Chapter 7

The Food-Water-Energy-GHG Nexus

7.1 Introduction

The eight per annum GDP growth for India, which is being targeted by the 10^{th} plan, crucially hinges on the growth of power availability at close to 15% per annum. If India is to meet this growth target for power availability, its entire requirement cannot come solely from supply augment. A major contribution will have to come from savings through better demand management and improvement in the end use efficiency.

The agriculture water pumping which is not only the major consumer of power in India (one third of total power consumption) but also one of the most inefficient users of the power will be the main important source for the savings through better demand management. This is also significant for the health of the power utilities in all the states which after selling a very high proportion of power (as high as 50%) for the agriculture pumping barely get a revenue return. This constitutes a of maximum 10% of the total revenue to them. The problem is further compounded by the fact that of the total water used in India – 25bcm – 83% goes for irrigation and of this amount half comes from the exploitation of the ground water resources. This not only creates stress on the water table but also is high energy intensive. Energy intensity of pumping is increasing further because of falling water table. This has implication for the sustainable development and its impact on the persons below the poverty line. This is because even today more than 60% of the work force in India is employed in farming activity and almost 70-80% of the poor in the country are either marginal farmers or the land-less labourers. A fall in the water table would first impact them and on their ability to pump ground water for irrigation.

Besides the above, the inefficient water pumping in the agriculture sector also has its impact on global warming and climate change though the emission of the green house gases (GHG). Carbon di oxide (CO_2) constitutes almost 90% of the total GHG emitted by burning of fossil fuel. In India, burning of coal in power plants emits nearly 50% of the total carbon emissions. This has both global as well as local implication for India.

Some of the global impacts of climate change and global warming are:

- Sea Level – rise of 1-3 feet in the next 100 years
- Health Impacts – Increased disease, particularly water borne disease
- Agriculture – Net loss on world's food supply

- Ecosystem – Rapid changes/movements of ecosystems; climate zone could move 150-550 km toward poles in mid-latitudes
- Property Damage – Increase in erosion, flooding, cyclonic activity, storm surges, sea roughness, torrential rain, $400 billion property damage in past decade
- Warming – Increase in global temperatures by 1-3.5 degrees C in next 100 years; higher at higher latitudes.

7.2 Global warming and climate change impacts for India.

7.2.1 Food Security

One of the major concerns in the region is meeting the food demand of the growing population. The region is largely agrarian and the agriculture sector is highly dependent on the summer monsoons. Variability in monsoons as a result of climate change is of great concern for food security in the region.

7.2.2 Agriculture

The main direct effects will be through changes in factors such as temperature, precipitation, length of growing season, and timing of extreme or critical threshold events relative to crop development, as well as through changes in atmospheric CO_2 concentration (which may have a beneficial effect on the growth of many crop types). Indirect effects will include potentially detrimental changes in diseases, pests and weeds, the effects of which have not yet been quantified in most available studies. In the tropics where some crops are near their maximum temperature tolerance and where dry land, non-irrigated agriculture predominates, yields are likely to decrease.

Both crops and livestock would be affected by increased pestilence of alien/invasive pests and diseases. An increase in temperature, despite a reduction in humidity, can reduce the ability of farmers to work. As a result, low-income rural populations that depend on traditional agricultural systems or on marginal lands are particularly vulnerable to climate change. The livelihoods of subsistence farmers, who make up a large portion of rural populations in some regions, would be adversely affected. In regions where there is a likelihood of decreased rainfall, agriculture could be significantly affected.

Rice crops can tolerate a maximum air temperature of around $30^{O}C$ during most of the growing period although it could be subjected to higher temperatures for shorter periods during breaks or early withdrawals in monsoons. Temperature influences the growth rates and productivity of rice crops. Higher temperatures have negative impact on the rice growth and productivity. The situation is similar for sorghum, and pearl millet, which are exposed to high temperatures in Rajasthan, India (Mitra, A.P., Dileep Kumar, K. Rupa Kumar, Y.P. Abrol, Naveen Kalra, M.Velayuthan, S.W.A. Naqvi, 2002).

