Energy Efficient Pump Systems for Indian Agriculture

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Abstract

The agricultural sector is responsible for some 18% of electricity use in India. The average emission factor in the power production, is due to the high share of coal, oil and gas 0.82 kg CO_2 per kWh. The largest part of the 170 TWh/a agriculture electricity is consumed by 20 million irrigation pumps. In recent years the use of agricultural irrigation systems with submersible open well and borehole pumps has increased. The necessary boreholes to reach underground water reservoirs are drilled deeper and deeper. Thus, the use of more powerful irrigation pumps is increasing every year.

The existing Indian efficiency standards and energylabels for submersible pumps are voluntary. In 2012 [1], 24% of pumps sold in the Indian market (by value) are without energy efficiency classification by the Bureau of Indian Standards (BIS). According to Bureau of Energy Efficiency (BEE), 24% of pump sales in 2014 were carrying the 5-star label. Thus 76% of the pumps can be below the 1-star or simply not showing the label.

A major barrier to the use of energy efficient pumps in the agricultural sector is that farmers are not required to pay the regular electricity tariff or not even meter their consumption. Because a large number of agricultural consumers draw power irregularly from the electric grid, it makes the supply highly volatile leading to heavy voltage drops and power failures. The use of energy efficient pumps is hampered by the instability of the grid supply. Besides mechanical failure of pump parts, burnouts of the pump motors happen frequently due to under-voltage.

In partnership with TERI and funded by the Swiss Agency for Development and Cooperation, Impact Energy is working on an efficiency program in the agricultural sector which includes irrigation efficiency, cost based electricity tariffs and incentives for the use of energy efficient pumps. Indian pump manufacturers, regional professional engineering associations and local testing laboratories will become part of a nationwide training, testing and incentive program. The immediate goal is to stimulate the production and sales of efficient pumps and lower the respective market barriers. The long term goal is to make irrigation more energy efficient, more ecological and more economical.

Irrigation pumps in India

Irrigation is the predominant use of electricity in Indian agriculture. It consumes around 18% of the national electricity demand. With its current fleet of power plants (82% is fossil power) and existing transportation and feeder lines, supplying farms in remote areas with power of constant frequency and voltage is a big challenge. Traditionally farmers in India are considered poor and receive access to very low priced or free electricity. The result of this policy gives only low incentives for power utilities for electricity supply and distribution companies (Discoms) to expand power production and transportation capacity respectively. Many publicly owned power utilities operate on deficits and are barely able to raise sufficient capital for their operating business. Governments subsidize on state and federal level this development, which is economically not sustainable. Also, for the farmers, the electricity supply is often reduced to a few hours per day and suffers from severe variation of voltage. Beyond the "acceptable" under-voltage of -15%, often times under-voltage down to -40% is observed which of course can interrupt the proper functioning of pumps and their motors and cause damage to any machine operating on the grid.

With very low priced electricity the farmers have no incentive to install and operate efficient irrigation pumps. They are aware of "when power is on, irrigations needs to run", even when and where it is not necessary. On the other hand they pay the price for damaged motors and pumps that suffer through overheating and burnouts while operating at under voltage.

The general observation in India [2] is that the percentage of farmers using electric pumps is steadily increasing, the pump efficiency is stagnant and the water table all over India according to the National Groundwater Board is sinking in dry areas steadily. A drop of the water table of up to 1 m per year has been monitored in certain dry areas for the last 10 years. Between 39% and 56% of the more than 20'000 wells monitored regularly [3] show a constant fall of the water table. The observations of the wells are monitored 4 times a year, before and after monsoon. In 11% to 15% of the water table of the wells the fall is more than 20 cm to 40 cm per year (see data of water table changes from 20'000 wells averaged over 10 years in Table 1).

The older open wells are now replaced by deeper drilled boreholes, which can easily go down to 100 m and beyond. But, without better use of surface water after the monsoon in check dams and without recharging of open wells the water table will continue to go down.

Table 1 Groundwater rise and fall in last decade during different season (Source: [3])

Groundwater Variation in India per Decade	DECADAL MEAN			
	(PREMONSOON-2004 TO PREMONSOON-2013) TO PREMONSOON-2014	(AUGUST-2004 TO AUGUST-2013) TO AUGUST-2014	(NOV-2004 TO NOV-2013) TO NOV-2014	(JAN 2005 TO JAN 2014) TO JAN 2015
From				
To				
Rise	60%	49%	43%	46%
less than 2 m	43%	39%	36%	38%
2 - 4 m	11%	8%	5%	6%
more than 4 m	6%	3%	2%	3%
Fall	39%	50%	56%	54%
less than 2 m	28%	35%	42%	39%
2 - 4 m	6%	9%	9%	8%
more than 4 m	5%	6%	6%	6%
Decline	Delhi, Gujarat, Haryana, Karnataka, Punjab, Rajasthan and Tamil Nadu	Andhra Pradesh, Chandigarh, Delhi, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Telangana and Tamil Nadu.	Andhra Pradesh, Delhi, Gujarat, Haryana, , Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Telangana ,Tamil Nadu and Uttarakhand.	Delhi, Gujarat, Haryana, Telangana, Punjab, Rajasthan, Andhra Pradesh and Tamil Nadu.
Maximum decline	in and around parts of Punjab, Rajasthan and Tamil Nadu.	in almost all parts of the country.	in and around parts of Punjab, Rajasthan, Gujarat, Karnataka, Uttar Pradesh, Assam and Tamil Nadu.	

Also, the irrigation methods widely used in Indian agriculture are still based on "flooding" the fields. The fountain spills out a large amount of water from the source which cannot be used efficiently near the roots of the crops. Modern water saving irrigation methods like sprinklers and dripping tubes are still rarely seen in the fields.

A large number of stakeholders are involved to improve the overall energy efficiency and to render agricultural irrigation more sustainable. From the central government, besides the Bureau of Indian Standards (BIS), the Bureau of Energy Efficiency (BEE) also the Central Groundwater Board are involved. Then, the Discoms, the pump manufacturers and their associations, the borehole drillers and the eventual users, the farmers are engaged in the entire process. In many cases old rules, also taboos, are involved which are difficult to change.

