आरोग्य, ऊर्जा, शिक्षण आणि पालकत्व
या विषयांतील विशेष प्रयत्न

Efficient well-based irrigation in India: Compilation of experiences with implementing irrigation efficiency

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Abstract:

Irrigation in India has become increasingly dependent on wells, with the consequent impacts on groundwater availability and on energy use for its extraction. Efforts have been made over the past three decades – from local pilot projects, to state-wide programmes – towards improving the efficiency with which groundwater is pumped, and for its re-charge and conservation. In this report, we have compiled the information available, from published reports and papers as well as news bulletins, on the field activities and studies carried out with respect to efficient water extraction and use for agriculture. Numerous programmes have been included – ranging from cases where a few pump sets were focused on, to large programmes addressing thousands of pump sets. However, most of the cases involve the replacement/retrofitting of electrically-powered irrigation pump sets.

This compilation has two purposes. Firstly, we are beginning a repository of such reports that is publicly accessible and can be expanded with more documents. As importantly, we intend eliciting lessons from past experiences that would benefit future programmes, thereby improving irrigation efficiency and contributing to the conservation of energy and water.

Acknowledgements:

We at the Asian branch of the International Energy Initiative have been involved in the assessment and promotion of efficient and clean energy services since the early 1990s'. We have worked on irrigation efficiency, from estimations of the costs of conserved energy through improvements in efficiency, to a recent field project at which pump sets were replaced and micro-irrigation systems installed. I therefore welcomed the suggestion from Mr Girish Sant, Prayas (Energy) Group regarding compilation of a list of experiences with improving irrigation efficiency.

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1. Background

Farmers in India have become increasingly dependent upon groundwater for irrigation and about 60% of India's net sown area[1] is irrigated with groundwater (MoA-GoI, 2003). With the increase in population dependent on agriculture, the *land* : *man* ratio has been declining from over 0.4 ha/person in 1900 to less than 0.1 ha/person in 2000 (Shah, 2009). Farmers perceived the need to secure the means of irrigation which could permit intensification and diversification of land use, and the availability of small mechanical pumps and boring rigs provided the required technological breakthrough. During the last 40 years, India has witnessed a decline in gravity-flow irrigation and consequently millions of small, private tube-wells have come into use.

Most State utilities have been supplying electricity for irrigation-pumping at very low (below-cost) rates for over two decades. Currently, electricity for irrigation is supplied practically free[2], with unit tariffs being very low or even nil, and only a fixed charge on connected load[3]. Farmers who can afford the cost of drilling a well can do so (on their own land), and if electricity can be accessed, water can be pumped out at negligible energy costs. Hence, there is no incentive for efficient electricity use.

This has led to increased rural demand and consequent overloading of the grid. Such un-remunerative supply has worsened the financial health of the utilities, leading to low investments in distribution system maintenance and improvements. Consequently, power supply quality to rural areas has worsened considerably and the resulting unreliable supply (outages, fluctuation in voltage, etc.) has caused frequent failure of motors. As a result, farmers have to spend regularly on repairs; they react by installing rugged locally-manufactured/retrofitted pump sets that can better withstand poor supply. But, these are inefficient and of higher capacity, overloading the system further and leading to more unscheduled power shutdowns. Utilities argue that failures of pump sets have been occurring due to the farmers' own problems, for example, use of non-standard pump sets, poorly-maintained and repaired motors, and non availability of LT capacitors (AP-CPDCL, 2009). As they get subsidized or free power, farmers cannot complain about quality. To cope with the unreliable hours of supply, pumps are used whenever electricity is available (through automatic switches). While individual irrigation pump sets are not metered (and separation of agricultural feeders has taken place in only a few states)[4], the agricultural sector is estimated to use about 23% of utility-supplied electricity (MoP&USAID, 2009a)

Further, enhanced use of groundwater has led to wells being bored increasingly deeper and farmers requiring higher-capacity pumps to lift water. This extraction has not only increased the costs to farmers and the utilities, but progressively worsened water availability in various regions. Of the 5,723 administrative units (blocks/*mandals*, *taluks*, districts) in the country assessed by the Central Ground Water Board, in 550 blocks, groundwater resources were found "semi-critical" or "grey" (in the sense that 70% or more of the known resource was already developed), 226 more blocks were "critical" or "dark", where 70-100% of the

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[1] This excludes the fields on which more than one crop/year is harvested. Of the country's *gross* irrigated of 80.54 million ha, 42.5 million ha are estimated to be watered with groundwater.
[2] Punjab, Tamil Nadu and Andhra Pradesh, provide free power to the agricultural sector.
[3] Even these charges are not paid in some regions.
[4] Gujarat (*Jyotigram*) and Punjab have separated farm from non-farm rural feeders; Andhra Pradesh and Karnataka are working on this.

resource was already developed, 839 blocks were declared "over-exploited" because their annual groundwater draft exceeded the long-term rate of annual recharge (CGWB-MoWR, 2006). Threatened blocks include semi-critical, critical and over-exploited, and at present, seven states (Andhra Pradesh, Tamil Nadu, Rajasthan, Punjab, Gujarat, Karnataka, and Haryana) in peninsular and western India account for 80% of these. Simultaneously, groundwater-stressed areas also have a high concentration of irrigation wells, with the majority in the peninsular region being fitted with electric pumps, as shown in Table 1.

Table 1: Groundwater availability and irrigation wells

State	**Annual ground-water draft** (billion m^3) (1)	**Net annual groundwater availability** (billion m^3) (2)	**Stage of ground-water use (%)** (3) = (1) / (2)	**Number of critical and over-exploited blocks** (4)	**Number of irrigation wells** (dug-wells, shallow-wells, deep-wells) (5)	**Wells with electrical pumps** (% of total wells) (6)
Andhra Pradesh	14.90	32.95	45	296	1,929,057	1,691,502 (87.7%)
Gujarat	11.50	15.02	76	43	1,082977	568,117 (52.5%)
Karnataka	10.71	15.30	70	68	860,363	807,377 (93.8%)
Rajasthan	12.99	10.38	125	190	1,341,118	510,020 (38.0%)
Tamil Nadu	17.65	20.76	85	175	1,891,761	1,412,697 (74.7%)
All-India	**231.00**	**398.70**	**58**	**1,065**	**18,503,268**	**9,943,486 (53.7%)**

Sources: For columns (1) to (4), *Dynamic Ground Water Resources of India, March 2004*, (CGWB-MoWR, 2006); for columns (5) and (6), *3rd Census of Minor Irrigation Schemes: 2000-01, (*MoWR, 2003).

As a result of continued exploitation, accessible water levels are sinking progressively deeper, with disastrous impacts. Wells are drying, and as small farmers cannot afford the costs of drilling/re-drilling for water, they are restricted (or forced to revert) to rain-fed farming. Cultivation only during the rainy season, or else without irrigation during essential periods of the crop cycle, puts their livelihood at risk, so that in addition to the vicious circle of "poor energy supply–inefficient energy use–worsening energy supply", there is the invidious vicious cycle of "low income-low inputs-low yields" and continued poverty.

Further still, over-extraction of groundwater has led to mining of underground aquifers. This has adversely affected the quality of water and since it is also the source of drinking water, health problems have ensued. Hence, for India, groundwater is now both critical and threatened.

In view of these mutually reinforced energy and water shortages and consequent problems, State departments and other organizations have tried to improve the efficiency with which energy and water are used.

2. Efficiency-improvement programmes in India

2.1 Progress of activities

In the early years of efficiency-improvement programmes, that is, in the 1980s' and 1990s', the focus was on improving the efficiency of irrigation pump sets. There are reports of large-scale pump set rectification through the Ministry of Energy (later Ministry of Power). There were also six major state programmes sponsored by the Rural Electrification Corporation during the 1980s' (CIRE, 2005). In the 1990s', there were state programmes sponsored by the Ministry of Power (MoP-GoI, 1997, 1998) as well as some State agencies. The activities included replacement of the entire pump set or replacement of some or all components – the suction and/or delivery piping and/or foot valves.

Thereafter, more states carried out programmes, at times with sponsorship from international aid agencies. Non-governmental organisations and consultant firms also got involved in these activities. The focus widened to include power system improvements, on the one hand, and water-conservation, through water-harvesting structures and application-efficiency (through drip and sprinkler systems), on the other. In parallel, many researchers have studied the systems and suggested ways forward, based on theoretical and empirical analyses.

States in the plateau region have tried to promote water conservation and restrict indiscriminate use of groundwater by introducing regulation regarding the drilling of deep wells. The Andhra Pradesh Water, Land and Trees Act (APWALTA) was passed in 2002, the Karnataka Groundwater (Regulation and Control) Act, in 2002, and the Tamil Nadu Groundwater Development and Management Act, 2003, all with restrictions on the over-exploitation of groundwater.

2.2 Purpose of this compilation

In this report, we have compiled a list of field projects and studies on the implementation of efficiency improvements in groundwater-based irrigation (with references listed in the Annexe). Details have been obtained from published articles, from reports and news bulletins on web sites, and from those who have answered our requests for information (included in the reference list). We have focused on energy-use for groundwater-based irrigation, which in turn depends on the efficiency of the pump and accessories, water depth, and the methods of irrigation (taking crop type as given) integrating efficiency of extraction with efficiency of water application and groundwater conservation and re-charge.

As most field programmes were sponsored by organisations of the power sector, their focus was on improving the efficiency of electricity use, i.e. on retrofitting or replacing the electrically-operated irrigation pumps. Hence, experiences with pump sets dominate this collection. However, we have also included efforts to conserve groundwater -- either through efficient micro-irrigation methods (i.e. drip and sprinkler systems) or through water harvesting structures (such as check dams and percolation tanks). This is because 150 km^3 of the 230 km^3 of groundwater used for irrigation each year are being lifted by electric pumps, and electricity use (and its impacts) can be decreased by raising the groundwater table and thereby reducing the pumping head from which groundwater is lifted.

We have *not* included changes in cropping patterns such as shifts to different (less-water-intensive) crops, different varieties of the same crop, and so on (unless they were a part of an integrated programme), in this compilation, because of the additional agronomical aspects to be considered.

We have also tried to focus on specific efforts – by a state or private organisation, in a particular location, rather than the aggregated efforts mentioned in national reports, as large numbers obscure the differences between the activities actually carried out. For example, "Demonstration schemes on rectification of inefficient agricultural pump sets has been undertaken on a large scale and 75,000 pump sets have been rectified during the year 1990-91" (MNES-GoI, 1993)[5]. If descriptions can include details that are pertinent, the activities can be juxtaposed with the results achieved, and one could elicit the factors that contributed to these results. However, it has to be accepted that with the passage of time, results are not verifiable; as importantly, estimates of electricity conservation are often not comparable because of differences in geographical location and natural changes (e.g. the fall in the water table) that have occurred.

The intention is to learn from these efforts, not to find fault with what was done, so that future efforts at meeting the needs of resource conservation and economic and agricultural considerations, could be more fruitful. If projects have been omitted, it has been inadvertent, and the author would be grateful if information could be sent for inclusion in this compilation.

2.3 Categories of projects

Projects have been categorized according to their main activities:- *A: Implementation* of efficiency-improvements, and *B: Studies* (empirical or theoretical), and listed in chronological order as far as possible.

A. Implementation activities have been disaggregated between (1) *executing pump-set efficiency improvements*, and (2) *executing efficient water-use* [6] that in turn affects the energy required for pumping. (A few projects, indicated with an asterisk, addressed both pump set and water application efficiency).
These include:

- *A.1 executing pump-set efficiency improvements*:

  A.1.1. for "shallow" (less than 100 feet) wells, replacement of the pump itself with a more efficient electric pump (with appropriate sizing or single phase replacing 3-phase), or any of the components -- replacing the existing suction and delivery piping with HDPE or RPVC piping, and/or replacing the foot valves (FV) with friction-less FV;

  in the case of water available at less then 25 feet, manual alternatives (e.g. treadle pumps);

[5] P.9, (Section 17 on Conservation for Energy), Performance Budget of Ministry of Power and Non-Conventional Energy Sources.

[6] Here, the efficiency of water use for irrigation is the ratio of consumptive use of water for plant nourishment to the gross amount of water supplied. "Productive" efficiency would refer to the quantum of crop production per unit of water utilized.

A.1.2 for deep- or bore- (greater than 100 feet) wells, chiefly replacing the pump with a more efficient pump[7];

A.1.3 other field experiences that could improve the energy-efficiency of pumping (e.g. installation of capacitors);

- *A.2 executing efficient water application and use*:

  A.2.1 groundwater conservation and re-charging through water harvesting structures (such as check dams and percolation tanks, etc.);

  A.2.2 installing micro-irrigation (drip/sprinkler) systems.

B. Studies on improving the efficiency of groundwater-based irrigation have been disaggregated between:

- B.1 those on the efficiency of irrigation pump-sets (including estimates of losses and possible estimates of reduction of these due to the replacement of specific components);
- B.2 those on the efficiency of groundwater use, including water application methods, groundwater re-charging, and other aspects of groundwater use;
- B.3 those on related aspects such as system improvement, pricing, policies, and management;

3. Programme experiences

This section gives an overview of the implementation projects and studies reviewed[8]. These range from cases where a few pump sets were focused on, to large programmes addressing thousands of pump sets, hence merely indicating the total number of cases would hide the differences between them. Moreover, there are, at times differences between reports regarding the number of retrofits/replacements that were affected at a particular project site, hence we have not aggregated the numbers in any category. Further, aggregating cases over a 30-year period – well past the life of the pumps/retrofits – is unlikely to be of relevance.

A. Implementation:

***A.1 Executing pump-set efficiency improvements*:**

- Gujarat - pilot projects (GEB/REC), 1978-88: There are two available reports on this period; it is not clear whether or not there is some overlapping between the projects described.

According to the Energy Conservation Dimension, Gujarat Electricity Board (GEB), Baroda, quoted in *Monitoring Results of REC's Pilot Projects*, a report of the Central Institute for Rural Electrification, (CIRE, 2005), there were two sets of activities carried out in those early pilot projects. They included: (i) replacement of suction pipes and foot-valves, (ii) complete replacement of pumps, piping and foot-valves, both implemented by GEB. Results reported by CIRE were (i) 1,108 component retrofits, with an estimated average 21.7% energy conservation, and (ii) 8 completed replacements with an estimated 51% energy conservation.

In addition, the observations made on "Energy Conservation in Agricultural Pump sets - Details of Demonstration on Efficient Pumping Systems to the farmers" (CIRE, 2005),

[7] Recently, in some parts of the country, particular the peninsular region, the depth of groundwater availability has fallen to the extent that only deep (> 100 feet and extending much deeper) wells are in use, so that component-replacement is no longer worthwhile and complete pump set replacement is being carried out.

[8] We do not claim that this compilation is exhaustive, but all the information contained here has been obtained from verifiable sources (as indicated).

indicate that several demonstrations of complete replacement were carried out. Of these, data on 16 cases are available; each of the existing pumps was replaced by a mono-block pump of lower capacity, but providing at least equivalent discharge. These farms were located in the Baroda(3), Anand(3), Sabarmati(3), Mehsana(3), Himmatnagar(2), Utran(2) Circles of GEB, and were witnessed by a total of about 700 farmers. In most cases, 10HP pumps were replaced with efficient 5HP pumps, with one case each of 20HP and 15HP replaced with 5HP. Initial energy saving ranged from 24 - 69%. The new pumps had lower ampere loading for comparable or greater water discharge; direct demand reduction ranged from 1.2 - 6 kW each.
However, another report (Patel and Pandey, 1993), refers to a total of 488 cases of complete replacement -- pump, motors, suction and delivery piping and foot-valves – by Gujarat State authorities, with the assistance of Kirloskar Brothers Ltd., Dewas (KBL) during the period 1983-88. Of these, between 1983 and 1985, 149 were sponsored by KBL and 151 by KBL and Gujarat State, and between 1986-88, 188 were sponsored by KBL and Gujarat State. For the sample of 488, the aggregated reduction in electricity use post-rectification amounted to 53%.

The Rural Electrification Corporation Ltd. (REC) sponsored six pump-set rectification projects during the 1980s': these were in Tamil Nadu, Gujarat, Madhya Pradesh, Karnataka, Andhra Pradesh, and Haryana. These were noteworthy not only because of the immediate achievements, but because in every case, post-project evaluation was carried out on a sample of pump-sets by independent agencies, as described below. (Based on the results of work in these six states, further pump set rectification was planned, but these results are not available).

- Tamil Nadu (TNEB/REC) pump-set rectification (with sample monitoring), 1980s': Replacement of suction and delivery piping (GI to RPVC) and foot-valves was completed by Tamil Nadu Electricity Board (TNEB) on 3,125 pump sets of 5 HP rating each, as per REC guidelines (CIRE, 2005). 500 cases were evaluated by National Productivity Council (NPC), Hyderabad, in 4 distribution areas -- Madurai, Periyar, Thiruvannamalai, and Vellore. NPC reported the energy reduction as 10% - 30% in about 70% of the sample, and about 19% for the entire sample. Replacement of GI pipes on both suction and delivery sides by the recommended RPVC led to both reduction in energy consumption and higher discharge rate of water. While energy use increased by 11.7**%** due to increase in the flow of water, the impact on the energy index was beneficial. NPC also reported that the energy saving by rectification of suction and delivery pipes alone was 8 – 14% of the overall saving of 19%.
- Gujarat (GEB/REC) pump-set rectification (with sample monitoring), 1985-86: Gujarat Electricity Board (GEB) carried out rectification of 3,100 pump sets, of which 500 pumps were studied by Power Utilisation Consultancy (PUC). The rectification work involved replacement of the inefficient foot valve by *Sujala* foot valve and replacement of the existing GI suction and delivery lines by RPVC pipes. Of the pumps studied by PUC, more than 80% improved in efficiency by 50%, with the average at 48% (CIRE, 2005). The average hourly electricity use increased by about 5.59% for 500 pump-sets; the increase for all 3,100 would be about 10.8 percent. However, due to the increased water discharge rate, there would be a saving in the total electricity use for irrigating the same land, estimated to be 1,505 kWh/pump set per year.
- Madhya Pradesh (MPEB/REC) pump-set rectification (with sample monitoring), mid 1980s': 3125 pump sets were rectified by Madhya Pradesh Electricity Board (MPEB). The Institute of Cooperative Management (ICM), Ahmedabad, monitored 527 pumps of

these (CIRE, 2005). The average rate of discharge increased from 9.87 LPS to 15.54 LPS after rectification. While electricity use increased by 12% per hour of use, the system efficiency increased from 23.08% to 32.94%.

- Karnataka (KEB/REC) pump set rectification (with sample monitoring), 1980s': 3,125 pump sets were retrofitted by the Karnataka Electricity Board (KEB) through the replacement of suction and delivery piping (GI to RPVC) and foot-valves. Of these, Karnataka Energy Consultants (Bangalore) evaluated 250-300 in the *taluks* of Indi (Bijapur district) and Kanakpura (Bangalore district) (CIRE, 2005). After rectification, pump set efficiency (output-input ratio) improved from 23.5% to 36.1% in Kanakpura, and from 26.7% to 38.8% in Indi. While there was no significant impact on system demand, the power factor improved from 0.6 to around 0.85 in 100 cases of the sample in Kanakpura.

- Andhra Pradesh (APSEB/REC) pump set rectification - 2nd phase, (with sample monitoring), 1985-86: REC had sanctioned rectification of 5,625 pump sets; during the 2nd phase, for which independent monitoring was carried out, APSEB rectified 2,500 pump sets of at least 5 HP each, with replacement of suction and delivery piping (GI to RPVC) and foot-valves, in the district of Chittoor. NPC, Hyderabad, evaluated the results in 505 cases of the 2nd phase of the project. Observations on the 505 pump sets taken together, showed that the 'Q' rate (of discharge of water from the delivery pipe) increased from 9.70 LPS to 13.58 LPS (41.4 per cent); the increase in the flow rate and consequent reduction in the usage time impressed the farmers. Energy consumption increased by 2% due to increased flow of water, but the overall energy saving was found to be 26.17%. (Rectification of suction pipe and foot-valve alone in a sub-sample of 5 sets yielded an energy saving of 10-15% as compared with the total of 26% achieved by changing the entire piping system).

- Haryana (HSEB/REC) pump set rectification (with sample monitoring), 1985-86: While REC sanctioned a project for the rectification of 3,956 pump sets, Haryana State Electricity Board completed 3,757 pump set retrofits by May 1986 (CIRE, 2005). The rectification involved replacement of the existing Gl delivery line by a suitable size of RPVC pipes. Initially, in a few cases, insertion of 90 mm RPVC pipe with *Sujala* reflux valve into the existing 100 mm Gl suction line were tried. As the results were not found encouraging it was decided to rectify only the delivery line. All the pump sets were of 3HP to 7.5HP capacity. Of these, 569 pumps were monitored by M/s. K Consulting Associates. About 25% increase in water discharge per unit input was observed. Average decrease in consumption of energy for the same discharge was found to be 24% and the loading on the system reduced by 4%.

- Andhra Pradesh - Chittoor dist. (DFID), 1987-90: *This project was mentioned in one list (Singh, 2009), but further details are not available.* (DFID had funded several other irrigation activities in the same state, and as the REC-sponsored project was also in the same district, there could be an error in the listing).

- Gujarat pump replacement (ICM/MoE), 1988–93: The Institute of Co-operative Management, Ahmedabad, replaced at least 500[9] irrigation pumps with more efficient mono-block pumps during the period 1988 – 1993 (Patel and Pandey, 1993, as quoted by Sant and Dixit, 1995; Goyal, 2009; Singh, 2009). This was funded by the Ministry of Energy (later MoP), GoI, and the farmers themselves, approximately in the ratio 2:3. Reported connected

[9] The number has been given as 500 in Sant and Dixit (1995), 1,009 in Goyal (2009), and 521 in Singh (2009).

load reduced from about 4,062 kW to 2,216 kW, and average efficiency improved from 20.8% to 44.9%.

- Gujarat pump replacement and/or retrofitting (GEB/MoE), 1988-94: There were 4 types of replacements carried out by GEB with the financial support of the Ministry of Energy, (later Ministry of Power): FFVs only, FFVs and RPVC piping (suction and delivery), 5-HP pump-sets only, and all of these; but most of these were FV and piping replacements (GEDA personal communication, 2010). Of the funds made available by the Power ministry, complete rectification of 345 agricultural pump sets was completed by 1992. Another scheme of partial rectification of 20,000 agricultural pumps sets in Gujarat was also sanctioned. About 9,000 pump sets had already been rectified by 1992 (CIRE, 2005[10]; MNES-GoI, 1992[11]). Such retrofits continued to take place in subsequent years, with partial support from the MoP. Demonstrations of the relative superior performance of the ISI / BIS marked agriculture pumping components were conducted; the impact was so impressive that in Kheda district alone more than 1000 farmers rectified their defective pump sets on their own (CIRE, 2005). While there was no metering by the utility, the installation contractors measured the flow with portable meters. Farmers were conscious of the shortage of water (with wells unlikely to be recharged, if excessive pumping took place), hence with more efficient pumping systems, the pumping duration was reduced and energy saved (GEDA personal communication, 2010).