According to Panayotou et al., (1999) India will suffer severely from potential changes in temperature and precipitation. Sinha and Swaminathan (1991) have shown that a 1^0 C increase in temperature will reduce the duration of the wheat crop by one week. A one-week reduction in crop duration may lead to a reduction in yield by 400 to 500 kg/ha. Hence, the potential rise in temperature would have disastrous consequences on wheat production in India. Adverse changes in precipitation will affect rice production adversely since nearly 60% of the rice area is rain fed. Wheat and rice contribute nearly 75% to total cereal production in the country (Swaminathan M.S., 2002). Also studies carried out in the later half of the 1990s (Gadgil, 1995; Sinha, 1997; Lal et al., 1998; Sinha et al, 1998; Watson et al., 1998; Kumar and Parikh, 1998) indicate that grain yield of wheat in Punjab will reduce by 8.1%, 18.7% and 25.7% if the temperature increases by 1^oC, 2^oC and 3^oC respectively. In Bangladesh, the impact of climate change on high yield rice varieties using the CERES-Rice model and several scenarios and sensitivity analysis found that increased CO_2 levels increased rice yields. However the high temperatures reduced rice yields in all seasons and in most locations. The detrimental effect of temperature rise more than offset the positive effects of increased CO_2 levels (McLean, M.F., Sinha, S.K., Mirza, M.Q., and Lal ,M. 1998).

Vulnerability of agricultural production to climate change depends not only on the physiological response of the affected plant, but also on the ability of the affected socio-economic systems of production to cope with changes in yield, as well as to changes in the frequency of droughts or floods. The adaptability of farmers in India is severely restricted by their heavy reliance on the vagaries of monsoon and the paucity of complementary inputs and/or institutional support systems. Dr Swaminnathan suggests a proactive methodology of monsoon management for agriculture (Swaminathan M.S., 2002).

Basically he suggests three components – i) train people at different levels, ii) to conserve and manage water, and iii) develop contingency plans to suit different rainfall patterns and work out a compensatory production programme.

7.2.3 Infrastructure

Given increasing population density in coastal zones in India, long lead times for implementation of many adaptation measures, and institutional, financial and technological limitations (particularly in many developing countries), coastal systems should be considered vulnerable to changes in climate.

7.2.4 Mountainous regions and glaciers

Substantial elevation shifts of ecosystems in the mountains and uplands of Tropical Asia are projected. At high elevation, weedy species can be expected to displace tree species, though the rates of vegetation change could be slow compared to the rate of climate change and constrained by increased erosion in the Greater Himalayas. The Himalayas have a critical role in the provision of water to continental monsoon Asia. Increased temperatures and increased seasonal variability in precipitation are expected to result in increased recession of glaciers and increasing danger from glacial floods.

The Gangotri glacier in the Himalayas is the source of water for the perennial river Ganga. This glacier like many others all over the world has also felt the impact of climate change. Studies carried out in the past few years have shown that the glacier is retreating at a speed of about 30 metres every year. If warming continues, it will melt rapidly, releasing large volumes of water but once this source begins drying, there may be dry periods with very little water flowing in the river (IPCC 2001).

7.2.5 Forests

Though there are uncertainties with respect to projections of climate change on forest ecosystems, evidence is growing to show that climate change coupled with socio-economic and land use pressures is likely to adversely impact forest biodiversity, biomass productivity, carbon sink and/or carbon uptake rates. Planning and implementation of adaptation strategies in forestry sector would require long term planning and long gestation periods unlike, say, changing crop production practices. Thus, developing countries must initiate long-term studies for assessing the vulnerability and impacts of climate change on forests and tree plantations (Ravindranath N.H. 2002).

7.2.6 Coastal regions and natural ecosystems

Changes in climate will affect coastal systems through sea-level rise and an increase in storm-surge hazards and possible changes in the frequency and/or intensity of extreme events. Large numbers of people also are potentially affected by sea-level rise. For example, tens of millions of people in Bangladesh would be displaced by a 1-m increase (the top of the range of IPCC Working Group I estimates for 2100) in the absence of adaptation measures. The Asian Development Bank (ADB, 1994) study indicates that for a 1 m sea level rise, about 50% of the total Indian population, which is residing along the Indian coast will be impacted.

Socio-economic impacts could be felt in major cities and ports, tourist resorts, commercial fishing, coastal agriculture and infrastructure development.