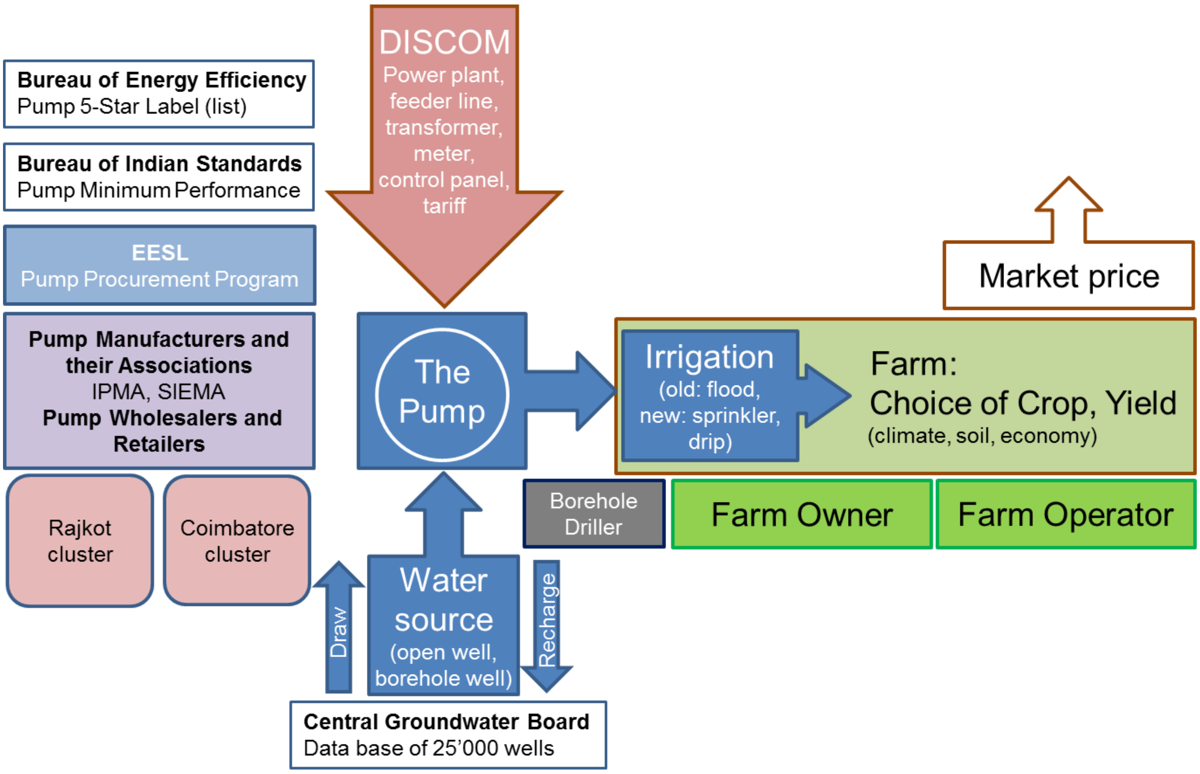

Figure 1 The key stakeholders involved in Indian agricultural irrigation

Pump use for irrigation

Electricity is used to pump surface water from open wells and underground water from boreholes. The atmospheric pressure limits the installation of simple surface mounted pumps (Monobloc) to about 6 m in depth, see Figure 2. Below this depth submersible pumps are used in open wells down to some 10 or 20 meters with the pump hung from a cable guiding also the electric line, see Figure 3, left.

The current drop of the water table has increasingly favored the use of borehole pumps (see Figure 3, right). This includes the costly borehole-drilling, sometimes also the insertion of a sleeve on the upper part of the hole and then the installation below ground of the pump which is linked with an electric cable and hooked to a robust vertical tube towards the surface. Specialized companies for drilling, hydraulic and electric installation support the farmers.

Figure 2 Surface Monobloc pump (Source: Prakash Pumps, 2016)

Submersible pump for open wells
(Source: Lowara, 2016)

Vertical submersible borehole pump (multi-stage)
(Source: Grundfos pump handbook, 2004)

Figure 3 Submersible pumps

The borehole drilling bares a high risk of not being successful in tapping a sufficiently abundant water source. Depending on the soil condition (rock, sand) and its permeability the chances are 1:10 to 1:3 to find a sufficient well with the borehole.

Ideally, the irrigation for most crops should happen during the cooler part of the day, mainly between evening and morning, to avoid inefficient evaporation. On the other hand, the Discom is looking for an even distribution of its capacity. This means, it allocates most of the times power not according to transparent daily and weekly cycles of water need.

Electricity use in submersible pumps

The majority of the pumps use 2-pole induction motors trimmed to the special geometry of the borehole: a 10 to 20 cm diameter is most often used with an elongated motor of between 1 kW and 10 kW to reach sufficient torque.

Based on the current stage of knowledge, after desk research and interviews of a number of stakeholders, a submersible pump in a borehole for agricultural irrigation India has the following typical properties:

Table 2 Typical properties of borehole pump in India

•	Diameter of the borehole and the pump is 10 cm (V4) to 15 cm (V6)
•	The borehole depth (static head) is 60 m to 150 m for V4 pumps and 200 m to 300 m for V6 pumps
•	The flow of water for the irrigation is 5 to 12.5 liter per second for V4 pumps and around 2.5 liter per second for V6 pumps
•	Electric motors have an output power of 0.7 - 1.1 kW for V4 pumps and 3.7 - 7.4 kW for V6 pumps
•	Electric motors are mostly 2-pole with synchronous speed of 3'000 rpm at 50 Hz

•	Electric pump motors are designed for and operated at 415 V (accepted variation in Indian pump standards is +6%, -15%). The real voltage varies often down to -40% (250 V) and below, causing severe operating problems and damages[1]. The voltage variations have to do with large and unannounced heavy electric loads from not-metered consumers within the same area of the grid.
•	A typical pump uses (when operated 2 - 5 hours per day during 300 days a year, total circa 1'200 to 1'500 hours per year) circa 5'000 to 7'000 kWh/a electricity (the national average from statistics of national electricity consumption for agriculture and number of pumps is 6'143 kWh/a).
•	With a nominal price for electricity of 0.01 cents/kWh for agriculture in India[2] the electricity cost of a pump amounts to about 40 to 70 EUR per year.
•	A major issue is that farmers in India often consume electricity without a metering system, and generally pay between zero and only 20% of the actual electricity price and thereby distorting the economy and destroying the cost savings incentive of high efficient pumps.
•	The pump purchase costs are about 200 to 400 EUR for 2.2 kW and 3.7 kW five star labeled pumps. A smart control panel with additional capabilities (remote control, etc.) costs more than the pump.
•	To drill the borehole costs about 2.4 to 3 EUR per meter: for a 60 m borehole circa 180 EUR, for 150 m circa 450 EUR, for 200 m circa 600 EUR, for 300 m circa 900 EUR.
•	The replacement of pumps is typically made by farmers every 5 - 10 years due to wear.

