BIO-SEQUESTRATION OF CARBON-DI-OXIDE- CASE STUDY OF KOTA THERMAL POWER STATION , INDIA

Hema Nagpal*

ABSTRACT

Sequester means to withdraw. Bio-sequestration implies sequestering via natural ways. Furthermore, Carbon sequestration, as the name suggests, involves in capturing carbon-di-oxide from the atmosphere. It's a long-term storage of carbon-di-oxide or other forms of carbon to either mitigate or defer global warming. The paper attempts to analyse the use of algae cultivation ponds as a technique for bio-sequestration of carbon and it's forms. Furthermore, the proposal to establish the same technique at Kota thermal Power Plant is considered as a case study to bring out the possibility and success factor of such a technology in India.

KEY WORDS: BIO-SEQUESTRATION, ALGAE CULTIVATION PONDS, KOTA THERMAL POWER PLANT, CARBON TRADING, COST BENEFIT ANALYSIS, NET BENEFIT, NET PRESENT VALUE, INTERNAL RATE OF RETURN, SOCIAL RATE OF DISCOUNT

* Assistant Professor, Department of Economics, Shaheed Bhagat Singh College (Eve.), University of Delhi

1. Introduction

The atmospheric concentration of carbon-di-oxide has increased from 280 ppm in pre-industrial times to more than 380 ppm in 2005 and is currently to the tune of 393.71 ppm, in the year 2011 (**Earth System Research Laboratory, 2006**). This increase is, on major part, due to vanishing ocean and green sinks that capture carbon-di-oxide from the Earth's atmosphere.

Developed countries account for two-third of energy consumption and a similar level of carbon-di-oxide emissions (**Low Carbon Strategies for Growth, Planning Commission, 2011**). The energy consumption of developing countries is estimated to rise by 4 to 5 percent over the next 20 years and emissions would also increase in line with such a growth in energy consumption.

India is one of the lowest Greenhouse Gas (GHG) emitters in the world, though its present day emissions are growing due to accelerating pace of growth and energy and consumption. Their per-capita emission of 1.18 tonnes of carbon-di-oxide in 2008 was nearly one-fourth of the corresponding global average of 4.38 tonnes. In order to solve the problem of climate change, which is largely due to the historical emissions of the developed countries, India has announced that it will reduce the emissions intensity of its GDP by 20-25 percent over the 2005 levels by the year 2020, through pursuit of proactive policies. India's Twelfth Five Year Plan, launched on 1st of April, 2012 has a low carbon inclusive growth, as one of its key pillars.

Of various industries that emit GHG into the atmosphere, power generation sector is one of the prominent players.

83 steam plants were in operation in India (**Central Electricity Authority of India, as of March 31, 1998**).These plants generated almost 80% of total generated power for the nation. Coal consumption by various plants in the country during the year 1997-98 was almost 203 million metric tons. As of May 2010, the total generation from coal and lignite power plants was 461 billion kWh (at bus-bar) leading to carbon-di-oxide emissions of 508 million tons during 2008 – 09. The old and less efficient coal power plants emit as high as 2 kg per kWh. In contrast, gas based power production, which is an attractive power generation option due to low cost of capital and low levels of carbon-di-oxide emissions, is only 0.4 kg per kWh. The consumption of fuels such as furnace oil decreased by more than 32.5%, while the consumption of lignite coal, a low-sulphur heavy stock (LSHS), a high sulphur heavy stock (HHS), and diesel oil increased

by 7.54%, 31.91% and 33.9%, respectively, having a large impact on the level of carbon emissions.

The main emissions from coal combustion at thermal power plants are carbon dioxide (CO_2), nitrogen oxides (NO), sulphur oxides (SO), chlorofluorocarbons (CFCs), and air- borne inorganic particles such as fly ash, soot, and other trace gas species.

Rajasthan uses three major sources of energy – firewood/dung cakes in rural area, electricity and petroleum products. Increasing demand for energy & limited alternative sources impose a huge pressure on this sector. In light of this, coal based thermal power is the only viable source of energy available.

One of the Thermal Power Plants in India, Kota Thermal Power Station (KTPS) is located on the left bank of river Chambal in Rajasthan's principal industrial city, Kota. It meets majority of the electricity needs of the state of Rajasthan. Currently there are 2 units of 110MW, 3 units of 210 MW and 2 units of 195MW each. (**Comprehensive Environmental Impact Assessment of Kota Thermal Power Station, Rajasthan State Electricity Board**). The highest consumption of energy is by the industrial sector followed by the agriculture and commercial sector. The requirement of energy has been growing steadily over the years thereby increasing the pressure on fossil fuels like coal on one hand and rising pollution levels to meet the mounting energy needs on the other.

Within the KTPS, high chimney and proper treatment mechanisms are provided for sulphur and Nitrous oxides. For Fly Ash, which accounts for a major chunk of the residual, Electronic Precipitators are established for treating the same. KTPS also ensures that it follows the requirement set by the Central Pollution Control Board (CPCB) and disposes of the 100% of Fly Ash every 9 years (**Pollution Control Implementation Division – II, Thermal power Plants, Environmental Regulations, CPCB**).

However, no treatment per se is done for the carbon-di-oxide emissions. In light of the global warming, it has, therefore, become indispensable to undertake immediate measures to check the carbon-di-oxide levels in the atmosphere. The current total carbon-di-oxide emissions of

KTPS are 5,462,720 tons per annum. (**Rajasthan Rajya Vidyut Utpadan Nigam Limited Feasibility Report, Kota Thermal Power Station**).

Ways to lower the atmospheric concentration of carbon-di-oxide include not only reducing emissions but also encouraging **carbon sequestration**—the capture and storage of carbon-di-oxide to prevent its release into the atmosphere. Algae cultivation ponds are used as technique to sequester carbon naturally. This technology has been successfully functioning in different parts of the world.

In order to test the possibility of using algae cultivation ponds technique in India for bio-sequestration of carbon and it's forms and an attempt to reduce the emission levels, it is proposed to establish this particular technology at the Kota Thermal Power Station location. The case study uses cost benefit analysis to determine the success or failure of the technology. Whereas, on one end, the cost involved will be that of establishment and adequate functioning of the technology at the Plant location, the benefit, on the other end, would not only be in terms of reduced annual carbon emissions from the region, but also the monetary benefits that can be reaped from trading the units of carbon sequestered in the world carbon market.