Especially at risk are large delta regions of India and Bangladesh. Extent of coast and coastal wetlands, including mangroves is large in India and Bangladesh (Sunderbans), which will undergo major change, depending on the rate of climate change. Coral reefs may be able to keep up with the rate of sea-level rise but will suffer bleaching from higher temperatures. In India sea level rise will affect many regions, with the Andaman and Nicobar islands, the Lakshadweep islands in its South western part, the low lying deltaic region in West Bengal, and the Kutch region in Gujarat are likely to be the most vulnerable areas (Asthana, 1993).

7.2.7 Power

An increase in atmospheric temperature results in a higher rate of water evaporation from the hydro reservoirs, thus reducing available reserves for power generation. The limited availability of water in the reservoirs will require the addressing of complex water management issues in the areas of power generation and irrigation in multipurpose reservoirs. The efficiencies of thermal generation plants, other industrial thermal installations and engines used in vehicular transport are directly related to the atmospheric temperature. Therefore, any increase in atmospheric temperature results in lower plant efficiencies thereby affecting overall efficiency of the plants. Also, with increased atmospheric temperature, the efficiencies of cooling equipment drop affecting all forms of industrial, commercial and domestic sector installations involving a cooling component. Further, there will be an increased demand for air-conditioning and ventilation due to high temperature environment. This in turn increases GHG emissions per unit of energy output.

7.3 Objective of the Study

The objective of the current study is to explore the food-water-energy-environment nexus (see figure 7.1). The study attempts to quantify the correlation between the water table and its implication on global warming and climate change. This is established through quantification of the energy use in ground water pumping for irrigation and tracking it to the amount of green house gases emitted by burning of fossil fuel like coal and diesel. The study also addresses the effects of changes in ground water level to the emission of green house gases. Haryana and Andhra Pradesh are selected as the representative states, because ground water pumping is quite predominant in these states.

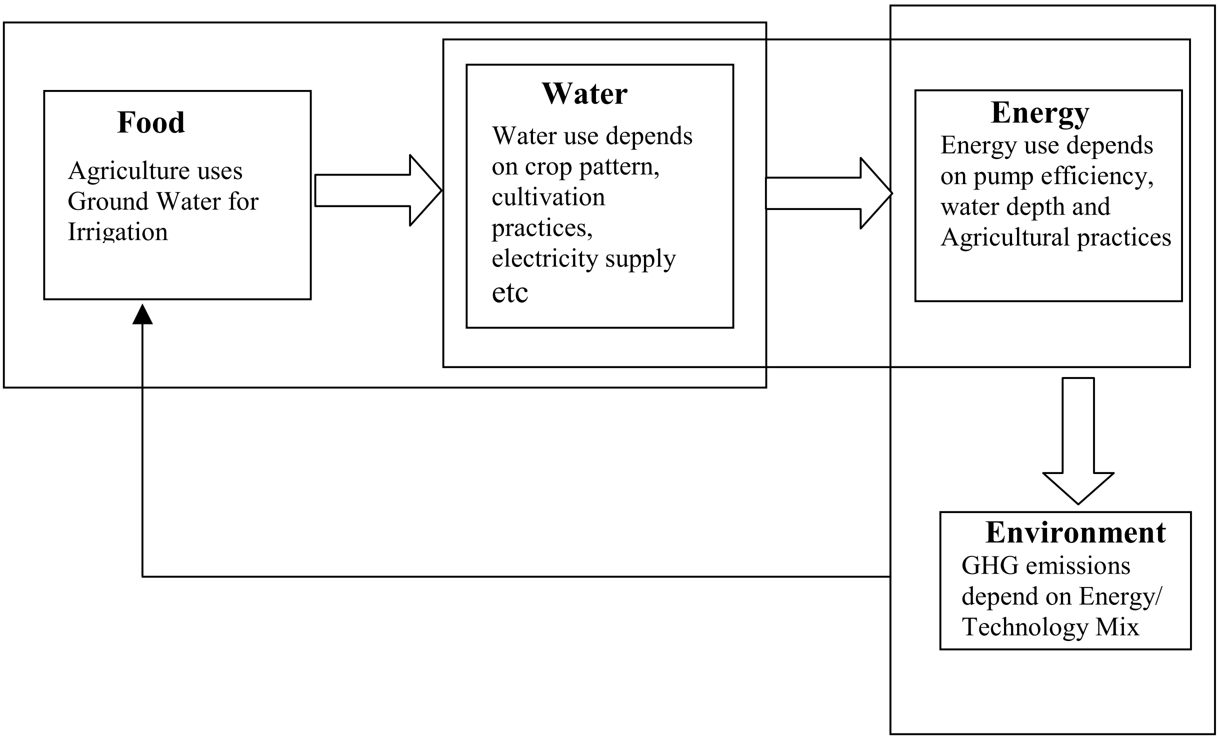

Figure 7.1 The food-water-energy-environment nexus

The study is also quantifies other factors, which contribute to extra consumption of power in ground water pumping for irrigation. The other factors include the different losses in the system right form the point of generation to the point of use. This quantified loss at different stages is translated into the additional fossil fuel burnt thereby leading to additional green house gasses generated.