According to a consumer survey in Rajkot, cost of accessories like cable, piping, normal control panel costs more than the pump cost; these costs are external to the pump cost and are cost burden to farmers as no subsidy is available for accessories.

The pump is rarely professionally sized by head and flow during the purchase and installation process. A typical size (by neighbors or the farmer's own experience) is bought, lowered into the borehole, installed and then the water supply is inspected. If it is sufficient, the pump was well chosen. If the supply is lower than expected, a stronger pump (or pump motor) is chosen and installed. If during operation the supply due to sand and subsequent wear of the impeller goes down the pumps are overhauled and eventually replaced typically by a more performant pump. Also, with the water table going down, after 3 to 5 years the pump has to be lowered and/or the borehole has to be drilled deeper.

The farmers have no professional support. The electrical and mechanical installations are mostly primitive and self-made. The owner has no metering of the pressure and the electric power; sometimes an empty barrel is available to meter the flow by clocking the time to fill the barrel. If the farmer is lucky the Discom has installed a kWh-meter and he can check his current and voltage as well as the monthly and annually electricity consumption.

Pump manufacturers and their local dealers compete for clients. The performance data are printed in catalogues and should be based on Indian standard (BIS: For submersible borehole pumps in IS no 8034, see Figure 4 and Figure 5). The motor efficiencies are given in Table 4. Theoretically, also pump diagrams with data for head, flow and efficiency (for motors, pumps and combined) should be available in the technical documentation accompanying the pump. The more efficient pumps should carry an energylabel (5-star scheme by BEE, see Table 5). The evidence [1] is that 24% of the pumps in 2012 are not explicitly IS-rated and 93% do not carry a 5-Star Label (see Table 5).

Indian pump efficiency standards

India has a long-standing tradition for national performance standards for a variety of pump types, issued by the Bureau of Indian Standards (BIS). In Table 3 the major standards for submersible pumps are shown.

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[1] Under-voltage shoots up the current and lowers the efficiency and the flow of water, so often motors are overheated and get damaged.

[2] Information from IPMA and distribution companies (Discom), 2016

Table 3 Indian standards for submersible pumps (BIS)

Number	Title	Type of standard: T (testing) C (classification)	Date of publication (last revision)
IS 8034	Submersible Pumpsets - Specification (MED 20: Mechanical Engineering)	C	2002 Second revision, Amendment no. 4: June 2015, see Figure 4 and Figure 5, Table 4
IS 9079	Electric Monoset Pumps for Clear, Cold Water for Agricultural and Water Supply purposes (MED 20: Mechanical Engineering)	C	2002 Second Revision: September 2004
IS 11346	Tests for Agricultural and Water Supply Pumps - Code of Acceptance (MED 20: Pumps)	T	2002 First Revision: December 2002
IS 14220	Openwell Submersible Pumpsets (MED 20: Mechanical Engineering)	C	1994 First Revision: 1994, Amendment 5: November 2002, New WC draft February 2015

IS 8034 is the major Indian performance standard for submersible pumps giving MEPS for the pump based on head and flow (see Figure 4 and Figure 5) as well as for the pump motor (see Table 4).

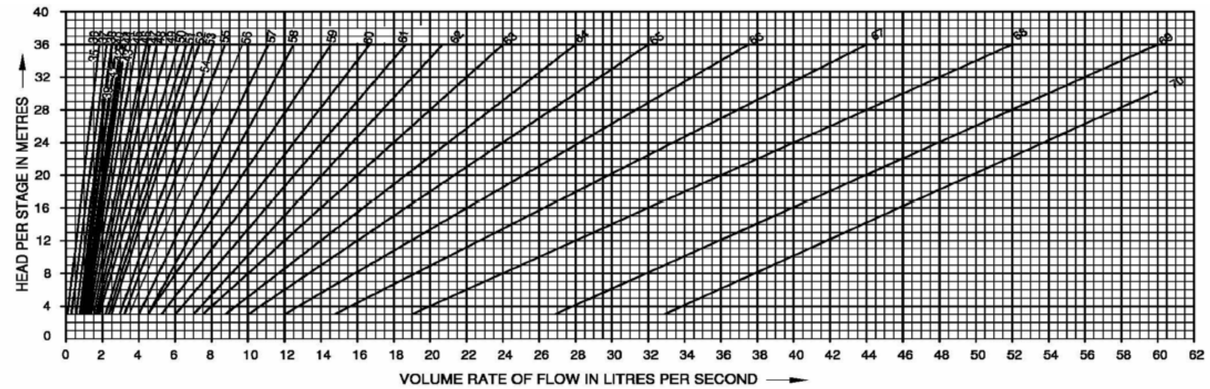


Figure 4 Minimal efficiency (%) for 2-pole submersible borehole pumps with 3 or more stages between 4 and 60 l/s in India (Source: BIS 8034, amendment 2012)

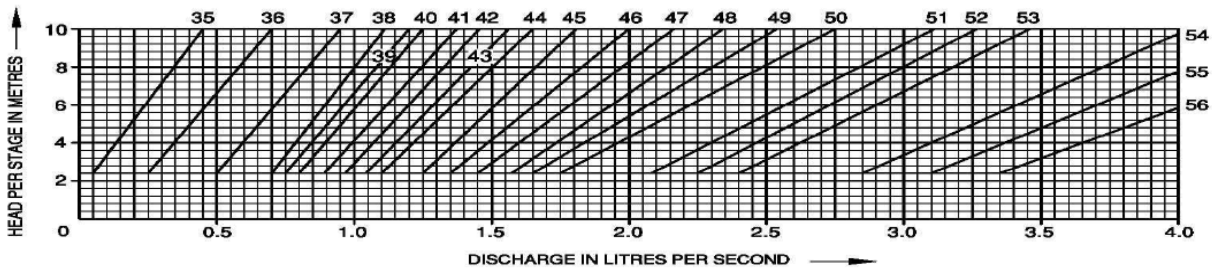


Figure 5 Minimal efficiency (%) for 2-pole submersible borehole pumps with 3 or more stages between 0 and 4 l/s in India (Source: BIS 8034, amendment 2012)

Motor MEPS for submersible pumps are given in Table 4. It is obvious that a motor with only 10 to 20 cm diameter for a borehole pump cannot reach the efficiencies of standard motors with IE1-IE4 (IEC

60034-30-1). The geometry leads to small diameters and long frames. The operation of pump motors in boreholes requires the filling of the stator with water. Also, the inclusion of a waterproofing can for the protection of the stator, increases the gap between rotor and stator. All these special elements of submersible pump motors diminish the motor efficiency to a level below or around IE1 for standard motors (see Figure 6).

