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Carbon credits for energy self sufficiency in rural India – A case study

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Abstract

Carbon Credits are a tradable permit scheme under UNFCCC (United Nations Framework Convention for Climate Change) which give the owner the right to emit one metric tonne of carbon-di-oxide equivalent. They provide an efficient mechanism to reduce the green house gas emissions by monetizing the reduction in emissions. Rural India has a tremendous potential to earn carbon credits by setting up household based energy substitution or fuel switching projects like biogas plants, solar cookers and solar cells, smokeless chulhas etc. In this study, we propose a generalised mathematical model that will estimate the economic viability and feasibility of a Programmatic CDM (Clean Development Mechanism) based household biogas plant project for energy self sufficiency in rural India. The design variables are rank ordered using statistical analysis. The basis of this model is the research study conducted in 10 villages of Jhunjhunu district of Rajasthan, India spanning a population of around 31,000 people. This model can be applied to any village in India. It can calculate the number of years the Programmatic CDM based household biogas plant project should be sustained so that the income generated from the sale of carbon credits earned by the project makes the project economically viable.

Keywords: carbon credits, global warming, rural India, modelling, biogas plants

Nomenclature:

W: Willingness to Invest in a biogas plant: Estimated on a scale of 1-10 based on a questionnaire
C: Cost of fuel per day per household in INR
P: Prior knowledge of biogas plants: Estimated on a scale of 1-5 based on a questionnaire
E: Energy needs for cooking of an household, is taken to be proportional to number of family members
A: Annual income per household in thousands (INR)
N: Number of cattle per household

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1. Introduction

Global warming is an imminent catastrophe with irreversible consequences. The Kyoto Protocol was adopted in Kyoto, Japan on 11th December 1997 and entered into force on 16th February 2005. 180 countries have ratified the treaty to date. It aims to reduce the green house gas emissions by 5.2% against the 1990 levels over the five year period 2008-2012. Developed countries are categorized under Annex 1 countries and are legally bound by the protocol while the developing nations, categorised as Non Annex 1 countries, which ratify the protocol are not legally bound by it. The Kyoto Protocol has three mechanisms: Joint Implementation (JI), Clean Development Mechanism (CDM) and International Emission Trading (IET).

The CDM mechanism allows Annex 1 countries to meet their reduction targets by implementing emission reduction projects in Non Annex-1 developing nations. A CER (certified emission reduction) is a certificate given by the CDM board to projects in developing countries to certify that they have reduced green house gas emissions by one metric tonne of carbon-di- oxide equivalent per year. These CERs are bought by the Annex 1 countries to meet their emission reduction targets.

Under Joint Implementation (JI), an Annex 1 party may implement an emission reduction project or a project that enhances removal by sinks in another Annex 1 country. It can use the resulting ERUs (emission reduction units) for meeting its target.

Under the International Emission Trading (IET) mechanism, the countries can trade their surplus credits in the international carbon credits market to those countries with quantified emission limitation and reduction commitments under the Kyoto Protocol. Amongst the developing nations, India is considered as one of the largest beneficiary of the carbon trade through the Clean Development Mechanism (CDM).

2. Methodology

2. 1. Background

Global warming is caused due to the emission of greenhouse gases (GHGs) which get trapped in the atmosphere. Table 1 shows the global warming (GW) potential of gases. The potent green house gases are the following: carbon-di-oxide, methane, nitrous oxide, hydroflourocarbons, perflourocarbons and sulfur hexafluoride.

CERs awarded = Tons of GHG reduced x GW potential of the gas (metric tons of C) (1)

Table 2. Global warming potential of gases

Greenhouse Gas	Global Warming Potential
Carbon-di-oxide	1
Methane	21
Nitrous Oxide	310
Hydroflourocarbons	140-11,700
Perflourocarbons	7,000-9,200
Sulfur Hexaflouride	23,900

CDM projects are designed to have a leveraging effect on sustainable development [1, 2]. The outcomes of a CDM project must be aligned with the criteria for sustainable development of the host country. Clearance for sustainability is granted by the National CDM Authority and in India it is spearheaded by the Union ministry of environment and forests. The basic tenets of sustainable development are economic well being, environmental well being and technological well being.