- Maharashtra – pump retrofitting (MEDA), 1989-94: Considering the potential for energy conservation, MEDA undertook a program of agricultural pump set rectification, from 1989 to 1994, in 17 different blocks of IREP of Maharashtra. According to this program, an average of 350 to 400 pump sets were rectified each year and financial assistance was provided for improving energy efficiency through measures such as piping & foot-valve replacement (p.15, IIEC-MEDA, 2005). Hence, a total of 1,750 - 2,000 replacements should have been completed; no details of monitoring are available. The IIEC-MEDA study of 2005 recommended large-scale (100,000) pump rewinding/replacement, quoting these earlier efforts, and also proposed funding from MSEB through avoided cost of supply, and from MEDA for capacity-building.

- Andhra Pradesh - Warrangal dist. (JBIC), 1993-96: *This project was mentioned in one list (Singh, 2009), but further details have not been obtained.*

***The following reports of agricultural pump set efficiency pilot programmes in the states of Tamil Nadu, Punjab, Haryana, Gujarat and Andhra Pradesh, appeared in the Annual Reports of the Ministry of Power and the 9th Five Year Plan[12] documents*:**

- Tamil Nadu (MoP), 1991-92: 10,000 pump sets were rectified by replacement of foot-valves in Tamil Nadu, according to the Department of Power Annual Report 1991-92 (MNES-GoI, 1992).

- Punjab (MoP), 1992-98: Annual Reports of the Ministry of Power during the1990s'[13] mention that demonstration/pilot projects on improvement of energy efficiency (through

[10] Energy Conservation Dimension, GEB, Baroda, quoted by Central Institute for Rural Electrification

[11] (p.22, Section 2.28 Energy Conservation – item 5) Department of Power Annual Report 1991-92

[12] 9th FYP, Vol.2 (Section 6.133)

[13] Department of Power Annual Report 1991-92 p.22, (Section 2.28 Energy Conservation – item 5); Annual Report 1996-97, p.20 (Section 5.1.2. Demand-side Energy Conservation: Agricultural Sector); Annual Report '97-98, p.18 (Section 5.1.2. Demand-side Energy Management: Agriculture Sector)

rectification/partial rectification) of 1,350 agricultural pump sets were being implemented in Punjab.

- Haryana (MoP), 1997-98: Likewise, Annual Reports of 1996-97 and 1997-98 mention that demonstration pilot projects on improvement of energy efficiency of 800 agricultural pump sets were being implemented in Haryana (MoP-GoI, 1997; 1998).

- Gujarat (MoP), 1997-98: Similarly, Annual Reports of 1996-97 and 1997-98 mention that demonstration/pilot projects on improvement of energy efficiency of 5,000 agricultural pump sets were being implemented in Gujarat (MoP-GoI, 1997; 1998).

- Andhra Pradesh (MoP), 1996-99: As with Punjab, Haryana and Gujarat, demonstration/pilot projects on improvement of energy efficiency of agricultural pump sets were reported in the Annual Reports of 1996-97 and 1997-98 (MoP-GoI, 1997; 1998). Details included: rectification of 1000 pump sets completed during 1996-97, and replacement of foot valves in 20,000 pump sets and setting up 5 demonstration centres of energy-efficient electric lift irrigation, during 1997-98.

- Andhra Pradesh - Nalgonda dist. (APTRANSCO/DFID) 1998 - 2000, and follow-up study: The first tranche of the funding from DFID (1996-2002) for several improvements in the power sector, included the Nalgonda distribution project (100% funding), to be undertaken by the APSEB and later APTRANSCo. This part of the scheme[14] envisaged conversion of the existing 3 phase low voltage distribution system into single phase high voltage distribution system (HVDS) in the 16 villages covered under Nakrekal 33/11 KV Substation and also installing 3,216 energy-efficient single phase motor pump-sets in place of 3-phase pump-sets (NIRD, 2002).

A sample of 1,000 pump-sets was chosen in order to study the impacts, particularly on the pump-sets and their efficiency (3EC, 2005). Several observations of that study were notable, as listed below.

On the pre-project situation:

- The existing pumps did not conform to IS specifications, were improperly maintained, and the installation workmanship was poor. No power factor correction capacitor was installed. Flexible PVC pipes were commonly used for both suction and delivery sides.
- Pump capacity was supposed to be between 3HP and 5 HP. But, difficulties were faced in noting down the capacity, as almost all the pump-sets were installed and protected within the wells. In some places farmers had locked the pump-houses/starter-boxes and had made provisions for automatic starting of pumps, either by auto-starter or by leaving the starter on continuously during the season, defeating interlocks.
- The average burn-out rate of motors was reported to be about 2.8 per year due to poor power supply and/or absence of maintenance. (The average input voltage to the pump-sets was in the range of 200 – 350V, instead of 415V ±10V).
- Installation of pump-sets according to water levels/head is important for efficiency, but improper selection had been made in many of the cases checked.

With the project changes:

- Due to the project's pump-replacement commitment, farmers demanded replacement on the same day despite knowing that it normally took 3-4 days for rewinding a 3- phase motor on their own. This created operational problems.
- Motor manufacturers are not liable to replace damaged motors even within the guarantee period, if failures occur due to variation of system parameters. This often occurred, for

[14] The project also included SCADA in Hyderabad, 8 new 33/11 kV Substations, 33 kV interlinking in 3 districts, etc.

example, farmers used mud for priming, causing damages to motors. As a goodwill measure, manufacturers initially provided replacements, but when the burnt-out cases increased, they began asking for reimbursement.
- Farmers were apprehensive about replacement / rectification of burnt-out motors after the guarantee period, due to inadequate repair facilities.
- In the case of single-phase HVDS being implemented partly, farmers were availing of 18 hours/day supply (as against the assured 9 hours) but were still non-co-operative regarding the implementation of the project. (Running hours should actually have been reduced with increased efficiency of the pumps).
- Consumers holding unauthorized connections were found in almost all the villages. APTRANSCO agreed to regularize them by collecting Rs 1,000 per HP with the condition that they would purchase their own single-phase pump-sets. Although some of the consumer paid the charges, they demanded that new pump-sets be supplied and installed by APTRANSCO.
- Few consumers would not allow replacement of their existing pump-sets with single - phase pump sets as per their contract-load, because they had been operating higher-rated pump sets.
- Some local mechanics also created problems with the new motors as their livelihood was adversely affected by the farmers' refusing to engage them (because of the one-year warranty period).
- Due to the improved voltage conditions and non-failure of the single-phase transformers the farmers had enjoyed quality power supply, resulting in good crops during the year 1998-99. As a result, some would not allow the removal of the 3-phase transformers (and the two additional wires of LT network) on the plea that they should get back to the 3-phase system.
- Replacement of the existing pumps increased the project cost; moreover, technical training of the contractors and of the local mechanics, and user-training of the farmers would increase the costs further.
- However, efficiency improved with the single-phase pumps: While the weighted average efficiency of the sample (1,000 cases) of 3-phase pump-sets had been 27% (and only 4% of these pumps with above 40% efficiency), the corresponding efficiency of a sample of 157 new single-phase pumps was found to be 36% (and nearly a half the pumps with over 40%). Hence running hours and energy use would be reduced.
- Further the life of the motors was expected to increase, with lower losses and improved supply quality through HVDS.
- Spares/accessories should have been made available locally for better maintenance.
- Technically, equal loading on all three phases of the power transformers at the sub-station was difficult to achieve. Power supply duration could not be controlled / segregated easily, since both the lighting & agricultural loads were on the same feeders.

Till September 2000 when the scheme was closed prematurely, 1,641 pump-sets in 11 villages were replaced (NIRD, 2002).

- Andhra Pradesh - Karimnagar and Chittoor districts (part of WB-Norway AIJ project), intended for Sept.1998 -Aug. 2000: The *Integrated Agricultural Demand-Side Management – Activities Implemented Jointly (AIJ) Pilot Project* (in Chittoor and Karimnagar districts, AP) was intended to improve the efficiency of agricultural pump sets through the following technical measures in an integrated package to generate electricity saving and greenhouse gas emission reductions (APSEB, 1998):
(a) improvement of the distribution efficiency by conversion of the existing low voltage distribution network to high voltage distribution network, (b) reduction in system demand and line losses, as well as improved service to non-agricultural customers, through the use of

automated load control, (providing a VHF master station with computers, load management software and a one way VHF transmitter with a controller at each 33/11 KV substation for control of agricultural pumps), (c) improvements in end-use efficiency by replacement of pump-sets (3-phase to single-phase motors) and associate piping and valves (high resistance foot valves and GI suction and delivery piping, with low resistance foot valves and RPVC piping).

This pilot project was intended for 5,800 pump-sets on 8 feeders in two geographically separate areas (Chittoor and Karimnagar districts) of Andhra Pradesh. The funding for the pilot project was from the World Bank / Norway AIJ Program. (The AIJ component was estimated at US$ 4.61 million, out of a total of $ 5.18 million). The main intended benefits were: for the utility and the country -- reduced energy/power and consequently reduced emissions from power generation, and for the farmers -- avoided costs of replacing (and re-winding) pump sets, better quality of power supply and improved crop yields from adequate irrigation at the required time (Hambleton, *et al*.; APSEB, 1998). *No information on project completion was obtained.*

- Karnataka (Bantwal Taluk Rural Co-op. Society), 2003: Bantwal Rural Electricity Cooperative Society had wanted to take over the distribution of electricity within the Bantwal taluk of Mangalore District. Its efforts were frustrated mainly because the erstwhile KEB did not agree to part with its distribution rights over the area to the society (p.30-31, Section 5.4, Gokak Committee Report, 2003). The society had proposed converting 750 km of low tension lines into high tension lines, replacing 145 out of the 773 distribution transformers that had failed, and replacing all the 13,143 irrigation pump sets. *The actual achievements have not been reported.*

- MP - Western zone, (Kirloskar/Econoler/CIDA), 2004: Between 2002 and 2004, Econoler International initiated and implemented a DSM initiative financed by the Canadian Climate Change Development Fund (CCCDF). During this project, Econoler International developed an approach with the support of Indian partners, testing innovative financial solutions to the inefficiency in the agricultural pumping sector in the state of Madhya Pradesh (Econoler, 2005). It performed a feasibility study for the replacement of inefficient pumps with more efficient ones. This program, run by the utility, was to be tied to the establishment of HVDS for the rural network. Large-scale implementation in this state and others was supposed to be funded by the World Bank.

With funding from the Canadian International Development Agency (CIDA) and consultancy from Econoler, Kirloskar Brothers Ltd. (KBL) implemented a pilot project during 2003-04 in the area served by MPSEB West DisCom (Indore, Ujjain, Dewas). KBL conducted energy audits and then replaced 50 pumps in wells of less than 70 feet depth, with more efficient Kirloskar pumps (KBL, 2004). At the project, most 5 HP pumps were replaced with 3 HP pumps of almost equivalent discharge. Examples of two cases indicate energy saving of 33.8% and 43%. The total connected load reduced from 213 kW to 117 kW; hence 96 kW of power was saved at Rs 6 lakhs (installation only). With an energy saving of 45% per hour of use, the payback was said to be 27 months. KBL estimated that 1,000 MW demand could be avoided through the replacement of 6.25 lakh pump sets (at a cost of Rs 450 crore, subtracting farmers' contribution of 25-25%, and scrap value of existing pumps). Lessons learnt (Tayal, 2010): (i) the starters should have been changed along with the pump sets (which was not done during this project), (ii) financial participation from farmers (even to a small extent) is essential to have their involvement and ownership.

- Gujarat – 5 taluks (GEDA/farmers), 2007-09: During 2007-2009, 6,000 submersible electric pumps were replaced all over the state with more efficient 5HP BEE-star-rated pumps, and GI piping replaced with RPVC piping (GEDA, 2010; Singh, 2009). 67% was paid for by the State Govt., and 33% by the farmers. There are three payment categories: per/kWh used, per HP connected, and co-operative members. Even those who did not have to pay for kWh usage were willing to join the scheme because of the advantage of a new improved pump for a third of the price (GEDA, 2010). The limited hours of power supply also motivated participation in the pump-replacement scheme, as the water requirement could be obtained at about 60% of the earlier duration. Further, pumps were not used for longer periods than required because farmers were aware of the water shortage and the difficulty of re-charge.

- Haryana (HAREDA/farmers), 2000s' (ongoing): There are nearly 4.50 lakh irrigation pump (IP) sets in Haryana; surveys have pointed out that over 80% of the installed IP sets are either "established local brands" or pump sets assembled by dealers or rewinding shops. The efficiency of these pump sets is low, with many of the assembled sets having efficiencies below 25% (pp.67, DHBVN, 2008). The Regulatory Commission had directed the utility to develop "a specific scheme for promotion of DSM programme for Agriculture Pump set consumers involving Energy Service Companies (ESCOs) for carrying out energy audit and replacing the existing inefficient pump sets with energy efficient equipment - - " (HERC, 2003). Provisions under the EC Act concerning agricultural sector strategies include: to issue Govt. regulation on use of energy efficient motors & pump sets; to institute fiscal and financial incentives scheme (capital grant for rectification / replacement / installation of energy efficient motors and pumps); and to implement programmes on the use of energy efficient pump sets (Yadav, 2007).
Since January 2006, there is a program of installing LT MDI meters on every new tube-well connection (as directed by HERC). However, the installation of MDI meters on tube wells is being resisted by the farmers. DHBVN has a comprehensive plan to determine correct rural feeder loss on 11 KV rural feeders; it has issued work orders for third party verification of all the existing farmers to M/s HESL, so that load and distribution losses vis-a vis energy audit can be carried out. (pp.79) There is also a proposal to replace the existing 2 lakh pump sets and motors with BEE-star rated pumps, and subsequently recover the expenditure from the farmers from their reduced energy bills (pp.106, DHBVNL, 2008).
Currently, an agriculture DSM scheme is in operation in Haryana to encourage the installation of efficient pump sets. HAREDA provides 50% of the cost difference between ISI and non-ISI electric motor/pump sets, at Rs 400/- per HP to a maximum of Rs 5,000 per pump set, on the purchase of ISI marked pump sets by the farmers. Till 2008-09, 14,668 new ISI-marked pump sets were installed through this scheme (HAREDA, 2009).

- Karnataka - (WENEXA)[15] pilot pump set project (and related research), Doddaballapur sub-division, Bangalore district 2006-08: The purpose of the pilot project was to assess the impact of installation of energy-efficient pump sets in the absence of improved network voltage, the responsiveness of farmers to energy-efficient pumps and drip irrigation, and potential reduction in energy and water consumption through these measures.

[15] The Water and Energy Nexus Project (WENEXA) Project is under the Indo-US Bilateral Agreement on Energy Conservation and Commercialization, between the Governments of India and the United States, with the Ministry of Power as the Indian Government's authorized nodal agency. The agreement finances various energy conservation initiatives and includes the USAID Distribution Reform Upgrade Management (DRUM) program.

It consisted of replacement of pump-sets in the Doddaballapur sub-division (Feeder lines DF 12 and 13 service areas) of Bangalore Electric Supply Company (BESCOM)[16], Karnataka. An energy audit of a 10% sample of the functioning pump sets showed that 91% operate with efficiency of less than 30%. A network survey determined the voltage profile on both feeder lines which was found to be, in most areas, inadequate to support the quality of power needed for the operation of pump-sets meeting BIS specifications. Fifteen farmers agreed to participate: the pumps in use were replaced with new efficient and correctly sized pumps, in return for the farms shifting at least 1 acre of flood-irrigated crop-land to drip irrigation. (Pump rectification was considered, but because of the depth of groundwater in the area, this option – involving removal and re-insertion of the pump -- is at least as expensive as replacement. Furthermore, there is no way to control rates of discharge which could exacerbate the groundwater overexploitation.) All the original 15 pumps were oversized and only three met BIS specifications. Their average age was two years. Pump motors were generally repaired at least once a year because of severe fluctuations in voltage. All fifteen farms used flood irrigation and planned to shift grapes, mulberry, and sapodilla into drip irrigation.

With pump replacement, the average capacity was reduced by 2 HP, the average number of pump-set stages was increased from 18 to 21, and the average depth where pumps were seated in the wells declined from 156.3m to 152.1m—all factors contributing to reduced energy use. Power consumption and water discharge measurements were taken prior to de-installation of the old pump sets, at installation of the new pump sets, and six-months after operation began. The combined total power demand reduced from 71,782 watts to 51,559 watts immediately after installation, but was measured at 55,334 watts after six-months of operation. Water discharge rates remained essentially unchanged. However, within six months after installation, two of the new pump sets were returned for repair, as a result of frequent voltage fluctuations, and within nine-months, six farms had reported pump burnout. The use of energy efficient, right-sized pump sets, in conjunction with drip irrigation systems resulted in an overall 70% reduction in energy consumption and a 60% reduction in water consumption (calculated using connected load and water discharge discussed above, and self-reported data from farmers on the number of pumping hours per week with the old and new pumps). However, with six of the fifteen newly installed efficient pump sets burning out within a nine-month period, it was clear that without simultaneous investments in network system upgrades, voltage fluctuations would reduce pump set life expectancy well below financially-viable levels (Oza, 2007).

It was estimated that if the savings from the reduction in electricity use through efficient pumping could be sustained and the total cost of the electricity saved exceeded the total installed costs (of the pump over its useful life plus related operation and maintenance), there would be a net economic gain. WENEXA’s conducting an Ag DSM pilot project planned for a site in Karnataka provided them with a learning laboratory that suggested how a workable, financially viable, replicable and sustainable model could be achieved.

For successful implementation of DSM, one should consider that:

- a high quality power distribution system is required, but this may not be financially viable for the distribution utility in the current scenario of “free” agricultural supply;
- the potential electricity conservation is highly location-specific (depending on the existing equipment in the area) and time-specific (midnight savings are worth much less than peaking power), so generalisation is not possible;

[16] Karnataka’s electricity distribution was unbundled between the regional distribution companies BESCOM, HESCOM, GESCOM, and MESCOM in 2002.

- accurate metering and regular data collection are essential; (The accuracy and precision of the measurement of results achieved will vary in direct proportion to the quality and extensiveness of metering. The ideal would be the installation of reliable meters at the consumer level, but that is a controversial issue).
- farmers' co-operation and the participation of all stakeholders (PA Govt., Services Inc., 2008)

- Karnataka - pilot (capacitor) project, Doddaballapur, Bangalore district (BESCOM/DRUM), 2008: As a part of the DRUM initiative in the same Doddaballapur region, installation of 63 capacitor banks of 600 KVAR each, on various 11 kV feeders was proposed (BESCOM, 2008). Switched capacitors were proposed, as the power supply on the rural feeders is staggered according to the State Government policy, and 3-phase power supply is given for a restricted period of 8 to 10 hours per day. Agricultural pump sets – the dominant load on all rural feeders -- work only at these periods, during which reactive power compensation is required. The equipment consists of a set of 3 capacitor units for each phase and an 11KV on-load switch for operating the capacitor bank. A simple pole mounting design was selected and the equipment mounted on single 9 meter RCC poles. Of the existing 56 feeders, 32 were selected for installation of capacitors, 19 of which were rural feeders. Three feeders were selected for the sample study. Data was obtained for the period covering three months prior to the installation of capacitors and six months after commissioning of capacitors. This 9-month (Jan – Oct'08) data study found these to be cost-effective in terms of the reduction of losses on the feeders (with a payback period of 14 months).

- Andhra Pradesh (CWS-Prayas/AEI), 2008-10: This exploratory pilot study was conducted by the Natural Resource Management (NRM) desk of Centre for World Solidarity (CWS), Prayas Energy Group and two local NGOs -- Nava Jyothi and Centre for Rural Operation Programmes Society (CROPS), working in 2 villages (Rama Mohan and Sreekumar, 2009). The study was done at two levels: one at the grass-root level, in those 2 villages (one with 8 open wells and 11 bore wells, the other with 6 open wells and 23 bore-wells), and the other at the State level, in the form of interactions with government and non-governmental agencies. The focus was on the problems faced and solutions to these. Field observations included: metering of key electricity parameters, such as voltage, current, power, power factor at the DTs and selected pump-sets (to understand the quality of power and consumption by pump-sets), and assessment of the use/problems with the new shunt capacitors that had been supplied earlier. Measurement of hydraulic parameters such as discharge, total head etc. was carried out with clearly defined methods, to relate hydraulic power with power consumed by the pump-sets. Field interventions were on power and water use efficiency by making trial interventions (such as installing voltage & current meters, capacitors on pump-sets). There were interactions with various actors at local and State levels and the way forward (including proposed interventions) drawn up on the basis of this collaborative approach of learning.
Lessons learnt at the local level: (i) the importance of intervening at the grass-roots, taking DT as the primary unit and bringing about construction engagement between connected farmers, local organizations, the Distribution Company and the regulators; (ii) using simpler interventions such as installing capacitors on pump-sets; (iii) reducing the length of LT service wires with proper location of LT poles; (iv) metering DTs and monitoring; (v) training DT level groups in day-to-day maintenance that can be implemented within in the existing policy framework. At the macro-level, models to implement energy efficiency need to be evolved within the existing free power policy framework instead of a radical shift to

either metering of all pump-sets or changing to HVD systems, which involves huge investments. Only an Integrated Resource Management approach that involves all the actors would bring sustainable results.

- Karnataka - DT metering and pump replacement, Doddaballapur, Bangalore district (BESCOM/ESCo), 2009: Bangalore Electricity Supply Company (BESCOM) had, in January 2009, announced its RfP for the implementation of an irrigation pump-set project (replacement of the existing with efficient pumps from approved star-rated brands), in the Doddaballapur Sub-division area. Two 11-kV feeder lines Heggedehalli (DF 12) and Melekote (DF 13)[17] with predominantly agricultural consumers, which had earlier been studied during the WENEXA project, were selected for these (WENEXA-II) activities (BESCOM, 2009 a, b). A GIS-based pump set inventory had identified 950 irrigation pump sets connected to the feeder lines, of which only 663 were operational, as the remaining 287 had failed. Because of the groundwater depths here, all the pump sets in use are submersible. The average pump set capacity is 9 HP, and ranges from 3–15 HP. Bidders could be from among energy service companies (ESCos), pump-set manufacturers/suppliers, etc., with a specified minimum turnover and staff. Bidders were provided with information from the USAID/PAConsulting studies (USAID, 2006a; PA Consulting Inc., 2008).

This utility-ESCo model covers a very small component of the distributing utility's base – less than 700 pump sets of BESCOM's 6.2 lakh pump sets. BESCOM has the responsibility of investment in the required infrastructure – conversion of pilot feeders to high voltage distribution system (HVDS) with one distribution transformer (DT) for each pump, installation of capacitor banks, fault passage indicators, and fixing of meters on all DTs and is responsible for maintaining the power supply system. The ESCo is responsible for planning, financing, and implementing the pump replacement (with an 18-month warranty), and also maintenance (Box 1). The value of electricity saving effected (as compared with baseline readings), will be monetized at the pool cost of power purchase; this will be shared during the 10-year contract period between the utility and the ESCo on a pre-agreed basis (MoP and USAID, 2009a).

BESCOM has installed the required HVDS and 665 independent DTs, one for each pump. While it was intended that an energy meter be immediately installed at each DT for accurate baseline energy estimation, there was resistance from some farmers (with eight meters being removed by them) despite pre-project meetings. This necessitated further negotiation and installation in stages (Box 2). The installation of all the required meters was completed on the 3rd April '09, and on the 6th July '09 an agreement was signed between BESCOM and Enzen Global Solutions Private Ltd. (ENZEN) for this project.