Table 4 Performance characteristics for 2-pole, 415 Volt, 3-phase, motors for submersible pumps with 150 mm in India (Source: BIS 8034, amendment 3, 2012)

Motor Rating	Maximum Current	Permissible Limit of Maximum Current in the Operating Head Range for Checking the Non-overloading Requirements	Minimum Starting Torque(In terms of percentage of Full Load Torque)	Motor Efficiency factor
(kW)	(Amp)	(Amp)	(percent)	
(1)	(2)	(3)	(4)	(5)
1.1	3.3	3.5	125	57
1.5	4.5	4.8	125	66
2.2	6.5	6.9	125	67
3.0	8.5	9.1	125	67
3.7	10.0	10.7	125	68
4.5	12.0	12.8	125	70
5.5	14.5	15.5	125	73
7.5	19.5	20.9	125	74
9.3	25.0	26.7	125	75
11.0	29.0	31.0	125	76
13.0	34.0	36.4	125	77
15.0	39.0	41.7	125	78

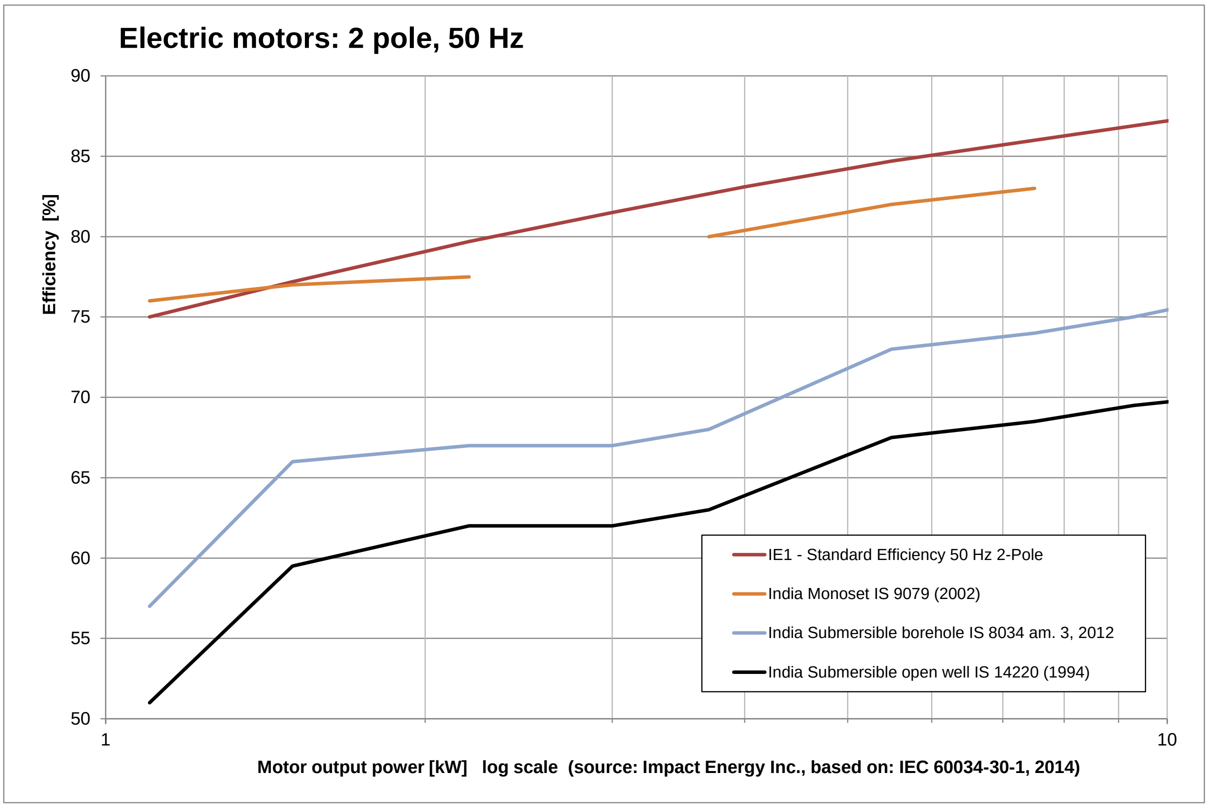
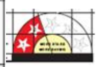


Figure 6 Comparison of Indian minimum standards (2-pole motors from 1 to 10 kW) for submersible pumps with IE-code for standard motors

Based on the MEPS for submersible pumps in IS 8034, the Indian Bureau of Energy Efficiency (BEE) has issued an energy label, based on a 5-star rating (see Table 5), for pumps exceeding the MEPS by 5 to over 20% (see Figure 9). With the current low MEPS level from the BIS 8034 standard, the more efficient 5-star rating is easily achievable.

Table 5 Definition of Indian Star Label rating for pump sets based on BIS Minimum Energy Performance Standards (Source: BEE, Schedule No.: 7 Pump Set, Revision: 3, 3 November, 2015)

Star Rating	Overall Efficiency of the Pump Set* (higher than the BIS value)	
1 Star	≥ 0 to < 5%	
2 Star	≥ 5 to < 10%	
3 Star	≥ 10 to < 15%	
4 Star	≥ 15 to < 20%	
5 Star	≥ 20%	

Market survey of Indian and global pump manufacturers

Pump manufacturers in India

According to the Indian Pump Manufacturer's Association IPMA, in 2016 there are 3'000 Indian pump manufacturers, 2 millions of agricultural pumps are sold annually and 21 millions of pumps are the installed base in the Indian agricultural sector [4]. India has a wide range of small, medium and large pump manufacturers that supply mostly for the Indian market. Interestingly, a large percentage of pump manufacturers are located in two clusters in India: in Rajkot in Gujarat in the West and Coimbatore in Tamil Nadu in the South.

In order to compare Indian and internationally produced pump efficiencies, a survey with 11 Indian pump manufacturers supplying data for borehole pumps was made from December 2016 to January 2017. The 61 pump and motor efficiency data were supplied by manufacturers and/or taken from publicly accessible BEE-label registration data files. They have not been verified by tests.