The following section explains the technique of carbon sequestration and carbon trading. It is followed by a brief on the scenario of carbon trading in India. After the understanding of the concept, the paper discusses the case study of the technology at Kota Thermal Power Station. It gives a brief summary of the costs that will be incurred and the benefits that can be reaped so as to calculate the net benefit, that further is brought to the present value by the concept of Net Present Value, for better understanding and relevant discussions. Also, in order to test for the viability of the technology, the logic of Internal rate of Return is also applied.

2. BASICS OF CARBON-DI-OXIDE SEQUESTRATION

2.1. Concept And Various Ways of Carbon-di-oxide Sequestration

Greenhouse gases are increasing in the atmosphere and causing climate change. Scientist, policy makers, and citizens are trying to determine how to decrease and possibly reverse the emission of greenhouse gases, especially carbon-di-oxide.

Tribal Energy and Environment Information Clearing House propose that there are three primary methods for reducing the amount of carbon dioxide in the atmosphere:

a) Employing energy efficiency and conservation practices, involving practises to reduce the consumption of carbon emitting fuels such coal, petroleum etc. and adopting daily practises that could conserve energy.

b) Using carbon-free or reduced-carbon energy resources i.e. to use carbon-free or reduced-carbon sources of energy.

c) Capturing and storing carbon either from fossil fuels or from the atmosphere which involves the capture and storage of carbon dioxide that would otherwise be present in the atmosphere.

Analysing and summarizing the various ways of carbon capturing and storage, we get the following diagram:

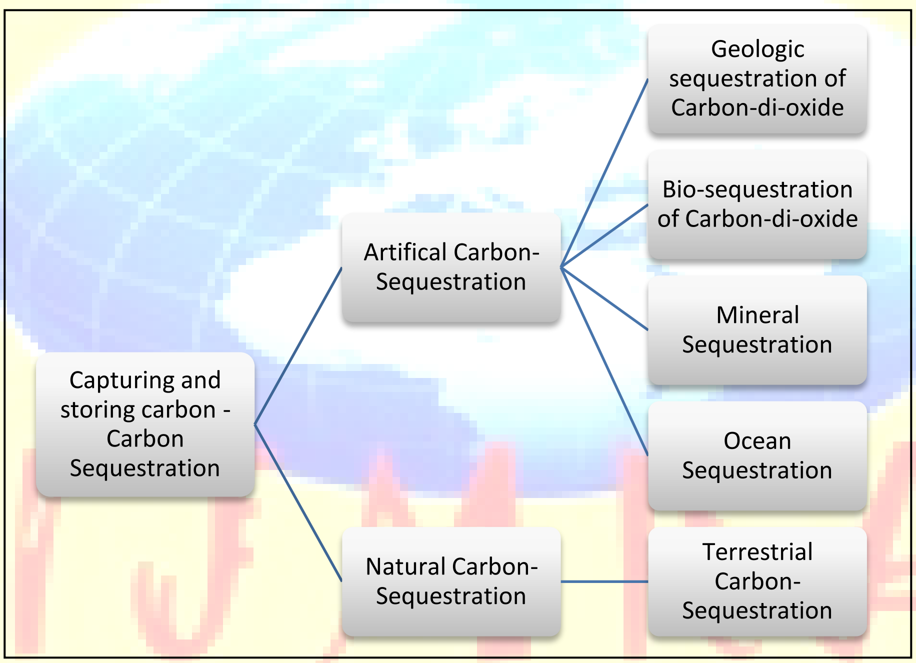


Figure 1: Various ways of sequestering carbon-di-oxide

Source: Generated by Author specifically for the purpose of the study

The following table summarizes various types of methods that sequester carbon-di-oxide.

Table 1: Table showing various ways of sequestering carbon-di-oxide

Type of Sequestration	
Natural Sequestration of Carbon-di-Oxide	
Terrestrial Sequestration	Natural carbon sequestration is a cycle that's been happening on this planet for billions of years. It's simply the process by which nature has achieved a balance of carbon- di-oxide in our atmosphere suitable for sustaining life. Terrestrial sequestration involves the capture and storage of carbon-di-oxide by plants and the storage of carbon in soil. During photosynthesis, carbon from atmospheric carbon- di-oxide is transformed into components necessary for plants to live and grow. As part of this process, the carbon present in the atmosphere as carbon-di-oxide becomes part of the plant: a leaf, stem, root, etc. Long-lived plants like trees might keep the carbon sequestered for a long period of time.
Artificial Sequestration of carbon-di-oxide	
Geologic Sequestration of carbon-di-oxide	Geologic sequestration involves three main processes: capturing , transporting and placing the carbon-di-oxide in a geologic formation for permanent or semi-permanent storage. The carbon-di-oxide is placed into the geologic formation by means of a system of injection wells. An injection well is like an oil well or water well, except that instead of drawing material (oil or water) out of the ground, carbon dioxide is injected into the well. Injection wells are also used for the disposal of various types of wastes and to enhance oil recovery in some areas.
Ocean sequestration of carbon-di-oxide	One proposed method is whereby carbon-di-oxide is injected deep into the ocean, forming lakes of carbon-di-oxide. In theory, the carbon-di-oxide will stay down deep due to the pressure and temperature of the surrounding water; gradually dissolving into that water over time.
Mineral Sequestration of	Carbon-di-oxide is injected into areas rich in Magnesium or

carbon-di-oxide	Calcium. The carbon-di-oxide will react with those elements and combine to form calcium carbonate (limestone) and magnesium carbonate (magnesite).
Bio-Sequestration of Carbon-di-oxide	This process involves use of species such as algae that use carbon-di-oxide for their basic activities such as photosynthesis and hence can capture carbon permanently from the atmosphere. The industrial emissions of carbon-dioxide can be directed towards artificially constructed ponds that contain such species as a part of the process of sequestration of carbon-dioxide. Biological carbon sequestration might be the most promising, environmentally friendly and cost-effective means of reducing carbon-di-oxide emissions in the energy sector (**Velea et al, 2009**). Some selected strains of microalgae act as enhanced natural sinks for carbon-di-oxide because they are 20 times more efficient than terrestrial plants in utilizing carbon-di-oxide per square meter of fuel gas.