Thus far, this is the only utility-ESCo collaboration for demand side management in the agricultural sector. For the successful operation of such agreements, likely challenges to be overcome include farmers' reluctance to participate (particularly with metering of electricity use) and maintenance of the supply system (MoP and USAID, 2009b; Bhatiani and Goyal, 2009). *Data on how many pumps have actually being replaced and the proportion of electricity use that has been reduced have not been obtained thus far.*

- Karnataka - demonstration project (IEI), 2009-10: IEI-Bangalore conducted a field project on energy conservation practices for sustainable agriculture. The purpose was to implement efficient resource use at a sample of 50 small farms -- for improved crop yields that benefit the farmers, and to reduce groundwater extraction, and the need for electricity

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[17] This area falls within the jurisdictions of three *gram panchayats*, Melekote, Heggedehalli, and Tubagere (in the upper catchments of the Arkavathy River of the Kundanvathy watershed).

and chemical fertilizers[18], that benefit the environment and the state. These farms are located in rural *Bengalooru* (now called *Ramanagara*) and *Tumakooru* districts of Karnataka state, and are currently cultivating fruit, vegetables and subsistence grain. 34 farms had some irrigation facility while 16 were rain-fed at project commencement.

The first (*baseline resource-use assessment*) stage of the project, completed before the onset of the rainy season, was devoted to measurement of baseline resource-use. An energy-meter was installed at the pump-set available at each of the 34 irrigated farms; water discharge was also assessed by clocking the time taken to fill a receptacle of a specified volume. During the second (*efficient system implementation*) stage, energy-efficient water extraction and conservative water application equipment were installed. Pertinent to the current study, the 34 existing inefficient/re-wound pumps were replaced with new "starred" efficient pumps providing at least the same water discharge. After pump-replacement, the energy meters used for the baseline assessment were used to meter electricity use; water discharge was also measured at each of the irrigated farms. The rated capacity of most of the new pumps is of 5 HP (or 3.73 kW) and 11 stages. Due to the depth of the water availability and the area to be irrigated, 2 pumps of 6 HP/14 stages and one of 7.5 HP/10 stages were installed. These are providing at least equivalent discharge, at much lower power rating, with the metered connected load reduced by 44%. (However, due to voltage and current fluctuation at various points of the grid system, the connected load actually metered varies over the sample). Each existing pump-owner had to give up his old inefficient pump or pay the re-sale value for it. The 16 rain-fed farms were provided with shared (4 each) first-time access to deep/bore wells fitted with similar new "starred" efficient pumps. A token contribution was taken from each farmer for this irrigation access.

Each of the 50 farms was provided with either or both systems for 1-2 acres, amounting to a total of 71.2 acres, depending on the crops being grown/intended to be grown. The purposes of such micro-irrigation facilities are threefold: enabling farmers to grow crops that would not be possible with conventional irrigation because of the lack of water, increasing the yield/unit area through focused water application, and reducing the labour (for ensuring watering and for fertilizer application that can now be applied with the micro-irrigation system or “fertigation”). Installation of drip systems has been a learning experience all around, and while there have been problems, some agents from the retailers have been very helpful (IEI, 2010).

During the third (*resource use monitoring*) stage, the changes in electricity and water use were quantified and documented, for comparison with the baseline. Metered electricity use fell by 41.5% for a comparable 90-day period. Even with additional electricity for extending irrigation to 17 farms, the aggregate reduction is 31.4%. Similarly, during 3 months each of dry-season irrigation, the water use fell by 60% at the 51.2 acres where micro-irrigation systems were installed at pre-irrigated farms; considering the entire sown area of 111.3 acres at all 50 farms, the reduction in water use is 22% (compared to the baseline), both because 36.6 acres of the crop-land that continues to be watered with the existing large pipelines and the additional irrigation of 23.5 acres of land that were earlier only rain-fed.

Thus far, the lessons learnt: (i) Power supply quality continues to be a problem: 2 pump motors were burnt (twice in one case) during a period of 4 months. (ii) all the farmers have indicated their satisfaction with the new facilities, particularly those rain-fed farms that have access to irrigation for the first time, as they have been able to grow crops during the dry season and with short-term crops (e.g. vegetables) have already earned cash income; (iii) the efficient water-application facilities are more valuable to the farmers than the efficient pump,

[18] The shifts from chemical fertilizers to natural manure, composting and inter-cropping with leguminous plants are not being described here.

but despite the state-subsidy, the farmers' cost component continues to be beyond the poor and the procedures for obtaining it make it difficult to collect[19].

- Maharashtra, Gujarat, Rajasthan, Haryana, Punjab - pump set replacement and system improvement (BEE) proposed/ongoing: The Bureau of Energy Efficiency (BEE) in their schemes for promoting energy efficiency have included agricultural pump-sets in the list of 11 products for efficiency standards and labelling. Pertinent to our study, five states -- Maharashtra, Gujarat, Rajasthan, Haryana, and Punjab – were selected for Phase-1 implementation of agricultural pump DSM projects. Metering of electricity use on selected feeders has been carried out and a specified number of pumps are to be replaced with starred efficient pumps, through ESCOs (BEE, 2009).

Table 2: BEE proposed plans with respect to agricultural pumps

State	
Maharashtra	Energy audit of a total of 2,215 pumps connected to 4 feeders in Mangalvedha sub-division of Solapur District; MSEDCL should convert the selected feeders to HVDS under the R-APDRP scheme by the time our phase-II of the project gets started.
Rajasthan	audit of a total of 2,000 pumps connected to 13 feeders
Gujarat	audit of a total of 1,600 pumps on 6 feeders from 3 circles
Haryana	audit of a total of 2,100 pumps on 14 feeders
Punjab	audit of a total of 2,100 pumps on 6 feeders

Source: *Schemes for Promoting Energy Efficiency in India during the XI Plan* (BEE, 2009)

A.2 Executing efficient water application and use:

- AP, Gujarat, MP, and Rajasthan - groundwater (Aga Khan RSP), '90s' till date: Over 400 structures have been created in the states of Andhra Pradesh, Gujarat, Madhya Pradesh, and Rajasthan, for harvesting and storage of rainwater that is directly lifted for irrigation, or else recharging the groundwater aquifers for more rational extraction through wells (http://www.akdn.org/india_rural.asp). These have led to an additional 4,000 hectares of irrigated croplands in the programme areas, which is being further expanded through the adoption of water saving devices such as drip irrigation and sprinklers.

- AP (Anantpur and Mahbubnagar) & Karnataka (Tumkur) - groundwater (CRIDA,ANGRAU,BAIF/DFID), early 2000s: The purpose of this particular DFID[20] project (R8192) was to identify and promote strategies for sustainable management of natural resources to improve the livelihoods of landless, small and marginal farmers and herders (including women) and to do so by applying existing technical and social research knowledge

[19] Down to Earth (2003) quoting IDE and the Aga Khan Rural Support Programme had reached similar conclusions. The difficulties of installing drip systems included the high initial investment (despite the subsidy) for small farmers, a wide range of product prices from dealers, and a many-step procedure for obtaining the state-subsidy that includes paper-work, delays, and the unscheduled charges (or bribes!) that have to be paid at some stages.

[20] DFID had provided £39 million to the Government of Andhra Pradesh for community-based water management through the Andhra Pradesh Rural Livelihoods Project (June 1999 to December 2007). Technical support, worth a further £147,000, was provided to increase the ability of the Andhra Pradesh state Government irrigation department to effectively manage irrigation systems in the state (Foster, 2009, regarding DFID funding of irrigation in AP).

and skills within an enabling environment. The project was executed by an inter-disciplinary partnership, comprising scientists from CRIDA (Central Research Institute for Dryland Agriculture), the Andhra Pradesh and Karnataka State Agricultural Universities, ICRISAT, and staff members from an NGO BIRD-K (Bharatiya Agro Industries Foundation Institute for Rural Development-Karnataka). Project sites covered 8 villages within 3 semi-arid districts (Mahbubnagar and Anantpur in AP, and Tumkur in Karnataka).

The project had given top priority to augmenting ground water resources and efficient management of limited water resources through participatory natural resource management (NRM). It was found that all the open wells in the project area had dried up and that the farmers had to leave most of their paddy lands fallow for a couple of years due to drought and depletion of the water level in bore-wells. Though the Andhra Pradesh Water, Land and Tree Act (AP–WALTA) had been formulated, its implementation had not yet occurred. Farmers were willing to try something new that required less water and helped conserve more water *in situ*. The focus-group discussions scientists had with the villagers brought out the need for simple technology to augment groundwater and increase water–use efficiency.

Under the project, several interventions were taken up through people's (individual and at community) participation. Only one of the field activities concerns our study – water conservation. This involved: i) Monitoring the water level in bore-wells in different locations of the villages through the use of a simple water level indicator (made by ICRISAT) with the help of project staff, so as to keep track of groundwater fluctuations over time.

ii) Diverting runoff to abandoned / dry open wells for recharging groundwater through people's co-operation.

iii) Contributing towards construction and maintenance of soil and water conservation structures like trench-cum-bunds, percolation ponds, check dams, gully control structures etc., as measures to improve groundwater status in the project area.

Many farmers were initially reluctant to participate in activities that removed some of their land from cultivation. The success of the project in overcoming this reluctance is attributed to its effective use of action learning tools such as a rainfall simulator, exposure visits to other communities having water conservation structures, village *Salaha Samithi* (advisory committee) elected by the villagers to help in the implementation of agreed interventions, and the use of participatory monitoring. A few bore-wells owned by cultivators of different locations were identified. The water table level was measured periodically in the presence of the owners so they would understand how fast the water table was depleting and therefore the need for conservation.

Throughout the project area, farmers reported increased ground water levels in bore-wells even before the good 2005 monsoon and believed that this was due, at least partially, to the water harvesting structures. A few farmers were able to use their farm pond water for life-saving irrigation of nearby vegetables or groundnuts and, by the end of the project two farmers were adapting their ponds for fish farming. Farmers valued both the groundwater recharge and the immediate benefit of the structures on crop productivity (Ramakrishna and Subrahmanyam, 2005; CRIDA and BAIF, 2005; CRIDA, ANGRAU and BAIF, 2005).

- Gujarat state – rainwater harvesting (state and local), 2000 – present: Gujarat has one of the largest community based check-dam programmes in the country. A few villages[21] had

[21] For example, young men of Khopala, a village in water scarce Saurashtra, grew tired of the poor agriculture productivity due to water shortage and decided to solve their problem themselves instead of waiting for a government scheme. They collected money from within the village and from those who had migrated to urban areas. With community labour and native intelligence, they constructed 200 check dams, small and large, in a six month period before the monsoons. The water harvested during monsoon transformed their village economy (Oza, 2007).

been constructing check dams on their own initiative with their own funding and labour, increasing the area under irrigation and improving the availability of drinking water. Word of these successes was spread by local leaders, NGOs and the regional media and thousands of other villages chose the same path. The Government, in tandem with the mood of the masses, developed an easy-to-access scheme called the *Sardar Patel Sahakari Jal Sanchaya Yojana*, wherein the State funded 60% of the cost while the community contributed 40% through labour, material, and cash (it was changed to 80:20 in 2005). The irrigation department was restructured to support this scheme which had very simple design parameters for the dams and simplified application procedures. Since January 2000, over one lakh check dams are reported to have been constructed in the Saurashtra region alone. The average cost is about Rs 5 lakh and storage varies between 0.15 Mm^3 to 0.35 Mm^3 (Oza, 2007). The improved availability of groundwater for irrigation is believed to have helped the earlier dry regions of Saurashtra, Kachchh and North Gujarat perform better than the canal-irrigated areas of central and south Gujarat. For the state as a whole, by December 2008, nearly 5,00,000 structures were created – 1,13,738 check dams, 55,917 *bori bandhs*, 2,40,199 farm ponds, besides 62,532 large and small check dams -- under the supervision of the Water Resources Department of the Government of Gujarat. Arguably, mass-based water harvesting (along with farm power reforms) has helped energise Gujarat's agriculture (Shah, *et al*., 2009). (While Gujarat state had this high profile '*Sardar Patel Sahakari Jal Sanchay Yojana*', other states too have their Government-promoted schemes: for example, Madhya Pradesh has a '*Jalabhishek Yojana*' and Rajasthan has a '*Jalbiradari*' scheme).

- Himachal Pradesh (HP) - Hamirpur district: water harvesting (state and local), 2000-08: While NASA satellite data indicate a foot/year drop in groundwater levels across most parts of Punjab, Haryana, Rajasthan and Delhi, the district of Hamirpur, HP, has in striking contrast shown an increase of over a meter/year (Thakur, 2009). The CGWB's observation well near Baghnalla has shown increases every year from 2000 to 2008. Traditionally, people used *khatris* – burrows dug into pervious rock that allowed the water to filter through to collect in the impervious rock below. About 10 years ago, Hamirpur embarked on "*Jal Samvardhan*" journey focusing on reviving the old and building new check dams. 65 older dams were cleaned with community involvement and developed for fish farming. Around 2,000 small *nallah* bunds, ponds, and check dams, and nearly 1,500 soil conservation and silt retention structures were constructed. The basis for the activities was the paradigm that small catchments collect relatively more water than larger areas, by avoiding losses through evaporation and run-off (as was proven by the Israelis in the Negev desert). Results indicate that drinking water supply schemes have been revived, irrigated croplands have increased, fodder production has increased. (Cropping patterns now include vegetables, rather than only maize and wheat, and the number of small dams with fish rearing has increased from 81 with a yield of 120 tonnes in 2002, to 152 with a yield of 244 tonnes in 2008).

-Tamil Nadu - part of multi-disciplinary project (Hanumannadi basin), 2003-05: As a part of a Water Resources Management project in the Hanumannadi basin Tamil Nadu, (WRM-TN Water Resources Organisation), efficient water conveyance (through piping instead of open channels) and efficient application through drip and sprinkler methods are together estimated to have raised irrigation efficiency from 38.5 to 67.5%. Recharging of wells (through building check dams, channels for surface run-off, etc.) was also being included in the project.

- Gangetic plains - affordable drip systems (and also treadle pumps) (IDEI) 2000s: The International Development Enterprise India (IDEI) has developed an affordable drip

irrigation technology (ADITI) that consists of simple and ready-to-use packaged kits, available in small units. IDEI has three models which it has been promoting in the market: these can be broadly classified as bucket kit, drum kit, and easy drip, and also customized kits. ADITI kits have been designed for a range of crops and are applicable in a wide range of plot sizes varying from 20 square meters to 1000 square meters, with prices ranging from Rs 250 to Rs 4000. Divisible and available in convenient packages which the farmers can install and maintain themselves, the farmers also have the option to begin with one unit and expand later at their convenience. Tests in different regions have confirmed average discharge uniformity of 85%. Till date, IDEI reports that it has facilitated the sale of more than 85,000 drip irrigation kits (http://www.ide-india.org/ide/aditi.shtml).
Also, since 1991, IDEI has been implementing a programme of mass marketing of treadle pumps (with the brand name *Krishak Bandhu*) in Eastern India (earlier called the KB East Programme). An estimated 7,50,000 pumps have been in use (www.ide-india.org/ide/treadlepump.shtml). Treadle pumps are foot-operated water lifting devices that can irrigate small plots of land in areas where the water table is easily reachable (not deeper than 25 feet). They enable small/marginal farmers to increase their earning by extending the cropping period into the dry seasons, and are environmentally-friendly by avoiding the need for fuel. In West Bengal and Orissa, farmers cultivate *boro* or winter crops, while in UP and Bihar farmers use treadle pumps to irrigate vegetable-crops.

- REEEP-financed drip irrigation scheme, 2009: The Renewable Energy and Energy-Efficiency Partnership (REEEP) supplied the seed funding (€100,000) for a project that, in its initial implementation, is enabling 25,000 farmers in India to secure drip irrigation systems worth €15 million in the states of Maharashtra, Gujarat, and Rajasthan. The drip irrigation deal is part of a larger project with Yes Bank to develop (along with Jain Irrigation Systems) a new credit practice to supply financing bundles (each averaging (€594) for small-scale renewable energy and energy efficiency projects in rural and per-urban India.

- National programme on water resources for agriculture (MoWR-GoI) 2004 -05 onwards: A national project for the repair, renovation and restoration of water-bodies directly linked to agriculture was begun in the year 2004-05 by the Ministry of Water Resources, Government of India. Pilot projects in 16 districts have been completed. Details are awaited.
In 2007-08, a Rs 1,800 crore national programme for artificial recharge of groundwater through dug-wells was announced. The scheme envisages recharging 4.45 million wells in seven states groundwater-stressed States – Tamil Nadu, Rajasthan, Andhra Pradesh, Gujarat, Madhya Pradesh, Maharashtra, and Karnataka (MoWR-GoI, 2008). Direct subsidies are intended to be given to farmers – 100% to marginal and small farmers (owning up to 2 ha of land each), and 50% to the others. However, the state departments were expected to give lists of beneficiaries; the progress of the programme has not been reported.

Table 3 summarises the implementation projects described above.

Table 3: List of implementation projects reviewed
(Cases marked with an asterisk * indicate that the project aimed at both pump set and water-application efficiency. In the cases marked with an ampersand &, further details are awaited. Number in brackets [] (in first column), are for sources listed among the references.)

Project: location (implementation /funding) dates	Activities reported	Achievements reported	Post-project evaluation, if any
A.1 Executing pump set efficiency improvements:			
Gujarat - pilot projects (GEB/REC) - 1978-88 [16], [86]	For (i)-(iii), between '78-85: (i) Replacement of suction pipes and foot-valves by GEB; (ii) Complete replacement of pumps, piping and foot-valves by GEB; (iii) Replacement of mono-block pumps of appropriate capacity (using 3 - 7.5HP instead of 5 - 20 HP, respectively) and demonstration to farmers in different Circles; (iv) Between '86-88: 488 cases of complete rectification by Gujarat State authorities and Kirloskar Brothers Ltd., Dewas	(i) 1,108 completed --estimated 21.7% energy conservation; (ii) 8 completed -- estimated 51% energy conservation; (iii) demonstration of pump replacements at 16 farms, witnessed by about 700 farmers; initial energy saving 24 - 69%; the new pumps had lower ampere loading for comparable or greater water discharge; direct demand reduction from 1.2 - 6 kW each. (iv) aggregate energy reduction of 53% at the time of rectification;	
Tamil Nadu - (TNEB/REC) pump set rectification (with sample monitoring) - 1980s'[16]	Replacement of suction and delivery piping (GI to RPVC) and foot-valves, at pump sets of 5 HP rating	3,125 completed;	500 cases evaluated by NPC: while system efficiency and water discharge improved, energy consumption increased by 11.7% due to the increased water flow; energy saving estimated at 19%.

Gujarat - (GEB/REC) pump set rectification (with sample monitoring) - 1985-86 [16], [31]	(i) Replacement of pumps and foot-valves; (ii) Replacement of suction and delivery piping (GI by RPVC) and foot-valves	(i) 3,128 cases - replacing (5 HP) pumps and FFVs, estimated 34.7% energy conservation; (ii) 9,782 cases -piping and FFVs replaced; estimated 30% energy conservation	500 cases evaluated by Power Utilisation Consultancy: 48% reduction in energy required per unit of water discharged; water discharge increased by 59.3%; however, energy consumption increased by about 5.6 percent, and the increase in all the 3100 pump sets was about 10.8 percent.
Madhya Pradesh - (MPEB/REC) pump set rectification (with sample monitoring) - 1980s'[16]	Replacement of suction and delivery piping (GI to RPVC) and foot-valves	3,125 sets completed;	527 cases evaluated by ICM; water discharge improved by 57.5%, energy consumption increased by 12% due to the increased water flow; overall system efficiency improved from 23% to 33%.
Andhra Pradesh - (APSEB/REC) pump set - 2nd phase (with sample monitoring) – 1985-86[16]	Replacement of suction and delivery piping (GI to RPVC) and foot-valves	2,500 sets completed in the 2nd phase (1st phase data not available);	505 cases evaluated by NPC: system efficiency and water discharge improved considerably, energy consumption increased by 2% due to the increased water flow; but energy saving estimated as 26%.
Andhra Pradesh - Chittoor dist., DFID, 1987-90	Details not available		

&[119]			
Gujarat pump replacement (ICM/MoE) – 1988 – 94 [102], [119], [34]	Complete replacement of about 500 mono-block pumps, by Institute of Co-operative Management, Ahmedabad		
Gujarat pump replacement and/or retrofitting (GEB/MoE) – 1988-94 [16], [62], [31]	There were 4 types of replacements: FFVs only, FFVs and RPVC piping (suction and delivery), 5-HP pump-sets only, and all of these. There were relatively few of the last two types.	Over 20,000 replacements are reported to have taken place.	While there was no metering by the utility, the installation contractors measured the flow with portable meters.
Maharashtra (MSEB/MEDA) - 1989-94 [60]	An average of 350 to 400 pump sets were rectified each year through measures such as piping & foot-valve replacement	A total of 1,750 - 2,000 replacements should have been completed; no details of monitoring are available. The IIEC-MEDA study of 2005 recommends large-scale (100,000) pump rewinding/replacement, quoting these earlier efforts, and proposes funding from MSEB through avoided cost of supply and from MEDA for capacity-building.	
Andhra Pradesh - Warrangal dist., (JBIC), 1993-96 &[119]	Details not available		

Tamil Nadu (MoP) – 1991-92 [62]	10,000 pump sets were intended for rectification by replacement of foot-valves		
Punjab (MoP) - 1997-98 [66]	Demonstration/pilot projects on rectification of 1,350 pump sets		
Haryana (MoP) - 1997-98 [66]	Rectification of 800 pump sets		
Gujarat (MoP) - 1997-98 [66]	Rectification of 5,000 pump sets		
Andhra Pradesh (MoP) – 1996-99 [66]	Rectification of 1000 pump sets completed during 1996-97, and replacement of foot valves in 20,000 pump sets and setting up 5 demonstration centres of energy efficient electric lift irrigation, during 1997-98		

Andhra Pradesh - Nalgonda dist. (APTRANSCO /DFID) 1998 - 2000, and follow-up study [79], [1], [122]	In this part of the project: for 16 villages covered under Nakerkal 33/11 KV Substation: conversion of the existing 3 phase low voltage distribution system into single phase HVDS and installing 3,216 single phase motor pump-sets in place of 3-phase pump-sets.	Till September 2002, when the scheme ended, 1,641 pump-sets in 11 villages were replaced.	3EC evaluated the project: while the average efficiency of pumping improved from 27% to 36%, there were several operational problems due to which the scheme was prematurely ended.
Andhra Pradesh - Karimnagar and Chittoor districts (APSEB/WB-Norway-AIJ), intended for Sept.1998 -Aug. 2000 [6], [36]	Integrated package for electricity saving and GHG emission reductions through: (a) distribution efficiency by conversion to HVD network, (b) reduction in system demand and line losses, through load control, etc. (c) replacement of pump-sets (3-phase to single-phase motors) and associated piping and valves		
Karnataka - Bantwal taluk (Co-op society) - 2003 [&] [33]	Replace all the inefficient 13,143 irrigation pump sets		The society did not get distribution rights in the area, hence it is unlikely that the project was successful.
MP – Western zone, (Kirloskar/Econoler/CIDA funded) – 2004 [50], [27], [128]	50 pumps replaced with efficient pumps; (the longer-term goal was to replace 30,000 pumps in all 3 zones – West, Central and East – of MPSEB).	All the pumps were in shallow wells (at best 70 feet). Most 5 HP pumps were replaced with 3 HP pumps of almost equivalent discharge. Examples of two cases indicate energy saving of 33.8% and 43%. The total connected load reduced from 213 kW to 117 kW; hence 96 kW of power was saved at Rs 6 lakhs (installation only). With an energy saving of 45% per hour of use, the payback was said to be 27 months.	KBL estimated avoiding 1,000 MW demand through the replacement of 6.25 lakh pump sets, at a cost of Rs 450 crores (subtracting farmers' contribution of 25-25% and scrap value of existing pumps). Econoler had performed feasibility studies during 2002-

			05 for the DSM program; this program, run by the utility, would be tied to the establishment of HVDS for the rural network.
Gujarat - 5 taluks (GEDA/farmers) - 2007-09[31]	Replacement of existing submersible pumps with 5 HP efficient pumps	about 6,000 pumps replaced	Saving has occurred through the use of more efficient (BEE-certified) pumps, and of appropriate capacity.
Haryana (HAREDA /farmers) – 2000s' [38], [142], [23]	Scheme of providing 50% of the cost difference between ISI and non ISI electric motor/pump sets @ Rs. 400/- per HP to a maximum of Rs. 5,000 per pump set, on the purchase of ISI marked pump sets by the farmers; also DHBVNL's scheme of installing LT MDI meters on every new tube well connection (in place since Jan'06) to get information about agricultural consumption, load pattern & rural feeder losses, and plug the loophole in energy accounting.		Till 2008-09, 14,668 ISI-marked pump sets were installed which resulted in saving of 46.6 MU (38.8 MW) of electricity. -- The method of arriving at the electricity saving through pump set replacement has not been specified.