The study also covers the Sensitivity of Different Parameters on the Green house Gas Emission. Based upon specific trends observed in the total system of Ground Water Usage as a Source of Irrigation in the country, the Study tries to provide Futuristic View on the Emission Level of Green House Gas.

The entire methodology has been further developed into a user-friendly spread-sheet model for the replicable calculation of the GHG impacts of ground water pumping in agriculture.

7.4 Findings of the study

The actual calories used by the farmers after burning of 100 Calories at the power plant is barely 2%.

DEMAND CHAIN	SUPPLY CHAIN
Amount of Water Required For Cropping x Head	EXTRA POWER TO BE CONSUMED DUE TO THE WATER TABLE FALL and OTHER AGRONOMIC PRACTICES
Energy Required To Lift Water given the Water Table (static head)	**OUTPUT AT THE FARM-2%** THE LOSSES DUE TO POOR WATER MGMT-60% (approx)
Energy Required x Efficiency of the Pump-Set = Energy @pump to lift water	**PUMP OUTPUT OF 5%** PUMP-SET EFFICIENCY 27% (approx)
Energy@pump x Distribution efficiency x transmission efficiency	**DISCOM-OUTPUT OF-18.63%** DISTRIBUTION LOSSES 25% (approx)
ENERGY REQUIRED X GENERATION EFFICIENCY	**TRANSCOM-OUTPUT OF 24.84 %** TECHNICAL LOSSES 8% (estimated)
GHG EMISSION	GENERATION-OUTPUT OF 27% (ESTIMATED) ▪ CONVERSION EFFICIENCY ▪ OPERATION EFFICIENCY ▪ AUXILIARY CONSUMPTION

GHG emission will also be due to transportation of fuel and mining of the fuel. These have however been excluded from the current estimation.

Figure 7.2 Supply and demand chain of ground water pumping for agriculture

The rest of the calories are lost in the system either due to conversion losses or due to inefficient use. This is illustrated in figure 7.2. The diagram also depicts the methodology adopted for the calculation of GHG emission due to water pumping in the agriculture sector.

The impact and quantum of GHG emission from ground water pumping are dependent on a number of factors. These factors as identified based on the case study of the two target states are:

- Area under different crops
- Static Head (Ground Water Table)
- Friction Head
- Velocity Head
- Leakage
- Water intensity of the crops
- Irrigation Efficiency
- Pump and motor efficiency
- Farmers distribution losses
- Share of the diesel pump-set in total
- Losses due to power quality
- Losses due to untimely supply/improper agricultural practices/lack of knowledge about other crops/alternate use of water and power/lack of metering
- Transmission and distribution losses
    - Reactive losses
    - Transformer Losses
    - Distribution Losses
- Conversion loss and auxiliary consumption at the power plant

Some of the above factors are not found to be very significant in terms of their impact on their GHG emission and have been estimated based on the qualitative interaction with the concerned stakeholders. But there were others, which were found to have a huge impact on GHG emission. These factors, which were found to be significant in terms of their impact were calculated based on data available in the two-target states. Figure 7.3 gives the build up for GHG emission from agriculture ground water pumping.