After throwing a glimpse on the concept of various ways of carbon-di-oxide sequestration, we now glance through the Economic models on the same, followed by its application across the world.

2.2. Econometric Models Defining Relationship Between Carbon-di-oxide Sequestration And Benefits Carbon Emission Reduction

Randall et al. in their paper on Tradeable Permit Tariffs : How Local Air Pollution Affects Carbon Emissions Permit Trading provide for an econometric model to show that trade of carbon units in the world market can induce domestic industries to adopt techniques for carbon emission reductions and acquire benefits from trade. Also, they show that under welfare-maximizing policies, the prices at which carbon-emissions would be supplied in the international markets would vary significantly with the nature of local air pollution.

Elizebeth et al show that trades of sequestration services i.e. trade of sequestered units of carbon-di-oxide or any such green house gas, are complicated because of growing time and monitoring difficulties. They have developed a delayed-response, optimal-control model, considering both sequestration and emission reduction possibilities. The aim was to clarify the role that time played in defining the nature of related transactions and trade.

They develop the dynamics of forests, which are considered as Carbon Sinks, over a continuous time frame and use optimal control model involving time delays. They have categorized sequestration into permanent and temporary sequestration, used different discount rates and produced varying results for present values of sequestration benefits.

Lubowski et al. develop econometric analysis on natural carbon sequestration and compare it with energy based carbon abatement analyses. They extend previous studies and add a variety of features such as land use, land quality, micro level analysis and relate the prices of commodities influencing carbon unit's availability in the carbon credit market, as endogenous. On application of the model on national level, in US, for empirical analysis, they obtain estimates of the marginal costs of carbon sequestration and compare it with estimates of costs from energy-based carbon abatement measures. They find that the estimated carbon sequestration supply function is roughly similar to the central tendency of the carbon abatement supply function, indicating that about a third of the US target under the Kyoto Protocol would be cost-effectively achieved by employing forest-based sequestration policies, in addition to energy-based carbon abatement strategies. This suggests that forest-based carbon sequestration merits consideration as part of a cost-effective portfolio of domestic US climate change policies.

Hongli Feng et al. in their work on Time Path and Implementation of carbon sequestration develop a dynamic model to investigate the optimal time paths of carbon emissions, sequestration and the carbon stock. They show that carbon sinks should be utilized as early as possible, and carbon flow into sinks should last until the atmospheric carbon concentration is stabilized. They rule out any cyclical patterns of carbon sequestration and release. They propose and assess three mechanisms to efficiently introduce sequestration into a carbon permit trading market: a pay-as-you-go system, a variable-length-contract system and a carbon annuity account system. They highlight that although the three mechanisms may not be equally feasible to implement, they are all efficient.

Results showed that carbon sequestration should be used as early as possible (as long as it is efficient to use it) to reduce the pressure on emission abatement, and the carbon flow into sinks lasts until the atmospheric carbon concentration is stabilized. However, despite the clear theoretical role for carbon sequestration, it was stated that it should not be treated the same as carbon emission reductions. Quoting Feng's work "Sequestration, by its nature, always has the potential to be temporary; consequently, it cannot be attributed the same value that emission reductions have if an efficient solution is to be obtained. The correct view is that sequestration has value, but the value is different from (and less than) the value of direct emission reduction." Therefore, the need to use of special mechanisms to address the difference was mentioned.

In the article by **Zili Yang et al.** carbon-di-oxide sequestration as a strategy to manage future climate change in an optimal economic growth framework, is analysed. The problem is approached in two ways: first, by the use of a simple analytical model, and second, by the use a numerical optimization model which allowed exploration of the problem in a more realistic setting. Sequestration is not a perfect substitute for avoiding carbon-di-oxide production because carbon-di-oxide leaks back to the atmosphere and hence, imposes future costs. The "efficiency factor" of carbon-di-oxide sequestration is expressed as the ratio of the avoided emissions to the economically equivalent amount of sequestered carbon-di-oxide emissions. A simple analytical model in terms of a net-present value criterion suggested that short-term sequestration methods such as afforestation could be somewhat (60 %) efficient, while long term sequestration (such as deep aquifer or deep ocean sequestration) could be very (90%) efficient. A numerical study indicated that carbon-di-oxide sequestration methods at a cost within the range of present estimates reduced the economically optimal carbon-di-oxide concentrations and climate related damages.

2.3. Evidence Of Use Of The Technology Across The Globe

Through her work, **Ami Ben-Amotz**, of The National Institute of Oceanography Nature Beta Technologies Ltd. Nikken Sohonsha Co, Japan Seambiotic Ltd. ISRAEL, has shown how large open algal ponds have been established and are being used to sequester carbon.

Seambiotic, Israel, An Israeli company has found a way to produce biofuel by channelling smokestack carbon dioxide emissions through pools of algae that clean it. The growing algae thrive on the added nutrients, and become a useful biofuel. The company tested their idea with an electric utility company - *a coal burning power plant in the southern city of Ashkelon operated by the Israel Electric Company (IEC). The company's prototype algae farm in Ashkelon uses the tiny plants to suck up carbon dioxide emissions from power plants. Seambiotic's eight shallow algae pools, covering about a quarteracre, are filled with the same seawater used to cool the power plant. A small percentage of gases are siphoned off from the power plant flue and are channelled directly into the algae ponds. Originally when the prototype started operating, a common algae called Nannochloropsis was culled from the sea and used in the ponds. Within months, the research team noticed an unusual strain of algae growing in the pools - skeletonema - a variety believed to be very useful for producing biofuel.*

The pond in Israel had dimension of 3000 square meter and that in USA had 3400 square metre.

Ami, in her work, made the following observations:

a) The basic requirement of carbon to be sequestered through microalgae species, as observed in the two cases, is that the temperature should be above 15 degree Centigrade.

b) The pond, for which the optimal size is 300 to 4000square meter, should be in the open and have access to a good source of light.

c) The pond should have a motor / paddle that will facilitate constant movement of the water in the pond and would avoid stagnation.

d) At the same time, one should take notice that the pond is not very deep as the species are required to float at the surface or close to the surface to remain close to the light source.

e) The pond should have a lining so that there is no water leakage and that there is concrete so that there is no breakage.

f) The dimension of the paddle wheel is dependent on the specie of algae used. For example, Spirulina specie requires a smaller paddle size as compared to any other specie of algae.

g) Apart from the basic functioning, there are technical and mechanical equipments were used to measure as well as control the salinity of the water as well can be used to clean the pond at regular intervals.