Karnataka - pilot (pump set) project, Doddaballapur sub-division, Bangalore district (WENEXA, USAID) – 2006-08 *[72], [84]	Energy audit 10% of the functioning pump sets showed 91% operate with efficiency of less than 30%; voltage profile on both feeders was found inadequate to support the quality of power needed for the operating BIS pumps. 15 farmers agreed to participate: the pumps in use were replaced with new efficient and correctly sized pumps, in return for the farms shifting at least 1 acre of flood-irrigated crop-land to drip irrigation.	All the original 15 pumps were oversized and only three met BIS specifications. Their average age was two years. Pump motors were generally repaired at least once a year because of severe fluctuations in voltage.	Average pump capacity was reduced by 2 HP, the average number of pump set stages increased from 18 to 21, and the average depth where pumps were seated in the wells declined from 156.3m to 152.1m; combined power demand reduced from 71,782 watts to 51,559 watts immediately after installation, but was 55,334 watts after six-months of operation. Water discharge rates remained essentially unchanged. Within 6 months, 2 new pump sets were returned for repair as a result of frequent voltage fluctuations and within 9-months of installation 6 farms were reported burnout. The use of energy efficient, right-sized pump sets, & drip irrigation systems resulted in an overall 70% reduction in energy and a 60% reduction in water consumption (calculated using connected load and water discharge, and self-reporting data from farmers on pumping hours/week).

Karnataka - pilot (capacitor) project, Doddaballapur, Bangalore district (BESCOM/DRUM -MoP/USAID) – 2008 [8]	Of the existing 56 feeders 32 feeders were selected for installation of capacitors, 19 of which are rural feeders, one industrial, and one catering to combined urban and rural loads; 63 capacitor banks of 600 KVAR each were to be installed.	The installation was completed in 3 months; three feeders were selected for conducting the sample study -- the 9-month (Jan – Oct'08) data study found these to be cost-effective in terms of the reduction of losses.	
Andhra Pradesh (CWS-Prayas/AEI) - 2008-09 [92], [122]	(i) Field work in 2 villages (one with 8 open wells and 11 bore wells, the other with 6 open wells and 23 bore wells); (ii) "thinking through" approach for future plans	Field observations included: metering of key electricity parameters, such as voltage, current, power, power factor at the DTs and selected pump-sets (to understand the quality of power and consumption by pump-sets), and assessment of the use/problems with the new shunt capacitors that had been supplied earlier. Measurement of hydraulic parameters such as discharge, total head etc. was carried out with clearly defined methods, to relate hydraulic power with power consumed by the pump-set. Field interventions were on power and water use efficiency by making trial interventions (such as installing voltage & current meters, capacitors on pump-sets).	

Karnataka - DT metering and pump replacement, Doddaballapur, Bangalore district (BESCOM/ESCo) – 2009 [9], [10], [67], [68], [133], [83], [11]	This public-private project, being adopted for the first time, is fairly small in comparison with the distributing utility's base – less than 700 pump sets of BESCOM's 6.2 lakh pump sets would be included. BESCOM has the responsibility of investment in the required infrastructure – conversion of pilot feeders to high voltage distribution system (HVDS) with one distribution transformer (DT) for each pump, installation of capacitor banks, fault passage indicators, and fixing of meters on all DTs and is responsible for maintaining the power supply system. The ESCo is responsible for planning, financing, and implementing the pump replacement (with an 18-month warranty), and also maintenance. The value of electricity saving effected (as compared with baseline readings), will be monetized at the pool cost of power purchase; this will be shared during the 10-year contract period between the utility and the ESCo on a pre-agreed basis. Bidders could be from among energy service companies (ESCo)s, pump-set manufacturers, suppliers, etc., with a specified minimum turnover and staff.	BESCOM has installed the required HVDS and 665 independent DTs, one for each pump. While it was intended that an energy meter be immediately installed at each DT for accurate baseline energy estimation, there was resistance from some farmers, necessitating further negotiation and installation in stages. The installation of all the required meters was completed on the 3rd April '09, and on the 6th July '09 an agreement was signed between BESCOM and Enzen Global Solutions Private Ltd. (ENZEN). This is the only utility-ESCo collaboration for demand side management in the agricultural sector. For the successful operation of such agreements, likely challenges to be overcome include farmers' reluctance to participate (particularly with metering of electricity use) and maintenance of the supply system.	
Karnataka - demonstration project (IEI) * 2009-10 [42]	At the 50 selected farms in the 2 districts: (i) An energy-meter was installed at each of the 34 deep-well irrigated farms; thereafter the pumps were replaced with new "starred" efficient pumps providing at least the same water discharge and the power and energy saving measured. The rated capacity of most	Results for electricity and water use: Metered electricity use fell by 41.5% for existing irrigated farms; including the extension of irrigation to 17 farms, the aggregate reduction is 31.4%. Similarly, during 3 months each of dry-season irrigation, water use fell by 60% at the 51.2 acres where micro-irrigation systems were installed at	

	of the new pumps is of 5 HP (or 3.73 kW) and 11 stages. Due to the depth of the water availability and the area to be irrigated, 2 pumps of 6 HP/14 stages and one of 7.5 HP/10 stages were installed. However, due to voltage and current fluctuation at various points of the grid system, the connected load actually metered varies over the sample. Each existing pump-owner had to give up his old inefficient pump or pay the re-sale value for it;(ii) The 16 rain-fed farms were provided with shared (4 each) access to 4 deep/bore wells fitted with similar new "starred" efficient pumps. (iii) The water discharge was measured at each of the irrigated farms before and after pump-replacement. During the project, every farm is being provided with 1-2 acres of drip/sprinkler facilities, depending on the crops being grown/intended to be grown; the water saving will be estimated, depending on the hours of use reported.	pre-irrigated farms; considering the entire sown area of 111.3 acres at all 50 farms, the reduction in water use is 22%, (because 36.6 acres of crop-land continues to be watered with the existing large pipelines, 23.5 acres of additional is being irrigated).	
Maharashtra, Gujarat, Rajasthan, Haryana, Punjab - pump set replacement and system improvement (BEE) – ongoing [7]	Phase I: Metering of electricity use on selected feeders has been carried out and a specified number of pumps are to be replaced with starred efficient pumps, through ESCOs	Maharashtra: Energy audit of a total of 2,215 pumps connected to 4 feeders in Mangalvedha sub-division of Solapur District; Rajasthan: audit of a total of 2,000 pumps connected to 13 feeders; Gujarat: audit of a total of 1,600 pumps on 6 feeders from 3 circles; Haryana: audit of a total of 2,100 pumps on 14 feeders; Punjab: audit of a total of 2,100 pumps on 6 feeders.	

A.2 Executing efficient water application and use:			
AP, Gujarat, MP, Rajasthan - groundwater (Aga Khan RSP) - '90s' – present [3]	Over 400 structures created for harvesting and storage of rainwater that is directly lifted for irrigation, or recharging the groundwater aquifers for more rational extraction through wells.	An additional 4,000 hectares of irrigated croplands in the programme areas, which is being further expanded through the adoption of water saving devices such as drip irrigation and sprinklers;	
AP & Karnataka (CRIDA, ANGRAU, BAIF/DFID NRS R8192) - early 2000s[18], [19], [94]	The project purposes were wider but those activities pertinent to this study are: augmenting ground water resources and efficient water-resource management through participatory NRM	These interventions were supposed to have been taken up through people's (individual and community) participation: i) monitoring the water level in bore-wells in different locations, to keep track of fluctuations, through a simple water level indicator (made by ICRISAT) with the help of project staff ; (ii) diverting runoff to abandoned / dry open wells for recharging groundwater through people's co-operation; (iii) construction and maintenance of soil and water conservation structures like trench-cum-bunds, check dams, etc., as measures to improve groundwater status; (iv) shifting to less water-intensive crops. Village *Salaha Samithi* were formed through selection of a few leaders by villagers themselves to help in the implementation of agreed interventions.	In the project areas, farmers reported increased ground water levels in (bore) wells even before the good 2005 monsoon and believed that this was due, at least partially, to the water harvesting structures. A few farmers were able to use their farm pond water for life-saving irrigation of nearby vegetables or groundnuts and by the end of the project two farmers were adapting their ponds for fish farming. Farmers valued both the groundwater recharge and the immediate benefit of the structures on crop productivity.

Gujarat state: rainwater harvesting (State Govt. and local people) - 2000 – present[82], [113]	Rain-water harvesting and groundwater recharge activities;	While the scheme was most successful in Saurashtra and Kachchh (where over a lakh structures were constructed), in the state as a whole, by December 2008, nearly 5,00,000 structures were created – 1,13,738 check dams, 55,917 *bori bandhs*, 2,40,199 farm ponds, besides 62,532 large and small check dams constructed.	1
Himachal Pradesh - Hamirpur district: water harvesting (State Govt., and local people) - 2000-08 [131]	"Jal Samvardhan" -- focusing on water-harvesting, reviving the old and building new check dams.	65 older dams were cleaned with community involvement and developed for fish farming. Around 2,000 small *nallah* bunds, ponds, and check dams, and nearly 1,500 soil conservation and silt retention structures were constructed.	Drinking water supply schemes have been revived, irrigated croplands have increased, fodder production has increased, cropping patterns now include vegetables (rather than only maize and wheat), and the number of small dams with fish rearing has increased from 81 with a yield of 120 tonnes in 2002, to 152 with a yield of 244 tonnes in 2008.
Tamil Nadu - part of multi-disciplinary Hanumannadi basin project (TN Govt.) – 2003-05 *[138]	Efficient water conveyance (through piping instead of open channels) and efficient application through drip and sprinkler methods that, together, are estimated to have raised irrigation efficiency from 38.5 to 67.5%. Recharging of wells through building check dams, channels for surface run-off, etc. was also being included in the project.		

Genetic plains - affordable drip systems (and also treadle pumps) (IDEI-commercial) – 2000s *[40]	Affordable drip irrigation technologies (ADITI) are simple and ready-to-use packaged kits -- "bucket kit", "drum kit", "easy drip" and "customized kits". -- designed for a range of crops and are applicable in a wide range of plot sizes varying from 20 square meters to 1000 square meters, with prices ranging from Rs 250 to Rs 4000. Divisible and available in convenient packages (in the form of kits), the farmers can install and maintain them themselves, & have the option to begin with one unit and expand later;	IDEI has suitably adapted this technology to meet the needs of poor farm families by making the technology simpler and affordable. Till date, IDEI reports that it has facilitated the sale of more than 85,000 drip irrigation kits. Promotional efforts are being carried out for generating awareness. With funding from USAID, IDEI has started implementing a project on commercializing micro irrigation, tailored to the needs of the poor. 'AMIT (Affordable Micro-irrigation Technology) Plus Programme' will develop and build the capacity of networks of providers; after developing networks, IDE staff will exit from an area, monitor results and move on to another area.	
Maharashtra, Rajasthan, Gujarat Drip financing (REEEP) – 2009[100]	Enabling 25,000 farmers in India to secure drip irrigation systems worth €15 million, through credit packages from YES Bank/Jain Irrigation		
National programme on water resources for agriculture (MoWR-GoI) – 2004 -05 onwards [71]	A national project for the repair, renovation and restoration of water-bodies directly linked to agriculture. In 2007-08, a national programme for artificial recharge of groundwater through dug-wells was announced. Recharging 4.45 million wells in seven states groundwater-stressed States – Tamil Nadu, Rajasthan, Andhra Pradesh, Gujarat, Madhya Pradesh, Maharashtra, and Karnataka is envisaged (MoWR-GoI, 2008).	Pilot projects in 16 districts were completed. Direct subsidies are intended to be given to farmers – 100% to marginal and small farmers (owning up to 2 ha of land each), and 50% to the others, via NABARD. However, the state departments were expected to first provide lists of beneficiaries. Reports on the progress of the programme are not available.	

***B. Studies**:*

There have been numerous studies that have dealt with energy conservation in the agricultural sector; the following are being described in so far as they consider improving the efficiency with which groundwater is used for irrigation in India – (i) the efficiency of water extraction and the costs of implementing such activities, (ii) groundwater re-charge and efficient water-application, (iii) system and resource management and pricing issues.

- Pump set CCE (and economic implication of utility's implementation) - Karnataka (IISc/IEI), 1990, 1991, 1993: As part of the estimation of the costs of generated and saved electricity in Karnataka, the cost per kWh and per kW avoided through irrigation pump set retrofits had been calculated. The retrofits included replacing the existing foot-valves (FV) with friction-less FV and the GI pipes with HDPE piping. In addition to the estimates of electricity use avoided (or cost of conserved electricity, CCE), the potential for energy conservation based on the irrigation pumps in use in Karnataka at that time was also estimated (Reddy *et al*., 1990; 1991). The purpose was to evaluate measures of bridging the demand-supply gap in alternative costing scenarios, for drawing up alternative scenarios and deriving an appropriate development-focused end-use oriented approach. Later, the possibility of the utility's implementing such replacement and financing it through the revenue from alternative sales of saved electricity to other (higher-tariff) sectors was evaluated (Reddy and D'Sa, 1993).

- Assessment of irrigation pump set efficiency - Colleges of Agriculture (Karnataka and AP), 1994:[22] Field studies on the performance of irrigation pump sets, possible ways to improve their efficiency, and the impacts of these measures on electricity use, had been undertaken by Colleges of Agriculture in Andhra Pradesh, Karnataka and Haryana.

- **Efficiency improvement measures – Andhra Pradesh** - A sample of 87 diesel- and 87 submersible pump sets in Kurnool district, Andhra Pradesh, was tested for efficiency and the reasons for inefficiency identified (Varshney, *et al*., 1990s). The efficiency of diesel pump sets was found to be 4.78% to 13.04% in direct-coupled and 5.6% to 11.29% in belt-driven pumps, and from 27% to 41% at electrically-driven submersible pumps. The efficiency-improvement measures identified were: (i) low-friction foot-valves (available in 3 different sizes), (ii) RPVC instead of GI piping, that could increase discharge by 15-30%, and reduce the energy requirement by 30%.

- **Reasons for inefficiency – Karnataka** -A study was conducted on 110 pump sets in two taluks (Honnali and Channagiri) of Shimoga district, Karnataka, to estimate the operational efficiency of the pump sets and farmers' awareness of pump efficiency (Shashidhar *et al*., 1990s). Most pump sets were found to be operating at low efficiency and a majority of the farmers were not aware of the efficiency levels despite purchasing the pump sets form the SEB-recommended agents. When reasons for inefficiency were studied, it was found that: 97% experienced piping friction losses, 92% had inefficient foot valve, 60% had poor maintenance and around 40% had improper alignment. Other factors such as fittings losses, poor foundation, use of sharp bends and leaky suction were also present.

- **Reasons for inefficiency and alternatives for efficiency improvement - AP** - A field survey was carried out in Andhra Pradesh, with a sample of 5,625 pump sets in Warangal, 436 in Karimnagar, and 426 in Chittoor districts (Reddy *et al*., 1994). Various reasons such as improper selection of the size of prime movers, inefficient pumps, incorrectly-sized

[22] These and others were presented at "National Seminar on Conservation of Energy in Agricultural Pumping Systems", 28-29th December. Only typed-scripts of these reports are available.

suction and delivery piping, poor condition of wells, clogging of foot-valves, and incorrect installation procedures, were identified as causes for low efficiency. It was estimated that 21% - 23% of energy could be saved by partial rectifications such as suction line and foot-valve replacement. This saving could be increased to 30% - 35%, by changing the delivery lines, to 40% - 45%, by pump replacement alone, and to the extent of 60%, by changing the complete system. For periodic care and maintenance of the pumping systems, it was suggested that a separate division be created, headed by an agriculture engineer, with supporting staff from ITI and the Electricity Board.

- Assessing energy conservation through improved irrigation practices – Haryana - A field study was undertaken to examine the on-farm efficiency of pump sets and irrigation management practices on 25 fields in Karnal and Kurukshetra districts of Haryana (Singh, et al., 1994). The study included topography of the fields, crop geometry, soil type, available discharge of wells, and model simulation of the recommended irrigation depth. The study showed that improper selection of pumps and prime mover, use of locally made foot-valves, and excessive suction head were the primary factors responsible for lower efficiency. In the case of irrigation practices at wheat, paddy and sugarcane fields, land grading and water application methods were not as recommended, resulting in low irrigation efficiency. The study concluded that about 18% of the water requirement could be saved through shifting from the border-strip to the check and furrow methods of irrigation, and over 30% of the energy could be saved through efficient pumping and reduced water use.

Studies of improved pumps and accessories, 1994:

- Improved motor systems – PSG, Coimbatore (TN): This paper discussed specially-designed induction motors for conserving energy through agricultural pumping systems (Suresh Babu, *et al*., 1994). The motor would have to exhibit constant efficiency over ranges of voltage and load, and be able to withstand the temperature rise due to voltage fluctuation. A variable speed drive with an additional power factor controller has been suggested. Data were obtained from tests on Kirloskar motors. The analysis indicated that the additional cost of improved systems could be recovered through energy saving.

- Design and evaluation of efficient foot valves - 2 cases: A foot-valve was developed at the College of Engineering, Bapatla (AP) as an improvement on the existing foot-valves in the market as also on the earlier version developed at the same institution. Details of construction and assessment of performance were given (Srinivasulu, *et al*., 1994). An assessment of two improved types of foot-valves, in the experimental stage was also carried out in Coimbatore (Krishnamurthy, 1994).

- Correct pipe fittings – GB Pant University of Agriculture and Technology – Laboratory and field studies of the relative performance of centrifugal pumps -- with standard pipe fittings vis-à-vis the fittings in use, indicated that the use of standard fittings could increase discharge by 26% - 60%, and simultaneously reduce the energy use per unit of discharge by 20% to 46% (Sharma, *et al*., 1994).

- Improper matching of wells and pump sets – REC Case study of tube-wells in Bharatpur (Rajasthan), 1994: This paper discusses factors affecting the efficiency of pumping water from wells (Satyanarayana, 1994). It focuses on the estimation of well efficiency losses, and the selection of appropriately-sized pumps, depending on the required and optimal discharge rates. Data from Rara village, Bharatpur district, Rajasthan has been used for illustration.

- Reducing line losses through LT capacitors (MSEB), 1994: A scheme of leasing LT capacitors for agricultural feeders was developed by the then Maharashtra State Electricity

Board (Sonavane and Rathi - MSEB, 1994). LT switched capacitors were being installed at the secondary of distribution transformers (DTs), on rural feeders with predominantly agricultural loads. This would reduce the reactive loading on the DTs, thereby reducing the losses, and as the overloading due to the reactive load would be lower, there would be improvement in the voltage and a reduction in DT failure. LT capacitors could be leased out, if a power factor of 0.9 is maintained. The paper discusses the advantages of the scheme that was being installed during 1994-95 at 15,000 distribution transformers in Maharashtra.

- Pump set CCE - Maharashtra (LBL), 2005: For the agricultural sector in Maharashtra, previous studies have been used to estimate the const of conserved energy (CCE), to reduce the electricity shortage (Phadke *et al*., 2005). The financial implications have been considered in three options: replacing the existing pumps with efficient new pumps when replacement is due, only retrofitting (changing the piping and FV), and immediately replacing the existing pumps with efficient alternatives.

- Maharashtra - state use and all-India pump and component standards (Prayas), 1995: The Prayas team studied the component-wise efficiency improvements effected on irrigation pump sets through earlier studies, to assess the importance of component changes and the prevailing standards, as well as to analyse the irrigation pump set electricity use in Maharashtra. They concluded that the BIS norms needed improvement, in particular: upward revision of the efficiency norms, accounting of the nature of the head-efficiency curve, good suction characteristics, and appropriate flange sizes (Sant and Dixit, 1995).

- Tamil Nadu – one village pump set study, 1997-98: An attempt has been made in the paper to study the electricity use pattern in Tamil Nadu among different categories of farmers and its implications for the efficiency issues. For this purpose, data have been collected from 64 electrified pump-set owning farmers in a bore-well dominated village of Pudukottai district in Tamil Nadu, pertaining to the year 1997-98. The study has analysed the farm-wise data on pump set installation, irrigation intensity, cropping pattern, productivity, electricity use and sale of water. As the cost of electricity is not known in the absence of electricity meter reading (due to 100 per cent subsidy), the cost has been estimated for different categories of farmers (Iyyampillai & Abdallah, 1998).

- UP, Bihar, Orissa – treadle pumps, early 2000s': The TERI team surveyed 144 households in UP, Bihar and Orissa, regarding the performance of treadle pumps (in areas where surface irrigation is possible). The sample size was 54 households in Bihar, 51 households in Uttar Pradesh and 39 households in Orissa. Such pumps are low-speed, foot-operated reciprocating pumps, which can be operated by standing on two bamboo levers and depressing them alternately using the feet. They are able to provide a discharge of 1-2 litres per second. The study indicates the suitability of treadle pumps for water-lifting at small/marginal farms because of convenience of operation and efficiency (as compared with diesel pumps) (Srinivas and Jalajakshi, 2004).

- All India - electrical device efficiency (LBL) early 2000s': The LBL team considered four types of electrical device, among which are a prototype agricultural motor of 5 HP (˜ 3.8 kW). An estimated 2% improvement in the efficiency (from 83% to 85%, at 75% rated capacity) of each motor could result in an annual conservation of 117 kWh. However, the corresponding price increase of 15% would not be acceptable to farmers, though preferable for the utility, as the cost/kWh of conserved electricity would be less than that of delivery (McNeil *et al*., 2008).