Programmatic CDM is a new approach for developing CDM projects and is registered with UNFCCC as a PoA (Program of Activities). It is a voluntary coordinated action by a public or private entity consisting of unlimited number of CDM Project Activities (CPAs). A PoA can be formed of either large scale CPAs or of small scale CPAs. All projects under PoA must have an implementing entity authorized by host country DNAs (designated national authority).

Programmatic project activities are restricted to measures or initiatives where the induced greenhouse gas abatement activities and sources of emission reductions can be clearly identified and verified. Thus a policy that abolishes a subsidy on fossil fuels or implements a national or sectoral cap-and-trade system is not considered a programmatic project unless the induced actions are clearly identifiable, attributable to the measure and verifiable ex post [3]. The core characteristics of a programmatic CDM project are:

- They occur as a result of a deliberate program that is either a public sector measure or a private sector initiative.
- The program results in a multitude of dispersed actions that are induced by the program and would not occur but for the enactment of the program
- The GHG reducing actions do not necessarily occur at the same time.
- The type, the size and the timing of the emission reducing actions induced by the program may not be known at the time of project registration.

2.2. Execution

The methodology of execution of the research study is shown in Figure 1. The execution methodology consisted of the following stages:

2.2.1 Survey-1

The first stage of the research study involved survey and study of current energy sources and energy needs in villages near Pilani.

2.2.1.1 Selection of Villages

Surveys were conducted in 10 villages spanning the district of Jhunjhunu, Rajasthan, India. The selection of the villages was done to have a diverse sample space taking into account the following factors:

- Economic background of the village
- Population of the village
- Historical Background

On basis of the above parameters the following villages from Jhunjhunu district, Rajasthan, India were selected.

a. Baas

b. Dhandar
c. Jherli
d. Kazi
e. Kulhariyon ka Baaz
f. Likhowa
g. Naurangpura
h. Nuhand
i. Raila
j. Thirpali

The above villages each have population of around 2000-4000 people.