For this, a set of 10 most often sold pump sizes were chosen from the vast numbers of types and size. They were identified to be the most widely used types in Indian irrigation pumps for agriculture (see Table 6).

Table 6 **Head and flow of the 10 most often used borehole pump types in India, with 15 cm diameter and 2-poles**

Diameter	Head	Flow
cm	m	m3/h
15	35	23
15	40	32
15	40	44
15	55	27
15	60	15
15	70	13
15	70	23
15	100	13
15	100	16
15	110	13

The Indian data for efficiency and cost were also checked with compliance to the BIS 8034 MEPS as well as their 5-star rating.

Also, besides performance and cost, the type of impeller manufacturing was compared. The most often used types and materials of impeller manufacturing are:

- Cast iron
- Cast stainless steel
- Welded stainless steel
- One piece pressed stainless steel

In wells with various water qualities, content of solids, sand, etc., stainless steel impellers have a durability advantage against corrosion. On the other hand, cast impellers with thicker walls have an advantage for wear from erosion from sand, cavitation, etc. Stainless steel sheet metal for welded or stamped impellers is thinner and makes them more lightweight and has an efficiency advantage.

The comparison of Indian pump, motor and combined pump efficiencies shows a wide variation between best and lowest products. The pump efficiencies have the widest spread while motor efficiencies are considerably closer together (see results of efficiency comparison vs. pump head in Figure 7 and vs. pump flow in Figure 8).