- Gangetic basin – diesel pumps (IDE), 2008: Within the IDE Micro diesel R&D program, a market study has been conducted in the Gangetic basin in India and Nepal on the irrigation practices of smallholder farmers using small diesel or petrol pump-sets or treadle pumps. The specific aim of the study was to collect pump use and performance data from the field by measuring output of the pumps as well as fuel efficiency. Also user data on irrigation practices was collected using semi-structured interviews. The information from this study would help in assessing the specific requirements a small engine driven pump-set has to meet, to suit the irrigation needs of a smallholder farmer. The study will feed into the next phases of the micro diesel development within the IDE project (IDE (USA and Nepal) and Center for the Development of Human Initiatives, (Jalpaiguri, West Bengal), 2008).

- Haryana and AP (all-India estimation) - pumping to GHG (Development First), early 2000s': The part of this Development First study that is pertinent to our report is the Food-Water-Energy-GHG Nexus (Development First, 2003). The study attempts to quantify the correlation between the changes in the water table and global warming, through quantification of the energy use in ground water pumping for irrigation, tracked to the amount of GHG emitted by burning of fossil fuels for electricity generation (ignoring the extraction and transport components). Haryana and Andhra Pradesh are selected because ground water pumping is predominant, and the corresponding co-efficients for India are estimated as a simple average. Important results include: Under the present conditions, every meter fall in the ground water table will mean an increase of 4.374% in GHG emission for Haryana and 6% for Andhra Pradesh considering all other variables remaining constant. Also, for every percentage increase in efficiency, the fall in GHG will be 0.9 % for pumps and 0.85% for motors. The study shows that three important modifications can improve the efficiency of the ground water pumping:- decreasing the discharge velocity, improving the pump efficiency by better selection & design, and improving the motor efficiency by better selection & design.

- Gujarat - energy and groundwater demand management (IWMI), 2003: The paper presents a theoretical model to analyze farmers' response to changes in power tariff and water allocation regimes *vis à vis* energy and groundwater use. It validates the model by analyzing water productivity in groundwater irrigation under different electricity pricing structures and water allocation regimes. Data was obtained from 81 farms (30 well owners who are also sellers, 10 water-purchasers, 20 sharecroppers, and 21 tube-well co-operative members) in Banaskantha district, North Gujarat. Important conclusions: The overall (gross and net) water productivity exclusive of irrigation cost is the highest for shareholders of tube-well cooperatives, followed by water buyers, and lowest for well owners who are also water sellers. This means that farmers try to achieve highest economic efficiencies in water use when water is priced on volumetric basis and allocation is rationed. However, shareholders achieve higher returns than insecure water-buyers, because the former know their water quota and can "budget" their water-use accordingly whereas the latter are at the mercy of the sellers; hence, net return from crop production is less elastic to the cost of irrigation than the reliability of irrigation (Dinesh Kumar, 2003).

- Karnataka - Doddaballapur sub-division, Bangalore district (WENEXA II), 2004-08: This study on water & energy conservation and crop changes was carried out in the Doddaballapur sub-division (Feeder lines DF 12 and 13 service area) of Bangalore Electric

Supply Company (BESCOM)[23], Karnataka, under the Water and Energy Nexus Project (WENEXA) project that supports USAID's Strategic Objective of "Improved Access to Clean Energy and Water in Selected States" (USAID, 2006).

Pertinent to our study, the team collected site-based data (on cropping, energy use, etc.[24]), and then focused on irrigation pump-set efficiency, shifts to less water intensive crops, efficient irrigation techniques and tillage practices (e.g. shifting from flood to drip irrigation)[25], and the financing and management required to facilitate the adoption of these. As the groundwater in this area was found to be over-exploited (with the average water depth declining from 214 to 615 feet between 1971 and 2004), no further expansion of groundwater use was recommended. Instead, shifting at least 53% of the net sown area irrigated through bore-wells to drip irrigation, and growing crops that would yield the highest income while saving water and energy, were recommended. Three options for financing efficient water-application (through drip installations) were assessed: 1) Self-financing; 2) Financing through Women's Self Help Groups; and 3) Financing through the utility under a performance contract with a Water/Energy Service Company in conjunction with a corresponding pump-set replacement program. The third was found to have the most advantages.

- Tamil Nadu - 3 river basins (IDRC), 2006: Surveys had been conducted regarding access to groundwater, costs of well-irrigation, impacts of water-level decline, etc. Data was collected on 1,100 wells in 27 villages of the Vaigai river basin (in southern Tamil Nadu), and from 7,120 wells in 51 villages in the Palar basin. With the progressive decline in the water table, farmers have resorted to the competitive deepening of wells. This has resulted in increased costs of well irrigation and in a new inequity among the well-owners, and between well-owning and non-well-owning farmers. The authors show how the degradation of the groundwater resource base through over-extraction contributes to inequity, conflicts, competition and, above all, to indebtedness and poverty (Janakarajan and Moench, 2006).

- Conference on Water Security in India, (Columbia University), 2009: The Conference on Water Security in India, conducted at the Columbia Water Center aimed to create (i) need statements for specific technical estimation and scenario generation products, (ii) a White Paper on land-water-energy-agriculture issues in India with a focused assessment of the current situation that provides projections for water availability and its agro-economic impacts, and (iii) strategy documents for the development and testing of specific proposed mechanisms.

The White Paper should also identify potential opportunities for public, private, and public-private action at different levels to address the challenge—this would include potential reforms in government subsidies, directions for infrastructure development and management for surface and groundwater systems, ways to improve crop selection locally and regionally for higher income using fewer resources, and potential mechanisms for the private sector to positively impact agriculture and water resources. The mechanisms would include: mechanisms for targeted crop selection to maximize income per water drop through cooperatives, contract farming or global/national market development; subsidy /incentive/crop procurement reform, especially targeted at electricity usage in groundwater

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[23] Karnataka's electricity distribution was unbundled between the regional distribution companies BESCOM, HESCOM, GESCOM, and MESCOM in 2002.

[24] The Institute of Youth and Development conducted a household survey for water and energy use.

[25] The University of Agricultural Sciences, Bangalore recommended best practices (i.e. water and fertilizer use per acre) for each of the crops grown in the region and methods of energy and water conservation for irrigated agriculture.

acquisition; insurance at different levels of aggregation, farmer or product aggregator; and Infrastructure Development and Management.

- Eastern UP – tube-well irrigation – private markets (IWMI-Tata), 1990s'- 2000s': Studies of small farmers in eastern UP have indicated that private tube-well markets have brought better service to farmers there than for similar farmers in the neighbouring states (Bihar, W. Bengal, and Orissa). Interviews with about 200 small farmers in the Gorakhpur, Maharajganj and Deoria districts of eastern Uttar Pradesh confirmed that with the emergence of the diesel-pump dealer, the procedure for obtaining a well (with the state subsidy) is much quicker and even cheaper than with the earlier departmental clearances[26]. The cost of the pump is (8–10%) higher but this is a relatively small service fee to pay. An estimated 800,000 small diesel-pump-operated tube wells have been installed in eastern UP under the scheme, in two decades since 1985. These wells irrigate an estimated 2.4–3.2 million hectares of their owners' and water buyers' lands, and provide the much-needed vertical drainage to the region (IWMI-Tata, 2002).

- Nine states –Evaluation of REC's Pump set Programme (TERI), 2004: While evaluating REC's pump set programme in 9 states (Maharashtra, WB, Karnataka, AP, Rajasthan, UP, Punjab, TN, Gujarat), TERI has considered the extent to which REC's Pump-set Energization programmes provide assured irrigation facilities to farmers. Its recommendations for expansion and sustainability include creation of business development cells, formulation of nodal agencies consisting of groundwater-use stakeholders, prioritization of districts, including the selection of implementing agencies (such as the state utility in the case of "*Sujalam Sufalam Yojana*" in Gujarat), financing crop diversification and drip/sprinkler installation.

- Costs of Un-served Energy (CUE), (TERI), Gujarat-2001, Karnataka-2006: The study[27] estimated the cost of un-served energy (CUE) for agriculture in Karnataka, based on the estimated net production lost, as also the farmers' willingness to pay (using contingent valuation methodology), based on responses from about 900 farmers in various parts of Karnataka during the period December '98 – May '99 (Bose, *et al*., 2006). In the latter case, while farmers were willing to pay more per HP, the hours of supply demanded implied the same price per kWh (in '99). Likewise, a survey of 285 rural households from a random sample of electrified villages of different landholding groups had been used to estimate willingness to pay in Gujarat (Bose and Shukla, 2001).

- Subsidised electricity prices with AP, Punjab data (IFPRI), 2007: Based on the increasing use of electricity and water by the agricultural sector in the states of AP and

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[26] Now, in eastern UP, an eligible small farmer provides his photograph and land documents to the dealer of the brand of diesel pump he prefers. The dealer completes the entire process of getting approvals and clearances from the government departments involved and the bank. The pump and pipes are issued to the farmer on the same day. He is free to hire local rig operators to get his boring done, and within a week of applying, his tube well is commissioned. Earlier, even with all the paperwork in order, the decision on his application under the Free Boring Scheme took about 11 months, because of the clearances required from the relevant state Departments, the procedures with Departments, designated bank and dealers, and the fact that only the Minor Irrigation Department could drill the wells. Further, the sum of "payments" could consumer 35-40% of the subsidy!

[27] TERI's research project titled Cost of Un-served Energy, prepared in association with London Economics with financial support provided by the World Bank and Department for International Development, 2000

Punjab and the resulting burden of electricity subsidies, a study was conducted for the purpose of proposing alternative pricing methods for the sector. Data on landholdings and household electricity use were taken from the 54th and 55th NSS rounds, and along with the elasticity estimates of earlier authors, used to estimate household price elasticities of demand. A strategy of price discrimination has been proposed, based on the size of the farmers' plots and on the implementation of a common two part tariff mechanism. Specifically, three types of consumers were identified: small (with = 1.8 ha), medium (with > 1.8 ha but = 3.64 ha), and large (> 3.64 ha). The first price scheme was a simple two part payment schedule: expenditure of smallholders would not be affected as they would continue to receive the current subsidy at unchanged electricity use; medium and large holders would also be subsidized, but only up to the average used by smallholders; additional use would be charged at the marginal cost. The second mechanism intended reducing (but not eliminating) the burden of the subsidy by cross subsidizing small holders with the revenues from large holders. It considered a fixed rate under which a household received the same units of electricity as before, but consumption exceeding that was charged with a marginal cost for households using less than a specified amount, while those exceeding it would pay a still higher rate for the additional units. Simulation of results indicated that Punjab would need higher rates than AP, for appropriate cross-subsidy, due to its land ownership being more skewed. The third pricing mechanism had the objective of completely eliminating the subsidy burden. Hence, not only were the variable parameters introduced as in the previous tariff schedule, but the fixed rate was raised, reducing the subsidy for the small holders (IFPRI, 2007a).

- Fertilizer and electricity pricing policy reform (IFPRI), 2007: This study assesses the policies concerning two agricultural inputs: fertilizers and electricity for groundwater-based irrigation, focusing on the political feasibility of reform options.
Their analysis of the range of policy options has the following conclusions. Those options that are neither confronted with major political challenges nor budget constraints include decentralization and devolution of both groundwater management and electricity supply, monitoring of electricity quality by citizen groups, and the promotion of independent farmers' cooperatives for the marketing of less water-intensive crops. Reform options that are not confronted with major political resistance, but face possible budget constraints include the following: expansion of the High Voltage Distribution System to reduce to improve the quality of electricity supply and reduce power theft; expanding and improving surface water irrigation; intensifying research and extension on water-saving production techniques and less water-intensive crops; improving the marketing of less water-intensive crops; regulation of new bore wells; and promotion of energy-saving technologies. Reform options that are confronted with major political challenges include, not surprisingly, the ones that have been tried without major success for the last decade: increase of the electricity price paid by farmers in combination with the introduction of metering; and the privatization of the power sector.
They emphasize the use of research-based options such as specific research on issues for which empirical evidence is lacking, promoting debates, and establishing a repository of studies from where information can be more easily accessed.

- West Bengal -farm survey, 2007: The author has studied West Bengal, where groundwater is easily available (i.e. through relatively shallow wells, as compared with many other regions). Alternative institutional arrangements for water use from wells have been discussed based on surveys of two villages -- (a) kinship group-owned electric submersible pump-operated wells in Dunipara village in Birbhum district, (b) private water market with price

regulation by *panchayat samiti* in Mohanpur village of Hugli district (Mukherji, 2007a). The first case is not really relevant as it is only applicable to similar clusters of kinsfolk and others even in the same village are not helped. The second method is applicable wherever the village-level decision-makers are powerful enough to impose their authority and enables small farmers to improve their cultivation at reasonable rates.
The author also considers both major sources of energy for pumping groundwater, viz. electricity and diesel. While most have looked only at the 'electricity-irrigation' nexus, she considers the 'diesel-irrigation nexus' (Mukherji, 2007b). The author has used primary field data from 40 villages in West Bengal, through a questionnaire administered in August – December 2004, to 294 well-owning (164 electric pumps and 130 diesel pumps) and 286 water-buying (158 from electrically-operated pumps, 128 from diesel-operated pumps) households. Diesel price increases reduced the sale of water for irrigation and thereby reduced the water-intensive but profitable summer paddy crop. Since groundwater is plentiful in that region, irrigation can be encouraged through electric pumps. With a flat-rate tariff, pump-owners would sell water willingly and the pump would be effectively used. She thereby makes a case for rapid rural electrification and continuation of high flat-rate tariff, which would in turn support the development of groundwater markets (where owners would sell irrigation water facilities to small farmers) and thereby provide access to irrigation to the poor and marginal farmers.

<u>- Franchisee system of distribution (TERI), 2007:</u> While utility-ESCo agreements have not taken off, the franchisee model for improvement of service in rural areas has been established in several parts of the country, as part of the *Rajiv Gandhi Grameen Vidyutikaran Yojana* (RGGVY) complete electrification effort. Essentially, a distribution transformer (that is installed and maintained by the utility) is assigned to each franchisee. The electricity supplied through it (at a charge per unit) has to be paid for by the franchisee who has the tasks of metering, billing, collecting payments from all the consumers, and serving new consumers in that area. Pertinent to our study is that agricultural consumers are also metered and billed, with progressive reductions in the tariff rate for installation of ISI-marked pumps, PVC piping and appropriate shunt capacitors. This study was based on franchisee systems in the districts of Nagaon (Assam), Gulbarga (Karnataka), and Damoh (Madhya Pradesh) (TERI, 2007).

<u>- Diesel price increases on farming (IWMI), 2007:</u> Responses regarding the three most important effects of the diesel price rise on farming were obtained in a survey of 15 villages. The villages were located as follows: Assam -1, WB – 2, Orissa – 2, MP – 2, Bihar – 1, UP – 2, Haryana – 1, Punjab – 1, Rajasthan – 1, Gujarat – 1, Maharashtra -1. These impacts of the diesel price rise included: shifts to other crops, reduction of irrigation of the same crops, concentrating irrigation on high-value cash crops, turning to electric pumps, if possible, running diesel-pumps on kerosene, and shifting away from farming to non-farm livelihood (or temporarily leasing out farm lands). The author's responses to what could be done in the short term to counter the energy squeeze include: Promoting fuel-efficient diesel/kerosene pumps of the Chinese variety; making PDS kerosene allocation to poor farmers for pumps (as in Kerala); providing subsidised diesel to farmers, as is done for trawler-operating fisher folk in some states; improving manual irrigation technologies; and better management of surface water bodies for gravity flow irrigation; helping marginal farmers own pumps, saving them from the monopoly rents contained in the prevailing pump irrigation prices. In the longer term, electricity supply to agriculture would have to be improved, at least with a specified number of hours of 3-phase full voltage supply.

- Gujarat state: Jyotigram meeting agricultural needs through Power Supply management, 2008-09: The Gujarat government invested in separating agricultural feeders from non-agricultural feeders throughout the state. In this system, villages get 24 hours/day three-phase supply for non-agricultural consumers (metered and paid for at specified tariffs), while agricultural-wells get eight hours/day scheduled supply, alternately during the day and the night, and expected to be at full voltage. Fixed annual payments (Rs 850/HP/year) rather than per kWh charges continue to be imposed, except in the case of new connections, but here too, the unit tariff is highly subsidised (Rs 0.5/kWh, or Rs 0.7/kWh for *tatkal* connections). The efficiency of the pump-sets has not been considered (except implicitly in the case of the metered connections). The authors, based on their own assessments and that of other studies, have drawn the conclusions that while *Jyotigram* has helped the non-agricultural categories of users, and most farmers who own wells, the marginal farmers are worse off. This is because they were earlier purchasing pumped water from wealthier farmers who could run their pump-sets for even 18-20 hours/day on single-phase supply, using capacitors. With the reduced hours of supply, water sharing has been reduced. However, the situation could be improved with hours of supply adjusted seasonally to suit the farming calendar (instead of the fixed 8 or 8.5 hours/day), thereby continuing to permit shared access to irrigation (Shah and Verma, 2008; Shah et al., 2009). During the past two years, other states are following this model – for example, Punjab has fully separated farm from non-farm feeders, Andhra Pradesh has done this in many districts, *Nirantara Jyoti* is in progress in Karnataka. However, the Gujarat system provides rationed power supply to agricultural users, but at 430-440 V, and on a strict schedule, with few interruptions.

4. Case study conclusions

It would be useful to assess what could be learnt from the numerous studies described. From within this compilation, there were independent evaluations (based on sample surveys) only for the REC-sponsored projects in six states during the 1980s' (CIRE, 2005), and the Nalgonda (AP) project during 1998-2000 (3EC, 2005). These evaluations were conducted several years after the specific project activities were ended, and while all reported improved energy-efficiency, it is not clear if the improvement was based on estimation or metering. In cases where the project team itself assessed the results, for example, the WENEXA pilot project (2006-08) and the IEI project (2009-10), both in Karnataka, a few cases of pump failure were reported during and immediately after project completion. However, we have not been able to locate any study on the deterioration of pump set performance, over time.

From the experiences reported by the implementers and monitoring agencies and, in some cases, personal communication, factors that affect implementation have been elicited. These factors are being categorised as: (1) Operational, (2) Technical, (3) Financial, (4) Training, maintenance, and monitoring (5) Integrative, (6) Location-specific, and (7) Institutional.

4.1 Operational factors:

- *Farmers' co-operation:* Farmers have to perceive the pump set replacement programme favourably from the onset itself, as this determines their willingness to be co-operate. At times, despite pre-programme interaction, there have been difficulties, for example, at the Doddaballapur project, Karnataka, even installing meters took several months to complete (Box 2, MoP-GoI and USAID, 2009).

- *State-run schemes perceived to be entitlements:* As with “free” electricity for agricultural pumping, improved pumping systems are, at times, perceived to be state-provided and therefore an entitlement. If such is the perception, farmers’ demands are difficult to meet and project operation is hampered. For example, due to the project’s pump-replacement commitment, at the Nalgonda district (AP) project, farmers demanded repairs on the same day (although it normally took 3-4 days for rewinding a 3- phase motor on their own). Further even with 18 hours/day supply (as against the assured 9 hours) they were still non-co-operative (3EC, 2005). This adversely affected the operation of the programme.
- *Unauthorised connections and/or connected load:* There are numerous farmers with unauthorized connections in most parts of the country. When such pumps have to be replaced, problems invariably occur, because of the need to “regularise” such connections. APTRANSCO had agreed to regularize such connections at a fee, but farmers expected to also get new pumps free (3EC, 2005). At times, because tariffs are collected per HP, people are tempted to change the name plate details to show lower HP rating (Subramanyam, NPC). Some farmers then object to replacement of their existing pump-sets as per their contract-load, because they had been operating higher rated pump sets (3EC, 2005).
- *Need-based decisions:* In contrast, the farmers’ urgent need for meeting their crop requirements within the limited power supply period and/or the desire for new and better pumps, at a discount (GEDA, 2010) have spurred them to even pay a part of the price, as seen in price-sharing programmes in Gujarat (Patel and Pandey, 1993, GEDA, 2010) and Haryana (HAREDA, 2009).
- *Implementation procedures:* As with any implementation programme, procedures can facilitate or hamper efficiency-improvement implementation for example, obtaining the subsidies/loans for micro-irrigation systems can be cumbersome (DTE, 2003; IEI, 2010). However, even in such cases, the mediation of agents/retailers can reduce waiting periods, as with drip systems in Karnataka (IEI, 2010), or diesel pumps in Eastern UP (IWMI-Tata, 2002; Shah, 2007).
- *Replacement rather than addition:* It is preferable that the existing pump sets are removed from the location after the installation of the efficient pumps, to prevent their continuing in use in the region and thereby negating the energy conservation.

4.2 Technical factors:

- *Pump sizing:* Pump efficiency would obviously improve with better selection & design, and likewise, motor efficiency (Sant and Dixit, 1995; Development First, 2003). However, these have to be dealt with on a case-by-case basis.
- *Low-cost improvements with relatively simple interventions:* Ensuring that the required system components and accessories are provided would contribute to the programmes’ results, for example, new starters should have been provided at the KBL pump-replacement project in western MP (KBL, 2004). As found in the recent study in AP, relatively easy measures (“obvious low hanging fruit”) such as installing capacitors on pump-sets, reducing the length of LT service wires and proper location of LT poles -- within the existing free power policy framework -- can contribute positively (Rama Mohan and Sreekumar, 2010).
- *Major system improvement*: Poor quality of supply – low end-of-line voltage, fluctuations, etc – has led to motor burn-outs even at small-scale experiments (3EC, 2005; Oza, 2007; IEI, 2010). In some cases, equal loading on all three phases of the power transformers at the sub-station has been difficult to achieve. Power supply duration could not be controlled / segregated easily, since both the lighting and agricultural loads were on the same feeder (3EC, 2005). It has been suggested that bringing high voltage till the distribution transformers (DT)s would bring about much-needed improvements: technical losses

(attributable to high LT current on the network) would be reduced, commercial losses (i.e. pilferage) from accessible LT lines would be avoided, high peak power losses due to unauthorised loads would be reduced, end-of-the-line voltage would be ensured (that in turn prevents transformer and pump failure) and unreliability of supply, consequent upon over-loading of LT lines would be reduced (NPCL, 2004; Chari, 2006). Installing high voltage distribution systems (HVDS) involves high initial investment; however, a case study (NPCL, 2004) indicated that the capital outlay could be recovered in 2.75 years, through the reduction in technical (transmission and distribution line) losses and pilferage[28].
- *Regulated/reliable supply*: As was noted (Dinesh Kumar, 2003), reliability of energy (and thereby water) supply is important for productivity, for example, sharecroppers achieve higher returns than insecure water-buyers, because the former know their water quota and can "budget" their water-use accordingly whereas the latter are at the mercy of the sellers. Hence, net return from crop production is less elastic to the cost of irrigation than to its reliability. Such a reliable solution (recommended by the International Water Management Institute for several years) involves (a) rationing farm power supply to fit irrigation demand (through rostering schedules), (b) providing this limited supply on a fixed, pre-announced schedule, and (c) overcoming farmer resistance by providing this limited supply at full voltage and without interruptions (Shah and Verma, 2008; Shah et al., 2009).