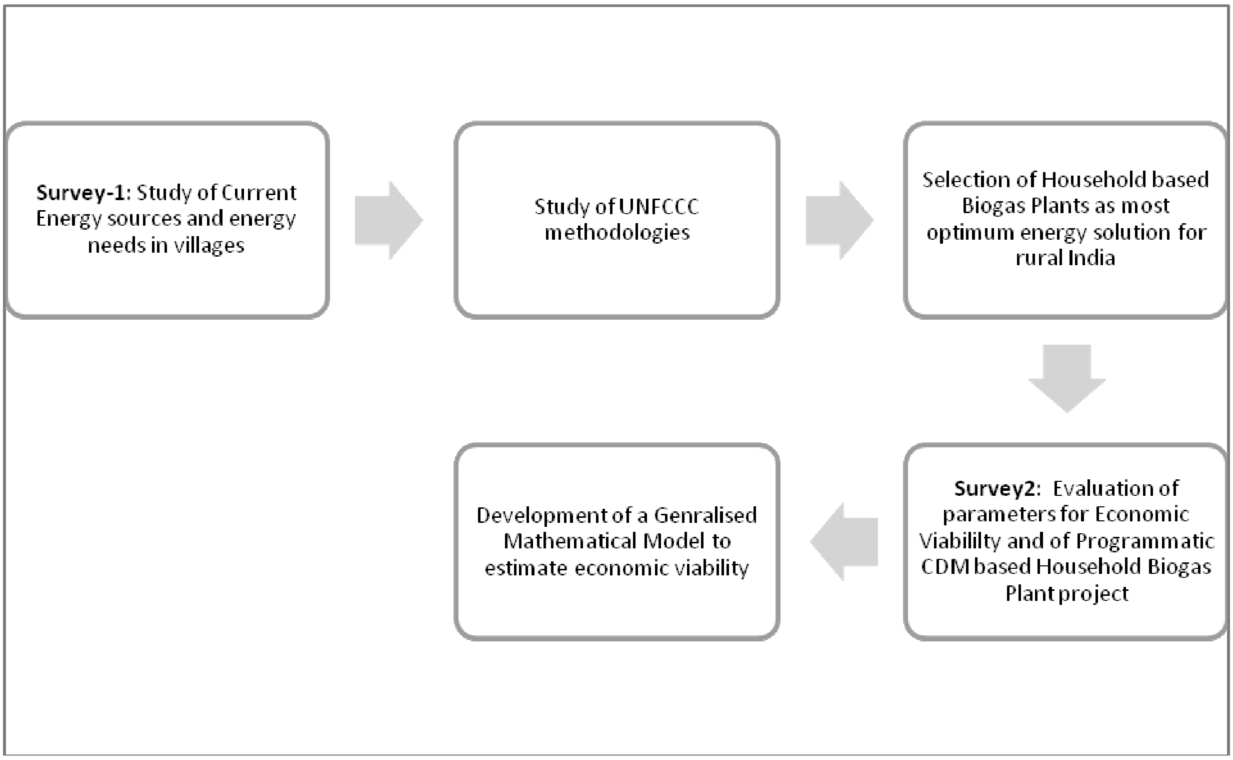

Fig. 1. Methodology of execution.

2.2.2 Study of UNFCCC methodologies

Clean Development Mechanism (CDM) small scale methodologies under UNFCCC relevant to the above selected villages pertaining to Energy Industries (renewable and non-renewable energy resources, sector-1), Agriculture (sector-13) and Waste handling and disposal (sector-15) were studied.

2.2.3 Selection of household based biogas plants

Biogas Plants were concluded to be the best solution to rural India's increasing energy needs and insufficient energy supply. Biogas plants also have the greatest potential to earn income from carbon credits amongst all other possible solutions like solar power, wind power etc.

2.2.4. Survey-2

Survey-2 was conducted in the same villages as Survey-1. This survey included evaluation of parameters for economic viability and feasibility for the Programmatic CDM based Biogas Plant project.

2.2.5. Development of generalised mathematical model

Based on the observations and analysis of Survey-2 a generalized mathematical model was formulated to estimate the economic viability of a Programmatic CDM based household biogas plant project.

3. Results and discussions

3.1. Research surveys

3.1.1. Survey -1

The objective of the first survey was to study the current energy sources and energy needs of the villagers. The parameters evaluated during the course of the first survey were:

a. Primary fuel used for cooking
b. Average consumption of fuel per day
c. Average distance travelled per day to obtain fuel for cooking
d. Electricity availability in hours per day
e. Appliances working on electricity and their daily power consumption

3.1.2 Survey-2

The biogas plants would be setup as a Programmatic CDM based project. The parameters evaluated in the second survey were:

1. *Willingness to Invest in a biogas plant:* Estimated on a scale of 1-10 based on a questionnaire-**W**
2. *Cost of fuel:* Cost of fuel per day per household in INR-**C**
3. *Prior knowledge of biogas plants:* Estimated on a scale of 1-5 based on a questionnaire-**P**
4. *Energy needs:* Energy needs for cooking of an household, is taken to be proportional to number of family members-**E**
5. *Annual income:* Calculated per household in thousands (INR)- **A**
6. *Number of cattle:* Calculated per household-**N**

The above parameters are the most critical for a biogas plant project implementation.

3.2. Observations

Typical observations for the village of Dhandar are shown in Fig. 2.