The above functioning, analysed by Ami in her work, forms the crux of the ponds set up in USA and Israel. The sequestration of carbon by these ponds has been on a relatively high scale and has set an example for the World to use such environment friendly technique.

The working of the model, explained by Ami, has been used as the background for the case study of setting up the technology at KTPS for bio-sequestration of carbon-di-oxide emissions.

3. CARBON TRADING

3.1. Concept

The popular approach to the problem of global warming became the "project of building a single, liquid global carbon market worth many trillions of dollars – backed by the UN, national governments, economists, environmentalists and many in the business sector." (**COP and Carbon Trading by Mary Thibodeau**) With the Kyoto Protocol in 1997, polluter countries that have agreed to emission targets are given emission credits, which are equivalent to their reduction commitments from 1990 levels. Credit quotas are then distributed nationally through 'grandfather'clauses, which allow the biggest polluters to receive the largest allocation of credits. If the polluter does not use the entire pollution credit quota, they can either 'bank' the credits for the future or sell the credits on the open market to be purchased by another polluter. In contrast, if they use up all their credits, they must purchase more from a polluting country that has not used up its full allocation, or invest in projects in other countries through either Joint Implementation (JI) or the Clean Development Mechanism (CDM).

Emission trading entails the creation of a carbon market which allows countries with emission credits to spare to sell them to countries unable to meet their targets. Credit is transferred for emission reductions accumulated through projects to form units which are equivalent to one tonne of Carbon-di-oxide.

3.2. Carbon Markets and India

India per se doesn't have a well established carbon market (**MCX, India**). However, India, being one of the leading generators of CERs through CDM, has a large scope in emissions trading. Analysts forecast that its trading in carbon credits would touch US$ 100 billion by 2010. The number of expected annual CERs in India is hovering around 28 million and considering that each of these CERs is sold for around 15 euros, on an average, the expected value is going to be around Rs 2,500 crore.

Hence, there is a large scope of carbon markets India that are yet to be tapped. Implementing CDM projects and adopting environmental friendly techniques such as bio-sequestration of carbon-di-oxide can be a huge add on for India not only in terms of a clean environment, but also huge monetary benefits that can be reaped from active participation in carbon markets and carbon trading.

4. CASE STUDY :BIO-SEQUESTRATION AT KOTA THERMAL POWER STATION (KTPS)

The setup of the model is basically to establish Monoethanolamine (MEA) plant within the Thermal Power Plant, which would separate carbon-di-oxide emissions from other emissions. These carbon-di-oxide emissions would then be let out to open algae ponds, through pipes. The algae present in the ponds would use the carbon-di-oxide for the process of photosynthesis and henceforth, capture the same from the atmosphere. This would not only drastically reduce carbon-di-oxide emissions in the thermal power plant area of Kota, but also would create opportunities for carbon trading in Rajasthan. The proposal is to combine the joint advantage of technology with nature and if successfully implemented would prove to be a major breakthrough in the sphere of carbon sequestration within India.

As observed, India has a vast opportunity to explore in terms of CDM and carbon-credits. Through its giant ongoing infrastructure projects and projects on non-conventional energy sources, a new phase of development is still to be observed, moderate start of which has already begun. The question hence forth entails towards relating the carbon credit market with the Bio-sequestration of carbon-di-oxide model at KTPS, Rajathan, India.

The idea is that the number of units of carbon-di-oxide saved through bio-sequestration technology can be traded in the world market, at prices determined in the carbon credit market, with the industry that is producing carbon-di-oxide emissions beyond the permitted level. This would provide insight on the monetary benefits of the technology and lend itself to conduct cost benefit analysis of the technology. The discounting rates and scaling factors can be derived from the theoretical models in the literature that are empirically tested and proven.
On the basis of the back ground mentioned above, further analysis aim to:

a) To check for the efficiency of Bio-sequestration as a technology at KTPS.
b) Relate Bio-sequestration technology at KTPS with the World carbon credit market and enumerate the monetary benefits the technology could bring.

4.1. Cost Benefit Analysis

Cost-benefit analysis (CBA) is a tool employed to evaluate projects. It produces an aggregative measure that helps to assess the feasibility of the project. Conceptually simple, its results are easy for decision makers to comprehend, and it enjoys a great deal of favour in project assessments. The end product of the procedure is a measure that compares the total benefits to the total costs. CBA fulfils the need for a consistent rule for choosing how one project outcome is better than another from a societal perspective. It provides a set of rules for choice among alternatives, based on principles of economic theory.

CBA thus involves making decisions by comparing gains and losses from a project; based on the principle of maximisation of net gains. It involves societal balancing of gains and losses, where gains enhance well-being and losses diminish it. The cost-benefit rule is therefore simply maximising the difference between these two.

In practice, CBA is quite complex because it requires a number of assumptions about the scope of the assessment, the discount rate, the time frame, as well as issues involved with identifying and measuring benefits and costs. Where there are significant externalities of economic activity, measurement poses an even greater challenge, for instance in evaluating the costs (such as pollution control costs) and benefits associated with projects that impact the environment.

Cost-benefit analysis of various programs can help policy makers decide whether such a project should be undertaken or not. If the CBA is undertaken ex-post, i.e. after the project is over, it shows whether the project benefits outweighed its costs, or whether the project was a success. If it is undertaken ex-ante, i.e. before the project begins, it indicates whether or not the project should be undertaken at all.

Before beginning the cost-benefit analysis of a project, certain decisions relating to the choice of key parameters must be made. These include:

a) Factors influencing the costs and benefits of the project: What factors form the components of the costs section and the benefit section and influence the values of these two crucial variables.
b) The choice of discount rate: at what rate should costs and benefits be discounted?
c) Choice of time period of analysis: for how many years should the analysis be conducted
d) Choice of the decision rule: Should the analysis use net present values, internal rates of return, or benefit-cost ratios to make decisions.
e) Choice of the numeraire: Should the analysis be in domestic currency at the domestic price level, domestic currency at the border price level, or foreign currency at the border price level.

