industry and its impact on the distribution sector. A brief description of the present performance of the electricity distribution companies is presented. Based on this discussion the need of a study to analyze the impact of institutional change on technological innovation in the distribution sector is outlined. Building on the concept of socio-technical system, the Institutions of Sustainability framework is modified according to the need of the research questions. The theory of institutional change and transaction cost theory along with the evolutionary theory of technical change are adopted as the main theories to answer specific research questions. It is described how a combination of case studies and agent-based modelling and simulation methods can complement each other. Past studies of application of the agent-based modelling technique in infrastructure sector is also reviewed. Finally, the criteria for selection of cases and a preliminary design of agent-based model are described.

Acknowledgement:

I would like to thank Christine Werthmann and colleagues at the Division of Resource Economics for their valuable comments in an earlier draft of the paper. The financial support provided by German Academic Exchange Services is gratefully acknowledged. The usual disclaimer applies.

7 References:

Alagh Y. 2010 Transmission and Distribution of Electricity in India: Regulation, Investment and Efficiency. Indian Institute of Rural Management, Anand (Gijarat). (http://www.oecd.org/dataoecd/35/33/46235043.pdf).

Arrow K. J., 1962 'The Economic implication of Learning-by-doing', Review of Economic Studies (29) 155-173.

Beckmann V., Padmanabhan M., 2009 Analysing Institutions: What Method to Apply? Institutions and Sustainability. Springer.

Berglund c., Soderholm P., 2006 Modelling technical change in energy system analysis: analyzing the introduction of learning by doing in the bottom up energy models. Energy Policy (34) 1344-1356.

Bergek A. Hekkert M., Jacobsson S., 2008 Functions in innovation systems: A framework for analyzing energy system dynamics and identifying goals for system building activities by entrepreneurs and policy makers. Innovation for a low carbon economy. Edited by Foxon T. J., Kohler J., and Oughton C. Edward Elgar, Cheltenham, UK.

Bonabeau E., 2001 Agent-based modelling: methods and techniques for simulating human systems. In Proc. National Academy of Sciences (99) 7280-7287.

CESDT 2009 Technology: Enabling the Transformation of Power Distribution (www.cstep.in/docs/Power_Sector_Report.pdf).

Chaminade C., Edquist C., 2006 From theory to practice: The use of the systems of Innovation approach in innovation policy. Innovation, science and Institutional change. Edited by Hage J. And Meeus M. Oxford University Press.

Chang M. H., Harrington Jr. J. E., 2006 Agent based models of organizations. Handbook of Computational Economics, Volume 2. Edited by Tesfatsion L. and Judd K. L. Elsevier.

Chappin E. J. L., Dijkema G. P. J., 2008 Agent based modelling of energy infrastructure transitions. (http://chappin.com/v2/docs/Chappin08a.pdf).

Chattopadhyay P. 2004 Cross-subsidy in electricity tariffs: evidence from India. Energy Policy (32) 673-684.

CMIE 2008 Economic Intelligence service – Energy, November 2008 Mumbai.

CPDCL 2010 ARR and Tariff Proposal for the Retail Supply Business for the year 2010-11.Central Power Distribution Company of Andhra Pradesh Limited.

Dam K. H. V., 2009 Capturing socio-technical syatems with Agent Based Modeling. PhD theis. Energy and Industry Group, Faculty of Technology, Policy and Management , Delft University of Technology.

Dasti R., Afsharnia S., Ghaderi F., 2010 AGA (Asset Governance Assessment) for analyzing affect of subsidy on MC (Marginal Cost) in electricity distribution sector. Energy (35) 4996-5007.

Dawid H., Fagiolo G., 2008 Agent-based models for economic policy design: Introduction to the special issue. Journal of Economic Behaviour & Organization (67) 351-354.

Dawid H.2006, Agent-Based Models of Innovation and Technological Change. Handbook of Computational Economics, Volume 2. Edited by Tesfatsion L. and Judd K. L. Elsevier.

Devaiah D. 2010 Government of Gujarat: Joytigram Yojana. Erehwon Innovation Consulting.