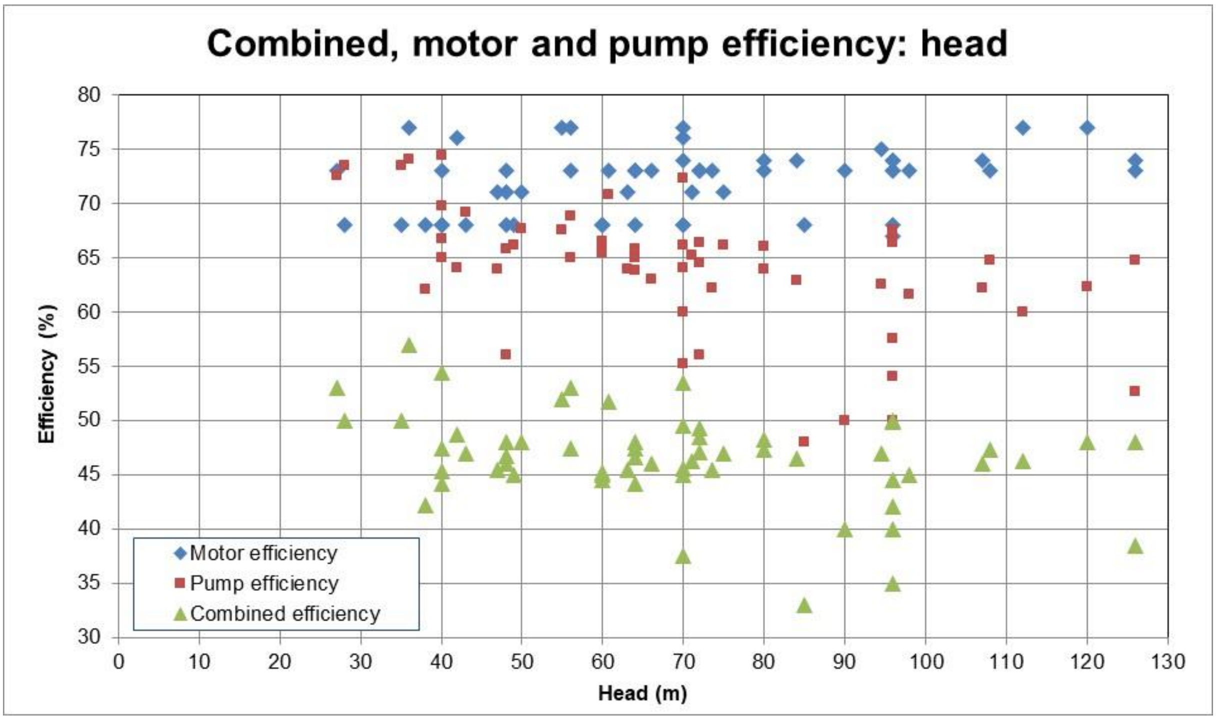


Figure 7 **Comparison of Indian pumps: efficiency vs. head**

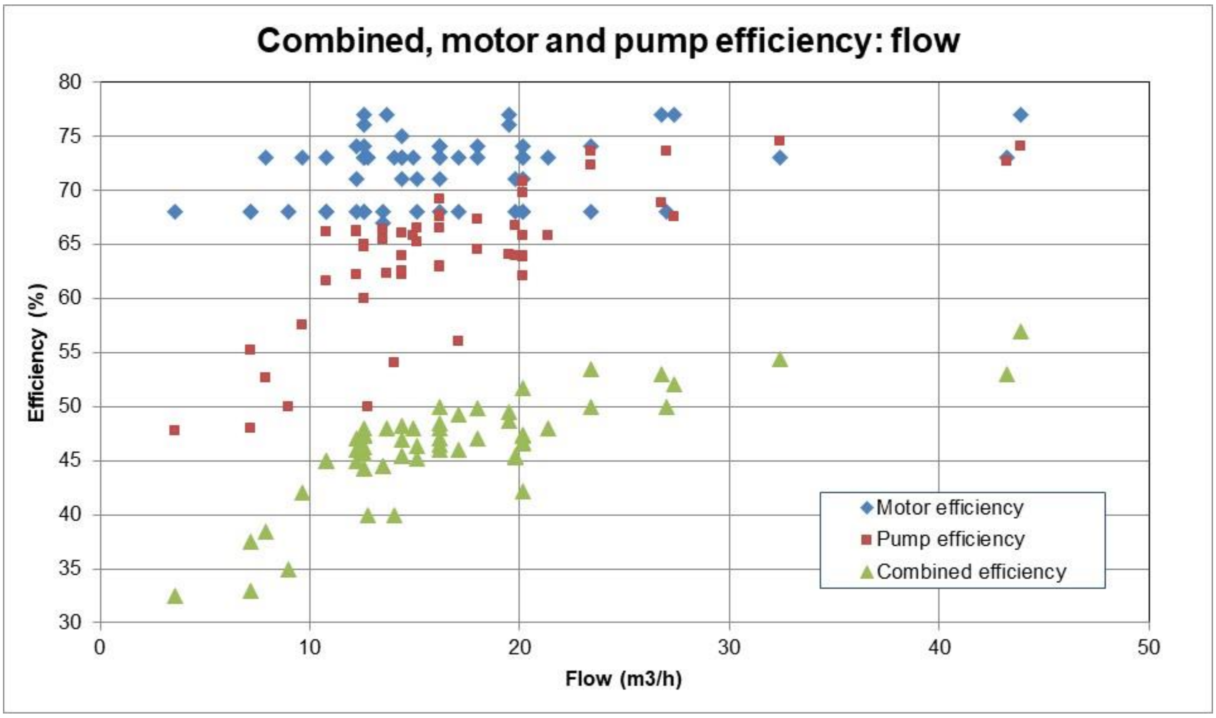


Figure 8 Comparison of Indian pumps: efficiency vs. flow

The relationship of the Indian pumps with Indian MEPS and 5-star label scheme shows that all pumps except 2 pass the BIS-MEPS and 10 are on or even exceed the 5-Star label line.

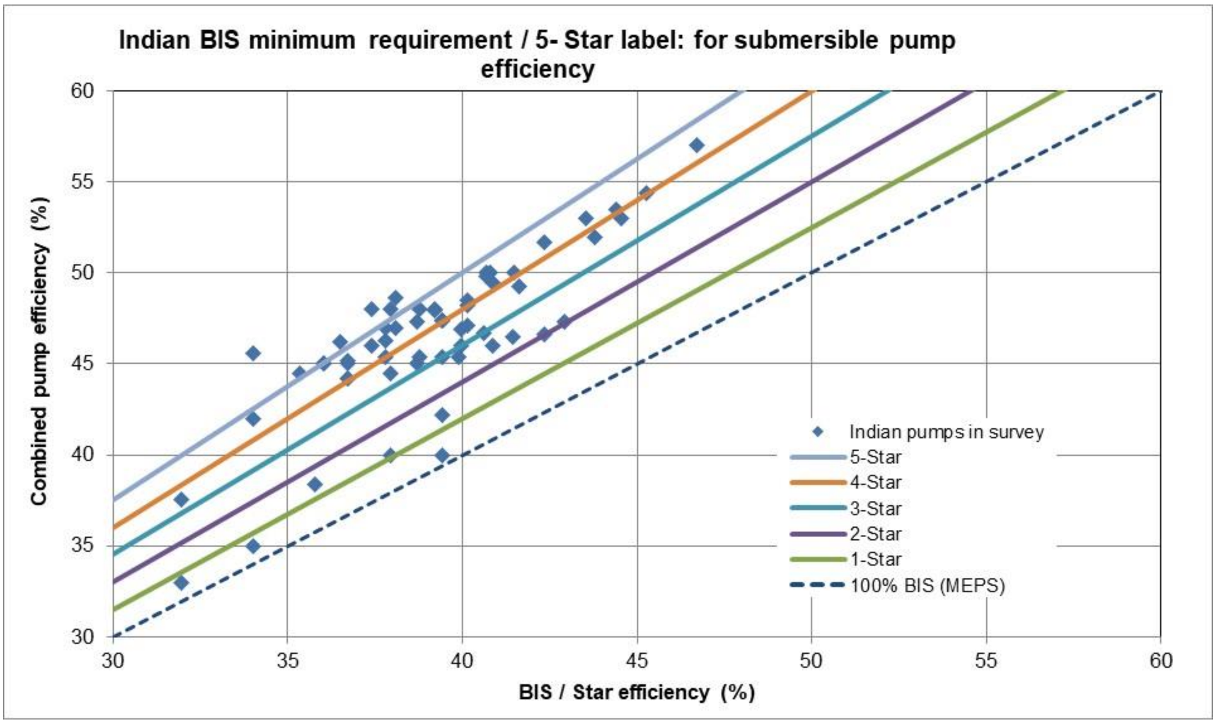


Figure 9 Indian pump efficiency requirements compared to market products

International pump manufacturers

There are a number of globally active pump manufacturers that supply submersible pumps for agriculture. In Europe, the Minimum Performance Standards for pumps (Ecodesign no 547, 2012), defines the required Minimum Efficiency Index for pumps (MEI). In February and March 2017 a survey was made with major 3 international pump manufactures using the same typology of most often used pumps in India. These manufactures delivered their data for performance, efficiency and impeller manufacturing for 30 submersible pumps. Also, these data were not verified by tests.

Comparison of Indian and international borehole pump performance

The comparison of the efficiencies with Indian and international products shows that the international products show a considerably higher overall efficiency when compared with head, flow and mechanical output (see Figure 10, Figure 11 and Figure 12). The efficiencies are all compared at the same level (best efficiency point) and do not take part load conditions into account.