Figure 2-a gives a set of 10 observations from the village of Dhandar for the parameter- “Willingness to Invest” on a scale of 1 to 10. Figure 2-b gives a set of 10 observations from the village of Dhandar for the parameter “Cost of Fuel” in INR (Indian Rupees) per day for a

family. Fig. 2-c gives a set of 10 observations from the village of Dhandar for the parameter "Annual Income" in Thousands of INR (Indian Rupees). Fig. 2-d gives a set of 10 observations from the village of Dhandar for the parameter "Energy needs" or the number of persons in a family. Fig. 2-e gives a set of 10 observations from the village of Dhandar for the parameter "Number of cattle" in a rural household of India. Fig. 2-f gives a set of 10 observations from the village of Dhandar for the parameter "Prior Knowledge about biogas plants" in a family on a scale from 1 to 5.

Similarly data was collected from the other 9 villages and was analyzed.

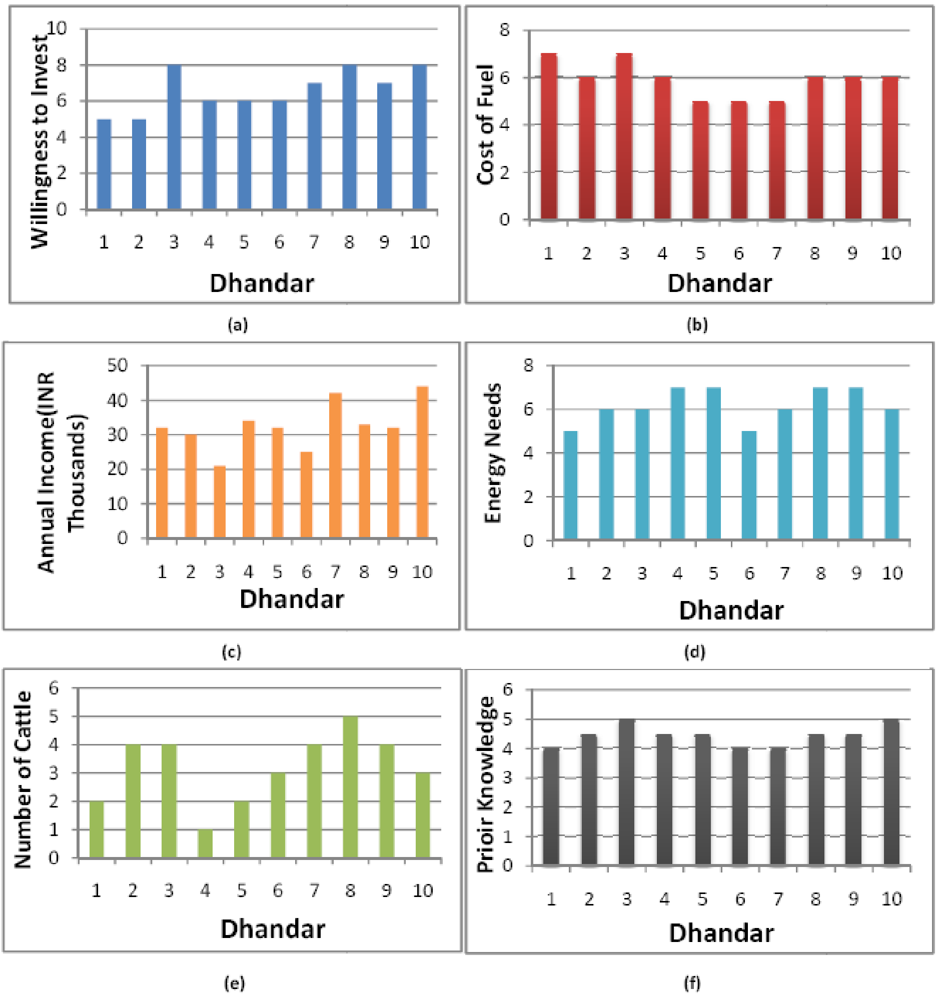

Fig. 2. Parameters of observation in the village Dhandar.