The sections ahead on methodology, costs, benefits and its analysis will respond to the above questions and determine the cost efficiency via. Cost Benefit Analysis of the technology in consideration.

4.2. Data Analysis: Key Features And Methodology

The proposal of establishing a technology for Bio-Sequestration of carbon-di-oxide at Kota Thermal Power Plant, Rajasthan, India has been made. The entire research and analysis, therefore, is to determine the long term cost effectiveness of the technology using the cost benefit analysis approach.

Key Features of the Analysis: The following are the key points that should be kept in mind while conducting research and analysis:

a) The time period considered for the purpose of analysis is from January 2012 to December 2020.

b) The analysis is carried out on monthly basis, thereby, listing out an array of 108 months time frame under study.

c) The word carbon used in the analysis is equivalent to carbon-di-oxide. NO other variant of carbon is dealt with, under this study.

d) The original cost structure was obtained in US Dollars. The Prices obtained from the European Carbon Market were mentioned in terms of Euros. Hence, in order to create uniformity through out and for the sake of analysis, standard unit of Indian Rupee will be followed. The exchange rate followed is at the rate of Rs. 50/- for per unit of dollar and Rs. 65 for per unit of Euro, for the purpose of conversion.

Methodology: Economic and econometric tools have been used extensively in order to determine the cost, the benefits, the NPV of the net benefits, calculate the Internal rate of Return and henceforth establish the cost effectiveness of the technology.

4.2.1. Cost

Cost Structure: All the categories of costs that are incurred in the establishment and effective functioning of technology have been considered to determine the total costs incurred for the project establishment and functioning. The summary of the costs is provided below :

The *Fixed Cost* to be incurred in the construction of the ponds and the Extraction plant need to be deducted in the first year of functioning of the technology. The Land as a fixed cost will have to be incurred each year. Hence, the total fixed cost analysis is summarized in the table below.

Table 2: Table showing summary of Fixed Costs

Fixed Cost for year 1	
Annual Rental Value of Land	Rs. 2,520,000/=
Pond construction and paddle wheel	Rs. 4,600,000/=
MEA Extraction Plant	Rs. 1,365,680,000/=
Total Annual Fixed Cost for year 1	Rs. 1,372,800,000/=
Total Monthly Fixed Cost to be incurred for the period 1 i.e. (Total Annual Fixed Cost for year 1 / 12 months)	Rs. 114,400,000/=
Fixed Cost after year 1	
Annual Rental Value of Land i.e. Annual Fixed cost after year 1	Rs. 2,520,000/=
Monthly Rental Value of Land i.e. Monthly Fixed Cost after year 1	Rs. 210,000/=

Sources: Author's compilation and calculation from Data Available from Real Estate Personnel from EARTH INFRASTRUCTURE Company and Mr. Goel, owner of GCC Goel Construction Company, New Delhi.

Variable Cost : The following table summarizes the variable cost that will be incurred each year for the functioning of the plant.

Table 3: Table showing summary of Monthly Variable Costs

Variable Cost to be incurred each month	**Cost (In INR)**
Operational Expenses	Rs. 875,000/=
Obtaining Algae and nutrients required for it's sustenance	Rs. 180,000/=
Miscellaneous Expenses	Rs. 83,333/34
Total Monthly Variable Costs	Rs. 1,138,333/34

Source: Author's Compilation from data collected from Rajasthan Rajya Vidyut Utpadan Nigam Ltd., Kota Thermal Power Station and consultation with Mr. Mathur, Senior Chemist, KTPS

Total Cost: Total Cost is the addition of the Total Fixed Cost and total variable Cost. Since our analyses are monthly based, we will eventually calculate Total Cost to be incurred each month. Also, notice that since the Fixed Cost in the First year of technology is different from the cost incurred in the reaming years of the technology, we will have two sets of total costs. The First set will define the annual and henceforth, monthly cost that will be incurred in the First Year and the Second set will define the annual and henceforth, monthly cost that will be incurred in the remaining years of the analysis.

Table 4: Table showing summary of Total Costs

Total Cost in the first year	
Total Monthly Fixed Cost to be incurred for the year 1	Rs. 114,400,000/=
Total Monthly Variable Costs	Rs. 1,138,333.34
Total Monthly Cost in the first year = Total Monthly Fixed Cost to be incurred for the year 1 + Total Monthly Variable Costs	**Rs. 115,538,333/34**
Total Cost in the remaining years	
Total Monthly Fixed Cost to be incurred for the year 1	Rs. 210,000/=
Total Monthly Variable Costs	Rs. 1,138,333/34
Total Cost in the first time period = Total Monthly Fixed Cost to be incurred for the year 1 + Total Monthly Variable Costs	**Rs. 1,348,333.34**

Source: Author's Compilation

Note that the probability for the incidence of under estimation of costs is low because extensive analyses have been done to determine the same to the nearest proximity of the actual costs. Also, a section of miscellaneous expenses has been created to account for the difference between actual and estimated costs, in case the former is more than the latter.

4.2.2. Price Determination for Benefit

Benefit Structure: In our technology, the simplest way to determine the benefit is to give the same a monetary value (Since the technology is environment friendly and concerns emission reduction, it is bound to have other non-monetary benefits as well, but the determination of this non-monetary benefit is beyond the scope of present study). This section deals with forecasting the monthly prices for the time period January 2012 to December 2020 by using time series analysis, on the basis of data available for the time period May 2004 to January 2012 for the European Carbon Markets (as it is the most active market at present and is expected to sustain for a longer period of time than any other market, based on the outcome of the Durban Meet in December 2011). Once the prices are forecasted on the basis of previous years price level, we consider the volatility element in the model. Since high degree of volatility is a special feature of carbon market, an entire band of prices will be estimated to account for the same. These additional set of prices will be determined on the basis of the forecasted prices. The next step involves in the determination of the number of units of carbon sequestered through the use of the technology. The product of the prices obtained and units sequestered will give us the value of the benefits obtained.