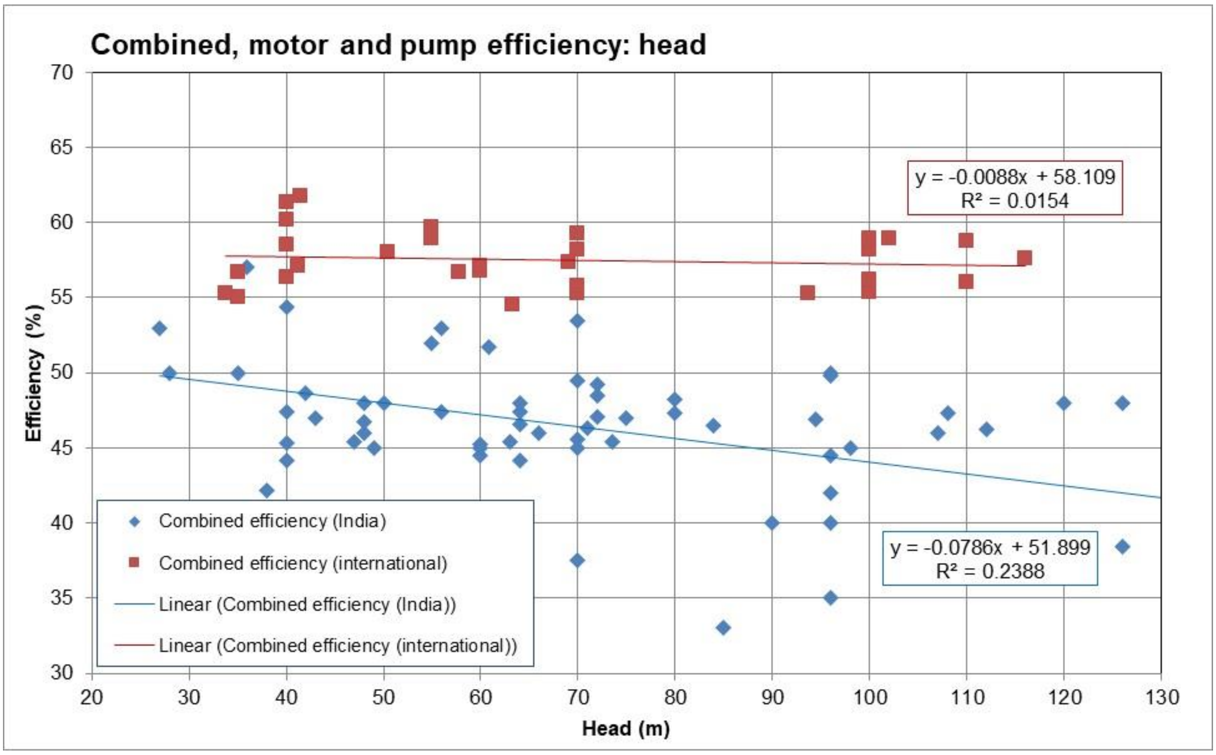


Figure 10 **Indian and international pumps, combined efficiency: head**
(linear correlation with equation and R^2 is given for Indian and international pumps)

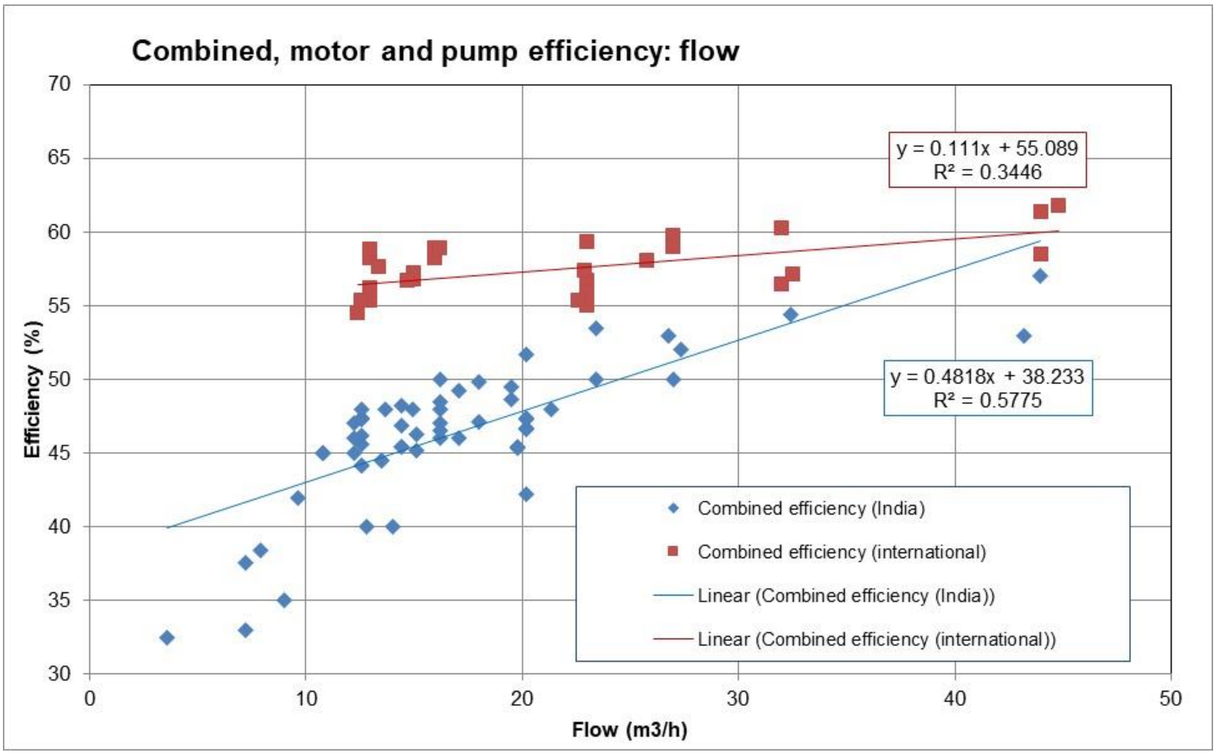


Figure 11 **Indian and international pumps, combined efficiency: flow**
(linear correlation with equation and R^2 is given for Indian and international pumps)