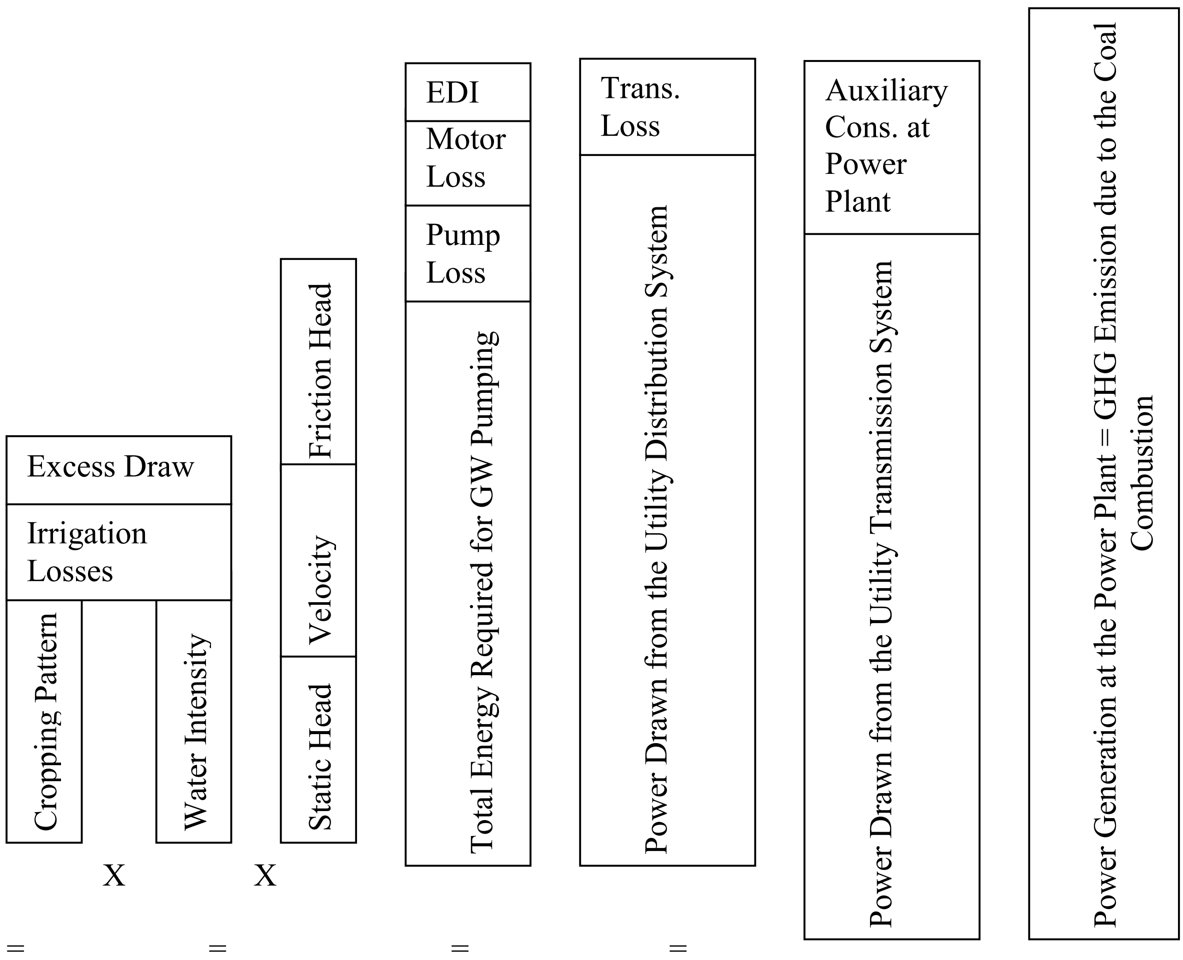

Figure 7. 3 Build up for GHG emission from agriculture ground water pumping

7.5 The GHG -Model

This is a genetic model and can be used for any location. All the technical and behavioral factors involved in the process of ground water pumping for agriculture applications and its inter linkage with green house gad emission has been covered in this model. The model has two parts: one section that covers the GHG emission and the other section that covers the sensitivity of the factors to the GHG emission. In the subsequent sections the data requirement for operating the model is discussed, along with the application and limitations of the model.

7.5.1 Equation for impact on GHG Emission

The impact on GHG emission due to variation of different parameters differs from state to state. An example is worked out for the representative states of Haryana and Andhra Pradesh and the model can be use to determine the coefficient of different parameters. There are in all twenty-seven parameters that, when varied, will cause a change in GHG emission, but some of them are insignificant in case of the representative states and hence have been eliminated from the equation. The equation is given below:

$$\delta E = \alpha C + \beta G + \lambda D + \mu W + \theta I + \tau P + \omega M + \Psi TD.$$

Where:

δE	: Change in the level of GHG emission in percentage
α	: Coefficient for change in crop area
C	: Change in crop area
β	: Coefficient for share of ground water irrigation in percentage
G	: Change in share of ground water irrigation in percentage
λ	: Coefficient for share of diesel pump-sets
D	: Change in share of Diesel pump-sets.
μ	: Coefficient for change in ground water level
W	: Change in the ground water table in percentage
θ	: Coefficient for change in irrigation efficiency
I	: Change in the irrigation efficiency
τ	: Coefficient for change in pump efficiency
P	: Change in the pump efficiency in percentage
ω	: Coefficient for change in motor efficiency
M	: Change in motor efficiency in percentage
Ψ	: Coefficient for distribution loss (both reactive and active)
TD	: Change in distribution loss (both active and reactive) in percentage.