Dev K., Garg A., Rommel K., 2009 Energy Management for the emerging Megacity Hyderabad Studying Demand, supply and Gaps and Exploring Technical, Social and Institutional factors. Background Study, Division of Resource Economics, Humboldt University Berlin.

Dosi, G., Nelson R. R., 1994 An introduction to evolutionary theories in economics Journal of Evolutionary Economics (4) 153-172.

Dosi G., 1982 ‘Technological Paradigms and Technological Trajectories’, Research Policy (11) 147-162.

Dossani R. 2004 Reorganization of the power distribution sector in India. Energy Policy (32) 1277-1289.

Edquist, C. 1997 System of innovation: technologies, institutions and organizations Printer Publishers.

Fagiolo G., Birchenhall C., Windrum P., 2007 Special issue on empirical validation in Agent-based models. Computational economics (30) 3.

Filippini M., Hrovatin N., Zoric J., 2004 Efficiency and regulation of the Slovenian electricity distribution companies. Energy Policy (32) 335-344.

Foxon T., Kohler J., Neuhoff K., 2008 Innovation in energy systems: Learning from economic, institutional and management approaches. Innovation of a Low carbon economy Edited by Foxon T. J., Kohler J., and Oughton C. Edward Elgar, Cheltenham, UK.

Gheel F. W., 2004 From sectoral systems of innovation to socio-technical systems Insights about dynamics and change from sociology and institutional theory. Research Policy (33) 897-920.

Hagedorn K. 2008 Particular requirements for institutional analysis in nature-related sectors. European Review of Agricultural Economics, 35(3), 357-384.

Hagedorn Konrad, Katja Arzt, and Ursula Peters. 2002. "Institutional arrangements for environmental co-operatives: a conceptual framework." In Environmental Cooperation and Institutional Change: Theories and Policies for European Agriculture, ed. Konrad Hagedorn. Cheltenham, UK: Edward Elgar, 3–25.

Hamilton D.J., Nuttall W.J., Roques F.A., 2009 Agent based simulation of technology adoption. Electricity Policy Research Group working paper 0923 University of Cambridge (www.electricitypolicy.org.uk).

Hendry C., Brown J., Harbone P., 2008 Firms, markets and the fuel cell technology innovation system in an international prespective. Innovation for a low carbon economy. Edited by Foxon T. J., Kohler J., and Oughton C. Edward Elgar, Cheltenham, UK.

Hinnells M., Boardman B., 2008 Market transformation: Innovation theory and practice. Innovation for a low carbon economy. Edited by Foxon T. J., Kohler J., and Oughton C. Edward Elgar, Cheltenham, UK.

Hughes, T. P. (1987). The evolution of large technological systems. The social construction of technological systems. New directions in the sociology and history of technology, Edited by W. E. Bijker, T. Hughes & T. J. Pinch, MIT Press, Cambridge, pp. 51–82.

IEEMA Journal 2007 Energy Efficient distribution transformers. Emerging trends in distribution sector.

Janssen M. A., Ostrom E., 2007 Emperically based, agent-based models. Ecology and society, (11) article 37 (www.ecologyandsociety.org/vol11/isse/art37/).

Kadam G., Majumdar S., Gosh A., 2009 Power Distribution Utilities: Rising subsidies remains a key concern. ICRA (www.icra.in/Files/Articles/2009-September-PDU.pdf).

Kodwani D. 2009 Regulatory institutions and regulatory practice Issues in electricity tariff determination in reformed electricity industry in India. Open University Business School UK (http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1517180).

Li H., Sun J., Tesfatsion L., 2010 Testing Institutional Arrangements via Agent-Based Modeling: A U.S. electricity market application. Computational Methods in Economic Dynamics Edited by David H., Semmler W. Springer.

Macal C. M., North M. J., 2007 Agent based modelling and simulation: Desktop ABMS. Proceedings of the 2007 winter simulation conference.

Ma T., Nakamori Y., 2009 Modeling technological change in energy systems- From optimization to agent-based modelling. Energy (34) 873-879.

Marks R. 2006 Market design using agent based models. Handbook of Computational Economics, Volume 2. Edited by Tesfatsion L. and Judd K. L. Elsevier.