4.3 Financial factors:

– *Conservation justifying investment:* While the idea of financing pump-set improvements through the value of energy saving was considered several years ago[29], programmes have been implemented in Gujarat (GEDA, 2010) and Haryana (HAREDA, 2009; DHBVNL, 2008), in which the cost of improved pumps has been shared by those benefiting – the utility and the farmers.
- *Energy/water Service Companies:* When options for financing efficient water-application were assessed (USAID, 2006), financing through the utility under a performance contract with a Water/Energy Service Company was found to have the most advantages. Currently a programme involving pump replacement and system improvement is being financed jointly by the utility and an ESCo in Doddaballapur, Karnataka (MoP & USAID, 2009a &b). (The responsibilities of the utility, the ESCo, and all those involved are indicated in Box 2). The costs are supposed to be recovered from the value[30] of electricity saving, being shared as per the proportions in their agreement.
- *Farmers' contribution compulsory:* Some financial contribution from all parties involved should be included; hence, even the farmers should pay some - even a small - proportion of the costs (KBL, 2004; IEI, 2010).
- *Agricultural electricity subsidies should be linked with efficiency:* As agricultural energy subsidies do not reach the poorest, i.e. those with no land or with no well (IEI, 2010; Howes & Murgai, 2003), they need to be justified in terms of agricultural productivity and therefore efficiency. For example, in the rural franchisee model recently implemented (TERI, 2007) [31], agricultural consumers are also metered and billed, but with progressive reductions in the tariff rate for installation of ISI-marked pumps, PVC piping and appropriate shunt capacitors.

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[28] The cost of electricity was taken to be Rs 2.73/kWh.
[29] A study for Karnataka in used this principle (Reddy and D'Sa, 1993).
[30] This would vary with the region, as the financial value of electricity conserved would vary with the supply-demand position of the region and the time-of-the-day saving.
[31] This study was based on franchisee systems in the districts of Nagaon (Assam), Gulbarga (Karnataka), and Damoh (Madhya Pradesh)

- *Linkage with water conservation:* When linked with water conservation through micro-irrigation (discussed further in Section 4.5), the costs of improved pumping efficiency can be recovered through the value of improved crop output -- more crops per year, higher yields per acre, and the possibility of growing better-than-subsistence crops (IEI, 2010). This would enable farmers to pay annual/bi-annual instalments from revenue earned, towards the costs of improved irrigation systems.

4.4 Training, maintenance and monitoring:

- *Training for correct operation:* Training in the correct use of the newly-installed equipment is essential, or else mistakes occur resulting in the need for repairs and additional expenditure[32] (IEI, 2010). Motors manufacturers are not liable to replace damaged motors even within the guarantee period, if failures occur due to variation of system parameters; this causes further problems (3EC, 2005).
- *Local repair network and availability of spares*: Adequate local maintenance support is required, including qualified mechanics and appropriate spare parts and accessories. Training of mechanics is necessary, for many learn "on-the-job" and inadvertently commit errors. Further, as observed at the AP-Nalgonda project (3EC, 2005), local mechanics created problems as their livelihood was adversely affected by the farmers' refusing to engage them during the warranty period, and farmers were apprehensive about replacement / rectification of burnt out motors after the guarantee period.
- *Other maintenance issues:* Several other seemingly minor issues can turn out to be serious. For example, in the case of deep wells, pump removal can be very difficult[33]; this hinders repairs/replacement (IEI, 2010).
- *Monitoring:* While monitoring energy use and conservation through actual metering/measurement is obviously essential, most of the projects reviewed have not had independent monitoring. At the REC-sponsored projects conducted during the 1980s', sample monitoring was undertaken and results verified; at the DFID-sponsored AP-Nalgonda project details regarding implementation and operation were also checked. These have helped in eliciting the other factors required for successful implementation.

4.5 Integrative issues:

- *Energy conservation linked to water conservation:* It has been estimated that every one metre reduction in the average depth from which farmers pump groundwater saves the country 1.365 billion kWh of electricity[34] at generating stations. Obviously, groundwater conservation needs to be addressed along with energy conservation. As researchers (Shah et al., 2003, Shah *et al*., 2008; Scott and Sharma, 2009) have noted, co-ordinated energy and water management represents the most effective set of policy options to allow for sustainable use of groundwater, equitable access to water, improved rural livelihoods, and reversal of power utility fortunes. Integrated management of resources would therefore appear to be the most preferable.
- *Integration for programme implementation and financing:* When assessing the options for financing efficient water-application too, financing through the utility in conjunction with a

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[32] For example, the change-over switch (from 3-phase to single-phase and back) was incorrectly used and a motor was burnt.
[33] In such cases, piping of RPVC rather than HDPE has to be used.
[34] This is based on the assumption that with average pump efficiency of 40% and T&D losses of 25% in delivering generated electricity to rural pump sets, it takes 0.0091 kWh (Shah, 2009) to lift a m^3 of water to a dynamic head of 1 m; $150 km^3$ of groundwater is used for irrigation annually.

corresponding pump-set replacement programme was found advantageous (USAID, 2006). Even those who were not paying per kWh for electricity use were willing to pay a component of the new pump cost because of the water shortage and the need for obtaining water efficiently (GEDA, 2010).
- *Water/energy conservation impacts:* The broader impacts such as avoided CO_2 emissions and GHG impacts have been estimated (Shah, 2009; Development First, 2003). Hence investments towards reduction of impacts can help in grass-root level efficiency improvement.
- *Sharing and community participation:* Sharing of groundwater sources has proved to be efficient both in terms of resource use and crop productivity, in several case studies (for e.g., D. Kumar, 2003; IEI, 2010). This involves sharing both the water and the pump facility of the well (with either joint-ownership, or the owners "selling" pumped water to sharecroppers or limited buyers). In such cases, although tariffs per HP do not encourage efficient use of irrigation pumps, the systems of sharing/bartering/selling pumped water lead to more effective use of each pump-set. On a larger scale, village/community management of groundwater re-charge and conservation structures has reduced energy requirements for pumping (for e.g., Shah *et al*., 2009; Oza, 2007).
- *Groundwater stressed areas*: In already over-exploited groundwater regions, integration of water and energy management is not only recommended but essential. This would involve efficient pumping systems as well as water conservation through efficient application and managed aquifers. Water conservation on vast arable lands, run-off harvesting and its efficient and economic utilization through efficient irrigation practices are also vital. However, both for "stressed" (overexploited, critical and semi-critical) and "safe" areas, integration of energy and water conservation through efficient pumping and application systems would be beneficial. States have rules regarding the boring of deep wells, but only the implementation of controls on both drilling for and pumping out water would be effective in the long-term.

4.6 Location-specific issues:

- *Geographical differences*: In groundwater-safe areas, for example the eastern Gangetic areas, groundwater extraction can be encouraged. If public investment focused on improving and expanding the power grid, it would enable farmers to increase irrigation and thereby cropping and income, both through their own investment and arrangements for sharing/selling water (IWMI-Tata, 2002). On the contrary, water conservation and harvesting are essential when considering irrigation in several parts of western and peninsular India[35]. Instead of further groundwater exploitation, conservation through the restoration of traditional tanks/reservoirs that are still viable, as well as new groundwater-recharge efforts are recommended. Hence a region-specific approach to energy and water use is required.
- *Farmers' perception varying in different regions of the country:* Implementing agricultural energy-pricing policies also varies between different regions of the country, as a result of farmers' perceptions (Mukherji, 2006)[36]; these are important for project implementation.

[35] In Rajasthan, most districts are over-exploited already, per capita water availability during 2001 was 840 m^3 and it is expected to be only 439 m^3 by the year 2050 (Narain, et al., 2005). In the Doddaballapur sub-division (in Karnataka), the average depth at which groundwater was accessible increased from 214 to 615 feet between 1971 and 2004 (USAID, 2006).
[36] The author found that in West Bengal, although there was no pressing groundwater crisis, the state government was able to successfully implement groundwater regulations along with a drastic increase in electricity tariff, without any form of visible farmer protest, though these measures negatively affected farmer incomes. On the other hand, in Gujarat, where there was a grave groundwater crisis,

4.7 Institutional factors:

- *Involvement of all those concerned*: The distribution utilities, grass-root-level organizations (local NGOs, village co-operatives, SHGs, etc.) and the farmers themselves, at the local level, as well as the regulatory agencies at the state-level need to be involved for the successful implementation of large-scale programmes. In order to solve problems, there should be "thinking through together" (Rama Mohan and Sreekumar, 2010).
- *Intermediaries:* At times, agents from the retailers have been very helpful, whether for diesel pump installation in Eastern UP (Shah, 2007) or for drip systems in some regions of Karnataka (IEI, 2010). These can quicken the process of obtaining irrigation facilities.

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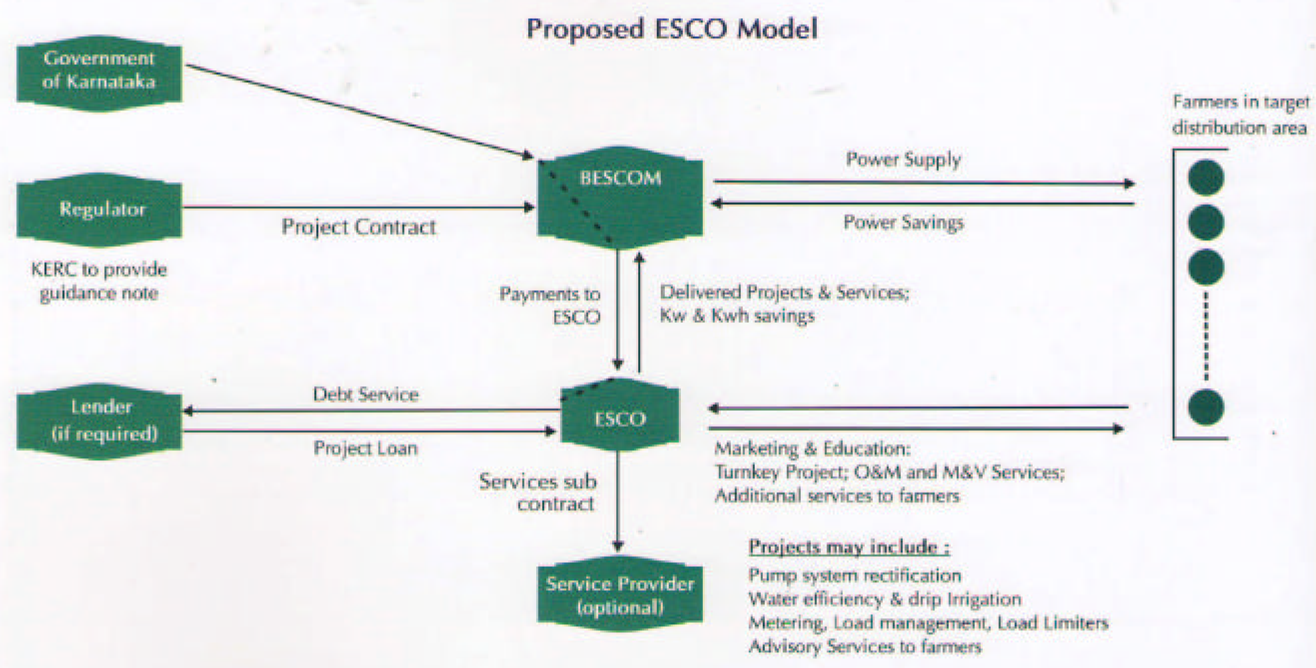
the state had neither been able to implement strict groundwater regulations, nor to increase electricity tariff substantially.

Box 1: Extract from the report on the utility-ESCo model, *DRUM Beats*, Vol. V, April 2009 (MoP-GoI and USAID, 2009a)



- **Necessary Preconditions are:**
  - High Voltage Distribution System (HVDS) installed with mostly one transformer one pump basis
  - Each Transformer has a meter.
  - NGO working with farmers for education, motivation and encouragement
  - Updated detailed data on existing pumps, water level, rainfall and pump efficiency
- **Responsibilities of Utility:**
  - Operation, maintenance and repair/replacement of power supply system to New High Efficiency Pump (NHEP).
  - Installation of one transformer for one pump
  - Installation of Electronic meters. Ensuring that each pump has a separate meter physically located on the Distribution Transformer (DT).
  - Installation of switch capacitors on 11 KV systems.
  - Making payments on a monthly basis to the ESCO based on the share of energy savings derived from the competitive bidding process. Utility to provide payment guarantee to ESCO through default ESCROW or letter of credit.
  - Seeking Government and Regulator support for implementation of proposed project.
  - Arranging site visit of the interested ESCOs.
- **Responsibilities of ESCO**
  - Planning the New High Efficiency Pump (NHEP) procurement, installation, maintenance and repair/replacement.
  - Financing, implementing and operating the project.
  - Dismantling the pump and ensuring its disposal in a manner that it can not be used as irrigation pumpset anywhere in India.
  - Providing a reasonable warranty to the NHEP.
  - Provides ongoing O&M support to farmers and establishes a site office.
  - Results reported to utility on an ongoing basis
  - Maintain a log of easily visible serial numbers and markings in the casting on the products. (For purposes of record and scrutiny against tampering of the IP set.)
  - Execute an agreement with Utility.
  - Execute an agreement with farmers.
- **Joint Responsibilities of Utility & ESCO:**
  - Agreements to be signed between ESCO & Utility
  - Utility to facilitate signing of agreement between ESCO & farmers.
  - ESCO, jointly with Utility, to implement a monitoring and verification (M&V) protocol. ESCO and Utility to undertake joint metering reading exercise.

Box 2: Extract from the report on the BESCOM-ESCo project in Karnataka, *DRUM Beats*, Vol. VI, July 2009 (MoP-GoI and USAID, 2009b)

Journey Towards Metering IP set consumption at DRUM project site, Doddaballapura, BESCOM

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Doddaballapur sub-division is one of the four sites in the country chosen by Ministry of Power & USAID for implementation of DRUM project to create 'Centers of excellence' in Distribution sector. This site was also chosen for another USAID program called Water Energy Nexus –II (WENEXA-II). WENEXA-II seeks to improve co-management of energy and water resources in the agriculture, urban and industrial sector through enhanced power distribution and end-use efficiency, coupled with sound water management practices.

Two 11 KV feeders DF-12, and DF-13 predominantly feeding to agriculture category were selected under WENEXA-II project for improving end use efficiency. HVDS was carried out on these two feeders by providing 665 independent distribution transformers (DT) to the IP set installations for improving power quality.

The purpose of installing meter at DT is to establish a robust baseline to measure energy consumption under WENEXA-II, it was decided to fix energy meters on all DTC's by 31st March 2009. As a precursor to this exercise a farmers meeting was held in January 2009 to educate them on the proposed project and the benefits from such an initiative to all the stakeholders. In the meet farmers were told that as part of the project meters would be installed on all DTs.

BESCOM expected based on prior experience of installing consumer meters and DT metering that this will not be a challenge. But it turned out to be entirely different. Farmers started resisting installation of meters as they apprehended that it is a step to ultimately raise bill through metered electricity consumption. Besides the enormity of the task and other technical issues involved, this 'Change-Factor' fear in the mind of farmers became a key determinant challenge. The journey can be narrated as:-

1. The first major resistance came from the farmers, in the form of removal of eight meters fixed on DTCs. The matter was brought to the notice of the Doddaballapur area elected representative, who in turn summoned farmers & BESCOM officials for a discussion. BESCOM officials explained in detail about the DRUM Pilot Project and WENEXA-II project. BESCOM officials explained the benefits farmers are getting due to HVDS in form of better voltage and more reliable power supply. The fixing of meters is only to measure the consumption as well as savings for the purpose Agriculture Demand Side Management (Ag DSM) implementation in WENEXA-II. It was also explained to the farmers that under WENEXA-II program they would get free of cost new energy efficient pump.
2. BESCOM officers & local contractor took up the work village wise (commencing from villages where the resistance is least) and started convincing the farmers for fixing of meters on DTCs. By this way, about one-third of Meters were fixed by mid-February 2009. A farmer meet in the village before starting the installation of meters was adopted as an standard practice.
3. However on 15th February, some groups, local leaders, and farmers arranged a large gathering to discuss the pros and cons of BESCOM meter fixing at a village in the pilot site area. The Karnataka State level Raitha Sangha (An influential social political Association) leaders also participated and deliberated that there would be danger to farmers if the meters are fixed. But the BESCOM officials, contractor who were present in the meeting narrated the good will of BESCOM behind fixing of meters and assured that it will not harm the farmers and no farmers will be deprived from the facilities given by the State Government. Director (Technical) of BESCOM also spoke to leaders and sought co-operation in implementing the project works.
4. After this meeting, BESCOM officers and contractor started again to convince the farmers village-wise and the metering work began in multiple villages simultaneously. In some villages the farmers co-operated, while in other places there was still some resistance. The installation of meters reached to about one half by 25th February.
5. After covering the easier pockets, the focus shifted to more difficult areas. As expected, resistance was encountered in these villages. To tackle this problem, a local meeting of farmers and leaders was called on 26th February at Kenchiganahalli village. During interaction, the farmers put forth some local electrical distribution problems and wanted to know the exact reasons for fixing meters to IP sets. BESCOM officials explained the reasons in detail once again. BESCOM officials also gave assurance to address the local distribution problems of the consumers and make adequate provision for refurbishment works. This paved the way for continuation of metering work and the progress came to two-third by the end of first week of March 09.
6. Then the BESCOM team and the contractor moved to Heggadanahalli Panchayath Area and the field officers of BESCOM conducted two meeting on 2nd and 3rd March 2009 to convince the farmers. There were rival groups, one group accepted the DTC metering while the other the other group started to resist. The workers engaged by the contractor were threatened by the farmers and warned not to enter lands of farmers where the transformers centers were situated. BESCOM team again went to the field and conducted joint meeting of farmers group and explained in detail the need and the benefits of HVDS and the purpose of installing meters. Parallely, refurbishment works like providing intermediate poles, replacement of damaged poles solving the local problems of villagers were also carried out which helped in progressing with the metering work. Based on these initiatives the farmers allowed meter installation to be carried out.

To summaries, meeting with consumers prior to start of work, the day to day interactions with farmers, explaining them the benefits of HVDS and other projects, hearing and solving their electricity distribution problems, taking the local leaders, elected representative and influential farmers into confidence and meetings with senior officials of BESCOM and participation with village community in local festival helped in completing the total installation by 3rd April 2009.

Besco - Esco Partnership Agreement Signed for Agriculture Demand Side Management

A pioneering effort under the USAID-funded Water and Energy Nexus Activity (WENEXA) Project has recently accomplished an important milestone by assisting Bangalore Electricity Supply Company in signing the first Agricultural Demand Side Management project of its kind in the country. The Public Private Partnership agreement for the commencement of the project was signed between BESCOM and the energy supply company, Enzen Global Solutions Pvt. Ltd., on July 06, 2009. PA consultancy is implementation partner to USAID for this WENEXA project.

References:

1. 3EC, 2005. Case Study on Agricultural Pump Set (Nalgonda district, AP) (Sponsored by USAID, Ministry of Power, and Power Finance Corporation, under the DRUM Training Programme), August, accessed in December 2009 from http://www.drumindia.org/UserFiles/File/AgriculturePumpSets/7-Case%20Studies/RDSM%207-1%20Case%20study%20on%20Agriculture%20Pump%20Set%20-%20AP.doc [Contact: Energy Economy & Environmental Consultants, 506, 15th Cross, Indiranagar II Stage, Bangalore – 560 038; Phone: 25213986 – 89, 25256171; Fax: 2525 9172; E-mail: mail@3ecindia.com, eeec@vsnl.com]

2. Adolph, B., Osman, M., Anwar, S.K., and Gupta, A.K., 2005. *Can grassroots influence policy*, Common pool resources in semiarid India; dynamics, management and livelihood contribution, DFID-NRSP R7877, accessed in January 2010 from http://www.nrsp.org/pdfs/highlights/24_R7877_grassroots.pdf [Contact: M.Osman, Central Research Institute for Dryland Agriculture (CRIDA), Santoshnagar, Hyderabad 500 059, Andhra Pradesh, E-mail: mdosman@crida.ap.nic.in; S. K. Anwar, Centre for World Solidarity House No. 12-13-438, Street No.1 Tarnaka, Secunderabad 500 017, Andhra Pradesh, E-mail: cwsy@hd1.vsnl.net.in; A K. Gupta, Aga Khan Rural Support Programme (India), 2nd floor, Choice Building, Swastik Char Rasta, Navrangpura, Ahmedabad 380 009, Gujarat, E-mail: akrspi@icenet.net]

3. Aga Khan Rural Support Programme, accessed in February '10 from http://www.akdn.org/india_rural.asp [Contact:Aga Khan Rural Support Programme, Choice Premises, Swastik Crossroads Navrangpura, Ahmedabad, Gujarat; Email: arksp@icenet.net; Ph.(079) 6427729/ 7205/ 7029]

4. Ahluwalia, S. S., and Goyal, A., Energy Efficiency and Conservation: Status and Prospects (Retrofitting in pump sets on pp.34-35, quoting TERI DSM in agriculture sector of Uttar Pradesh-investment strategies and pilot design. 1996. TERI report code: 1995em52) accessed in January '10 from http://www.adb.org/Documents/Reports/Consultant/TAR-IND-4066/Energy/ahluwalia.pdf

5. AP-CPDCL, 2009. Answers from AP-Central Power Distribution Company Ltd. to queries from the public, 4th February, accessed in January '10 from www.apcentralpower.com/FINAL**REPLIES**ARR/Final%20**Replies**%20to%20Objections%2004-Feb-09.doc

6. APSEB, 1998. *India: Integrated Agricultural Demand-Side Management AIJ Pilot Project*, funded by the World Bank/Govt. of Norway, Uniform Reporting Format: Activities Implemented Jointly (AIJ) Under the Pilot Phase accessed in January '10 from http://unfccc.int/kyoto_mechanisms/aij/activities_implemented_jointly/items/1987.php

7. BEE, 2009. *Schemes for Promoting Energy Efficiency in India during the XI Plan*, Bureau of Energy Efficiency, Ministry of Power, Government of India, New Delhi, accessed in December 2009 from http://www.bee-india.nic.in/down1.php?f=schemes_for_promoting_energy_efficiency_in_India_during

the%20XI_Plan.pdf; Also, *BEE Agricultural Demand Side Management Programme* booklet.