3. 3. Description of mathematical model

Based on the data collected from survey-2, a mathematical model was formulated, having one dependant and five independent variables [4]. The willingness to invest-W is the dependant variable and is a function of the independent parameters-number of cattle per household-N, annual income-A, prior knowledge of biogas plants-P, energy needs -E, cost of fuel-C are the independent variables respectively.

$$W = f(A,P,C,E,N) \qquad (2)$$

$$W = 0.189 \times \ln[(A)^2 + 1.216) + 0.541P + 0.287 \times e^{0.178C} + 0.134 \times (0.312 \times E^2 + 1.147 \times E) + 0.201 \times \ln(2.916 \times N) \quad (3)$$

Where;

W-Willingness to Invest

C- Cost of Fuel

E- Energy needs

N- number of cattle per household

A - Annual income per household

P- prior knowledge

The standard sizes for household based biogas plants in India are $1m^3$, $2m^3$, $3m^3$ and $4m^3$ respectively. But we have taken the most popular $3m^3$ *DeenBandhu* fixed dome model-Biogas plant, which has sold the highest number of units in India. Its output is sufficient to meet the basic energy requirements for cooking of an average Indian family.

The co-relation between size and CERs earned is 1.26 CERs for every one cubic metre volume of a fixed dome type biogas plant. This was calculated using UNFCCC small scale methodology- AMS-III.R [5] applied to Jhunjhunu district, Rajasthan, India.

3.4. Model application

The function gives the value of willingness to invest in a household biogas plant, which lies in the range of 1 to 10. With this value, it is possible to estimate the number of years the biogas plant should be sustained to make the project economically feasible. The model application is as follows:

-For a particular household the willingness to invest calculated from the proposed mathematical model is-"k" where k is an integer from 1-10.

-The cost of a $3m^3$ *Deenbandhu* biogas plant is INR 11,000 (including installation cost).

-The number of CERs (Certified Emission Reductions) per biogas plant of size 3cum is 3.48 [5].

3.5. Sensitivity analysis

The rank order parameter for each parameter was calculated using Eq. 4.

$$R = \sum |\partial F(A, P, C, E, N) / \partial y| * \Delta y \quad (4)$$

This rank order parameter indicates whether we are trading large positive incremental costs for large negative incremental costs or small positive incremental costs for small negative incremental costs [6].

From the sensitivity analysis performed on the function, it was found that the energy needs parameter was the highest rank order parameter (Fig. 3). The parameters such as cost of fuel and prior knowledge were also significant. The parameters namely; the number of cattle and average monthly income are less dominant when compared to the other parameters of prior knowledge, cost of fuel and energy needs.

Calculations : 1. Amount of money paid by the farmer $= \frac{k}{10} \times 11000$ 2. Ancillary cost per biogas plant including CDM registration cost, DOE verification cost, maintenance cost is assumed to be 20% of each biogas plant cost 3. Effective cost of each biogas plant= INR13200 4. Amount of money to be got from carbon credits $= \frac{(10-k)\times 13200}{10}$ 5. The price of CERs = 10USD= INR406(*primary CER market rate as of March, 2008) 6. The number of years the biogas plant should be sustained $= \frac{(10-k)\times 13200}{10\times 406\times 3.48}$	For a Sample Household in rural India with the following parameters: 1. Annual Income=INR 33000 2. Cost of Fuel per day= INR 7 3. Number of Cattle=2 4. Prior Knowledge of Biogas plants-3.5 5. Energy Needs- 6 6. From the Mathematical model, the willingness to invest is calculated to be-k=6.99 7. Hence the number of years, the plant should be sustainable= 2.81 years