All the coefficients were calculated for the representative states of Haryana and Andhra Pradesh. Based on them the coefficient for India was calculated as a simple average. Table 7.1 shows the value of the coefficients for representative states along with the national values.

Table 7.1: Value of coefficients

Coefficients	Haryana	Andhra Pradesh	India
α - Crop Area	2.15	2.2	2.2
β - Share of GW Irrigation	2.15	2.2	2.2
λ - Share of diesel pumps	-0.5	-0.1	-0.3
μ - Ground water level	0.44	0.39	0.43
θ - Irrigation efficiency	-2	-2.2	-2.1
τ - Pump efficiency	-0.8	-1.0	-0.9
ω - Motor efficiency	-0.7	-1.0	-0.85
Ψ - TD losses	0.4	0.3	0.35

7.5.2 Data Analysis

Analysis of the available data gives the following results:

- Under the present condition, every meter change in the ground water table will mean a change of 4.374% in GHG emission for Haryana and 6% for Andhra Pradesh considering all other variables remaining constant.
- The coefficient behaves as a constant for a variation in ground water level up to +/- 25%
- For every percentage increase in cropping the GHG emission increased by 2.2%. The cropped irrigated area has increased by CAGR 3 % per annum in 1990s and hence the total impact of cropped area under irrigation on the GHG emission is 6.6% per annum.
- The GHG emission increases by 2.2% for every percent increase in the share of ground water irrigation.
- Share of diesel pump-set had an inverse correlation of 0.3% with the GHG emission for every percentage increase in the share of diesel pump-set indicating that the variable is not very significant
- Irrigation efficiency has a major impact on GHG emission. For every percentage change in irrigation efficiency, GHG emission inversely by 2.1%. But there is little exogenous control on this factor for it to be a major policy tool for GHG mitigation.
- Motor and Pump Efficiency
    - Inverse exponential curve, but with in a range of +/- 25% the value of the coefficient remains stable in the range of 0.9 for pump efficiency & 0.85 for motor efficiency.
    - For every percentage change in efficiency the fall in GHG will be 0.9 % for pumps and 0.85% for motors. This is an attractive policy tool

    - Improvement of pump efficiency from the current level of 37% to 41% would mean GHG saving of 9%
    - Improvement of motor efficiency from the current level of 70% to 77% would mean fall in GHG by 8.5%.
- T & D Losses both active and reactive
    - The relationship indicates that for every percentage change in T & D losses the GHG emission is affected by 0.35%.
    - Sample survey in Haryana have indicated that the T & D losses in agricultural sector due to poor supply voltage. The power factor of the surveyed sample indicated an average of 0.85, which is healthy.

7.6 Conclusion

The potential for improving the irrigation system in India is very high. The study shows that three important modifications can be easily done in the system to improve the efficiency of the ground water pumping. The parameters are state independent and thus can be altered without much policy interventions. The three parameters are:

- Decreasing the discharge velocity.
- Improving the pump efficiency by better selection & design.
- Improving the motor efficiency by better selection & design.

The three parameters are farm dependent and would require active participation of the end users. This will involve capacity building in the end user community for sustainability of the project. Pilot projects can be developed along these lines and later extended to other areas.

The major stakeholders for this project would include the State Electricity Boards (SEBs), the generators, the lenders, government and other end users. India being predominantly a power-deficit state, it would require considerable investments in the power sector to meet power shortfalls. This would divert the capital from other more lucrative areas to this sector through fiscal measures, which would affect the growth of other sectors. The receipts from the agriculture sector to the power sector are insignificant affecting the health of SEB's. Thus, implementing a type of the above-discussed project will primarily benefit the SEB's and also other stakeholders like generators, material suppliers, alternate users and government.