8. BESCOM, 2008. "Installation of switched capacitors on 11 kV feeders: Study during January '08 – October '08" accessed in December 2009 from http://www.drumindia.org/case_listing.asp

9. BESCOM, 2009a. "Pre-Bid Meeting for Agricultural Demand Side Management RfP" – Presentation on 22nd January, accessed in December 2009 from http://www.bescom.org/Pre-BID_meeting_22-1-09.ppt and Revised RfP, http://www.bescom.org/Revised_RFP.pdf

10. BESCOM, 2009b. "Proceedings of the Pre-bid meeting held at Bescom corporate office" on 22nd January 2009 at 3.00 P.M. in connection with Energy Efficient Pump sets Programme on HVDS feeders at Bescom's Doddaballapur sub-division", accessed in January 2010 from http://www.bescom.org/MoM.pdf [Contact: Tushar Girinath, MD, BESCOM, Corporate Office, K.R.Circle, Bangalore 560 001; Ph: 80 22354929, E-mail: mdbescom@bescom.org; G.V.Balaram, CGM(Projects) - Corporate Office, Ph: 80 22081547, E-mail: cgmprojects@bescom.org]

11. Bhatiani, G. and R. Goyal (USAID), 2009. "Energy Efficiency Bidding in Agriculture Irrigation Pumping: Indian Experience" presented at the 2nd Energy Efficiency Technology Conference, 17th November, accessed in January 2010 from www.greenbusinesscentre.com/.../21---Dr_Gaurav_Bhatiani,_USAID_and_Mr_Rakesh_Gumar_Goel,PA_Consulting.pdf [Contact: Gaurav Bhatiani, Principal Energy Specialist, USAID-lndia, US Embassy, Chanakyapuri, New Delhi 11002l; E-mail: gbhatiani@usaid.gov, 'Phones: + 91 9899295018, +91 11 24198712; Rakesh Kumar Goyal - Chief of Party, PA Government Services, Inc., New Delhi, Tel: +91 9871055119, +91 124 4737410; Email: RakeshKumar.Goyal@PAConsulting.com]

12. Bose, R.K. and Shukla, M., 2001. "Electricity tariffs in India: an assessment of consumers' willingness and ability to pay in Gujarat", *Energy Policy*, Vol. 29, pp.465-478; and a similar approach for Karnataka: Bose, R.K., Shukla, M., Srivastava, L., and Yaron, G., 2006. "Cost of unserved power in Karnataka, India", *Energy Policy*, Vol. 34, pp.1434-47. [Contact: Ranjan Bose, The Energy and Resources Institute, Habitat Place, Lodi Road, New Delhi 110003, E-mail address: rbose@teri.res.in];

13. CGWB-MoWR (GoI), 2005. "Master Plan for Artificial Recharge to Groundwater in India", Central Groundwater Board, Ministry of Water Resources, New Delhi, accessed in December 2009 from http://cgwb. gov.in/documents/MASTER%20PLAN 20%Final_ 2002.pdf

14. CGWB-MoWR (GoI), 2006. *Dynamic Ground Water Resources of India (March 2004)*, Central Ground Water Board, Ministry of Water Resources, Government of India, Faridabad, 2006, accessed in November 2009 from http://cgwb.gov.in/GroundWater/GW_assessment.htm

15. Chari, C.S.V. (CIRE), 2006. "High Voltage Distribution System", for the DRUM programme (MoP and USAID), accessed in March 2010 from http://www.drumindia.org/UserFiles/File/ruralpart/RPS%207-8%20HVDS.doc

16. CIRE, 2005. "Monitoring Results of REC's Pilot Projects", Central Institute for Rural Electrification (CIRE), Hyderabad, for the DRUM programme (MoP and USAID), accessed in December 2009 from http://www.drumindia.org/UserFiles/File/AgriculturePumpSets/7-Case%20Studies/RDSM%207-4%20MONITORING%20RESULTS%20OF%20REC%20PILOT%20PROJECTS.doc [Contact: CIRE, National Police Academy Post, Shivarampally, Hyderabad - 500 052. Phones: 040 - 24018583, 24015897, 24018584; Fax : 040 – 24015896; E-Mail: cire@sancharnet.in]

17. Columbia Water Center, 2009. Conference on Water Security in India, Columbia Water Center, The Earth Institute at Columbia University, April 15-19, Introductory Note, accessed in November 2009 from http://water.columbia.edu/sitefiles/file/India%20Conference/India%20Conference.pdf [Contact: watercenter@columbia.edu]

18. CRIDA and BAIF, 2005. *Groundwater Management – Decision Support System with People's Participation*, DFID Natural Resource Systems Programme project R8192 - Improved Natural Resource Management for Better Livelihoods, Policy Brief 1, accessed in January 2010 from http://www.crida.ernet.in/DFID/PolicyBrief1.pdf

19. CRIDA, ANGRAU and BAIF, 2005. *Rainwater Management for Drought Proofing - Farm Pond Technology for Sustainable Groundwater Technology in Anantpur (Andhra Pradesh)*, DFID Natural Resource Systems Programme project R8192 "Enabling rural poor for better livelihood through Improved Natural Resource Management in SAT India", Case Study -2, [implemented by CRIDA (Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad-500 059 A.P.), ANGRAU (Agricultural Research Station, ANGRAU, Kamalanagar, Anantapur-515 001 A.P.) and BAIF Institute for Rural Development-K, Tiptur-572 202] in Anantapur district, Andhra Pradesh, accessed in January 2010 from http://www.crida.ernet.in/DFID/Casestudy2.pdf

20. Development First (P.R.Shukla), 2003. "The Food-Water-Energy-GHG Nexus", *Development and Climate: An Assessment for India*, Chapter 7: pp.87-98, accessed in December 2009 from http://www.developmentfirst.org/india/report/chapter7.pdf

21. DFID, 2004. "Agricultural sustainability". Agriculture and Poverty Reduction Working Paper 12, DFID, London, available at http://dfidagricultureconsultation.nri.org/process.htm

22. DFID, 2005. Growth and poverty reduction: The role of agriculture, A DFID Policy paper, DFID, December, accessed in January 2010 from http://www.dfid.gov.uk/Documents/publications/growth-poverty-agriculture.pdf

23. DHBVNL, 2008. Executive Summary of Annual Revenue Requirement for FY 2008-09, Dakshin Haryana Bijli Vitran Nigam Ltd. (Distribution and Retail Supply Business

submitted to HERC), accessed in February '10 from http://www.dhbvn.com/main/arr/executivesummary-2008-09.pdf [Contact: Vidyut Sadan, Vidyut Nagar, Hisar -125005 Ph:01662-223089-90-91-92]

24. Dinesh Kumar, M., 2005. "Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: analysis from western India" *Energy Policy*, Vol. 33, pp.39-51. [Contact: d.kumar@cgiar.org]

25. Down to Earth, 2003. "Why the poor have dropped out", A *Down to Earth* Supplement on Water, Centre for Science and Environment, 15th November, available at http://old.cseindia.org/dte-supplement/water20031115/droped_out.htm

26. Dubash, N.K., 2007. "The Electricity-Groundwater Conundrum: Case for a Political Solution to a Political Problem", *Economic and Political Weekly*, Vol. XLII, No.52, December 29, Review of Agriculture, pp.45-55

27. Econoler, 2007. *Energy Efficiency in Agricultural Pumping*, Econoler (160 Rue Saint Paul, Bureau 200, Québec, Canada G1K 3W1), accessed in December 2009 from http://www.econoler.com/realisation.aspx?i=487

28. ELROMA, 1992. Proceedings of ELROMA (including "On the development of energy efficient high performance motors for irrigation pumps" – S.S. Murthy *et al.*, "Energy conservation in agricultural pumping system" – V.J. Ambwani, and "Energy-efficient motors and drives and various energy-saving measures – their relevance to the present energy crisis" – D. Dasgupta), January, Bombay.

29. Fernandes, Jyoti, 2003. "Andhra Pradesh: The land is ours", Comment in *Open Democracy*, 28th July, (This concerned Vision 20/20 and problems of focusing on a few cash crops, to the detriment of crop diversity and food and employment security) accessed in January 2010 from http://www.opendemocracy.net/people-foodwithoutfrontiers/article_1391.jsp

30. Foster, M, 2009. Reply in the House of Commons regarding DFID funding of irrigation in AP, accessed in January 2010 from http://services.parliament.uk/hansard/Commons/ByDate/20090209/writtenanswers/part014.html

31. GEDA, 2010. Personal communication (10-11th February). [Contact: Mr R.N.Pandya, Senior Project Engineer, Gujarat Energy Development Agency (GEDA). 4th floor, Block No. 11 & 12, Udyog Bhavan, Sector -11, Gandhinagar, Gujarat, Phone : +91-079-23257258, Fax : +91-079-23247097, e-mail: rprasad58@yahoo.com]

32. GEDA & ECO III Workshop on Agricultural Demand Side Management, 2007. "The WENEXA Ag-DSM Project Field Experiences and Lessons Learnt", Gandhinagar, September 29, accessed in December 2009 from http://www.waterenergynexus.com/pdf/AgDSM%20Ahmedabad%20-%20ppt.pdf

33. Gokak Committee, 2003. Gokak Committee Report, (p.30-31, Section 5.4), accessed in January '10 from http://www.powermin.nic.in/reports/pdf/gokak_report.pdf

34. Goyal, R.K., 2009. Electricity and Water, Presentation from PA Consulting Group, 9th February. [Contact: Tel: +91 9871055119, +91 124 4737410; Email: RakeshKumar.Goyal@PAConsulting.com]

35. Gulati, Ashok, Ruth Meinzen-Dick and K.V. Raju, 2005. *Institutional reforms in Indian Irrigation*, Sage Publications, New Delhi, (quoted in Oza, 2007)

36. Hambleton, A., Figueres, C., and Chatterjee, K., "Do AIJ Projects support sustainable development goals of the host country?", *Sustainable Development Contributions*, Chapter IX, accessed in January '10 from http://figueresonline.com/publications/AIJ%20lessons8.pdf [Contact: Kalipada Chatterjee, Global Environment Systems Group, Development Alternatives, B-32 Tara Crescent, Qutab Inst. Area, New Delhi 110016; Fax : 91-11-686-6031, E-mail: tara@sdalt.ernet.in]

37. Haryana Electricity Regulatory Commission (HERC), 2003. Commission's Order on Electricity Consumer Grievances and Related Issues, 21st August, pp.42, accessed in January '10 http://www.herc.nic.in/orders/pdf/consurig.pdf [Contact: Mahavir Singh, HCS, Secretary, HERC, SCO 180, Sector - 5, Panchkula 134 109, Haryana, Ph: 0172 2582531, Ext.206]

38. HAREDA, 2009. Report to BEE, awarded the 2nd prize for State-designated agencies, available at www.**bee**-india.nic.in/down.php?f=Award2008_Winners.pdf[Contact: Haryana Renewable Energy Development Agency (HAREDA), SCO No. 48, Sector-26, Chandigarh, Ph: 0172-2790918, 2791917, 2792119, Fax No: 0172-2790928; E-Mail: hareda@chd.nic.in, drehareda@gmail.com]

39. Howes, S. and Murgai, R., 2003. "Karnataka: Incidence of Agricultural Power Subsidies: An Estimate", *Economic and Political Weekly*, Vol. XXXVIII, April 19, Commentary, pp. 1533-35.

40. International Development Enterprises India (IDEI), 2010. "Affordable drip irrigation technology intervention (ADITI) schemes and implementation", accessed in January '10 from http://www.ide-india.org/ide/aditi.shtml [Contact: IDE (India), C5-43 Safdarjung Development Area , First Floor, New Delhi 110016,
(011) 696 9812 /13; E-mail: www.ide-india.org;
Tapan Patanayak, Chief General Manager (Orissa, West Bengal & Chattisgarh), A-7, Nilakantha Nagar, Behind Pollution Control Board, Unit -8, Nayapalli, Bhubaneswar – 751012 (Orissa) Tel : +91 - 674 – 2561727, Fax: +91 - 674 – 2561717 Email: ideors@ide-india.org; Pawan Kumar Singh, Chief General Manager (Uttar Pradesh, Uttarakhand, Bihar & Jharkhand), 1/150, Vivek Khand, Gomti Nagar, Lucknow – 226010, Uttar Pradesh, Tel : +91 - 522 - 2303563, 4005678, Fax: +91 - 522 – 2397763, E-mail: ideup@ide-india.org] Also, "Krishak Bandhu treadle pumps", accessed in January '10 from www.ide-india.org/ide/treadlepump.shtml

41. IDE (USA and Nepal) and Center for the Development of Human Initiatives, (Jalpaiguri, West Bengal), 2008. "Field study on diesel pump performance and small scale irrigation practices in India", accessed in November 2009 from http://www.practicafoundation.nl/services/consultancy/field-study-pump-performance-india/

42. International Energy Initiative (IEI), Bangalore, 2010. *Integrating energy conservation practices towards sustainable agriculture: the case of small farms in India* – Project Final Report, International Energy Initiative, Bangalore, (chief sponsor: Wuppertal Institut für Klima, Umwelt, Energie GmbH, through their 5th Round of Sustainable Energy Project Support), April, available at www.iei-asia.org/IEI-Bangalore-SustainableAgriculture-DemonstrationReport.pdf [Contact: Antonette D'Sa, K.V. Narasimha Murthy, E-mail:ieiblr@vsnl.com]

43. International Food Policy Research Institute (IFPRI), 2007a. *Power and Irrigation Subsidies in Andhra Pradesh & Punjab*, prepared by S. Chowdhury and M. Torero, IFPRI, Washington, D.C., March, accessed in December 2009 from http://pdf.usaid.gov/pdf_docs/PNADK228.pdf [Contact: Maximo Torero, E-mail: m.torero@cgiar.org]

44. IFPRI, 2007b. *The Political Economy of Agricultural Policy Reform in India: The Case of Fertilizer Supply and Electricity Supply for Groundwater Irrigation*, prepared by R. Birner, S. Gupta, N. Sharma, N. Palaniswamy, International Food Policy Research Institute (IFPRI), New Delhi, March, accessed in December 2009 from http://pdf.usaid.gov/pdf_docs/PNADK227.pdf [Contact: Regina Birner, Senior Research Fellow, IFPRI, Washington D.C.; Email: r.birner@cgiar.org; Ashok Gulati, Director in Asia, IFPRI, New Delhi Office; Email: a.gulati@cgiar.org]

45. IWMI, 2002. *Poverty focused small holder water management systems: Promoting innovative water harvesting and irrigation systems to support sustainable livelihoods in South Asia*, Theme 2: Land, water, and livelihoods, Project (Jan.2000 – Dec.2002) sponsored by DFID, accessed in January 2010 from http://www.iwmi.cgiar.org/Research_Impacts/Research_Themes/LandWaterandLivelihoods/poverty/lessons.aspx
Also, other publications on water harvesting and integrated water management, at http://www.iwmi.cgiar.org/Research_Impacts/Research_Themes/LandWaterandLivelihoods/poverty/Outputs.aspx [IWMI has water management programmes in north Gujarat which also promote low-cost drip and field trials of use of drip. Madhu Kapadia, Coordinator, Maulik Bhatt, Engineer, Field Station IWMI,
20, Karmachari Nagar, Hanuman Tekri, Egola Road, Palanpur, Gujarat; Ph.(02742) 255609]

46. IWMI-Tata, 2002. "Bringing pumps to people: Giving the poor better access to groundwater irrigation: Sustainable approaches and options for eastern India", *Water Policy Briefing*, Issue 2, March, IWMI-Tata Water Policy Research Program, accessed in December 2009 from http://pdf.usaid.gov/pdf_docs/PNADD529.pdf; and http://www.iwmi.cgiar.org/iwmi-tata_html/policy_briefings/policy_briefing_issue2.htm ; and http://www.lk.iwmi.org/waterpolicybriefing/files/wpb02.doc [Contact: iwmi-tata@cgiar.org]

47. Iyyampillai, S. and M, Abdallah Eltoum A., 1998. "Electricity use pattern in borewell dominated agriculture", *Indian Journal of Agricultural Economics*, July, Abstract accessed in December 2009 from http://www.highbeam.com/doc/1P3-40493672.html)

48. Janakarajan, S., and Moench, M., 2006. “Are Wells a Potential Threat to Farmers’ Wellbeing? Case of Deteriorating Groundwater Irrigation in Tamil Nadu”, *Economic and Political Weekly*, Vol. XLI, September 16, pp.3977-87. [Contact: Email: janak@mids.ac.in; moenchm@i-s-e-t.org]

49. Kaur, S., Singh., S., and Gulati, H.S., 2009. “On farm-water management practices in Punjab”, *Current Science*, Vol.97, No.4, 25 August, Scientific Correspondence, pp.479-80.

50. KBL, 2004. *Power Generation (Power Saved is Power Generated)*, presentation by P. Tayal accessed in December 2009 from www.waterenergynexus.com/.../KSL%20Energy%20Conservation.pdf [Contact: Puneet Tayal, Corporate Global Marketing and Strategy, Kirloskar Brothers Ltd., “Yamuna”, Survey No. 98 (3-7), Baner, Pune 411 045; Ph: 020 27211096; 95525 47207; e-mail: tayalpk@kbl.co.in]

51. Kishore, A., Sharma, A., and Scott, C.A., 2000, IWMI-Tata Water Policy Highlight: “Power Supply to Agriculture, Reassessing the Options” accessed in December 2009 from http://www.iwmi.cgiar.org/iwmi-tata_html/PM2003/PDF/07_Highlight.pdf

52. Krishnamurthy, K.N. (Sri Vigneswara Group Concerns), 1994. “Conservation of energy – Energy-efficient Foot-valves”, presented at the *National Seminar on Conservation of Energy in Agricultural Pumping Systems*, 28-29th December.

53. Kumar, A., and Kandpal, T.C., 2007. “Renewable energy technologies for irrigation water pumping in India: A preliminary attempt towards potential estimation”, *Energy*, Vol.32, pp.861-870.

54. Kumar, Dinesh. 2005. “Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: analysis from Western India”, *Energy Policy*, 33:39-51 [Contact: International Water Management Institute, India Project Office, Elecon Building, Anand-Sojitra Road, VV Nagar, 388120; E-mail: d.kumar@cgiar.org]

55. Kumar, M.D., Singhal, L., and Rath, P., 2004. “Value of Groundwater, Case Studies in Banaskantha”, *Economic and Political Weekly*, Vol. XXXIX, July 31, pp. 3498-3503.

56. Kumar, R., Singh, R.D., and Sharma, K.D., 2005. “Water Resources of India” *Current Science*, Vol.89, No.5, 10 September, Special Section: Water, pp.794-811.

57. Kurien, J., and Sinha, Ashutosh, K., 2007. “Ground Water Governance Issues in Irrigation Development - A Perspective”, *Technical Digest*, Issue 10, pp.4-9, accessed in January ‘10 from http://www.nabard.org/fileupload/DataBank/TechnicalDigest/ContentEnglish/GROUND.pdf

58. Mahajan, K.C., and Srivastava, P.K., (Core International Inc.,), 2005. “DSM Opportunities and Experiences”, (USAID DRUM Training Programme, Ministry of Power, and Power Finance Corporation), accessed in December 2009 from

http://www.drumindia.org/UserFiles/File/DSM/6-Lecture%20Notes/DSM%206-5%20Energy%20Conservation%20Act%202001.doc

59. McNeil, M., M. Iyer, S. Meyers, V.E. Letschert, J. McMahon, 2008. "Potential benefits from improved energy efficiency of key electrical products: The case of India', *Energy Policy*, Vol. 36, pp.3467-76. [Contact: Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 90R4000, Berkeley, CA 94720, USA; Michael McNeil:MAMcNeil@lbl.gov]

60. MEDA, IIEC, 2005. Maharashtra pump set rectification programme 1989-94, quoted in *Maharashtra Energy Development Agency (MEDA) Strategic Energy Conservation Plan*, Draft (prepared by IIEC under USAID ECO II Program), February 2005, accessed in January '10 from http://gaia.lbl.gov/india/intranet/Draft-MEDA-Strategic-EC-Plan.pdf

61. Menon, V., Paul, A., and Nair K.N., 2005. "Dynamics of Irrigation Institutions, Case Study of a Village Panchayat in Kerala", *Economic and Political Weekly*, Vol. XL, February 26, pp.893-904.

62. MNES - GoI, 1992. Department of Power Annual Report 1991-92, Ministry of Non-Conventional Energy Sources (now Ministry of New and Renewable Energy) Govt. of India, New Delhi, accessed in February '10 from http://www.powermin.nic.in/reports/pdf/ar91-92.pdf

63. MNES - GoI, 2007. Annual Report 2006-07, Integrated Rural Energy Programme (IREP) – Chapter 4 Renewable Energy for Rural Applications accessed in January '10 from http://mnes.nic.in/annualreport/2006_2007_English/HTML/ch4_pg1.htm

64. MoA-GoI, 2003. *All India report on agricultural census, 2001–02*, Ministry of Agriculture, Government of India, New Delhi.

65. Moench, M.H., 1992. "Chasing the Watertable: Equity and Sustainability in Groundwater Management", *Economic and Political Weekly*, Vol. XXVII, December 19-26, Special Section.

66. MoP - GoI, 1997, 1998. Annual Report '96-97, p.20 (Section 5.1.2. Demand-side Energy Conservation: Agricultural Sector), accessed in January '10 from http://www.powermin.nic.in/reports/pdf/ar96-97.pdf and Annual Report '97-98, p.18 (Section 5.1.2. Demand-side Energy Management: Agriculture Sector) accessed in February '10 from http://www.powermin.nic.in/reports/pdf/ar97-98.pdf

67. MoP - GoI and USAID (DRUM), 2009a. "Excerpts from the interview with Mr Tushar Girinath, MD, BESCOM" and "Highlights of Model adopted by BESCOM for Agriculture DSM", *DRUM Beats: Newsletter Vol.V, April*, accessed in January 2010 from http://www.waterenergynexus.com/pdf/newsletter_volume_5.pdf [Contact: Tushar Girinath, MD, BESCOM, Corporate Office, K.R.Circle, Bangalore 560 001; Ph: 80 22354929, E-mail: mdbescom@bescom.org]

68. MoP - GoI and USAID (DRUM), 2009b. *DRUM Beats: Newsletter Vol.VI*, July, from http://www.drumindia.org/Newsletterpdf/Newsletter_volume_6.pdf [Contact: D.

Nagarjuna, SE(e) (C,O&M) - Bangalore Circle (Rural), BESCOM, Ph: 80 22100412, E-mail: seebcrural@bescom.org; K. Shivalingappa, (Retd. SEE), DRUM Co-ordinator; M. K. Goel - Director (lD&A) Power Finance Corporation Ltd. 'Urjanidhi', 1 Barakhamba Lane, Connaught Place New Delhi-110001, Phone+: 91 11 23456000]

69. MoP – GoI and USAID (DRUM), 2009c. Award given for the pilot project accessed in January 2010 from http://www.drumindia.org/award_whatnew201109.asp

70. MoWR – GoI, 2003. *3rd Census of Minor Irrigation Schemes: 2000-01*, Ministry of Water Resources, Government of India, New Delhi, relevant Tables available at http://mowr.gov.in/micensus/mi3census/reports/national/dug/1p.pdf, http://mowr.gov.in/micensus/mi3census/reports/integrated/23.pdf, http://mowr.gov.in/micensus/mi3census/reports/integrated/1.pdf

71. MoWR-GoI, 2008. Report on the recharge of groundwater through dug-wells, 28th February, Ministry of Water Resources, Government of India, New Delhi.