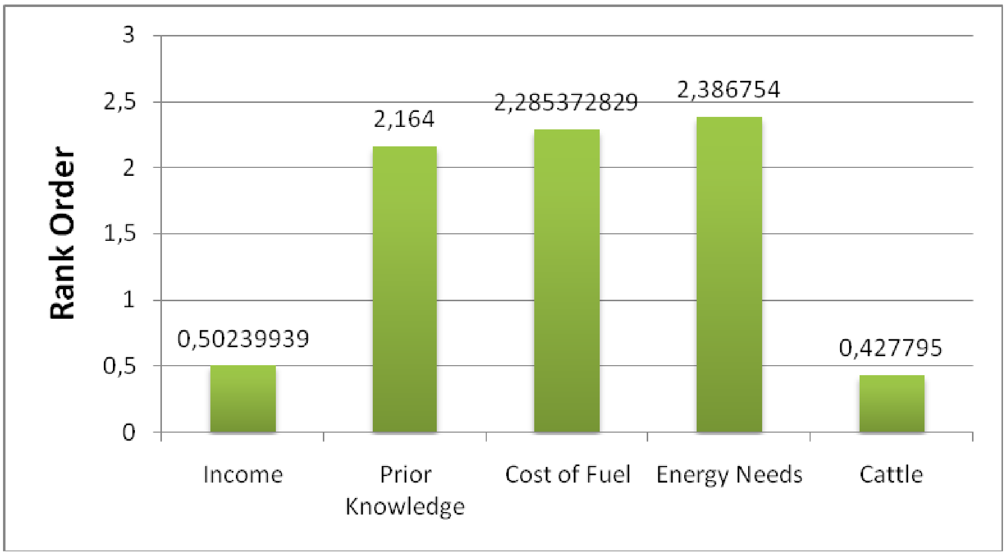

Fig. 3. Sensitivity analysis.

-Willingness to Invest

The willingness to invest depends on the parameters-annual income, prior knowledge, cost of fuel, energy needs and number of cattle. Since the rural population of India is facing an acute energy crisis, the willingness to invest in a renewable energy source like biogas plant is significant. They have easy access to the raw material-cow dung and require no technical expertise to operate the personalised household based biogas plant. This also helps to save the expenditure on procurement of daily fuel like wood, coal, kerosene etc. Unlike a community biogas plant, which will face many hurdles in installation and operation, this personalized biogas plant can be used according to the families' discretion.

The willingness to invest in biogas plants depends on the following parameters:

-Energy needs

Energy needs is the most dominant factor in the willingness to invest in biogas plants in rural India. Energy needs is taken to be directly proportional to the number of people in the household which is around 6 in the rural Indian scenario. Electricity supply in majority of rural India is limited to 6-8 hours a day. The current sources of energy are inadequate to meet the growing energy demands of rural India. Hence the willingness to invest in a biogas plant which serves as an excellent alternative energy source is very high.

-Cost of fuel

The cost of fuel is also a dominant variable in the willingness to invest in biogas plants in rural India. Due to the lack of electric supply as well as rising energy needs, the other sources of energy like kerosene, charcoal and wood have become expensive. Spending a significant portion of their limited income on procurement of fuels critically affects the standard of living of rural India. Hence cost of fuel becomes a dominant parameter in the willingness to invest in a biogas plant.

-Prior Knowledge

The prior knowledge of biogas plants is also a dominant variable in the willingness to invest.The prior knowledge was evaluated based on a questionnaire on a scale of 1 to 5. Lack of prior knowledge has been a major deterrent in the penetration of biogas plants in rural India. Hence prior knowledge has a significant contribution in the willingness to invest.

-Annual Income

The average annual income of rural India is low compared to its urban India. As a result, the rural masses are unable to switch to the more expensive sources of energy like LPG (Liquefied Petroleum Gas). The amount to be invested in the biogas plant is affordable for the rural masses and the input animal dung required is available at a nominal cost. Hence the contribution of the parameter -annual income towards the willingness to invest is not significant. If the income from carbon credits is included, the significance of annual income reduces further.

-Number of cattle

India has a cattle population of 289 million [7] and as a result cow dung is available in abundance and at a nominal cost. Hence less number of cattle per family does not affect the willingness to invest significantly.

3.6. Error analysis

Error of the values predicted by the model lies in the range of ± 10% (Figure-4). This suggests that the model is considerably accurate. There are 5 sets of data which lie outside this ± 10% error range. These are random errors due to faulty observations.