Mowery D. C., Rosenberg N., 1979 The influence of market demand upon innovation: A critical review of some recent empirical studies. Research Policy (8) 103-153.

Mulder Peter 2005 The Economics of Technology Diffusion and Energy Efficiency. Edward Elgar Publishing Limited Cheltenham, UK.

Murphy J., 2007 Governing technology for sustainability, ESRC sustainable Technologies programme – Governance of sustainable Technologies Network, London: Earthscan.

Murthy Ramachandra K V S, Ramalinga Raju M. 2009 Analysis on electrical energy consumption of agricultural sector in Indian context. ARPN Journal of Engineering and Applied Sciences 6-9.

Nelson R. R., Nelson K. 2002 Technology, institutions and innovation systems Research Policy (31) 265-272.

Nelson R. R., Samphat B. N. 2001 Making sence of institutions as a factor shaping economic performance Journal of economic behavior and Organization 44, 31-54.

Nelson R. R., Winter S. G., 1982 An evolutionary theory of economic change. Cambridge, MA: Harvard University Press.

Ottens, M., Franssen, M., Kroes, P. & van de Poel, I. (2006). Modelling infrastructures as socio-technical systems, International Journal of Critical Infrastructures 2(2/3): 133–145.

Parto 2003 Technological change and institutions: A case study. MERIT – Infonomics Research Memorandum series 2003-033 (www.infonomics.nl).

Passey R. Betz R. MacGill I. 2009 An energy efficiency policy model that addresses the influences of the ‘Infrastructure of Provision’. ECEEE 2009 summer study.

Pezzini P., Bellmunt O., Valentiet J., Andreu A. 2010 Energy efficiency optimization in distribution transformers considering Spanish distribution regulation policy. Energy (35) 4685-4690.

Planning Commission 2010 Mid-term appraisal report of the eleventh five year plan (www.planningcommision.nic.gov.in).

Prayas 2010 Clean energy regulation and civil society in India Need and challenges to effective participation. Electricity Governance Initiative. (http://electricitygovernance.wri.org/publications/clean-energy-regulation-and-civil-society-india-need-and-challenges-effective-participa).

Reddy A. K. N. 1991 Barriers to improvement in energy efficiency. Energy Policy, 953-961.

Reddy B. S., Assenza G. B., Assenza D. Hasselmann F., 2009 Energy Efficiency and Climate Change. Sage Publication India Pvt. Ltd.

Reddy B S, Assenza G. 2007 Barriers and drivers to energy efficiency – a new taxonomical approach. Energy – The International Journal.

Raghu K., Reddy M. T., Sreekumar N., Reddy D. N., 2003 Power sector reforms in Andhra Pradesh (India).People’s Monitoring Group on Electricity Regulation, Hyderabad. (http://www.pmger.org/articles/AP%20Power%20Sector.pdf).

RamaMohan RV, Sreekumar N. Evolving an integrated approach for improving efficiency of ground water pumping for agriculture using electricity: A few pointers from the field. Discussion Paper–2009 (www.indiawaterportal.org).

Romer P. M., 1986 ‘Increasing returns and long-run growth’, Journal of Political Economy (94) 1002-1037.

Ruttan V. W., 2001 Sources of Technical change: Induced innovation, Evolutionary theory and Path Dependence(http://www.ima.kth.se/im/3c1395/pdf/Ruttan.pdf).

Sanstad A. H., Howarth R. B. 1994 ‘Normal’ markets, market imperfections and energy efficiency. Energy Policy 1994 22(10) 811-818.

Schumpeter J. A., 1934 The theory of economic development, Cambridge, MA: Harvard University Press.

Sensfuss F. Ragwitz M., Genoese M., Most D., 2007 Agent based simulation of electricity markets – A literature review. Working paper sustainability and innovation No. S 5/2007 Fraunhofer Institute for systems and Innovation Research, Karlsruhe, Germany.

Shah T., 2009 Climate change and groundwater: India's opportunities for mitigation and adaptation. Environmental research letters. (http://stacks.iop.org/ERL/4/035005).

Shah T., Verma S., 2008 Co-Management of electricity and Groundwater: An Assessment of Gijarat's Joytigram Scheme.