72. Mukherji, A., 2006. "Political ecology of groundwater: The contrasting case of water-abundant West Bengal and water-scarce Gujarat, India" *Hydrogeology Journal*, Volume 14, Issue 3, March, pp. 392-406. [Contact:a.mukherji@cgiar.org]

73. Mukherji, A., 2007a. "Implications of Alternative Institutional Arrangements in Groundwater Sharing, Evidence from West Bengal", *Economic and Political Weekly*, Vol. XLII, June 30, pp. 2543-51. [Contact: Email: am523@cam.ac.uk]

74. Mukherji, A., 2007b. "The energy-irrigation nexus and its impact on groundwater markets in eastern Indo-Gangetic basin: Evidence from West Bengal" *Energy Policy*, Vol. 35, pp.6413-30. [Contact: a.mukherji@cgiar.org]

75. Mukherji, A., Das, B., Majumdar, N., Nayak, N.C., Sethi, R.R., and Sharma, B.R., 2009. "Metering of agricultural power supply in West Bengal, India: Who gains and who loses?" *Energy Policy*, Vol. 37, pp.5530-39. [Contact: Aditi Mukherji at a.mukherji@cgiar.org, Bhaskar Das at bhaskar.ju@gmail.com, Nabendu Majumdar at nabendumajumdar@yahoo.com, N.C. Nayak at nayaknc@rediffmail.com, R.R. Sethi at ranurani@yahoo.com, and Bharat Sharma at b.sharma@cgiar.org].

76. Narain, P., Khan, M. A., and Singh, G., 2005. *Potential for water conservation and harvesting against drought in Rajasthan, India*. Working Paper 104 (Drought Series: Paper 7). Colombo, Sri Lanka: International Water Management Institute (IWMI) [Contact: iwmi@cgiar.org; Dr. Pratap Narain, Director, Central Arid Zone Research Institute (CAZRI), Indian Council of Agricultural Research (ICAR), Jodhpur, Rajasthan; Dr. M. A. Khan, Head, Integrated Land Use Management Division at CAZRI; Dr. Gurbachan Singh, Assistant Director General (Agronomy) at ICAR, New Delhi, India]

77. Narendranath, G., Shankari, U., and Reddy, K.R., 2005. "To Free or Not to Free Power, Understanding the Context of Free Power to Agriculture", *Economic and Political Weekly*, Vol. XL, December 31, pp.5561-70. [Contact: Email: umanarendranath@yahoo.co.in]

78. Nexant, 2004. *Challenges and Opportunities for Improving Rural Energy Services in Karnataka - A Policy and Program Framework for the PRESK Cell* prepared for the USAID SARI/Energy Program (Contract No. 386-C-00-03-00135-00), October 29, accessed in December 2009 from http://pdf.usaid.gov/pdf_docs/PNADD529.pdf

79. NIRD, 2002. *A.P. Energy Efficiency Project* (implemented by APTRANSCo, funded by DFID, UK), National Institute of Rural Development (NIRD), Hyderabad, accessed in January '10 from http://nird.ap.nic.in/clic/energy.html

80. NPC, 2004. *Integrated Rural Energy Planning (IREP) for Anantapur & Ranga Reddy Districts*, National Productivity Council, Hyderabad. [Contact: 10th Floor, Gagan Vihar, M.J. Road, Hyderabad 500 001; Ph: 040-24733473; (E-mail of Mr G.Subramanyam, Sr. Dy. Director: g_subramanyam@hotmail.com)]

81. NPCL, 2004. "High Voltage Distribution System for Agricultural Pumps – *A Case Study*", accessed in March '10 from http://www.powermin.gov.in/distribution/apdrpbestprac/NPCL-HVDS.pdf

82. Oza, A., 2007. "Part 1 Irrigation: Achievements and Challenges", Chapter 7, India Infrastructure Report 2007, pp.178-196, accessed in December 2009 from http://www.iitk.ac.in/3inetwork/html/reports/IIR2007/07-Irrigation.pdf

83. PA Consulting Inc., 2008. "Opportunity Knocks – BESCOM's Pioneering Agricultural Demand Side Project" (adapted from the article by J.Hogan in India Infrastructure Report 2007), accessed in December 2009 from http://www.drumindia.org/admine/newsevent-file/ne_11_20_2008_5_27_17_PM2717.pdf [Contact: Jim Hogan, E-mail: Jim.Hogan@paconsulting.com]

84. PA Government Services Inc., 2008. *Water Energy Nexus Activity (WENEXA II) Project*, Concept Note on Agricultural DSM, January 15, accessed in January 2010 from http://www.bescom.org/en/news/Ann_A.pdf [Contact: Jim Hogan, E-mail: Jim.Hogan@paconsulting.com; Rakesh Kumar Goyal**,** Chief of Party, PA Government Services, Inc., New Delhi, Tel: +91 9871055119, +91 124 4737410; Email: RakeshKumar.Goyal@PAConsulting.com ; Anupam Chakraborty, Sr. Distribution Specialist, Tel: +91 9650010975, +91 124 4737414
Email: Anupam.Chakraborty@paconsulting.com]

85. Pant, N., "Control of and Access to Groundwater in UP", *Economic and Political Weekly*, Vol. XL, June 25, pp.2672-80. [Contact: pantn@sify.com]

86. Patel, S.M. and Pandey, M.K., (1993) *Report on complete rectifications of agricultural pumps in Gujarat state*, Institute of Co-operative Management, Ahmedabad, sponsored by the Ministry of Energy, Government of India, (quoted by Sant and Dixit, 1995).

87. Phadke, A.A., Sathaye, J.A., and Padmanabhan, S., 2005. *Economic Benefits of Reducing Maharashtra's Electricity Shortage through End-Use Efficiency Improvement*, Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory (LBNL 57053), (sponsored by USAID under Contract

No. DE-AC02-05CH11231), 7th November, accessed in January 2010 from http://ies.lbl.gov/iespubs/57053.pdf

88. Planning Commission, GoI, 1993. Performance Budget of Ministry of Power and Non-Conventional Energy Sources, Govt. of India, 1992-93, p.9, (Section 17 on Conservation for Energy), accessed in January '10 from http://www.powermin.nic.in/reports/pdf/Pb92-93.pdf

89. Planning Commission, GoI, 1997. 9th Five-Year Plan, Vol.2 – Energy section, accessed in February '10 from http://planningcommission.nic.in/plans/planrel/fiveyr/9th/vol2/v2c6-2-1.htm

90. Québec Agence de l'efficacité energetique, Econoler International, IREDA, TERI. "Demand-side management from a sustainable development perspective: experiences from Québec (Canada) and India", accessed in December 2009 from www.icpeeb.org/p/UpLoad/idb/skumardeepa/f/dsm_english.pdf

91. Rajagopalan, M. and H. Demaine, 1994. "Issues in energy subsidies for irrigation pumping: A case study from Mahbubnagar District, Andhra Pradesh, India", *Energy Policy, Volume 22, Issue 1, pp. 89-95.*

92. Rama Mohan, R.V. and Sreekumar, N., 2010. *Improving Efficiency of Groundwater Pumping for Agriculture: Thinking Through Together*, Discussion Paper, January, Centre for World Solidarity (CWS) and Prayas (Energy Group) [Contact:Rama Mohan at ramamohan@cwsy.org, N. Sreekumar at sreekumar@prayaspune.org]

93. Ramachandra Murthy, K.V.S., and Ramalinga Raju, M., 2009. "Analysis on Electrical Energy Consumption of Agricultural Sector in Indian Context", *ARPN Journal of Engineering and Applied Sciences*, Vol.4, No.2, pp. 6-9, accessed in December 2009 from http://www.arpnjournals.com/jeas/research_papers/rp_2009/jeas_0409_165.pdf

94. Ramakrishna, Y.S. and K.V. Subrahmanyam, 2005. "Enabling Rural Poor for Better Livelihoods through Improved Natural Resource Management in SAT, India", Final Technical Report on DFID-NRSP Project R8192, Central Research Institute for Dryland Agriculture, Hyderabad (AP), accessed in January 2010 from http://www.nrsp.org/database/documents/2279.pdf [Contact: Y.S. Ramakrishna, Director, CRIDA, and K.V. Subrahmanyam, Head and Principal Investigator, DFID-NRSP-R8192]

95. Raman, S., *Micro irrigation for Electricity Saving in Gujarat - A Potentiality Assessment*, Gujarat Green Revolution Company, Vadodara, accessed in December 2009 from http://www.ggrc.co.in/ExpertAdvice.pdf

96. Rao, P.M.M., 2005. "Participatory Rural Electricity Supply in Karnataka (PRESK): A Case Study" (USAID DRUM Training Programme, Ministry of Power, and Power Finance Corporation), accessed in December 2009 from http://www.drumindia.org/UserFiles/File/ruralpart/RPS%207-2%20%20PRESK.doc

97. Reddy, A.K.N. and A. D'Sa, 1993. "Improvement of the efficiency of irrigation pumpsets: An implementation package", Workshop on *Integrated Electricity Planning*, International Energy Initiative (IEI), 8th -12th March, Bangalore.

98. Reddy, A.K.N., Sumithra, G., Balachandra, P. and D'Sa, A., 1990. "Comparative Costs of Electricity Conservation and Centralised and Decentralised Electricity Generation", *Economic and Political Weekly*, Vol., XXV, No.22, pp.1201-1216.

99. Reddy, K. S., Rao, B.V.G., Reddy, S.Y., and Manohar, K.R., 1994. "Impact of rectification of pump sets on energy consumption in Andhra Pradesh – A Case Study", Department of Agricultural Engineering, College of Agriculture, APAU, and NEDCAP, Hyderabad, presented at the *National Seminar on Conservation of Energy in Agricultural Pumping Systems*, 28-29th December.

100. REEEP, 2009. "REEEP assists €15 million drip irrigation buy in India", Cleantech Group, May 14, accessed in December 2009 from http://www.google.com/search?hl=en&q=irrigation+pump+efficiency+Maharashtra&start=10&sa=N

101. Samal, C.K. and Kolanu, T.R., 2004. "Rural Poverty Reduction through Research for Development: Water Pricing and Decentralized Irrigation Management in Andhra Pradesh – Schism between Objectives and Realities", [Contact: Chandan K. Samal, Andhra Pradesh Rural Livelihoods Programme, Programme Management Unit, Office of the Commissioner, Rural Development, 5th Floor, Insurance Building, Tilak Road, Hyderabad; e-mail: chandansamal@yahoo.com] accessed in January 2010 from http://www.cgg.gov.in/workingpapers/Water%20Pricing%20&%20Decentralised%20Irrigation%20Management.pdf

102. Sant, G. and Dixit, S., 1995. *Analysis of Electricity Consumption of Irrigation Pump-sets in the State of Maharashtra*, Prayas, Pune, (sponsored by the International Energy Initiative, Bangalore), and "Agricultural pumping efficiency in India: the role of standards", *Energy for Sustainable Development*, The Journal of the International Energy Initiative, Vol. III, No.1, May 1996, pp.29-37. [Contact: Prayas (Energy Group), c/o Amrita Clinic, Athawale Corner, Karve Road, Deccan Gymkhana Corner, Pune 411 004, Ph: 20 2542 0720/5620 5726; e-mail: girish@prayaspune.org]

103. Satyanarayana, C., (REC), 1994. "Improper matching of the wells and pump sets – Need for carrying out step draw down tests in representative wells", Rural Electrification Corporation, Project Office - Hyderabad, presented at the *National Seminar on Conservation of Energy in Agricultural Pumping Systems*, 28-29th December.

104. Scott, C.A., and Sharma, B., 2009. "Energy supply and the expansion of groundwater irrigation in the Indus-Ganges Basin", *International Journal of River Basin Management*, Volume 7, Issue 2, pp. 119-124. [Contact: Bharat Sharma at b.sharma@cgiar.org], also accessible at http://cpwfbfp.pbworks.com/f/Energy+supply+and+irrigation+expansion_IGB.pdf

105. Shah, T. 2001. *Wells and welfare in the Ganga basin: Public policy and private initiative in eastern Uttar Pradesh, India* Research Report 54. Colombo, Sri Lanka:

International Water Management Institute, accessed in February 2010 from http://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/pub054/Report54.pdf[Contact: Dr. Tushaar Shah, IWMI, Elecon, Anand-Sojitra Road, Vallabh Vidyanagar 388 001, Gujarat, or International Water Management Institute, P.O. Box 2075, Colombo, Sri Lanka; E-mail: t.shah@cgiar.org]

106. Shah, T., 2007. "Crop Per Drop of Diesel? Energy Squeeze on India's Smallholder Irrigation" *Economic and Political Weekly*, Vol. XLII, Issue 39, September 29, pp. 4002-09.

107. Shah, T., 2008. "India's Master Plan for Groundwater Recharge: An Assessment and Some Suggestions for Revision", Special Article, *Economic and Political Weekly*, Vol. XLIII, December 20, pp. 41-49.

108. Shah, T., 2009. "Climate change and groundwater: India's opportunities for mitigation and adaptation" in *Environmental Research Letters*, Vol. 4, No. 3, July-September, accessed in March '10 from http://iopscience.iop.org/1748-9326/4/3/035005/fulltext?ejredirect=migration

109. Shah, T., Scott, C., Kishore, A., and Sharma, A., 2003. "Energy-Irrigation Nexus in South Asia: Improving Groundwater Conservation and Power Sector Viability", Research Report 70, InternationalWater Management Institute, accessed in December 2009 from http://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/pub070/Report70.pdf

110. Shah, T., Giordano, M., and Wang, J., 2004. "Irrigation Institutions in a Dynamic Economy, What is China Doing Differently from India?" *Economic and Political Weekly*, Vol. XXXIX, July 31, pp. 3452-61. [Contact: Dr. Tushaar Shah, E-mail: t.shah@cgiar.org]

111. Shah, T. and Verma, S., 2008. "Co-Management of Electricity and Groundwater: An Assessment of Gujarat's Jyotigram Scheme", Special Article, *Economic and Political Weekly*, Vol. XLIII, No.7, February 16-22, pp.59-66.

112. Shah, T., Bhatt, S., Shah, R. K., Talati, J., 2008. "Groundwater governance through electricity supply management: assessing an innovative intervention in Gujarat, western India", *Agricultural Water Management*, 95:1233-1242

113. Shah, T., Gulati, A., Hemant, P., Shreedhar, G., Jain, R.C., 2009. "Secret of Gujarat's Agrarian Miracle after 2000", *Economic and Political Weekly*, Review of Agriculture, Vol. XLIV, No. 52, December 26, pp. 45-55. [Contact: Tushaar Shah at the International Water Management Institute, Gujarat, Ashok Gulati, Hemant P and Ganga Shreedhar at the International Food Policy Research Institute, and R C Jain at the Central Groundwater Board, New Delhi].

114. Shah, T., Kishore, A., and Hemant, P., 2009. "Will the impact of the 2009 drought be different from 2002?" Commentary, *Economic and Political Weekly*, Vol. XLIV, No.37, September 12, pp.11-14. [Contact Dr. Tushaar Shah, E-mail: t.shah@cgiar.org]

115. Shaheen, F.A., and Shiyani, R.L., 2005. "Equity Redistribution, Groundwater Bore-wells in North Gujarat", *Economic and Political Weekly*, Vol. XL, January 22, pp.307-12. [Contact: fashaheen@yahoo.com; rlshiyani@yahoo.com]

116. Sharma, H.C., Sewa Ram, and Ambrish Kumar, 1994. "Energy conservation in irrigation pump sets through the use of correct pipe fittings", Department of Irrigation and Drainage Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Nainital (U.P.), presented at the *National Seminar on Conservation of Energy in Agricultural Pumping Systems*, 28-29th December.

117. Sharma, K.D., 2009. "Groundwater management for food security" *Current Science*, Vol.96, No.11, 10 June, Opinion, pp.1444-47.

118. Shashidhar, K.C., Kulkarni, P.G., and Maurya, N.L., 1994. "Pump set efficiency and farmers' awareness on pump efficiency – A case study of Shimoga district", College of Agriculture, Dharwad, presented at the *National Seminar on Conservation of Energy in Agricultural Pumping Systems*, 28-29th December.

119. Singh, A., 2009. *A Policy for Improving Efficiency of Agriculture Pump sets in India: Drivers, Barriers and Indicators*, a part of the project International Support for Domestic Action (ISDA), Climate Strategies, September, accessed in November 2009 from http://www.eprg.group.cam.ac.uk/wp-content/uploads/2009/09/isda_indian-power-sector_september-2009-report1.pdf, Also, personal communication [Contact: Associate Professor, Department of Industrial & Management Engineering, Indian Institute of Technology, Kanpur 208 016, Ph: +91–512–2259 7679; E-mail: anoops@iitk.ac.in]

120. Singh, R., Singh, J., and Jhorar, R.K., 1994. "On-farm energy conservation through improved irrigation and pumping unit efficiency", Department of Soil Science, CCS Haryana Agricultural University, Hisar, Haryana, presented at the *National Seminar on Conservation of Energy in Agricultural Pumping Systems*, 28-29th December.

121. Sonavane, V.L. and Rathi, H.K. (MSEB), 1994. "Reducing of line losses by leasing of LT capacitors in Maharashtra state", presented at the *National Seminar on Conservation of Energy in Agricultural Pumping Systems*, 28-29th December.

122. Sreekumar, N., 2009-10. Personal communication, contact: sreekumar@prayaspune.org

123. Srinivas, S.N., and Jalajakshi, C.K., 2004. "Alternatives to Micro-Irrigation: Evaluation of the Treadle Pump", *Economic and Political Weekly*, Vol. XXXIX, September 18, pp. 4271-75.

124. Srinivasulu, A., Yella Reddy, K., and Appa Rao, D., 1994. "Design and evaluation of an efficient foot-valve", College of Agricultural Engineering, Bapatla, AP, presented at the *National Seminar on Conservation of Energy in Agricultural Pumping Systems*, 28-29th December.

125. Striver, 2008. *Strategies for rainfed and irrigated agriculture: Tungabhadra basin , India and Tagus basin, Spain and Portugal*, Task Report 9.2, September '08, [A part

of *Strategy and methodology for improved IWRM* - An integrated interdisciplinary assessment in four twinning river basins, Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)] accessed in February '10 from http://kvina.niva.no/striver/Portals/0/documents/

126. Subramanyam, G., (NPC). Note on the electricity saving potential of agricultural pumpsets accessed in December 2009 from http://www.energymanagertraining.com/announcements/EE20_result/04GSubramanyam.pdf [Contact: Sr. Dy. Director, NPC, 10th Floor, Gagan Vihar, M.J.Road, Hyderabad 500 001; Ph: 040-24733473; E-mail: g_subramanyam@hotmail.com]

127. Suresh Babu, S., Sharma, K.M., Palanichamy, S., and Abhyankar, C.R., 1994. "Investigations on energy-efficient operational techniques for irrigation pump motors", Department of Electrical and Electronics Engineering, PSG College of Technology, and Kirloskar Electric Co., Coimbatore (Tamil Nadu), presented at the *National Seminar on Conservation of Energy in Agricultural Pumping Systems*, 28-29th December.

128. Tayal, P.K., 2010. Personal communication, 24-25th February, Corporate Global Marketing and Strategy, Kirloskar Brothers Ltd., "Yamuna", Survey No. 98 (3-7), Baner, Pune 411 045; Ph: 020 27211096; 95525 47207; E-mail: tayalpk@kbl.co.in]

129. TERI, 2004. Techno-economic evaluation of REC's pump set energisation (sponsored by REC), accessed in February '10 from http://www.teriin.org/upfiles/projects/ES/ES2004RA23.pdf (management issues only)

130. TERI, 2007. *Evaluation of Franchisee system in selected districts of Assam, Karnataka, and Madhya Pradesh* (prepared for Rural Electrification Corporation Ltd.) The Energy and Resources Institute, New Delhi, [Project Report No 2006ER39] accessed in February '10 from http://recindia.gov.in/download/Franchisee_Eval_TERI.pdf

131. Thakur, Anuradha, 2009. "Let's Catch Water Where it Flows", *The Economic Times*, (Bangalore edition), 1st October, p.11.

132. Thimma Reddy, M. *Power and Agriculture Crisis in Andhra Pradesh*, Centre for Environment Concerns Hyderabad, accessed in December 2009 from http://www.pmger.org/Articles/Agriculture%20Crisis%20and%20Power.pdf

133. USAID, 2006. Water Energy Nexus Project: Technical Report No. 7, *Detailed Project Report: Irrigation Efficiency Improvements in the BESCOM Doddaballapur Subdivision Feeder Lines DF 12 and 13 Service Area*, (prepared by PA Government Services Inc., the University of Agricultural Sciences, Bangalore, and the Institute for Youth and Development under Contract Number: GS-10F-0052P for USAID, authors: Britton, B. R., Suryaprakash, S., Reddy, V.C., Devkumar, N., Bandi, A.G., Suresha, S.V., Joshi, M., Shamsuddeen, B.,) for USAID, New Delhi, April, accessed in December 2009 from http://www.bescom.org/en/news/Ann_G.pdf

134. Vaidyanathan, A., and Sivasubramaniyan, K., 2004. "Efficiency of Water Use in Agriculture" *Economic and Political Weekly*, Vol. XXXIX, July 3, Special Article, pp. 2989-96.

135. Vakulabharanam, V., 2004. "Agricultural Growth and Irrigation in Telengana, A Review of Evidence", *Economic and Political Weekly*, Vol. XXXIX, March 27, pp. 1421-26.

136. Varshney, K.G., Reddy, K.S., Manohar, K.R., and Muralikrishna Rao, M., 1994. "Performance of diesel and submersible pump sets in Kurnool district of Andhra Pradesh - A Case Study", Department of Agricultural Engineering, College of Agriculture, Rajendranagar, Hyderabad, *presented at "National Seminar on Conservation of Energy in Agricultural Pumping Systems", 28-29th December.*

137. Water and Environmental Sanitation Network - Solution Exchange, accessed in January 2010 from http://www.solutionexchange-un.net.in/food/cr-public/cr-se-food-wes-23090501-public.pdf

138. Water Resources Management, Government of Tamil Nadu - Water Resources Organisation, presentation by Deenadayalan, accessed in December 2009 from www.tn.gov.in/spc/workshop/WRM_DEENADAYALAN.PPT

139. World Bank, 2001. India Power Supply To Agriculture, Volume 1 Summary Report, Report No. 22171-IN, Energy Sector Unit South Asia Regional Office**,** June 15, http://siteresources.worldbank.org/INDIAEXTN/Resources/Reports-Publications/PowerAgriculture/summary_report.pdf; All Annexes (including Case Studies of Haryana and Andhra Pradesh, and determinants of choice of irrigation, metering results, etc.) accessed in Jan 2010 from http://www.worldbank.org.in/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/INDIAEXTN/0,,contentMDK:20167431~menuPK:295589~pagePK:1497618~piPK:217854~theSitePK:295584~isCURL:Y~isCURL:Y,00.html

140. World Bank, 2002. *Why are Power Sector Reforms Important for the Poor* accessed in December 2009 from http://siteresources.worldbank.org/INDIAEXTN/Resources/Reports-Publications/Power_sector_reforms.pdf

141. World Bank, 2010. Bids called for *Andhra Pradesh Water Sector Improvement Project in India* accessed in January 2010 from http://www.devex.com/projects/andhra-pradesh-water-sector-improvement-project-in-india-3

142. Yadav, B.S. (Dept. of Renewable Energy, Haryana), 2007. "Haryana Energy Conservation Action Plan & Haryana's Initiatives on Energy Conservation", presented at the *State level Seminar on Energy Conservation*, Chandigarh, 18th December, accessed in January '10 from http://www.hareda.gov.in/B.S.YADAV.ppt [Contact: Additional Director Technical, Department of Renewable Energy, Haryana, SCO No. 48, Sector-26, Chandigarh; Tel.Nos.0172-2791917, 2790117; Web-site: hareda@gov.in; Email: hareda@chd.nic.in]