The time series model used for forecasting of the prices, after checking for the stationarity of the series using Dickey-Fuller Tests, we obtain the following equations :

$$D(P_t) = 0.5386 + 0.3039\ D(P_{t-1}) + 0.8112\ D(P_{t-2}) - 0.2132\ D(P_{t-3}) + 0.1457\ D(P_{t-4}) + 0.9483U_{t-2} - 0.8112U_{t-5}$$

se = (5.2713) (0.5034) (0.1639) (0.0721)
(0.0462) (0.1255) (0.1786)

t = (9.2450)* (6.5672)* (5.8735)* (4.8957)*
(6.5278)* (5.5492)* (4.8628)*

* indicates significant at 5% level of significance.

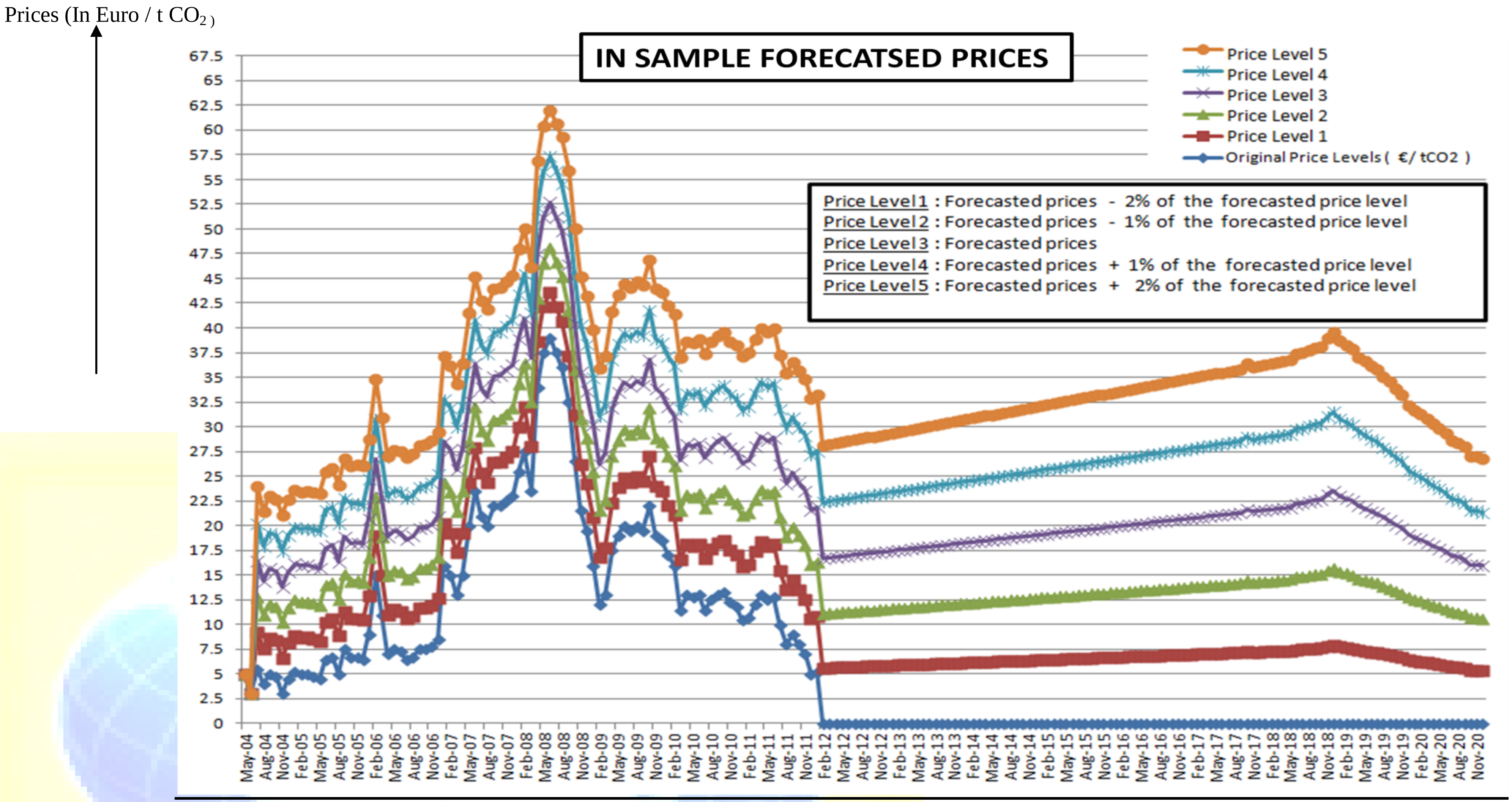


Figure 2: Forecasted Prices Levels

Source : Author's Compilation From Data Generated

With the help of this equation, we obtain the forecasted price for per tonne carbon in Euro terms and convert it into INR terms, with the help of exchange rate of Rs. 65 per unit of Euro. Note that this exchange rate is assumed to be constant through out the period of analysis.

As mentioned earlier, volatility is an important factor of the carbon markets. Hence, we establish four new sets of prices that are derived from the forecasted level of prices and consider all of them for the purpose of our analysis. The derived set of prices would be through simple calculations given below and provide us with five sets of prices:

Price Level 1: Forecasted prices - 2% of the forecasted price level
Price Level 2: Forecasted prices - 1% of the forecasted price level
Price Level 3: Forecasted prices
Price Level 4: Forecasted prices + 1% of the forecasted price level
Price Level 5: Forecasted prices + 2% of the forecasted price level

The justification for use of ±1% and ± 2% and not any other numeric change is that in the original data, except a few outliers, the change in market prices from one month to another, has not been very huge. Hence, we use these values to determine an entire range for prices and then, the net benefits.

4.2.3. Units

For the purpose of calculation of number units of carbon that will be sequestered and be made available for the purpose of trade, it is known that per acre of land can sustain approximately 200 tons of algae provided the algae are sustained in its optimal conditions. The climatic conditions of KTPS provides for the optimal conditions required for the sustenance of Chlorella, Spirulina species of algae.

Scientific analysis have shown that 1.8 tons of carbon-di-oxide is sequestered by approximately by 1 ton of algae (Sazdanoff)

The 21 acre ponds contain and easily sustain 4,157.32 tons of algae per day (the difference taken to account for slight changes in optimality conditions for algae sustenance). At the rate of 1.8 tons of carbon sequestered by 1 ton of algae, we can sequester 7,483.178 tons of Carbon-di-oxide per day i.e.