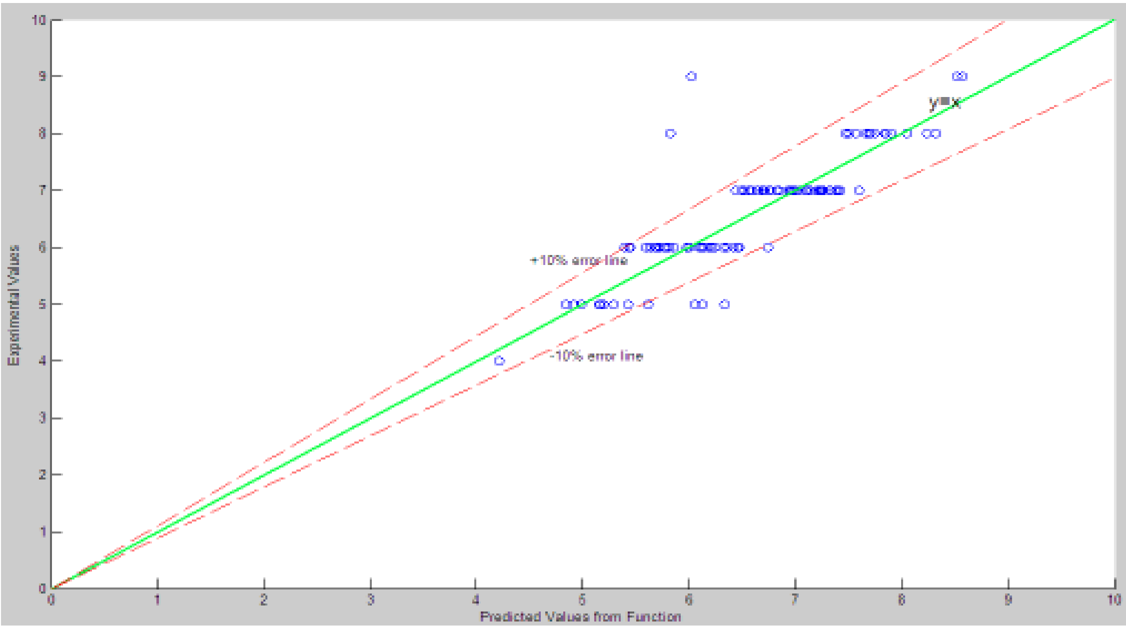

Fig. 4. Error analysis.

The average percentage error and standard deviation are calculated. If Yexp is the experimental value of the quantity and Ycal is the value obtained from the modelling equation, then the average percentage error Epa is defined as follows:

$$Epa = \frac{\sum_{i=2}^{N}\{[(Yexp - Ycal)/Yexp]\times 100\}}{N} \tag{5}$$

The standard deviation (SD) is calculated by the following formula,

$$SD = [\sqrt{\frac{\sum_{i=1}^{N}[Yexp - Ycal)/Yexp]^2}{(N-1)}}] \tag{6}$$

The average percentage error is 0.17468341 and the standard deviation is 0.07691088

4. Conclusions

- This model can be applied to any village in India, to calculate the number of years the Programmatic CDM based household biogas plant project should be sustained so that the income generated from the sale of carbon credits earned by the project makes the project economically viable.
- The parameters used to calculate the willingness to invest in biogas plants can be obtained directly from the Census of India data.
- This model can help identify the best region suitable for a biogas plant based Programmatic CDM project.
- The average willingness to invest in biogas plants, to meet the rising energy needs of the villages of Jhunjhunu district, Rajasthan, India, is high. The average value of the willingness to invest is 6.64 on a scale of 1 to 10.
- For the average value of willingness to invest=6.64, the number of years the biogas plant should be sustainable for economic viability=3.14 years.
- Energy needs is the most dominant parameter in the willingness to invest in a biogas plant. This also signifies that rural India currently faces a huge energy deficit.
- Cost of fuel and Prior knowledge has intermediate significance in the willingness to invest in a biogas plant.
- Annual income and number of cattle are comparatively less significant in the willingness to invest.
- The cost of fuel saved on account of substitution with biogas is not taken into account. If this amount is taken into account then the household based biogas plant project becomes economically more attractive.

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