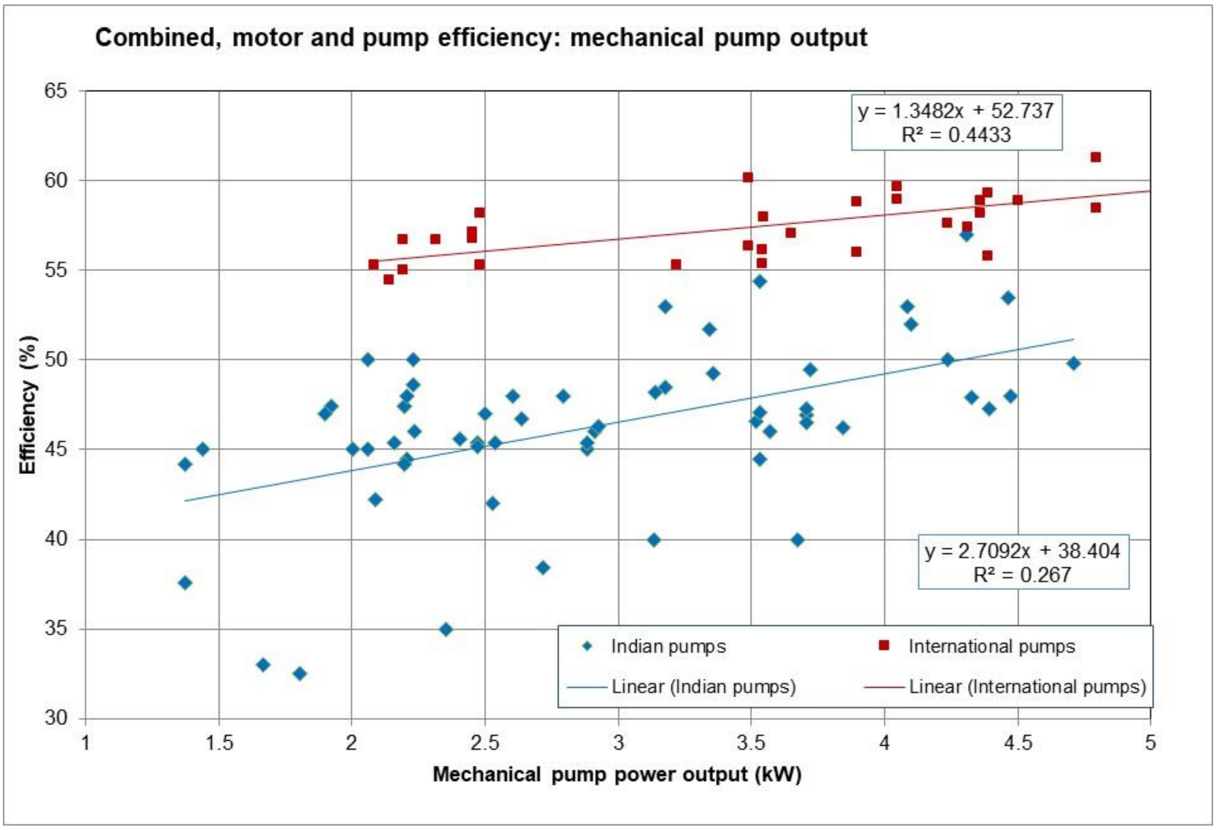


Figure 12 **Indian and international pumps, combined efficiency: mechanical pump output**
(linear correlation with equation and R^2 is given for Indian and international pumps)

Indian procurement program

The goal of the Indian procurement and financial incentive programs is to increase the market share of 5-Str pumps and due to bulk purchase lower their price premium. The current tendering and allocation program in 6 states with 5-star pumps by the Energy Efficiency Services Limited (EESL) program is a good point in case. EESL, an energy service company under administrative control of Ministry of Power, Government of India, has taken up the initiative of accelerating the implementation of Agriculture Demand Side Management (AgDSM) program in India. Initially, the program aims to expand through four states targeting nearly 7 million pump sets across the states of Andhra Pradesh, Maharashtra, Rajasthan and Karnataka. EESL has successfully completed its first AgDSM pilot project for 590 pump sets in Byadgi and Nippani circles under the Hubli Electricity Supply Company Limited (HESCOM) in the State of Karnataka. Additionally, it has also completed the replacement of 1'337 pump sets in Mandya District under the Chamundeshwari Electricity Supply Corporation Limited (CESC) in the State of Karnataka. Presently, EESL is replacing 2'496 pump sets at Rajanagaram Mandal in East Godavari District under the Eastern Power Distribution Company of A.P. Limited in the State of Andhra Pradesh.

Under AgDSM projects, EESL would bear the upfront capital cost in implementation of the AgDSM projects, hence leading to no upfront capital investment of the State Electricity Utilities or the State Governments. The investments made by EESL are recovered from the State Electricity Utilities over a fixed project duration through the energy savings achieved by replacement of the existing inefficient pump sets with Energy Efficient Pump Sets. By replacing the existing inefficient pump sets with BEE Star Rated Energy Efficient Pump Sets, the demand of electricity consumption in the Agricultural Sector in India is expected to reduce, and thereby help in the Prime Minister’s vision of achieving energy efficiency and reduction of carbon footprint.

Table 7 Features of National Energy Efficient Agriculture Pumps program by EESL

Smart BEE star rated Energy Efficient Agricultural Pump sets be distributed to farmers.
Farmers can replace their inefficient agricultural pump sets free of cost.
Pumps to come with Smart Control Panes that has a SIM card and a Smart Meter.
Smart Control Panel will enable a farmer to switch on or switch off these pumps through his mobile and sitting at the comfort of his home.
Smart meters to ensure the farmers to monitor consumption on real time basis.
EESL to distribute 200'000 BEE star rated pump sets to the farmers under this program, which will lead to 30% of energy savings by 2019. This translates into an annual savings of approximately EUR 3 billion (INR 200 billion) on agricultural subsidies or electricity savings of 50 TWh/a.

Source: Press Information Bureau, Government of India, Ministry of Power, 7 April 2016

The way forward: pilot projects

It is evident that energy efficient pumps alone cannot solve the problem of sustainable irrigation in Indian agriculture. Besides opting for further improvement of efficiency and durability of domestic pumps and motors and the respective market transformation with more efficient pumps, the following pilot projects are under consideration:

1. Technical assistance: Know how exchange for pump manufacturers and support the development of testing and training centers to improve the efficiency and durability of pumps and motors.

2. Capacity building: Training programs for borehole drillers and farmers to bring efficient pumps into efficient operation.

3. Adaptation: Pilot field with new irrigation methods and harvesting of water during monsoon in order to better recharge the wells. The irrigation method and water source and their necessary

recharging techniques have to be readjusted in order to provide well growing nutritional crops with much less water.

4. Policy dialogue. To improve and internationally harmonize Indian standards and labels for pumps with round robin tests.

5. Documentation. Publish guidelines for sustainable irrigation, best practices in pump manufacturing, maintenance and installation practices

6. Electric power: Pilot electric installations, controls and monitoring for pump stations. This serves as a basic element for the electric power production, supply and distribution system to developing more economical terms for consumers.

Only with positive economic incentives (separate from subsidies for crop production) the power plants, the Discoms and the farmers can survive sustainably on the Indian market.

Summary

Preliminary findings from a survey of 61 Indian pumps from 11 Indian manufacturers with 30 international pumps from 3 global manufacturers seem to confirm that the Indian products still have some possibilities to improve their efficiencies, both in the motor, the pump and combined. This means also that the Indian MEPS and the based upon 5-Star label scheme can be upgraded in the next years and converted into a mandatory scheme. The market transformation envisaged in the next decade that can replace the entire pump stock within their expected lifecycle will require considerable investments both from manufacturers and discoms and will also have to include farmers.

On the other hand, this efficiency research also shows that the larger problem of sustainable irrigation for Indian agriculture also needs to engage both in the water side (more efficient irrigation techniques and sustainable wells with recharging) as well as in the electricity supply which has so far been outside of the economic sphere and thus providing negative incentives for efficiency improvement and sustainability. The proposed pilot projects will help to develop a clearer avenue for a larger campaign toward sustainable agriculture.

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