Shukla P. R., Biswas D., Nag T., Yajnik A., Heller T., Victor D. G. 2004 Impact of power sector reforms on Technology, Efficiecy and Emissions: Case Study of Andhra Pradesh, India. PESD Working Paper#20.

Singh A. 2006 Power sector reform in India current issues and prospects. Energy Policy (34) 2480-2490.

Sinha S. 2003 Management of Power Supply to Agriculture Indian Institute of Management Ahmadabad.

Solow R. M., 1956 'A contribution to the theory of Economic Growth', Quaterly Journal of Economics (70) 65-94.

Sorrell S., Malley E. O., Schleich J., Scott S. 2004 The Economics of Energy Efficiency. Edward Elgar Publishing Limited.

Soete L., Verspagen B., Weel B. T., 2010 Systems of innovation. Economics of Innovation. Edited by Hall B. H., and Rosenberg N. vol. II 1159-1178.Elsevier.

Sreekumar N., Reddy M. T., Rao K. U., 2003 Analysis of Policy Process in Power Sector in Andhra Pradesh. Power Policy. People's Monitoring Group on Electricity Regulation Hyderabad (www.pmger.org/articles/AP%20Power%20Sector.pdf).

Subramaniam K. 2004 Thirteen years of Power sector reforms in India Are we still groping in the dark ? Centre for the Advanced Study of India, University of Pennsylvania. CASI Occasional Paper Number 15.

Swan T. W., 1956 'Economic Growth and Capital Accumulation', Economic Record (32), 334-61.

Teece D. J., 2010 Technological innovation and the theory of the firm: The role of enterprise-level knowledge, complementarities, and (dynamic) capabilities. 679-730. Economics of Innovation. Edited by Arrow K. J., and Intriligator M. D., vol. 1 Elsevier.

Tongia R. 2006. The political economy of Indian power sector. Cambridge University Press.

Totare N. P., Pandit S., 2010 Power sector reforms in Maharashtra, India. Energy Policy (38) 7082-7092.

Vatn, Arild. 2005 Institutions and the Environment. Cheltenham, UK: Edward Elgar.

Veblen T. 1898 'Why is economics not an evolutionary science?' , Quaterly Journal of Economics, (12) 373-397.

Vine E., Hamrin J., Eyre N., Crossley D., Maloney M., Watt G., 2003 Public policy analysis of energy efficiency and load management in changing electricity businesses. Energy Policy (31) 405-430.

Wackerle M., Radax W., Rengs B., 2009. An agent –based approach to institutional change (http://eaepe.org/files/Wackerle_Radax_Rengs_EAEPE2009_0.pdf)

Wang N. 2003 Measuring Transaction Costs: An incomplete survey. The University of Chicago. (Paper presented at the conference on Transaction Costs organized by Ronald Coase Institution Feb. 21-23 Chicago.)

Weijnen M. P. C., Bouwmans I., 2006 Innovation in networked infrastructures: coping with complexity. International Journal of Critical Infrastructures 2(2/3) 121–132.

Wene C. O., 2008 A cybernetic perspective on technology learning. Innovation of a low carbon economy edited by Foxon T. J., Kohler J., Oughton C. Edward Elgar Cheltenham UK.

Williamson O. 1985 The economic institutions of capitalism. New York: Free Press.

Windrum P., Fagiolo G., Moneta A., 2007 Empirical validation of agent-based models: alternatives and prospects. Journal of Artificial Societies and Social Simulation 10 (2), 8.

World Bank 2002 Energy Strategies for Rural India: Evidence from six states, joint UNDP/World Bank Energy sector Management Assistance Program (ESMAP).

Yadav V. K., Padhy N. P., Gupta H. O., 2010 A micro level study of an Indian utility for energy efficiency. Energy (35) 4053-4063.

Yin R. K., 2003 Case Study Research Design and Methods. Sage Publication California.

Zho Z., Chan W.K., Cho J. H., 2007 Agentbased simulation of electricity markets: a survey of tools. Aetif Intell Rev (28) 305-342.

Zon A. V., Yetkiner I. H. 2003 An endogenous growth model with embodied energy-saving technical change. Resource and Energy Economics (25) 81-103.