1.8 tons of Carbon-di-oxide sequestered per tonnes of algae per day	*	**4,157.32 tons of algae per day**	=	**7,483.178 tons of Carbon-di-oxide sequestered per day.**

Accounting for 365 days of the year, we can sequester around 2,731,360 tons of Carbon-di-oxide emissions per year, at the rate of 7483.178 tons of Carbon-di-oxide sequestered per day.

7,483.178 tons of Carbon-di-oxide sequestered per day	*	**365 days**	=	**~ 2,731,360 tons of Carbon-di-oxide sequestered per year.**

Therefore, to obtain approximate units of carbon sequestered each month, we obtain:

2,731,360 tonnes of Carbon-di-oxide sequestered per year	/	**12 months**	=	**~ 227,613 tons of Carbon-di-oxide sequestered per month.**

The total emissions of Carbon-di-oxide, by KTPS are 5,462,720 tons per year. The obtained sequestration through establishment of the 21 ponds of 1 acre each in the KTPS region would sequester ~50% of the Carbon-di-oxide emissions per year.

Finally, the benefits are obtained by the product of units of carbon sequestered and the forecasted prices.

4.2.4. Net Benefit

Net Benefit: Difference between the benefits and costs for each time period / month is taken to establish the Net Benefit.

Net Benefit = Benefit (i.e. Price * Units of Carbon sequestered) - Total cost for that point of time

4.2.5. Net Present Value

Rate of Discount and Net Present Value : Monthly compounded rate of discount calculated from the annual rate of interest (three levels of annual rate of interest: 3%, 5% and 10%). Monthly compounded rates of discount are used to find the NPV corresponding to different price levels and rate of discounts.

The logic is that it is important to convert future flows of costs and benefits from an investment project into the same units as current values from a social perspective. That is, the flows of benefits and costs which accrue to some future time period, must be brought to their present value, for the sake of analysis. This is done with the help of Social Rate of Discount, calculated by summation of marginal elasticity of utility and per capita growth rate of consumption. This rate is generally applied to public sector investment projects. In a without uncertainty world, when projects are independent and there are no externalities, using a given SDR, the net present value of benefit of each project can be calculated and the projects can be ranked on the basis of their net present values. The decision problem becomes choice of a project which yields the highest net present value of benefit. The results of a cost-benefit analysis are very sensitive to the choice of social discount rate. Setting the discount rate too high could prevent potentially desirable projects from being undertaken, whereas selecting a discount rate that is too low could result in making investments that are economically inefficient.

Hence, in order to generate analysis that reflects the true picture, we consider three rates of discounts, 3%, 5% and 10%. The choice is made so that effective representation of domain of both social and private rate of discounts is made.

The sum of all discounted costs and benefits from the project is called the Net Present Value (NPV). The sum reflects how much the project will earn. If the NPV is negative, clearly the costs outweigh the benefits and the project is not economically feasible. If the NPV is positive, however, it indicates economic feasibility of the project and shows that the project is desirable because the present value of its benefits exceeds the present value of its costs (This also corresponds to equating marginal cost and marginal benefit). If the NPV is positive, the project should be undertaken. When choosing among a range of project choices, all of which yield a positive NPV, allocative efficiency dictates that the project with the highest NPV be chosen. In other words, the project with the maximum difference between present value of benefits and present value of costs is chosen.

Summarizing all the analysis and all the calculations explained above, NPV at various price levels and at different rates of discounts is listed out in the form of a table below.

Table 5: Table showing NPV At Various Forecasted Price Levels And Discount Rates

NPV (In Billion Rs.) / Rates of Discounts	Prices	For Net Benefit at Price Level 1	For Net Benefit at Price Level 2	For Net Benefit at Price Level 3	For Net Benefit at Price Level 4	For Net Benefit at Price Level 5
3% annual rate of discount		7.493/=	7.584/=	7.676/=	7.767/=	7.859/=
5% annual rate of discount		6.788/=	6.872/=	6.956/=	7.040/=	7.124/=
10% annual rate of discount		5.378/=	5.448/=	5.517/=	5.586/=	5.655/=

Source: Author's Compilation

Note: The price levels mentioned in the above table are as follows:

Price Level 1: Forecasted prices - 2% of the forecasted price level

Price Level 2: Forecasted prices - 1% of the forecasted price level

Price Level 3: Forecasted prices

Price Level 4: Forecasted prices + 1% of the forecasted price level

Price Level 5: Forecasted prices + 2% of the forecasted price level

4.2.6. Internal Rate of return

Internal Rate of Return: IRR is another way to establish the cost effectiveness of the technology, which are calculated for different Net Benefits (arising out of various price levels).

Another way of analysing the costs and benefits of a project is calculating its Internal Rate of Return (IRR). The IRR is the rate with which the sum of discounted costs of the investment equals the sum of discounted benefits from the investment, i.e. the rate at which the net present value of the project is zero. It represents the rate of return on a project for which the discounted benefits and costs are equal. The IRR may be used to choose between different projects. A project with higher IRR is preferred to a project with lower IRR. The IRR is given by

$$\sum \frac{\text{Net Benefit}}{\{1 + R\}^{t}} = 0$$

Where, R is the Internal rate of Return.

Net Benefit: Benefit – Cost

't' represents the time period for analysis

Using the above formula, so as to determine the cost effectiveness of the technology, we compute IRR at different levels of prices. We obtain the following table:

Table 6: IRR at Various Forecasted Price Levels

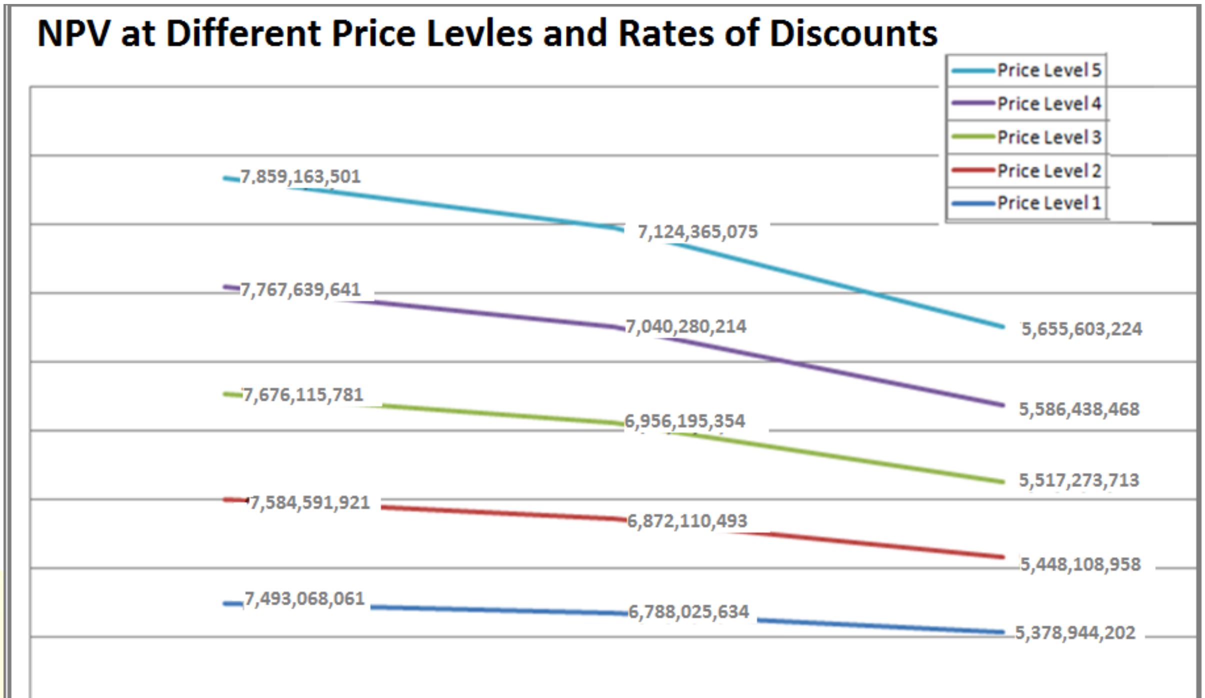
Price Levels	Associated IRR
Price Level 1	11.00%
Price Level 2	11.00%
Price Level 3	11.84%
Price Level 4	12.09%
Price Level 5	12.00 %

Source: Author's Compilation

4.3 Results, conclusion and recommendation

4.3.1 Implications and Results From NPVs And IRRs

In the above Cost Benefit Analysis of the bio-sequestration technology, thorough comparisons have been made considering the extensive cost structure involved in the establishment and functioning of the technology and monetary benefits that can reaped from the sale of carbon units in carbon markets across the world. The analysis extends over the span of 9 years. Since, the benefits are to be generated in future, discounting has been done in order to evaluate the future benefits in present times.



	3% annual rate of discount	5% annual rate of discount	10% annual rate of discount
Price Level 5	7859163502	7124365075	5655603224
Price Level 4	7767639641	7040280215	5586438468
Price Level 3	7676115781	6956195354	5517273713
Price Level 2	7584591921	6872110494	5448108958
Price Level 1	7493068061	6788025634	5378944202

Figure 3: NPV Band Range at Forecasted Prices Levels

Source: NPV Value generated in Table 13

The results, as shown in the methodology section, ultimately represent the NPV generated at different price levels and different rates of discounts. Hence, we can summarize the following for NPV :

The table shows that irrespective of rate of discount considered, be it as low as 3% or 5% annual rate which is in proximity with Social Rate of discount or be it 10% annual rate of discount, which is closer to the private rate of discount, the NPV stands to be way above zero (In billion Rupees).

Since we are dealing with European markets, even if we convert these NPV into Euros, or for that matter, any other currency that has a per unit exchange rate for Rupee greater than zero, the result would still remain to be same i.e. the technology produces positive *benefits with trade in the European Market and can easily cover the costs it would encounter in the functioning of the technology.*

The logic behind using these different variations of forecasted price levels is the key feature of Carbon Markets, its high volatility. The market experiences huge fluctuation. In order, to account for these fluctuations and high degree of volatility, an entire range around forecasted price values is considered. The different ranges of values provide a different NPV level, that help to generate a range in which the future benefits can lie.

The analysis shows that price variation has little impact on the values of NPV generated i.e. NPV is not very sensitive to the price levels. The volatility factor would, hence, have little impact on the NPV of the future benefits. Therefore, even if the prices do fall down to a very low level, the technology would still maintain its benefit generating capacity.

The hypothesis to test for cost effectiveness of the technology, hence, holds in favour of the technology, due to high positive values of NPVs of future benefits and their insensitivity to the price levels prevailing in carbon market.

In terms of Internal rate of Return, the lowest IRR obtained is 11%, which, is higher than the maximum SRD considered in the model i.e. 10%. The cost benefit analysis also holds in favour of the technology. They depict positive profitability generated from the technology, in future.

4.3.2 Conclusion and Recommendations

The analysis, from various angles, shows that the technology, if monitored and is put into efficient functioning, long term substantial monetary benefits can be reaped. It can stand as an example to the world to take up such environmental friendly techniques along with usual production processes.

From the perspective of Government Sector, an IRR of approximately 3-5% provides justification enough to consider the project for the purpose of investments. From the point of view of private sector, same result holds: an IRR of 11% or more provides sufficient incentive for investment in the technology. The NPV, at first place, is also high enough to support these conclusions. Hence, the venture shows that there can be such technological establishments that can incentivise both public and private sector to take up such investments and reduce emissions as well as generate long term benefits.

An added dimension can be that of "Public-Private Partnership", which calls for joint investment by both the sectors. The added feature is that the benefits obtained, in this case, would be shared amongst a larger section of people and would not be concentrated in the hands of few.

The technology, if successful can be extended to other Thermal Power Plant locations across the country, as well. Infact, it can also be applied to industries where the production processes generate high emission levels, to control for the impact of the same, on environment.

Algae can also be used for medicinal purposes. Hence, the technology, after adequate research, can be extended to incorporate additional medicinal benefits that can be extacted from algae used in the ponds.

Further research and analysis can be carried out as well, in future, to look for alternate and cheaper investment options instead of using MEA Extraction plant to separate carbon emissions from other emissions, at the plant site.

In short, the cost benefit analysis provide for a green signal to adopt this environmental friendly technology and calls for immediate action to undertake more of such investments, both at private and public level.

This shows that there is a tremendous scope to extend the use of this green and clean technology in India and increase it's participation n carbon markets to generate monetary benefits as well.

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